

axiomTM



The 30 Year Horizon

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Volume 10: Axiom Algebra: Categories

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New Foreword

On October 1, 2001 Axiom was withdrawn from the market and ended life as a commercial product. On September 3, 2002 Axiom was released under the Modified BSD license, including this document. On August 27, 2003 Axiom was released as free and open source software available for download from the Free Software Foundation's website, Savannah.

Work on Axiom has had the generous support of the Center for Algorithms and Interactive Scientific Computation (CAISS) at City College of New York. Special thanks go to Dr. Gilbert Baumslag for his support of the long term goal.

The online version of this documentation is roughly 1000 pages. In order to make printed versions we've broken it up into three volumes. The first volume is tutorial in nature. The second volume is for programmers. The third volume is reference material. We've also added a fourth volume for developers. All of these changes represent an experiment in print-on-demand delivery of documentation. Time will tell whether the experiment succeeded.

Axiom has been in existence for over thirty years. It is estimated to contain about three hundred man-years of research and has, as of September 3, 2003, 143 people listed in the credits. All of these people have contributed directly or indirectly to making Axiom available. Axiom is being passed to the next generation. I'm looking forward to future milestones.

With that in mind I've introduced the theme of the "30 year horizon". We must invent the tools that support the Computational Mathematician working 30 years from now. How will research be done when every bit of mathematical knowledge is online and instantly available? What happens when we scale Axiom by a factor of 100, giving us 1.1 million domains? How can we integrate theory with code? How will we integrate theorems and proofs of the mathematics with space-time complexity proofs and running code? What visualization tools are needed? How do we support the conceptual structures and semantics of mathematics in effective ways? How do we support results from the sciences? How do we teach the next generation to be effective Computational Mathematicians?

The "30 year horizon" is much nearer than it appears.

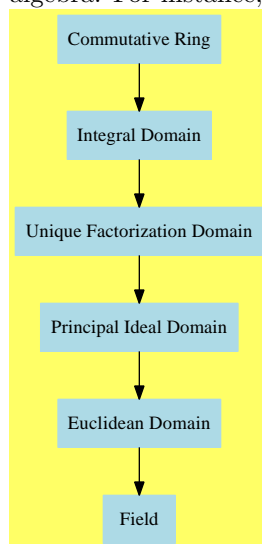
Tim Daly
CAISS, City College of New York
November 10, 2003 ((iHy))

Chapter 1

Categories

Axiom has 3 main algebra components, Categories, Domains, and Packages. If we make an analogy to dressmaking, you can consider the Categories to be hierarchies of properties of things, like patterns, colors, or fabrics. Domains are instances of things based on category choices, such as a dress with a particular style, fabric, color, etc. Packages are tools that work with dresses such as irons, sewing machines, etc.

Axiom is based on abstract algebra and uses it as a scaffolding for constructing well-formed algebra. For instance, in abstract algebra there is a strict subset hierarchy, like:



— algebrahierarchy.dotpic —

```
digraph pic {  
  fontsize=10;
```



```

bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"Commutative Ring"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=COMRING"];
"Integral Domain"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=INTDOM"];
"Unique Factorization Domain"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=UFD"];
"Principal Ideal Domain"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PID"];
"Euclidean Domain"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=EUCDOM"];
"Field"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FIELD"];

"Commutative Ring" -> "Integral Domain"
"Integral Domain" -> "Unique Factorization Domain"
"Unique Factorization Domain" -> "Principal Ideal Domain"
"Principal Ideal Domain" -> "Euclidean Domain"
"Euclidean Domain" -> "Field"

}

```

Chapter 2

Category Layer 1

In general, we use several colors in the graph images. The “lightblue” color indicates a category that is in the direct inheritance path. The “green” (#00EE00) color indicates a category or domain used in the exports. The “seagreen” (a dark green, indicates a category or domain which is used but does not correspond to the signature of an existing category. The system can infer that this “subsumption node” matches the category. A “yellow” color indicates a domain.

Category (CATEGORY)



This is the root of the category hierarchy and is not represented by code.

See:

- ⇒ “ArcHyperbolicFunctionCategory” (AHYP) [2](#) on page [13](#)
- ⇒ “ArcTrigonometricFunctionCategory” (ATRIG) [2](#) on page [15](#)
- ⇒ “BasicType” (BASTYPE) [2](#) on page [23](#)
- ⇒ “CoercibleTo” (KOERCE) [2](#) on page [33](#)
- ⇒ “CombinatorialFunctionCategory” (CFCAT) [2](#) on page [36](#)
- ⇒ “ConvertibleTo” (KONVERT) [2](#) on page [41](#)
- ⇒ “ElementaryFunctionCategory” (ELEMFUN) [2](#) on page [45](#)
- ⇒ “Eltable” (ELTAB) [2](#) on page [48](#)
- ⇒ “FullyEvaluableOver” (FEVALAB) [4](#) on page [209](#)
- ⇒ “HyperbolicFunctionCategory” (HYPCAT) [2](#) on page [53](#)
- ⇒ “InnerEvalable” (IEVALAB) [2](#) on page [56](#)

⇒ “Logic” (LOGIC) [3](#) on page [145](#)
 ⇒ “ModularAlgebraicGcdOperations” (MAGCDOC) [2](#) on page [65](#)
 ⇒ “OpenMath” (OM) [2](#) on page [76](#)
 ⇒ “PartialTranscendentalFunctions” (PTRANFN) [2](#) on page [81](#)
 ⇒ “Patternable” (PATAB) [2](#) on page [86](#)
 ⇒ “PrimitiveFunctionCategory” (PRIMCAT) [2](#) on page [89](#)
 ⇒ “RadicalCategory” (RADCAT) [2](#) on page [92](#)
 ⇒ “RetractableTo” (RETRACT) [2](#) on page [95](#)
 ⇒ “SpecialFunctionCategory” (SPFCAT) [2](#) on page [103](#)
 ⇒ “TrigonometricFunctionCategory” (TRIGCAT) [2](#) on page [106](#)
 ⇒ “Type” (TYPE) [2](#) on page [109](#)

— CATEGORY.dotabb —

```
"CATEGORY"
[color=lightblue,href="bookvol10.2.pdf#nameddest=CATEGORY"];
```

—————

— CATEGORY.dotfull —

```
"Category"
[color=lightblue,href="bookvol10.2.pdf#nameddest=CATEGORY"];
```

—————

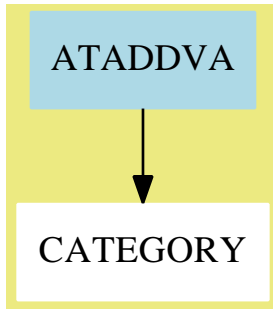
— CATEGORY.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Category" [color=lightblue];
}
```

—————

AdditiveValuationAttribute (ATADDVA)



— AdditiveValuationAttribute.input —

```

)set break resume
)sys rm -f AdditiveValuationAttribute.output
)spool AdditiveValuationAttribute.output
)set message test on
)set message auto off
)clear all
  
```

```

--S 1 of 1
1
--E 1
)spool
)lisp (bye)
  
```

— AdditiveValuationAttribute.help —

```

=====
AdditiveValuationAttribute
=====
  
```

```

The class of all euclidean domains such that
euclideanSize(a*b) = euclideanSize(a)*euclideanSize(b)
  
```

See Also:

```

o )show AdditiveValuationAttribute
  
```

— category ATADDVA AdditiveValuationAttribute —

```

)abbrev category ATADDVA AdditiveValuationAttribute
  
```

```

++ Description:
++ The class of all euclidean domains such that
++ \spad{euclideanSize(a*b) = euclideanSize(a)+euclideanSize(b)}

AdditiveValuationAttribute(): Category == with nil

```

— ATADDVA.dotabb —

```

"ATADDVA"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATADDVA" ];
"ATADDVA" -> "CATEGORY"

```

— ATADDVA.dotfull —

```

"AdditiveValuationAttribute()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATADDVA" ];
"AdditiveValuationAttribute()" -> "Category"

```

— ATADDVA.dotpic —

```

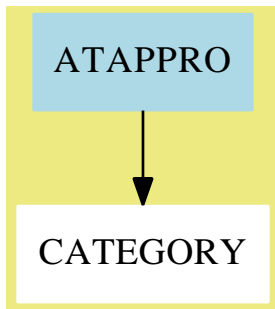
digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "AdditiveValuationAttribute()" [color=lightblue];
    "AdditiveValuationAttribute()" -> "Category"

    "Category" [color=lightblue];
}

```

ApproximateAttribute (ATAPPRO)



— ApproximateAttribute.input —

```

)set break resume
)sys rm -f ApproximateAttribute.output
)spool ApproximateAttribute.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)
  
```

—————

— ApproximateAttribute.help —

```

=====
ApproximateAttribute
=====

An approximation to the real numbers.

See Also:
o )show ApproximateAttribute
  
```

—————

— category ATAPPRO ApproximateAttribute —

```

)abbrev category ATAPPRO ApproximateAttribute
  
```

```

++ Description:
++ An approximation to the real numbers.

```

```

ApproximateAttribute(): Category == with nil

```

— ATAPPRO.dotabb —

```

"ATAPPRO"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATAPPRO"];
"ATAPPRO" -> "CATEGORY"

```

— ATAPPRO.dotfull —

```

"ApproximateAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATAPPRO"];
"ApproximateAttribute()" -> "Category"

```

— ATAPPRO.dotpic —

```

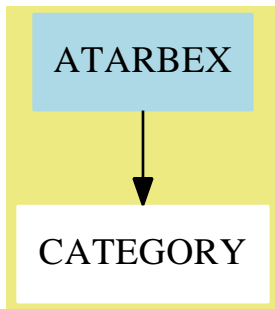
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ApproximateAttribute()" [color=lightblue];
  "ApproximateAttribute()" -> "Category"

  "Category" [color=lightblue];
}

```

ArbitraryExponentAttribute (ATARBEX)



— ArbitraryExponentAttribute.input —

```

)set break resume
)sys rm -f ArbitraryExponentAttribute.output
)spool ArbitraryExponentAttribute.output
)set message test on
)set message auto off
)clear all

```

```

--S 1 of 1
1
--E 1
)spool
)lisp (bye)

```

—————

— ArbitraryExponentAttribute.help —

```

=====
ArbitraryExponentAttribute
=====

```

Approximate numbers with arbitrarily large exponents

See Also:

```
o )show ArbitraryExponentAttribute
```

—————

— category ATARBEX ArbitraryExponentAttribute —

```
)abbrev category ATARBEX ArbitraryExponentAttribute
```



```

++ Description:
++ Approximate numbers with arbitrarily large exponents

```

```

ArbitraryExponentAttribute(): Category == with nil

```

— ATARBEX.dotabb —

```

"ATARBEX"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATARBEX"];
"ATARBEX" -> "CATEGORY"

```

— ATARBEX.dotfull —

```

"ArbitraryExponentAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATARBEX"];
"ArbitraryExponentAttribute()" -> "Category"

```

— ATARBEX.dotpic —

```

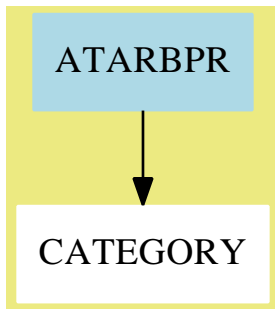
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ArbitraryExponentAttribute()" [color=lightblue];
  "ArbitraryExponentAttribute()" -> "Category"

  "Category" [color=lightblue];
}

```

ArbitraryPrecisionAttribute (ATARBPR)



— ArbitraryPrecisionAttribute.input —

```

)set break resume
)sys rm -f ArbitraryPrecisionAttribute.output
)spool ArbitraryPrecisionAttribute.output
)set message test on
)set message auto off
)clear all
  
```

```

--S 1 of 1
1
--E 1
)spool
)lisp (bye)
  
```

— ArbitraryPrecisionAttribute.help —

```

=====
ArbitraryPrecisionAttribute
=====
  
```

Approximate numbers for which the user can set the precision
for subsequent calculations.

See Also:

```
o )show ArbitraryPrecisionAttribute
```

— category ATARBPR ArbitraryPrecisionAttribute —

```

)abbrev category ATARBPR ArbitraryPrecisionAttribute
++ Description:
++ Approximate numbers for which the user can set the precision
++ for subsequent calculations.

```

```

ArbitraryPrecisionAttribute(): Category == with nil

```

— ATARBPR.dotabb —

```

"ATARBPR"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATARBPR"];
"ATARBPR" -> "CATEGORY"

```

— ATARBPR.dotfull —

```

"ArbitraryPrecisionAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATARBPR"];
"ArbitraryPrecisionAttribute()" -> "Category"

```

— ATARBPR.dotpic —

```

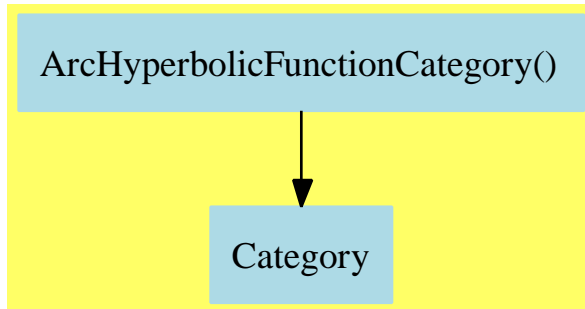
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ArbitraryPrecisionAttribute()" [color=lightblue];
  "ArbitraryPrecisionAttribute()" -> "Category"

  "Category" [color=lightblue];
}

```

ArcHyperbolicFunctionCategory (AHYP)



— ArcHyperbolicFunctionCategory.input —

```

)set break resume
)sys rm -f ArcHyperbolicFunctionCategory.output
)spool ArcHyperbolicFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ArcHyperbolicFunctionCategory
--R ArcHyperbolicFunctionCategory is a category constructor
--R Abbreviation for ArcHyperbolicFunctionCategory is AHYP
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for AHYP
--R
--R----- Operations -----
--R acosh : % -> %          acoth : % -> %
--R asch : % -> %          asech : % -> %
--R asinh : % -> %         atanh : % -> %
--R
--E 1

)spool
)lisp (bye)

```

— ArcHyperbolicFunctionCategory.help —

```

=====
ArcHyperbolicFunctionCategory examples
=====

This is the Category for the inverse hyperbolic trigonometric functions

```

See Also:

o)show ArcHyperbolicFunctionCategory

See:

⇒ “TranscendentalFunctionCategory” (TRANFUN) [3](#) on page [166](#)

⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

acosh acoth acsch asech asinh atanh

These are directly exported but not implemented:

```
acosh : % -> %
acoth : % -> %
acsch : % -> %
asech : % -> %
asinh : % -> %
atanh : % -> %
```

— category AHYP ArcHyperbolicFunctionCategory —

```
)abbrev category AHYP ArcHyperbolicFunctionCategory
```

```
++ Date Last Updated: 14 May 1991
```

```
++ Description:
```

```
++ Category for the inverse hyperbolic trigonometric functions;
```

```
ArcHyperbolicFunctionCategory(): Category == with
```

```
  acosh: $ -> $ ++ acosh(x) returns the hyperbolic arc-cosine of x.
  acoth: $ -> $ ++ acoth(x) returns the hyperbolic arc-cotangent of x.
  acsch: $ -> $ ++ acsch(x) returns the hyperbolic arc-cosecant of x.
  asech: $ -> $ ++ asech(x) returns the hyperbolic arc-secant of x.
  asinh: $ -> $ ++ asinh(x) returns the hyperbolic arc-sine of x.
  atanh: $ -> $ ++ atanh(x) returns the hyperbolic arc-tangent of x.
```

— AHYP.dotabb —

```
"AHYP"
```

```
  [color=lightblue,href="bookvol10.2.pdf#nameddest=AHYP"];
```

```
"AHYP" -> "CATEGORY"
```

— AHYP.dotfull —

```
"ArcHyperbolicFunctionCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=AHYP"];
"ArcHyperbolicFunctionCategory()" -> "Category"
```

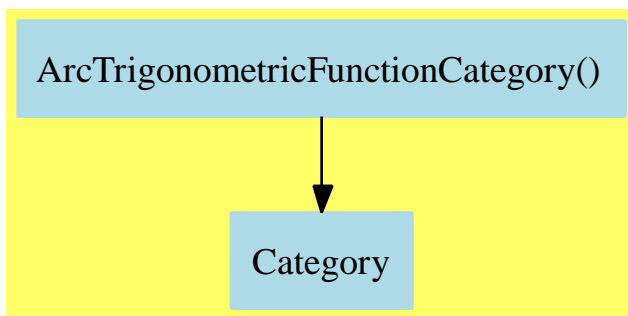
— AHYP.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ArcHyperbolicFunctionCategory()" [color=lightblue];
  "ArcHyperbolicFunctionCategory()" -> "Category"

  "Category" [color=lightblue];
}
```

ArcTrigonometricFunctionCategory (ATRIG)



The `asec` and `acsc` functions were modified to include an intermediate test to check that the argument has a reciprocal values.

— ArcTrigonometricFunctionCategory.input —

```

)set break resume
)sys rm -f ArcTrigonometricFunctionCategory.output
)spool ArcTrigonometricFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ArcTrigonometricFunctionCategory
--R ArcTrigonometricFunctionCategory is a category constructor
--R Abbreviation for ArcTrigonometricFunctionCategory is ATRIG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ATRIG
--R
--R----- Operations -----
--R acos : % -> %          acot : % -> %
--R acsc : % -> %          asec : % -> %
--R asin : % -> %          atan : % -> %
--R
--E 1

)spool
)lisp (bye)

```

— ArcTrigonometricFunctionCategory.help —

```

=====
ArcTrigonometricFunctionCategory examples
=====

```

This is the Category for the inverse trigonometric functions

See Also:

o)show ArcTrigonometricFunctionCategory

See:

⇒ “TranscendentalFunctionCategory” (TRANFUN) [3](#) on page [166](#)

⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

acos acot acsc asec asin atan

These are directly exported but not implemented:

```
acos : % -> %
acot : % -> %
asin : % -> %
atan : % -> %
```

These are implemented by this category:

```
acsc : % -> %
asec : % -> %
```

— category ATRIG ArcTrigonometricFunctionCategory —

```
)abbrev category ATRIG ArcTrigonometricFunctionCategory
++ Date Last Updated: 14 May 1991
++ Description:
++ Category for the inverse trigonometric functions;

ArcTrigonometricFunctionCategory(): Category == with
  acos: $ -> $      ++ acos(x) returns the arc-cosine of x.
  acot: $ -> $      ++ acot(x) returns the arc-cotangent of x.
  acsc: $ -> $      ++ acsc(x) returns the arc-cosecant of x.
  asec: $ -> $      ++ asec(x) returns the arc-secant of x.
  asin: $ -> $      ++ asin(x) returns the arc-sine of x.
  atan: $ -> $      ++ atan(x) returns the arc-tangent of x.
add
  if $ has Ring then
    asec(x) ==
      (a := recip x) case "failed" => error "asec: no reciprocal"
      acos(a::$)
    acsc(x) ==
      (a := recip x) case "failed" => error "acsc: no reciprocal"
      asin(a::$)
```

— ATRIG.dotabb —

```
"ATRIG"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATRIG" ];
"ATRIG" -> "CATEGORY"
```

— ATRIG.dotfull —


```
"ArcTrigonometricFunctionCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATRIG"];
"ArcTrigonometricFunctionCategory()" -> "Category"
```

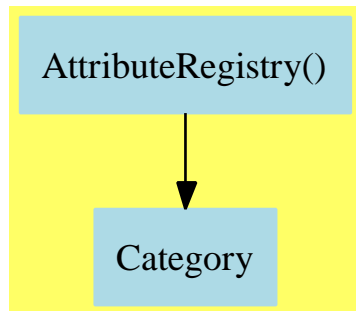
— ATRIG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ArcTrigonometricFunctionCategory()" [color=lightblue];
  "ArcTrigonometricFunctionCategory()" -> "Category"

  "Category" [color=lightblue];
}
```

AttributeRegistry (ATTREG)



— AttributeRegistry.input —

```
)set break resume
)sys rm -f AttributeRegistry.output
)spool AttributeRegistry.output
)set message test on
)set message auto off
)clear all
```

```
--S 1 of 1
)show AttributeRegistry
--E 1

)spool
)lisp (bye)
```

— AttributeRegistry.help —

=====

AttributeRegistry examples

=====

This category exports the attributes in the AXIOM Library.

See Also:

o)show BasicType

See:

⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports: Nothing

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?**(a,b) returns true if and only if **unitCanonical**(a) = **unitCanonical**(b).

- **canonicalsClosed** is true if
`unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **arbitraryPrecision** means the user can set the precision for subsequent calculations.
- **partiallyOrderedSet** is true if a set with $<$ which is transitive, but not($a < b$ or $a = b$) does not necessarily imply $b < a$.
- **central** is true if, given an algebra over a ring R , the image of R is the center of the algebra, i.e. the set of members of the algebra which commute with all others is precisely the image of R in the algebra.
- **noetherian** is true if all of its ideals are finitely generated.
- **additiveValuation** implies
`euclideanSize(a*b)=euclideanSize(a)+euclideanSize(b)`.
- **multiplicativeValuation** implies
`euclideanSize(a*b)=euclideanSize(a)*euclideanSize(b)`.
- **NullSquare** means that $[x, x] = 0$ holds. See `LieAlgebra`.
- **JacobiIdentity** means that $[x, [y, z]] + [y, [z, x]] + [z, [x, y]] = 0$ holds. See `LieAlgebra`.
- **canonical** is true if and only if distinct elements have distinct data structures. For example, a domain of mathematical objects which has the **canonical** attribute means that two objects are mathematically equal if and only if their data structures are equal.
- **approximate** means “is an approximation to the real numbers”.
- **complex** means that this domain has $\sqrt{-1}$

— category ATTREG AttributeRegistry —

```
)abbrev category ATTREG AttributeRegistry
++ Description:
++ This category exports the attributes in the AXIOM Library

AttributeRegistry(): Category == with
  finiteAggregate
    ++ \spad{finiteAggregate} is true if it is an aggregate with a
    ++ finite number of elements.
  commutative("*")
    ++ \spad{commutative("*")} is true if it has an operation
    ++ \spad{"*": (D,D) -> D} which is commutative.
  shallowlyMutable
    ++ \spad{shallowlyMutable} is true if its values
    ++ have immediate components that are updateable (mutable).
    ++ Note that the properties of any component domain are irrelevant
    ++ to the \spad{shallowlyMutable} proper.
```

```

unitsKnown
  ++ \spad{unitsKnown} is true if a monoid (a multiplicative semigroup
  ++ with a 1) has \spad{unitsKnown} means that
  ++ the operation \spadfun{recip} can only return "failed"
  ++ if its argument is not a unit.
leftUnitary
  ++ \spad{leftUnitary} is true if \spad{1 * x = x} for all x.
rightUnitary
  ++ \spad{rightUnitary} is true if \spad{x * 1 = x} for all x.
noZeroDivisors
  ++ \spad{noZeroDivisors} is true if \spad{x * y \~~= 0} implies
  ++ both x and y are non-zero.
canonicalUnitNormal
  ++ \spad{canonicalUnitNormal} is true if we can choose a canonical
  ++ representative for each class of associate elements, that is
  ++ \spad{associates?(a,b)} returns true if and only if
  ++ \spad{unitCanonical(a) = unitCanonical(b)}.
canonicalsClosed
  ++ \spad{canonicalsClosed} is true if
  ++ \spad{unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)}.
arbitraryPrecision
  ++ \spad{arbitraryPrecision} means the user can set the
  ++ precision for subsequent calculations.
partiallyOrderedSet
  ++ \spad{partiallyOrderedSet} is true if
  ++ a set with \spadop{<} which is transitive,
  ++ but \spad{not(a < b or a = b)}
  ++ does not necessarily imply \spad{b<a}.
central
  ++ \spad{central} is true if, given an algebra over a ring R, the image
  ++ of R is the center of the algebra, For example, the set of members of
  ++ the algebra which commute with all others is precisely the image of
  ++ R in the algebra.
noetherian
  ++ \spad{noetherian} is true if all of its ideals are finitely generated.
additiveValuation
  ++ \spad{additiveValuation} implies
  ++ \spad{euclideanSize(a*b)=euclideanSize(a)+euclideanSize(b)}.
multiplicativeValuation
  ++ \spad{multiplicativeValuation} implies
  ++ \spad{euclideanSize(a*b)=euclideanSize(a)*euclideanSize(b)}.
NullSquare
  ++ \axiom{NullSquare} means that \axiom{[x,x] = 0} holds.
  ++ See \axiomType{LieAlgebra}.
JacobiIdentity
  ++ \axiom{JacobiIdentity} means that
  ++ \axiom{[x,[y,z]]+[y,[z,x]]+[z,[x,y]] = 0} holds.
  ++ See \axiomType{LieAlgebra}.
canonical
  ++ \spad{canonical} is true if and only if distinct elements have

```

```

++ distinct data structures. For example, a domain of mathematical
++ objects which has the \spad{canonical} attribute means that two
++ objects are mathematically equal if and only if their data
++ structures are equal.
approximate
++ \spad{approximate} means "is an approximation to the real numbers".

```

— ATTREG.dotabb —

```

"ATTREG"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATTREG" ];
"ATTREG" -> "CATEGORY"

```

— ATTREG.dotfull —

```

"AttributeRegistry()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATTREG" ];
"AttributeRegistry()" -> "Category"

```

— ATTREG.dotpic —

```

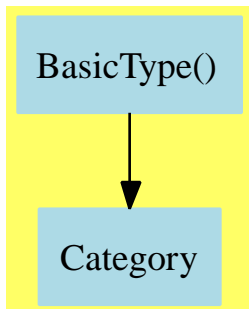
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "AttributeRegistry()" [color=lightblue];
  "AttributeRegistry()" -> "Category"

  "Category" [color=lightblue];
}

```

BasicType (BASTYPE)



— BasicType.input —

```

)set break resume
)sys rm -f BasicType.output
)spool BasicType.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show BasicType
--R BasicType is a category constructor
--R Abbreviation for BasicType is BASTYPE
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for BASTYPE
--R
--R----- Operations -----
--R ?=? : (%,% ) -> Boolean          ?~=? : (%,% ) -> Boolean
--R
--E 1

)spool
)lisp (bye)
  
```

— BasicType.help —

```

=====
BasicType examples
=====
  
```

```

BasicType is the basic category for describing a collection
of elements with = (equality).
  
```

See Also:

o `)show BasicType`

See:

⇒ “BlowUpMethodCategory” (BLMETCT) [4](#) on page [177](#)

⇒ “SetCategory” (SETCAT) [3](#) on page [162](#)

⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

`?=? ?~=?`

These are directly exported but not implemented:

`?=? : (%,%) -> Boolean`

These are implemented by this category:

`?~=? : (%,%) -> Boolean`

— category **BATYPE** **BasicType** —

```
)abbrev category BATYPE BasicType
--% BasicType
++ Description:
++ BasicType is the basic category for describing a collection
++ of elements with = (equality).

BasicType(): Category == with
  "=: (%,% ) -> Boolean    ++ x=y tests if x and y are equal.
  "~=: (%,% ) -> Boolean  ++ x~y tests if x and y are not equal.
add
  _~_(x:%,y:%) : Boolean == not(x=y)
```

— **BATYPE.dotabb** —

```
"BATYPE"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=BATYPE" ];
"BATYPE" -> "CATEGORY"
```

— BASTYPE.dotfull —

```
"BasicType()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=BASTYPE"];
"BasicType()" -> "Category"
```

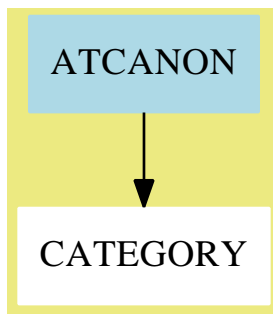
— BASTYPE.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "Category" [color=lightblue];
}
```

CanonicalAttribute (ATCANON)



— CanonicalAttribute.input —

```
)set break resume
)sys rm -f CanonicalAttribute.output
)spool CanonicalAttribute.output
```



```
)set message test on
)set message auto off
)clear all
```

```
--S 1 of 1
1
--E 1
)spool
)lisp (bye)
```

— CanonicalAttribute.help —

```
=====
CanonicalAttribute
=====
```

The class of all domains which have canonical representation,
that is, mathematically equal elements have the same data structure.

See Also:
o)show CanonicalAttribute

— category ATCANON CanonicalAttribute —

```
)abbrev category ATCANON CanonicalAttribute
++ Description:
++ The class of all domains which have canonical representation,
++ that is, mathematically equal elements have the same data structure.
```

```
CanonicalAttribute(): Category == with nil
```

— ATCANON.dotabb —

```
"ATCANON"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATCANON"];
"ATCANON" -> "CATEGORY"
```

— ATCANON.dotfull —

```
"CanonicalAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATCANON"];
"CanonicalAttribute()" -> "Category"
```

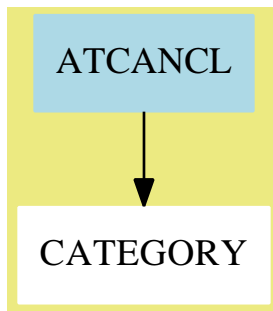
— ATCANON.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CanonicalAttribute()" [color=lightblue];
  "CanonicalAttribute()" -> "Category"

  "Category" [color=lightblue];
}
```

CanonicalClosedAttribute (ATCANCL)



— CanonicalClosedAttribute.input —

```
)set break resume
)sys rm -f CanonicalClosedAttribute.output
)spool CanonicalClosedAttribute.output
)set message test on
```

```

)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)

```

— CanonicalClosedAttribute.help —

```

=====
CanonicalClosedAttribute
=====

The class of all integral domains such that
unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)

See Also:
o )show CanonicalClosedAttribute

```

— category ATCANCL CanonicalClosedAttribute —

```

)abbrev category ATCANCL CanonicalClosedAttribute
++ Description:
++ The class of all integral domains such that
++ \spad{unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)}

CanonicalClosedAttribute(): Category == with nil

```

— ATCANCL.dotabb —

```

"ATCANCL"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATCANCL"];
"ATCANCL" -> "CATEGORY"

```

— ATCANCL.dotfull —

```
"CanonicalClosedAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATCANCL"];
"CanonicalClosedAttribute()" -> "Category"
```

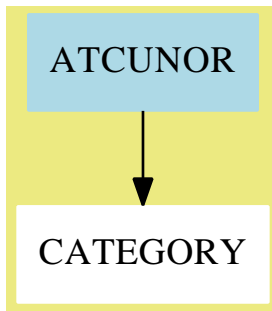
— ATCANCL.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CanonicalClosedAttribute()" [color=lightblue];
  "CanonicalClosedAttribute()" -> "Category"

  "Category" [color=lightblue];
}
```

CanonicalUnitNormalAttribute (ATCUNOR)



— CanonicalUnitNormalAttribute.input —

```
)set break resume
)sys rm -f CanonicalUnitNormalAttribute.output
)spool CanonicalUnitNormalAttribute.output
)set message test on
)set message auto off
)clear all
```

```
--S 1 of 1
1
--E 1
)spool
)lisp (bye)
```

— CanonicalUnitNormalAttribute.help —

```
=====
CanonicalUnitNormalAttribute
=====
```

The class of all integral domains such that we can choose a canonical representative for each class of associate elements. That is, `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`

See Also:
o `)show CanonicalUnitNormalAttribute`

— category ATCUNOR CanonicalUnitNormalAttribute —

```
)abbrev category ATCUNOR CanonicalUnitNormalAttribute
++ Description:
++ The class of all integral domains such that we can choose a canonical
++ representative for each class of associate elements. That is,
++ \spad{associates?(a,b)} returns true if and only if
++ \spad{unitCanonical(a)} = \spad{unitCanonical(b)}
```

```
CanonicalUnitNormalAttribute(): Category == with nil
```

— ATCUNOR.dotabb —

```
"ATCUNOR"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATCUNOR"];
"ATCUNOR" -> "CATEGORY"
```

— ATCUNOR.dotfull —

```
"CanonicalUnitNormalAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATCUNOR"];
"CanonicalUnitNormalAttribute()" -> "Category"
```

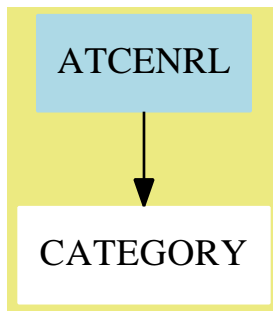
— ATCUNOR.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CanonicalUnitNormalAttribute()" [color=lightblue];
  "CanonicalUnitNormalAttribute()" -> "Category"

  "Category" [color=lightblue];
}
```

CentralAttribute (ATCENRL)



— CentralAttribute.input —

```
)set break resume
)sys rm -f CentralAttribute.output
)spool CentralAttribute.output
)set message test on
```

```

)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)

```

— CentralAttribute.help —

```

=====
CentralAttribute
=====

```

Central is true if, given an algebra over a ring R , the image of R is the center of the algebra. For example, the set of members of the algebra which commute with all others is precisely the image of R in the algebra.

See Also:
o)show CentralAttribute

— category ATCENRL CentralAttribute —

```

)abbrev category ATCENRL CentralAttribute
++ Description:
++ Central is true if, given an algebra over a ring R, the image of R
++ is the center of the algebra. For example, the set of members of the
++ algebra which commute with all others is precisely the image of R
++ in the algebra.

CentralAttribute(): Category == with nil

```

— ATCENRL.dotabb —

```

"ATCENRL"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATCENRL"];

```

"ATCENRL" -> "CATEGORY"

— ATCENRL.dotfull —

```
"CentralAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATCENRL"];
"CentralAttribute()" -> "Category"
```

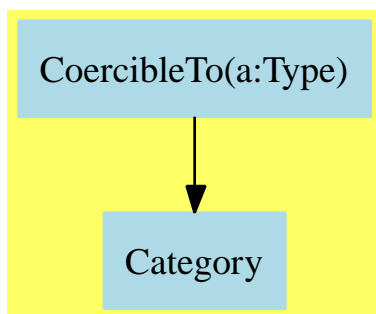
— ATCENRL.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CentralAttribute()" [color=lightblue];
  "CentralAttribute()" -> "Category"

  "Category" [color=lightblue];
}
```

CoercibleTo (KOERCE)



— CoercibleTo.input —


```

)set break resume
)sys rm -f CoercibleTo.output
)spool CoercibleTo.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show CoercibleTo
--R
--R CoercibleTo(S: Type) is a category constructor
--R Abbreviation for CoercibleTo is KOERCE
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for KOERCE
--R
--R----- Operations -----
--R coerce : % -> S
--R
--E 1

)spool
)lisp (bye)

```

— CoercibleTo.help —

=====

CoercibleTo examples

=====

A is coercible to B means any element of A can automatically be converted into an element of B by the interpreter.

See Also:

o)show CoercibleTo

See:

- ⇒ “BlowUpMethodCategory” (BLMETCT) [4](#) on page [177](#)
- ⇒ “DirectProductCategory” (DIRPCAT) [12](#) on page [1051](#)
- ⇒ “FortranProgramCategory” (FORTCAT) [3](#) on page [133](#)
- ⇒ “PlottablePlaneCurveCategory” (PPCURVE) [3](#) on page [148](#)
- ⇒ “PlottableSpaceCurveCategory” (PSCURVE) [3](#) on page [151](#)
- ⇒ “PolynomialSetCategory” (PSETCAT) [6](#) on page [520](#)

⇒ “SetCategory” (SETCAT) 3 on page 162

⇐ “Category” (CATEGORY) 2 on page 3

Exports:

coerce

This is directly exported but not implemented:

```
coerce : % -> S
```

— category KOERCE CoercibleTo —

```
)abbrev category KOERCE CoercibleTo
++ Author: Manuel Bronstein
++ Date Last Updated: 14 May 1991
++ Description:
++ A is coercible to B means any element of A can automatically be
++ converted into an element of B by the interpreter.
```

```
CoercibleTo(S:Type): Category == with
  coerce: % -> S
  ++ coerce(a) transforms a into an element of S.
```

— KOERCE.dotabb —

```
"KOERCE"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=KOERCE"];
"KOERCE" -> "CATEGORY"
```

— KOERCE.dotfull —

```
"CoercibleTo(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=KOERCE"];
"CoercibleTo(a:Type)" -> "Category"

"CoercibleTo(OutputForm)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KOERCE"];
"CoercibleTo(OutputForm)" ->
  "CoercibleTo(a:Type)"
```

```
"CoercibleTo(List(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet()))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KOERCE"];
"CoercibleTo(List(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet()))"
  -> "CoercibleTo(a:Type)"
```

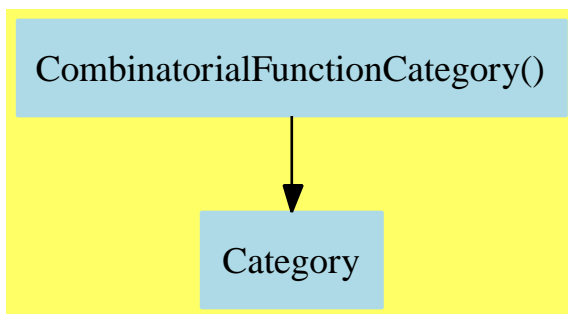
— KOERCE.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

CombinatorialFunctionCategory (CFCAT)



— CombinatorialFunctionCategory.input —

```
)set break resume
)sys rm -f CombinatorialFunctionCategory.output
)spool CombinatorialFunctionCategory.output
)set message test on
)set message auto off
```

```

)clear all

--S 1 of 1
)show CombinatorialFunctionCategory
--R CombinatorialFunctionCategory is a category constructor
--R Abbreviation for CombinatorialFunctionCategory is CFCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for CFCAT
--R
--R----- Operations -----
--R binomial : (%,% ) -> %          factorial : % -> %
--R permutation : (%,% ) -> %
--R
--E 1

)spool
)lisp (bye)

```

— CombinatorialFunctionCategory.help —

=====

CombinatorialFunctionCategory examples

=====

This is the Category for the usual combinatorial functions

See Also:

o)show CombinatorialFunctionCategory

See:

⇒ “CombinatorialOpsCategory” (COMBOPC) [3](#) on page [119](#)

⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)

⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

binomial factorial permutation

These are directly exported but not implemented:

```

binomial : (%,% ) -> %
factorial : % -> %
permutation : (%,% ) -> %

```

— category CFCAT CombinatorialFunctionCategory —

```

)abbrev category CFCAT CombinatorialFunctionCategory
++ Author: Manuel Bronstein
++ Date Last Updated: 14 May 1991
++ Description:
++ Category for the usual combinatorial functions;

CombinatorialFunctionCategory(): Category == with
  binomial : ($, $) -> $
    ++ binomial(n,r) returns the \spad{(n,r)} binomial coefficient
    ++ (often denoted in the literature by \spad{C(n,r)}).
    ++ Note that \spad{C(n,r) = n!/(r!(n-r)!)} where \spad{n >= r >= 0}.
    ++
    ++X [binomial(5,i) for i in 0..5]
  factorial : $ -> $
    ++ factorial(n) computes the factorial of n
    ++ (denoted in the literature by \spad{n!})
    ++ Note that \spad{n! = n (n-1)! when n > 0}; also, \spad{0! = 1}.
  permutation: ($, $) -> $
    ++ permutation(n, m) returns the number of
    ++ permutations of n objects taken m at a time.
    ++ Note that \spad{permutation(n,m) = n!/(n-m)!}.

```

— CFCAT.dotabb —

```

"CFCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=CFCAT"];
"CFCAT" -> "CATEGORY"

```

— CFCAT.dotfull —

```

"CombinatorialFunctionCategory()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=CFCAT"];
"CombinatorialFunctionCategory()" -> "Category"

```

— CFCAT.dotpic —

```

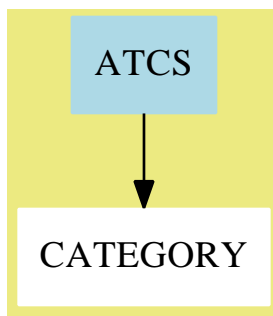
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CombinatorialFunctionCategory()" [color=lightblue];
  "CombinatorialFunctionCategory()" -> "Category"

  "Category" [color=lightblue];
}

```

CommutativeStarAttribute (ATCS)



— CommutativeStarAttribute.input —

```

)set break resume
)sys rm -f CommutativeStarAttribute.output
)spool CommutativeStarAttribute.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)

```

— CommutativeStarAttribute.help —

```
=====
CommutativeStarAttribute
=====
```

The class of all commutative semigroups in multiplicative notation.
 In other words domain D with $"*": (D,D) \rightarrow D$ which is commutative.
 Typically applied to rings.

See Also:

o)show CommutativeStarAttribute

— category ATCS CommutativeStarAttribute —

```
)abbrev category ATCS CommutativeStarAttribute
++ Description:
++ The class of all commutative semigroups in multiplicative notation.
++ In other words domain \spad{D} with \spad{"*": (D,D) -> D} which is
++ commutative. Typically applied to rings.
```

```
CommutativeStarAttribute(): Category == with nil
```

— ATCS.dotabb —

```
"ATCS"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATCS" ];
"ATCS" -> "CATEGORY"
```

— ATCS.dotfull —

```
"CommutativeStarAttribute()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATCS" ];
"CommutativeStarAttribute()" -> "Category"
```

— ATCS.dotpic —

```

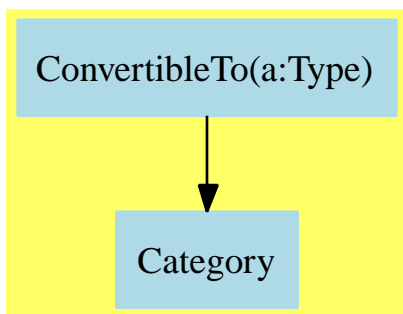
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CommutativeStarAttribute()" [color=lightblue];
  "CommutativeStarAttribute()" -> "Category"

  "Category" [color=lightblue];
}

```

ConvertibleTo (KONVERT)



— ConvertibleTo.input —

```

)set break resume
)sys rm -f ConvertibleTo.output
)spool ConvertibleTo.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ConvertibleTo
--R
--R ConvertibleTo(S: Type) is a category constructor
--R Abbreviation for ConvertibleTo is KONVERT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for KONVERT
--R
--R----- Operations -----

```



```
--R convert : % -> S
--R
--E 1
```

```
)spool
)lisp (bye)
```

— ConvertibleTo.help —

```
=====
ConvertibleTo examples
=====
```

A is convertible to B means any element of A can be converted into an element of B, but not automatically by the interpreter.

See Also:

o)show ConvertibleTo

See:

⇒ “Collection” (CLAGG) [5](#) on page [341](#)
 ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
 ⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)
 ⇒ “MonogenicAlgebra” (MONOGEN) [19](#) on page [1651](#)
 ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
 ⇒ “RealConstant” (REAL) [3](#) on page [155](#)
 ⇒ “RealNumberSystem” (RNS) [17](#) on page [1451](#)
 ⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

convert

This is directly exported but not implemented:

```
convert : % -> S
```

— category KONVERT ConvertibleTo —

```
)abbrev category KONVERT ConvertibleTo
++ Author: Manuel Bronstein
```

```

++ Date Last Updated: 14 May 1991
++ Description:
++ A is convertible to B means any element of A
++ can be converted into an element of B,
++ but not automatically by the interpreter.

```

```

ConvertibleTo(S:Type): Category == with
  convert: % -> S
  ++ convert(a) transforms a into an element of S.

```

— KONVERT.dotabb —

```

"KONVERT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=KONVERT"];
"KONVERT" -> "CATEGORY"

```

— KONVERT.dotfull —

```

"ConvertibleTo(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(a:Type)" -> "Category"

"ConvertibleTo(DoubleFloat)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(DoubleFloat)" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(Float)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(Float)" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(InputForm)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(InputForm)" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(Integer)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(Integer)" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(Pattern(Integer))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(Pattern(Integer))" -> "ConvertibleTo(a:Type)"

```

```

"ConvertibleTo(Pattern(Float))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(Pattern(Float))" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(Complex(Float))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(Complex(Float))" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(Complex(DoubleFloat))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(Complex(DoubleFloat))" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(String)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(String)" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(Symbol)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(Symbol)" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(SExpression)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(SExpression)" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(Pattern(Base))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(Pattern(Base))" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(List(Integer))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(List(Integer))" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(List(Character))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(List(Character))" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(UnivariatePolynomialCategory(CommutativeRing))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=KONVERT"];
"ConvertibleTo(UnivariatePolynomialCategory(CommutativeRing))" ->
  "ConvertibleTo(a:Type)"

```

— KONVERT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";

```

```

node [shape=box, color=white, style=filled];

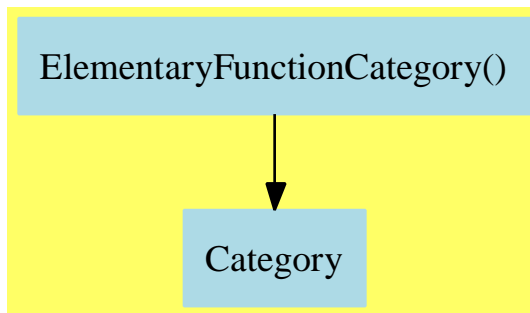
"ConvertibleTo(a:Type)" [color=lightblue];
"ConvertibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];
}

```

—————

ElementaryFunctionCategory (ELEMFUN)



— ElementaryFunctionCategory.input —

```

)set break resume
)sys rm -f ElementaryFunctionCategory.output
)spool ElementaryFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ElementaryFunctionCategory
--R ElementaryFunctionCategory is a category constructor
--R Abbreviation for ElementaryFunctionCategory is ELEMFUN
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ELEMFUN
--R
--R----- Operations -----
--R ***? : (%,%) -> %          exp : % -> %
--R log : % -> %
--R
--E 1

```

```
)spool
)lisp (bye)
```

— ElementaryFunctionCategory.help —

```
=====
ElementaryFunctionCategory examples
=====
```

This is the Category for the elementary functions.

See Also:

o)show ElementaryFunctionCategory

See:

⇒ “TranscendentalFunctionCategory” (TRANFUN) [3](#) on page [166](#)

⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

```
***? exp log
```

These are directly exported but not implemented:

```
exp : % -> %
log : % -> %
```

These are implemented by this category:

```
***? : (%,% ) -> %
```

— category ELEMFUN ElementaryFunctionCategory —

```
)abbrev category ELEMFUN ElementaryFunctionCategory
++ Category for the elementary functions
++ Author: Manuel Bronstein
++ Date Last Updated: 14 May 1991
++ Description:
++ Category for the elementary functions;
```

```
ElementaryFunctionCategory(): Category == with
```

```

log : $ -> $      ++ log(x) returns the natural logarithm of x.
exp : $ -> $      ++ exp(x) returns %e to the power x.
"**": ($, $) -> $ ++ x**y returns x to the power y.
add
  if $ has Monoid then
    x ** y == exp(y * log x)

```

— **ELEMFUN.dotabb** —

```

"ELEMFUN"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ELEMFUN"];
"ELEMFUN" -> "CATEGORY"

```

— **ELEMFUN.dotfull** —

```

"ElementaryFunctionCategory()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ELEMFUN"];
"ElementaryFunctionCategory()" -> "Category"

```

— **ELEMFUN.dotpic** —

```

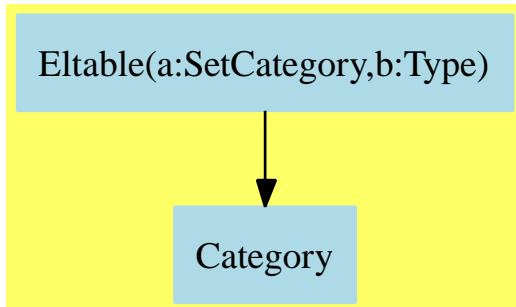
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ElementaryFunctionCategory()" [color=lightblue];
  "ElementaryFunctionCategory()" -> "Category"

  "Category" [color=lightblue];
}

```

Eltable (ELTAB)



— Eltable.input —

```

)set break resume
)sys rm -f Eltable.output
)spool Eltable.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show Eltable
--R Eltable(S: SetCategory,Index: Type) is a category constructor
--R Abbreviation for Eltable is ELTAB
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ELTAB
--R
--R----- Operations -----
--R ?.? : (% ,S) -> Index
--R
--E 1

)spool
)lisp (bye)

```

— Eltable.help —

```

=====
Eltable examples
=====

```

An eltable over domains D and I is a structure which can be viewed as a function from D to I. Examples of eltable structures range from

data structures, e.g. those of type `List`, to algebraic structures like `Polynomial`.

See Also:

o `)show Eltable`

See:

⇒ “`EltableAggregate`” (`ELTAGG`) [3](#) on page [125](#)

⇒ “`LinearOrdinaryDifferentialOperatorCategory`” (`LODOCAT`) [11](#) on page [1023](#)

⇒ “`UnivariatePolynomialCategory`” (`UPOLYC`) [17](#) on page [1522](#)

⇐ “`Category`” (`CATEGORY`) [2](#) on page [3](#)

Exports:

???

This syntax for `elt` is supported by the interpreter and compiler.

This is directly exported but not implemented:

??? : `(%,S) -> Index`

— category **ELTAB Eltable** —

```
)abbrev category ELTAB Eltable
++ Author: Michael Monagan; revised by Manuel Bronstein and Manuel Bronstein
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ An eltable over domains D and I is a structure which can be viewed
++ as a function from D to I. Examples of eltable structures range from
++ data structures, For example, those of type List, to algebraic
++ structures like Polynomial.
```

```
Eltable(S:SetCategory, Index:Type): Category == with
  elt : (%, S) -> Index
    ++ elt(u,i) (also written: u . i) returns the element of u indexed by i.
    ++ Error: if i is not an index of u.
```

— **ELTAB.dotabb** —

"ELTAB" [color=lightblue,href="bookvol10.2.pdf#nameddest=ELTAB"];

"ELTAB" -> "CATEGORY"

— ELTAB.dotfull —

```
"Eltable(a:SetCategory,b:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ELTAB"];
"Eltable(a:SetCategory,b:Type)" -> "Category"

"Eltable(a:UnivariatePolynomialCategory(a:Ring),b:UnivariatePolynomialCategory(a:Ring))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ELTAB"];
"Eltable(a:UnivariatePolynomialCategory(a:Ring),b:UnivariatePolynomialCategory(a:Ring))" ->
  "Eltable(a:SetCategory,b:Type)"

"Eltable(a:Ring,b:Ring)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ELTAB"];
"Eltable(a:Ring,b:Ring)" ->
  "Eltable(a:SetCategory,b:Type)"

"Eltable(a:SetCategory,b:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ELTAB"];
"Eltable(a:SetCategory,b:SetCategory)" ->
  "Eltable(a:SetCategory,b:Type)"
```

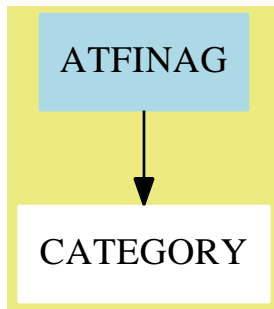
— ELTAB.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Eltable(a:SetCategory,b:Type)" [color=lightblue];
  "Eltable(a:SetCategory,b:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

FiniteAggregateAttribute (ATFINAG)



— FiniteAggregateAttribute.input —

```

)set break resume
)sys rm -f FiniteAggregateAttribute.output
)spool FiniteAggregateAttribute.output
)set message test on
)set message auto off
)clear all
  
```

```

--S 1 of 1
1
--E 1
)spool
)lisp (bye)
  
```

—————

— FiniteAggregateAttribute.help —

```

=====
FiniteAggregateAttribute
=====
  
```

The class of all aggregates with a finite number of arguments

See Also:

```

o )show FiniteAggregateAttribute
  
```

—————

— category ATFINAG FiniteAggregateAttribute —

```

)abbrev category ATFINAG FiniteAggregateAttribute
  
```

```

++ Description:
++ The class of all aggregates with a finite number of arguments

```

```

FiniteAggregateAttribute(): Category == with nil

```

— ATFINAG.dotabb —

```

"ATFINAG"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATFINAG"];
"ATFINAG" -> "CATEGORY"

```

— ATFINAG.dotfull —

```

"FiniteAggregateAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATFINAG"];
"FiniteAggregateAttribute()" -> "Category"

```

— ATFINAG.dotpic —

```

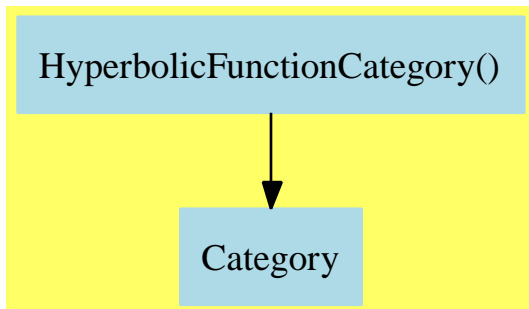
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FiniteAggregateAttribute()" [color=lightblue];
  "FiniteAggregateAttribute()" -> "Category"

  "Category" [color=lightblue];
}

```

HyperbolicFunctionCategory (HYPCAT)



The `csch` and `sech` functions were modified to include an intermediate test to check that the argument has a reciprocal values.

— HyperbolicFunctionCategory.input —

```

)set break resume
)sys rm -f HyperbolicFunctionCategory.output
)spool HyperbolicFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show HyperbolicFunctionCategory
--R HyperbolicFunctionCategory is a category constructor
--R Abbreviation for HyperbolicFunctionCategory is HYPCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for HYPCAT
--R
--R----- Operations -----
--R cosh : % -> %           coth : % -> %
--R csch : % -> %           sech : % -> %
--R sinh : % -> %          tanh : % -> %
--R
--E 1

)spool
)lisp (bye)

```

— HyperbolicFunctionCategory.help —

```
=====
```

HyperbolicFunctionCategory examples

=====

This is the Category for the hyperbolic trigonometric functions.

See Also:

o)show HyperbolicFunctionCategory

See:

⇒ “TranscendentalFunctionCategory” (TRANFUN) [3](#) on page [166](#)

⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

cosh coth csch sech sinh tanh

These are implemented by this category:

```
cosh : % -> %
coth : % -> %
csch : % -> %
sech : % -> %
sinh : % -> %
tanh : % -> %
```

— category HYPCAT HyperbolicFunctionCategory —

```
)abbrev category HYPCAT HyperbolicFunctionCategory
```

```
++ Date Last Updated: 14 May 1991
```

```
++ Category for the hyperbolic trigonometric functions;
```

```
HyperbolicFunctionCategory(): Category == with
```

```
  cosh: $ -> $      ++ cosh(x) returns the hyperbolic cosine of x.
  coth: $ -> $      ++ coth(x) returns the hyperbolic cotangent of x.
  csch: $ -> $      ++ csch(x) returns the hyperbolic cosecant of x.
  sech: $ -> $      ++ sech(x) returns the hyperbolic secant of x.
  sinh: $ -> $      ++ sinh(x) returns the hyperbolic sine of x.
  tanh: $ -> $      ++ tanh(x) returns the hyperbolic tangent of x.
```

```
add
```

```
  if $ has Ring then
```

```
    csch x ==
```

```
      (a := recip(sinh x)) case "failed" => error "csch: no reciprocal"
```

```
      a::$
```

```
    sech x ==
```

```
      (a := recip(cosh x)) case "failed" => error "sech: no reciprocal"
```

```

a::$
tanh x == sinh x * sech x
coth x == cosh x * csch x
if $ has ElementaryFunctionCategory then
  cosh x ==
    e := exp x
    (e + recip(e)::$) * recip(2::$)::$
sinh(x):$ ==
  e := exp x
  (e - recip(e)::$) * recip(2::$)::$

```

— HYPCAT.dotabb —

```

"HYPCAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=HYPCAT" ];
"HYPCAT" -> "CATEGORY"

```

— HYPCAT.dotfull —

```

"HyperbolicFunctionCategory()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=HYPCAT" ];
"HyperbolicFunctionCategory()" -> "Category"

```

— HYPCAT.dotpic —

```

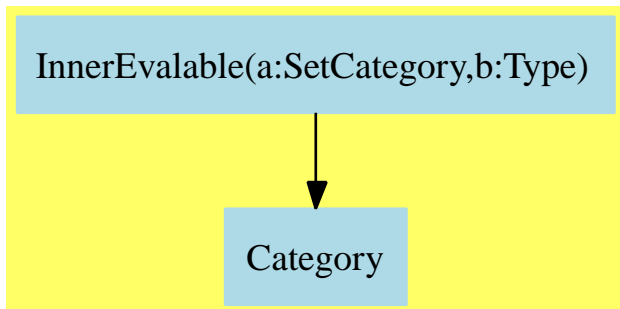
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "HyperbolicFunctionCategory()" [color=lightblue];
  "HyperbolicFunctionCategory()" -> "Category"

  "Category" [color=lightblue];
}

```

InnerEvalable (IEVALAB)



— InnerEvalable.input —

```

)set break resume
)sys rm -f InnerEvalable.output
)spool InnerEvalable.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show InnerEvalable
--R
--R InnerEvalable(A: SetCategory,B: Type) is a category constructor
--R Abbreviation for InnerEvalable is IEVALAB
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for IEVALAB
--R
--R----- Operations -----
--R eval : (%,A,B) -> %          eval : (%,List(A),List(B)) -> %
--R
--E 1

)spool
)lisp (bye)

```

— InnerEvalable.help —

```

=====
InnerEvalable examples
=====

This category provides eval operations. A domain may belong to this

```

category if it is possible to make "evaluation" substitutions. The difference between this and Evalable is that the operations in this category specify the substitution as a pair of arguments rather than as an equation.

See Also:

o)show InnerEvalable

See:

⇒ "DesingTreeCategory" (DSTRCAT) [4](#) on page [181](#)
 ⇒ "Evalable" (EVALAB) [3](#) on page [129](#)
 ⇒ "ExpressionSpace" (ES) [5](#) on page [355](#)
 ⇒ "MultivariateTaylorSeriesCategory" (MTSCAT) [15](#) on page [1243](#)
 ⇒ "PolynomialCategory" (POLYCAT) [16](#) on page [1305](#)
 ⇐ "Category" (CATEGORY) [2](#) on page [3](#)

Exports:

eval

These are directly exported but not implemented:

```
eval : (% , A, B) -> %
```

These are implemented by this category:

```
eval : (% , List A, List B) -> %
```

— category IEVALAB InnerEvalable —

```
)abbrev category IEVALAB InnerEvalable
-- FOR THE BENEFIT OF LIBAXO GENERATION
++ Date Last Updated: June 3, 1991
++ Description:
++ This category provides \spadfun{eval} operations.
++ A domain may belong to this category if it is possible to make
++ 'evaluation' substitutions. The difference between this
++ and \spadtype{Evalable} is that the operations in this category
++ specify the substitution as a pair of arguments rather than as
++ an equation.
```

```
InnerEvalable(A:SetCategory, B:Type): Category == with
  eval: ($, A, B) -> $
  ++ eval(f, x, v) replaces x by v in f.
```



```

eval: ($, List A, List B) -> $
  ++ eval(f, [x1,...,xn], [v1,...,vn]) replaces xi by vi in f.
add
  eval(f:$, x:A, v:B) == eval(f, [x], [v])

```

— IEVALAB.dotabb —

```

"IEVALAB"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=IEVALAB"];
"IEVALAB" -> "CATEGORY"

```

— IEVALAB.dotfull —

```

"InnerEvalable(a:SetCategory,b:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=IEVALAB"];
"InnerEvalable(a:SetCategory,b:Type)" -> "Category"

```

```

"InnerEvalable(a:SetCategory,b:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=IEVALAB"];
"InnerEvalable(a:SetCategory,b:SetCategory)" ->
  "InnerEvalable(a:SetCategory,b:Type)"

```

```

"InnerEvalable(a:OrderedSet,b:Ring)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=IEVALAB"];
"InnerEvalable(a:OrderedSet,b:Ring)" ->
  "InnerEvalable(a:SetCategory,b:Type)"

```

```

"InnerEvalable(a:OrderedSet,b:PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=IEVALAB"];
"InnerEvalable(a:OrderedSet,b:PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  "InnerEvalable(a:SetCategory,b:Type)"

```

```

"InnerEvalable(a:Ring,MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=IEVALAB"];
"InnerEvalable(a:Ring,MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet))"
  -> "InnerEvalable(a:SetCategory,b:Type)"

```

```

"InnerEvalable(Kernal(ExpressionSpace),ExpressionSpace)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=IEVALAB"];
"InnerEvalable(Kernal(ExpressionSpace),ExpressionSpace)" ->
  "InnerEvalable(a:SetCategory,b:Type)"

```

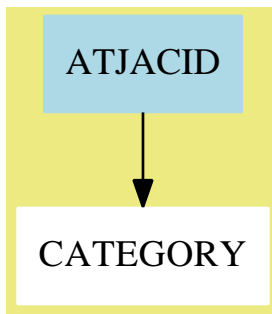
— IEVALAB.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "InnerEvalable(a:SetCategory,b:Type)" [color=lightblue];
  "InnerEvalable(a:SetCategory,b:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

JacobiIdentityAttribute (ATJACID)



— JacobiIdentityAttribute.input —

```
)set break resume
)sys rm -f JacobiIdentityAttribute.output
)spool JacobiIdentityAttribute.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)
```

— JacobiIdentityAttribute.help —

```
=====
JacobiIdentityAttribute
=====
```

JacobiIdentity means that $[x, [y, z]] + [y, [z, x]] + [z, [x, y]] = 0$ holds.
See LieAlgebra.

See Also:

o)show JacobiIdentityAttribute

— category ATJACID JacobiIdentityAttribute —

```
)abbrev category ATJACID JacobiIdentityAttribute
++ Description:
++ JacobiIdentity means that \spad{[x,[y,z]]+[y,[z,x]]+[z,[x,y]] = 0} holds.
++ See LieAlgebra.
```

```
JacobiIdentityAttribute(): Category == with nil
```

— ATJACID.dotabb —

```
"ATJACID"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATJACID"];
"ATJACID" -> "CATEGORY"
```

— ATJACID.dotfull —

```
"JacobiIdentityAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATJACID"];
"JacobiIdentityAttribute()" -> "Category"
```

— ATJACID.dotpic —

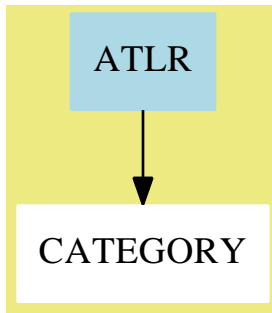
```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "JacobiIdentityAttribute()" [color=lightblue];
  "JacobiIdentityAttribute()" -> "Category"

  "Category" [color=lightblue];
}
```

—————

LazyRepresentationAttribute (ATLR)



— LazyRepresentationAttribute.input —

```
)set break resume
)sys rm -f LazyRepresentationAttribute.output
)spool LazyRepresentationAttribute.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)
```

—————

— LazyRepresentationAttribute.help —

```
=====
LazyRepresentationAttribute
=====
```

The class of all domains which have a lazy representation

See Also:

o)show LazyRepresentationAttribute

— category ATLR LazyRepresentationAttribute —

```
)abbrev category ATLR LazyRepresentationAttribute
```

```
++ Description:
```

```
++ The class of all domains which have a lazy representation
```

```
LazyRepresentationAttribute(): Category == with nil
```

— ATLR.dotabb —

```
"ATLR"
```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATLR"];
```

```
"ATLR" -> "CATEGORY"
```

— ATLR.dotfull —

```
"LazyRepresentationAttribute()"
```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATLR"];
```

```
"LazyRepresentationAttribute()" -> "Category"
```

— ATLR.dotpic —

```

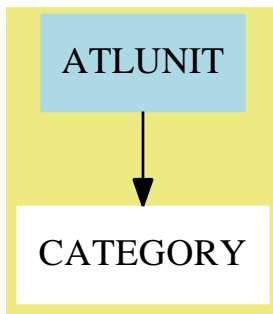
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "LazyRepresentationAttribute()" [color=lightblue];
  "LazyRepresentationAttribute()" -> "Category"

  "Category" [color=lightblue];
}

```

LeftUnitaryAttribute (ATLUNIT)



— LeftUnitaryAttribute.input —

```

)set break resume
)sys rm -f LeftUnitaryAttribute.output
)spool LeftUnitaryAttribute.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)

```

— LeftUnitaryAttribute.help —

```
=====
LeftUnitaryAttribute
=====
```

LeftUnitary is true if $1 * x = x$ for all x .

See Also:

o)show LeftUnitaryAttribute

— category ATLUNIT LeftUnitaryAttribute —

```
)abbrev category ATLUNIT LeftUnitaryAttribute
++ Description:
++ LeftUnitary is true if \spad{1 * x = x} for all x.
```

```
LeftUnitaryAttribute(): Category == with nil
```

— ATLUNIT.dotabb —

```
"ATLUNIT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATLUNIT" ];
"ATLUNIT" -> "CATEGORY"
```

— ATLUNIT.dotfull —

```
"LeftUnitaryAttribute()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATLUNIT" ];
"LeftUnitaryAttribute()" -> "Category"
```

— ATLUNIT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
```

```

node [shape=box, color=white, style=filled];

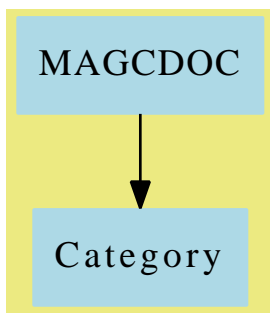
"LeftUnitaryAttribute()" [color=lightblue];
"LeftUnitaryAttribute()" -> "Category"

"Category" [color=lightblue];
}

```

—————

ModularAlgebraicGcdOperations (MAGCDOC)



— ModularAlgebraicGcdOperations.input —

```

)set break resume
)sys rm -f ModularAlgebraicGcdOperations.output
)spool ModularAlgebraicGcdOperations.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ModularAlgebraicGcdOperations
--R ModularAlgebraicGcdOperations(MPT: Type,MD: Type) is a category constructor
--R Abbreviation for ModularAlgebraicGcdOperations is MAGCDOC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MAGCDOC
--R
--R----- Operations -----
--R degree : MPT -> Integer          pseudoRem : (MPT,MPT,MD) -> MPT
--R zero? : MPT -> Boolean
--R MPtoMPT : (Polynomial(Integer),Symbol,List(Symbol),MD) -> MPT
--R canonicalIfCan : (MPT,MD) -> Union(MPT,"failed")

```



```

--R packExps : (Integer,Integer,MD) -> SortedExponentVector
--R packModulus : (List(Polynomial(Integer)),List(Symbol),Integer) -> Union(MD,"failed")
--R repack1 : (MPT,U32Vector,Integer,MD) -> Void
--R
--E 1

)spool
)lisp (bye)

```

— ModularAlgebraicGcdOperations.help —

```

=====
ModularAlgebraicGcdOperations
=====

```

This category specifies operations needed by ModularAlgebraicGcd package. Since we have multiple implementations we specify interface here and put implementations in separate packages. Most operations are done using special purpose abstract representation. Appropriate types are passed as parameters: MPT is type of modular polynomials in one variable with coefficients in some algebraic extension. MD is type of modulus. Final results are converted to packed representation, with coefficients (from prime field) stored in one array and exponents (in main variable and in auxiliary variables representing generators of algebraic extension) stored in parallel array.

Exports:

```

canonicalIfCan  degree  MPtoMPT  packExps  packModulus
pseudoRem      repack1  zero?

```

These are directly exported but not implemented:

```

canonicalIfCan : (MPT,MD) -> Union(MPT,"failed")
degree : MPT -> Integer
MPtoMPT : (Polynomial(Integer),Symbol,List(Symbol),MD) -> MPT
packExps : (Integer,Integer,MD) -> SortedExponentVector
packModulus : (List(Polynomial(Integer)),List(Symbol),Integer) ->
               Union(MD,"failed")
pseudoRem : (MPT,MPT,MD) -> MPT
repack1 : (MPT,U32Vector,Integer,MD) -> Void
zero? : MPT -> Boolean

```

— category MAGCDOC ModularAlgebraicGcdOperations —

```

)abbrev category MAGCDOC ModularAlgebraicGcdOperations
++ Description: This category specifies operations needed by
++ ModularAlgebraicGcd package. Since we have multiple
++ implementations we specify interface here and put
++ implementations in separate packages. Most operations
++ are done using special purpose abstract representation.
++ Appropriate types are passed as parameters: MPT is type
++ of modular polynomials in one variable with coefficients
++ in some algebraic extension. MD is type of modulus.
++ Final results are converted to packed representation,
++ with coefficients (from prime field) stored in one
++ array and exponents (in main variable and in auxiliary
++ variables representing generators of algebraic extension)
++ stored in parallel array.
ModularAlgebraicGcdOperations(MPT : Type, MD : Type) : Category ==
Exports where
  MP ==> Polynomial Integer
  PA ==> U32Vector
Exports ==> with
  pseudoRem : (MPT, MPT, MD) -> MPT
    ++ pseudoRem(x, y, m) computes pseudoremainder of x by y
    ++ modulo m.
  canonicalIfCan : (MPT, MD) -> Union(MPT, "failed")
    ++ canonicalIfCan(x, m) tries to divide x by its leading
    ++ coefficient modulo m.
  packModulus : (List MP, List(Symbol), Integer) -> Union(MD, "failed")
    ++ packModulus(lp, ls, p) converts lp, ls and prime p which
    ++ together describe algebraic extension to packed
    ++ representation.
  MPtoMPT : (MP, Symbol, List(Symbol), MD) -> MPT
    ++ MPtoMPT(p, s, ls, m) converts p to packed representation.
  zero? : MPT -> Boolean
    ++ zero?(x) checks if x is zero.
  degree : MPT -> Integer
    ++ degree(x) gives degree of x.
  packExps : (Integer, Integer, MD) -> SortedExponentVector
    ++ packExps(d, s, m) produces vector of exponents up
    ++ to degree d. s is size (degree) of algebraic extension.
    ++ Use together with repack1.
  repack1 : (MPT, PA, Integer, MD) -> Void
    ++ repack1(x, a, d, m) stores coefficients of x in a.
    ++ d is degree of x. Corresponding exponents are given
    ++ by packExps.

```

```
"MAGCDOC"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MAGCDOC"];
"MAGCDOC" -> "CATEGORY"
```

— MAGCDOC.dotfull —

```
"ModularAlgebraicGcdOperations()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MAGCDOC"];
"ModularAlgebraicGcdOperations(a:Type,b:Type)" -> "Category"
```

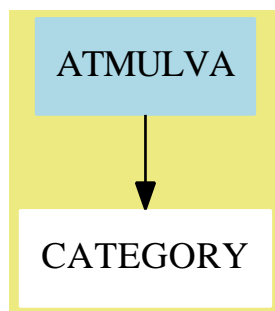
— MAGCDOC.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "MAGCDOC" [color=lightblue];
  "MAGCDOC" -> "Category"

  "Category" [color=lightblue];
}
```

MultiplicativeValuationAttribute (ATMULVA)



— MultiplicativeValuationAttribute.input —

```

)set break resume
)sys rm -f MultiplicativeValuationAttribute.output
)spool MultiplicativeValuationAttribute.output
)set message test on
)set message auto off
)clear all

```

```

--S 1 of 1
1
--E 1
)spool
)lisp (bye)

```

— MultiplicativeValuationAttribute.help —

```

=====
MultiplicativeValuationAttribute
=====

```

The class of all euclidean domains such that
 $\text{euclideanSize}(a*b) = \text{euclideanSize}(a) * \text{euclideanSize}(b)$

See Also:

o)show MultiplicativeValuationAttribute

— category ATMULVA MultiplicativeValuationAttribute —

```

)abbrev category ATMULVA MultiplicativeValuationAttribute
++ Description:
++ The class of all euclidean domains such that
++ \spad{euclideanSize(a*b)=euclideanSize(a)*euclideanSize(b)}

```

MultiplicativeValuationAttribute(): Category == with nil

— ATMULVA.dotabb —

```

"ATMULVA"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATMULVA"];

```

"ATMULVA" -> "CATEGORY"

— ATMULVA.dotfull —

```
"MultiplicativeValuationAttribute()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATMULVA"];
"MultiplicativeValuationAttribute()" -> "Category"
```

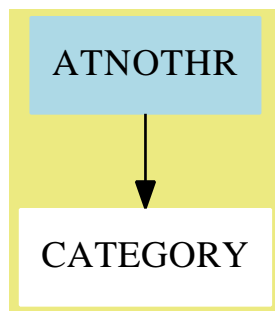
— ATMULVA.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "MultiplicativeValuationAttribute()" [color=lightblue];
  "MultiplicativeValuationAttribute()" -> "Category"

  "Category" [color=lightblue];
}
```

NotherianAttribute (ATNOTHR)



— NotherianAttribute.input —

```
)set break resume
)sys rm -f NotherianAttribute.output
)spool NotherianAttribute.output
)set message test on
)set message auto off
)clear all
```

```
--S 1 of 1
1
--E 1
)spool
)lisp (bye)
```

— NotherianAttribute.help —

```
=====
NotherianAttribute
=====
```

Notherian is true if all of its ideals are finitely generated.

See Also:

o)show NotherianAttribute

— category ATNOTHR NotherianAttribute —

```
)abbrev category ATNOTHR NotherianAttribute
++ Description:
++ Notherian is true if all of its ideals are finitely generated.
```

NotherianAttribute(): Category == with nil

— ATNOTHR.dotabb —

```
"ATNOTHR"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATNOTHR"];
"ATNOTHR" -> "CATEGORY"
```

— ATNOTHR.dotfull —

```
"NotherianAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATNOTHR"];
"NotherianAttribute()" -> "Category"
```

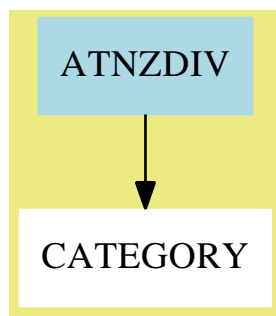
— ATNOTHR.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "NotherianAttribute()" [color=lightblue];
  "NotherianAttribute()" -> "Category"

  "Category" [color=lightblue];
}
```

NoZeroDivisorsAttribute (ATNZDIV)



— NoZeroDivisorsAttribute.input —

```
)set break resume
)sys rm -f NoZeroDivisorsAttribute.output
)spool NoZeroDivisorsAttribute.output
```

```
)set message test on
)set message auto off
)clear all
```

```
--S 1 of 1
1
--E 1
)spool
)lisp (bye)
```

— NoZeroDivisorsAttribute.help —

```
=====
NoZeroDivisorsAttribute
=====
```

The class of all semirings such that $x * y \neq 0$ implies both x and y are non-zero.

See Also:

o)show NoZeroDivisorsAttribute

— category ATNZDIV NoZeroDivisorsAttribute —

```
)abbrev category ATNZDIV NoZeroDivisorsAttribute
++ Description:
++ The class of all semirings such that \spad{x * y != 0} implies
++ both x and y are non-zero.
```

```
NoZeroDivisorsAttribute(): Category == with nil
```

— ATNZDIV.dotabb —

```
"ATNZDIV"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATNZDIV"];
"ATNZDIV" -> "CATEGORY"
```

— ATNZDIV.dotfull —

```
"NoZeroDivisorsAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATNZDIV"];
"NoZeroDivisorsAttribute()" -> "Category"
```

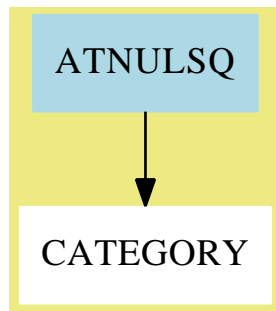
— ATNZDIV.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "NoZeroDivisorsAttribute()" [color=lightblue];
  "NoZeroDivisorsAttribute()" -> "Category"

  "Category" [color=lightblue];
}
```

NullSquareAttribute (ATNULSQ)



— NullSquareAttribute.input —

```
)set break resume
)sys rm -f NullSquareAttribute.output
)spool NullSquareAttribute.output
)set message test on
```

```
)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)
```

— NullSquareAttribute.help —

```
=====
NullSquareAttribute
=====
```

NullSquare means that $[x,x] = 0$ holds. See LieAlgebra.

See Also:

o)show NullSquareAttribute

— category ATNULSQ NullSquareAttribute —

```
)abbrev category ATNULSQ NullSquareAttribute
++ Description:
++ NullSquare means that \spad{[x,x] = 0} holds. See LieAlgebra.

NullSquareAttribute(): Category == with nil
```

— ATNULSQ.dotabb —

```
"ATNULSQ"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATNULSQ" ];
"ATNULSQ" -> "CATEGORY"
```

— ATNULSQ.dotfull —

```
"NullSquareAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATNULSQ"];
"NullSquareAttribute()" -> "Category"
```

—————→

— ATNULSQ.dotpic —

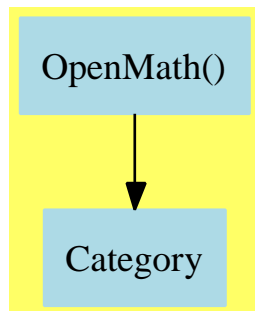
```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "NullSquareAttribute()" [color=lightblue];
  "NullSquareAttribute()" -> "Category"

  "Category" [color=lightblue];
}
```

—————→

OpenMath (OM)



— OpenMath.input —

```
)set break resume
)sys rm -f OpenMath.output
)spool OpenMath.output
)set message test on
)set message auto off
)clear all
```

```

--S 1 of 1
)show OpenMath
--R OpenMath is a category constructor
--R Abbreviation for OpenMath is OM
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OM
--R
--R----- Operations -----
--R OMwrite : % -> String          OMwrite : (%,Boolean) -> String
--R OMwrite : (OpenMathDevice,%) -> Void
--R OMwrite : (OpenMathDevice,%,Boolean) -> Void
--R
--E 1

)spool
)lisp (bye)

```

— OpenMath.help —

=====

OpenMath examples

=====

OpenMath provides operations for exporting an object in OpenMath format.

See Also:

o)show OpenMath

See:

⇒ “StringCategory” (STRICAT) [10](#) on page [972](#)

⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

OMwrite

These are directly exported but not implemented:

```

OMwrite : % -> String
OMwrite : (%,Boolean) -> String
OMwrite : (OpenMathDevice,%) -> Void
OMwrite : (OpenMathDevice,%,Boolean) -> Void

```

— category OM OpenMath —

```

)abbrev category OM OpenMath
++ Author: Mike Dewar & Vilya Harvey
++ Basic Functions: OMwrite
++ Description:
++ \spadtype{OpenMath} provides operations for exporting an object
++ in OpenMath format.

OpenMath(): Category == with
  OMwrite : % -> String
  ++ OMwrite(u) returns the OpenMath XML encoding of \axiom{u} as a
  ++ complete OpenMath object.
  OMwrite : (% , Boolean) -> String
  ++ OMwrite(u, true) returns the OpenMath XML encoding of \axiom{u}
  ++ as a complete OpenMath object; OMwrite(u, false) returns the
  ++ OpenMath XML encoding of \axiom{u} as an OpenMath fragment.
  OMwrite : (OpenMathDevice, %) -> Void
  ++ OMwrite(dev, u) writes the OpenMath form of \axiom{u} to the
  ++ OpenMath device \axiom{dev} as a complete OpenMath object.
  OMwrite : (OpenMathDevice, %, Boolean) -> Void
  ++ OMwrite(dev, u, true) writes the OpenMath form of \axiom{u} to
  ++ the OpenMath device \axiom{dev} as a complete OpenMath object;
  ++ OMwrite(dev, u, false) writes the object as an OpenMath fragment.

```

— OM.dotabb —

```

"OM"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OM"];
"OM" -> "CATEGORY"

```

— OM.dotfull —

```

"OpenMath()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OM"];
"OpenMath()" -> "Category"

```

— OM.dotpic —

```

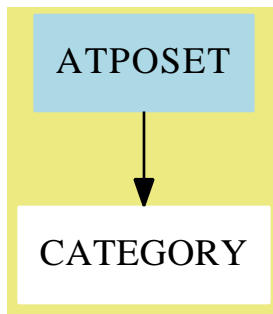
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OpenMath()" [color=lightblue];
  "OpenMath()" -> "Category"

  "Category" [color=lightblue];
}

```

PartiallyOrderedSetAttribute (ATPOSET)



— PartiallyOrderedSetAttribute.input —

```

)set break resume
)sys rm -f PartiallyOrderedSetAttribute.output
)spool PartiallyOrderedSetAttribute.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)

```

— PartiallyOrderedSetAttribute.help —

```
=====
PartiallyOrderedSetAttribute
=====
```

PartiallyOrderedSet is true if a set with $<$ is transitive,
but not $(a < b \text{ or } a = b)$. It does not imply $b < a$.

See Also:

o)show PartiallyOrderedSetAttribute

— category ATPOSET PartiallyOrderedSetAttribute —

```
)abbrev category ATPOSET PartiallyOrderedSetAttribute
++ Description:
++ PartiallyOrderedSet is true if a set with \spad{<} is transitive,
++ but \spad{not(a < b or a = b)}. It does not imply \spad{b < a}
```

```
PartiallyOrderedSetAttribute(): Category == with nil
```

— ATPOSET.dotabb —

```
"ATPOSET"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATPOSET"];
"ATPOSET" -> "CATEGORY"
```

— ATPOSET.dotfull —

```
"PartiallyOrderedSetAttribute()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ATPOSET"];
"PartiallyOrderedSetAttribute()" -> "Category"
```

— ATPOSET.dotpic —

```
digraph pic {
```

```

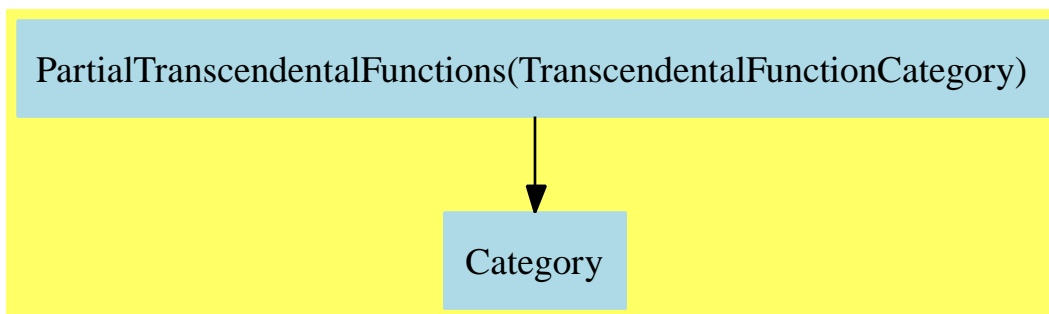
fontsize=10;
bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"PartiallyOrderedSetAttribute()" [color=lightblue];
"PartiallyOrderedSetAttribute()" -> "Category"

"Category" [color=lightblue];
}

```

PartialTranscendentalFunctions (PTRANFN)



— PartialTranscendentalFunctions.input —

```

)set break resume
)sys rm -f PartialTranscendentalFunctions.output
)spool PartialTranscendentalFunctions.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PartialTranscendentalFunctions
--R
--R PartialTranscendentalFunctions(K: TranscendentalFunctionCategory) is a category constructor
--R Abbreviation for PartialTranscendentalFunctions is PTRANFN
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PTRANFN
--R
--R----- Operations -----
--R acosIfCan : K -> Union(K,"failed")    acotIfCan : K -> Union(K,"failed")

```



```

--R acscIfCan : K -> Union(K,"failed")      asecIfCan : K -> Union(K,"failed")
--R asinIfCan : K -> Union(K,"failed")      atanIfCan : K -> Union(K,"failed")
--R cosIfCan : K -> Union(K,"failed")      coshIfCan : K -> Union(K,"failed")
--R cotIfCan : K -> Union(K,"failed")      cothIfCan : K -> Union(K,"failed")
--R cscIfCan : K -> Union(K,"failed")      cschIfCan : K -> Union(K,"failed")
--R expIfCan : K -> Union(K,"failed")      logIfCan : K -> Union(K,"failed")
--R secIfCan : K -> Union(K,"failed")      sechIfCan : K -> Union(K,"failed")
--R sinIfCan : K -> Union(K,"failed")      sinhIfCan : K -> Union(K,"failed")
--R tanIfCan : K -> Union(K,"failed")      tanhIfCan : K -> Union(K,"failed")
--R acoshIfCan : K -> Union(K,"failed")
--R acothIfCan : K -> Union(K,"failed")
--R acschIfCan : K -> Union(K,"failed")
--R asechIfCan : K -> Union(K,"failed")
--R asinhIfCan : K -> Union(K,"failed")
--R atanhIfCan : K -> Union(K,"failed")
--R nthRootIfCan : (K,NonNegativeInteger) -> Union(K,"failed")
--R
--E 1

)spool
)lisp (bye)

```

— PartialTranscendentalFunctions.help —

```

=====
PartialTranscendentalFunctions examples
=====

```

This is the description of any package which provides partial functions on a domain belonging to TranscendentalFunctionCategory.

See Also:

o)show PartialTranscendentalFunctions

See:

⇐ “Category” (CATEGORY) 2 on page 3

Exports:

| | | | | |
|--------------|------------|------------|------------|------------|
| acosIfCan | acoshIfCan | acotIfCan | acothIfCan | acscIfCan |
| acschIfCan | asecIfCan | asechIfCan | asinIfCan | asinhIfCan |
| atanIfCan | atanhIfCan | cosIfCan | coshIfCan | cotIfCan |
| cothIfCan | cscIfCan | cschIfCan | expIfCan | logIfCan |
| nthRootIfCan | secIfCan | sechIfCan | sinIfCan | sinhIfCan |
| tanIfCan | tanhIfCan | | | |

These are directly exported but not implemented:

```

acosIfCan : K -> Union(K,"failed")
acoshIfCan : K -> Union(K,"failed")
acotIfCan : K -> Union(K,"failed")
acothIfCan : K -> Union(K,"failed")
acscIfCan : K -> Union(K,"failed")
acschIfCan : K -> Union(K,"failed")
asecIfCan : K -> Union(K,"failed")
asechIfCan : K -> Union(K,"failed")
asinIfCan : K -> Union(K,"failed")
asinhIfCan : K -> Union(K,"failed")
atanIfCan : K -> Union(K,"failed")
atanhIfCan : K -> Union(K,"failed")
cosIfCan : K -> Union(K,"failed")
coshIfCan : K -> Union(K,"failed")
cotIfCan : K -> Union(K,"failed")
cothIfCan : K -> Union(K,"failed")
cscIfCan : K -> Union(K,"failed")
cschIfCan : K -> Union(K,"failed")
expIfCan : K -> Union(K,"failed")
logIfCan : K -> Union(K,"failed")
nthRootIfCan : (K,NonNegativeInteger) -> Union(K,"failed")
secIfCan : K -> Union(K,"failed")
sechIfCan : K -> Union(K,"failed")
sinIfCan : K -> Union(K,"failed")
sinhIfCan : K -> Union(K,"failed")
tanIfCan : K -> Union(K,"failed")
tanhIfCan : K -> Union(K,"failed")

```

— category PTRANFN PartialTranscendentalFunctions —

```

)abbrev category PTRANFN PartialTranscendentalFunctions
++ Author: Clifton J. Williamson
++ Date Created: 12 February 1990
++ Date Last Updated: 14 February 1990
++ Description:
++ A package which provides partial transcendental
++ functions, for example, functions which return an answer or "failed"
++ This is the description of any package which provides partial
++ functions on a domain belonging to TranscendentalFunctionCategory.

```

```

PartialTranscendentalFunctions(K): Category == Definition where
  K :      TranscendentalFunctionCategory
  NNI ==> NonNegativeInteger

  Definition ==> with

--% Exponentials and Logarithms

  nthRootIfCan: (K,NNI) -> Union(K,"failed")
    ++ nthRootIfCan(z,n) returns the nth root of z if possible,
    ++ and "failed" otherwise.
  expIfCan: K -> Union(K,"failed")
    ++ expIfCan(z) returns exp(z) if possible, and "failed" otherwise.
  logIfCan: K -> Union(K,"failed")
    ++ logIfCan(z) returns log(z) if possible, and "failed" otherwise.

--% TrigonometricFunctionCategory

  sinIfCan : K -> Union(K,"failed")
    ++ sinIfCan(z) returns sin(z) if possible, and "failed" otherwise.
  cosIfCan: K -> Union(K,"failed")
    ++ cosIfCan(z) returns cos(z) if possible, and "failed" otherwise.
  tanIfCan: K -> Union(K,"failed")
    ++ tanIfCan(z) returns tan(z) if possible, and "failed" otherwise.
  cotIfCan: K -> Union(K,"failed")
    ++ cotIfCan(z) returns cot(z) if possible, and "failed" otherwise.
  secIfCan: K -> Union(K,"failed")
    ++ secIfCan(z) returns sec(z) if possible, and "failed" otherwise.
  cscIfCan: K -> Union(K,"failed")
    ++ cscIfCan(z) returns csc(z) if possible, and "failed" otherwise.

--% ArcTrigonometricFunctionCategory

  asinIfCan: K -> Union(K,"failed")
    ++ asinIfCan(z) returns asin(z) if possible, and "failed" otherwise.
  acosIfCan: K -> Union(K,"failed")
    ++ acosIfCan(z) returns acos(z) if possible, and "failed" otherwise.
  atanIfCan: K -> Union(K,"failed")
    ++ atanIfCan(z) returns atan(z) if possible, and "failed" otherwise.
  acotIfCan: K -> Union(K,"failed")
    ++ acotIfCan(z) returns acot(z) if possible, and "failed" otherwise.
  asecIfCan: K -> Union(K,"failed")
    ++ asecIfCan(z) returns asec(z) if possible, and "failed" otherwise.
  acscIfCan: K -> Union(K,"failed")
    ++ acscIfCan(z) returns acsc(z) if possible, and "failed" otherwise.

--% HyperbolicFunctionCategory

  sinhIfCan: K -> Union(K,"failed")
    ++ sinhIfCan(z) returns sinh(z) if possible, and "failed" otherwise.

```

```

coshIfCan: K -> Union(K,"failed")
  ++ coshIfCan(z) returns cosh(z) if possible, and "failed" otherwise.
tanhIfCan: K -> Union(K,"failed")
  ++ tanhIfCan(z) returns tanh(z) if possible, and "failed" otherwise.
cothIfCan: K -> Union(K,"failed")
  ++ cothIfCan(z) returns coth(z) if possible, and "failed" otherwise.
sechIfCan: K -> Union(K,"failed")
  ++ sechIfCan(z) returns sech(z) if possible, and "failed" otherwise.
cschIfCan: K -> Union(K,"failed")
  ++ cschIfCan(z) returns csch(z) if possible, and "failed" otherwise.

--% ArcHyperbolicFunctionCategory

asinhIfCan: K -> Union(K,"failed")
  ++ asinhIfCan(z) returns asinh(z) if possible, and "failed" otherwise.
acoshIfCan: K -> Union(K,"failed")
  ++ acoshIfCan(z) returns acosh(z) if possible, and "failed" otherwise.
atanhIfCan: K -> Union(K,"failed")
  ++ atanhIfCan(z) returns atanh(z) if possible, and "failed" otherwise.
acothIfCan: K -> Union(K,"failed")
  ++ acothIfCan(z) returns acoth(z) if possible, and "failed" otherwise.
asechIfCan: K -> Union(K,"failed")
  ++ asechIfCan(z) returns asech(z) if possible, and "failed" otherwise.
acschIfCan: K -> Union(K,"failed")
  ++ acschIfCan(z) returns acsch(z) if possible, and "failed" otherwise.

```

— PTRANFN.dotabb —

```

"PTRANFN"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PTRANFN"];
"PTRANFN" -> "CATEGORY"

```

— PTRANFN.dotfull —

```

"PartialTranscendentalFunctions(TranscendentalFunctionCategory)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PTRANFN"];
"PartialTranscendentalFunctions(TranscendentalFunctionCategory)" ->
"Category()"

```

— PTRANFN.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

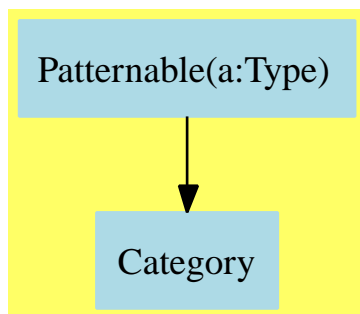
  "PartialTranscendentalFunctions(TranscendentalFunctionCategory)"
    [color=lightblue];
  "PartialTranscendentalFunctions(TranscendentalFunctionCategory)" ->
    "Category"

  "Category" [color=lightblue];
}

```

—————→

Patternable (PATAB)



— Patternable.input —

```

)set break resume
)sys rm -f Patternable.output
)spool Patternable.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show Patternable
--R
--R Patternable(R: Type) is a category constructor
--R Abbreviation for Patternable is PATAB
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PATAB
--R
--R----- Operations -----
--R convert : % -> Pattern(Integer) if R has KONVERT(PATTERN(INT))
--R convert : % -> Pattern(Float) if R has KONVERT(PATTERN(FLOAT))
--R
--E 1

)spool
)lisp (bye)

```

— Patternable.help —

=====

Patternable examples

=====

Category of sets that can be converted to useful patterns. An object *S* is Patternable over an object *R* if *S* can lift the conversions from *R* into Pattern(Integer) and Pattern(Float) to itself.

See Also:

o)show Patternable

See:

⇒ “ComplexCategory” (COMPCAT) [20](#) on page [1671](#)
 ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
 ⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)
 ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
 ⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

convert

These exports come from (p[41](#)) ConvertibleTo(Pattern(Integer)):

```
convert : % -> Pattern Integer if R has KONVERT PATTERN INT
```

These exports come from (p[41](#)) ConvertibleTo(Pattern(Float)):

```
convert : % -> Pattern Float if R has KONVERT PATTERN FLOAT
```

— category PATAB Patternable —

```

)abbrev category PATAB Patternable
++ Author: Manuel Bronstein
++ Date Created: 29 Nov 1989
++ Date Last Updated: 29 Nov 1989
++ Description:
++ Category of sets that can be converted to useful patterns
++ An object S is Patternable over an object R if S can
++ lift the conversions from R into \spadtype{Pattern(Integer)} and
++ \spadtype{Pattern(Float)} to itself;

Patternable(R:Type): Category == with
  if R has ConvertibleTo Pattern Integer then
    ConvertibleTo Pattern Integer
  if R has ConvertibleTo Pattern Float then
    ConvertibleTo Pattern Float

```

— PATAB.dotabb —

```

"PATAB"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PATAB"];
"PATAB" -> "CATEGORY"

```

— PATAB.dotfull —

```

"Patternable(a:Type)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PATAB"];
"Patternable(a:Type)" -> "Category"

"Patternable(IntegralDomain)"
[color=seagreen,href="bookvol10.2.pdf#nameddest=PATAB"];
"Patternable(IntegralDomain)" -> "Patternable(a:Type)"

"Patternable(OrderedSet)"
[color=seagreen,href="bookvol10.2.pdf#nameddest=PATAB"];
"Patternable(OrderedSet)" -> "Patternable(a:Type)"

"Patternable(CommutativeRing)"
[color=seagreen,href="bookvol10.2.pdf#nameddest=PATAB"];
"Patternable(CommutativeRing)" -> "Patternable(a:Type)"

```

— PATAB.dotpic —

```

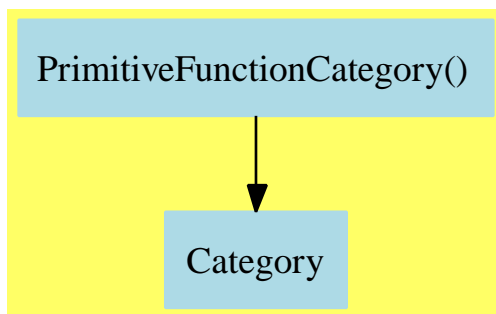
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Patternable(a:Type)" [color=lightblue];
  "Patternable(a:Type)" -> "Category"

  "Category" [color=lightblue];
}

```

PrimitiveFunctionCategory (PRIMCAT)



— PrimitiveFunctionCategory.input —

```

)set break resume
)sys rm -f PrimitiveFunctionCategory.output
)spool PrimitiveFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PrimitiveFunctionCategory
--R
--R PrimitiveFunctionCategory  is a category constructor

```



```

--R Abbreviation for PrimitiveFunctionCategory is PRIMCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PRIMCAT
--R
--R----- Operations -----
--R integral : (%,Symbol) -> %
--R integral : (%,SegmentBinding(%)) -> %
--R
--E 1

)spool
)lisp (bye)

```

— PrimitiveFunctionCategory.help —

=====

PrimitiveFunctionCategory examples

=====

This is the Category for the functions defined by integrals.

See Also:

o)show PrimitiveFunctionCategory

See:

⇒ “LiouvillianFunctionCategory” (LFCAT) [4](#) on page [244](#)

⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

integral

These are directly exported but not implemented:

```

integral : (%,Symbol) -> %
integral : (%,SegmentBinding %) -> %

```

— category PRIMCAT PrimitiveFunctionCategory —

```

)abbrev category PRIMCAT PrimitiveFunctionCategory
++ Author: Manuel Bronstein
++ Date Last Updated: 14 May 1991

```

```

++ Description:
++ Category for the functions defined by integrals;

PrimitiveFunctionCategory(): Category == with
  integral: ($, Symbol) -> $
    ++ integral(f, x) returns the formal integral of f dx.
  integral: ($, SegmentBinding $) -> $
    ++ integral(f, x = a..b) returns the formal definite integral
    ++ of f dx for x between \spad{a} and b.

```

— PRIMCAT.dotabb —

```

"PRIMCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PRIMCAT"];
"PRIMCAT" -> "CATEGORY"

```

— PRIMCAT.dotfull —

```

"PrimitiveFunctionCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PRIMCAT"];
"PrimitiveFunctionCategory()" -> "Category"

```

— PRIMCAT.dotpic —

```

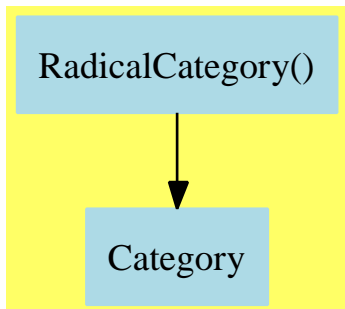
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PrimitiveFunctionCategory()" [color=lightblue];
  "PrimitiveFunctionCategory()" -> "Category"

  "Category" [color=lightblue];
}

```

RadicalCategory (RADCAT)



— RadicalCategory.input —

```

)set break resume
)sys rm -f RadicalCategory.output
)spool RadicalCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RadicalCategory
--R
--R RadicalCategory is a category constructor
--R Abbreviation for RadicalCategory is RADCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RADCAT
--R
--R----- Operations -----
--R nthRoot : (%,Integer) -> %          sqrt : % -> %
--R ??? : (%,Fraction(Integer)) -> %
--R
--E 1

)spool
)lisp (bye)
  
```

— RadicalCategory.help —

```

=====
RadicalCategory examples
=====
  
```

The `RadicalCategory` is a model for the rational numbers.

See Also:

o `)show RadicalCategory`

See:

⇒ “AlgebraicallyClosedField” (ACF) [17](#) on page [1343](#)
 ⇒ “IntervalCategory” (INTCAT) [14](#) on page [1200](#)
 ⇒ “RealClosedField” (RCFIELD) [17](#) on page [1441](#)
 ⇒ “RealNumberSystem” (RNS) [17](#) on page [1451](#)
 ⇒ “UnivariateLaurentSeriesCategory” (ULSCAT) [17](#) on page [1499](#)
 ⇒ “UnivariatePuisseuxSeriesCategory” (UPXSCAT) [17](#) on page [1511](#)
 ⇒ “UnivariateTaylorSeriesCategory” (UTSCAT) [16](#) on page [1327](#)
 ⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

`nthRoot` `sqrt` `***?`

These are directly exported but not implemented:

`***? : (% , Fraction Integer) -> %`

These are implemented by this category:

`nthRoot : (% , Integer) -> %`
`sqrt : % -> %`

— category **RADCAT** `RadicalCategory` —

`)abbrev category RADCAT RadicalCategory`
`++ Description:`

`RadicalCategory(): Category == with`
`sqrt : % -> %`
`++ sqrt(x) returns the square root of x.`
`nthRoot: (% , Integer) -> %`
`++ nthRoot(x,n) returns the nth root of x.`
`*_ : (% , Fraction Integer) -> %`
`++ x ** y is the rational exponentiation of x by the power y.`
`add`
`sqrt x == x ** inv(2::Fraction(Integer))`
`nthRoot(x, n) == x ** inv(n::Fraction(Integer))`

— RADCAT.dotabb —

```
"RADCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RADCAT"];
"RADCAT" -> "CATEGORY"
```

— RADCAT.dotfull —

```
"RadicalCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RADCAT"];
"RadicalCategory()" -> "Category"
```

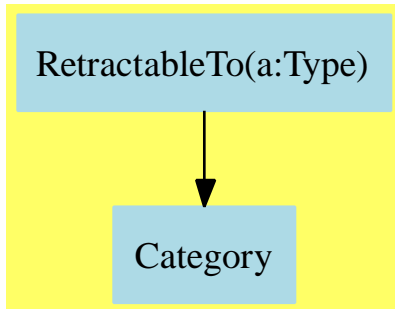
— RADCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "RadicalCategory()" [color=lightblue];
  "RadicalCategory()" -> "Category"

  "Category" [color=lightblue];
}
```

RetractableTo (RETRACT)



— RetractableTo.input —

```

)set break resume
)sys rm -f RetractableTo.output
)spool RetractableTo.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RetractableTo
--R
--R RetractableTo(S: Type) is a category constructor
--R Abbreviation for RetractableTo is RETRACT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RETRACT
--R
--R----- Operations -----
--R coerce : S -> %                retract : % -> S
--R retractIfCan : % -> Union(S,"failed")
--R
--E 1

)spool
)lisp (bye)

```

— RetractableTo.help —

```

=====
RetractableTo examples
=====

```

A is retractable to B means that some elements of A can be converted into elements of B and any element of B can be converted into an element of A.

See Also:

o)show RetractableTo

See:

⇒ “DifferentialPolynomialCategory” (DPOLCAT) [17](#) on page [1356](#)
 ⇒ “DifferentialVariableCategory” (DVARCAT) [5](#) on page [348](#)
 ⇒ “ExtensionField” (XF) [18](#) on page [1562](#)
 ⇒ “ExpressionSpace” (ES) [5](#) on page [355](#)
 ⇒ “FiniteAlgebraicExtensionField” (FAXF) [19](#) on page [1635](#)
 ⇒ “FortranMachineTypeCategory” (FMTC) [13](#) on page [1158](#)
 ⇒ “FreeAbelianMonoidCategory” (FAMONC) [7](#) on page [617](#)
 ⇒ “FreeModuleCat” (FMCAT) [10](#) on page [912](#)
 ⇒ “FullyRetractableTo” (FRETRCT) [3](#) on page [136](#)
 ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
 ⇒ “GradedAlgebra” (GRALG) [5](#) on page [367](#)
 ⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)
 ⇒ “IntervalCategory” (INTCAT) [14](#) on page [1200](#)
 ⇒ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)
 ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
 ⇒ “RealNumberSystem” (RNS) [17](#) on page [1451](#)
 ⇒ “UnivariateLaurentSeriesConstructorCategory” (ULSCCAT) [18](#) on page [1606](#)
 ⇒ “UnivariatePuisseuxSeriesConstructorCategory” (UPXSCCA) [18](#) on page [1623](#)
 ⇒ “XFreeAlgebra” (XFALG) [11](#) on page [1042](#)
 ⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

coerce retract retractIfCan

These are directly exported but not implemented:

```
coerce : S -> %
retractIfCan : % -> Union(S,"failed")
```

These are implemented by this category:

```
retract : % -> S
```

— category RETRACT RetractableTo —

```

)abbrev category RETRACT RetractableTo
++ Date Last Updated: 14 May 1991
++ Description:
++ A is retractable to B means that some elements of A can be converted
++ into elements of B and any element of B can be converted into an
++ element of A.

RetractableTo(S: Type): Category == with
  coerce:      S -> %
  ++ coerce(a) transforms a into an element of %.
  retractIfCan: % -> Union(S,"failed")
  ++ retractIfCan(a) transforms a into an element of S if possible.
  ++ Returns "failed" if a cannot be made into an element of S.
  retract:      % -> S
  ++ retract(a) transforms a into an element of S if possible.
  ++ Error: if a cannot be made into an element of S.
add
  retract(s) ==
    (u:=retractIfCan s) case "failed" => error "not retractable"
    u

```

— RETRACT.dotabb —

```

"RETRACT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=RETRACT"];
"RETRACT" -> "CATEGORY"

```

— RETRACT.dotfull —

```

"RetractableTo(a:Type)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=RETRACT"];
"RetractableTo(a:Type)" -> "Category"

"RetractableTo(SetCategory)"
[color=seagreen,href="bookvol10.2.pdf#nameddest=RETRACT"];
"RetractableTo(SetCategory)" -> "RetractableTo(a:Type)"

"RetractableTo(OrderedSet)"
[color=seagreen,href="bookvol10.2.pdf#nameddest=RETRACT"];
"RetractableTo(OrderedSet)" -> "RetractableTo(a:Type)"

"RetractableTo(Symbol)"

```



```

[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(Symbol)" -> "RetractableTo(a:Type)"

"RetractableTo(Integer)"
[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(Integer)" -> "RetractableTo(a:Type)"

"RetractableTo(NonNegativeInteger)"
[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(NonNegativeInteger)" -> "RetractableTo(a:Type)"

"RetractableTo(Fraction(Integer))"
[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(Fraction(Integer))" -> "RetractableTo(a:Type)"

"RetractableTo(Float)"
[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(Float)" -> "RetractableTo(a:Type)"

"RetractableTo(Kernel(ExpressionSpace))"
[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(Kernel(ExpressionSpace))" -> "RetractableTo(a:Type)"

"RetractableTo(CommutativeRing)"
[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(CommutativeRing)" -> "RetractableTo(a:Type)"

"RetractableTo(UnivariatePuisseuxSeriesCategory(Ring))"
[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(UnivariatePuisseuxSeriesCategory(Ring))"
-> "RetractableTo(a:Type)"

"RetractableTo(Field)"
[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(Field)" -> "RetractableTo(a:Type)"

"RetractableTo(IntegralDomain)"
[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(IntegralDomain)" -> "RetractableTo(a:Type)"

"RetractableTo(OrderedFreeMonoid(OrderedSet))"
[ color=seagreen, href="bookvol10.2.pdf#nameddest=RETRACT" ];
"RetractableTo(OrderedFreeMonoid(OrderedSet))" -> "RetractableTo(a:Type)"

```

```

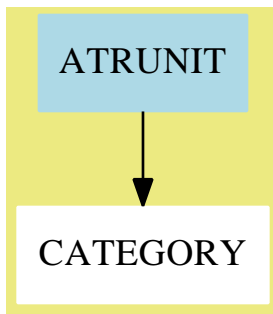
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "RetractableTo(a:Type)" [color=lightblue];
  "RetractableTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}

```

RightUnitaryAttribute (ATRUNIT)



— RightUnitaryAttribute.input —

```

)set break resume
)sys rm -f RightUnitaryAttribute.output
)spool RightUnitaryAttribute.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)

```

— RightUnitaryAttribute.help —

```
=====
RightUnitaryAttribute
=====
```

RightUnitary is true if $x * 1 = x$ for all x .

See Also:

o)show RightUnitaryAttribute

— category ATRUNIT RightUnitaryAttribute —

```
)abbrev category ATRUNIT RightUnitaryAttribute
++ Description:
++ RightUnitary is true if \spad{x * 1 = x} for all x.

RightUnitaryAttribute(): Category == with nil
```

— ATRUNIT.dotabb —

```
"ATRUNIT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATRUNIT" ];
"ATRUNIT" -> "CATEGORY"
```

— ATRUNIT.dotfull —

```
"RightUnitaryAttribute()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ATRUNIT" ];
"RightUnitaryAttribute()" -> "Category"
```

— ATRUNIT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
```

```

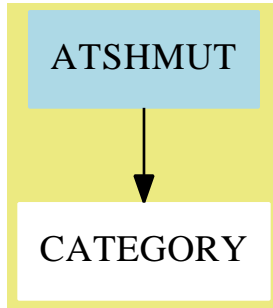
node [shape=box, color=white, style=filled];

"RightUnitaryAttribute()" [color=lightblue];
"RightUnitaryAttribute()" -> "Category"

"Category" [color=lightblue];
}

```

ShallowlyMutableAttribute (ATSHMUT)



— ShallowlyMutableAttribute.input —

```

)set break resume
)sys rm -f ShallowlyMutableAttribute.output
)spool ShallowlyMutableAttribute.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)

```

— ShallowlyMutableAttribute.help —

=====

ShallowlyMutableAttribute

=====

The class of all domains which have immediate components that are updateable in place (mutable). The properties of any component domain are irrelevant to the ShallowlyMutableAttribute.

See Also:

o)show ShallowlyMutableAttribute

— category ATSHMUT ShallowlyMutableAttribute —

)abbrev category ATSHMUT ShallowlyMutableAttribute

++ Description:

++ The class of all domains which have immediate components that are updateable in place (mutable). The properties of any component domain are irrelevant to the ShallowlyMutableAttribute.

ShallowlyMutableAttribute(): Category == with nil

— ATSHMUT.dotabb —

"ATSHMUT"

[color=lightblue,href="bookvol10.2.pdf#nameddest=ATSHMUT"];

"ATSHMUT" -> "CATEGORY"

— ATSHMUT.dotfull —

"ShallowlyMutableAttribute()"

[color=lightblue,href="bookvol10.2.pdf#nameddest=ATSHMUT"];

"ShallowlyMutableAttribute()" -> "Category"

— ATSHMUT.dotpic —

digraph pic {

```

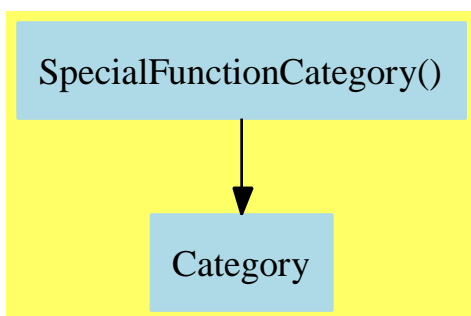
fontsize=10;
bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"ShallowlyMutableAttribute()" [color=lightblue];
"ShallowlyMutableAttribute()" -> "Category"

"Category" [color=lightblue];
}

```

SpecialFunctionCategory (SPFCAT)



— SpecialFunctionCategory.input —

```

)set break resume
)sys rm -f SpecialFunctionCategory.output
)spool SpecialFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show SpecialFunctionCategory
--R SpecialFunctionCategory is a category constructor
--R Abbreviation for SpecialFunctionCategory is SPFCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SPFCAT
--R
--R----- Operations -----
--R Beta : (%,%) -> %          Gamma : % -> %
--R Gamma : (%,%) -> %        abs : % -> %

```

```

--R airyAi : % -> %
--R bessellI : (%,% ) -> %
--R bessellK : (%,% ) -> %
--R digamma : % -> %
--R
--R
--E 1

)spool
)lisp (bye)

```

— SpecialFunctionCategory.help —

```

=====
SpecialFunctionCategory examples
=====

```

This is the Category for the other special functions.

See Also:

o)show SpecialFunctionCategory

See:

⇐ “Category” (CATEGORY) 2 on page 3

Exports:

```

abs          airyAi  airyBi  bessellI  bessellJ
bessellK     bessellY Beta    digamma   Gamma
polygamma

```

These are directly exported but not implemented:

```

abs : % -> %
airyAi : % -> %
airyBi : % -> %
bessellI : (%,% ) -> %
bessellJ : (%,% ) -> %
bessellK : (%,% ) -> %
bessellY : (%,% ) -> %
Beta : (%,% ) -> %
digamma : % -> %
Gamma : % -> %
Gamma : (%,% ) -> %
polygamma : (%,% ) -> %

```

— category SPFCAT SpecialFunctionCategory —

```

)abbrev category SPFCAT SpecialFunctionCategory
++ Author: Manuel Bronstein
++ Date Last Updated: 11 May 1993
++ Description:
++ Category for the other special functions;

SpecialFunctionCategory(): Category == with
  abs :      $ -> $
      ++ abs(x) returns the absolute value of x.
  Gamma:     $ -> $
      ++ Gamma(x) is the Euler Gamma function.
  Beta:      ($,$)->$
      ++ Beta(x,y) is \spad{Gamma(x) * Gamma(y)/Gamma(x+y)}.
  digamma:   $ -> $
      ++ digamma(x) is the logarithmic derivative of \spad{Gamma(x)}
      ++ (often written \spad{psi(x)} in the literature).
  polygamma: ($, $) -> $
      ++ polygamma(k,x) is the \spad{k-th} derivative of \spad{digamma(x)},
      ++ (often written \spad{psi(k,x)} in the literature).
  Gamma:     ($, $) -> $
      ++ Gamma(a,x) is the incomplete Gamma function.
  bessellJ: ($,$) -> $
      ++ bessellJ(v,z) is the Bessel function of the first kind.
  bessellY: ($,$) -> $
      ++ bessellY(v,z) is the Bessel function of the second kind.
  bessellI: ($,$) -> $
      ++ bessellI(v,z) is the modified Bessel function of the first kind.
  bessellK: ($,$) -> $
      ++ bessellK(v,z) is the modified Bessel function of the second kind.
  airyAi:    $ -> $
      ++ airyAi(x) is the Airy function \spad{Ai(x)}.
  airyBi:    $ -> $
      ++ airyBi(x) is the Airy function \spad{Bi(x)}.

```

— SPFCAT.dotabb —

```

"SPFCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=SPFCAT"];
"SPFCAT" -> "CATEGORY"

```

— SPFCAT.dotfull —

```
"SpecialFunctionCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SPFCAT"];
"SpecialFunctionCategory()" -> "Category"
```

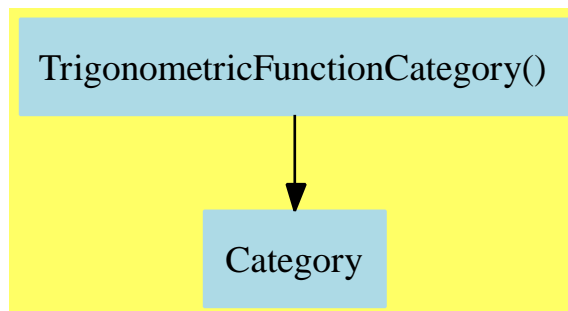
— SPFCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "SpecialFunctionCategory()" [color=lightblue];
  "SpecialFunctionCategory()" -> "Category"

  "Category" [color=lightblue];
}
```

TrigonometricFunctionCategory (TRIGCAT)



The `csc` and `sec` functions were modified to include an intermediate test to check that the argument has a reciprocal values.

— TrigonometricFunctionCategory.input —

```
)set break resume
```

```

)sys rm -f TrigonometricFunctionCategory.output
)spool TrigonometricFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show TrigonometricFunctionCategory
--R TrigonometricFunctionCategory is a category constructor
--R Abbreviation for TrigonometricFunctionCategory is TRIGCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for TRIGCAT
--R
--R----- Operations -----
--R cos : % -> %          cot : % -> %
--R csc : % -> %          sec : % -> %
--R sin : % -> %          tan : % -> %
--R
--E 1

)spool
)lisp (bye)

```

— TrigonometricFunctionCategory.help —

```

=====
TrigonometricFunctionCategory examples
=====

```

This is the Category for the trigonometric functions.

See Also:

o)show TrigonometricFunctionCategory

See:

⇒ “TranscendentalFunctionCategory” (TRANFUN) [3](#) on page [166](#)

⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

cos cot csc sec sin tan

These are directly exported but not implemented:

```
cos : % -> %
sin : % -> %
```

These are implemented by this category:

```
cot : % -> %
csc : % -> %
sec : % -> %
tan : % -> %
```

— category **TRIGCAT** *TrigonometricFunctionCategory* —

```
)abbrev category TRIGCAT TrigonometricFunctionCategory
++ Date Last Updated: 14 May 1991
++ Description:
++ Category for the trigonometric functions;

TrigonometricFunctionCategory(): Category == with
  cos: $ -> $      ++ cos(x) returns the cosine of x.
  cot: $ -> $      ++ cot(x) returns the cotangent of x.
  csc: $ -> $      ++ csc(x) returns the cosecant of x.
  sec: $ -> $      ++ sec(x) returns the secant of x.
  sin: $ -> $      ++ sin(x) returns the sine of x.
  tan: $ -> $      ++ tan(x) returns the tangent of x.
add
  if $ has Ring then
    csc x ==
      (a := recip(sin x)) case "failed" => error "csc: no reciprocal"
      a::$
    sec x ==
      (a := recip(cos x)) case "failed" => error "sec: no reciprocal"
      a::$
    tan x == sin x * sec x
    cot x == cos x * csc x
```

—

— **TRIGCAT**.dotabb —

```
"TRIGCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=TRIGCAT"];
"TRIGCAT" -> "CATEGORY"
```

—

— **TRIGCAT**.dotfull —

```
"TrigonometricFunctionCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=TRIGCAT"];
"TrigonometricFunctionCategory()" -> "Category"
```

—————

— TRIGCAT.dotpic —

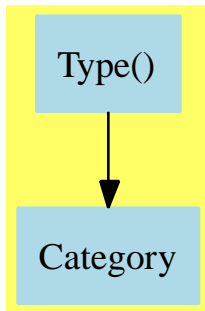
```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "TrigonometricFunctionCategory()" [color=lightblue];
  "TrigonometricFunctionCategory()" -> "Category"

  "Category" [color=lightblue];
}
```

—————

Type (TYPE)



— Type.input —

```
)set break resume
)sys rm -f Type.output
)spool Type.output
)set message test on
)set message auto off
)clear all
```

```
--S 1 of 1
)show Type
--E 1

)spool
)lisp (bye)
```

— Type.help —

```
=====
Type examples
=====
```

The fundamental Type.

See Also:
o)show Type

See:

⇒ “Aggregate” (AGG) [3](#) on page [115](#)
 ⇒ “FortranProgramCategory” (FORTCAT) [3](#) on page [133](#)
 ⇒ “FullyPatternMatchable” (FPATMAB) [3](#) on page [141](#)
 ⇒ “SegmentCategory” (SEGCAT) [3](#) on page [158](#)
 ⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Attributes exported:

- nil

— category TYPE Type —

```
)abbrev category TYPE Type
++ Author: Richard Jenks
++ Date Created: 14 May 1992
++ Date Last Updated: 14 May 1992
++ Description:
++ The fundamental Type;
```

```
Type(): Category == with nil
```

— TYPE.dotabb —

```
"TYPE" [color=lightblue,href="bookvol10.2.pdf#nameddest=TYPE"];
"TYPE" -> "CATEGORY"
```

— TYPE.dotfull —

```
"Type()" [color=lightblue,href="bookvol10.2.pdf#nameddest=TYPE"];
"Type()" -> "Category"
```

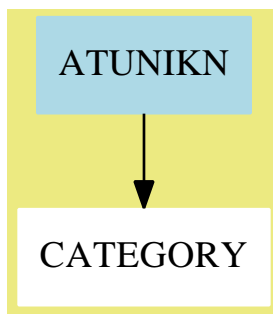
— TYPE.dotpic —

```
digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "Type()" [color=lightblue];
    "Type()" -> "Category"

    "Category" [color=lightblue];
}
```

UnitsKnownAttribute (ATUNIKN)



— UnitsKnownAttribute.input —

```

)set break resume
)sys rm -f UnitsKnownAttribute.output
)spool UnitsKnownAttribute.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
1
--E 1
)spool
)lisp (bye)

```

— UnitsKnownAttribute.help —

```

=====
UnitsKnownAttribute
=====

The class of all monoids (multiplicative semigroups with a 1)
such that the operation recop can only return "failed"
if its argument is not a unit.

See Also:
o )show UnitsKnownAttribute

```

— category ATUNIKN UnitsKnownAttribute —

```

)abbrev category ATUNIKN UnitsKnownAttribute
++ Description:
++ The class of all monoids (multiplicative semigroups with a 1)
++ such that the operation recop can only return "failed"
++ if its argument is not a unit.

UnitsKnownAttribute(): Category == with nil

```

— ATUNIKN.dotabb —

```
"ATUNIKN"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATUNIKN"];
"ATUNIKN" -> "CATEGORY"
```

— ATUNIKN.dotfull —

```
"UnitsKnownAttribute()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ATUNIKN"];
"UnitsKnownAttribute()" -> "Category"
```

— ATUNIKN.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

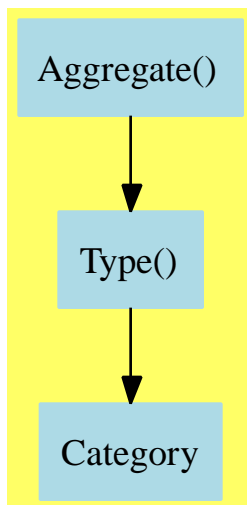
  "UnitsKnownAttribute()" [color=lightblue];
  "UnitsKnownAttribute()" -> "Category"

  "Category" [color=lightblue];
}
```

Chapter 3

Category Layer 2

Aggregate (AGG)



— Aggregate.input —

```
)set break resume
)sys rm -f Aggregate.output
)spool Aggregate.output
)set message test on
)set message auto off
)clear all
```

--S 1 of 1

```

)show Aggregate
--R Aggregate is a category constructor
--R Abbreviation for Aggregate is AGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for AGG
--R
--R----- Operations -----
--R copy : % -> %                      empty : () -> %
--R empty? : % -> Boolean              eq? : (%,%) -> Boolean
--R sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R less? : (%,NonNegativeInteger) -> Boolean
--R more? : (%,NonNegativeInteger) -> Boolean
--R size? : (%,NonNegativeInteger) -> Boolean
--R
--E 1

)spool
)lisp (bye)

```

— Aggregate.help —

=====

Aggregate examples

=====

The notion of aggregate serves to model any data structure aggregate, designating any collection of objects, with heterogenous or homogeneous members, with a finite or infinite number of members, explicitly or implicitly represented. An aggregate can in principle represent everything from a string of characters to abstract sets such as "the set of x satisfying relation $r(x)$ "

An attribute "finiteAggregate" is used to assert that a domain has a finite number of elements.

See Also:
o)show Aggregate

See:

⇒ "HomogeneousAggregate" (HOAGG) [4](#) on page [233](#)

⇐ "Type" (TYPE) [2](#) on page [109](#)

Attributes exported:

- nil

Exports:

empty? eq? less? more? sample size?

Attributes Used:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.

These are implemented by this category:

```
empty? : % -> Boolean
eq? : (%,% ) -> Boolean
less? : (% ,NonNegativeInteger) -> Boolean
more? : (% ,NonNegativeInteger) -> Boolean
sample : () -> %
size? : (% ,NonNegativeInteger) -> Boolean
```

— category AGG Aggregate —

```
)abbrev category AGG Aggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ The notion of aggregate serves to model any data structure aggregate,
++ designating any collection of objects, with heterogenous or homogeneous
++ members, with a finite or infinite number of members, explicitly or
++ implicitly represented. An aggregate can in principle represent
++ everything from a string of characters to abstract sets such
++ as "the set of x satisfying relation r(x)"
++ An attribute "finiteAggregate" is used to assert that a domain
++ has a finite number of elements.
```

Aggregate: Category == Type with

```
eq?: (%,% ) -> Boolean
++ eq?(u,v) tests if u and v are same objects.

copy: % -> %
++ copy(u) returns a top-level (non-recursive) copy of u.
++ Note that for collections, \axiom{copy(u) == [x for x in u]}.

empty: () -> %
++ empty()$D creates an aggregate of type D with 0 elements.
++ Note that The $D can be dropped if understood by context,
++ for example \axiom{u: D := empty()}.
```

```

empty?: % -> Boolean
  ++ empty?(u) tests if u has 0 elements.

less?: (% , NonNegativeInteger) -> Boolean
  ++ less?(u,n) tests if u has less than n elements.

more?: (% , NonNegativeInteger) -> Boolean
  ++ more?(u,n) tests if u has greater than n elements.

size?: (% , NonNegativeInteger) -> Boolean
  ++ size?(u,n) tests if u has exactly n elements.

sample: constant -> %
  ++ sample yields a value of type %

if % has finiteAggregate then
  "#": % -> NonNegativeInteger
  ++ # u returns the number of items in u.
add

eq?(a,b) == EQ(a,b)$Lisp

sample() == empty()

if % has finiteAggregate then

  empty? a    == #a = 0

  less?(a,n) == #a < n

  more?(a,n) == #a > n

  size?(a,n) == #a = n

  _____

  — AGG.dotabb —

  "AGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=AGG"];
  "AGG" -> "TYPE"

  _____

  — AGG.dotfull —

  "Aggregate()"

```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=AGG"];
"Aggregate()" -> "Type()"
```

— AGG.dotpic —

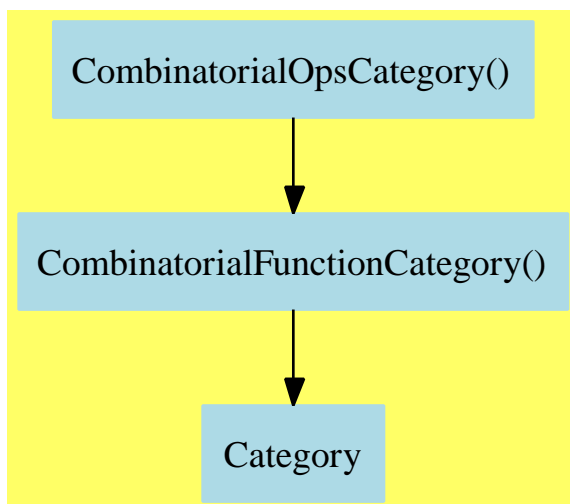
```
digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "Aggregate()" [color=lightblue];
    "Aggregate()" -> "Type()"

    "Type()" [color=lightblue];
    "Type()" -> "Category"

    "Category" [color=lightblue];
}
```

CombinatorialOpsCategory (COMBOPC)



— CombinatorialOpsCategory.input —

```

)set break resume
)sys rm -f CombinatorialOpsCategory.output
)spool CombinatorialOpsCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show CombinatorialOpsCategory
--R
--R CombinatorialOpsCategory is a category constructor
--R Abbreviation for CombinatorialOpsCategory is COMBOPC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for COMBOPC
--R
--R----- Operations -----
--R binomial : (%,%) -> %          factorial : % -> %
--R factorials : (%,Symbol) -> %    factorials : % -> %
--R permutation : (%,%) -> %        product : (%,Symbol) -> %
--R summation : (%,Symbol) -> %
--R product : (%,SegmentBinding(%)) -> %
--R summation : (%,SegmentBinding(%)) -> %
--R
--E 1

)spool
)lisp (bye)

```

— CombinatorialOpsCategory.help —

```

=====
CombinatorialOpsCategory examples
=====

```

CombinatorialOpsCategory is the category obtaining by adjoining summations and products to the usual combinatorial operations;

See Also:

o)show CombinatorialOpsCategory

See:

⇐ “CombinatorialFunctionCategory” (CFCAT) 2 on page 36

Exports:

```
binomial    factorial  factorials  permutation  product
summation
```

These are directly exported but not implemented:

```
factorials : % -> %
factorials : (% , Symbol) -> %
product : (% , Symbol) -> %
product : (% , SegmentBinding %) -> %
summation : (% , Symbol) -> %
summation : (% , SegmentBinding %) -> %
```

These exports come from (p36) CombinatorialFunctionCategory():

```
binomial : (% , %) -> %
factorial : % -> %
permutation : (% , %) -> %
```

— category COMBOPC CombinatorialOpsCategory —

```
)abbrev category COMBOPC CombinatorialOpsCategory
++ Author: Manuel Bronstein
++ Date Last Updated: 22 February 1993 (JHD/BMT)
++ Description:
++ CombinatorialOpsCategory is the category obtaining by adjoining
++ summations and products to the usual combinatorial operations;

CombinatorialOpsCategory(): Category ==
  CombinatorialFunctionCategory with
    factorials : $ -> $
      ++ factorials(f) rewrites the permutations and binomials in f
      ++ in terms of factorials;
    factorials : ($ , Symbol) -> $
      ++ factorials(f, x) rewrites the permutations and binomials in f
      ++ involving x in terms of factorials;
    summation : ($ , Symbol) -> $
      ++ summation(f(n), n) returns the formal sum S(n) which verifies
      ++ S(n+1) - S(n) = f(n);
    summation : ($ , SegmentBinding $) -> $
      ++ summation(f(n), n = a..b) returns f(a) + ... + f(b) as a
      ++ formal sum;
    product : ($ , Symbol) -> $
      ++ product(f(n), n) returns the formal product P(n) which verifies
      ++ P(n+1)/P(n) = f(n);
```



```

product      : ($, SegmentBinding $) -> $
  ++ product(f(n), n = a..b) returns f(a) * ... * f(b) as a
  ++ formal product;

```

— COMBOPC.dotabb —

```

"COMBOPC"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=COMBOPC"];
"COMBOPC" -> "CFCAT"

```

— COMBOPC.dotfull —

```

"CombinatorialOpsCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=COMBOPC"];
"CombinatorialOpsCategory()" -> "CombinatorialFunctionCategory()"

```

— COMBOPC.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

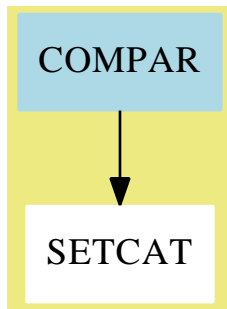
  "CombinatorialOpsCategory()" [color=lightblue];
  "CombinatorialOpsCategory()" -> "CombinatorialFunctionCategory()"

  "CombinatorialFunctionCategory()" [color=lightblue];
  "CombinatorialFunctionCategory()" -> "Category"

  "Category" [color=lightblue];
}

```

Comparable (COMPAR)



— Comparable.input —

```

)set break resume
)sys rm -f Comparable.output
)spool Comparable.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show Comparable
--R Comparable is a category constructor
--R Abbreviation for Comparable is COMPAR
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for COMPAR
--R
--R----- Operations -----
--R ?=? : (%,%) -> Boolean          coerce : % -> OutputForm
--R hash : % -> SingleInteger      latex : % -> String
--R smaller? : (%,%) -> Boolean    ?~=? : (%,%) -> Boolean
--E 1

)spool
)lisp (bye)

```

— Comparable.help —

```

=====
Comparable examples
=====

```

See Also:

o)show Comparable

See:

?=? coerce hash latex smaller? ?~=?

— category COMPAR Comparable —

```
)abbrev category COMPAR Comparable
++ Description:
++ The class of set equipped with possibly unnatural linear order
++ (needed for technical reasons).
Comparable(): Category == SetCategory with
--operations
  smaller?: (%,% ) -> Boolean
  ++ smaller?(x, y) is a strict total ordering on the elements of the set.
```

— COMPAR.dotabb —

```
"COMPAR" [color=lightblue,href="bookvol10.2.pdf#nameddest=COMPAR"];
"COMPAR" -> "SETCAT"
```

— COMPAR.dotfull —

```
"Comparable()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=COMPAR"];
"Comparable()" -> "SetCategory()"
```

— COMPAR.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Comparable()" [color=lightblue];
```

```

"Comparable()" -> "SetCategory()"

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

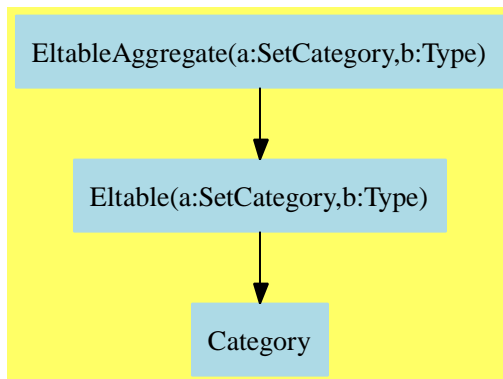
"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];
}

```

EltableAggregate (ELTAGG)



— EltableAggregate.input —

```

)set break resume
)sys rm -f EltableAggregate.output
)spool EltableAggregate.output
)set message test on
)set message auto off
)clear all

```

```

--S 1 of 1
)show EltableAggregate
--R EltableAggregate(Dom: SetCategory,Im: Type) is a category constructor
--R Abbreviation for EltableAggregate is ELTAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ELTAGG
--R
--R----- Operations -----
--R elt : (% ,Dom,Im) -> Im          ?.? : (% ,Dom) -> Im
--R qelt : (% ,Dom) -> Im
--R qsetelt! : (% ,Dom,Im) -> Im if $ has shallowlyMutable
--R setelt : (% ,Dom,Im) -> Im if $ has shallowlyMutable
--R
--E 1

)spool
)lisp (bye)

```

— EltableAggregate.help —

=====

EltableAggregate examples

=====

An eltable aggregate is one which can be viewed as a function.
 For example, the list [1,7,4] can applied to 0,1, and 2 respectively
 will return the integers 1, 7, and 4; thus this list may be viewed
 as mapping 0 to 1, 1 to 7 and 2 to 4. In general, an aggregate
 can map members of a domain Dom to an image domain Im.

See Also:
 o)show EltableAggregate

See:

⇒ “IndexedAggregate” (IXAGG) [5](#) on page [372](#)
 ⇐ “Eltable” (ELTAB) [2](#) on page [48](#)

Exports:

elt qelt qsetelt! setelt ?.?

Attributes Used:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are part of this category's direct exports:

```
elt : (%,Dom,Im) -> Im
setelt : (%,Dom,Im) -> Im if $ has shallowlyMutable
```

These are implemented by this category:

```
qelt : (%,Dom) -> Im
qsetelt! : (%,Dom,Im) -> Im if $ has shallowlyMutable
```

These exports come from (p48) Eltable():

```
?.? : (%,Dom) -> Im
```

— category ELTAGG EltableAggregate —

```
)abbrev category ELTAGG EltableAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ An eltable aggregate is one which can be viewed as a function.
++ For example, the list [1,7,4] can applied to 0,1, and 2 respectively
++ will return the integers 1, 7, and 4; thus this list may be viewed as
++ mapping 0 to 1, 1 to 7 and 2 to 4. In general, an aggregate
++ can map members of a domain Dom to an image domain Im.

EltableAggregate(Dom:SetCategory, Im:Type): Category ==
-- This is separated from Eltable
-- and series won't have to support qelt's and setelt's.
Eltable(Dom, Im) with
  elt : (%, Dom, Im) -> Im
    ++ elt(u, x, y) applies u to x if x is in the domain of u,
    ++ and returns y otherwise.
    ++ For example, if u is a polynomial in \axiom{x} over the rationals,
    ++ \axiom{elt(u,n,0)} may define the coefficient of \axiom{x}
    ++ to the power n, returning 0 when n is out of range.
  qelt: (%, Dom) -> Im
    ++ qelt(u, x) applies \axiom{u} to \axiom{x} without checking whether
    ++ \axiom{x} is in the domain of \axiom{u}. If \axiom{x} is not
    ++ in the domain of \axiom{u} a memory-access violation may occur.
    ++ If a check on whether \axiom{x} is in the domain of \axiom{u}
    ++ is required, use the function \axiom{elt}.
  if % has shallowlyMutable then
```

```

setelt : (% , Dom, Im) -> Im
  ++ setelt(u,x,y) sets the image of x to be y under u,
  ++ assuming x is in the domain of u.
  ++ Error: if x is not in the domain of u.
  -- this function will soon be renamed as setelt!.
qsetelt_!: (% , Dom, Im) -> Im
  ++ qsetelt!(u,x,y) sets the image of \axiom{x} to be \axiom{y}
  ++ under \axiom{u}, without checking that \axiom{x} is in
  ++ the domain of \axiom{u}.
  ++ If such a check is required use the function \axiom{setelt}.
add
  qelt(a, x) == elt(a, x)
  if % has shallowlyMutable then
    qsetelt_!(a, x, y) == (a.x := y)

```

— ELTAGG.dotabb —

```

"ELTAGG"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ELTAGG"];
"ELTAGG" -> "ELTAB"

```

— ELTAGG.dotfull —

```

"EltableAggregate(a:SetCategory,b:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ELTAGG"];
"EltableAggregate(a:SetCategory,b:Type)" -> "Eltable(a:SetCategory,b:Type)"

```

— ELTAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "EltableAggregate(a:SetCategory,b:Type)" [color=lightblue];
  "EltableAggregate(a:SetCategory,b:Type)" -> "Eltable(a:SetCategory,b:Type)"

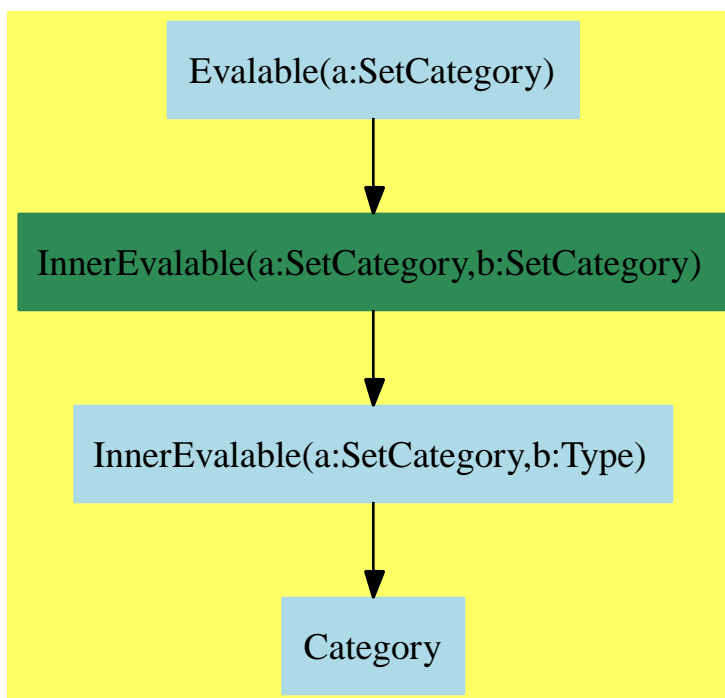
  "Eltable(a:SetCategory,b:Type)" [color=lightblue];
  "Eltable(a:SetCategory,b:Type)" -> "Category"

```

```
"Category" [color=lightblue];
}
```

—————

Evalable (EVALAB)



— Evalable.input —

```
)set break resume
)sys rm -f Evalable.output
)spool Evalable.output
)set message test on
)set message auto off
)clear all
```

```
--S 1 of 1
)show Evalable
--R
```



```

--R Evalable(R: SetCategory) is a category constructor
--R Abbreviation for Evalable is EVALAB
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for EVALAB
--R
--R----- Operations -----
--R eval : (%,Equation(R)) -> %          eval : (%,R,R) -> %
--R eval : (%,List(R),List(R)) -> %
--R eval : (%,List(Equation(R))) -> %
--R
--E 1

)spool
)lisp (bye)

```

— Evalable.help —

```

=====
Evalable examples
=====

```

This category provides eval operations. A domain may belong to this category if it is possible to make "evaluation" substitutions.

See Also:
o)show Evalable

See:

⇒ “ExpressionSpace” (ES) [5](#) on page [355](#)
 ⇒ “MultivariateTaylorSeriesCategory” (MTSCAT) [15](#) on page [1243](#)
 ⇒ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)
 ⇐ “InnerEvalable” (IEVALAB) [2](#) on page [56](#)

Exports:

eval

These are directly exported but not implemented:

```
eval : (%,List Equation R) -> %
```

These are implemented by this category:

```
eval : (%,Equation R) -> %
eval : (%,List R,List R) -> %
```

These exports come from (p56) InnerEvalable(R:SetCategory,R:SetCategory):

```
eval : (%,R,R) -> %
```

— category EVALAB Evalable —

```
)abbrev category EVALAB Evalable
++ Date Last Updated: June 3, 1991
++ Description:
++ This category provides \spadfun{eval} operations.
++ A domain may belong to this category if it is possible to make
++ ‘‘evaluation’’ substitutions.

Evalable(R:SetCategory): Category == InnerEvalable(R,R) with
  eval: ($, Equation R) -> $
    ++ eval(f,x = v) replaces x by v in f.
  eval: ($, List Equation R) -> $
    ++ eval(f, [x1 = v1,...,xn = vn]) replaces xi by vi in f.
add
  eval(f:$, eq:Equation R) == eval(f, [eq])
  eval(f:$, xs:List R,vs:List R) == eval(f,[x=v for x in xs for v in vs])
```

— EVALAB.dotabb —

```
"EVALAB"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=EVALAB"];
"EVALAB" -> "IEVALAB"
```

— EVALAB.dotfull —

```
"Evalable(a:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=EVALAB"];
"Evalable(a:SetCategory)" -> "InnerEvalable(a:SetCategory,b:SetCategory)"

"Evalable(MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=EVALAB"];
"Evalable(MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet))" ->
  "Evalable(a:SetCategory)"
```

```

"Evalable(ExpressionSpace)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=EVALAB"];
"Evalable(ExpressionSpace)" -> "Evalable(a:SetCategory)"

"Evalable(PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=EVALAB"];
"Evalable(PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet))"
  -> "Evalable(a:SetCategory)"

```

— EVALAB.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Evalable(a:SetCategory)" [color=lightblue];
  "Evalable(a:SetCategory)" -> "InnerEvalable(a:SetCategory,b:SetCategory)"

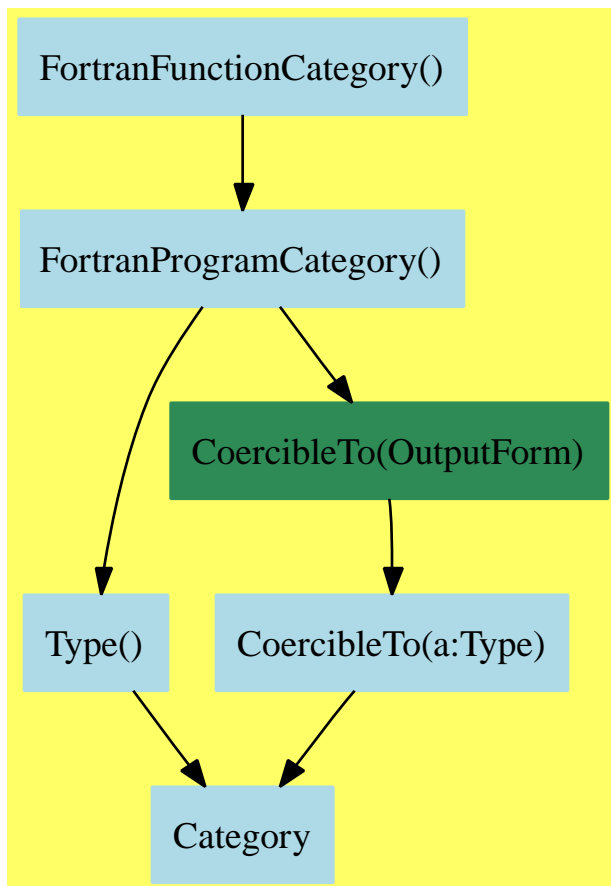
  "InnerEvalable(a:SetCategory,b:SetCategory)" [color=seagreen];
  "InnerEvalable(a:SetCategory,b:SetCategory)" ->
    "InnerEvalable(a:SetCategory,b:Type)"

  "InnerEvalable(a:SetCategory,b:Type)" [color=lightblue];
  "InnerEvalable(a:SetCategory,b:Type)" -> "Category"

  "Category" [color=lightblue];
}

```

FortranProgramCategory (FORTCAT)



— FortranProgramCategory.input —

```

)set break resume
)sys rm -f FortranProgramCategory.output
)spool FortranProgramCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FortranProgramCategory
--R FortranProgramCategory is a category constructor
--R Abbreviation for FortranProgramCategory is FORTCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FORTCAT

```

```

--R
--R----- Operations -----
--R coerce : % -> OutputForm          outputAsFortran : % -> Void
--R
--E 1

)spool
)lisp (bye)

```

— FortranProgramCategory.help —

```

=====
FortranProgramCategory examples
=====

```

FortranProgramCategory provides various models of FORTRAN subprograms.
These can be transformed into actual FORTRAN code.

See Also:

o)show FortranProgramCategory

See:

⇒ “FortranFunctionCategory” (FORTFN) [4](#) on page [186](#)
 ⇒ “FortranMatrixCategory” (FMC) [4](#) on page [191](#)
 ⇒ “FortranMatrixFunctionCategory” (FMFUN) [4](#) on page [195](#)
 ⇒ “FortranVectorCategory” (FVC) [4](#) on page [200](#)
 ⇒ “FortranVectorFunctionCategory” (FVFUN) [4](#) on page [204](#)
 ⇐ “CoercibleTo” (KOERCE) [2](#) on page [33](#)
 ⇐ “Type” (TYPE) [2](#) on page [109](#)

Exports:

coerce outputAsFortran

Attributes:

- nil

These are directly exported but not implemented:

outputAsFortran : % -> Void

These exports come from (p[33](#)) CoercibleTo(OutputForm):

```
coerce : % -> OutputForm
```

— category FORTCAT FortranProgramCategory —

```
)abbrev category FORTCAT FortranProgramCategory
++ Author: Mike Dewar
++ Date Created: November 1992
++ Description:
++ FortranProgramCategory provides various models of FORTRAN subprograms.
++ These can be transformed into actual FORTRAN code.

FortranProgramCategory():Category == Join(Type,CoercibleTo OutputForm) with
  outputAsFortran : $ -> Void
  ++ \axiom{outputAsFortran(u)} translates \axiom{u} into a legal FORTRAN
  ++ subprogram.
```

— FORTCAT.dotabb —

```
"FORTCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FORTCAT"];
"FORTCAT" -> "KOERCE"
"FORTCAT" -> "TYPE"
```

— FORTCAT.dotfull —

```
"FortranProgramCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FORTCAT"];
"FortranProgramCategory()" -> "Type()"
"FortranProgramCategory()" -> "CoercibleTo(OutputForm)"
```

— FORTCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];
```

```

"FortranProgramCategory()" [color=lightblue];
"FortranProgramCategory()" -> "Type()"
"FortranProgramCategory()" -> "CoercibleTo(OutputForm)"

"Type()" [color=lightblue];
"Type()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

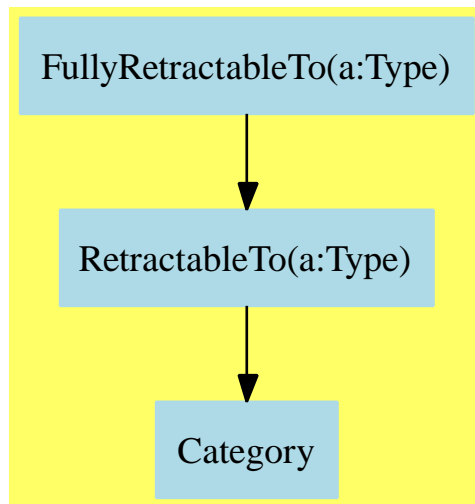
"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];
}

```

—————→

FullyRetractableTo (FRETRCT)



— FullyRetractableTo.input —

```

)set break resume
)sys rm -f FullyRetractableTo.output
)spool FullyRetractableTo.output
)set message test on

```

```

)set message auto off
)clear all

--S 1 of 1
)show FullyRetractableTo
--R
--R FullyRetractableTo(S: Type) is a category constructor
--R Abbreviation for FullyRetractableTo is FRETRCT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FRETRCT
--R
--R----- Operations -----
--R coerce : S -> %                      retract : % -> S
--R coerce : Integer -> % if S has RETRACT(INT)
--R coerce : Fraction(Integer) -> % if S has RETRACT(FRAC(INT))
--R retract : % -> Integer if S has RETRACT(INT)
--R retract : % -> Fraction(Integer) if S has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer,"failed") if S has RETRACT(INT)
--R retractIfCan : % -> Union(Fraction(Integer),"failed") if S has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(S,"failed")
--R
--E 1

)spool
)lisp (bye)

```

— FullyRetractableTo.help —

=====

FullyRetractableTo examples

=====

A is fully retractable to B means that A is retractable to B and if B is retractable to the integers or rational numbers then so is A. In particular, what we are asserting is that there are no integers (rationals) in A which don't retract into B.

See Also:

o)show FullyRetractableTo

See:

⇒ “ComplexCategory” (COMPCAT) [20](#) on page [1671](#)

⇒ “DirectProductCategory” (DIRPCAT) [12](#) on page [1051](#)

⇒ “FiniteAbelianMonoidRing” (FAMR) [14](#) on page [1191](#)
 ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
 ⇒ “MonogenicAlgebra” (MONOGEN) [19](#) on page [1651](#)
 ⇒ “OctonionCategory” (OC) [12](#) on page [1109](#)
 ⇒ “QuaternionCategory” (QUATCAT) [12](#) on page [1120](#)
 ⇒ “RealClosedField” (RCFIELD) [17](#) on page [1441](#)
 ⇒ “SquareMatrixCategory” (SMATCAT) [12](#) on page [1131](#)
 ⇒ “UnivariateSkewPolynomialCategory” (OREPCAT) [10](#) on page [982](#)
 ⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

Exports:

```
coerce retract retractIfCan
```

These are implemented by this category:

```

coerce : Integer -> %
  if S has RETRACT INT
coerce : Fraction Integer -> %
  if S has RETRACT FRAC INT
retract : % -> Integer
  if S has RETRACT INT
retract : % -> Fraction Integer
  if S has RETRACT FRAC INT
retractIfCan : % -> Union(Integer,"failed")
  if S has RETRACT INT
retractIfCan : % -> Union(Fraction Integer,"failed")
  if S has RETRACT FRAC INT

```

These exports come from (p[95](#)) RetractableTo(S:Type):

```

coerce : S -> %
retract : % -> S
retractIfCan : % -> Union(S,"failed")

```

— category FRETRCT FullyRetractableTo —

```

)abbrev category FRETRCT FullyRetractableTo
++ Author: Manuel Bronstein
++ Date Created: March 1990
++ Date Last Updated: 9 April 1991
++ Description:
++ A is fully retractable to B means that A is retractable to B and
++ if B is retractable to the integers or rational numbers then so is A.
++ In particular, what we are asserting is that there are no integers
++ (rationals) in A which don't retract into B.

```

FullyRetractableTo(S: Type): Category == RetractableTo(S) with

```

    if (S has RetractableTo Integer) then RetractableTo Integer
    if (S has RetractableTo Fraction Integer) then
        RetractableTo Fraction Integer
add
if not(S is Integer) then
    if (S has RetractableTo Integer) then -- induction
        coerce(n:Integer):% == n::S::%
        retract(r:%):Integer == retract(retract(r)@S)

        retractIfCan(r:%):Union(Integer, "failed") ==
            (u:= retractIfCan(r)@Union(S,"failed")) case "failed"=> "failed"
            retractIfCan(u::S)

if not(S is Fraction Integer) then
    if (S has RetractableTo Fraction Integer) then -- induction
        coerce(n:Fraction Integer):% == n::S::%
        retract(r:%):Fraction(Integer) == retract(retract(r)@S)

        retractIfCan(r:%):Union(Fraction Integer, "failed") ==
            (u:=retractIfCan(r)@Union(S,"failed")) case "failed"=>"failed"
            retractIfCan(u::S)

```

— FRETRCT.dotabb —

```

"FRETRCT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FRETRCT"];
"FRETRCT" -> "RETRACT"

```

— FRETRCT.dotfull —

```

"FullyRetractableTo(a:Type)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FRETRCT"];
"FullyRetractableTo(a:Type)" -> "RetractableTo(a:Type)"

"FullyRetractableTo(a:Ring)"
[color=seagreen,href="bookvol10.2.pdf#nameddest=FRETRCT"];
"FullyRetractableTo(a:Ring)" -> "FullyRetractableTo(a:Type)"

"FullyRetractableTo(a:CommutativeRing)"
[color=seagreen,href="bookvol10.2.pdf#nameddest=FRETRCT"];
"FullyRetractableTo(a:CommutativeRing)" -> "FullyRetractableTo(a:Type)"

```

```

"FullyRetractableTo(a:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FRETRCT"];
"FullyRetractableTo(a:SetCategory)" -> "FullyRetractableTo(a:Type)"

"FullyRetractableTo(Fraction(Integer))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FRETRCT"];
"FullyRetractableTo(Fraction(Integer))" -> "FullyRetractableTo(a:Type)"

```

— FRETRCT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

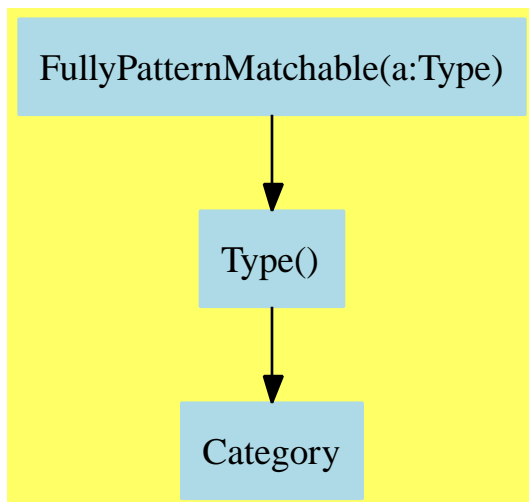
  "FullyRetractableTo(a:Type)" [color=lightblue];
  "FullyRetractableTo(a:Type)" -> "RetractableTo(a:Type)"

  "RetractableTo(a:Type)" [color=lightblue];
  "RetractableTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}

```

FullyPatternMatchable (FPATMAB)



— FullyPatternMatchable.input —

```

)set break resume
)sys rm -f FullyPatternMatchable.output
)spool FullyPatternMatchable.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FullyPatternMatchable
--R
--R FullyPatternMatchable(R: Type) is a category constructor
--R Abbreviation for FullyPatternMatchable is FPATMAB
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FPATMAB
--R
--R----- Operations -----
--R ==? : (%,% ) -> Boolean if R has PATMAB(INT) or R has PATMAB(FLOAT)
--R coerce : % -> OutputForm if R has PATMAB(INT) or R has PATMAB(FLOAT)
--R hash : % -> SingleInteger if R has PATMAB(INT) or R has PATMAB(FLOAT)
--R latex : % -> String if R has PATMAB(INT) or R has PATMAB(FLOAT)
--R patternMatch : (% ,Pattern(Integer),PatternMatchResult(Integer,%)) -> PatternMatchResult(Integer,% ) if R
--R patternMatch : (% ,Pattern(Float),PatternMatchResult(Float,%)) -> PatternMatchResult(Float,% ) if R has P
--R ?~=? : (%,% ) -> Boolean if R has PATMAB(INT) or R has PATMAB(FLOAT)
--R
--E 1

```

```
)spool
)lisp (bye)
```

— FullyPatternMatchable.help —

```
=====
FullyPatternMatchable examples
=====
```

A set S is `PatternMatchable` over R if S can lift the pattern-matching functions of S over the integers and float to itself (necessary for matching in towers).

See Also:

o `)show FullyPatternMatchable`

See:

⇒ “ComplexCategory” (COMPCAT) [20](#) on page [1671](#)

⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)

⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)

⇐ “Type” (TYPE) [2](#) on page [109](#)

Attributes exported:

- `nil`

Exports:

```
coerce  hash  latex  patternMatch  ?=?
?~=?
```

These exports come from (p[279](#)) `PatternMatchable(Integer)`:

```
coerce : % -> OutputForm
  if R has PATMAB INT
  or R has PATMAB FLOAT
hash : % -> SingleInteger
  if R has PATMAB INT
  or R has PATMAB FLOAT
latex : % -> String
  if R has PATMAB INT
  or R has PATMAB FLOAT
patternMatch :
```

```

(%,Pattern Integer,PatternMatchResult(Integer,%))
  -> PatternMatchResult(Integer,%) if R has PATMAB INT
?=? : (%,%) -> Boolean
  if R has PATMAB INT
  or R has PATMAB FLOAT
?~=? : (%,%) -> Boolean
  if R has PATMAB INT
  or R has PATMAB FLOAT

```

These exports come from (p279) PatternMatchable(Float):

```

patternMatch :
(%,Pattern Float,PatternMatchResult(Float,%))
  -> PatternMatchResult(Float,%) if R has PATMAB FLOAT

```

These exports come from (p109) Type():

— category FPATMAB FullyPatternMatchable —

```

)abbrev category FPATMAB FullyPatternMatchable
++ Author: Manuel Bronstein
++ Date Created: 28 Nov 1989
++ Date Last Updated: 29 Nov 1989
++ Description:
++ A set S is PatternMatchable over R if S can lift the
++ pattern-matching functions of S over the integers and float
++ to itself (necessary for matching in towers).

FullyPatternMatchable(R:Type): Category == Type with
  if R has PatternMatchable Integer then PatternMatchable Integer
  if R has PatternMatchable Float   then PatternMatchable Float

```

— FPATMAB.dotabb —

```

"FPATMAB"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FPATMAB"];
"FPATMAB" -> "TYPE"

```

— FPATMAB.dotfull —

```

"FullyPatternMatchable(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FPATMAB"];
"FullyPatternMatchable(a:Type)" -> "Type()"

"FullyPatternMatchable(IntegralDomain)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FPATMAB"];
"FullyPatternMatchable(IntegralDomain)" ->
  "FullyPatternMatchable(a:Type)"

"FullyPatternMatchable(OrderedSet)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FPATMAB"];
"FullyPatternMatchable(OrderedSet)" ->
  "FullyPatternMatchable(a:Type)"

"FullyPatternMatchable(CommutativeRing)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FPATMAB"];
"FullyPatternMatchable(CommutativeRing)" ->
  "FullyPatternMatchable(a:Type)"

```

— FPATMAB.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

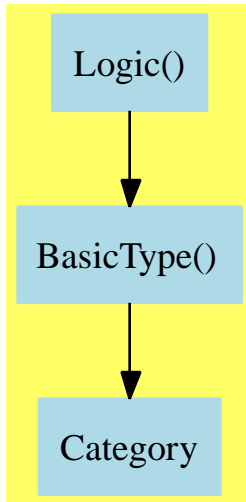
  "FullyPatternMatchable(a:Type)" [color=lightblue];
  "FullyPatternMatchable(a:Type)" -> "Type()"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "Category" [color=lightblue];
}

```

Logic (LOGIC)



— Logic.input —

```

)set break resume
)sys rm -f Logic.output
)spool Logic.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show Logic
--R Logic is a category constructor
--R Abbreviation for Logic is LOGIC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LOGIC
--R
--R----- Operations -----
--R ?/\? : (%,% ) -> %               ?? : (%,% ) -> Boolean
--R ?\/? : (%,% ) -> %               ~? : % -> %
--R ?~=? : (%,% ) -> Boolean
--R
--E 1

)spool
)lisp (bye)

```


— **Logic.help** —

===== Logic examples =====

Logic provides the basic operations for lattices, e.g., boolean algebra.

See Also:

o)show Logic

See:

⇒ “BitAggregate” (BTAGG) [9](#) on page [787](#)

⇐ “BasicType” (BASTYPE) [2](#) on page [23](#)

Exports:

$?/\backslash?$ $?=?$ $?/\backslash?$ $\sim?$ $?^{\sim}=?$

These are directly exported but not implemented:

$\sim?$: $(\%,\%) \rightarrow \%$
 $?/\backslash?$: $(\%,\%) \rightarrow \%$

These are implemented by this category:

$?/\backslash?$: $(\%,\%) \rightarrow \%$

These exports come from (p23) BasicType():

$?=?$: $(\%,\%) \rightarrow \text{Boolean}$
 $?^{\sim}=?$: $(\%,\%) \rightarrow \text{Boolean}$

— **category LOGIC Logic** —

)abbrev category LOGIC Logic

++ Description:

++ Logic provides the basic operations for lattices,
 ++ for example, boolean algebra.

Logic: Category == BasicType with

\sim : $\% \rightarrow \%$

 ++ $\sim(x)$ returns the logical complement of x.

```

_/_\:      (% , %) -> %
++ \spadignore{/\} returns the logical 'meet', for example, 'and'.
_\/\:      (% , %) -> %
++ \spadignore{\/} returns the logical 'join', for example, 'or'.
add
_\/_(x: %,y: %) == _~( _/_\(_~(x), _~(y))

```

— LOGIC.dotabb —

```

"LOGIC"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=LOGIC" ];
"LOGIC" -> "BASTYPE"

```

— LOGIC.dotfull —

```

"Logic()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=LOGIC" ];
"Logic()" -> "BasicType()"

```

— LOGIC.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

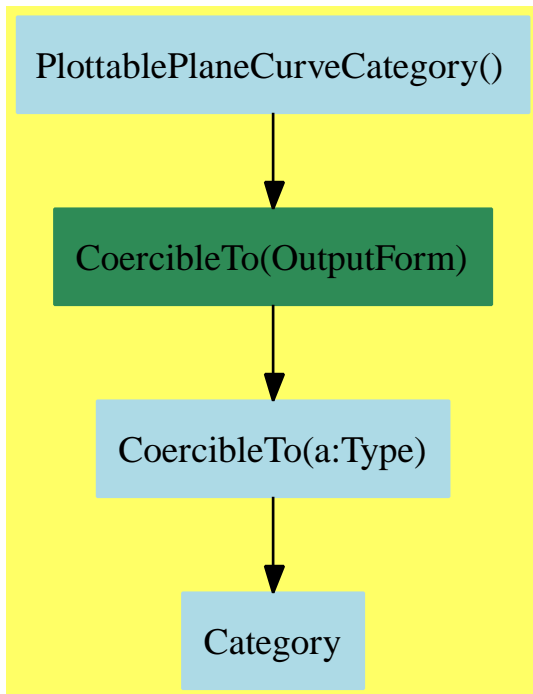
  "Logic()" [color=lightblue];
  "Logic()" -> "BasicType()"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "Category" [color=lightblue];
}

```

PlottablePlaneCurveCategory (PPCURVE)



— PlottablePlaneCurveCategory.input —

```

)set break resume
)sys rm -f PlottablePlaneCurveCategory.output
)spool PlottablePlaneCurveCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PlottablePlaneCurveCategory
--R
--R PlottablePlaneCurveCategory is a category constructor
--R Abbreviation for PlottablePlaneCurveCategory is PPCURVE
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PPCURVE
--R
--R----- Operations -----
--R coerce : % -> OutputForm
--R listBranches : % -> List(List(Point(DoubleFloat)))
--R xRange : % -> Segment(DoubleFloat)

```

```
--R yRange : % -> Segment(DoubleFloat)
--R
--E 1
```

```
)spool
)lisp (bye)
```

— PlottablePlaneCurveCategory.help —

```
=====
PlottablePlaneCurveCategory examples
=====
```

PlottablePlaneCurveCategory is the category of curves in the plane which may be plotted via the graphics facilities. Functions are provided for obtaining lists of lists of points, representing the branches of the curve, and for determining the ranges of the x-coordinates and y-coordinates of the points on the curve.

See Also:

```
o )show PlottablePlaneCurveCategory
```

See:

⇐ “CoercibleTo” (KOERCE) [2](#) on page [33](#)

Exports:

```
coerce listBranches xRange yRange
```

These are directly exported but not implemented:

```
listBranches : % -> List List Point DoubleFloat
xRange : % -> Segment DoubleFloat
yRange : % -> Segment DoubleFloat
```

These exports come from (p[33](#)) CoercibleTo(OutputForm):

```
coerce : % -> OutputForm
```

— category PPCURVE PlottablePlaneCurveCategory —

```
)abbrev category PPCURVE PlottablePlaneCurveCategory
```

```

++ Author: Clifton J. Williamson
++ Date Created: 11 January 1990
++ Date Last Updated: 15 June 1990
++ Description:

```

```

PlottablePlaneCurveCategory(): Category == Definition where

```

```

  L    ==> List
  SEG  ==> Segment
  SF    ==> DoubleFloat
  POINT ==> Point DoubleFloat

```

```

Definition ==> CoercibleTo OutputForm with

```

```

  listBranches: % -> L L POINT
    ++ listBranches(c) returns a list of lists of points, representing the
    ++ branches of the curve c.
  xRange: % -> SEG SF
    ++ xRange(c) returns the range of the x-coordinates of the points
    ++ on the curve c.
  yRange: % -> SEG SF
    ++ yRange(c) returns the range of the y-coordinates of the points
    ++ on the curve c.

```

— PPCURVE.dotabb —

```

"PPCURVE"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PPCURVE"];
"PPCURVE" -> "KOERCE"

```

— PPCURVE.dotfull —

```

"PlottablePlaneCurveCategory()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PPCURVE"];
"PlottablePlaneCurveCategory()" -> "CoercibleTo(OutputForm)"

```

— PPCURVE.dotpic —

```

digraph pic {
  fontsize=10;

```

```

bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"PlottablePlaneCurveCategory()" [color=lightblue];
"PlottablePlaneCurveCategory()" -> "CoercibleTo(OutputForm)"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

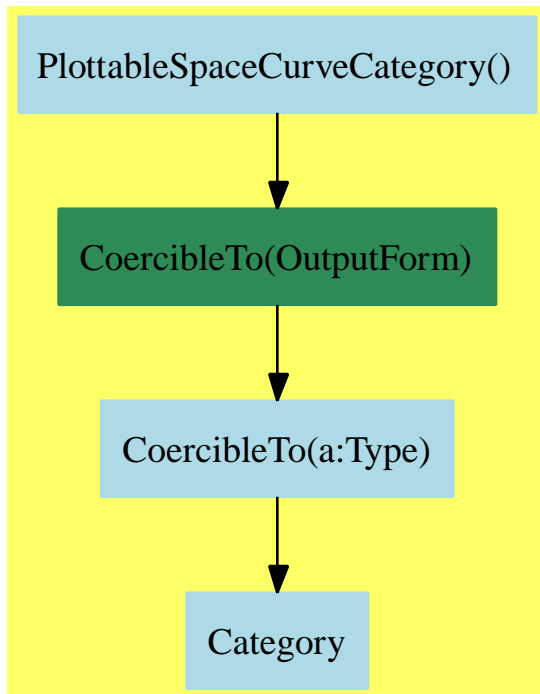
"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];
}

```

—————

PlottableSpaceCurveCategory (PSCURVE)



— PlottableSpaceCurveCategory.input —

```

)set break resume
)sys rm -f PlottableSpaceCurveCategory.output
)spool PlottableSpaceCurveCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PlottableSpaceCurveCategory
--R
--R PlottableSpaceCurveCategory is a category constructor
--R Abbreviation for PlottableSpaceCurveCategory is PSCURVE
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PSCURVE
--R
--R----- Operations -----
--R coerce : % -> OutputForm
--R listBranches : % -> List(List(Point(DoubleFloat)))
--R xRange : % -> Segment(DoubleFloat)
--R yRange : % -> Segment(DoubleFloat)
--R zRange : % -> Segment(DoubleFloat)
--R
--E 1

)spool
)lisp (bye)

```

— PlottableSpaceCurveCategory.help —

```

=====
PlottableSpaceCurveCategory examples
=====

```

PlottableSpaceCurveCategory is the category of curves in 3-space which may be plotted via the graphics facilities. Functions are provided for obtaining lists of lists of points, representing the branches of the curve, and for determining the ranges of the x-, y-, and z-coordinates of the points on the curve.

See Also:
o)show PlottableSpaceCurveCategory

See:

⇐ “CoercibleTo” (KOERCE) 2 on page 33

Exports:

```
coerce listBranches xRange yRange zRange
```

These are directly exported but not implemented:

```
listBranches : % -> List List Point DoubleFloat
xRange : % -> Segment DoubleFloat
yRange : % -> Segment DoubleFloat
zRange : % -> Segment DoubleFloat
```

These exports come from (p33) CoercibleTo(OutputForm):

```
coerce : % -> OutputForm
```

— category PSCURVE PlottableSpaceCurveCategory —

```
)abbrev category PSCURVE PlottableSpaceCurveCategory
++ Author: Clifton J. Williamson
++ Date Created: 11 January 1990
++ Date Last Updated: 15 June 1990
++ Description:
++ PlottableSpaceCurveCategory is the category of curves in
++ 3-space which may be plotted via the graphics facilities. Functions are
++ provided for obtaining lists of lists of points, representing the
++ branches of the curve, and for determining the ranges of the
++ x-, y-, and z-coordinates of the points on the curve.
```

```
PlottableSpaceCurveCategory(): Category == Definition where
```

```
  L      ==> List
  SEG    ==> Segment
  SF      ==> DoubleFloat
  POINT  ==> Point DoubleFloat
```

```
Definition ==> CoercibleTo OutputForm with
```

```
  listBranches: % -> L L POINT
    ++ listBranches(c) returns a list of lists of points, representing the
    ++ branches of the curve c.
  xRange: % -> SEG SF
    ++ xRange(c) returns the range of the x-coordinates of the points
    ++ on the curve c.
  yRange: % -> SEG SF
    ++ yRange(c) returns the range of the y-coordinates of the points
    ++ on the curve c.
  zRange: % -> SEG SF
    ++ zRange(c) returns the range of the z-coordinates of the points
    ++ on the curve c.
```

— PSCURVE.dotabb —

```
"PSCURVE"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PSCURVE"];
"PSCURVE" -> "KOERCE"
```

— PSCURVE.dotfull —

```
"PlottableSpaceCurveCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PSCURVE"];
"PlottableSpaceCurveCategory()" -> "CoercibleTo(OutputForm)"
```

— PSCURVE.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

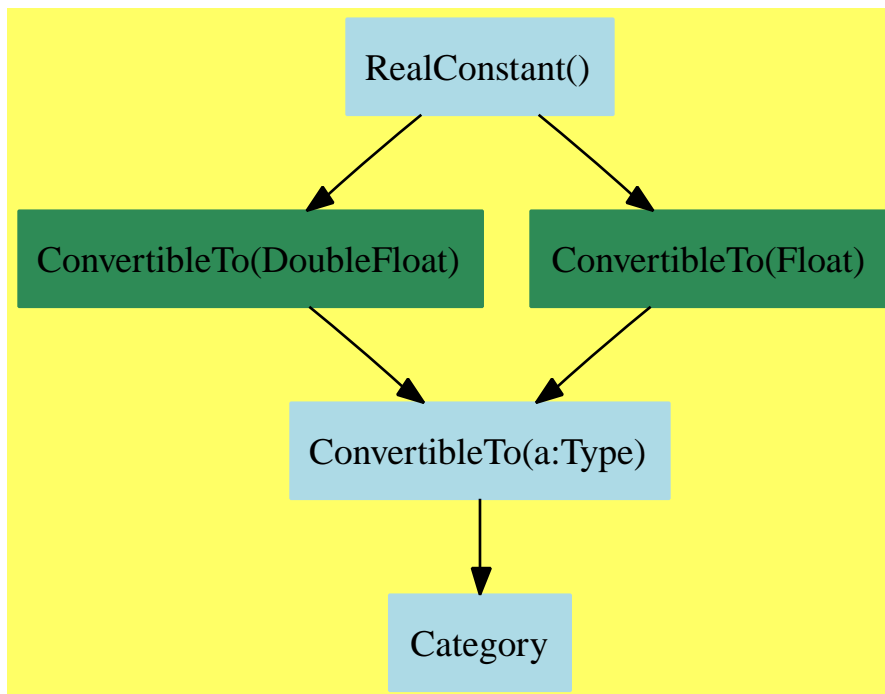
  "PlottableSpaceCurveCategory()" [color=lightblue];
  "PlottableSpaceCurveCategory()" -> "CoercibleTo(OutputForm)"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

RealConstant (REAL)



— RealConstant.input —

```

)set break resume
)sys rm -f RealConstant.output
)spool RealConstant.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RealConstant
--R RealConstant is a category constructor
--R Abbreviation for RealConstant is REAL
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for REAL
--R
--R----- Operations -----
--R convert : % -> Float          convert : % -> DoubleFloat
--R
--E 1

```

```
)spool
)lisp (bye)
```

— RealConstant.help —

```
=====
RealConstant examples
=====
```

The category of real numeric domains, i.e. convertible to floats.

See Also:

o)show RealConstant

See:

⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)
 ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
 ⇒ “RealNumberSystem” (RNS) [17](#) on page [1451](#)
 ⇐ “ConvertibleTo” (KONVERT) [2](#) on page [41](#)

Exports:

convert

These exports come from ([p41](#)) ConvertibleTo(DoubleFloat):

```
convert : % -> DoubleFloat
```

These exports come from ([p41](#)) ConvertibleTo(Float):

```
convert : % -> Float
```

— category REAL RealConstant —

```
)abbrev category REAL RealConstant
```

```
++ Description:
```

```
++ The category of real numeric domains, that is, convertible to floats.
```

```
RealConstant(): Category ==
```

```
  Join(ConvertibleTo DoubleFloat, ConvertibleTo Float)
```

— REAL.dotabb —

```
"REAL"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=REAL"];
"REAL" -> "KONVERT"
```

— REAL.dotfull —

```
"RealConstant()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=REAL"];
"RealConstant()" -> "ConvertibleTo(DoubleFloat)"
"RealConstant()" -> "ConvertibleTo(Float)"
```

— REAL.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "RealConstant()" [color=lightblue];
  "RealConstant()" -> "ConvertibleTo(DoubleFloat)"
  "RealConstant()" -> "ConvertibleTo(Float)"

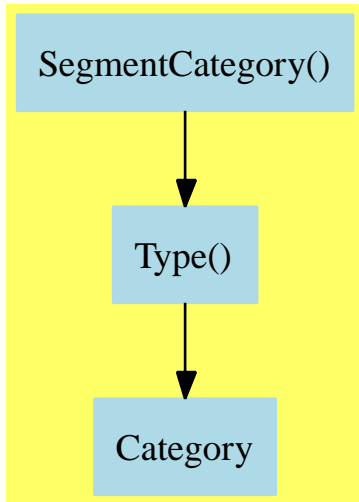
  "ConvertibleTo(DoubleFloat)" [color=seagreen];
  "ConvertibleTo(DoubleFloat)" -> "ConvertibleTo(a:Type)"

  "ConvertibleTo(Float)" [color=seagreen];
  "ConvertibleTo(Float)" -> "ConvertibleTo(a:Type)"

  "ConvertibleTo(a:Type)" [color=lightblue];
  "ConvertibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

SegmentCategory (SEGCAT)



— SegmentCategory.input —

```

)set break resume
)sys rm -f SegmentCategory.output
)spool SegmentCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show SegmentCategory
--R
--R SegmentCategory(S: Type) is a category constructor
--R Abbreviation for SegmentCategory is SEGCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SEGCAT
--R
--R----- Operations -----
--R BY : (%,Integer) -> %          ?..? : (S,S) -> %
--R convert : S -> %              hi : % -> S
--R high : % -> S                  incr : % -> Integer
--R lo : % -> S                    low : % -> S
--R segment : (S,S) -> %
--R
--E 1

)spool
)lisp (bye)

```

— SegmentCategory.help —

```
=====
SegmentCategory examples
=====
```

This category provides operations on ranges, or segments as they are called.

See Also:

o)show SegmentCategory

See:

⇒ “SegmentExpansionCategory” (SEGXCAT) [4](#) on page [288](#)

⇐ “Type” (TYPE) [2](#) on page [109](#)

Exports:

```
BY  convert  hi      high  incr
lo  low      segment  ?..?
```

Attributes Exported:

- nil

These are directly exported but not implemented:

```
BY : (%,Integer) -> %
convert : S -> %
hi : % -> S
high : % -> S
incr : % -> Integer
lo : % -> S
low : % -> S
segment : (S,S) -> %
?..? : (S,S) -> %
```

— category SEGCAT SegmentCategory —

```
)abbrev category SEGCAT SegmentCategory
++ Author:  Stephen M. Watt
++ Date Created:  December 1986
++ Date Last Updated:  June 3, 1991
```

```

++ Description:
++ This category provides operations on ranges, or segments
++ as they are called.

SegmentCategory(S:Type): Category == Type with
  SEGMENT: (S, S) -> %
    ++ \spad{l..h} creates a segment with l and h as the endpoints.
  BY: (% , Integer) -> %
    ++ \spad{s by n} creates a new segment in which only every
    ++ \spad{n}-th element is used.
  lo: % -> S
    ++ lo(s) returns the first endpoint of s.
    ++ Note that \spad{lo(l..h) = l}.
  hi: % -> S
    ++ hi(s) returns the second endpoint of s.
    ++ Note that \spad{hi(l..h) = h}.
  low: % -> S
    ++ low(s) returns the first endpoint of s.
    ++ Note that \spad{low(l..h) = l}.
  high: % -> S
    ++ high(s) returns the second endpoint of s.
    ++ Note that \spad{high(l..h) = h}.
  incr: % -> Integer
    ++ incr(s) returns \spad{n}, where s is a segment in which every
    ++ \spad{n}-th element is used.
    ++ Note that \spad{incr(l..h by n) = n}.
  segment: (S, S) -> %
    ++ segment(i,j) is an alternate way to create the segment
    ++ \spad{i..j}.
  convert: S -> %
    ++ convert(i) creates the segment \spad{i..i}.

```

— SEGCAT.dotabb —

```

"SEGCAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=SEGCAT" ];
"SEGCAT" -> "TYPE"

```

— SEGCAT.dotfull —

```

"SegmentCategory(a:Type)"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=SEGCAT" ];

```

```

"SegmentCategory(a:Type)" -> "Type()"

"SegmentCategory(OrderedRing)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=SEGCAT"];
"SegmentCategory(OrderedRing)" -> "SegmentCategory(a:Type)"

```



```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "SegmentCategory(a:Type)" [color=lightblue];
  "SegmentCategory(a:Type)" -> "Type()"

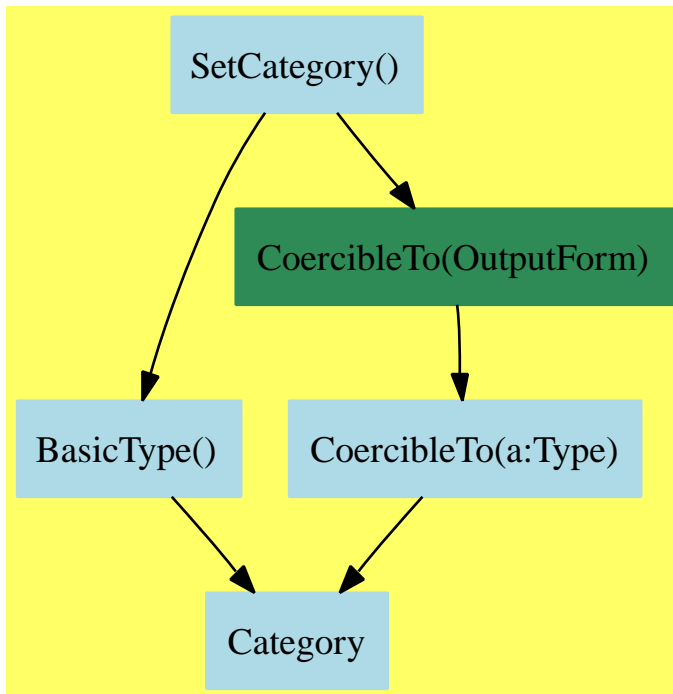
  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "Category" [color=lightblue];
}

```



SetCategory (SETCAT)



— SetCategory.input —

```

)set break resume
)sys rm -f SetCategory.output
)spool SetCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show SetCategory
--R SetCategory is a category constructor
--R Abbreviation for SetCategory is SETCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SETCAT
--R
--R----- Operations -----
--R ?=? : (% , %) -> Boolean          coerce : % -> OutputForm
--R hash : % -> SingleInteger        latex : % -> String
--R ?~=? : (% , %) -> Boolean
--R

```

```
--E 1
```

```
)spool
)lisp (bye)
```

— SetCategory.help —

=====

SetCategory examples

=====

SetCategory is the basic category for describing a collection of elements with = (equality) and coerce to output form.

Conditional Attributes canonical data structure equality is the same as =

See Also:

o)show SetCategory

See:

- ⇒ “AbelianSemiGroup” (ABELSG) [4](#) on page [173](#)
- ⇒ “BlowUpMethodCategory” (BLMETCT) [4](#) on page [177](#)
- ⇒ “FileCategory” (FILECAT) [4](#) on page [213](#)
- ⇒ “FileNameCategory” (FNCAT) [4](#) on page [222](#)
- ⇒ “Finite” (FINITE) [4](#) on page [218](#)
- ⇒ “GradedModule” (GRMOD) [4](#) on page [226](#)
- ⇒ “HomogeneousAggregate” (HOAGG) [4](#) on page [233](#)
- ⇒ “IndexedDirectProductCategory” (IDPC) [4](#) on page [240](#)
- ⇒ “NumericalIntegrationCategory” (NUMINT) [4](#) on page [254](#)
- ⇒ “NumericalOptimizationCategory” (OPTCAT) [4](#) on page [259](#)
- ⇒ “OrderedSet” (ORDSET) [4](#) on page [269](#)
- ⇒ “OrdinaryDifferentialEquationsSolverCategory” (ODECAT) [4](#) on page [264](#)
- ⇒ “PartialDifferentialEquationsSolverCategory” (PDECAT) [4](#) on page [274](#)
- ⇒ “PatternMatchable” (PATMAB) [4](#) on page [279](#)
- ⇒ “PolynomialSetCategory” (PSETCAT) [6](#) on page [520](#)
- ⇒ “RealRootCharacterizationCategory” (RRCC) [4](#) on page [283](#)
- ⇒ “SemiGroup” (SGROUP) [4](#) on page [292](#)
- ⇒ “SetAggregate” (SETAGG) [6](#) on page [546](#)
- ⇒ “SExpressionCategory” (SEXCAT) [4](#) on page [299](#)
- ⇒ “StepThrough” (STEP) [4](#) on page [305](#)
- ⇒ “StringCategory” (STRICAT) [10](#) on page [972](#)

⇒ “ThreeSpaceCategory” (SPACEC) [4](#) on page [309](#)

⇐ “BasicType” (BASTYPE) [2](#) on page [23](#)

⇐ “CoercibleTo” (KOERCE) [2](#) on page [33](#)

Exports:

```
coerce hash latex ==? ?~=?
```

These are implemented by this category:

```
hash : % -> SingleInteger
latex : % -> String
```

These exports come from (p[23](#)) BasicType():

```
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
```

These exports come from (p[33](#)) CoercibleTo(OutputForm):

```
coerce : % -> OutputForm
```

— category SETCAT SetCategory —

```
)abbrev category SETCAT SetCategory
++ Date Last Updated: November 10, 2009 tpd happy birthday
++ Description:
++ \spadtype{SetCategory} is the basic category for describing a collection
++ of elements with \spadop{=} (equality) and \spadfun{coerce} to
++ output form.
++
++ Conditional Attributes\br
++ \tab{5}canonical\tab{5}data structure equality is the same as \spadop{=}

SetCategory(): Category == Join(BasicType,CoercibleTo OutputForm) with
  hash: % -> SingleInteger
    ++ hash(s) calculates a hash code for s.
  latex: % -> String
    ++ latex(s) returns a LaTeX-printable output
    ++ representation of s.
add
  hash(s : %): SingleInteger == SXHASH(s)$Lisp
  latex(s : %): String      == "\mbox{\bf Unimplemented}"
```

— SETCAT.dotabb —

```

"SETCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SETCAT"];
"SETCAT" -> "BASTYPE"
"SETCAT" -> "KOERCE"

```

— SETCAT.dotfull —

```

"SetCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SETCAT"];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

```

— SETCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

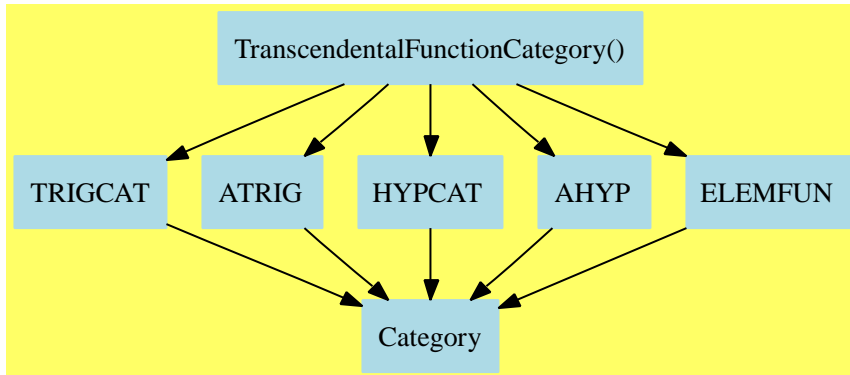
  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}

```

TranscendentalFunctionCategory (TRANFUN)



— TranscendentalFunctionCategory.input —

```

)set break resume
)sys rm -f TranscendentalFunctionCategory.output
)spool TranscendentalFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show TranscendentalFunctionCategory
--R TranscendentalFunctionCategory is a category constructor
--R Abbreviation for TranscendentalFunctionCategory is TRANFUN
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for TRANFUN
--R
--R----- Operations -----
--R ??? : (% , %) -> %
--R acos : % -> %
--R acosh : % -> %
--R acot : % -> %
--R acoth : % -> %
--R acsch : % -> %
--R asec : % -> %
--R asech : % -> %
--R asin : % -> %
--R asinh : % -> %
--R atan : % -> %
--R atanh : % -> %
--R cos : % -> %
--R cosh : % -> %
--R cot : % -> %
--R coth : % -> %
--R csc : % -> %
--R csch : % -> %
--R exp : % -> %
--R log : % -> %
--R pi : () -> %
--R sec : % -> %
--R sech : % -> %
--R sin : % -> %
--R sinh : % -> %
--R tan : % -> %
--R tanh : % -> %
--R

```

```
--E 1
```

```
)spool
)lisp (bye)
```

— **TranscendentalFunctionCategory.help** —

```
=====
TranscendentalFunctionCategory examples
=====
```

This is the Category for the transcendental elementary functions.

See Also:

```
o )show TranscendentalFunctionCategory
```

The `acsch`, `asech`, and `acoth` functions were modified to include an intermediate test to check that the argument has a reciprocal values.

See:

```
⇒ “IntervalCategory” (INTCAT) 14 on page 1200
⇒ “LiouvillianFunctionCategory” (LFCAT) 4 on page 244
⇒ “UnivariateLaurentSeriesCategory” (ULSCAT) 17 on page 1499
⇒ “UnivariatePuisseuxSeriesCategory” (UPXSCAT) 17 on page 1511
⇒ “UnivariateTaylorSeriesCategory” (UTSCAT) 16 on page 1327
⇐ “ArcHyperbolicFunctionCategory” (AHYP) 2 on page 13
⇐ “ArcTrigonometricFunctionCategory” (ATRIG) 2 on page 15
⇐ “ElementaryFunctionCategory” (ELEMFUN) 2 on page 45
⇐ “HyperbolicFunctionCategory” (HYPCAT) 2 on page 53
⇐ “TrigonometricFunctionCategory” (TRIGCAT) 2 on page 106
```

Exports:

| | | | | |
|-------|-------|-------|-------|-------|
| ***? | acos | acosh | acot | acoth |
| acsc | acsch | asec | asech | asin |
| asinh | atan | atanh | cos | cosh |
| cot | coth | csc | csch | exp |
| log | pi | sec | sech | sin |
| sinh | tan | tanh | | |

These are implemented by this category:

```
pi : () -> %
```

These exports come from (p106) `TrigonometricFunctionCategory()`:

```
cos : % -> %
cot : % -> %
csc : % -> %
sec : % -> %
sin : % -> %
tan : % -> %
```

These exports come from (p15) `ArcTrigonometricFunctionCategory()`:

```
acos : % -> %
acot : % -> %
acsc : % -> %
asec : % -> %
asin : % -> %
atan : % -> %
```

These exports come from (p53) `HyperbolicFunctionCategory()`:

```
cosh : % -> %
coth : % -> %
csch : % -> %
sech : % -> %
sinh : % -> %
tanh : % -> %
```

These exports come from (p13) `ArchHyperbolicFunctionCategory()`:

```
acosh : % -> %
acoth : % -> %
acsch : % -> %
asech : % -> %
asinh : % -> %
atanh : % -> %
```

These exports come from (p45) `ElementaryFunctionCategory()`:

```
?**? : (%,% ) -> %
exp : % -> %
log : % -> %
```

— category **TRANFUN** `TranscendentalFunctionCategory` —

```
)abbrev category TRANFUN TranscendentalFunctionCategory
++ Author: Manuel Bronstein
++ Date Last Updated: 14 May 1991
```

```

++ Description:
++ Category for the transcendental elementary functions;

TranscendentalFunctionCategory(): Category ==
  Join(TrigonometricFunctionCategory,ArcTrigonometricFunctionCategory,
        HyperbolicFunctionCategory,ArcHyperbolicFunctionCategory,
        ElementaryFunctionCategory) with
    pi : () -> $      ++ pi() returns the constant pi.
add
  if $ has Ring then
    pi() == 2*asin(1)
    acsch x ==
      (a := recip x) case "failed" => error "acsch: no reciprocal"
      asinh(a::$)
    asech x ==
      (a := recip x) case "failed" => error "asech: no reciprocal"
      acosh(a::$)
    acoth x ==
      (a := recip x) case "failed" => error "acoth: no reciprocal"
      atanh(a::$)
  if $ has Field and $ has sqrt: $ -> $ then
    asin x == atan(x/sqrt(1-x**2))
    acos x == pi()/2::$ - asin x
    acot x == pi()/2::$ - atan x
    asinh x == log(x + sqrt(x**2 + 1))
    acosh x == 2*log(sqrt((x+1)/2::$) + sqrt((x-1)/2::$))
    atanh x == (log(1+x)-log(1-x))/2::$

```

— TRANFUN.dotabb —

```

"TRANFUN"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=TRANFUN"];
"TRANFUN" -> "TRIGCAT"
"TRANFUN" -> "ATRIG"
"TRANFUN" -> "HYPCAT"
"TRANFUN" -> "AHYP"
"TRANFUN" -> "ELEMFUN"

```

— TRANFUN.dotfull —

```

"TranscendentalFunctionCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=TRANFUN"];

```



```

"TranscendentalFunctionCategory()" ->
  "TrigonometricFunctionCategory()"
"TranscendentalFunctionCategory()" ->
  "ArcTrigonometricFunctionCategory()"
"TranscendentalFunctionCategory()" ->
  "HyperbolicFunctionCategory()"
"TranscendentalFunctionCategory()" ->
  "ArcHyperbolicFunctionCategory()"
"TranscendentalFunctionCategory()" ->
  "ElementaryFunctionCategory()"

```

— TRANFUN.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "TranscendentalFunctionCategory()" [color=lightblue];
  "TranscendentalFunctionCategory()" ->
    "TRIGCAT"
  "TranscendentalFunctionCategory()" ->
    "ATRIG"
  "TranscendentalFunctionCategory()" ->
    "HYPCAT"
  "TranscendentalFunctionCategory()" ->
    "AHYP"
  "TranscendentalFunctionCategory()" ->
    "ELEMFUN"

  "TRIGCAT" [color=lightblue];
  "TRIGCAT" -> "Category"

  "ATRIG" [color=lightblue];
  "ATRIG" -> "Category"

  "HYPCAT" [color=lightblue];
  "HYPCAT" -> "Category"

  "AHYP" [color=lightblue];
  "AHYP" -> "Category"

  "ELEMFUN" [color=lightblue];
  "ELEMFUN" -> "Category"

  "Category" [color=lightblue];

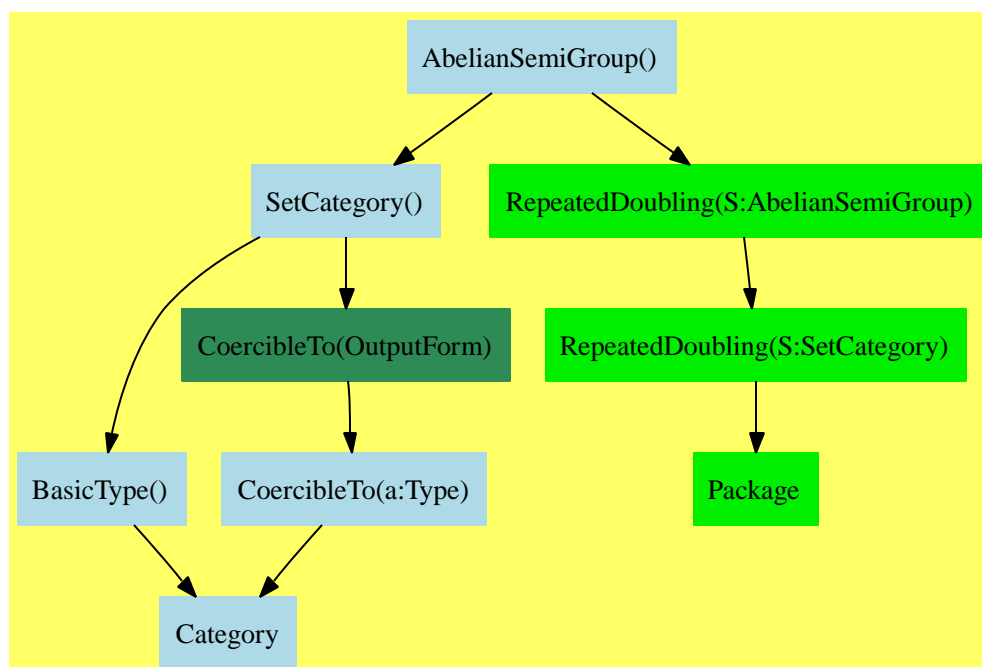
```

}

Chapter 4

Category Layer 3

AbelianSemiGroup (ABELSG)



— AbelianSemiGroup.input —

```
)set break resume  
)sys rm -f AbelianSemiGroup.output  
)spool AbelianSemiGroup.output
```

```

)set message test on
)set message auto off
)clear all

--S 1 of 1
)show AbelianSemiGroup
--R AbelianSemiGroup is a category constructor
--R Abbreviation for AbelianSemiGroup is ABELSG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ABELSG
--R
--R----- Operations -----
--R ?? : (PositiveInteger,%) -> %      ?? : (%,%) -> %
--R ?? : (%,%) -> Boolean              coerce : % -> OutputForm
--R hash : % -> SingleInteger          latex : % -> String
--R ~=? : (%,%) -> Boolean
--R
--E 1

)spool
)lisp (bye)

```

— AbelianSemiGroup.help —

```

=====
AbelianSemiGroup examples
=====

```

This is the class of all additive (commutative) semigroups, i.e.
a set with a commutative and associative operation +.

Axioms:

```

associative("+: (%,%) -> %")    (x+y)+z = x+(y+z)
commutative("+: (%,%) -> %")    x+y = y+x

```

See Also:
o)show AbelianSemiGroup

See:

⇒ “AbelianMonoid” (ABELMON) [5](#) on page [321](#)
⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

```
coerce hash latex ?? ?+?
?=? ?~=?
```

These are directly exported but not implemented:

```
?+? : (%,% ) -> %
```

These are implemented by this category:

```
?*? : (PositiveInteger,% ) -> %
```

These exports come from (p162) SetCategory():

```
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
```

— category ABELSG AbelianSemiGroup —

```
)abbrev category ABELSG AbelianSemiGroup
++ Description:
++ The class of all additive (commutative) semigroups, i.e.
++ a set with a commutative and associative operation \spadop{+}.
++
++ Axioms\br
++ \tab{5}\spad{associative("+":(%,% )->% )}\tab{5}\spad{ (x+y)+z = x+(y+z) }\br
++ \tab{6}\spad{commutative("+":(%,% )->% )}\tab{5}\spad{ x+y = y+x }

AbelianSemiGroup(): Category == SetCategory with
  "+": (%,% ) -> %          ++ x+y computes the sum of x and y.
  "*": (PositiveInteger,% ) -> %
    ++ n*x computes the left-multiplication of x by the positive
    ++ integer n. This is equivalent to adding x to itself n times.
add
import RepeatedDoubling(%)
if not (% has Ring) then
  n:PositiveInteger * x:% == double(n,x)
```

—————

— ABELSG.dotabb —

"ABELSG"

```

[color=lightblue,href="bookvol10.2.pdf#nameddest=ABELSG"];
"ABELSG" -> "SETCAT"
"ABELSG" -> "REPDB"

```

— ABELSG.dotfull —

```

"AbelianSemiGroup()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ABELSG"];
"AbelianSemiGroup()" -> "SetCategory()"
"AbelianSemiGroup()" -> "RepeatedDoubling(a:SetCategory)"

```

— ABELSG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "AbelianSemiGroup()" [color=lightblue];
  "AbelianSemiGroup()" -> "SetCategory()"
  "AbelianSemiGroup()" -> "RepeatedDoubling(AbelianSemiGroup)"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" ->
    "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "RepeatedDoubling(AbelianSemiGroup)" [color="#00EE00"];
  "RepeatedDoubling(AbelianSemiGroup)" -> "RepeatedDoubling(a:SetCategory)"

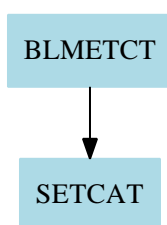
  "RepeatedDoubling(a:SetCategory)" [color="#00EE00"];
  "RepeatedDoubling(a:SetCategory)" -> "Package"
}

```

```
"Package" [color="#00EE00"];

"Category" [color=lightblue];
}
```

BlowUpMethodCategory (BLMETCT)



— BlowUpMethodCategory.input —

```
)set break resume
)sys rm -f BlowUpMethodCategory.output
)spool BlowUpMethodCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show BlowUpMethodCategory
--R
--R BlowUpMethodCategory is a category constructor
--R Abbreviation for BlowUpMethodCategory is BLMETCT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for BLMETCT
--R
--R----- Operations -----
--R ?? : (%,% ) -> Boolean          chartCoord : % -> Integer
--R coerce : List(Integer) -> %      coerce : % -> OutputForm
--R excepCoord : % -> Integer         hash : % -> SingleInteger
--R infClsPt? : % -> Boolean          latex : % -> String
--R quotValuation : % -> Integer      ramifMult : % -> Integer
--R transCoord : % -> Integer         ?~=? : (%,% ) -> Boolean
--R createHN : (Integer,Integer,Integer,Integer,Integer,Boolean,Union(left,center,right,vertical,horizontal))
--R type : % -> Union(left,center,right,vertical,horizontal)
--R
--E 1
```



```
)spool
)lisp (bye)
```

— BlowUpMethodCategory.help —

```
=====
BlowUpMethodCategory examples
=====
```

```
See Also:
o )show BlowUpMethodCategory
```

See:

⇐ “BasicType” (BASTYPE) [2](#) on page [23](#)
 ⇐ “CoercibleTo” (KOERCE) [2](#) on page [33](#)
 ⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

```
?=?          ?~=?          chartCoord  coerce  createHN
excepCoord   hash          infClsPt?    latex   quotValuation
ramifMult    transCoord    type
```

These are directly exported but not implemented:

```
coerce: List Integer -> %
excepCoord: % -> Integer
chartCoord: % -> Integer
transCoord: % -> Integer
createHN: ( Integer, Integer, Integer , Integer, Integer, Boolean, _
           Union("left","center","right","vertical","horizontal")) -> %
ramifMult: % -> Integer
infClsPt_? : % -> Boolean
quotValuation : % -> Integer
type: % -> Union("left","center","right","vertical","horizontal")
```

These exports come from (p[162](#)) SetCategory():

```
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
```

— category BLMETCT BlowUpMethodCategory —

```

)abbrev category BLMETCT BlowUpMethodCategory
BlowUpMethodCategory:Category == SetCategory with

  coerce: List Integer -> %

  excepCoord: % -> Integer

  chartCoord: % -> Integer

  transCoord: % -> Integer

  createHN: ( Integer, Integer, Integer , Integer, Integer, Boolean, _
              Union("left","center","right","vertical","horizontal")) -> %

  ramifMult: % -> Integer

  infClsPt_? : % -> Boolean

  quotValuation : % -> Integer

  type: % -> Union("left","center","right","vertical","horizontal")

```

— BLMETCT.dotabb —

```

"BLMETCT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=BLMETCT" ];
"BLMETCT" -> "SETCAT"

```

— BLMETCT.dotfull —

```

"BlowUpMethodCategory()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=BLMETCT" ];
"BlowUpMethodCategory()" -> "SetCategory()"

```

— BLMETCT.dotpic —

```

digraph pic {

```

```
fontSize=10;
bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"BlowUpMethodCategory()" [color=lightblue];
"BlowUpMethodCategory()" -> "SetCategory()"

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

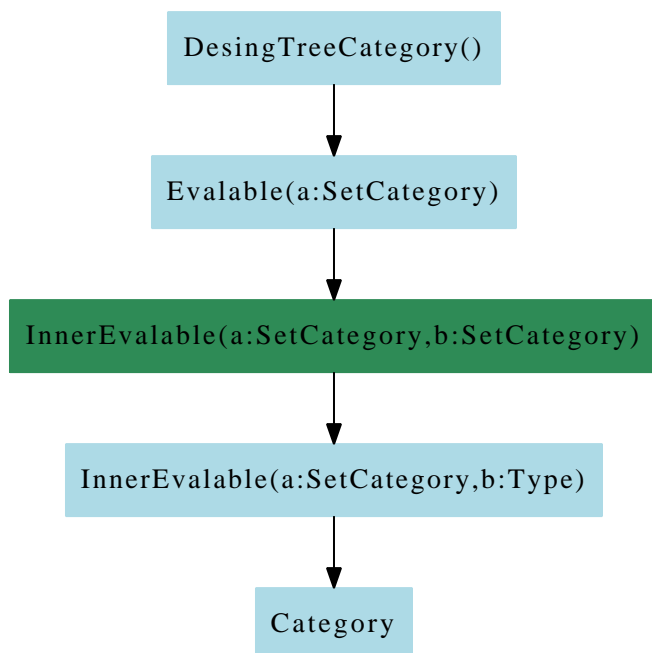
"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" ->
    "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];
}
```

DesingTreeCategory (DSTRCAT)



— DesingTreeCategory.input —

```

)set break resume
)sys rm -f DesingTreeCategory.output
)spool DesingTreeCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show DesingTreeCategory
--R
--R DesingTreeCategory(S: SetCategory) is a category constructor
--R Abbreviation for DesingTreeCategory is DSTRCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DSTRCAT
--R
--R----- Operations -----
--R children : % -> List(%)
--R cyclic? : % -> Boolean
--R ?.value : (%,value) -> S
--R empty? : % -> Boolean
--R leaf? : % -> Boolean
--R map : ((S -> S),%) -> %
--R copy : % -> %
--R distance : (%,%) -> Integer
--R empty : () -> %
--R eq? : (%,%) -> Boolean
--R leaves : % -> List(S)
--R nodes : % -> List(%)

```

```

--R sample : () -> %                                tree : List(S) -> %
--R tree : S -> %                                    tree : (S,List(%)) -> %
--R value : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ==? : (%,% ) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R child? : (%,% ) -> Boolean if S has SETCAT
--R coerce : % -> OutputForm if S has SETCAT
--R count : (S,% ) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,% ) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R node? : (%,% ) -> Boolean if S has SETCAT
--R parts : % -> List(S) if $ has finiteAggregate
--R setchildren! : (% ,List(%)) -> % if $ has shallowlyMutable
--R setelt : (% ,value,S) -> S if $ has shallowlyMutable
--R setvalue! : (% ,S) -> S if $ has shallowlyMutable
--R size? : (% ,NonNegativeInteger) -> Boolean
--R ~=? : (%,% ) -> Boolean if S has SETCAT
--R
--E 1

```

```

)spool
)lisp (bye)

```

— DesingTreeCategory.help —

```

=====
DesingTreeCategory examples
=====

```

This category is part of the PAFF package.

See Also:

o)show DesingTreeCategory

See:

⇒ “Evaluable” (EVALAB) [3](#) on page [129](#)

Exports:

| | | | | |
|---------|----------|--------------|--------|-----------|
| #? | ?.value | ?=? | ?~=? | any? |
| child? | children | coerce | copy | count |
| count | cyclic? | distance | empty | empty? |
| eq? | eval | every? | hash | latex |
| leaf? | leaves | less? | map | map! |
| member? | members | more? | node? | nodes |
| parts | sample | setchildren! | setelt | setvalue! |
| size? | tree | value | | |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```
tree : (S,List %) -> %
tree : List S -> %
tree : S -> %
```

These exports come from (p406) RecursiveAggregate(Type)

```
#? : % -> NonNegativeInteger if $ has finiteAggregate
?.value : (% ,value) -> S
==? : (% ,%) -> Boolean if S has SETCAT
?~=? : (% ,%) -> Boolean if S has SETCAT
any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
child? : (% ,%) -> Boolean if S has SETCAT
children : % -> List %
coerce : % -> OutputForm if S has SETCAT
copy : % -> %
count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
cyclic? : % -> Boolean
distance : (% ,%) -> Integer
empty : () -> %
empty? : % -> Boolean
eq? : (% ,%) -> Boolean
eval : (% ,Equation S) -> % if S has EVALAB S and S has SETCAT
eval : (% ,List Equation S) -> % if S has EVALAB S and S has SETCAT
```

```

eval : (%,List S,List S) -> % if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> % if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
leaf? : % -> Boolean
leaves : % -> List S
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
node? : (%,%) -> Boolean if S has SETCAT
nodes : % -> List %
parts : % -> List S if $ has finiteAggregate
sample : () -> %
setchildren! : (%,List %) -> % if $ has shallowlyMutable
setelt : (%,value,S) -> S if $ has shallowlyMutable
setvalue! : (%,S) -> S if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
value : % -> S

```

— category DSTRCAT DesingTreeCategory —

```

)abbrev category DSTRCAT DesingTreeCategory
++ Authors: Gaetan Hache
++ Date Created: jan 1998
++ Date Last Updated: May 2010 by Tim Daly
++ Description:
++ This category is part of the PAFF package
DesingTreeCategory(S: SetCategory):Category == RecursiveAggregate(S) with

  shallowlyMutable
  finiteAggregate

tree: (S,List %) -> %
  ++ tree(nd,ls) creates a tree with value nd, and children ls.

tree: S -> %
  ++ tree(nd) creates a tree with value nd, and no children

tree: List(S) -> %
  ++ tree(l) creates a chain tree from the list l

```

— DSTRCAT.dotabb —

```
"DSTRCAT" [color=lightblue,href="bookvol10.2.pdf#nameddest=DSTRCAT"];
"EVALAB" [color="#4488FF",href="bookvol10.2.pdf#nameddest=EVALAB"]
"DSTRCAT" -> "EVALAB"
```

— DSTRCAT.dotfull —

```
"DesingTreeCategory()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=DSTRCAT"];
"DesingTreeCategory()" -> "Evalable()"
```

— DSTRCAT.dotpic —

```
digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

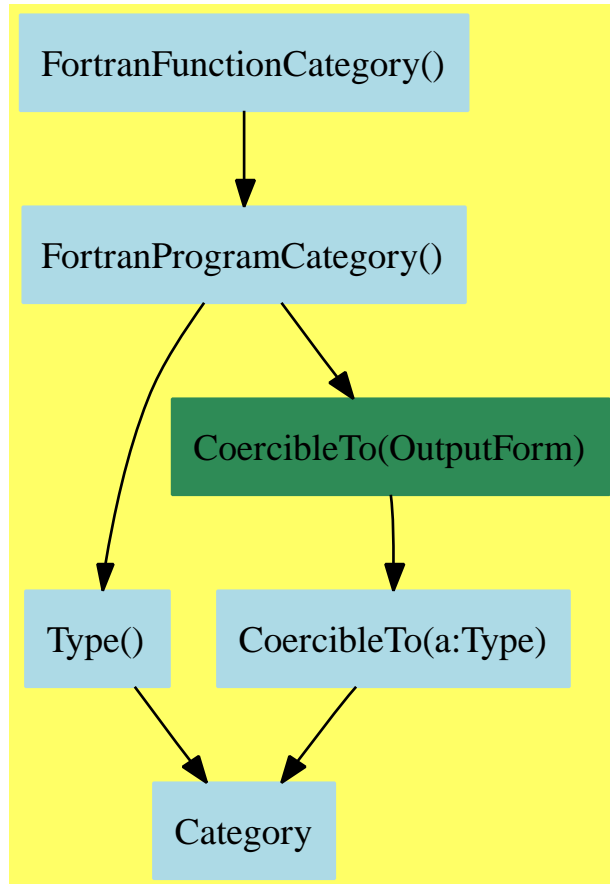
    "DesingTreeCategory()" [color=lightblue];
    "DesingTreeCategory()" -> "Evalable(a:SetCategory)"

    "Evalable(a:SetCategory)" [color=lightblue];
    "Evalable(a:SetCategory)" -> "InnerEvalable(a:SetCategory,b:SetCategory)"

    "InnerEvalable(a:SetCategory,b:SetCategory)" [color=seagreen];
    "InnerEvalable(a:SetCategory,b:SetCategory)" ->
        "InnerEvalable(a:SetCategory,b:Type)"

    "InnerEvalable(a:SetCategory,b:Type)" [color=lightblue];
    "InnerEvalable(a:SetCategory,b:Type)" -> "Category"

    "Category" [color=lightblue];
}
```


FortranFunctionCategory (FORTFN)

— FortranFunctionCategory.input —

```

)set break resume
)sys rm -f FortranFunctionCategory.output
)spool FortranFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FortranFunctionCategory
--R
--R FortranFunctionCategory is a category constructor
--R Abbreviation for FortranFunctionCategory is FORTFN
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FORTFN
--R
--R----- Operations -----
--R coerce : FortranCode -> %          coerce : List(FortranCode) -> %
--R coerce : % -> OutputForm          outputAsFortran : % -> Void
--R retract : Polynomial(Float) -> %    retract : Expression(Float) -> %
--R coerce : Record(localSymbols: SymbolTable,code: List(FortranCode)) -> %
--R retract : Fraction(Polynomial(Integer)) -> %
--R retract : Fraction(Polynomial(Float)) -> %
--R retract : Polynomial(Integer) -> %
--R retract : Expression(Integer) -> %
--R retractIfCan : Fraction(Polynomial(Integer)) -> Union(%, "failed")
--R retractIfCan : Fraction(Polynomial(Float)) -> Union(%, "failed")
--R retractIfCan : Polynomial(Integer) -> Union(%, "failed")
--R retractIfCan : Polynomial(Float) -> Union(%, "failed")
--R retractIfCan : Expression(Integer) -> Union(%, "failed")
--R retractIfCan : Expression(Float) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— FortranFunctionCategory.help —

```

=====
FortranFunctionCategory examples
=====

```

FortranFunctionCategory is the category of arguments to NAG Library routines which return (sets of) function values.

See Also:

o)show FortranFunctionCategory

See:

⇐ “FortranProgramCategory” (FORTCAT) [3](#) on page [133](#)

Exports:

coerce outputAsFortran retract retractIfCan

Attributes:

- **nil**

These are directly exported but not implemented:

```

coerce : FortranCode -> %
coerce : List FortranCode -> %
coerce : Record(localSymbols: SymbolTable,code: List FortranCode) -> %
retract : Expression Float -> %
retract : Expression Integer -> %
retract : Polynomial Float -> %
retract : Polynomial Integer -> %
retract : Fraction Polynomial Integer -> %
retract : Fraction Polynomial Float -> %
retractIfCan : Fraction Polynomial Integer -> Union(%, "failed")
retractIfCan : Fraction Polynomial Float -> Union(%, "failed")
retractIfCan : Polynomial Integer -> Union(%, "failed")
retractIfCan : Polynomial Float -> Union(%, "failed")
retractIfCan : Expression Integer -> Union(%, "failed")
retractIfCan : Expression Float -> Union(%, "failed")

```

These exports come from (p133) FortranProgramCategory():

```

coerce : % -> OutputForm
outputAsFortran : % -> Void

```

— category FORTFN FortranFunctionCategory —

```

)abbrev category FORTFN FortranFunctionCategory
++ Author: Mike Dewar
++ Date Created: 13 January 1994
++ Date Last Updated: 18 March 1994
++ Description:
++ \axiomType{FortranFunctionCategory} is the category of arguments to
++ NAG Library routines which return (sets of) function values.

```

```

FortranFunctionCategory():Category == FortranProgramCategory with
  coerce : List FortranCode -> $
    ++ coerce(e) takes an object from \spadtype{List FortranCode} and
    ++ uses it as the body of an ASP.
  coerce : FortranCode -> $
    ++ coerce(e) takes an object from \spadtype{FortranCode} and
    ++ uses it as the body of an ASP.
  coerce : Record(localSymbols:SymbolTable,code:List(FortranCode)) -> $
    ++ coerce(e) takes the component of \spad{e} from
    ++ \spadtype{List FortranCode} and uses it as the body of the ASP,
    ++ making the declarations in the \spadtype{SymbolTable} component.
  retract : Expression Float -> $
    ++ retract(e) tries to convert \spad{e} into an ASP, checking that

```

```

++ legal Fortran-77 is produced.
retractIfCan : Expression Float -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Expression Integer -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Expression Integer -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Polynomial Float -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Polynomial Float -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Polynomial Integer -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Polynomial Integer -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Fraction Polynomial Float -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Fraction Polynomial Float -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Fraction Polynomial Integer -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Fraction Polynomial Integer -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.

-- NB: These ASPs also have a coerce from an appropriate instantiation
--      of FortranExpression.

```

— FORTFN.dotabb —

```

"FORTFN"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FORTFN"];
"FORTFN" -> "FORTCAT"

```

— FORTFN.dotfull —

```
"FortranFunctionCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FORTFN"];
"FortranFunctionCategory()" -> "FortranProgramCategory()"
```

— FORTFN.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FortranFunctionCategory()" [color=lightblue];
  "FortranFunctionCategory()" -> "FortranProgramCategory()"

  "FortranProgramCategory()" [color=lightblue];
  "FortranProgramCategory()" -> "Type()"
  "FortranProgramCategory()" -> "CoercibleTo(OutputForm)"

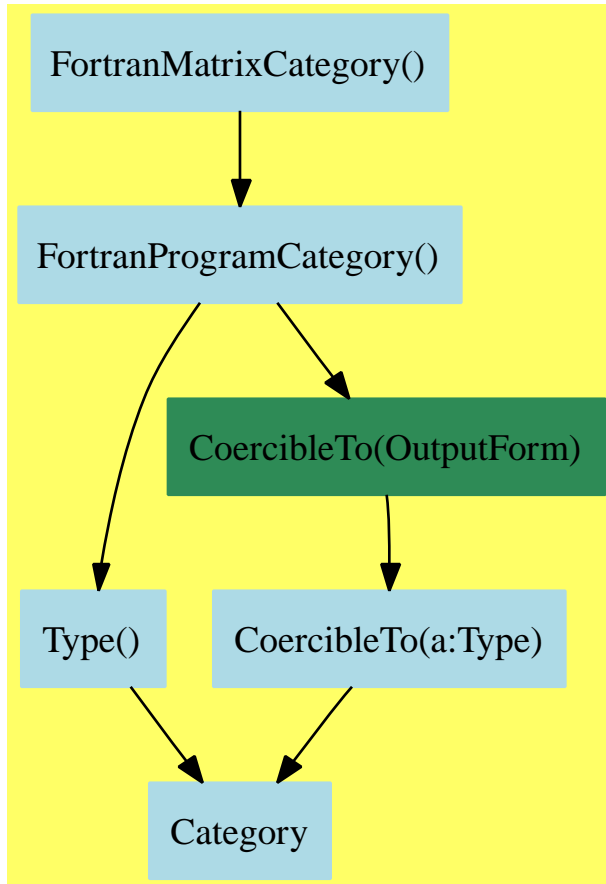
  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

FortranMatrixCategory (FMC)



— FortranMatrixCategory.input —

```

)set break resume
)sys rm -f FortranMatrixCategory.output
)spool FortranMatrixCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FortranMatrixCategory
--R
--R FortranMatrixCategory is a category constructor
--R Abbreviation for FortranMatrixCategory is FMC
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FMC
--R
--R----- Operations -----
--R coerce : FortranCode -> %           coerce : List(FortranCode) -> %
--R coerce : % -> OutputForm           outputAsFortran : % -> Void
--R coerce : Record(localSymbols: SymbolTable,code: List(FortranCode)) -> %
--R coerce : Matrix(MachineFloat) -> %
--R
--E 1

)spool
)lisp (bye)

```

— FortranMatrixCategory.help —

=====

FortranMatrixCategory examples

=====

FortranMatrixCategory provides support for producing Functions and Subroutines when the input to these is an AXIOM object of type Matrix or in domains involving FortranCode.

See Also:

- o)show FortranMatrixCategory

See:

⇐ “FortranProgramCategory” (FORTCAT) [3](#) on page [133](#)

Exports:

coerce outputAsFortran

Attributes:

- nil

These are directly exported but not implemented:

```

coerce : Matrix MachineFloat -> %
coerce : List FortranCode -> %
coerce : FortranCode -> %
coerce : Record(localSymbols: SymbolTable,code: List FortranCode) -> %

```

These exports come from (p133) FortranProgramCategory():

```
coerce : % -> OutputForm
outputAsFortran : % -> Void
```

— category FMC FortranMatrixCategory —

```
)abbrev category FMC FortranMatrixCategory
++ Author: Mike Dewar
++ Date Created: 21 March 1994
++ Description:
++ \axiomType{FortranMatrixCategory} provides support for
++ producing Functions and Subroutines when the input to these
++ is an AXIOM object of type \axiomType{Matrix} or in domains
++ involving \axiomType{FortranCode}.

FortranMatrixCategory():Category == FortranProgramCategory with
  coerce : Matrix MachineFloat -> $
    ++ coerce(v) produces an ASP which returns the value of \spad{v}.
  coerce : List FortranCode -> $
    ++ coerce(e) takes an object from \spadtype{List FortranCode} and
    ++ uses it as the body of an ASP.
  coerce : FortranCode -> $
    ++ coerce(e) takes an object from \spadtype{FortranCode} and
    ++ uses it as the body of an ASP.
  coerce : Record(localSymbols:SymbolTable,code:List(FortranCode)) -> $
    ++ coerce(e) takes the component of \spad{e} from
    ++ \spadtype{List FortranCode} and uses it as the body of the ASP,
    ++ making the declarations in the \spadtype{SymbolTable} component.
```

—————

— FMC.dotabb —

```
"FMC"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=FMC" ];
"FMC" -> "FORTCAT"
```

—————

— FMC.dotfull —

```
"FortranMatrixCategory()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=FMC" ];
"FortranMatrixCategory()" -> "FortranProgramCategory()"
```

— FMC.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FortranMatrixCategory()" [color=lightblue];
  "FortranMatrixCategory()" -> "FortranProgramCategory()"

  "FortranProgramCategory()" [color=lightblue];
  "FortranProgramCategory()" -> "Type()"
  "FortranProgramCategory()" -> "CoercibleTo(OutputForm)"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

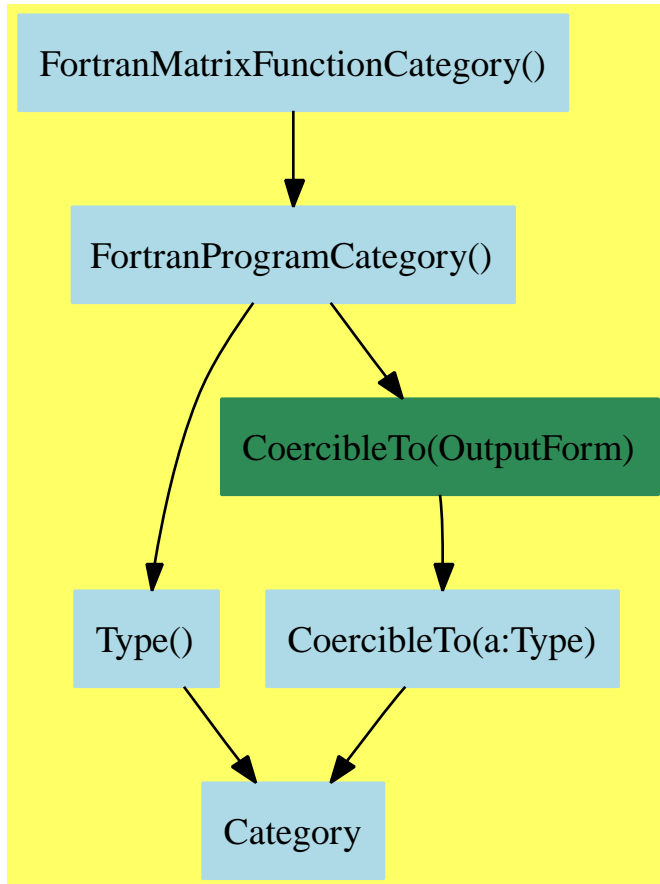
  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}

```

FortranMatrixFunctionCategory (FMFUN)



— FortranMatrixFunctionCategory.input —

```

)set break resume
)sys rm -f FortranMatrixFunctionCategory.output
)spool FortranMatrixFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FortranMatrixFunctionCategory
--R
--R FortranMatrixFunctionCategory is a category constructor
--R Abbreviation for FortranMatrixFunctionCategory is FMFUN
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FMFUN
--R
--R----- Operations -----
--R coerce : FortranCode -> %               coerce : List(FortranCode) -> %
--R coerce : % -> OutputForm               outputAsFortran : % -> Void
--R coerce : Record(localSymbols: SymbolTable,code: List(FortranCode)) -> %
--R retract : Matrix(Fraction(Polynomial(Integer))) -> %
--R retract : Matrix(Fraction(Polynomial(Float))) -> %
--R retract : Matrix(Polynomial(Integer)) -> %
--R retract : Matrix(Polynomial(Float)) -> %
--R retract : Matrix(Expression(Integer)) -> %
--R retract : Matrix(Expression(Float)) -> %
--R retractIfCan : Matrix(Fraction(Polynomial(Integer))) -> Union(%, "failed")
--R retractIfCan : Matrix(Fraction(Polynomial(Float))) -> Union(%, "failed")
--R retractIfCan : Matrix(Polynomial(Integer)) -> Union(%, "failed")
--R retractIfCan : Matrix(Polynomial(Float)) -> Union(%, "failed")
--R retractIfCan : Matrix(Expression(Integer)) -> Union(%, "failed")
--R retractIfCan : Matrix(Expression(Float)) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— FortranMatrixFunctionCategory.help —

```

=====
FortranMatrixFunctionCategory examples
=====

```

FortranMatrixFunctionCategory provides support for producing Functions and Subroutines representing matrices of expressions.

See Also:

o)show FortranMatrixFunctionCategory

See:

⇐ “FortranProgramCategory” (FORTCAT) 3 on page 133

Exports:

coerce outputAsFortran retract retractIfCan

Attributes:

- nil

These are directly exported but not implemented:

```
coerce : List FortranCode -> %
coerce : FortranCode -> %
coerce : Record(localSymbols: SymbolTable,code: List FortranCode) -> %
retract : Matrix Expression Float -> %
retract : Matrix Expression Integer -> %
retract : Matrix Polynomial Float -> %
retract : Matrix Polynomial Integer -> %
retract : Matrix Fraction Polynomial Float -> %
retract : Matrix Fraction Polynomial Integer -> %
retractIfCan : Matrix Fraction Polynomial Integer -> Union(%, "failed")
retractIfCan : Matrix Fraction Polynomial Float -> Union(%, "failed")
retractIfCan : Matrix Polynomial Integer -> Union(%, "failed")
retractIfCan : Matrix Polynomial Float -> Union(%, "failed")
retractIfCan : Matrix Expression Integer -> Union(%, "failed")
retractIfCan : Matrix Expression Float -> Union(%, "failed")
```

These exports come from (p133) FortranProgramCategory():

```
coerce : % -> OutputForm
outputAsFortran : % -> Void
```

— category FMFUN FortranMatrixFunctionCategory —

```
)abbrev category FMFUN FortranMatrixFunctionCategory
++ Author: Mike Dewar
++ Date Created: March 18 1994
++ Description:
++ \axiomType{FortranMatrixFunctionCategory} provides support for
++ producing Functions and Subroutines representing matrices of
++ expressions.

FortranMatrixFunctionCategory():Category == FortranProgramCategory with
  coerce : List FortranCode -> $
    ++ coerce(e) takes an object from \spadtype{List FortranCode} and
    ++ uses it as the body of an ASP.
  coerce : FortranCode -> $
    ++ coerce(e) takes an object from \spadtype{FortranCode} and
    ++ uses it as the body of an ASP.
  coerce : Record(localSymbols:SymbolTable,code:List(FortranCode)) -> $
    ++ coerce(e) takes the component of \spad{e} from
    ++ \spadtype{List FortranCode} and uses it as the body of the ASP,
    ++ making the declarations in the \spadtype{SymbolTable} component.
  retract : Matrix Expression Float -> $
    ++ retract(e) tries to convert \spad{e} into an ASP, checking that
```

```

++ legal Fortran-77 is produced.
retractIfCan : Matrix Expression Float -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Matrix Expression Integer -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Matrix Expression Integer -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Matrix Polynomial Float -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Matrix Polynomial Float -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Matrix Polynomial Integer -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Matrix Polynomial Integer -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Matrix Fraction Polynomial Float -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Matrix Fraction Polynomial Float -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Matrix Fraction Polynomial Integer -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Matrix Fraction Polynomial Integer -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.

-- NB: These ASPs also have a coerce from an appropriate instantiation
--      of Matrix FortranExpression.

```

— FMFUN.dotabb —

```

"FMFUN"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FMFUN"];
"FMFUN" -> "FORTCAT"

```

— FMFUN.dotfull —

```
"FortranMatrixFunctionCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FMFUN"];
"FortranMatrixFunctionCategory()" -> "FortranProgramCategory()"
```

— FMFUN.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FortranMatrixFunctionCategory()" [color=lightblue];
  "FortranMatrixFunctionCategory()" -> "FortranProgramCategory()"

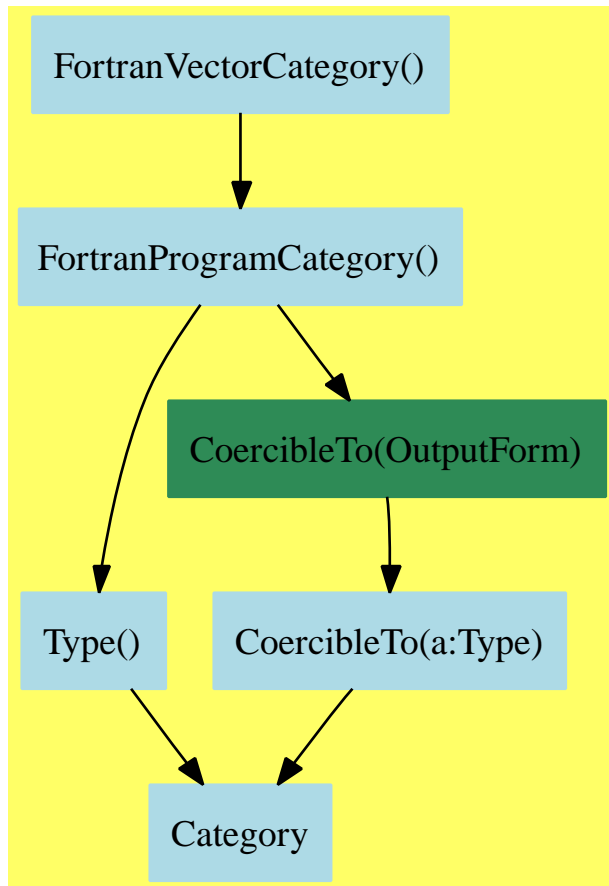
  "FortranProgramCategory()" [color=lightblue];
  "FortranProgramCategory()" -> "Type()"
  "FortranProgramCategory()" -> "CoercibleTo(OutputForm)"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

FortranVectorCategory (FVC)

— FortranVectorCategory.input —

```

)set break resume
)sys rm -f FortranVectorCategory.output
)spool FortranVectorCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FortranVectorCategory
--R
--R FortranVectorCategory is a category constructor
--R Abbreviation for FortranVectorCategory is FVC
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FVC
--R
--R----- Operations -----
--R coerce : FortranCode -> %           coerce : List(FortranCode) -> %
--R coerce : % -> OutputForm           outputAsFortran : % -> Void
--R coerce : Record(localSymbols: SymbolTable,code: List(FortranCode)) -> %
--R coerce : Vector(MachineFloat) -> %
--R
--E 1

)spool
)lisp (bye)

```

— FortranVectorCategory.help —

=====

FortranVectorCategory examples

=====

FortranVectorCategory provides support for producing Functions and Subroutines when the input to these is an AXIOM object of type Vector or in domains involving FortranCode.

See Also:

o)show FortranVectorCategory

See:

⇐ “FortranProgramCategory” (FORTCAT) [3](#) on page [133](#)

Exports:

Attributes:

- nil

These are directly exported but not implemented:

```

coerce : FortranCode -> %
coerce : List FortranCode -> %
coerce : Vector MachineFloat -> %
coerce : Record(localSymbols: SymbolTable,code: List FortranCode) -> %

```


These exports come from (p133) `FortranProgramCategory()`:

```
coerce : % -> OutputForm
outputAsFortran : % -> Void
```

— category FVC FortranVectorCategory —

```
)abbrev category FVC FortranVectorCategory
++ Author: Mike Dewar
++ Date Created: October 1993
++ Date Last Updated: 18 March 1994
++ Description:
++ \axiomType{FortranVectorCategory} provides support for
++ producing Functions and Subroutines when the input to these
++ is an AXIOM object of type \axiomType{Vector} or in domains
++ involving \axiomType{FortranCode}.

FortranVectorCategory():Category == FortranProgramCategory with
  coerce : Vector MachineFloat -> $
    ++ coerce(v) produces an ASP which returns the value of \spad{v}.
  coerce : List FortranCode -> $
    ++ coerce(e) takes an object from \spadtype{List FortranCode} and
    ++ uses it as the body of an ASP.
  coerce : FortranCode -> $
    ++ coerce(e) takes an object from \spadtype{FortranCode} and
    ++ uses it as the body of an ASP.
  coerce : Record(localSymbols:SymbolTable,code:List(FortranCode)) -> $
    ++ coerce(e) takes the component of \spad{e} from
    ++ \spadtype{List FortranCode} and uses it as the body of the ASP,
    ++ making the declarations in the \spadtype{SymbolTable} component.
```

— FVC.dotabb —

```
"FVC"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FVC"];
"FVC" -> "FORTCAT"
```

— FVC.dotfull —

```
"FortranVectorCategory()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FVC"];
```

```
"FortranVectorCategory()" -> "FortranProgramCategory()"
```

— FVC.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FortranVectorCategory()" [color=lightblue];
  "FortranVectorCategory()" -> "FortranProgramCategory()"

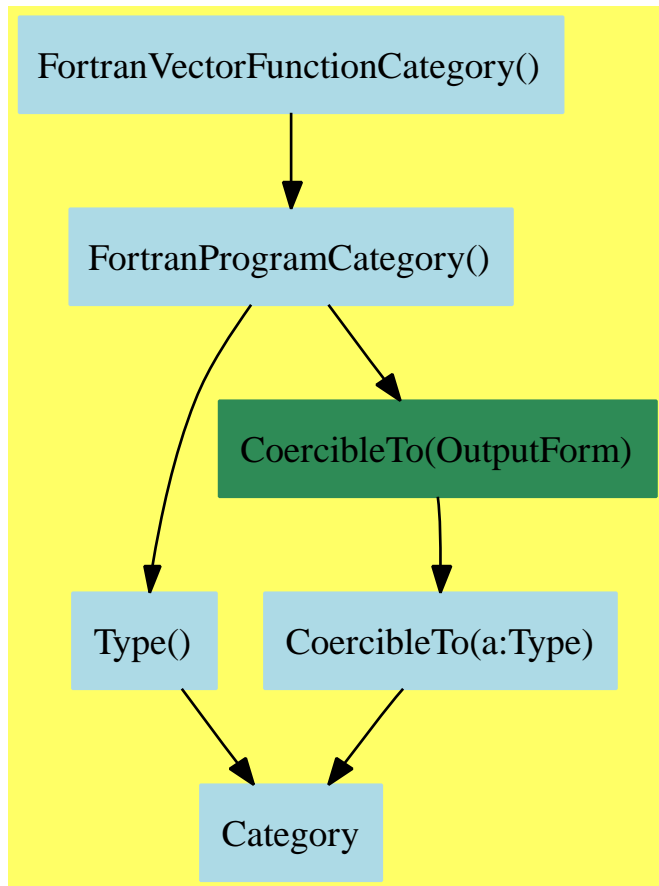
  "FortranProgramCategory()" [color=lightblue];
  "FortranProgramCategory()" -> "Type()"
  "FortranProgramCategory()" -> "CoercibleTo(OutputForm)"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

FortranVectorFunctionCategory (FVFUN)

— FortranVectorFunctionCategory.input —

```

)set break resume
)sys rm -f FortranVectorFunctionCategory.output
)spool FortranVectorFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FortranVectorFunctionCategory
--R
--R FortranVectorFunctionCategory is a category constructor
--R Abbreviation for FortranVectorFunctionCategory is FVFUN
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FVFUN
--R
--R----- Operations -----
--R coerce : FortranCode -> %                coerce : List(FortranCode) -> %
--R coerce : % -> OutputForm                outputAsFortran : % -> Void
--R coerce : Record(localSymbols: SymbolTable,code: List(FortranCode)) -> %
--R retract : Vector(Fraction(Polynomial(Integer))) -> %
--R retract : Vector(Fraction(Polynomial(Float))) -> %
--R retract : Vector(Polynomial(Integer)) -> %
--R retract : Vector(Polynomial(Float)) -> %
--R retract : Vector(Expression(Integer)) -> %
--R retract : Vector(Expression(Float)) -> %
--R retractIfCan : Vector(Fraction(Polynomial(Integer))) -> Union(%, "failed")
--R retractIfCan : Vector(Fraction(Polynomial(Float))) -> Union(%, "failed")
--R retractIfCan : Vector(Polynomial(Integer)) -> Union(%, "failed")
--R retractIfCan : Vector(Polynomial(Float)) -> Union(%, "failed")
--R retractIfCan : Vector(Expression(Integer)) -> Union(%, "failed")
--R retractIfCan : Vector(Expression(Float)) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— FortranVectorFunctionCategory.help —

```

=====
FortranVectorFunctionCategory examples
=====

```

FortranVectorFunctionCategory is the category of arguments
to NAG Library routines which return the values of vectors of functions.

See Also:

o)show FortranVectorFunctionCategory

See:

⇐ “FortranProgramCategory” (FORTCAT) [3](#) on page [133](#)

Exports:

coerce outputAsFortran retract retractIfCan

Attributes:

- `nil`

These are directly exported but not implemented:

```

coerce : FortranCode -> %
coerce : List FortranCode -> %
coerce : Record(localSymbols: SymbolTable,code: List FortranCode) -> %
retract : Vector Fraction Polynomial Integer -> %
retract : Vector Fraction Polynomial Float -> %
retract : Vector Polynomial Integer -> %
retract : Vector Polynomial Float -> %
retract : Vector Expression Integer -> %
retract : Vector Expression Float -> %
retractIfCan : Vector Fraction Polynomial Integer -> Union(%, "failed")
retractIfCan : Vector Fraction Polynomial Float -> Union(%, "failed")
retractIfCan : Vector Polynomial Integer -> Union(%, "failed")
retractIfCan : Vector Polynomial Float -> Union(%, "failed")
retractIfCan : Vector Expression Integer -> Union(%, "failed")
retractIfCan : Vector Expression Float -> Union(%, "failed")

```

These exports come from (p133) `FortranProgramCategory()`:

```

coerce : % -> OutputForm
outputAsFortran : % -> Void

```

— category FVFUN FortranVectorFunctionCategory —

```

)abbrev category FVFUN FortranVectorFunctionCategory
++ Author: Mike Dewar
++ Date Created: 11 March 1994
++ Date Last Updated: 18 March 1994
++ Description:
++ \axiomType{FortranVectorFunctionCategory} is the category of arguments
++ to NAG Library routines which return the values of vectors of functions.

```

```

FortranVectorFunctionCategory():Category == FortranProgramCategory with
  coerce : List FortranCode -> $
    ++ coerce(e) takes an object from \spadtype{List FortranCode} and
    ++ uses it as the body of an ASP.
  coerce : FortranCode -> $
    ++ coerce(e) takes an object from \spadtype{FortranCode} and
    ++ uses it as the body of an ASP.
  coerce : Record(localSymbols:SymbolTable,code:List(FortranCode)) -> $
    ++ coerce(e) takes the component of \spad{e} from
    ++ \spadtype{List FortranCode} and uses it as the body of the ASP,
    ++ making the declarations in the \spadtype{SymbolTable} component.
  retract : Vector Expression Float -> $
    ++ retract(e) tries to convert \spad{e} into an ASP, checking that

```

```

++ legal Fortran-77 is produced.
retractIfCan : Vector Expression Float -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Vector Expression Integer -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Vector Expression Integer -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Vector Polynomial Float -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Vector Polynomial Float -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Vector Polynomial Integer -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Vector Polynomial Integer -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Vector Fraction Polynomial Float -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Vector Fraction Polynomial Float -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retract : Vector Fraction Polynomial Integer -> $
++ retract(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.
retractIfCan : Vector Fraction Polynomial Integer -> Union($,"failed")
++ retractIfCan(e) tries to convert \spad{e} into an ASP, checking that
++ legal Fortran-77 is produced.

-- NB: These ASPs also have a coerce from an appropriate instantiation
--     of Vector FortranExpression.

```

— FVFUN.dotabb —

```

"FVFUN"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FVFUN"];
"FVFUN" -> "FORTCAT"

```

— FVFUN.dotfull —

```
"FortranVectorFunctionCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FVFUN"];
"FortranVectorFunctionCategory()" -> "FortranProgramCategory()"
```

— FVFUN.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FortranVectorFunctionCategory()" [color=lightblue];
  "FortranVectorFunctionCategory()" -> "FortranProgramCategory()"

  "FortranProgramCategory()" [color=lightblue];
  "FortranProgramCategory()" -> "Type()"
  "FortranProgramCategory()" -> "CoercibleTo(OutputForm)"

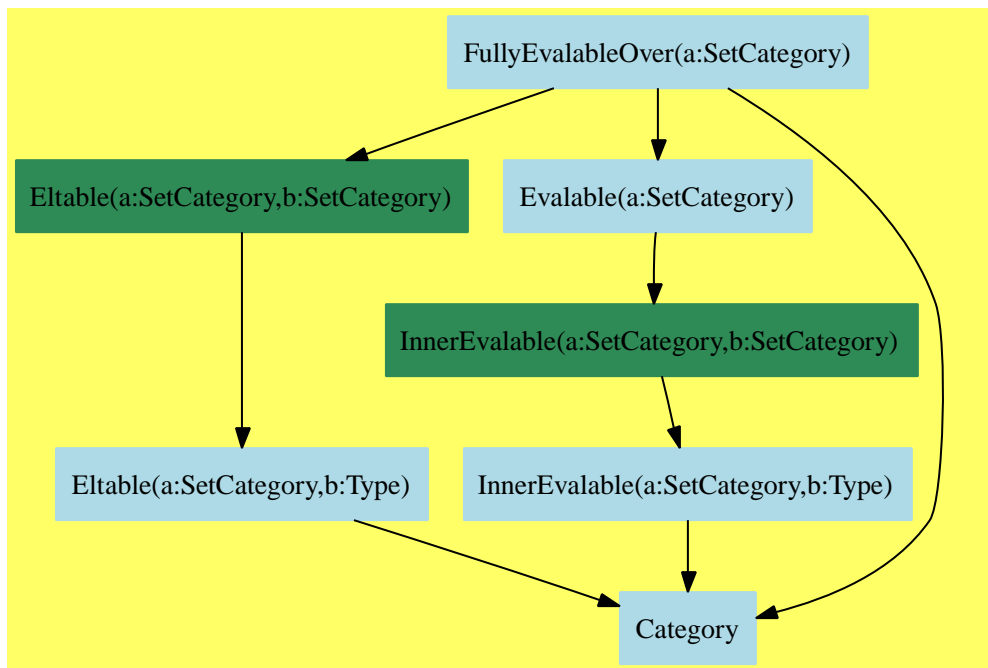
  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

FullyEvalableOver (FEVALAB)



— FullyEvalableOver.input —

```

)set break resume
)sys rm -f FullyEvalableOver.output
)spool FullyEvalableOver.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FullyEvalableOver
--R
--R FullyEvalableOver(R: SetCategory) is a category constructor
--R Abbreviation for FullyEvalableOver is FEVALAB
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FEVALAB
--R
--R----- Operations -----
--R map : ((R -> R),%) -> %
--R ?..? : (%,R) -> % if R has ELTAB(R,R)
--R eval : (%,List(R),List(R)) -> % if R has EVALAB(R)
--R eval : (%,R,R) -> % if R has EVALAB(R)

```



```

--R eval : (% ,Equation(R)) -> % if R has EVALAB(R)
--R eval : (% ,List(Equation(R))) -> % if R has EVALAB(R)
--R eval : (% ,List(Symbol),List(R)) -> % if R has IEVALAB(SYMBOL,R)
--R eval : (% ,Symbol,R) -> % if R has IEVALAB(SYMBOL,R)
--R
--E 1

)spool
)lisp (bye)

```

— **FullyEvalableOver.help** —

=====

FullyEvalableOver examples

=====

This category provides a selection of evaluation operations depending on what the argument type R provides.

See Also:

o)show FullyEvalableOver

See:

⇒ “ComplexCategory” (COMPCAT) [20](#) on page [1671](#)
 ⇒ “OctonionCategory” (OC) [12](#) on page [1109](#)
 ⇒ “QuaternionCategory” (QUATCAT) [12](#) on page [1120](#)
 ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
 ⇐ “Category” (CATEGORY) [2](#) on page [3](#)

Exports:

eval map ??

These are directly exported but not implemented:

map : ((R -> R),%) -> %

These are implemented by this category:

```

?? : (% ,R) -> % if R has ELTAB(R,R)
eval : (% ,Equation R) -> % if R has EVALAB R
eval : (% ,List Symbol,List R) -> % if R has IEVALAB(SYMBOL,R)

```

These exports come from (p129) Evaluable(a:Type):

```
eval : (%,List Equation R) -> % if R has EVALAB R
eval : (%,R,R) -> % if R has EVALAB R
eval : (%,List R,List R) -> % if R has EVALAB R
```

These exports come from (p56) InnerEvaluable(a:Symbol,b:SetCategory):

```
eval : (%,Symbol,R) -> % if R has IEVALAB(SYMBOL,R)
```

— category FEVALAB FullyEvaluableOver —

```
)abbrev category FEVALAB FullyEvaluableOver
++ Date Last Updated: June 3, 1991
++ Description:
++ This category provides a selection of evaluation operations
++ depending on what the argument type R provides.

FullyEvaluableOver(R:SetCategory): Category == with
  map: (R -> R, $) -> $
    ++ map(f, ex) evaluates ex, applying f to values of type R in ex.
  if R has Eltable(R, R) then Eltable(R, $)
  if R has Evaluable(R) then Evaluable(R)
  if R has InnerEvaluable(Symbol, R) then InnerEvaluable(Symbol, R)
add
  if R has Eltable(R, R) then
    elt(x:$, r:R) == map(y +-> y(r), x)

  if R has Evaluable(R) then
    eval(x:$, l:List Equation R) == map(y +-> eval(y, l), x)

  if R has InnerEvaluable(Symbol, R) then
    eval(x:$, ls:List Symbol, lv:List R) == map(y +-> eval(y, ls, lv), x)
```

— FEVALAB.dotabb —

```
"FEVALAB"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FEVALAB"];
"FEVALAB" -> "ELTAB"
"FEVALAB" -> "EVALAB"
"FEVALAB" -> "IEVALAB"
"FEVALAB" -> "CATEGORY"
```

— FEVALAB.dotfull —

```

"FullyEvaluableOver(a:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FEVALAB"];
"FullyEvaluableOver(a:SetCategory)" -> "Eltable(a:SetCategory,b:Type)"
"FullyEvaluableOver(a:SetCategory)" -> "Evaluable(a:SetCategory)"
"FullyEvaluableOver(a:SetCategory)" -> "Category"

"FullyEvaluableOver(IntegralDomain)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FEVALAB"];
"FullyEvaluableOver(IntegralDomain)" ->
  "FullyEvaluableOver(a:SetCategory)"

"FullyEvaluableOver(CommutativeRing)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FEVALAB"];
"FullyEvaluableOver(CommutativeRing)" ->
  "FullyEvaluableOver(a:SetCategory)"

```

— FEVALAB.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FullyEvaluableOver(a:SetCategory)" [color=lightblue];
  "FullyEvaluableOver(a:SetCategory)" -> "Eltable(a:SetCategory,b:SetCategory)"
  "FullyEvaluableOver(a:SetCategory)" -> "Evaluable(a:SetCategory)"
  "FullyEvaluableOver(a:SetCategory)" -> "Category"

  "Eltable(a:SetCategory,b:SetCategory)"
    [color=seagreen,href="bookvol10.2.pdf#nameddest=ELTAB"];
  "Eltable(a:SetCategory,b:SetCategory)" ->
    "Eltable(a:SetCategory,b:Type)"

  "Eltable(a:SetCategory,b:Type)" [color=lightblue];
  "Eltable(a:SetCategory,b:Type)" -> "Category"

  "Evaluable(a:SetCategory)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=EVALAB"];
  "Evaluable(a:SetCategory)" -> "InnerEvaluable(a:SetCategory,b:SetCategory)"

  "InnerEvaluable(a:SetCategory,b:SetCategory)" [color=seagreen];
  "InnerEvaluable(a:SetCategory,b:SetCategory)" ->
    "InnerEvaluable(a:SetCategory,b:Type)"

```

```

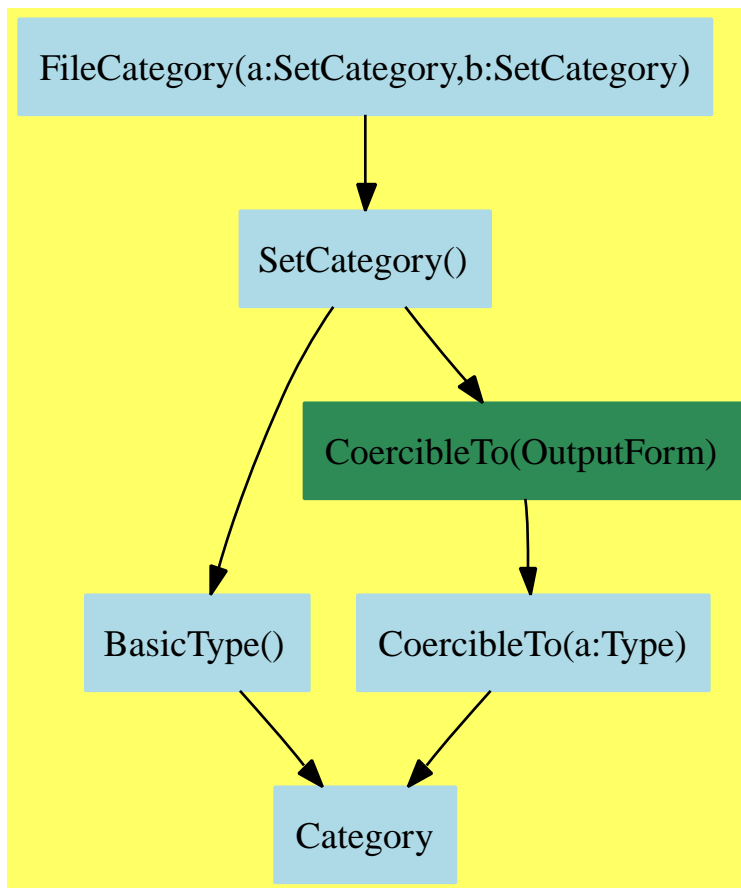
"InnerEvalable(a:SetCategory,b:Type)" [color=lightblue];
"InnerEvalable(a:SetCategory,b:Type)" -> "Category"

"Category" [color=lightblue];
}

```

—————

FileCategory (FILECAT)



— FileCategory.input —

```

)set break resume
)sys rm -f FileCategory.output
)spool FileCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FileCategory
--R FileCategory(Name: SetCategory,S: SetCategory) is a category constructor
--R Abbreviation for FileCategory is FILECAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FILECAT
--R
--R----- Operations -----
--R ?=? : (%,%) -> Boolean          close! : % -> %
--R coerce : % -> OutputForm       flush : % -> Void
--R hash : % -> SingleInteger      iomode : % -> String
--R latex : % -> String           name : % -> Name
--R open : (Name,String) -> %      open : Name -> %
--R read! : % -> S                reopen! : (%,String) -> %
--R write! : (%,S) -> S           ?~=? : (%,%) -> Boolean
--R
--E 1

)spool
)lisp (bye)

```

— FileCategory.help —

=====

FileCategory examples

=====

This category provides an interface to operate on files in the computer's file system. The precise method of naming files is determined by the Name parameter. The type of the contents of the file is determined by S.

See Also:

o)show FileCategory

See:

⇐ “SetCategory” (SETCAT) 3 on page 162

Exports:

```
close!  coerce  hash  iomode  latex
name    open    read!  reopen!  write!
?=?     ?~=?
```

These are directly exported but not implemented:

```
close! : % -> %
iomode : % -> String
name    : % -> Name
open    : Name -> %
open    : (Name,String) -> %
read!   : % -> S
reopen! : (% ,String) -> %
write!  : (% ,S) -> S
```

These exports come from SetCategory():

```
coerce : % -> OutputForm
hash    : % -> SingleInteger
latex   : % -> String
?=?     : (% ,%) -> Boolean
?~=?    : (% ,%) -> Boolean
```

— category FILECAT FileCategory —

```
)abbrev category FILECAT FileCategory
++ Author: Stephen M. Watt, Victor Miller
++ Date Last Updated: June 4, 1991
++ Description:
++ This category provides an interface to operate on files in the
++ computer's file system. The precise method of naming files
++ is determined by the Name parameter. The type of the contents
++ of the file is determined by S.

FileCategory(Name, S): Category == FCdefinition where
  Name:      SetCategory
  S:         SetCategory
  IOMode ==> String -- Union("input", "output", "closed")

FCdefinition == SetCategory with
  open: Name -> %
    ++ open(s) returns the file s open for input.

  open: (Name, IOMode) -> %
    ++ open(s,mode) returns a file s open for operation in the
    ++ indicated mode: "input" or "output".
```

```

reopen_!: (% , IOMode) -> %
++ reopen!(f,mode) returns a file f reopened for operation in the
++ indicated mode: "input" or "output".
++ \spad{reopen!(f,"input")} will reopen the file f for input.

close_!: % -> %
++ close!(f) returns the file f closed to input and output.

name: % -> Name
++ name(f) returns the external name of the file f.

iomode: % -> IOMode
++ iomode(f) returns the status of the file f. The input/output
++ status of f may be "input", "output" or "closed" mode.

read_!: % -> S
++ read!(f) extracts a value from file f. The state of f is
++ modified so a subsequent call to \spadfun{read!} will return
++ the next element.

write_!: (% ,S) -> S
++ write!(f,s) puts the value s into the file f.
++ The state of f is modified so subsequents call to \spad{write!}
++ will append one after another.

flush: % -> Void
++ flush(f) makes sure that buffered data is written out

```

— FILECAT.dotabb —

```

"FILECAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=FILECAT" ];
"FILECAT" -> "SETCAT"

```

— FILECAT.dotfull —

```

"FileCategory(a:SetCategory,b:SetCategory)"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=FILECAT" ];
"FileCategory(a:SetCategory,b:SetCategory)" -> "SetCategory()"

```

— FILECAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FileCategory(a:SetCategory,b:SetCategory)" [color=lightblue];
  "FileCategory(a:SetCategory,b:SetCategory)" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

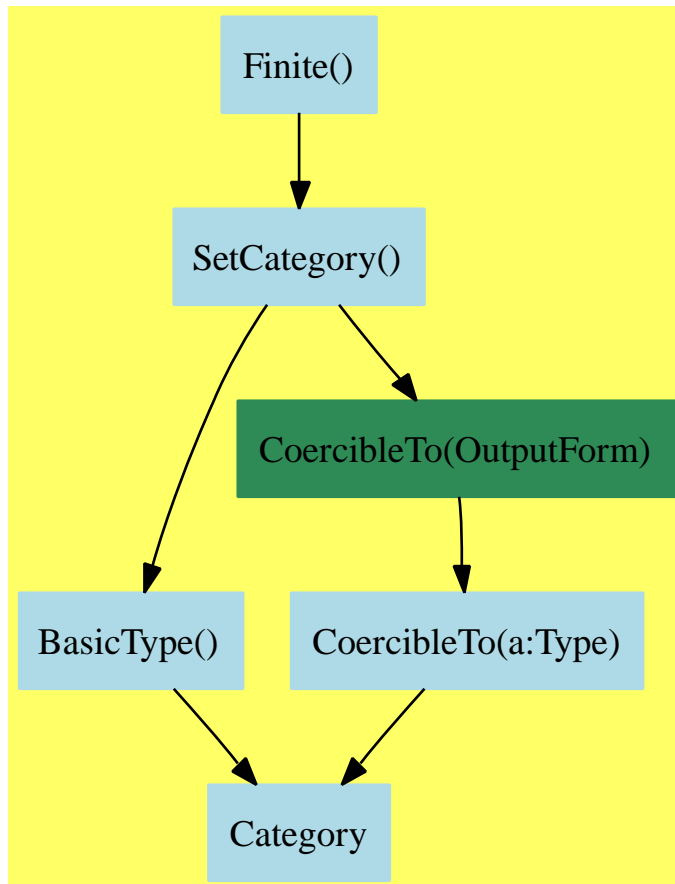
  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}

```

Finite (FINITE)

— Finite.input —

```

)set break resume
)sys rm -f Finite.output
)spool Finite.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show Finite
--R Finite is a category constructor
--R Abbreviation for Finite is FINITE
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FINITE

```

```

--R
--R----- Operations -----
--R ?? : (%,% ) -> Boolean          coerce : % -> OutputForm
--R enumerate : () -> List(%)       hash : % -> SingleInteger
--R index : PositiveInteger -> %    latex : % -> String
--R lookup : % -> PositiveInteger    random : () -> %
--R size : () -> NonNegativeInteger ?~=? : (%,% ) -> Boolean
--R
--E 1

```

```

)spool
)lisp (bye)

```

— Finite.help —

=====

Finite examples

=====

The category of domains composed of a finite set of elements. We include the functions `lookup` and `index` to give a bijection between the finite set and an initial segment of positive integers.

Axioms:

```

    lookup(index(n)) = n
    index(lookup(s)) = s

```

See Also:

o)show Finite

See:

⇒ “DirectProductCategory” (DIRPCAT) [12](#) on page [1051](#)
 ⇒ “FiniteFieldCategory” (FFIELDC) [18](#) on page [1570](#)
 ⇒ “OrderedFinite” (ORDFIN) [5](#) on page [391](#)
 ⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

```

coerce hash  index  latex  lookup  random
size        ?=?    ?~=?

```

These are directly exported but not implemented:

```

index : PositiveInteger -> %

```

```

lookup : % -> PositiveInteger
random : () -> %
size : () -> NonNegativeInteger

```

These exports come from (p162) SetCategory():

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean

```

— category FINITE Finite —

```

)abbrev category FINITE Finite
++ Description:
++ The category of domains composed of a finite set of elements.
++ We include the functions \spadfun{lookup} and \spadfun{index}
++ to give a bijection between the finite set and an initial
++ segment of positive integers.
++
++ Axioms:\br
++ \tab{5}\spad{lookup(index(n)) = n}\br
++ \tab{5}\spad{index(lookup(s)) = s}

Finite(): Category == SetCategory with

size: () -> NonNegativeInteger
++ size() returns the number of elements in the set.

index: PositiveInteger -> %
++ index(i) takes a positive integer i less than or equal
++ to \spad{size()} and
++ returns the \spad{i}-th element of the set.
++ This operation establishes a bijection
++ between the elements of the finite set and \spad{1..size()}.

lookup: % -> PositiveInteger
++ lookup(x) returns a positive integer such that
++ \spad{x = index lookup x}.

random: () -> %
++ random() returns a random element from the set.

enumerate: () -> List %
++ enumerate() returns a list of elements of the set
++
++X enumerate()$OrderedVariableList([p,q])

```

add

```
random() == index((1+random(size())$%))::PositiveInteger)

enumerate() == [index(i::PositiveInteger) for i in 1..size()]
```

— **FINITE.dotabb** —

```
"FINITE"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FINITE"];
"FINITE" -> "SETCAT"
```

— **FINITE.dotfull** —

```
"Finite()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FINITE"];
"Finite()" -> "SetCategory()"
```

— **FINITE.dotpic** —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Finite()" [color=lightblue];
  "Finite()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
```

```

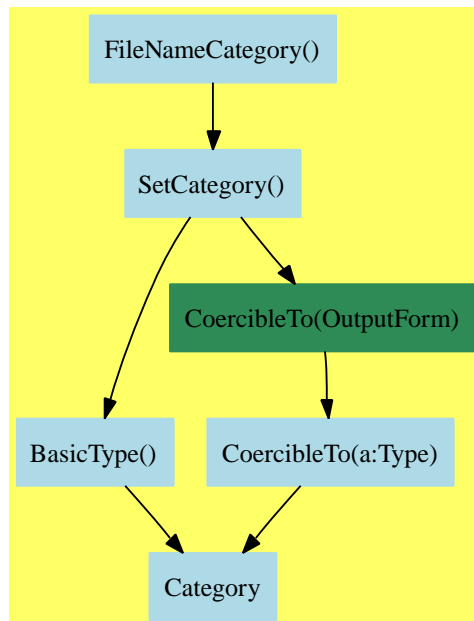
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];
}

```

—————→

FileNameCategory (FNCAT)



— FileNameCategory.input —

```

)set break resume
)sys rm -f FileNameCategory.output
)spool FileNameCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FileNameCategory
--R FileNameCategory is a category constructor

```

```

--R Abbreviation for FileNameCategory is FNCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FNCAT
--R
--R----- Operations -----
--R ?? : (%,% ) -> Boolean          coerce : % -> String
--R coerce : String -> %           coerce : % -> OutputForm
--R directory : % -> String        exists? : % -> Boolean
--R extension : % -> String        hash : % -> SingleInteger
--R latex : % -> String            name : % -> String
--R new : (String,String,String) -> % readable? : % -> Boolean
--R writable? : % -> Boolean       ?~=? : (%,% ) -> Boolean
--R filename : (String,String,String) -> %
--R
--E 1

```

```

)spool
)lisp (bye)

```

— FileNameCategory.help —

FileNameCategory examples

This category provides an interface to names in the file system.

See Also:

o)show FileNameCategory

See:

⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

| | | | | |
|-----------|-----------|---------|-----------|-----------|
| coerce | directory | exists? | extension | filename |
| hash | latex | name | new | readable? |
| writable? | ?=? | ?~=? | | |

These are directly exported but not implemented:

```

coerce : String -> %
coerce : % -> String
directory : % -> String

```

```

exists? : % -> Boolean
extension : % -> String
filename : (String,String,String) -> %
name : % -> String
new : (String,String,String) -> %
readable? : % -> Boolean
writable? : % -> Boolean

```

These exports come from (p162) SetCategory():

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean

```

— category FNCAT FileNameCategory —

```

)abbrev category FNCAT FileNameCategory
++ Author: Stephen M. Watt
++ Date Created: 1985
++ Date Last Updated: June 20, 1991
++ Description:
++ This category provides an interface to names in the file system.

FileNameCategory(): Category == SetCategory with
  coerce: String -> %
    ++ coerce(s) converts a string to a file name
    ++ according to operating system-dependent conventions.
  coerce: % -> String
    ++ coerce(fn) produces a string for a file name
    ++ according to operating system-dependent conventions.
  filename: (String, String, String) -> %
    ++ filename(d,n,e) creates a file name with
    ++ d as its directory, n as its name and e as its extension.
    ++ This is a portable way to create file names.
    ++ When d or t is the empty string, a default is used.
  directory: % -> String
    ++ directory(f) returns the directory part of the file name.
  name: % -> String
    ++ name(f) returns the name part of the file name.
  extension: % -> String
    ++ extension(f) returns the type part of the file name.
  exists?: % -> Boolean
    ++ exists?(f) tests if the file exists in the file system.
  readable?: % -> Boolean
    ++ readable?(f) tests if the named file exist and can it be opened
    ++ for reading.
  writable?: % -> Boolean

```

```

++ writable?(f) tests if the named file be opened for writing.
++ The named file need not already exist.
new: (String, String, String) -> %
++ new(d,pref,e) constructs the name of a new writable file with
++ d as its directory, pref as a prefix of its name and
++ e as its extension.
++ When d or t is the empty string, a default is used.
++ An error occurs if a new file cannot be written in the given
++ directory.

```

— FNCAT.dotabb —

```

"FNCAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=FNCAT" ];
"FNCAT" -> "SETCAT"

```

— FNCAT.dotfull —

```

"FileNameCategory()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=FNCAT" ];
"FileNameCategory()" -> "SetCategory()"

```

— FNCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FileNameCategory()"
  [ color=lightblue, href="bookvol10.2.pdf#nameddest=FNCAT" ];
  "FileNameCategory()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputStream)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

```



```

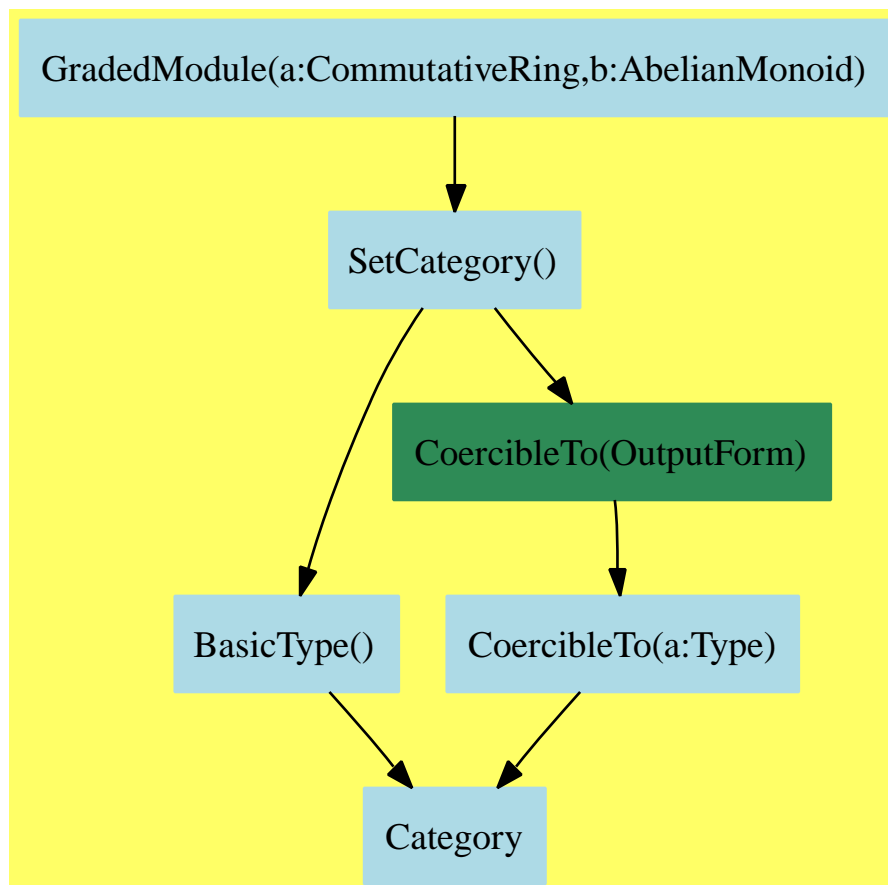
"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];
}

```

GradedModule (GRMOD)



— GradedModule.input —

```

)set break resume
)sys rm -f GradedModule.output
)spool GradedModule.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show GradedModule
--R GradedModule(R: CommutativeRing,E: AbelianMonoid) is a category constructor
--R Abbreviation for GradedModule is GRMOD
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for GRMOD
--R
--R----- Operations -----
--R ??? : (%,R) -> %           ??? : (R,%) -> %
--R ?+? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %               ?=? : (%,%) -> Boolean
--R 0 : () -> %               coerce : % -> OutputForm
--R degree : % -> E           hash : % -> SingleInteger
--R latex : % -> String       ?~=? : (%,%) -> Boolean
--R
--E 1

)spool
)lisp (bye)

```

— GradedModule.help —

=====

GradedModule examples

=====

GradedModule(R,E) denotes "E-graded R-module", i.e. collection of R-modules indexed by an abelian monoid E. An element g of $G[s]$ for some specific s in E is said to be an element of G with degree s . Sums are defined in each module $G[s]$ so two elements of G have a sum if they have the same degree.

Morphisms can be defined and composed by degree to give the mathematical category of graded modules.

See Also:

o)show GradedModule

See:

⇒ “GradedAlgebra” (GRALG) 5 on page 367

⇐ “SetCategory” (SETCAT) 3 on page 162

Exports:

```
0      coerce  degree  hash  latex
?~=?   ??      ?+?    ?-?   -?
?=?
```

These are directly exported but not implemented:

```
0 : () -> %
degree : % -> E
?? : (% , R) -> %
?? : (R , %) -> %
-? : % -> %
?+? : (% , %) -> %
```

These are implemented by this category:

```
?-? : (% , %) -> %
```

These exports come from (p162) SetCategory():

```
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?~=? : (% , %) -> Boolean
?=? : (% , %) -> Boolean
```

— category GRMOD GradedModule —

```
)abbrev category GRMOD GradedModule
++ Author: Stephen M. Watt
++ Date Created: May 20, 1991
++ Date Last Updated: May 20, 1991
++ References: Algebra 2d Edition, MacLane and Birkhoff, MacMillan 1979
++ Description:
++ GradedModule(R,E) denotes ‘‘E-graded R-module’’, that is, collection of
++ R-modules indexed by an abelian monoid E.
++ An element \spad{g} of \spad{G[s]} for some specific \spad{s} in \spad{E}
++ is said to be an element of \spad{G} with degree \spad{s}.
```

```

++ Sums are defined in each module \spad{G[s]} so two elements of \spad{G}
++ have a sum if they have the same degree.
++
++ Morphisms can be defined and composed by degree to give the
++ mathematical category of graded modules.

```

```

GradedModule(R: CommutativeRing, E: AbelianMonoid): Category ==
  SetCategory with

```

```

  degree: % -> E
    ++ degree(g) names the degree of g. The set of all elements
    ++ of a given degree form an R-module.

  0: constant -> %
    ++ \spad{0} denotes the zero of degree 0.

  _*: (R, %) -> %
    ++ r*g is left module multiplication.

  _*: (% , R) -> %
    ++ g*r is right module multiplication.

  _-: % -> %
    ++ -g is the additive inverse of g in the module of elements
    ++ of the same grade as g.

  _+: (% , %) -> %
    ++ g+h is the sum of g and h in the module of elements of
    ++ the same degree as g and h. Error: if g and h
    ++ have different degrees.

  _-: (% , %) -> %
    ++ g-h is the difference of g and h in the module of elements of
    ++ the same degree as g and h. Error: if g and h
    ++ have different degrees.

```

```

add

```

```

(x: %) - (y: %) == x+(-y)

```

— GRMOD.dotabb —

```

"GRMOD"
[color=lightblue,href="bookvol10.2.pdf#nameddest=GRMOD"];
"GRMOD" -> "SETCAT"

```

— GRMOD.dotfull —

```
"GradedModule(a:CommutativeRing,b:AbelianMonoid)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=GRMOD"];
"GradedModule(a:CommutativeRing,b:AbelianMonoid)" -> "SetCategory()"
```

— GRMOD.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "GradedModule(a:CommutativeRing,b:AbelianMonoid)" [color=lightblue];
  "GradedModule(a:CommutativeRing,b:AbelianMonoid)" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

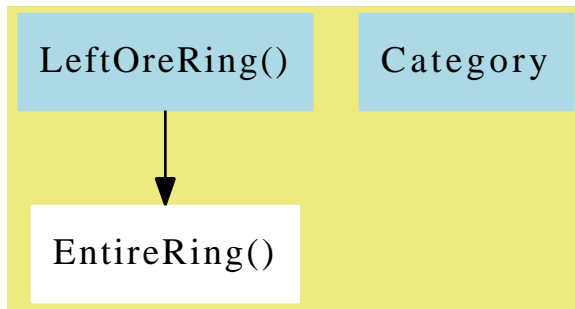
  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

LeftOreRing (LORER)



— LeftOreRing.help —

```
=====
LeftOreRing
=====
```

This is the category of left ore rings, that is, the commutative rings without zero divisors where we can compute least left common multiples.

See [Delenclos 06], [Bronstein 96a]

See Also:

o)show LeftOreRing

— category LORER LeftOreRing —

```
)abbrev category LORER LeftOreRing
```

```
++ Description:
```

```
++ This is the category of left ore rings, that is noncommutative
++ rings without zero divisors where we can compute the least left
++ common multiple.
```

```
LeftOreRing : Category == EntireRing with
```

```
  lcmCoef : (%, %) -> Record(llcm_res : %, coeff1 : %, coeff2 : %)
    ++ lcmCoef(c1, c2) computes (llcm_res, coeff1, coeff2) such that
    ++ llcm_res is least left common multiple of c1 and c2
    ++ and llcm_res = coeff1*c1 = coeff2*c2
```

— LORER.dotabb —

```
"LORER"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=LORER"];
"LORER" -> "BMODULE"
```

— LORER.dotfull —

```
"LeftOreRing()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=LORER"];
"LeftOreRing()" -> "EntireRing()"
```

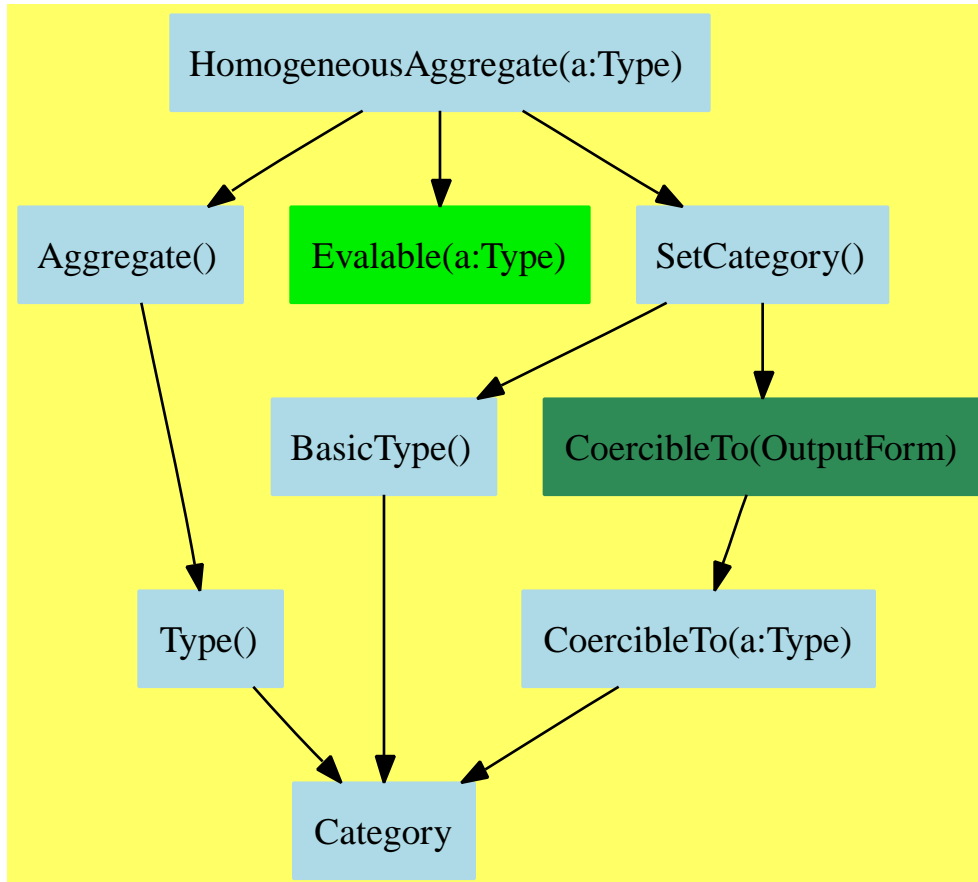
— LORER.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "LeftOreRing()" [color=lightblue];
  "LeftOreRing()" -> "EntireRing()"

  "Category" [color=lightblue];
}
```

HomogeneousAggregate (HOAGG)



— HomogeneousAggregate.input —

```

)set break resume
)sys rm -f HomogeneousAggregate.output
)spool HomogeneousAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show HomogeneousAggregate
--R
--R HomogeneousAggregate(S: Type) is a category constructor
--R Abbreviation for HomogeneousAggregate is HOAGG
--R This constructor is exposed in this frame.

```



```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for HOAGG
--R
--R----- Operations -----
--R copy : % -> %                                empty : () -> %
--R empty? : % -> Boolean                        eq? : (%,%) -> Boolean
--R map : ((S -> S),%) -> %                      sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (%,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R ?~=? : (%,%) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— HomogeneousAggregate.help —

=====

HomogeneousAggregate examples

=====

A homogeneous aggregate is an aggregate of elements all of the same type.

In the current system, all aggregates are homogeneous. Two attributes characterize classes of aggregates. Aggregates from domains with attribute "finiteAggregate" have a finite number of members. Those with attribute "shallowlyMutable" allow an element to be modified or updated without changing its overall value.

See Also:

o)show HomogeneousAggregate

See:

⇒ “BagAggregate” (BGAGG) [5](#) on page [331](#)
 ⇒ “Collection” (CLAGG) [5](#) on page [341](#)
 ⇒ “IndexedAggregate” (IXAGG) [5](#) on page [372](#)
 ⇒ “RectangularMatrixCategory” (RMATCAT) [10](#) on page [954](#)
 ⇒ “RecursiveAggregate” (RCAGG) [5](#) on page [406](#)
 ⇒ “TwoDimensionalArrayCategory” (ARR2CAT) [5](#) on page [412](#)
 ⇐ “Aggregate” (AGG) [3](#) on page [115](#)
 ⇐ “Evalable” (EVALAB) [3](#) on page [129](#)
 ⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Attributes exported:

- nil

Exports:

| | | | | |
|---------|--------|-------|--------|---------|
| any? | coerce | copy | count | empty |
| empty? | eq? | eval | every? | hash |
| latex | less? | map | map! | members |
| member? | more? | parts | sample | size? |
| #? | ?=? | ?~=? | | |

Attributes Used:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
parts : % -> List S if $ has finiteAggregate
```

These are implemented by this category:

```
any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
```

```

coerce : % -> OutputForm if S has SETCAT
count : (S,%) -> NonNegativeInteger
        if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
        if $ has finiteAggregate
eval : (%,List Equation S) -> %
        if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
member? : (S,%) -> Boolean
        if S has SETCAT and $ has finiteAggregate
#? : % -> NonNegativeInteger if $ has finiteAggregate
=? : (%,%) -> Boolean if S has SETCAT

```

These exports come from (p115) Aggregate:

```

copy : % -> %
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
less? : (%,NonNegativeInteger) -> Boolean
more? : (%,NonNegativeInteger) -> Boolean
sample : () -> %
size? : (%,NonNegativeInteger) -> Boolean

```

These exports come from (p129) Evalable(a:Type):

```

eval : (%,List S,List S) -> %
        if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
        if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
        if S has EVALAB S and S has SETCAT

```

These exports come from (p162) SetCategory():

```

hash : % -> SingleInteger if S has SETCAT
?~=? : (%,%) -> Boolean if S has SETCAT
latex : % -> String if S has SETCAT

```

— category HOAGG HomogeneousAggregate —

```

)abbrev category HOAGG HomogeneousAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991, May 1995
++ Description:
++ A homogeneous aggregate is an aggregate of elements all of the

```

```

++ same type.
++ In the current system, all aggregates are homogeneous.
++ Two attributes characterize classes of aggregates.
++ Aggregates from domains with attribute \spadatt{finiteAggregate}
++ have a finite number of members.
++ Those with attribute \spadatt{shallowlyMutable} allow an element
++ to be modified or updated without changing its overall value.

HomogeneousAggregate(S:Type): Category == Aggregate with
  if S has SetCategory then SetCategory
  if S has SetCategory then
    if S has Evaluable S then Evaluable S
  map      : (S->S,%) -> %
  ++ map(f,u) returns a copy of u with each element x replaced by f(x).
  ++ For collections, \axiom{map(f,u) = [f(x) for x in u]}.
  if % has shallowlyMutable then
    map_!: (S->S,%) -> %
    ++ map!(f,u) destructively replaces each element x of u
    ++ by \axiom{f(x)}.
  if % has finiteAggregate then
    any?: (S->Boolean,%) -> Boolean
    ++ any?(p,u) tests if \axiom{p(x)} is true for any element x of u.
    ++ Note that for collections,
    ++ \axiom{any?(p,u) = reduce(or,map(f,u),false,true)}.
    every?: (S->Boolean,%) -> Boolean
    ++ every?(f,u) tests if p(x) is true for all elements x of u.
    ++ Note that for collections,
    ++ \axiom{every?(p,u) = reduce(and,map(f,u),true,false)}.
    count: (S->Boolean,%) -> NonNegativeInteger
    ++ count(p,u) returns the number of elements x in u
    ++ such that \axiom{p(x)} is true. For collections,
    ++ \axiom{count(p,u) = reduce(+,[1 for x in u | p(x)],0)}.
    parts: % -> List S
    ++ parts(u) returns a list of the consecutive elements of u.
    ++ For collections, \axiom{parts([x,y,...,z]) = (x,y,...,z)}.
    members: % -> List S
    ++ members(u) returns a list of the consecutive elements of u.
    ++ For collections, \axiom{parts([x,y,...,z]) = (x,y,...,z)}.
  if S has SetCategory then
    count: (S,%) -> NonNegativeInteger
    ++ count(x,u) returns the number of occurrences of x in u. For
    ++ collections, \axiom{count(x,u) = reduce(+,[x=y for y in u],0)}.
    member?: (S,%) -> Boolean
    ++ member?(x,u) tests if x is a member of u.
    ++ For collections,
    ++ \axiom{member?(x,u) = reduce(or,[x=y for y in u],false)}.
  add
  if S has Evaluable S then
    eval(u:%,l:List Equation S):% == map(x --> eval(x,l),u)
  if % has finiteAggregate then

```

```

#c          == # parts c
any?(f, c)  == _or/[f x for x in parts c]
every?(f, c) == _and/[f x for x in parts c]
count(f:S -> Boolean, c:%) == _+/[1 for x in parts c | f x]
members x          == parts x
if S has SetCategory then
  count(s:S, x:%) == count(y +-> s = y, x)
  member?(e, c)   == any?(x +-> e = x, c)
  x = y ==
    size?(x, #y) and _and/[a = b for a in parts x for b in parts y]
  coerce(x:%):OutputForm ==
    bracket
      commaSeparate [a::OutputForm for a in parts x]$List(OutputForm)

```

— HOAGG.dotabb —

```

"HOAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=HOAGG"];
"HOAGG" -> "AGG"

```

— HOAGG.dotfull —

```

"HomogeneousAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=HOAGG"];
"HomogeneousAggregate(a:Type)" -> "Aggregate()"

"HomogeneousAggregate(Ring)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=HOAGG"];
"HomogeneousAggregate(Ring)"
  -> "HomogeneousAggregate(a:Type)"

```

— HOAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

"HomogeneousAggregate(a:Type)" [color=lightblue];
"HomogeneousAggregate(a:Type)" -> "Aggregate()"

```

```

"HomogeneousAggregate(a:Type)" -> "Evaluable(a:Type)"
"HomogeneousAggregate(a:Type)" -> "SetCategory()"

"Evaluable(a:Type)" [color="#00EE00"];

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

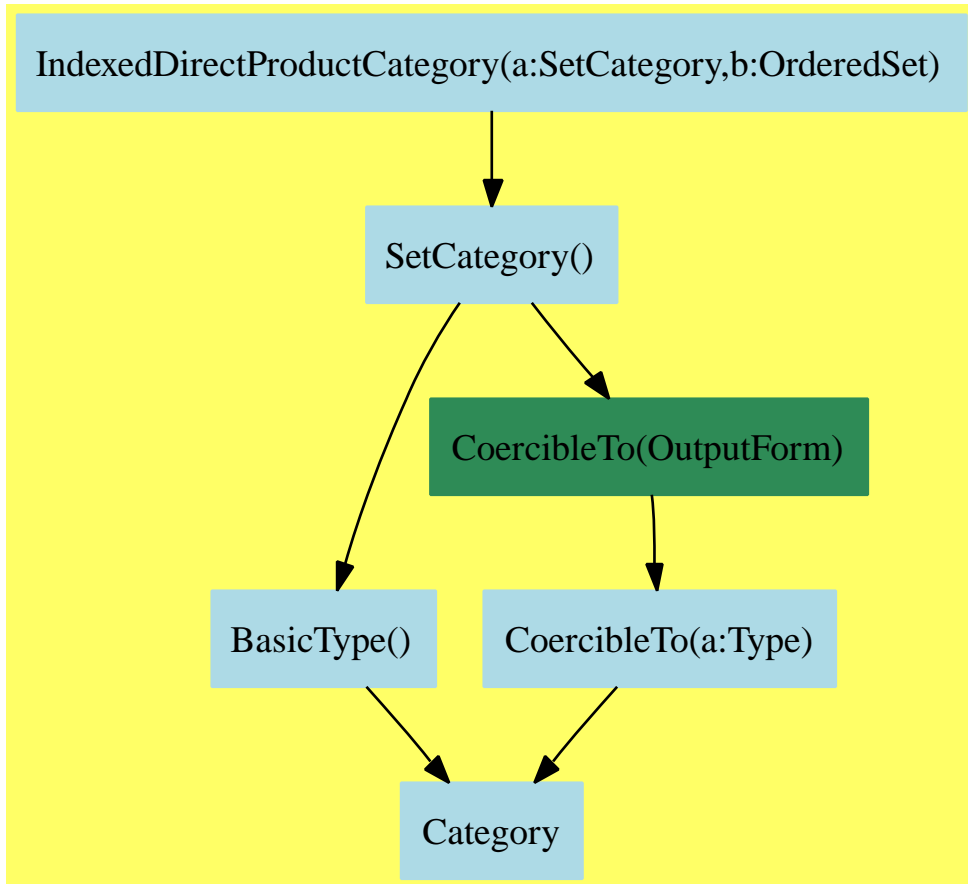
"Aggregate()" [color=lightblue];
"Aggregate()" -> "Type()"

"Type()" [color=lightblue];
"Type()" -> "Category"

"Category" [color=lightblue];

}

```

IndexedDirectProductCategory (IDPC)

— IndexedDirectProductCategory.input —

```

)set break resume
)sys rm -f IndexedDirectProductCategory.output
)spool IndexedDirectProductCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show IndexedDirectProductCategory
--R IndexedDirectProductCategory(A: SetCategory,S: OrderedSet) is a category constructor
--R Abbreviation for IndexedDirectProductCategory is IDPC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for IDPC

```

```

--R
--R----- Operations -----
--R ==? : (%,% ) -> Boolean      coerce : % -> OutputForm
--R hash : % -> SingleInteger    latex : % -> String
--R leadingCoefficient : % -> A  leadingSupport : % -> S
--R map : ((A -> A),%) -> %      monomial : (A,S) -> %
--R reductum : % -> %           ?~=? : (%,% ) -> Boolean
--R
--E 1

```

```

)spool
)lisp (bye)

```

— IndexedDirectProductCategory.help —

```

=====
IndexedDirectProductCategory examples
=====

```

This category represents the direct product of some set with respect to an ordered indexing set.

See Also:

o)show IndexedDirectProductCategory

See:

⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

| | | | | |
|--------|----------|----------|--------------------|----------------|
| coerce | hash | latex | leadingCoefficient | leadingSupport |
| map | monomial | reductum | ?=? | ?~=? |

These are directly exported but not implemented:

```

leadingCoefficient : % -> A
leadingSupport : % -> S
map : ((A -> A),%) -> %
monomial : (A,S) -> %
reductum : % -> %

```

These exports come from (p[162](#)) SetCategory():

```

coerce : % -> OutputForm

```



```

hash : % -> SingleInteger
latex : % -> String
?? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean

```

— category IDPC IndexedDirectProductCategory —

```

)abbrev category IDPC IndexedDirectProductCategory
++ Author: James Davenport
++ Description:
++ This category represents the direct product of some set with
++ respect to an ordered indexing set.

IndexedDirectProductCategory(A:SetCategory,S:OrderedSet): Category ==
SetCategory with
  map:      (A -> A, %) -> %
            ++ map(f,z) returns the new element created by applying the
            ++ function f to each component of the direct product element z.
  monomial:  (A, S) -> %
            ++ monomial(a,s) constructs a direct product element with the s
            ++ component set to \spad{a}
  leadingCoefficient: % -> A
            ++ leadingCoefficient(z) returns the coefficient of the leading
            ++ (with respect to the ordering on the indexing set)
            ++ monomial of z.
            ++ Error: if z has no support.
  leadingSupport: % -> S
            ++ leadingSupport(z) returns the index of leading
            ++ (with respect to the ordering on the indexing set) monomial of z.
            ++ Error: if z has no support.
  reductum:  % -> %
            ++ reductum(z) returns a new element created by removing the
            ++ leading coefficient/support pair from the element z.
            ++ Error: if z has no support.

```

—————

— IDPC.dotabb —

```

"IDPC"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=IDPC" ];
"IDPC" -> "SETCAT"

```

—————

— IDPC.dotfull —

```
"IndexedDirectProductCategory(a:SetCategory,b:OrderedSet)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=IDPC"];
"IndexedDirectProductCategory(a:SetCategory,b:OrderedSet)" ->
  "SetCategory()"
```

—————
 — IDPC.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "IndexedDirectProductCategory(a:SetCategory,b:OrderedSet)" [color=lightblue];
  "IndexedDirectProductCategory(a:SetCategory,b:OrderedSet)" ->
    "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

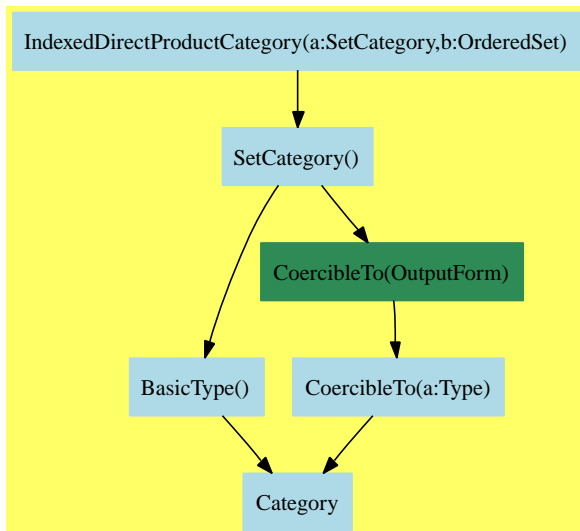
  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

—————

LiouvillianFunctionCategory (LFCAT)



— LiouvillianFunctionCategory.input —

```

)set break resume
)sys rm -f LiouvillianFunctionCategory.output
)spool LiouvillianFunctionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show LiouvillianFunctionCategory
--R
--R LiouvillianFunctionCategory is a category constructor
--R Abbreviation for LiouvillianFunctionCategory is LFCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LFCAT
--R
--R----- Operations -----
--R ***? : (% ,%) -> %          Ci : % -> %
--R Ei : % -> %                Si : % -> %
--R acos : % -> %              acosh : % -> %
--R acot : % -> %              acoth : % -> %
--R acsc : % -> %              acsch : % -> %
--R asec : % -> %              asech : % -> %
--R asin : % -> %              asinh : % -> %
--R atan : % -> %              atanh : % -> %
--R cos : % -> %              cosh : % -> %

```

```

--R cot : % -> %
--R csc : % -> %
--R dilog : % -> %
--R exp : % -> %
--R fresnelS : % -> %
--R li : % -> %
--R pi : () -> %
--R sech : % -> %
--R sinh : % -> %
--R tanh : % -> %
--R integral : (%,SegmentBinding(%)) -> %
--R
--E 1

)spool
)lisp (bye)

```

— LiouvillianFunctionCategory.help —

```

=====
LiouvillianFunctionCategory examples
=====

```

This is the Category for the transcendental Liouvillian functions.

See Also:

o)show LiouvillianFunctionCategory

See:

⇐ “PrimitiveFunctionCategory” (PRIMCAT) [2](#) on page [89](#)

⇐ “TranscendentalFunctionCategory” (TRANFUN) [3](#) on page [166](#)

Exports:

| | | | | |
|----------|----------|-------|-------|----------|
| Ci | Ei | Si | acos | acosh |
| acot | acoth | acsc | acsch | asec |
| asech | asin | asinh | atan | atanh |
| cos | cosh | cot | coth | csc |
| csch | dilog | erf | exp | frsenelC |
| frsenelS | integral | li | log | pi |
| sec | sech | sin | sinh | tan |
| tanh | ***? | | | |

These are directly exported but not implemented:

```

Ci : % -> %
dilog : % -> %
Ei : % -> %
erf : % -> %
li : % -> %
Si : % -> %
fresnelC : % -> %
fresnelS : % -> %

```

These exports come from (p89) `PrimitiveFunctionCategory()`

```

integral : (% , Symbol) -> %
integral : (% , SegmentBinding %) -> %

```

These exports come from (p166) `TranscendentalFunctionCategory()`:

```

***? : (% , %) -> %
acos : % -> %
acosh : % -> %
acot : % -> %
acoth : % -> %
acsc : % -> %
acsch : % -> %
asec : % -> %
asech : % -> %
asin : % -> %
asinh : % -> %
atan : % -> %
atanh : % -> %
cos : % -> %
cosh : % -> %
cot : % -> %
coth : % -> %
csc : % -> %
csch : % -> %
exp : % -> %
log : % -> %
pi : () -> %
sec : % -> %
sech : % -> %
sin : % -> %
sinh : % -> %
tan : % -> %
tanh : % -> %

```

— category LFCAT LiouvillianFunctionCategory —

```
)abbrev category LFCAT LiouvillianFunctionCategory
```

```

++ Category for the transcendental Liouvillian functions
++ Author: Manuel Bronstein
++ Date Last Updated: 14 May 1991
++ Description:
++ Category for the transcendental Liouvillian functions;

LiouvillianFunctionCategory(): Category ==
  Join(PrimitiveFunctionCategory, TranscendentalFunctionCategory) with

  Ei      : $ -> $
    ++ Ei(x) returns the exponential integral of x, that is,
    ++ the integral of \spad{exp(x)/x dx}.

  Si      : $ -> $
    ++ Si(x) returns the sine integral of x, that is,
    ++ the integral of \spad{sin(x) / x dx}.

  Ci      : $ -> $
    ++ Ci(x) returns the cosine integral of x, that is,
    ++ the integral of \spad{cos(x) / x dx}.

  li      : $ -> $
    ++ li(x) returns the logarithmic integral of x, that is,
    ++ the integral of \spad{dx / log(x)}.

  dilog   : $ -> $
    ++ dilog(x) returns the dilogarithm of x, that is,
    ++ the integral of \spad{log(x) / (1 - x) dx}.

  erf     : $ -> $
    ++ erf(x) returns the error function of x, that is,
    ++ \spad{2 / sqrt(%pi)} times the integral of \spad{exp(-x**2) dx}.

  fresnelS : $ -> $
    ++ fresnelS(x) is the Fresnel integral S, defined by
    ++ S(x) = integrate(sin(t^2),t=0..x)

  fresnelC : $ -> $
    ++ fresnelC(x) is the Fresnel integral C, defined by
    ++ C(x) = integrate(cos(t^2),t=0..x)

  _____

  — LFCAT.dotabb —

"LFCAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=LFCAT" ];
"LFCAT" -> "PRIMCAT"

```

"LFCAT" -> "TRANFUN"

— LFCAT.dotfull —

```
"LiouvillianFunctionCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=LFCAT"];
"LiouvillianFunctionCategory()" -> "PrimitiveFunctionCategory()"
"LiouvillianFunctionCategory()" -> "TranscendentalFunctionCategory()"
```

— LFCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "LiouvillianFunctionCategory()" [color=lightblue];
  "LiouvillianFunctionCategory()" -> "PrimitiveFunctionCategory()"
  "LiouvillianFunctionCategory()" -> "TranscendentalFunctionCategory()"

  "PrimitiveFunctionCategory()" [color=lightblue];
  "PrimitiveFunctionCategory()" -> "Category"

  "TranscendentalFunctionCategory()" [color=lightblue];
  "TranscendentalFunctionCategory()" ->
    "TRIGCAT"
  "TranscendentalFunctionCategory()" ->
    "ATRIG"
  "TranscendentalFunctionCategory()" ->
    "HYPCAT"
  "TranscendentalFunctionCategory()" ->
    "AHYP"
  "TranscendentalFunctionCategory()" ->
    "ELEMFUN"

  "TRIGCAT" [color=lightblue];
  "TRIGCAT" -> "Category"

  "ATRIG" [color=lightblue];
  "ATRIG" -> "Category"

  "HYPCAT" [color=lightblue];
```

```

"HYPCAT" -> "Category"

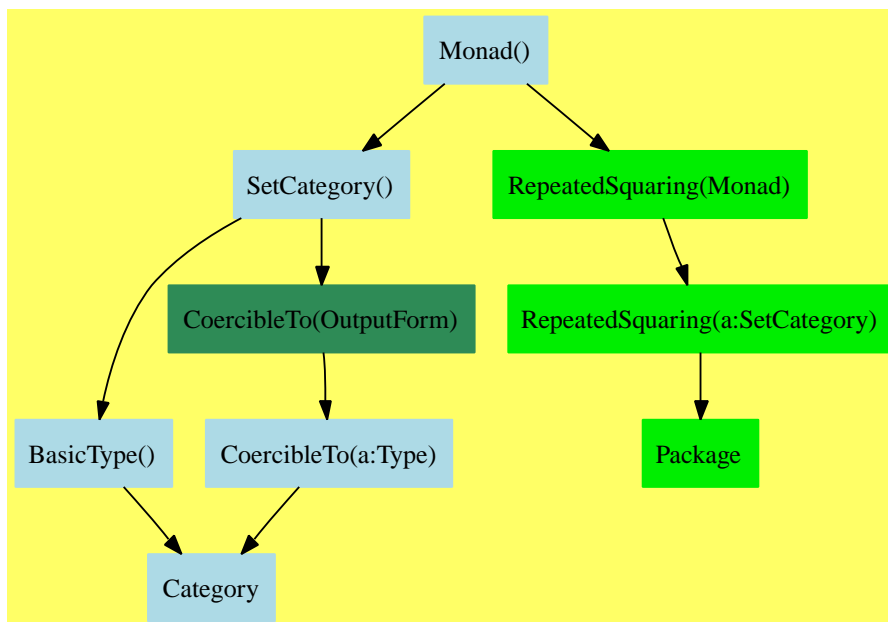
"AHYP" [color=lightblue];
"AHYP" -> "Category"

"ELEMFUN" [color=lightblue];
"ELEMFUN" -> "Category"

"Category" [color=lightblue];
}

```

Monad (MONAD)



— Monad.input —

```

)set break resume
)sys rm -f Monad.output
)spool Monad.output
)set message test on
)set message auto off

```



```

)clear all

--S 1 of 1
)show Monad
--R Monad is a category constructor
--R Abbreviation for Monad is MONAD
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MONAD
--R
--R----- Operations -----
--R ??? : (%,%) -> %                ??? : (%,PositiveInteger) -> %
--R ?=? : (%,%) -> Boolean          coerce : % -> OutputForm
--R hash : % -> SingleInteger       latex : % -> String
--R ?^=? : (%,%) -> Boolean
--R leftPower : (%,PositiveInteger) -> %
--R rightPower : (%,PositiveInteger) -> %
--R
--E 1

)spool
)lisp (bye)

```

— Monad.help —

```

=====
Monad examples
=====

```

Monad is the class of all multiplicative monads, i.e. sets with a binary operation.

See Also:
o)show Monad

See:

⇒ “MonadWithUnit” (MONADWU) [5](#) on page [380](#)
 ⇒ “NonAssociativeRng” (NARNG) [8](#) on page [734](#)

Exports:

```

coerce  hash  latex  leftPower  rightPower
?***?   ?*?   ?=?   ?^=?

```

These are directly exported but not implemented:

```
?? : (%,% ) -> %
```

These are implemented by this category:

```
leftPower : (% ,PositiveInteger) -> %
rightPower : (% ,PositiveInteger) -> %
***? : (% ,PositiveInteger) -> %
```

These exports come from (p162) SetCategory():

```
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?? : (% ,%) -> Boolean
?~=? : (% ,%) -> Boolean
```

— category MONAD Monad —

```
)abbrev category MONAD Monad
++ Authors: J. Grabmeier, R. Wisbauer
++ Date Created: 01 March 1991
++ Date Last Updated: 11 June 1991
++ Reference:
++ N. Jacobson: Structure and Representations of Jordan Algebras
++ AMS, Providence, 1968
++ Description:
++ Monad is the class of all multiplicative monads, that is sets
++ with a binary operation.
```

Monad(): Category == SetCategory with

```
"*": (% ,%) -> %
++ a*b is the product of \spad{a} and b in a set with
++ a binary operation.

rightPower: (% ,PositiveInteger) -> %
++ rightPower(a,n) returns the \spad{n}-th right power of \spad{a},
++ that is, \spad{rightPower(a,n) := rightPower(a,n-1) * a} and
++ \spad{rightPower(a,1) := a}.

leftPower: (% ,PositiveInteger) -> %
++ leftPower(a,n) returns the \spad{n}-th left power of \spad{a},
++ that is, \spad{leftPower(a,n) := a * leftPower(a,n-1)} and
++ \spad{leftPower(a,1) := a}.

***: (% ,PositiveInteger) -> %
++ a**n returns the \spad{n}-th power of \spad{a},
++ defined by repeated squaring.
```

```

add

import RepeatedSquaring(%)

x:% ** n:PositiveInteger == expt(x,n)

rightPower(a,n) ==
  (n = 1) => a
  res := a
  for i in 1..(n-1) repeat res := res * a
  res

leftPower(a,n) ==
  (n = 1) => a
  res := a
  for i in 1..(n-1) repeat res := a * res
  res

_____

— MONAD.dotabb —

"MONAD"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MONAD"];
"MONAD" -> "SETCAT"

_____

— MONAD.dotfull —

"Monad()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MONAD"];
"Monad()" -> "SetCategory()"
"Monad()" -> "RepeatedSquaring(Monad)"

_____

— MONAD.dotpic —

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Monad()" [color=lightblue];

```

```

"Monad()" -> "SetCategory()"
"Monad()" -> "RepeatedSquaring(Monad)"

"RepeatedSquaring(Monad)" [color="#00EE00"];
"RepeatedSquaring(Monad)" -> "RepeatedSquaring(a:SetCategory)"

"RepeatedSquaring(a:SetCategory)" [color="#00EE00"];
"RepeatedSquaring(a:SetCategory)" -> "Package"

"Package" [color="#00EE00"];

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

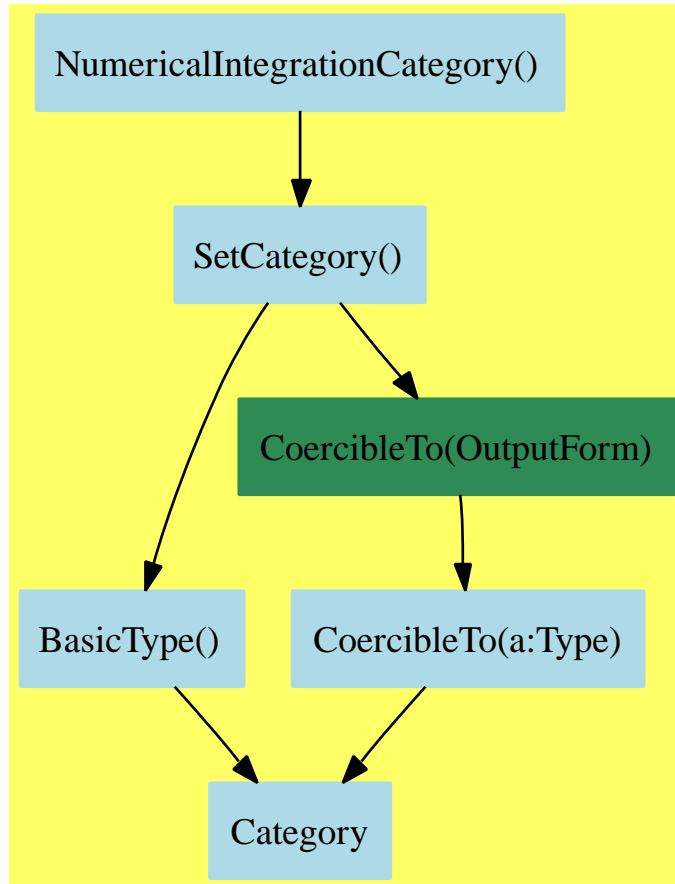
"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];

}

```

NumericalIntegrationCategory (NUMINT)



— NumericalIntegrationCategory.input —

```

)set break resume
)sys rm -f NumericalIntegrationCategory.output
)spool NumericalIntegrationCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show NumericalIntegrationCategory
--R
--R NumericalIntegrationCategory is a category constructor
--R Abbreviation for NumericalIntegrationCategory is NUMINT
--R This constructor is exposed in this frame.

```

```
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for NUMINT
```

```
--R
```

```
--R----- Operations -----
```

```
--R ==? : (%,% ) -> Boolean          coerce : % -> OutputForm
```

```
--R hash : % -> SingleInteger        latex : % -> String
```

```
--R ?~=? : (%,% ) -> Boolean
```

```
--R measure : (RoutinesTable,Record(fn: Expression(DoubleFloat),range: List(Segment(OrderedCompletion(DoubleFloat),
```

```
--R measure : (RoutinesTable,Record(var: Symbol,fn: Expression(DoubleFloat),range: Segment(OrderedCompletion(DoubleFloat),
```

```
--R numericalIntegration : (Record(fn: Expression(DoubleFloat),range: List(Segment(OrderedCompletion(DoubleFloat),
```

```
--R numericalIntegration : (Record(var: Symbol,fn: Expression(DoubleFloat),range: Segment(OrderedCompletion(DoubleFloat),
```

```
--R
```

```
--E 1
```

```
)spool
```

```
)lisp (bye)
```

— NumericalIntegrationCategory.help —

```
=====
```

```
NumericalIntegrationCategory examples
```

```
=====
```

NumericalIntegrationCategory is the category for describing the set of Numerical Integration domains with measure and numericalIntegration.

See Also:

```
o )show NumericalIntegrationCategory
```

See:

⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

```
coerce          hash  latex  measure
numericalIntegration  ==?  ?~=?
```

These are directly exported but not implemented:

```
measure :
(RoutinesTable,
Record(fn: Expression DoubleFloat,
range: List Segment OrderedCompletion DoubleFloat,
abserr: DoubleFloat,
relerr: DoubleFloat)) ->
```

```

      Record(measure: Float,explanations: String,extra: Result)
measure :
  (RoutinesTable,
    Record(var: Symbol,
      fn: Expression DoubleFloat,
      range: Segment OrderedCompletion DoubleFloat,
      abserr: DoubleFloat,
      relerr: DoubleFloat)) ->
    Record(measure: Float,explanations: String,extra: Result)
numericalIntegration :
  (Record(fn: Expression DoubleFloat,
    range: List Segment OrderedCompletion DoubleFloat,
    abserr: DoubleFloat,relerr: DoubleFloat),
    Result) ->
  Result
numericalIntegration :
  (Record(var: Symbol,
    fn: Expression DoubleFloat,
    range: Segment OrderedCompletion DoubleFloat,
    abserr: DoubleFloat,
    relerr: DoubleFloat),
    Result) ->
  Result

```

These exports come from (p162) SetCategory():

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean

```

— category NUMINT NumericalIntegrationCategory —

```

)abbrev category NUMINT NumericalIntegrationCategory
++ Author: Brian Dupee
++ Date Created: February 1994
++ Date Last Updated: March 1996
++ Description:
++ \axiomType{NumericalIntegrationCategory} is the \axiom{category} for
++ describing the set of Numerical Integration \axiom{domains} with
++ \axiomFun{measure} and \axiomFun{numericalIntegration}.

NumericalIntegrationCategory(): Category == Exports where

EDFE  ==> Expression DoubleFloat
SOCDFE ==> Segment OrderedCompletion DoubleFloat
DFE   ==> DoubleFloat
NIAE  ==> Record(var:Symbol,fn:EDFE,range:SOCDFE,abserr:DFE,relerr:DFE)

```

```
MDNIAE ==> Record(fn:EDFE,range:List SOCDFE,abserr:DFE,relerr:DFE)
```

```
Exports ==> SetCategory with
```

```
measure:(RoutinesTable,NIAE) -> _
Record(measure:Float,explanations:String,extra:Result)
  ++ measure(R,args) calculates an estimate of the ability of a particular
  ++ method to solve a problem.
  ++
  ++ This method may be either a specific NAG routine or a strategy (such
  ++ as transforming the function from one which is difficult to one which
  ++ is easier to solve).
  ++
  ++ It will call whichever agents are needed to perform analysis on the
  ++ problem in order to calculate the measure. There is a parameter,
  ++ labelled \axiom{sofar}, which would contain the best compatibility
  ++ found so far.
```

```
numericalIntegration: (NIAE, Result) -> Result
  ++ numericalIntegration(args,hints) performs the integration of the
  ++ function given the strategy or method returned by \axiomFun{measure}.
```

```
measure:(RoutinesTable,MDNIAE) -> _
Record(measure:Float,explanations:String,extra:Result)
  ++ measure(R,args) calculates an estimate of the ability of a particular
  ++ method to solve a problem.
  ++
  ++ This method may be either a specific NAG routine or a strategy (such
  ++ as transforming the function from one which is difficult to one which
  ++ is easier to solve).
  ++
  ++ It will call whichever agents are needed to perform analysis on the
  ++ problem in order to calculate the measure. There is a parameter,
  ++ labelled \axiom{sofar}, which would contain the best compatibility
  ++ found so far.
```

```
numericalIntegration: (MDNIAE, Result) -> Result
  ++ numericalIntegration(args,hints) performs the integration of the
  ++ function given the strategy or method returned by \axiomFun{measure}.
```

— NUMINT.dotabb —

```
"NUMINT"
```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=NUMINT"];
```

```
"NUMINT" -> "SETCAT"
```

— NUMINT.dotfull —

```
"NumericalIntegrationCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=NUMINT"];
"NumericalIntegrationCategory()" -> "SetCategory()"
```

— NUMINT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "NumericalIntegrationCategory()" [color=lightblue];
  "NumericalIntegrationCategory()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

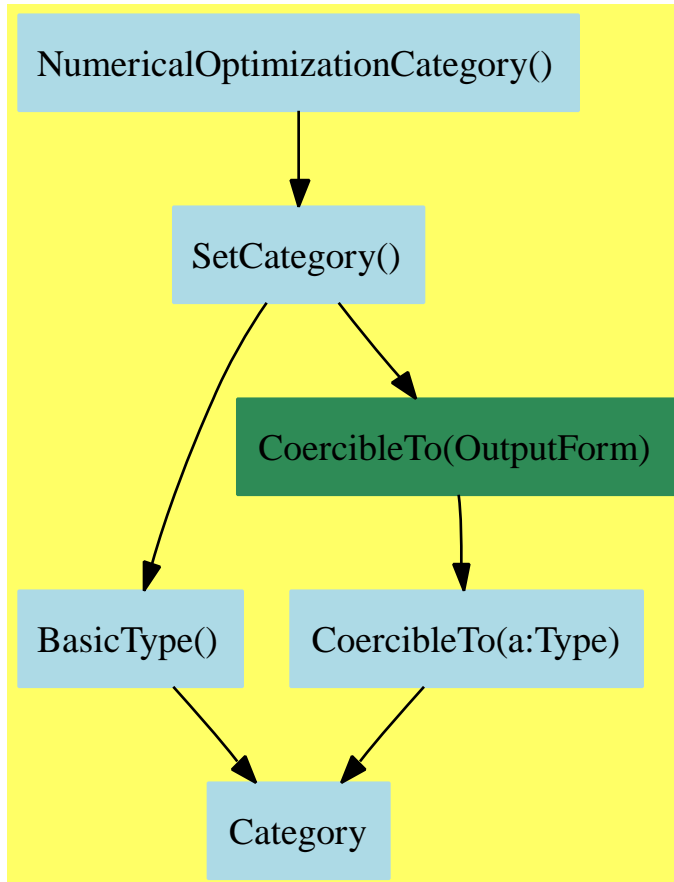
  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

NumericalOptimizationCategory (OPTCAT)



— NumericalOptimizationCategory.input —

```

)set break resume
)sys rm -f NumericalOptimizationCategory.output
)spool NumericalOptimizationCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show NumericalOptimizationCategory
--R
--R NumericalOptimizationCategory is a category constructor
--R Abbreviation for NumericalOptimizationCategory is OPTCAT
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OPTCAT
--R
--R----- Operations -----
--R ?=? : (%,% ) -> Boolean          coerce : % -> OutputForm
--R hash : % -> SingleInteger        latex : % -> String
--R ?~=? : (%,% ) -> Boolean
--R measure : (RoutinesTable,Record(lfn: List(Expression(DoubleFloat)),init: List(DoubleFloat)))
--R measure : (RoutinesTable,Record(fn: Expression(DoubleFloat),init: List(DoubleFloat),lb: List
--R numericalOptimization : Record(fn: Expression(DoubleFloat),init: List(DoubleFloat),lb: List(
--R numericalOptimization : Record(lfn: List(Expression(DoubleFloat)),init: List(DoubleFloat)) -
--R
--E 1

)spool
)lisp (bye)

```

— NumericalOptimizationCategory.help —

```

=====
NumericalOptimizationCategory examples
=====

```

NumericalOptimizationCategory is the category for describing the set of Numerical Optimization domains with measure and optimize.

See Also:
o)show NumericalOptimizationCategory

See:

← “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

```

coerce          hash  latex  measure
numericalOptimization  ?=?  ?~=?

```

These are directly exported but not implemented:

```

measure :
(RoutinesTable,
Record(lfn: List Expression DoubleFloat,
      init: List DoubleFloat)) ->
Record(measure: Float,explanations: String)
measure :

```

```

(RoutinesTable,
  Record(fn: Expression DoubleFloat,
    init: List DoubleFloat,
    lb: List OrderedCompletion DoubleFloat,
    cf: List Expression DoubleFloat,
    ub: List OrderedCompletion DoubleFloat)) ->
  Record(measure: Float, explanations: String)
numericalOptimization :
  Record(fn: Expression DoubleFloat,
    init: List DoubleFloat,
    lb: List OrderedCompletion DoubleFloat,
    cf: List Expression DoubleFloat,
    ub: List OrderedCompletion DoubleFloat) ->
  Result
numericalOptimization :
  Record(lfn: List Expression DoubleFloat,
    init: List DoubleFloat) ->
  Result

```

These exports come from (p162) SetCategory():

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean

```

— category OPTCAT NumericalOptimizationCategory —

```

)abbrev category OPTCAT NumericalOptimizationCategory
++ Author: Brian Dupee
++ Date Created: January 1996
++ Date Last Updated: March 1996
++ Description:
++ \axiomType{NumericalOptimizationCategory} is the \axiom{category} for
++ describing the set of Numerical Optimization \axiom{domains} with
++ \axiomFun{measure} and \axiomFun{optimize}.

```

NumericalOptimizationCategory(): Category == Exports where

```

LDFH ==> List DoubleFloat
LEDFH ==> List Expression DoubleFloat
LSAH ==> Record(lfn:LEDFH, init:LDFH)
EDFH ==> Expression DoubleFloat
LOCDFH ==> List OrderedCompletion DoubleFloat
NOAH ==> Record(fn:EDFH, init:LDFH, lb:LOCDFH, cf:LEDFH, ub:LOCDFH)

```

Exports ==> SetCategory with

```

measure:(RoutinesTable,NOAH)->Record(measure:Float,explanations:String)
++ measure(R,args) calculates an estimate of the ability of a particular
++ method to solve an optimization problem.
++
++ This method may be either a specific NAG routine or a strategy (such
++ as transforming the function from one which is difficult to one which
++ is easier to solve).
++
++ It will call whichever agents are needed to perform analysis on the
++ problem in order to calculate the measure. There is a parameter,
++ labelled \axiom{sofar}, which would contain the best compatibility
++ found so far.

measure:(RoutinesTable,LSAH)->Record(measure:Float,explanations:String)
++ measure(R,args) calculates an estimate of the ability of a particular
++ method to solve an optimization problem.
++
++ This method may be either a specific NAG routine or a strategy (such
++ as transforming the function from one which is difficult to one which
++ is easier to solve).
++
++ It will call whichever agents are needed to perform analysis on the
++ problem in order to calculate the measure. There is a parameter,
++ labelled \axiom{sofar}, which would contain the best compatibility
++ found so far.

numericalOptimization:LSAH -> Result
++ numericalOptimization(args) performs the optimization of the
++ function given the strategy or method returned by \axiomFun{measure}.

numericalOptimization:NOAH -> Result
++ numericalOptimization(args) performs the optimization of the
++ function given the strategy or method returned by \axiomFun{measure}.

```

— OPTCAT.dotabb —

```

"OPTCAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=OPTCAT" ];
"OPTCAT" -> "SETCAT"

```

— OPTCAT.dotfull —

```

"NumericalOptimizationCategory()"

```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=OPTCAT"];
"NumericalOptimizationCategory()" -> "SetCategory()"
```

— OPTCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "NumericalOptimizationCategory()" [color=lightblue];
  "NumericalOptimizationCategory()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

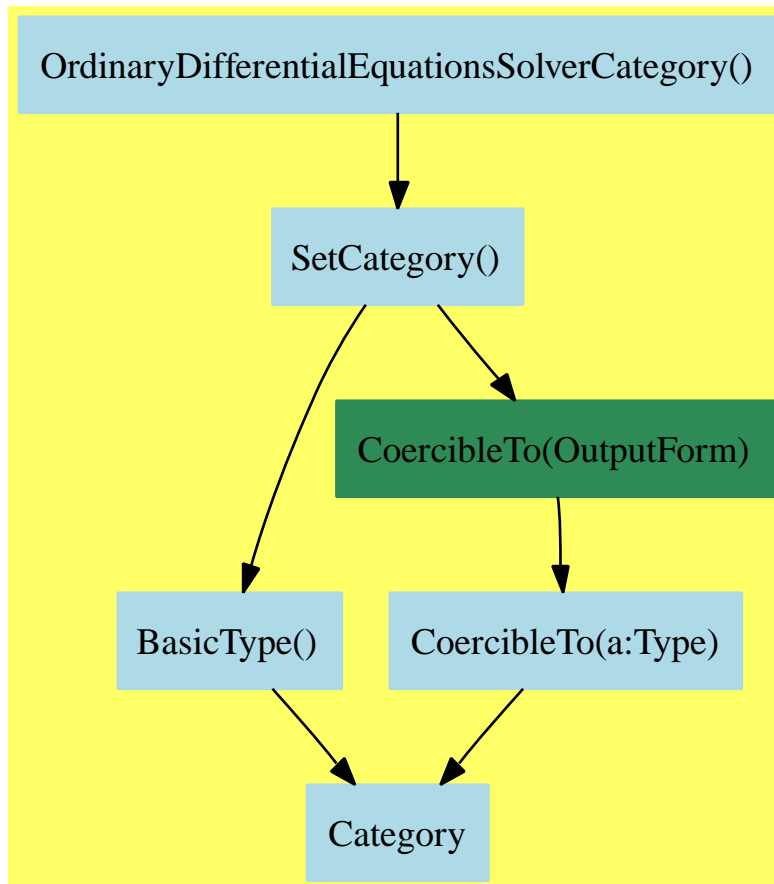
  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

OrdinaryDifferentialEquationsSolverCategory (ODECAT)



— OrdinaryDifferentialEquationsSolverCategory.input —

```

)set break resume
)sys rm -f OrdinaryDifferentialEquationsSolverCategory.output
)spool OrdinaryDifferentialEquationsSolverCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrdinaryDifferentialEquationsSolverCategory
--R
--R OrdinaryDifferentialEquationsSolverCategory is a category constructor
--R Abbreviation for OrdinaryDifferentialEquationsSolverCategory is ODECAT
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ODECAT
--R
--R----- Operations -----
--R ==? : (%,% ) -> Boolean          coerce : % -> OutputForm
--R hash : % -> SingleInteger        latex : % -> String
--R ~=? : (%,% ) -> Boolean
--R ODESolve : Record(xinit: DoubleFloat,xend: DoubleFloat,fn: Vector(Expression(DoubleFloat)),yinit: List(DoubleFloat))
--R measure : (RoutinesTable,Record(xinit: DoubleFloat,xend: DoubleFloat,fn: Vector(Expression(DoubleFloat))))
--R
--E 1

```

```

)spool
)lisp (bye)

```

— OrdinaryDifferentialEquationsSolverCategory.help —

```

=====
OrdinaryDifferentialEquationsSolverCategory examples
=====

```

OrdinaryDifferentialEquationsSolverCategory is the category for describing the set of ODE solver domains with measure and ODESolve.

See Also:

o)show OrdinaryDifferentialEquationsSolverCategory

See:

⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

```

coerce  hash  latex  measure  ODESolve
==?     ~=?

```

These are directly exported but not implemented:

```

ODESolve :
Record(xinit: DoubleFloat,
      xend: DoubleFloat,
      fn: Vector Expression DoubleFloat,
      yinit: List DoubleFloat,
      intvals: List DoubleFloat,
      g: Expression DoubleFloat,
      abserr: DoubleFloat,

```



```

        relerr: DoubleFloat) ->
    Result
measure :
(RoutinesTable,
  Record(xinit: DoubleFloat,
    xend: DoubleFloat,
    fn: Vector Expression DoubleFloat,
    yinit: List DoubleFloat,
    intvals: List DoubleFloat,
    g: Expression DoubleFloat,
    abserr: DoubleFloat,
    relerr: DoubleFloat)) ->
  Record(measure: Float, explanations: String)

```

These exports come from (p162) SetCategory():

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean

```

— category ODECAT OrdinaryDifferentialEquationsSolverCategory

```

)abbrev category ODECAT OrdinaryDifferentialEquationsSolverCategory
++ Author: Brian Dupee
++ Date Created: February 1995
++ Date Last Updated: June 1995
++ Description:
++ \axiomType{OrdinaryDifferentialEquationsSolverCategory} is the
++ \axiom{category} for describing the set of ODE solver \axiom{domains}
++ with \axiomFun{measure} and \axiomFun{ODEsolve}.

```

OrdinaryDifferentialEquationsSolverCategory(): Category == Exports where

```

DFF ==> DoubleFloat
VEDFF ==> Vector Expression DoubleFloat
LDFF ==> List DoubleFloat
EDFF ==> Expression DoubleFloat
ODEAF ==> Record(xinit:DFF,xend:DFF,fn:VEDFF,yinit:LDFF,intvals:LDFF,g:EDFF,abserr:DFF,relerr:DFF)

```

Exports ==> SetCategory with

```

measure:(RoutinesTable,ODEAF) -> Record(measure:Float,explanations:String)
++ measure(R,args) calculates an estimate of the ability of a particular
++ method to solve a problem.
++

```

```

++ This method may be either a specific NAG routine or a strategy (such
++ as transforming the function from one which is difficult to one which
++ is easier to solve).
++
++ It will call whichever agents are needed to perform analysis on the
++ problem in order to calculate the measure. There is a parameter,
++ labelled \axiom{sofar}, which would contain the best compatibility
++ found so far.

ODESolve: ODEAF -> Result
++ ODESolve(args) performs the integration of the
++ function given the strategy or method returned by \axiomFun{measure}.

```

— ODECAT.dotabb —

```

"ODECAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ODECAT"];
"ODECAT" -> "SETCAT"

```

— ODECAT.dotfull —

```

"OrdinaryDifferentialEquationsSolverCategory()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ODECAT"];
"OrdinaryDifferentialEquationsSolverCategory()" -> "SetCategory()"

```

— ODECAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrdinaryDifferentialEquationsSolverCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ODECAT"];
  "OrdinaryDifferentialEquationsSolverCategory()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

```

```
"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

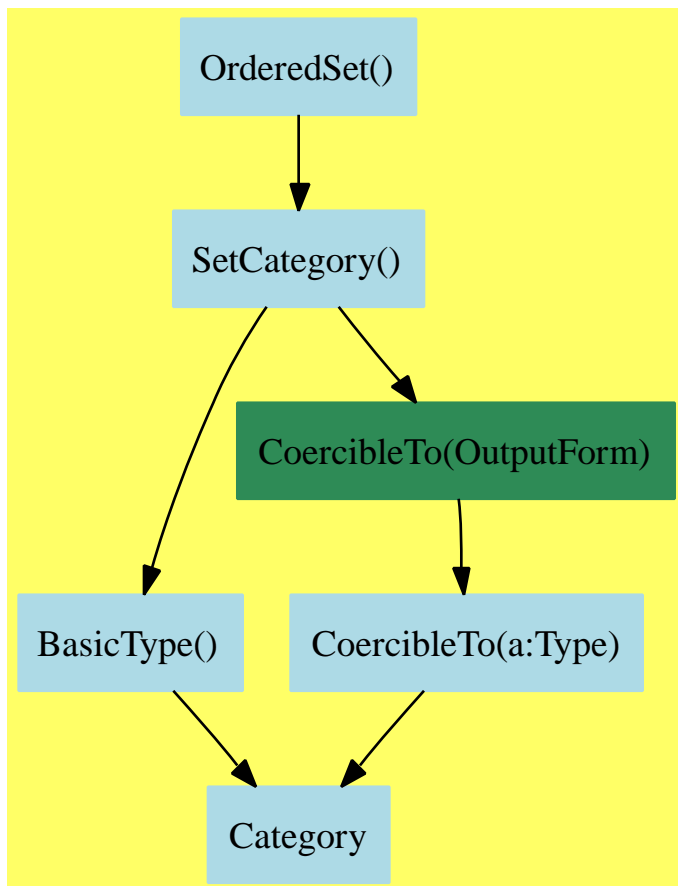
"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];

}
```

OrderedSet (ORDSET)



— OrderedSet.input —

```

)set break resume
)sys rm -f OrderedSet.output
)spool OrderedSet.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrderedSet
--R OrderedSet is a category constructor
--R Abbreviation for OrderedSet is ORDSET
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ORDSET

```

```

--R
--R----- Operations -----
--R ?<? : (%,% ) -> Boolean          ?<=? : (%,% ) -> Boolean
--R ?=? : (%,% ) -> Boolean          ?>? : (%,% ) -> Boolean
--R ?>=? : (%,% ) -> Boolean          coerce : % -> OutputForm
--R hash : % -> SingleInteger          latex : % -> String
--R max : (%,% ) -> %                  min : (%,% ) -> %
--R ?^=? : (%,% ) -> Boolean
--R
--E 1

```

```

)spool
)lisp (bye)

```

— OrderedSet.help —

=====

OrderedSet examples

=====

The class of totally ordered sets, that is, sets such that for each pair of elements (a,b) exactly one of the following relations holds $a < b$ or $a = b$ or $b < a$ and the relation is transitive, i.e. $a < b$ and $b < c \Rightarrow a < c$.

See Also:

- o)show OrderedSet

See:

- ⇒ “BitAggregate” (BTAGG) [9](#) on page [787](#)
- ⇒ “CachableSet” (CACHSET) [5](#) on page [337](#)
- ⇒ “DifferentialVariableCategory” (DVARCAT) [5](#) on page [348](#)
- ⇒ “ExpressionSpace” (ES) [5](#) on page [355](#)
- ⇒ “FortranMachineTypeCategory” (FMTC) [13](#) on page [1158](#)
- ⇒ “IntervalCategory” (INTCAT) [14](#) on page [1200](#)
- ⇒ “OrderedAbelianSemiGroup” (OASGP) [6](#) on page [511](#)
- ⇒ “OrderedFinite” (ORDFIN) [5](#) on page [391](#)
- ⇒ “OrderedMonoid” (ORDMON) [6](#) on page [516](#)
- ⇒ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)
- ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
- ⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

```

coerce  hash  latex  max  min
?<?    ?<=?  ?=?    ?>?  ?>=?
?~=?

```

These are directly exported but not implemented:

```
?<? : (%,% ) -> Boolean
```

These are implemented by this category:

```

max : (%,% ) -> %
min : (%,% ) -> %
?>? : (%,% ) -> Boolean
?>=? : (%,% ) -> Boolean
?<=? : (%,% ) -> Boolean

```

These exports come from (p162) SetCategory():

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean

```

— category ORDSET OrderedSet —

```

)abbrev category ORDSET OrderedSet
++ Description:
++ The class of totally ordered sets, that is, sets such that for each
++ pair of elements \spad{(a,b)}
++ exactly one of the following relations holds \spad{a<b or a=b or b<a}
++ and the relation is transitive, that is, \spad{a<b and b<c => a<c}.

```

OrderedSet(): Category == SetCategory with

```

"<": (%,% ) -> Boolean
++ x < y is a strict total ordering on the elements of the set.

">":      (%,% ) -> Boolean
++ x > y is a greater than test.

">=":      (%,% ) -> Boolean
++ x >= y is a greater than or equal test.

"<=":      (%,% ) -> Boolean
++ x <= y is a less than or equal test.

max: (%,% ) -> %
++ max(x,y) returns the maximum of x and y relative to "<".

```

```

min: (%,%) -> %
  ++ min(x,y) returns the minimum of x and y relative to "<".

add
  x,y: %

-- These really ought to become some sort of macro

max(x,y) ==
  x > y => x
  y

min(x,y) ==
  x > y => y
  x

((x: %) > (y: %)) : Boolean == y < x

((x: %) >= (y: %)) : Boolean == not (x < y)

((x: %) <= (y: %)) : Boolean == not (y < x)

_____

— ORDSET.dotabb —

"ORDSET"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ORDSET" ];
"ORDSET" -> "SETCAT"

_____

— ORDSET.dotfull —

"OrderedSet()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ORDSET" ];
"OrderedSet()" -> "SetCategory()"

_____

— ORDSET.dotpic —

digraph pic {
  fontsize=10;

```

```

bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"OrderedSet()" [color=lightblue];
"OrderedSet()" -> "SetCategory()"

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

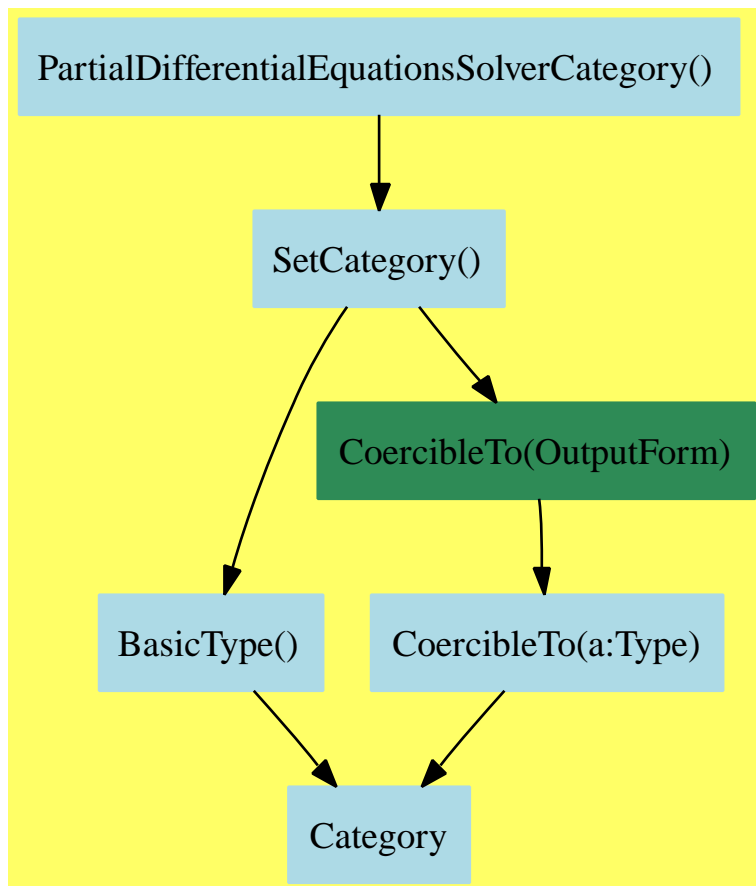
"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];
}

```

PartialDifferentialEquationsSolverCategory (PDECAT)

— PartialDifferentialEquationsSolverCategory.input —

```

)set break resume
)sys rm -f PartialDifferentialEquationsSolverCategory.output
)spool PartialDifferentialEquationsSolverCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PartialDifferentialEquationsSolverCategory
--R
--R PartialDifferentialEquationsSolverCategory is a category constructor
--R Abbreviation for PartialDifferentialEquationsSolverCategory is PDECAT
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PDECAT
--R
--R----- Operations -----
--R ==? : (%,% ) -> Boolean          coerce : % -> OutputForm
--R hash : % -> SingleInteger        latex : % -> String
--R ?~=? : (%,% ) -> Boolean
--R PDESolve : Record(pde: List(Expression(DoubleFloat)),constraints: List(Record(start: DoubleFloat,finish: DoubleFloat),
--R measure : (RoutinesTable,Record(pde: List(Expression(DoubleFloat)),constraints: List(Record(start: DoubleFloat,finish: DoubleFloat),
--R
--E 1

```

```

)spool
)lisp (bye)

```

— PartialDifferentialEquationsSolverCategory.help —

```

=====
PartialDifferentialEquationsSolverCategory examples
=====

```

PartialDifferentialEquationsSolverCategory is the category for describing the set of PDE solver domains with measure and PDESolve.

See Also:

o)show PartialDifferentialEquationsSolverCategory

See:

⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

```

coerce  hash  latex  measure  PDESolve
==?     ?~=?

```

These are directly exported but not implemented:

```

measure :
(RoutinesTable,
  Record(pde: List Expression DoubleFloat,
    constraints:
      List Record(start: DoubleFloat,
        finish: DoubleFloat,
        grid: NonNegativeInteger,
        boundaryType: Integer,

```

```

                                dStart: Matrix DoubleFloat,
                                dFinish: Matrix DoubleFloat),
    f: List List Expression DoubleFloat,
    st: String,
    tol: DoubleFloat)) ->
  Record(measure: Float, explanations: String)
PDESolve :
  Record(pde: List Expression DoubleFloat,
    constraints:
      List Record(start: DoubleFloat,
        finish: DoubleFloat,
        grid: NonNegativeInteger,
        boundaryType: Integer,
        dStart: Matrix DoubleFloat,
        dFinish: Matrix DoubleFloat),
    f: List List Expression DoubleFloat,
    st: String,
    tol: DoubleFloat) ->
  Result

```

These exports come from (p586) Dictionary(S:SetCategory):

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean

```

— category PDECAT PartialDifferentialEquationsSolverCategory —

```

)abbrev category PDECAT PartialDifferentialEquationsSolverCategory
++ Author: Brian Dupee
++ Date Created: February 1995
++ Date Last Updated: June 1995
++ Description:
++ \axiomType{PartialDifferentialEquationsSolverCategory} is the
++ \axiom{category} for describing the set of PDE solver \axiom{domains}
++ with \axiomFun{measure} and \axiomFun{PDESolve}.

-- PDEA      ==> Record(xmin:F,xmax:F,ymin:F,ymax:F,ngx:NNI,ngy:NNI,
--                    pde:List Expression Float, bounds:List List Expression Float,
--                    st:String, tol:DF)

-- measure:(RoutinesTable,PDEA) -> Record(measure:F,explanations:String)
-- ++ measure(R,args) calculates an estimate of the ability of a particular
-- ++ method to solve a problem.
-- ++
-- ++ This method may be either a specific NAG routine or a strategy (such
-- ++ as transforming the function from one which is difficult to one which

```

```

--      ++ is easier to solve).
--      ++
--      ++ It will call whichever agents are needed to perform analysis on the
--      ++ problem in order to calculate the measure. There is a parameter,
--      ++ labelled \axiom{sofar}, which would contain the best compatibility
--      ++ found so far.

-- PDESolve: PDEA -> Result
--      ++ PDESolve(args) performs the integration of the
--      ++ function given the strategy or method returned by \axiomFun{measure}.

PartialDifferentialEquationsSolverCategory(): Category == Exports where

DFG    ==> DoubleFloat
NNIG   ==> NonNegativeInteger
INTG   ==> Integer
MDFG   ==> Matrix DoubleFloat
PDECG  ==> Record(start:DFG, finish:DFG, grid:NNIG, boundaryType:INTG,
                  dStart:MDFG, dFinish:MDFG)
LEDFG  ==> List Expression DoubleFloat
PDEBG  ==> Record(pde:LEDFG, constraints:List PDECG, f:List LEDFG,
                  st:String, tol:DFG)
Exports ==> SetCategory with

measure:(RoutinesTable,PDEBG) -> Record(measure:Float,explanations:String)
  ++ measure(R,args) calculates an estimate of the ability of a particular
  ++ method to solve a problem.
  ++
  ++ This method may be either a specific NAG routine or a strategy (such
  ++ as transforming the function from one which is difficult to one which
  ++ is easier to solve).
  ++
  ++ It will call whichever agents are needed to perform analysis on the
  ++ problem in order to calculate the measure. There is a parameter,
  ++ labelled \axiom{sofar}, which would contain the best compatibility
  ++ found so far.

PDESolve: PDEBG -> Result
  ++ PDESolve(args) performs the integration of the
  ++ function given the strategy or method returned by \axiomFun{measure}.

```

— PDECAT.dotabb —

```

"PDECAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PDECAT"];
"PDECAT" -> "SETCAT"

```

— PDECAT.dotfull —

```
"PartialDifferentialEquationsSolverCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PDECAT"];
"PartialDifferentialEquationsSolverCategory()" -> "SetCategory()"
```

— PDECAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PartialDifferentialEquationsSolverCategory()" [color=lightblue];
  "PartialDifferentialEquationsSolverCategory()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

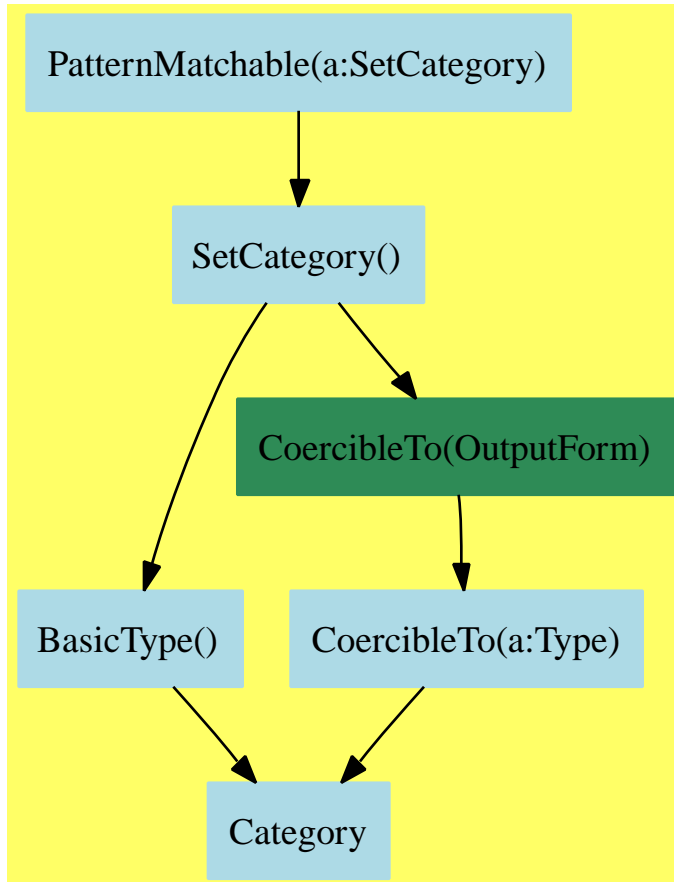
  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

PatternMatchable (PATMAB)



— PatternMatchable.input —

```

)set break resume
)sys rm -f PatternMatchable.output
)spool PatternMatchable.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PatternMatchable
--R
--R PatternMatchable(S: SetCategory) is a category constructor
--R Abbreviation for PatternMatchable is PATMAB
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PATMAB
--R
--R----- Operations -----
--R ?=? : (%,% ) -> Boolean          coerce : % -> OutputForm
--R hash : % -> SingleInteger        latex : % -> String
--R ?~=? : (%,% ) -> Boolean
--R patternMatch : (% ,Pattern(S),PatternMatchResult(S,%)) -> PatternMatchResult(S,%)
--R
--E 1

)spool
)lisp (bye)

```

— PatternMatchable.help —

=====
PatternMatchable examples
=====

A set R is PatternMatchable over S if elements of R can be matched to patterns over S.

See Also:
o)show PatternMatchable

See:

⇒ “RealNumberSystem” (RNS) [17](#) on page [1451](#)
⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

```

coerce  hash  latex  patternMatch  ?=?
?~=?

```

These are directly exported but not implemented:

```

patternMatch :
  (% ,Pattern S,PatternMatchResult(S,%))
  -> PatternMatchResult(S,%)

```

These exports come from (p[162](#)) SetCategory():

```

coerce : % -> OutputForm

```

```

hash : % -> SingleInteger
latex : % -> String
?? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean

```

— category PATMAB PatternMatchable —

```

)abbrev category PATMAB PatternMatchable
++ Category of sets that can be pattern-matched on
++ Author: Manuel Bronstein
++ Date Created: 28 Nov 1989
++ Date Last Updated: 15 Mar 1990
++ Description:
++ A set R is PatternMatchable over S if elements of R can
++ be matched to patterns over S.

PatternMatchable(S:SetCategory): Category == SetCategory with
  patternMatch: (% , Pattern S, PatternMatchResult(S, %)) ->
                                     PatternMatchResult(S, %)
  ++ patternMatch(expr, pat, res) matches the pattern pat to the
  ++ expression expr. res contains the variables of pat which
  ++ are already matched and their matches (necessary for recursion).
  ++ Initially, res is just the result of \spadfun{new}
  ++ which is an empty list of matches.

```

—————

— PATMAB.dotabb —

```

"PATMAB"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PATMAB"];
"PATMAB" -> "SETCAT"

```

—————

— PATMAB.dotfull —

```

"PatternMatchable(a:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PATMAB"];
"PatternMatchable(a:SetCategory)" -> "SetCategory()"

"PatternMatchable(Integer)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=PATMAB"];
"PatternMatchable(Integer)" -> "PatternMatchable(a:SetCategory)"

```



```
"PatternMatchable(Float)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=PATMAB"];
"PatternMatchable(Float)" -> "PatternMatchable(a:SetCategory)"
```

— PATMAB.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PatternMatchable(a:SetCategory)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=PATMAB"];
  "PatternMatchable(a:SetCategory)" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

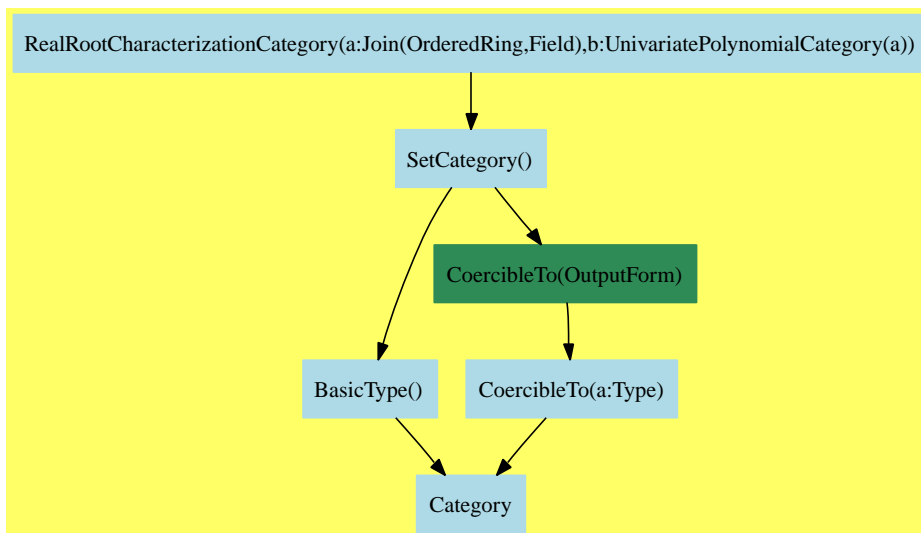
  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

RealRootCharacterizationCategory (RRCC)



— RealRootCharacterizationCategory.input —

```

)set break resume
)sys rm -f RealRootCharacterizationCategory.output
)spool RealRootCharacterizationCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RealRootCharacterizationCategory
--R
--R RealRootCharacterizationCategory(TheField: Join(OrderedRing,Field),ThePols: UnivariatePolynomialCategory)
--R Abbreviation for RealRootCharacterizationCategory is RRCC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RRCC
--R
--R----- Operations -----
--R ==? : (%,% ) -> Boolean          allRootsOf : ThePols -> List(%)
--R coerce : % -> OutputForm        definingPolynomial : % -> ThePols
--R hash : % -> SingleInteger        latex : % -> String
--R sign : (ThePols,% ) -> Integer    zero? : (ThePols,% ) -> Boolean
--R ==~? : (%,% ) -> Boolean
--R approximate : (ThePols,%,TheField) -> TheField
--R negative? : (ThePols,% ) -> Boolean
--R positive? : (ThePols,% ) -> Boolean
--R recip : (ThePols,% ) -> Union(ThePols,"failed")

```

```

--R relativeApprox : (ThePols,%,TheField) -> TheField
--R rootOf : (ThePols,PositiveInteger) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— RealRootCharacterizationCategory.help —

=====

RealRootCharacterizationCategory examples

=====

RealRootCharacterizationCategory provides common access functions for all real root codings.

See Also:

o)show RealRootCharacterizationCategory

See:

⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

| | | | |
|------------|----------------|-----------|--------------------|
| allRootsOf | approximate | coerce | definingPolynomial |
| hash | latex | negative? | positive? |
| recip | relativeApprox | rootOf | sign |
| zero? | ?=? | ?=? | |

These are directly exported but not implemented:

```

approximate : (ThePols,%,TheField) -> TheField
allRootsOf : ThePols -> List %
definingPolynomial : % -> ThePols
relativeApprox : (ThePols,%,TheField) -> TheField
sign : (ThePols,%) -> Integer

```

These are implemented by this category:

```

negative? : (ThePols,%) -> Boolean
positive? : (ThePols,%) -> Boolean
recip : (ThePols,%) -> Union(ThePols, "failed")

```

```

rootOf : (ThePols,PositiveInteger) -> Union(%, "failed")
zero? : (ThePols,%) -> Boolean

```

These exports come from (p162) SetCategory():

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean

```

— category RRCC RealRootCharacterizationCategory —

```

)abbrev category RRCC RealRootCharacterizationCategory
++ Author: Renaud Rioboo
++ Date Created: summer 1992
++ Date Last Updated: January 2004
++ Description:
++ \axiomType{RealRootCharacterizationCategory} provides common access
++ functions for all real roots of polynomials

```

RealRootCharacterizationCategory(TheField, ThePols) : Category == PUB where

```

TheField : Join(OrderedRing, Field)
ThePols : UnivariatePolynomialCategory(TheField)

Z ==> Integer
N ==> PositiveInteger

PUB ==>
  SetCategory with

    sign:          ( ThePols, $ ) ->          Z
    ++ \axiom{sign(pol,aRoot)} gives the sign of \axiom{pol}
    ++ interpreted as \axiom{aRoot}
    zero? :        ( ThePols, $ ) ->          Boolean
    ++ \axiom{zero?(pol,aRoot)} answers if \axiom{pol}
    ++ interpreted as \axiom{aRoot} is \axiom{0}
    negative?:     ( ThePols, $ ) ->          Boolean
    ++ \axiom{negative?(pol,aRoot)} answers if \axiom{pol}
    ++ interpreted as \axiom{aRoot} is negative
    positive?:     ( ThePols, $ ) ->          Boolean
    ++ \axiom{positive?(pol,aRoot)} answers if \axiom{pol}
    ++ interpreted as \axiom{aRoot} is positive
    recip:         ( ThePols, $ ) ->          Union(ThePols, "failed")
    ++ \axiom{recip(pol,aRoot)} tries to inverse \axiom{pol}
    ++ interpreted as \axiom{aRoot}
    definingPolynomial: $ ->          ThePols
    ++ \axiom{definingPolynomial(aRoot)} gives a polynomial

```

```

    ++ such that \axiom{definingPolynomial(aRoot).aRoot = 0}
allRootsOf:      ThePols      ->      List $
    ++ \axiom{allRootsOf(pol)} creates all the roots of \axiom{pol}
    ++ in the Real Closure, assumed in order.
rootOf:          ( ThePols, N ) ->      Union($,"failed")
    ++ \axiom{rootOf(pol,n)} gives the nth root for the order of the
    ++ Real Closure
approximate :   (ThePols,$,TheField) ->   TheField
    ++ \axiom{approximate(term,root,prec)} gives an approximation
    ++ of \axiom{term} over \axiom{root} with precision \axiom{prec}

relativeApprox : (ThePols,$,TheField) ->   TheField
    ++ \axiom{approximate(term,root,prec)} gives an approximation
    ++ of \axiom{term} over \axiom{root} with precision \axiom{prec}

add

zero?(toTest, rootChar) ==
    sign(toTest, rootChar) = 0

negative?(toTest, rootChar) ==
    sign(toTest, rootChar) < 0

positive?(toTest, rootChar) ==
    sign(toTest, rootChar) > 0

rootOf(pol,n) ==
    liste:List($):= allRootsOf(pol)
    # liste > n => "failed"
    liste.n

recip(toInv,rootChar) ==
    degree(toInv) = 0 =>
        res := recip(leadingCoefficient(toInv))
        if (res case "failed") then "failed" else (res::TheField::ThePols)
    defPol := definingPolynomial(rootChar)
    d := principalIdeal([defPol,toInv])
    zero?(d.generator,rootChar) => "failed"
    if (degree(d.generator) ^= 0 )
    then
        defPol := (defPol exquo (d.generator))::ThePols
        d := principalIdeal([defPol,toInv])
    d.coef.2

```

```
"RRCC"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RRCC"];
"RRCC" -> "SETCAT"
```

— RRCC.dotfull —

```
"RealRootCharacterizationCategory(a:Join(OrderedRing,Field),b:UnivariatePolynomialCategory(a))"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RRCC"];
"RealRootCharacterizationCategory(a:Join(OrderedRing,Field),b:UnivariatePolynomialCategory(a))"
  -> "SetCategory()"
```

— RRCC.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "RealRootCharacterizationCategory(a:Join(OrderedRing,Field),b:UnivariatePolynomialCategory(a))"
    [color=lightblue];
  "RealRootCharacterizationCategory(a:Join(OrderedRing,Field),b:UnivariatePolynomialCategory(a))"
    -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

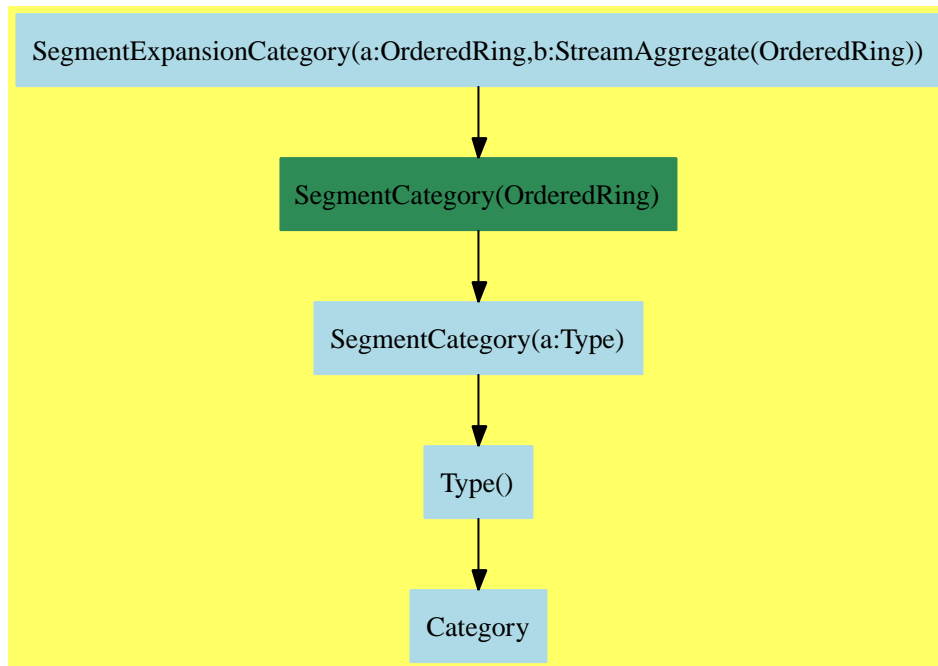
  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

SegmentExpansionCategory (SEGXCAT)



— SegmentExpansionCategory.input —

```

)set break resume
)sys rm -f SegmentExpansionCategory.output
)spool SegmentExpansionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show SegmentExpansionCategory
--R
--R SegmentExpansionCategory(S: OrderedRing,L: StreamAggregate(t#1)) is a category constructor
--R Abbreviation for SegmentExpansionCategory is SEGXCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SEGXCAT
--R
--R----- Operations -----
--R BY : (%,Integer) -> %          ?..? : (S,S) -> %
--R convert : S -> %              expand : % -> L
--R expand : List(%) -> L          hi : % -> S
--R high : % -> S                 incr : % -> Integer

```

```

--R lo : % -> S                                low : % -> S
--R map : ((S -> S),%) -> L                    segment : (S,S) -> %
--R
--E 1

```

```

)spool
)lisp (bye)

```

— SegmentExpansionCategory.help —

SegmentExpansionCategory examples

This category provides an interface for expanding segments to a stream of elements.

See Also:

o)show SegmentExpansionCategory

See:

⇐ “SegmentCategory” (SEGCAT) [3](#) on page [158](#)

Exports:

```

BY    convert  expand  hi    high
incr  lo       low    map   segment
?...?

```

Attributes exported:

- nil

These are directly exported but not implemented:

```

expand : % -> L
expand : List % -> L
map : ((S -> S),%) -> L

```

These exports come from (p[158](#)) SegmentCategory(OrderedRing):

```

BY : (% , Integer) -> %
convert : S -> %

```



```

hi : % -> S
high : % -> S
incr : % -> Integer
lo : % -> S
low : % -> S
segment : (S,S) -> %
?...? : (S,S) -> %

```

— category SEGXCAT SegmentExpansionCategory —

```

)abbrev category SEGXCAT SegmentExpansionCategory
++ Author: Stephen M. Watt
++ Date Created: June 5, 1991
++ Description:
++ This category provides an interface for expanding segments to
++ a stream of elements.

SegmentExpansionCategory(S: OrderedRing, L: StreamAggregate(S)): Category ==
  SegmentCategory(S) with
    expand: List % -> L
      ++ expand(l) creates a new value of type L in which each segment
      ++ \spad{l..h by k} is replaced with \spad{l, l+k, ... lN},
      ++ where \spad{lN <= h < lN+k}.
      ++ For example, \spad{expand [1..4, 7..9] = [1,2,3,4,7,8,9]}.
    expand: % -> L
      ++ expand(l..h by k) creates value of type L with elements
      ++ \spad{l, l+k, ... lN} where \spad{lN <= h < lN+k}.
      ++ For example, \spad{expand(1..5 by 2) = [1,3,5]}.
    map: (S -> S, %) -> L
      ++ map(f,l..h by k) produces a value of type L by applying f
      ++ to each of the successive elements of the segment, that is,
      ++ \spad{[f(l), f(l+k), ..., f(lN)]}, where \spad{lN <= h < lN+k}.

```

—

— SEGXCAT.dotabb —

```

"SEGXCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=SEGXCAT"];
"SEGXCAT" -> "SEGXCAT"

```

—

— SEGXCAT.dotfull —

```

"SegmentExpansionCategory(a:OrderedRing,b:StreamAggregate(OrderedRing))"

```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=SEGXCAT"];
"SegmentExpansionCategory(a:OrderedRing,b:StreamAggregate(OrderedRing))"
  -> "SegmentCategory(OrderedRing)"
```

— SEGXCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "SegmentExpansionCategory(a:OrderedRing,b:StreamAggregate(OrderedRing))"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=SEGXCAT"];
  "SegmentExpansionCategory(a:OrderedRing,b:StreamAggregate(OrderedRing))"
    -> "SegmentCategory(OrderedRing)"

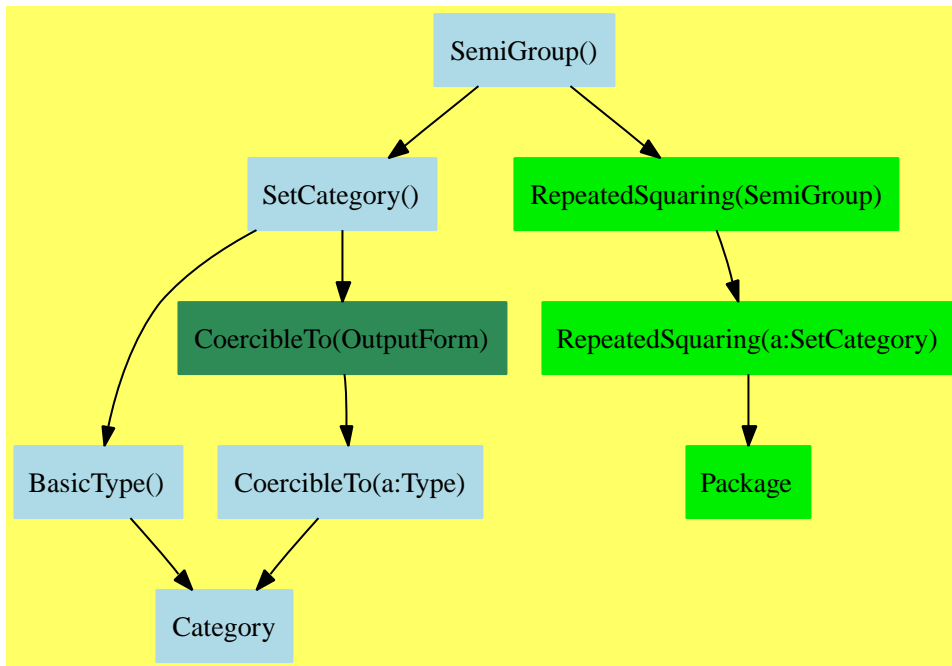
  "SegmentCategory(OrderedRing)"
    [color=seagreen,href="bookvol10.2.pdf#nameddest=SEGCAT"];
  "SegmentCategory(OrderedRing)" -> "SegmentCategory(a:Type)"

  "SegmentCategory(a:Type)" [color=lightblue];
  "SegmentCategory(a:Type)" -> "Type()"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "Category" [color=lightblue];
}
```

SemiGroup (SGROUP)



A Semigroup is defined as a set S with a binary multiplicative operator $*$. A Semigroup $G(S, *)$ is:

- a set S which can be null
- a binary multiplicative operator $*$
- associative. $\forall a, b, c \in S, a * (b * c) = (a * b) * c$

— SemiGroup.input —

```

)set break resume
)sys rm -f SemiGroup.output
)spool SemiGroup.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show SemiGroup
--R SemiGroup is a category constructor
--R Abbreviation for SemiGroup is SGROUP
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SGROUP

```

```

--R
--R----- Operations -----
--R ?? : (%,% ) -> %           ??? : (% ,PositiveInteger) -> %
--R ?? : (%,% ) -> Boolean      ?? : (% ,PositiveInteger) -> %
--R coerce : % -> OutputForm    hash : % -> SingleInteger
--R latex : % -> String         ?~=? : (%,% ) -> Boolean
--R
--E 1

```

```

)spool
)lisp (bye)

```

— SemiGroup.help —

=====

SemiGroup examples

=====

The class of all multiplicative semigroups, i.e. a set with an associative operation `*`.

Axioms:

associative("`*`":(%,%)->%) $(x*y)*z = x*(y*z)$

Conditional attributes:

commutative("`*`":(%,%)->%) $x*y = y*x$

See Also:

o)show SemiGroup

See:

⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)

⇒ “Monoid” (MONOID) [5](#) on page [386](#)

⇒ “Rng” (RNG) [8](#) on page [775](#)

⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

coerce hash latex ?? ???
 ?=? ?? ?~=?

These are directly exported but not implemented:

?? : (%,%) -> %

These are implemented by this category:

```
***? : (% , PositiveInteger) -> %
?? : (% , PositiveInteger) -> %
```

These exports come from (p162) SetCategory():

```
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?? : (% , %) -> Boolean
?~=? : (% , %) -> Boolean
```

— category SGROUP SemiGroup —

```
)abbrev category SGROUP SemiGroup
++ Description:
++ the class of all multiplicative semigroups, that is, a set
++ with an associative operation \spadop{*}.
++
++ Axioms\br
++ \tab{5}\spad{associative("": (% , %) -> %)}\tab{5}\spad{(x*y)*z = x*(y*z)}
++
++ Conditional attributes\br
++ \tab{5}\spad{commutative("": (% , %) -> %)}\tab{5}\spad{x*y = y*x}

SemiGroup(): Category == SetCategory with

"*": (% , %) -> %
++ x*y returns the product of x and y.

"***": (% , PositiveInteger) -> %
++ x**n returns the repeated product of x n times, exponentiation.

"^": (% , PositiveInteger) -> %
++ x^n returns the repeated product of x n times, exponentiation.
add
import RepeatedSquaring(%)

x:% ** n:PositiveInteger == expt(x,n)

_^ (x:% , n:PositiveInteger):% == x ** n
```

— SGROUP.dotabb —

```
"SGROUP"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SGROUP"];
"SGROUP" -> "SETCAT"
```

— SGROUP.dotfull —

```
"SemiGroup()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SGROUP"];
"SemiGroup()" -> "SetCategory()"
"SemiGroup()" -> "RepeatedSquaring(a:SemiGroup)"
```

— SGROUP.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "SemiGroup()" [color=lightblue];
  "SemiGroup()" -> "SetCategory()"
  "SemiGroup()" -> "RepeatedSquaring(a:SemiGroup)"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

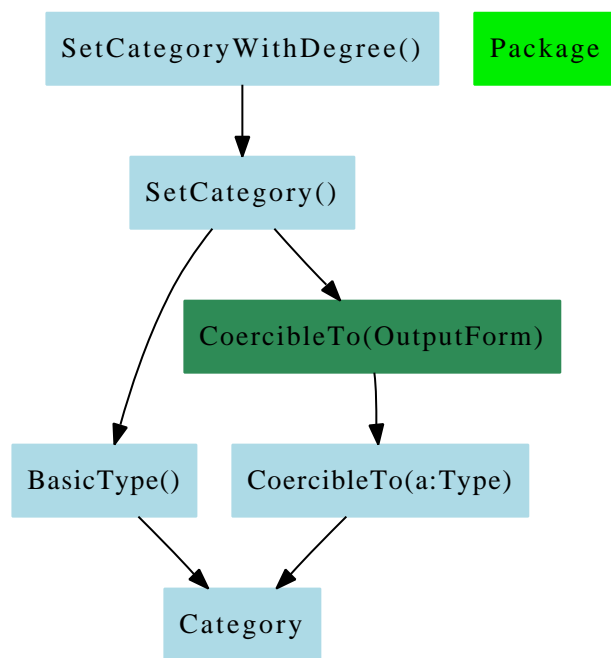
  "RepeatedSquaring(a:SemiGroup)" [color="#00EE00"];
  "RepeatedSquaring(a:SemiGroup)" -> "RepeatedSquaring(a:SetCategory)"

  "RepeatedSquaring(a:SetCategory)" [color="#00EE00"];
  "RepeatedSquaring(a:SetCategory)" -> "Package"

  "Package" [color="#00EE00"];
```

```
"Category" [color=lightblue];
}
```

SetCategoryWithDegree (SETCATD)



— SetCategoryWithDegree.input —

```

)set break resume
)sys rm -f SetCategoryWithDegree.output
)spool SetCategoryWithDegree.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show SetCategoryWithDegree
--R SetCategoryWithDegree is a category constructor
```

```

--R Abbreviation for SetCategoryWithDegree is SETCATD
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SETCATD
--R
--R----- Operations -----
--R ?? : (% , %) -> Boolean          coerce : % -> OutputForm
--R degree : % -> PositiveInteger    hash : % -> SingleInteger
--R latex : % -> String              ?~=? : (% , %) -> Boolean
--R
--E 1

)spool
)lisp (bye)

```

— SetCategoryWithDegree.help —

=====
SetCategoryWithDegree examples
=====

This is part of the PAFF package, related to projective space.

See Also:

o)show SetCategoryWithDegree

See:

⇒ “ProjectiveSpaceCategory” (PRSPCAT) [5](#) on page [400](#)

⇐ “BasicType” (BASTYPE) [2](#) on page [23](#)

⇐ “CoercibleTo” (KOERCE) [2](#) on page [33](#)

⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

coerce degree hash latex ?=? ?~=?

These are directly exported but not implemented:

degree : % -> PositiveInteger

These exports come from (p[162](#)) SetCategory():

coerce : % -> OutputForm


```

hash : % -> SingleInteger
latex : % -> String
?? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean

```

— category SETCATD SetCategoryWithDegree —

```

)abbrev category SETCATD SetCategoryWithDegree
++ Author: Gaetan Hache
++ Date Created: 17 nov 1992
++ Date Last Updated: May 2010 by Tim Daly
++ Description:
++ This is part of the PAFF package, related to projective space.
SetCategoryWithDegree:Category == SetCategory with
  degree: % -> PositiveInteger

```

—

— SETCATD.dotabb —

```

"SETCATD"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=SETCATD" ];
"SETCATD" -> "SETCAT"

```

—

— SETCATD.dotfull —

```

"SetCategoryWithDegree()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=SETCATD" ];
"SetCategoryWithDegree()" -> "SetCategory()"

```

—

— SETCATD.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "SetCategoryWithDegree()" [color=lightblue];
  "SetCategoryWithDegree()" -> "SetCategory()"

```

```

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

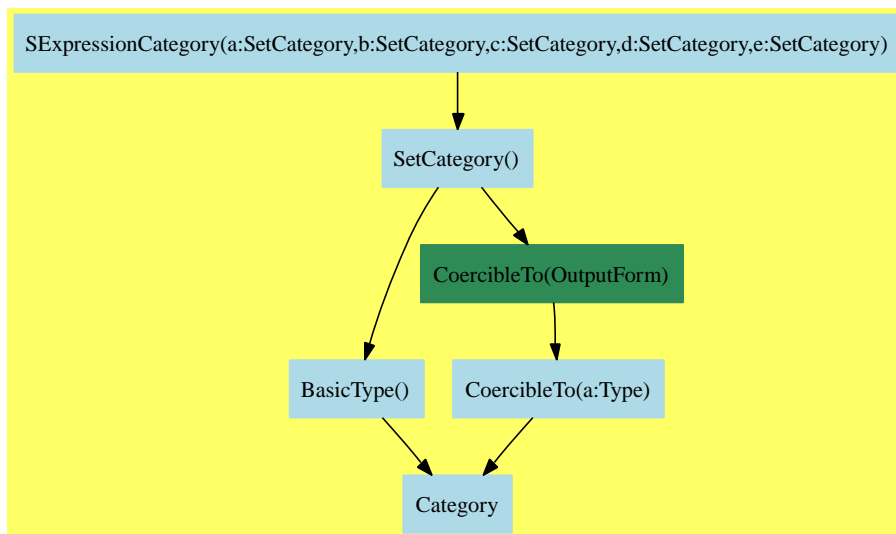
"Package" [color="#00EE00"];

"Category" [color=lightblue];

}

```

SExpressionCategory (SEXCAT)



— SExpressionCategory.input —

```

)set break resume
)sys rm -f SExpressionCategory.output
)spool SExpressionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show SExpressionCategory
--R
--R SExpressionCategory(Str: SetCategory,Sym: SetCategory,Int: SetCategory,Flt: SetCategory,Expr: SetCategory)
--R Abbreviation for SExpressionCategory is SEXCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SEXCAT
--R
--R----- Operations -----
--R #? : % -> Integer           ?? : (% ,%) -> Boolean
--R atom? : % -> Boolean       car : % -> %
--R cdr : % -> %              coerce : % -> OutputForm
--R convert : Expr -> %        convert : Flt -> %
--R convert : Int -> %         convert : Sym -> %
--R convert : Str -> %         convert : List(%) -> %
--R destruct : % -> List(%)    ?? : (% ,List(Integer)) -> %
--R ?? : (% ,Integer) -> %     eq : (% ,%) -> Boolean
--R expr : % -> Expr           float : % -> Flt
--R float? : % -> Boolean      hash : % -> SingleInteger
--R integer : % -> Int          integer? : % -> Boolean
--R latex : % -> String        list? : % -> Boolean
--R null? : % -> Boolean       pair? : % -> Boolean
--R string : % -> Str          string? : % -> Boolean
--R symbol : % -> Sym          symbol? : % -> Boolean
--R ~=? : (% ,%) -> Boolean
--R
--E 1

)spool
)lisp (bye)

```

— SExpressionCategory.help —

=====

SExpressionCategory examples

=====

This category allows the manipulation of Lisp values while keeping the grunge fairly localized.

See Also:

- o)show SExpressionCategory

See:

⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

| | | | | |
|----------|---------|----------|---------|---------|
| atom? | car | cdr | coerce | convert |
| destruct | eq | expr | float | float? |
| hash | integer | integer? | latex | list? |
| null? | pair? | string | string? | symbol |
| symbol? | #? | ?=? | ?~=? | ?..? |

These are directly exported but not implemented:

```
atom? : % -> Boolean
car : % -> %
cdr : % -> %
convert : Expr -> %
convert : Flt -> %
convert : Int -> %
convert : Sym -> %
convert : Str -> %
convert : List % -> %
destruct : % -> List %
eq : (%,% ) -> Boolean
expr : % -> Expr
float : % -> Flt
float? : % -> Boolean
integer : % -> Int
integer? : % -> Boolean
list? : % -> Boolean
null? : % -> Boolean
pair? : % -> Boolean
string : % -> Str
string? : % -> Boolean
symbol : % -> Sym
symbol? : % -> Boolean
#? : % -> Integer
?..? : (% ,List Integer) -> %
?..? : (% ,Integer) -> %
```

These exports come from (p[162](#)) SetCategory():

```
coerce : % -> OutputForm
```

```

hash : % -> SingleInteger
latex : % -> String
?? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean

```

— category SEXCAT SExpressionCategory —

```

)abbrev category SEXCAT SExpressionCategory
++ Author: S.M.Watt
++ Date Created: July 1987
++ Date Last Modified: 23 May 1991
++ Description:
++ This category allows the manipulation of Lisp values while keeping
++ the grunge fairly localized.
-- The coerce to expression lets the
-- values be displayed in the usual parenthesized way (displaying
-- them as type Expression can cause the formatter to die, since
-- certain magic cookies are in unexpected places).
-- SMW July 87

SExpressionCategory(Str, Sym, Int, Flt, Expr): Category == Decl where
  Str, Sym, Int, Flt, Expr: SetCategory

Decl ==> SetCategory with
  eq:      (%,% ) -> Boolean
    ++ eq(s, t) is true if EQ(s,t) is true in Lisp.
  null?:   % -> Boolean
    ++ null?(s) is true if s is the S-expression ().
  atom?:   % -> Boolean
    ++ atom?(s) is true if s is a Lisp atom.
  pair?:   % -> Boolean
    ++ pair?(s) is true if s has is a non-null Lisp list.
  list?:   % -> Boolean
    ++ list?(s) is true if s is a Lisp list, possibly ().
  string?: % -> Boolean
    ++ string?(s) is true if s is an atom and belong to Str.
  symbol?: % -> Boolean
    ++ symbol?(s) is true if s is an atom and belong to Sym.
  integer?: % -> Boolean
    ++ integer?(s) is true if s is an atom and belong to Int.
  float?:  % -> Boolean
    ++ float?(s) is true if s is an atom and belong to Flt.
  destruct: % -> List %
    ++ destruct((a1,...,an)) returns the list [a1,...,an].
  string:  % -> Str
    ++ string(s) returns s as an element of Str.
    ++ Error: if s is not an atom that also belongs to Str.
  symbol:  % -> Sym
    ++ symbol(s) returns s as an element of Sym.

```

```

++ Error: if s is not an atom that also belongs to Sym.
integer:  % -> Int
++ integer(s) returns s as an element of Int.
++ Error: if s is not an atom that also belongs to Int.
float:    % -> Flt
++ float(s) returns s as an element of Flt;
++ Error: if s is not an atom that also belongs to Flt.
expr:     % -> Expr
++ expr(s) returns s as an element of Expr;
++ Error: if s is not an atom that also belongs to Expr.
convert:  List % -> %
++ convert([a1,...,an]) returns an S-expression \spad{(a1,...,an)}.
convert:  Str  -> %
++ convert(x) returns the Lisp atom x;
convert:  Sym  -> %
++ convert(x) returns the Lisp atom x.
convert:  Int  -> %
++ convert(x) returns the Lisp atom x.
convert:  Flt  -> %
++ convert(x) returns the Lisp atom x.
convert:  Expr -> %
++ convert(x) returns the Lisp atom x.
car:      % -> %
++ car((a1,...,an)) returns a1.
cdr:      % -> %
++ cdr((a1,...,an)) returns \spad{(a2,...,an)}.
"#":      % -> Integer
++ #((a1,...,an)) returns n.
elt:      (% , Integer) -> %
++ elt((a1,...,an), i) returns \spad{ai}.
elt:      (% , List Integer) -> %
++ elt((a1,...,an), [i1,...,im]) returns \spad{(a_i1,...,a_im)}.

```

— SEXCAT.dotabb —

```

"SEXCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=SEXCAT"];
"SEXCAT" -> "SETCAT"

```

— SEXCAT.dotfull —

```

"SExpressionCategory(a:SetCategory,b:SetCategory,c:SetCategory,d:SetCategory,e:SetCategory)"

```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=SEXCAT"];
"SExpressionCategory(a:SetCategory,b:SetCategory,c:SetCategory,d:SetCategory,e:SetCategory)" ->
  "SetCategory()"
```

—————→

— SEXCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "SExpressionCategory(a:SetCategory,b:SetCategory,c:SetCategory,d:SetCategory,e:SetCategory)"
    [color=lightblue];
  "SExpressionCategory(a:SetCategory,b:SetCategory,c:SetCategory,d:SetCategory,e:SetCategory)" ->
    "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

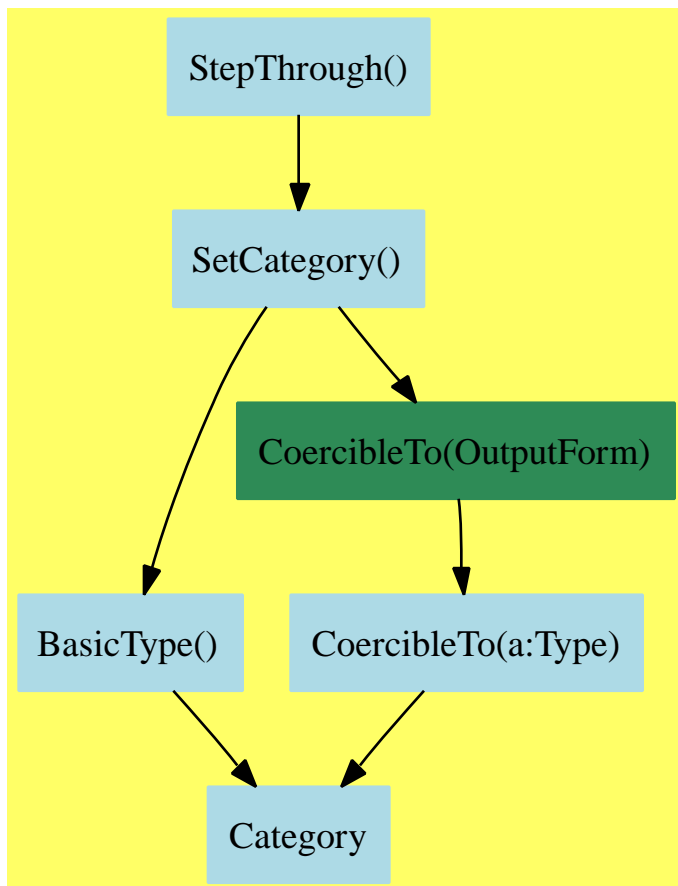
  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

—————→

StepThrough (STEP)



— StepThrough.input —

```

)set break resume
)sys rm -f StepThrough.output
)spool StepThrough.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show StepThrough
--R StepThrough is a category constructor
--R Abbreviation for StepThrough is STEP
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for STEP

```



```

--R
--R----- Operations -----
--R ?=? : (%,% ) -> Boolean          coerce : % -> OutputForm
--R hash : % -> SingleInteger        init : () -> %
--R latex : % -> String              ?~=? : (%,% ) -> Boolean
--R nextItem : % -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— StepThrough.help —

=====

StepThrough examples

=====

A class of objects which can be 'stepped through'.

Repeated applications of nextItem is guaranteed never to return duplicate items and only return "failed" after exhausting all elements of the domain. This assumes that the sequence starts with init(). For infinite domains, repeated application of nextItem is not required to reach all possible domain elements starting from any initial element.

Conditional attributes:

infinite -- repeated nextItem's are never "failed".

See Also:

o)show StepThrough

See:

⇒ "FiniteFieldCategory" (FFIELDC) [18](#) on page [1570](#)
 ⇒ "IntegerNumberSystem" (INS) [16](#) on page [1278](#)
 ⇒ "QuotientFieldCategory" (QFCAT) [17](#) on page [1427](#)
 ⇒ "UnivariatePolynomialCategory" (UPOLYC) [17](#) on page [1522](#)
 ⇐ "SetCategory" (SETCAT) [3](#) on page [162](#)

Exports:

```
coerce hash      init latex  ??
?~=?  nextItem
```

These are directly exported but not implemented:

```
init : () -> %
nextItem : % -> Union(%, "failed")
```

These exports come from (p162) SetCategory():

```
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
```

— category STEP StepThrough —

```
)abbrev category STEP StepThrough
++ Description:
++ A class of objects which can be 'stepped through'.
++ Repeated applications of \spadfun{nextItem} is guaranteed never to
++ return duplicate items and only return "failed" after exhausting
++ all elements of the domain.
++ This assumes that the sequence starts with \spad{init()}.
++ For infinite domains, repeated application
++ of \spadfun{nextItem} is not required to reach all possible domain elements
++ starting from any initial element.
++
++ Conditional attributes\br
++ \tab{5}infinite\tab{5}repeated nextItem's are never "failed".
```

```
StepThrough(): Category == SetCategory with
  init: constant -> %
    ++ init() chooses an initial object for stepping.
  nextItem: % -> Union(%, "failed")
    ++ nextItem(x) returns the next item, or "failed"
    ++ if domain is exhausted.
```

— STEP.dotabb —

```
"STEP" [color=lightblue,href="bookvol10.2.pdf#nameddest=STEP"];
"STEP" -> "SETCAT"
```

— STEP.dotfull —

```
"StepThrough()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=STEP"];
"StepThrough()" -> "SetCategory()"
```

— STEP.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "StepThrough()" [color=lightblue];
  "StepThrough()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

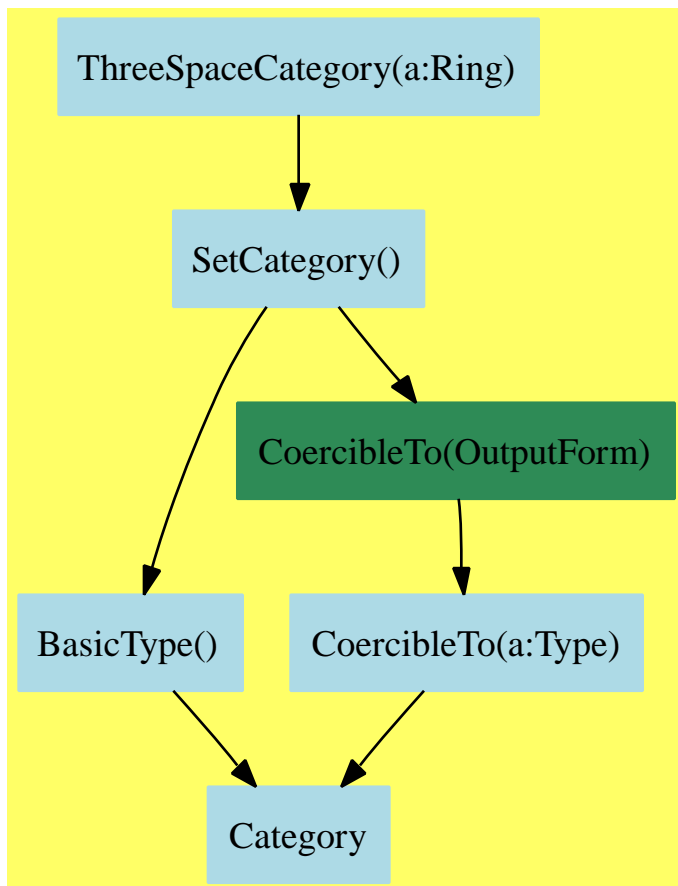
  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

ThreeSpaceCategory (SPACEC)



— ThreeSpaceCategory.input —

```

)set break resume
)sys rm -f ThreeSpaceCategory.output
)spool ThreeSpaceCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ThreeSpaceCategory
--R
--R ThreeSpaceCategory(R: Ring) is a category constructor
--R Abbreviation for ThreeSpaceCategory is SPACEC
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SPACEC
--R
--R----- Operations -----
--R ?=? : (% ,%) -> Boolean                check : % -> %
--R closedCurve : % -> List(Point(R))      closedCurve : List(Point(R)) -> %
--R closedCurve? : % -> Boolean             coerce : % -> OutputForm
--R components : % -> List(%)              composite : List(%) -> %
--R composites : % -> List(%)              copy : % -> %
--R create3Space : SubSpace(3,R) -> %       create3Space : () -> %
--R curve : % -> List(Point(R))            curve : List(Point(R)) -> %
--R curve : (% ,List(List(R))) -> %        curve : (% ,List(Point(R))) -> %
--R curve? : % -> Boolean                  hash : % -> SingleInteger
--R latex : % -> String                    lp : % -> List(Point(R))
--R merge : (% ,%) -> %                    merge : List(%) -> %
--R mesh : % -> List(List(Point(R)))        mesh : List(List(Point(R))) -> %
--R mesh? : % -> Boolean                    point : % -> Point(R)
--R point : Point(R) -> %                  point : (% ,List(R)) -> %
--R point : (% ,Point(R)) -> %              point? : % -> Boolean
--R polygon : % -> List(Point(R))           polygon : List(Point(R)) -> %
--R polygon : (% ,List(List(R))) -> %       polygon? : % -> Boolean
--R subspace : % -> SubSpace(3,R)           ?~=? : (% ,%) -> Boolean
--R closedCurve : (% ,List(List(R))) -> %
--R closedCurve : (% ,List(Point(R))) -> %
--R enterPointData : (% ,List(Point(R))) -> NonNegativeInteger
--R lllip : % -> List(List(List(NonNegativeInteger)))
--R lllp : % -> List(List(List(Point(R))))
--R llprop : % -> List(List(SubSpaceComponentProperty))
--R lprop : % -> List(SubSpaceComponentProperty)
--R mesh : (List(List(Point(R))),Boolean,Boolean) -> %
--R mesh : (% ,List(List(List(R))),Boolean,Boolean) -> %
--R mesh : (% ,List(List(Point(R))),Boolean,Boolean) -> %
--R mesh : (% ,List(List(List(R))),List(SubSpaceComponentProperty),SubSpaceComponentProperty) -> %
--R mesh : (% ,List(List(Point(R))),List(SubSpaceComponentProperty),SubSpaceComponentProperty) -> %
--R modifyPointData : (% ,NonNegativeInteger,Point(R)) -> %
--R numberOfComponents : % -> NonNegativeInteger
--R numberOfComposites : % -> NonNegativeInteger
--R objects : % -> Record(points: NonNegativeInteger,curves: NonNegativeInteger,polygons: NonNegativeInteger)
--R point : (% ,NonNegativeInteger) -> %
--R polygon : (% ,List(Point(R))) -> %
--R
--E 1

)spool
)lisp (bye)

```

=====

ThreeSpaceCategory examples

=====

The category ThreeSpaceCategory is used for creating three dimensional objects using functions for defining points, curves, polygons, constructs and the subspaces containing them.

See Also:

o)show ThreeSpaceCategory

See:

← “SetCategory” (SETCAT) [3](#) on page 162

Exports:

| | | | |
|--------------------|-------------|-----------------|--------------------|
| check | closedCurve | closedCurve? | coerce |
| components | composite | composites | copy |
| create3Space | curve | curve? | enterPointData |
| hash | latex | lllip | lllp |
| llprop | lp | lprop | merge |
| mesh | mesh? | modifyPointData | numberOfComponents |
| numberOfComposites | objects | point | point? |
| polygon | polygon? | subspace | ?=? |
| ?~=? | | | |

These are directly exported but not implemented:

```

check : % -> %
closedCurve : (%,List List R) -> %
closedCurve : (%,List Point R) -> %
closedCurve : List Point R -> %
closedCurve : % -> List Point R
closedCurve? : % -> Boolean
coerce : % -> OutputForm
components : % -> List %
composite : List % -> %
composites : % -> List %
copy : % -> %
create3Space : () -> %
create3Space : SubSpace(3,R) -> %
curve : (%,List List R) -> %
curve : (%,List Point R) -> %
curve : List Point R -> %
curve : % -> List Point R
curve? : % -> Boolean

```

```

enterPointData : (%,List Point R) -> NonNegativeInteger
l111p : % -> List List List NonNegativeInteger
l11lp : % -> List List List Point R
l1prop : % -> List List SubSpaceComponentProperty
lp : % -> List Point R
lprop : % -> List SubSpaceComponentProperty
merge : List % -> %
merge : (%,%) -> %
mesh : % -> List List Point R
mesh : List List Point R -> %
mesh : (List List Point R,Boolean,Boolean) -> %
mesh : (%,List List List R,Boolean,Boolean) -> %
mesh : (%,List List Point R,Boolean,Boolean) -> %
mesh : (%,List List List R,
        List SubSpaceComponentProperty,
        SubSpaceComponentProperty) -> %
mesh : (%,List List Point R,
        List SubSpaceComponentProperty,
        SubSpaceComponentProperty) -> %
mesh? : % -> Boolean
modifyPointData : (%,NonNegativeInteger,Point R) -> %
numberOfComponents : % -> NonNegativeInteger
numberOfComposites : % -> NonNegativeInteger
objects : % ->
    Record(points: NonNegativeInteger,
            curves: NonNegativeInteger,
            polygons: NonNegativeInteger,
            constructs: NonNegativeInteger)
point : (%,Point R) -> %
point : (%,List R) -> %
point : (%,NonNegativeInteger) -> %
point : Point R -> %
point : % -> Point R
point? : % -> Boolean
polygon : (%,List Point R) -> %
polygon : (%,List List R) -> %
polygon : List Point R -> %
polygon : % -> List Point R
polygon? : % -> Boolean
subspace : % -> SubSpace(3,R)

```

These exports come from (p162) SetCategory():

```

hash : % -> SingleInteger
latex : % -> String
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean

```

```

)abbrev category SPACEC ThreeSpaceCategory
++ Description:
++ The category ThreeSpaceCategory is used for creating
++ three dimensional objects using functions for defining points, curves,
++ polygons, constructs and the subspaces containing them.

ThreeSpaceCategory(R:Ring): Exports == Implementation where
I    ==> Integer
PI   ==> PositiveInteger
NNI  ==> NonNegativeInteger
L    ==> List
B    ==> Boolean
O    ==> OutputForm
SUBSPACE ==> SubSpace(3,R)
POINT  ==> Point(R)
PROP   ==> SubSpaceComponentProperty()
REP3D ==> Record(lp:L POINT, llliPt:L L L NNI, llProp:L L PROP, lProp:L PROP)
OBJ3D  ==> Record(points:NNI, curves:NNI, polygons:NNI, constructs:NNI)

Exports ==> Category
Implementation ==>
SetCategory with

create3Space : () -> %
++ create3Space() creates a \spadtype{ThreeSpace} object capable of
++ holding point, curve, mesh components and any combination.

create3Space : SUBSPACE -> %
++ create3Space(s) creates a \spadtype{ThreeSpace} object containing
++ objects pre-defined within some \spadtype{SubSpace} s.

numberOfComponents : % -> NNI
++ numberOfComponents(s) returns the number of distinct
++ object components in the indicated \spadtype{ThreeSpace}, s, such
++ as points, curves, polygons, and constructs.

numberOfComposites : % -> NNI
++ numberOfComposites(s) returns the number of supercomponents,
++ or composites, in the \spadtype{ThreeSpace}, s; Composites are
++ arbitrary groupings of otherwise distinct and unrelated components;
++ A \spadtype{ThreeSpace} need not have any composites defined at all
++ and, outside of the requirement that no component can belong
++ to more than one composite at a time, the definition and
++ interpretation of composites are unrestricted.

merge : L % -> %
++ merge([s1,s2,...,sn]) will create a new \spadtype{ThreeSpace} that
++ has the components of all the ones in the list; Groupings of
++ components into composites are maintained.

```



```

merge : (%,% ) -> %
++ merge(s1,s2) will create a new \spadtype{ThreeSpace} that has the
++ components of \spad{s1} and \spad{s2}; Groupings of components
++ into composites are maintained.

composite : L % -> %
++ composite([s1,s2,...,sn]) will create a new \spadtype{ThreeSpace}
++ that is a union of all the components from each
++ \spadtype{ThreeSpace} in the parameter list, grouped as a composite.

components : % -> L %
++ components(s) takes the \spadtype{ThreeSpace} s, and creates a list
++ containing a unique \spadtype{ThreeSpace} for each single component
++ of s. If s has no components defined, the list returned is empty.

composites : % -> L %
++ composites(s) takes the \spadtype{ThreeSpace} s, and creates a list
++ containing a unique \spadtype{ThreeSpace} for each single composite
++ of s. If s has no composites defined (composites need to be
++ explicitly created), the list returned is empty. Note that not all
++ the components need to be part of a composite.

copy : % -> %
++ copy(s) returns a new \spadtype{ThreeSpace} that is an exact copy
++ of s.

enterPointData : (% ,L POINT) -> NNI
++ enterPointData(s,[p0,p1,...,pn]) adds a list of points from p0
++ through pn to the \spadtype{ThreeSpace}, s, and returns the index,
++ to the starting point of the list;

modifyPointData : (% ,NNI,POINT) -> %
++ modifyPointData(s,i,p) changes the point at the indexed
++ location i in the \spadtype{ThreeSpace}, s, to that of point p.
++ This is useful for making changes to a point which has been
++ transformed.

-- 3D primitives

point : (% ,POINT) -> %
++ point(s,p) adds a point component defined by the point, p,
++ specified as a list from \spad{List(R)}, to the
++ \spadtype{ThreeSpace}, s, where R is the \spadtype{Ring} over
++ which the point is defined.

point : (% ,L R) -> %
++ point(s,[x,y,z]) adds a point component defined by a list of
++ elements which are from the \spad{PointDomain(R)} to the
++ \spadtype{ThreeSpace}, s, where R is the \spadtype{Ring} over
++ which the point elements are defined.

```

```

point      : (% , NNI) -> %
++ point(s,i) adds a point component which is placed into a component
++ list of the \spadtype{ThreeSpace}, s, at the index given by i.

point      : POINT -> %
++ point(p) returns a \spadtype{ThreeSpace} object which is composed
++ of one component, the point p.

point      : % -> POINT
++ point(s) checks to see if the \spadtype{ThreeSpace}, s, is
++ composed of only a single point and if so, returns the point.
++ An error is signaled otherwise.

point?     : % -> B
++ point?(s) queries whether the \spadtype{ThreeSpace}, s, is
++ composed of a single component which is a point and returns the
++ boolean result.

curve      : (% , L POINT) -> %
++ curve(s,[p0,p1,...,pn]) adds a space curve component defined by a
++ list of points \spad{p0} through \spad{pn}, to the
++ \spadtype{ThreeSpace} s.

curve      : (% , L L R) -> %
++ curve(s,[[p0],[p1],...,[pn]]) adds a space curve which is a list of
++ points p0 through pn defined by lists of elements from the domain
++ \spad{PointDomain(m,R)}, where R is the \spadtype{Ring} over which
++ the point elements are defined and m is the dimension of the
++ points, to the \spadtype{ThreeSpace} s.

curve      : L POINT -> %
++ curve([p0,p1,p2,...,pn]) creates a space curve defined
++ by the list of points \spad{p0} through \spad{pn}, and returns the
++ \spadtype{ThreeSpace} whose component is the curve.

curve      : % -> L POINT
++ curve(s) checks to see if the \spadtype{ThreeSpace}, s, is
++ composed of a single curve defined by a list of points and if so,
++ returns the curve, that is, list of points. An error is signaled
++ otherwise.

curve?     : % -> B
++ curve?(s) queries whether the \spadtype{ThreeSpace}, s, is a curve,
++ that is, has one component, a list of list of points, and returns
++ true if it is, or false otherwise.

closedCurve : (% , L POINT) -> %
++ closedCurve(s,[p0,p1,...,pn,p0]) adds a closed curve component
++ which is a list of points defined by the first element p0 through

```

```

++ the last element pn and back to the first element p0 again, to the
++ \spadtype{ThreeSpace} s.

closedCurve : (% , L L R) -> %
++ closedCurve(s, [[lr0], [lr1], ..., [lrn], [lr0]]) adds a closed curve
++ component defined by a list of points \spad{lr0} through
++ \spad{lrn}, which are lists of elements from the domain
++ \spad{PointDomain(m,R)}, where R is the \spadtype{Ring} over which
++ the point elements are defined and m is the dimension of the
++ points, in which the last element of the list of points contains
++ a copy of the first element list, lr0.
++ The closed curve is added to the \spadtype{ThreeSpace}, s.

closedCurve : L POINT -> %
++ closedCurve(lp) sets a list of points defined by the first element
++ of lp through the last element of lp and back to the first element
++ again and returns a \spadtype{ThreeSpace} whose component is the
++ closed curve defined by lp.

closedCurve : % -> L POINT
++ closedCurve(s) checks to see if the \spadtype{ThreeSpace}, s, is
++ composed of a single closed curve component defined by a list of
++ points in which the first point is also the last point, all of
++ which are from the domain \spad{PointDomain(m,R)} and if so,
++ returns the list of points. An error is signaled otherwise.

closedCurve? : % -> B
++ closedCurve?(s) returns true if the \spadtype{ThreeSpace} s
++ contains a single closed curve component, that is, the first element
++ of the curve is also the last element, or false otherwise.

polygon : (% , L POINT) -> %
++ polygon(s, [p0, p1, ..., pn]) adds a polygon component defined by a
++ list of points, p0 through pn, to the \spadtype{ThreeSpace} s.

polygon : (% , L L R) -> %
++ polygon(s, [[r0], [r1], ..., [rn]]) adds a polygon component defined
++ by a list of points \spad{r0} through \spad{rn}, which are lists of
++ elements from the domain \spad{PointDomain(m,R)} to the
++ \spadtype{ThreeSpace} s, where m is the dimension of the points
++ and R is the \spadtype{Ring} over which the points are defined.

polygon : L POINT -> %
++ polygon([p0, p1, ..., pn]) creates a polygon defined by a list of
++ points, p0 through pn, and returns a \spadtype{ThreeSpace} whose
++ component is the polygon.

polygon : % -> L POINT
++ polygon(s) checks to see if the \spadtype{ThreeSpace}, s, is
++ composed of a single polygon component defined by a list of

```

```

++ points, and if so, returns the list of points; An error is
++ signaled otherwise.

polygon?      : % -> B
++ polygon?(s) returns true if the \spadtype{ThreeSpace} s contains
++ a single polygon component, or false otherwise.

mesh          : (% ,L L POINT,L PROP,PROP) -> %
++ mesh(s,[[p0],[p1],...,[pn]],[props],prop) adds a surface component,
++ defined over a list curves which contains lists of points, to the
++ \spadtype{ThreeSpace} s; props is a list which contains the
++ subspace component properties for each surface parameter, and
++ prop is the subspace component property by which the points are
++ defined.

mesh          : (% ,L L L R,L PROP,PROP) -> %
++ mesh(s, LLLR, [props], prop)
++ where LLLR is of the form:
++ [[r10]...,[r1m]],[[r20]...,[r2m]],...,[rn0]...,[rnm]],
++ adds a surface component to the \spadtype{ThreeSpace} s, which is
++ defined over a rectangular domain of size WxH where W is the number
++ of lists of points from the domain \spad{PointDomain(R)} and H is
++ the number of elements in each of those lists; lprops is the list
++ of the subspace component properties for each curve list, and
++ prop is the subspace component property by which the points are
++ defined.

mesh          : (% ,L L POINT,B,B) -> %
++ mesh(s, LLP, close1, close2)
++ where LLP is of the form [[p0],[p1],...,[pn]] adds a surface
++ component to the \spadtype{ThreeSpace}, which is defined over a
++ list of curves, in which each of these curves is a list of points.
++ The boolean arguments close1 and close2 indicate how the surface
++ is to be closed. Argument close1 equal true
++ means that each individual list (a curve) is to be closed, that is,
++ the last point of the list is to be connected to the first point.
++ Argument close2 equal true
++ means that the boundary at one end of the surface is to be
++ connected to the boundary at the other end, that is, the boundaries
++ are defined as the first list of points (curve) and
++ the last list of points (curve).

mesh          : (% ,L L L R,B,B) -> %
++ mesh(s, LLLR, close1, close2)
++ where LLLR is of the form
++ [[r10]...,[r1m]],[[r20]...,[r2m]],...,[rn0]...,[rnm]],
++ adds a surface component to the \spadtype{ThreeSpace} s, which is
++ defined over a rectangular domain of size WxH where W is the number
++ of lists of points from the domain \spad{PointDomain(R)} and H is
++ the number of elements in each of those lists; the booleans close1

```

```

++ and close2 indicate how the surface is to be closed: if close1 is
++ true this means that each individual list (a curve) is to be
++ closed (that is,
++ the last point of the list is to be connected to the first point);
++ if close2 is true, this means that the boundary at one end of the
++ surface is to be connected to the boundary at the other end
++ (the boundaries are defined as the first list of points (curve)
++ and the last list of points (curve)).

mesh          : L L POINT -> %
++ mesh([[p0],[p1],...,[pn]]) creates a surface defined by a list of
++ curves which are lists, p0 through pn, of points, and returns a
++ \spadtype{ThreeSpace} whose component is the surface.

mesh          : (L L POINT,B,B) -> %
++ mesh([[p0],[p1],...,[pn]], close1, close2) creates a surface
++ defined over a list of curves, p0 through pn, which are lists of
++ points; the booleans close1 and close2 indicate how the surface is
++ to be closed: close1 set to true means that each individual list
++ (a curve) is to be closed (that is, the last point of the list is
++ to be connected to the first point); close2 set to true means
++ that the boundary at one end of the surface is to be connected to
++ the boundary at the other end (the boundaries are defined as the
++ first list of points (curve) and the last list of points (curve));
++ the \spadtype{ThreeSpace} containing this surface is returned.

mesh          : % -> L L POINT
++ mesh(s) checks to see if the \spadtype{ThreeSpace}, s, is
++ composed of a single surface component defined by a list curves
++ which contain lists of points, and if so, returns the list of
++ lists of points; An error is signaled otherwise.

mesh?         : % -> B
++ mesh?(s) returns true if the \spadtype{ThreeSpace} s is composed
++ of one component, a mesh comprising a list of curves which are lists
++ of points, or returns false if otherwise

lp            : % -> L POINT
++ lp(s) returns the list of points component which the
++ \spadtype{ThreeSpace}, s, contains; these points are used by
++ reference, that is, the component holds indices referring to the
++ points rather than the points themselves. This allows for sharing
++ of the points.

l11lip        : % -> L L L NNI
++ l11lip(s) checks to see if the \spadtype{ThreeSpace}, s, is
++ composed of a list of components, which are lists of curves,
++ which are lists of indices to points, and if so, returns the list
++ of lists of lists; An error is signaled otherwise.

```

```

lllp      : % -> L L L POINT    -- used by view3D
++ lllp(s) checks to see if the \spadtype{ThreeSpace}, s, is
++ composed of a list of components, which are lists of curves,
++ which are lists of points, and if so, returns the list of
++ lists of lists; An error is signaled otherwise.

llprop    : % -> L L PROP       -- used by view3D
++ llprop(s) checks to see if the \spadtype{ThreeSpace}, s, is
++ composed of a list of curves which are lists of the
++ subspace component properties of the curves, and if so, returns the
++ list of lists; An error is signaled otherwise.

lprop     : % -> L PROP         -- used by view3D
++ lprop(s) checks to see if the \spadtype{ThreeSpace}, s, is
++ composed of a list of subspace component properties, and if so,
++ returns the list; An error is signaled otherwise.

objects   : % -> OBJ3D
++ objects(s) returns the \spadtype{ThreeSpace}, s, in the form of a
++ 3D object record containing information on the number of points,
++ curves, polygons and constructs comprising the
++ \spadtype{ThreeSpace}..

check     : % -> %              -- used by mesh
++ check(s) returns lllpt, list of lists of lists of point information
++ about the \spadtype{ThreeSpace} s.

subspace  : % -> SUBSPACE
++ subspace(s) returns the \spadtype{SubSpace} which holds all the
++ point information in the \spadtype{ThreeSpace}, s.

coerce    : % -> 0
++ coerce(s) returns the \spadtype{ThreeSpace} s to Output format.

-----

-- SPACEC.dotabb --

"SPACEC"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=SPACEC" ];
"SPACEC" -> "SETCAT"

-----

-- SPACEC.dotfull --

"ThreeSpaceCategory(a:Ring)"

```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=SPACEC"];
"ThreeSpaceCategory(a:Ring)" -> "SetCategory()"
```

— SPACEC.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ThreeSpaceCategory(a:Ring)" [color=lightblue];
  "ThreeSpaceCategory(a:Ring)" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

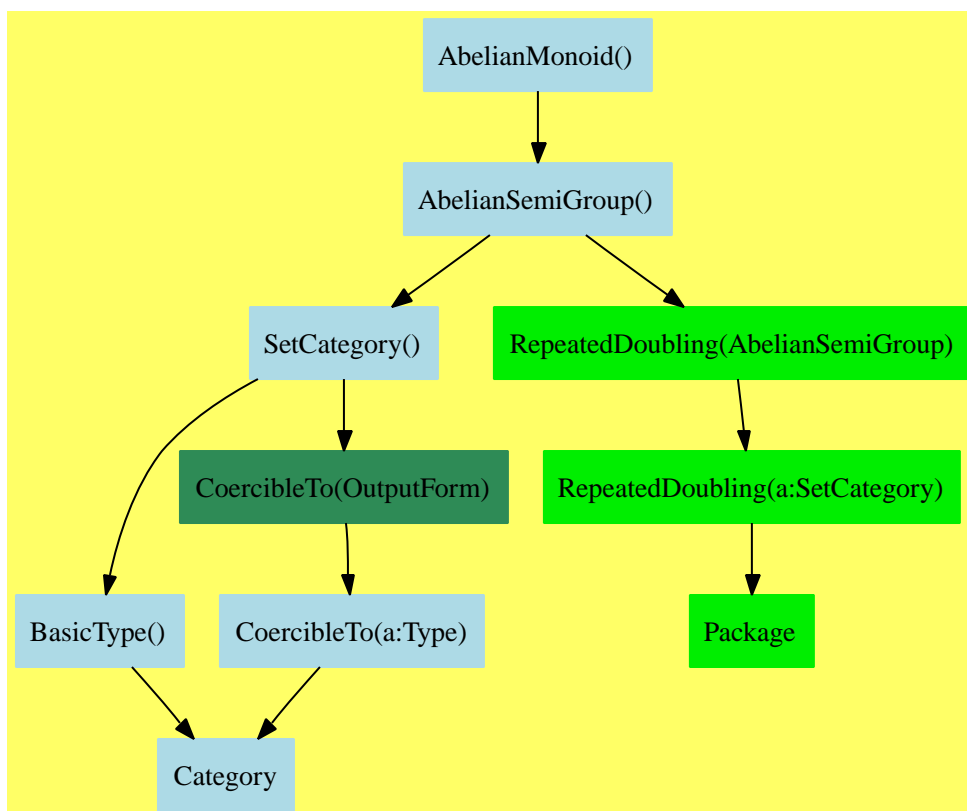
  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

Chapter 5

Category Layer 4

AbelianMonoid (ABELMON)



— AbelianMonoid.input —

```

)set break resume
)sys rm -f AbelianMonoid.output
)spool AbelianMonoid.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show AbelianMonoid
--R AbelianMonoid is a category constructor
--R Abbreviation for AbelianMonoid is ABELMON
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ABELMON
--R
--R----- Operations -----
--R ?? : (PositiveInteger,%) -> %      ?? : (%,%) -> %
--R ?? : (%,%) -> Boolean              0 : () -> %
--R coerce : % -> OutputForm          hash : % -> SingleInteger
--R latex : % -> String               sample : () -> %
--R zero? : % -> Boolean              ~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R
--E 1

)spool
)lisp (bye)

```

— AbelianMonoid.help —

```

=====
AbelianMonoid examples
=====

```

The class of multiplicative monoids, i.e. semigroups with an additive identity element.

Axioms:

```

leftIdentity("+":(%,%)->%,0)      0+x=x
rightIdentity("+":(%,%)->%,0)     x+0=x

```

See Also:

```

o )show AbelianMonoid

```

See:

⇒ “CancellationAbelianMonoid” (CABMON) [6](#) on page [434](#)
 ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
 ⇒ “OrderedAbelianMonoid” (OAMON) [7](#) on page [629](#)
 ⇒ “OrderedAbelianSemiGroup” (OASGP) [6](#) on page [511](#)
 ⇐ “AbelianSemiGroup” (ABELSG) [4](#) on page [173](#)

Exports:

```
0      coerce  hash  latex  sample
zero?  ??      ?+?   ?=?   ?~=?
```

These are directly exported but not implemented:

```
0 : () -> %
```

These are implemented by this category:

```
sample : () -> %
zero?   : % -> Boolean
??      : (PositiveInteger,%) -> %
??      : (NonNegativeInteger,%) -> %
```

These exports come from ([p173](#)) AbelianSemiGroup():

```
coerce : % -> OutputForm
hash    : % -> SingleInteger
latex   : % -> String
?=?     : (%,%) -> Boolean
?~=?    : (%,%) -> Boolean
?+?     : (%,%) -> %
```

— category ABELMON AbelianMonoid —

```
)abbrev category ABELMON AbelianMonoid
++ Description:
++ The class of multiplicative monoids, i.e. semigroups with an
++ additive identity element.
++
++ Axioms\br
++ \tab{5}\spad{leftIdentity("+":(%,%)>%,0)}\tab{5}\spad{ 0+x=x }\br
++ \tab{5}\spad{rightIdentity("+":(%,%)>%,0)}\tab{4}\spad{ x+0=x }
-- following domain must be compiled with subsumption disabled
-- define SourceLevelSubset to be EQUAL

AbelianMonoid(): Category == AbelianSemiGroup with
  0: constant -> %
```

```

    ++ 0 is the additive identity element.
sample: constant -> %
    ++ sample yields a value of type %
zero?: % -> Boolean
    ++ zero?(x) tests if x is equal to 0.
"*": (NonNegativeInteger,%) -> %
    ++ n * x is left-multiplication by a non negative integer
add
    import RepeatedDoubling(%)
    zero? x == x = 0
    n:PositiveInteger * x:% == (n::NonNegativeInteger) * x
    sample() == 0
    if not (% has Ring) then
        n:NonNegativeInteger * x:% ==
            zero? n => 0
            double(n pretend PositiveInteger,x)

```

— ABELMON.dotabb —

```

"ABELMON"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=ABELMON"];
"ABELMON" -> "ABELSG"

```

— ABELMON.dotfull —

```

"AbelianMonoid()"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=ABELMON"];
"AbelianMonoid()" -> "AbelianSemiGroup()"

```

— ABELMON.dotpic —

```

digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "AbelianMonoid()" [color=lightblue];
    "AbelianMonoid()" -> "AbelianSemiGroup()"

```

```

"AbelianSemiGroup()" [color=lightblue];
"AbelianSemiGroup()" -> "SetCategory()"
"AbelianSemiGroup()" -> "RepeatedDoubling(AbelianSemiGroup)"

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" ->
  "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"RepeatedDoubling(AbelianSemiGroup)" [color="#00EE00"];
"RepeatedDoubling(AbelianSemiGroup)" -> "RepeatedDoubling(a:SetCategory)"

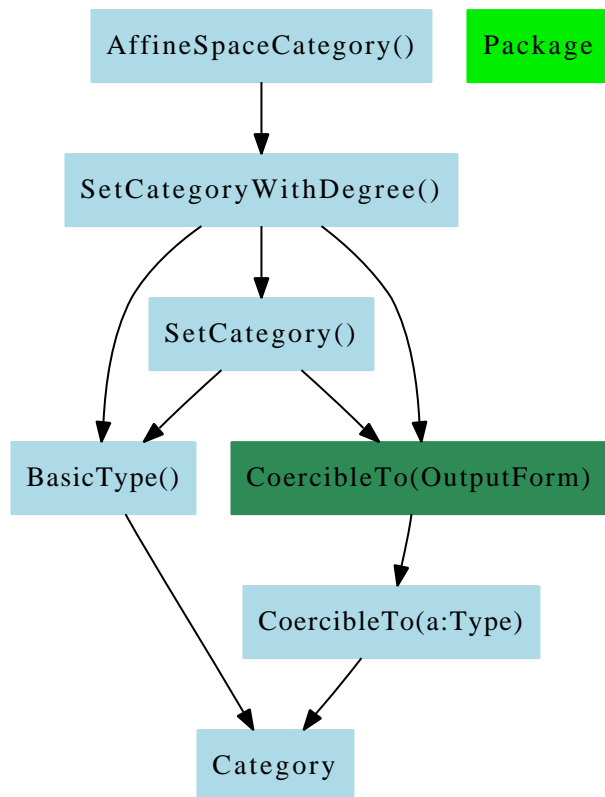
"RepeatedDoubling(a:SetCategory)" [color="#00EE00"];
"RepeatedDoubling(a:SetCategory)" -> "Package"

"Package" [color="#00EE00"];

"Category" [color=lightblue];
}

```

AffineSpaceCategory (AFSPCAT)



— AffineSpaceCategory.input —

```

)set break resume
)sys rm -f AffineSpaceCategory.output
)spool AffineSpaceCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show AffineSpaceCategory
--R
--R AffineSpaceCategory(K: Field) is a category constructor
--R Abbreviation for AffineSpaceCategory is AFSPCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for AFSPCAT
--R

```

```

--R----- Operations -----
--R ?=? : (%,% ) -> Boolean          affinePoint : List(K) -> %
--R coerce : List(K) -> %           coerce : % -> List(K)
--R coerce : % -> OutputForm        conjugate : % -> %
--R definingField : % -> K          degree : % -> PositiveInteger
--R ?.? : (%,Integer) -> K          hash : % -> SingleInteger
--R latex : % -> String             list : % -> List(K)
--R orbit : % -> List(%)            origin : () -> %
--R pointValue : % -> List(K)        rational? : % -> Boolean
--R setelt : (%,Integer,K) -> K      ?~=? : (%,% ) -> Boolean
--R conjugate : (%NonNegativeInteger) -> %
--R orbit : (%NonNegativeInteger) -> List(%)
--R rational? : (%NonNegativeInteger) -> Boolean
--R removeConjugate : List(%) -> List(%)
--R removeConjugate : (List(%),NonNegativeInteger) -> List(%)
--R
--E 1

)spool
)lisp (bye)

```

— AffineSpaceCategory.help —

AffineSpaceCategory examples

The following is all the categories and domains related to projective space and part of the PAFF package

See Also:

o)show AffineSpaceCategory

See:

⇐ “SetCategoryWithDegree” (SETCATD) 4 on page 296

Exports:

| | | | | |
|-----------------|---------------|--------|-------------|-----------|
| ?.? | ?=? | ?~=? | affinePoint | coerce |
| conjugate | definingField | degree | hash | latex |
| list | orbit | origin | pointValue | rational? |
| removeConjugate | setelt | | | |

These are directly exported but not implemented

```

?..? : (%,Integer) -> K
affinePoint : List K -> %
coerce : % -> List K
coerce : List K -> %
conjugate : % -> %
conjugate : (%,NNI) -> %
definingField : % -> K
list : % -> List K
orbit : % -> List %
orbit : (%,NNI) -> List %
origin : () -> %
pointValue : % -> List K
rational? : % -> Boolean
rational? : (%,NNI) -> Boolean
removeConjugate : (List %,NNI) -> List %
removeConjugate : List % -> List %
setelt : (%,Integer,K) -> K

```

These exports come from (p296) SetCategoryWithDegree

```

?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
coerce : % -> OutputForm
degree : % -> PositiveInteger
hash : % -> SingleInteger
latex : % -> String

```

— category AFSPCAT AffineSpaceCategory —

```

)abbrev category AFSPCAT AffineSpaceCategory
++ Author: Gaetan Hache
++ Date Created: 17 nov 1992
++ Date Last Updated: May 2010 by Tim Daly
++ Description:
++ The following is all the categories and domains related to projective
++ space and part of the PAFF package
AffineSpaceCategory(K:Field):Category == Implementation where

LIST ==> List
INT ==> Integer
NNI ==> NonNegativeInteger

Implementation ==>
SetCategoryWithDegree with

origin: () -> %

affinePoint: LIST(K) -> %
++ affinePoint creates a affine point from a list

```

```

definingField: % -> K

coerce: % -> List(K)

coerce: LIST(K) -> %
  ++ coerce a list of K to a affine point.

orbit: % -> LIST %
  ++ orbit(p) returns the orbit of the point p according to the
  ++ characteristic of K, that is, for q= char K,
  ++ orbit(p) = \{ p, p**q, p**(q**2), p**(q**3), ..... \}

orbit: (% ,NNI) -> LIST %
  ++ orbit(p,n) returns the orbit of the point p according to n, that is
  ++ orbit(p,n) = \{ p, p**n, p**(n**2), p**(n**3), ..... \}

conjugate: (% ,NNI) -> %
  ++ conjugate(p,n) returns p**n, that is all the coordinates of p
  ++ to the power of n

conjugate: % -> %
  ++ conjugate(p) returns conjugate(p,n) where n is the characteristic
  ++ of the ground field.

removeConjugate: (LIST(%),NNI) -> LIST(%)
  ++ removeConjugate(lp,n) returns a list of points such that no points
  ++ in the list is the conjugate (according to n) of another point.

removeConjugate: LIST(%) -> LIST(%)
  ++ removeConjugate(lp) returns removeConjugate(lp,n)
  ++ where n is the characteristic of the ground field.

rational?: (% ,NNI) -> Boolean
  ++ rational?(p,n) test if the point is rational according to n.

rational?: % -> Boolean
  ++ rational?(p) test if the point is rational according to the
  ++ characteristic of the ground field.

list : % -> LIST(K)
  ++ list returns the list of the coordinates

elt: (% ,INT) -> K
  ++ elt returns the value of a specified coordinates

setelt: (% ,INT,K) -> K
  ++ setelt sets the value of a specified coordinates

pointValue: % -> LIST(K)

```


++ pointValue returns the coordinates of the point or of the point
 ++ of origin that represent an infinitely close point

— AFSPCAT.dotabb —

```
"AFSPCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=AFSPCAT"];
"AFSPCAT" -> "SETCATD"
```

— AFSPCAT.dotfull —

```
"AffineSpaceCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=AFSPCAT"];
"AffineSpaceCategory()" -> "SetCategoryWithDegree()"
```

— AFSPCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "AffineSpaceCategory()" [color=lightblue];
  "AffineSpaceCategory()" -> "SetCategoryWithDegree()"

  "SetCategoryWithDegree()" [color=lightblue];
  "SetCategoryWithDegree()" -> "BasicType()"
  "SetCategoryWithDegree()" -> "CoercibleTo(OutputForm)"
  "SetCategoryWithDegree()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

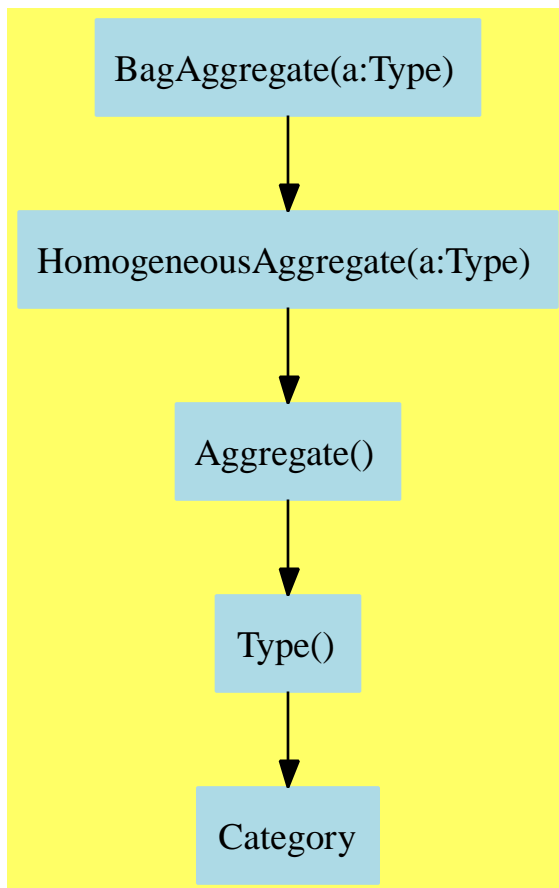
  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"
```

```
"CoercibleTo(a:Type)" [color=lightblue];  
"CoercibleTo(a:Type)" -> "Category"  
  
"Package" [color="#00EE00"];  
  
"Category" [color=lightblue];  
  
}
```

—————→

BagAggregate (BGAGG)



— BagAggregate.input —

```

)set break resume
)sys rm -f BagAggregate.output
)spool BagAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show BagAggregate
--R
--R BagAggregate(S: Type) is a category constructor
--R Abbreviation for BagAggregate is BGAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for BGAGG
--R
--R----- Operations -----
--R bag : List(S) -> %                copy : % -> %
--R empty : () -> %                  empty? : % -> Boolean
--R eq? : (%,% ) -> Boolean          extract! : % -> S
--R insert! : (S,% ) -> %           inspect : % -> S
--R map : ((S -> S),%) -> %         sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (%,% ) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R count : (S,% ) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,% ) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R size? : (% ,NonNegativeInteger) -> Boolean
--R ?~=? : (%,% ) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— BagAggregate.help —

=====

BagAggregate examples

=====

A bag aggregate is an aggregate for which one can insert and extract objects, and where the order in which objects are inserted determines the order of extraction. Examples of bags are stacks, queues, and dequeues.

See Also:

o)show BagAggregate

See:

⇒ “DictionaryOperations” (DIOPS) [6](#) on page [439](#)
 ⇒ “PriorityQueueAggregate” (PRQAGG) [6](#) on page [534](#)
 ⇒ “QueueAggregate” (QUAGG) [6](#) on page [540](#)
 ⇒ “StackAggregate” (SKAGG) [6](#) on page [554](#)
 ⇐ “HomogeneousAggregate” (HOAGG) [4](#) on page [233](#)

Exports:

| | | | | |
|----------|--------|---------|---------|---------|
| any? | bag | coerce | copy | count |
| empty | empty? | eq? | eval | every? |
| extract! | hash | insert! | inspect | latex |
| less? | map | map! | member? | members |
| more? | parts | sample | size? | #? |
| ?=? | ?~=? | | | |

Attributes Exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

These are directly exported but not implemented:

```
extract! : % -> S
insert! : (S,%) -> %
inspect : % -> S
```

These are implemented by this category:

```
bag : List S -> %
```

These exports come from (p233) HomogeneousAggregate(S:Type):

```
any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
coerce : % -> OutputForm if S has SETCAT
copy : % -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
members : % -> List S if $ has finiteAggregate
member? : (S,%) -> Boolean
      if S has SETCAT and $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
sample : () -> %
size? : (%,NonNegativeInteger) -> Boolean
\#? : % -> NonNegativeInteger if $ has finiteAggregate
?? : (%,%) -> Boolean if S has SETCAT
?~=? : (%,%) -> Boolean if S has SETCAT
```

— category BGAGG BagAggregate —

```
)abbrev category BGAGG BagAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
```

```

++ Description:
++ A bag aggregate is an aggregate for which one can insert and extract
++ objects, and where the order in which objects are inserted determines
++ the order of extraction.
++ Examples of bags are stacks, queues, and dequeues.

```

```

BagAggregate(S:Type): Category == HomogeneousAggregate S with
  shallowlyMutable
  ++ shallowlyMutable means that elements of bags may be
  ++ destructively changed.
  bag: List S -> %
  ++ bag([x,y,...,z]) creates a bag with elements x,y,...,z.
  extract_!: % -> S
  ++ extract!(u) destructively removes a (random) item from bag u.
  insert_!: (S,%) -> %
  ++ insert!(x,u) inserts item x into bag u.
  inspect: % -> S
  ++ inspect(u) returns an (random) element from a bag.
add
  bag(l) ==
    x:=empty()
    for s in l repeat x:=insert_!(s,x)
    x

```

— BGAGG.dotabb —

```

"BGAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=BGAGG"];
"BGAGG" -> "HOAGG"

```

— BGAGG.dotfull —

```

"BagAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=BGAGG"];
"BagAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

"BagAggregate(a:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=BGAGG"];
"BagAggregate(a:SetCategory)" -> "BagAggregate(a:Type)"

```

— BGAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "BagAggregate(a:Type)" [color=lightblue];
  "BagAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "Aggregate()"

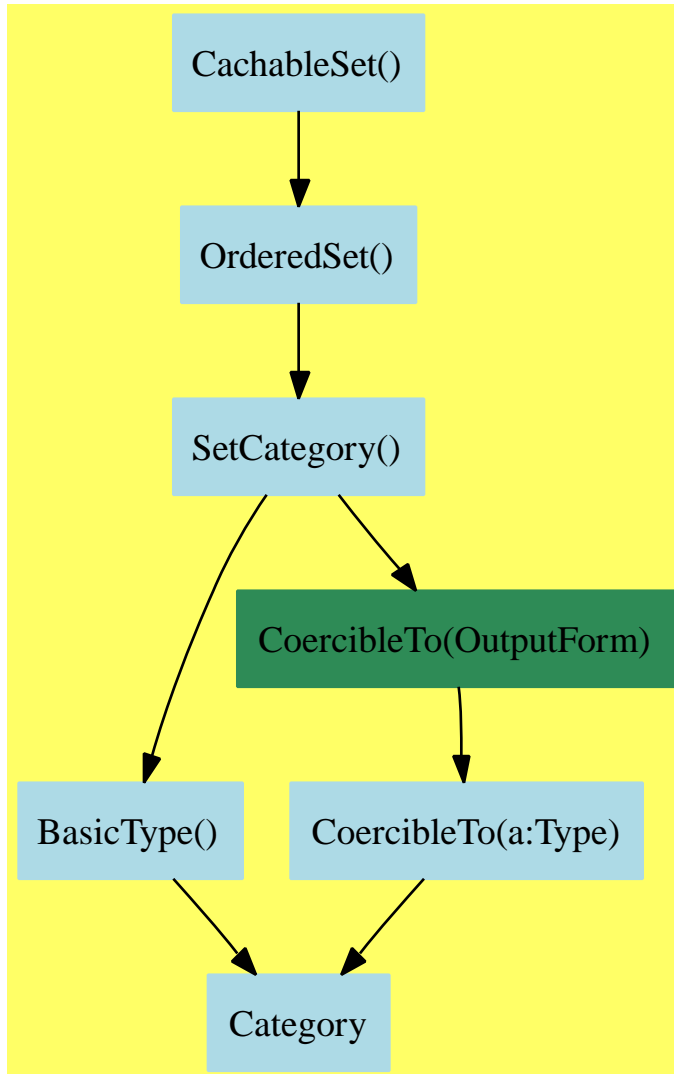
  "Aggregate()" [color=lightblue];
  "Aggregate()" -> "Type()"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "Category" [color=lightblue];
}

```

CachableSet (CACHSET)



— CachableSet.input —

```

)set break resume
)sys rm -f CachableSet.output
)spool CachableSet.output
)set message test on
)set message auto off
)clear all
  
```



```

--S 1 of 1
)show CachableView
--R CachableView is a category constructor
--R Abbreviation for CachableView is CACHVIEW
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for CACHVIEW
--R
--R----- Operations -----
--R ?<? : (%,% ) -> Boolean          ?<=? : (%,% ) -> Boolean
--R ?=? : (%,% ) -> Boolean          ?>? : (%,% ) -> Boolean
--R ?>=? : (%,% ) -> Boolean          coerce : % -> OutputForm
--R hash : % -> SingleInteger          latex : % -> String
--R max : (%,% ) -> %                  min : (%,% ) -> %
--R ?~=? : (%,% ) -> Boolean
--R position : % -> NonNegativeInteger
--R setPosition : (% ,NonNegativeInteger) -> Void
--R
--E 1

)spool
)lisp (bye)

```

— CachableView.help —

```

=====
CachableView examples
=====

```

A cachableView set is a set whose elements keep an integer as part of their structure.

See Also:

o)show CachableView

See:

⇐ “OrderedSet” (ORDSET) [4](#) on page [269](#)

Exports:

| | | | | |
|----------|-------------|-------|-----|------|
| coerce | hash | latex | max | min |
| position | setPosition | ?~=? | ?<? | ?<=? |
| ?=? | ?>? | ?>=? | | |

These are directly exported but not implemented:

```
position : % -> NonNegativeInteger
setPosition : (%,NonNegativeInteger) -> Void
```

These exports come from (p269) `OrderedSet()`:

```
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
max : (%,%) -> %
min : (%,%) -> %
?~=? : (%,%) -> Boolean
?<? : (%,%) -> Boolean
?<=? : (%,%) -> Boolean
?=? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean
```

— category CACHSET CachableViewSet —

```
)abbrev category CACHSET CachableViewSet
++ Author: Manuel Bronstein
++ Date Created: 31 Oct 1988
++ Date Last Updated: 14 May 1991
++ Description:
++ A cachableView set is a set whose elements keep an integer as part
++ of their structure.
```

```
CachableViewSet: Category == OrderedSet with
  position : % -> NonNegativeInteger
    ++ position(x) returns the integer n associated to x.
  setPosition: (%, NonNegativeInteger) -> Void
    ++ setPosition(x, n) associates the integer n to x.
```

— CACHSET.dotabb —

```
"CACHSET"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CACHSET"];
"CACHSET" -> "ORDSET"
```

— CACHSET.dotfull —

```
"CachableSet()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CACHSET"];
"CachableSet()" -> "OrderedSet()"
```

—————→

— CACHSET.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CachableSet()" [color=lightblue];
  "CachableSet()" -> "OrderedSet()"

  "OrderedSet()" [color=lightblue];
  "OrderedSet()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

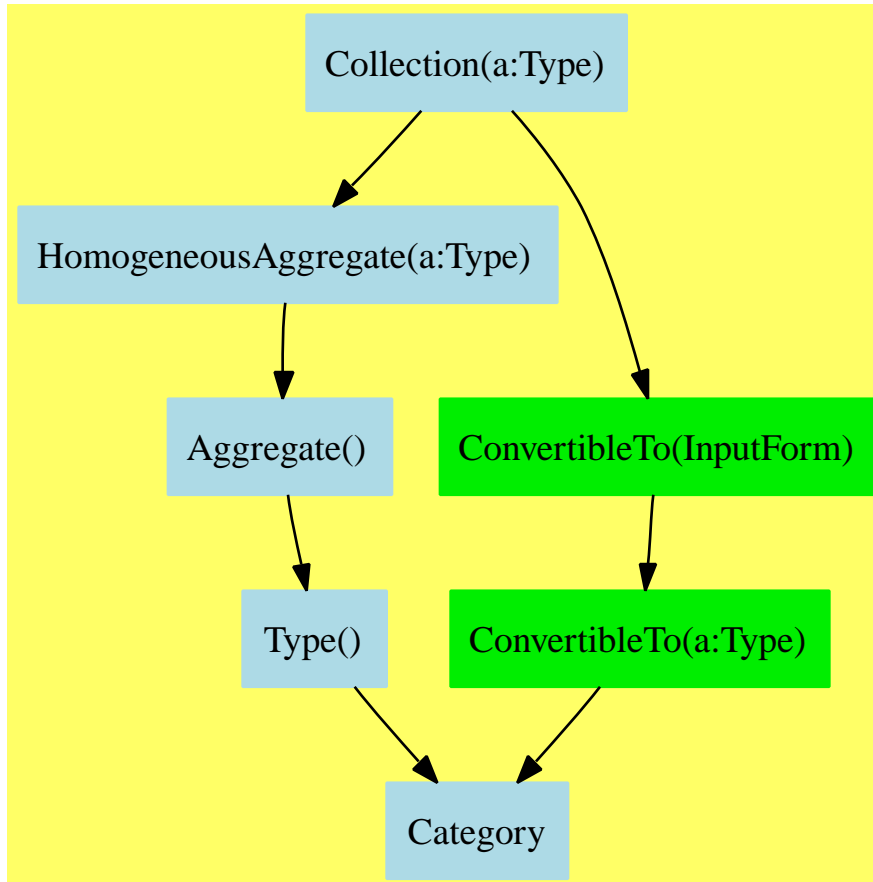
  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}
```

—————→

Collection (CLAGG)



— Collection.input —

```

)set break resume
)sys rm -f Collection.output
)spool Collection.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show Collection
--R
--R Collection(S: Type) is a category constructor
--R Abbreviation for Collection is CLAGG
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for CLAGG
--R
--R----- Operations -----
--R construct : List(S) -> %                copy : % -> %
--R empty : () -> %                        empty? : % -> Boolean
--R eq? : (%,% ) -> Boolean                map : ((S -> S),%) -> %
--R sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ==? : (%,% ) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R reduce : (((S,S) -> S),% ,S,S) -> S if S has SETCAT and $ has finiteAggregate
--R reduce : (((S,S) -> S),% ,S) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
--R remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (% ,NonNegativeInteger) -> Boolean
--R ==? : (%,% ) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— Collection.help —

=====
Collection examples

```
=====

A collection is a homogeneous aggregate which can built from
list of members. The operation used to build the aggregate is
generically named construct. However, each collection provides
its own special function with the same name as the data type,
except with an initial lower case letter, e.g.
list for List, flexibleArray for FlexibleArray, and so on.
```

See Also:

```
o )show Collection
```

See:

```
⇒ “DictionaryOperations” (DIOPS) 6 on page 439
⇒ “LinearAggregate” (LNAGG) 6 on page 458
⇒ “PolynomialSetCategory” (PSETCAT) 6 on page 520
⇒ “SetAggregate” (SETAGG) 6 on page 546
⇐ “ConvertibleTo” (KONVERT) 2 on page 41
⇐ “HomogeneousAggregate” (HOAGG) 4 on page 233
```

Exports:

| | | | | |
|--------|--------|-----------|------------------|---------|
| any? | coerce | construct | copy | convert |
| count | empty | empty? | eq? | eval |
| every? | find | hash | latex | less? |
| map | map! | member? | members | more? |
| parts | reduce | remove | removeDuplicates | sample |
| select | size? | #? | ?=? | ?~=? |

Attributes exported:

- nil

Attributes Used:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.

These are directly exported but not implemented:

```
construct: List S -> %
```

These are implemented by this category:

```
any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
```

```

count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
find : ((S -> Boolean),%) -> Union(S,"failed")
reduce : (((S,S) -> S),%,S,S) -> S
      if S has SETCAT and $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S if $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
removeDuplicates : % -> %
      if S has SETCAT and $ has finiteAggregate
select : ((S -> Boolean),%) -> % if $ has finiteAggregate
#? : % -> NonNegativeInteger if $ has finiteAggregate

```

These exports come from (p233) `HomogeneousAggregate(S:Type)`:

```

coerce : % -> OutputForm if S has SETCAT
copy : % -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
      if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
sample : () -> %
size? : (%,NonNegativeInteger) -> Boolean
=? : (%,%) -> Boolean if S has SETCAT
?~=? : (%,%) -> Boolean if S has SETCAT

```

These exports come from (p41) `ConvertibleTo(S:Type)`:

```
convert : % -> InputForm if S has KONVERT INFORM
```

— category CLAGG Collection —

```
)abbrev category CLAGG Collection
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A collection is a homogeneous aggregate which can built from
++ list of members. The operation used to build the aggregate is
++ generically named construct. However, each collection
++ provides its own special function with the same name as the
++ data type, except with an initial lower case letter, For example,
++ list for List, flexibleArray for FlexibleArray, and so on.

Collection(S:Type): Category == HomogeneousAggregate(S) with
construct: List S -> %
  ++ \axiom{construct(x,y,...,z)} returns the collection of elements
  ++ \axiom{x,y,...,z} ordered as given. Equivalently written as
  ++ \axiom{[x,y,...,z]$D}, where
  ++ D is the domain. D may be omitted for those of type List.
find: (S->Boolean, %) -> Union(S, "failed")
  ++ \axiom{find(p,u)} returns the first x in u such that
  ++ \axiom{p(x)} is true, and "failed" otherwise.
if % has finiteAggregate then
reduce: ((S,S)->S,%) -> S
  ++reduce(f,u) reduces the binary operation f across u.
  ++For example, if u is \axiom{[x,y,...,z]} then \axiom{reduce(f,u)}
  ++returns \axiom{f(..f(f(x,y),...),z)}.
  ++Note that if u has one element x, \axiom{reduce(f,u)} returns x.
  ++Error: if u is empty.
  ++
  ++C )clear all
  ++X reduce(+,[C[i]*x**i for i in 1..5])

reduce: ((S,S)->S,%,S) -> S
  ++ reduce(f,u,x) reduces the binary operation f across u, where x is
  ++ the identity operation of f.
  ++ Same as \axiom{reduce(f,u)} if u has 2 or more elements.
  ++ Returns \axiom{f(x,y)} if u has one element y,
  ++ x if u is empty.
  ++ For example, \axiom{reduce(+,u,0)} returns the
  ++ sum of the elements of u.
remove: (S->Boolean,%) -> %
  ++ remove(p,u) returns a copy of u removing all elements x such that
  ++ \axiom{p(x)} is true.
  ++ Note that \axiom{remove(p,u)} == [x for x in u | not p(x)].
select: (S->Boolean,%) -> %
```



```

++ select(p,u) returns a copy of u containing only those elements
++ such \axiom{p(x)} is true.
++ Note that \axiom{select(p,u) == [x for x in u | p(x)]}.
if S has SetCategory then
  reduce: ((S,S)->S,%,S,S) -> S
    ++ reduce(f,u,x,z) reduces the binary operation f across u,
    ++ stopping when an "absorbing element" z is encountered.
    ++ As for \axiom{reduce(f,u,x)}, x is the identity operation of f.
    ++ Same as \axiom{reduce(f,u,x)} when u contains no element z.
    ++ Thus the third argument x is returned when u is empty.
  remove: (S,%) -> %
    ++ remove(x,u) returns a copy of u with all
    ++ elements \axiom{y = x} removed.
    ++ Note that \axiom{remove(y,c) == [x for x in c | x ^= y]}.
  removeDuplicates: % -> %
    ++ removeDuplicates(u) returns a copy of u with all duplicates
    ++ removed.

if S has ConvertibleTo InputForm then ConvertibleTo InputForm
add
if % has finiteAggregate then
  #c == # parts c
  count(f:S -> Boolean, c:%) == _+/[1 for x in parts c | f x]
  any?(f, c) == _or/[f x for x in parts c]
  every?(f, c) == _and/[f x for x in parts c]
  find(f:S -> Boolean, c:%) == find(f, parts c)
  reduce(f:(S,S)->S, x:%) == reduce(f, parts x)
  reduce(f:(S,S)->S, x:%, s:S) == reduce(f, parts x, s)
  remove(f:S->Boolean, x:%) ==
    construct remove(f, parts x)
  select(f:S->Boolean, x:%) ==
    construct select(f, parts x)

if S has SetCategory then
  remove(s:S, x:%) == remove(y +-> y = s, x)
  reduce(f:(S,S)->S, x:%, s1:S, s2:S) == reduce(f, parts x, s1, s2)
  removeDuplicates(x) == construct removeDuplicates parts x

```

— CLAGG.dotabb —

"CLAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=CLAGG"];
 "CLAGG" -> "HOAGG"

— CLAGG.dotfull —

```

"Collection(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CLAGG"];
"Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"

"Collection(a:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=CLAGG"];
"Collection(a:SetCategory)" -> "Collection(a:Type)"

"Collection(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet()))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=CLAGG"];
"Collection(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet()))"
  -> "Collection(a:Type)"

```

— CLAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Collection(a:Type)" [color=lightblue];
  "Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"
  "Collection(a:Type)" -> "ConvertibleTo(InputForm)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "Aggregate()"

  "Aggregate()" [color=lightblue];
  "Aggregate()" -> "Type()"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

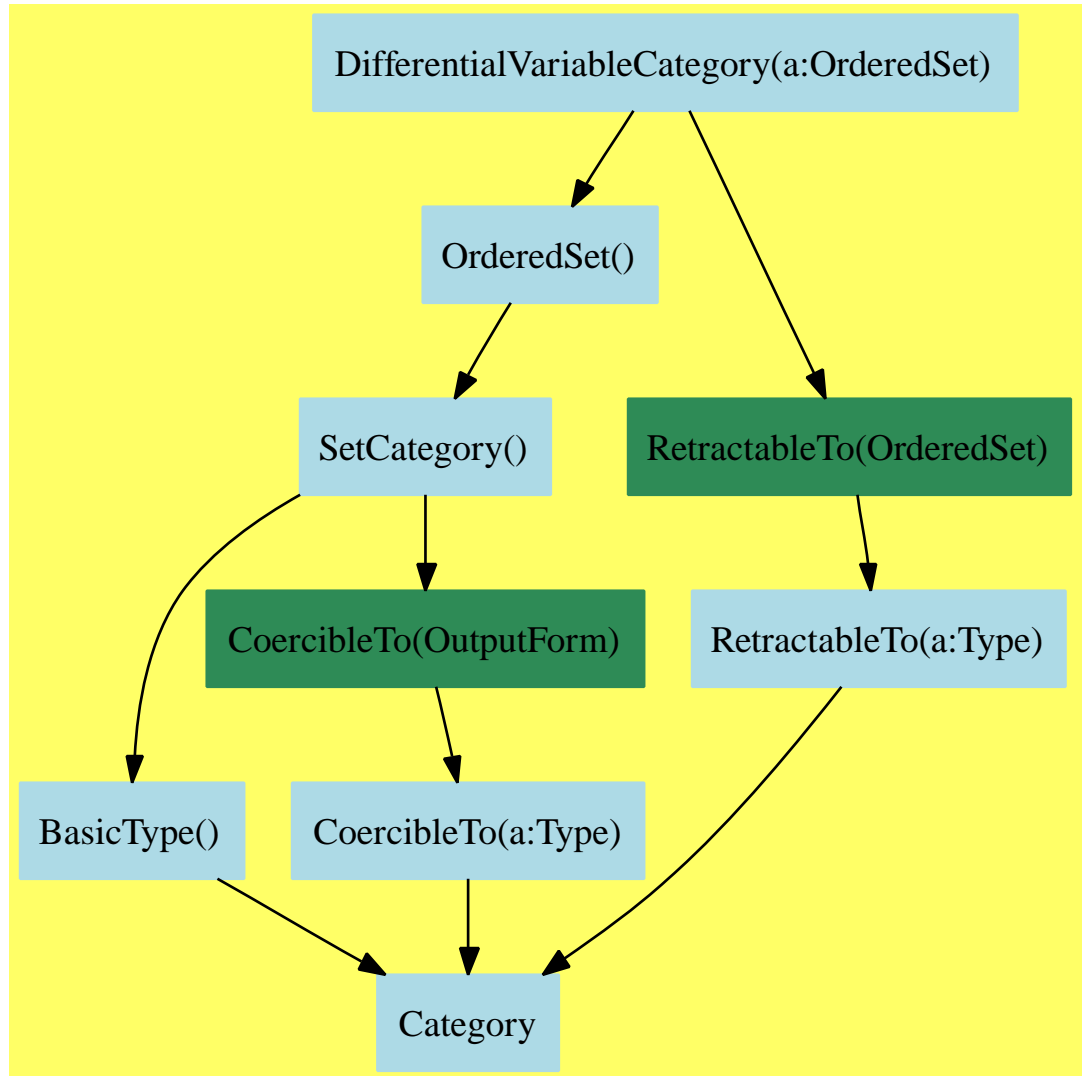
  "ConvertibleTo(InputForm)" [color="#00EE00"];
  "ConvertibleTo(InputForm)" -> "ConvertibleTo(a:Type)"

  "ConvertibleTo(a:Type)" [color="#00EE00"];
  "ConvertibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}

```

DifferentialVariableCategory (DVARCAT)



— DifferentialVariableCategory.input —

```

)set break resume
)sys rm -f DifferentialVariableCategory.output
)spool DifferentialVariableCategory.output
)set message test on
)set message auto off
)clear all
  
```

```

--S 1 of 1
)show DifferentialVariableCategory
--R
--R DifferentialVariableCategory(S: OrderedSet) is a category constructor
--R Abbreviation for DifferentialVariableCategory is DVARCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DVARCAT
--R
--R----- Operations -----
--R ?<? : (%,% ) -> Boolean          ?<=? : (%,% ) -> Boolean
--R ?=? : (%,% ) -> Boolean          ?>? : (%,% ) -> Boolean
--R ?>=? : (%,% ) -> Boolean          coerce : S -> %
--R coerce : % -> OutputForm          differentiate : % -> %
--R hash : % -> SingleInteger          latex : % -> String
--R max : (%,% ) -> %                  min : (%,% ) -> %
--R order : % -> NonNegativeInteger    retract : % -> S
--R variable : % -> S                  weight : % -> NonNegativeInteger
--R ?^=? : (%,% ) -> Boolean
--R differentiate : (% ,NonNegativeInteger) -> %
--R makeVariable : (S,NonNegativeInteger) -> %
--R retractIfCan : % -> Union(S,"failed")
--R
--E 1

)spool
)lisp (bye)

```

— DifferentialVariableCategory.help —

=====

DifferentialVariableCategory examples

=====

DifferentialVariableCategory constructs the set of derivatives of a given set of (ordinary) differential indeterminates. If x, \dots, y is an ordered set of differential indeterminates, and the prime notation is used for differentiation, then the set of derivatives (including zero-th order) of the differential indeterminates is

$x, x', x'', \dots, y, y', y'', \dots$

(Note that in the interpreter, the n -th derivative of y is displayed as y with a subscript n .) This set is viewed as a set of algebraic indeterminates, totally ordered in a way compatible with differentiation and the given order on the differential indeterminates. Such a total order is called a ranking of the differential indeterminates.

A domain in this category is needed to construct a differential

polynomial domain. Differential polynomials are ordered by a ranking on the derivatives, and by an order (extending the ranking) on the set of differential monomials. One may thus associate a domain in this category with a ranking of the differential indeterminates, just as one associates a domain in the category `OrderedAbelianMonoidSup` with an ordering of the set of monomials in a set of algebraic indeterminates. The ranking is specified through the binary relation `<`. For example, one may define one derivative to be less than another by lexicographically comparing first the order, then the given order of the differential indeterminates appearing in the derivatives. This is the default implementation.

The notion of weight generalizes that of degree. A polynomial domain may be made into a graded ring if a weight function is given on the set of indeterminates. Very often, a grading is the first step in ordering the set of monomials. For differential polynomial domains, this constructor provides a function `\spadfun{weight}`, which allows the assignment of a non-negative number to each derivative of a differential indeterminate. For example, one may define the weight of a derivative to be simply its order (this is the default assignment). This weight function can then be extended to the set of all differential polynomials, providing a graded ring structure.

See Also:

o `)show DifferentialVariableCategory`

See:

← “`OrderedSet`” (`ORDSET`) 4 on page 269

← “`RetractableTo`” (`RETRACT`) 2 on page 95

Exports:

| | | | | |
|-----------------------|----------------------------|----------------------|----------------------|---------------------------|
| <code>coerce</code> | <code>differentiate</code> | <code>hash</code> | <code>latex</code> | <code>makeVariable</code> |
| <code>max</code> | <code>min</code> | <code>order</code> | <code>retract</code> | <code>retractIfCan</code> |
| <code>variable</code> | <code>weight</code> | <code>?~=?</code> | <code>?<?</code> | <code>?<=?</code> |
| <code>?=?</code> | <code>?>?</code> | <code>?>=?</code> | | |

These are directly exported but not implemented:

```
makeVariable : (S,NonNegativeInteger) -> %
order : % -> NonNegativeInteger
variable : % -> S
```

These are implemented by this category:

```
coerce : S -> %
```

```

coerce : % -> OutputForm
differentiate : % -> %
differentiate : (% , NonNegativeInteger) -> %
retract : % -> S
retractIfCan : % -> Union(S, "failed")
weight : % -> NonNegativeInteger
?<? : (% , %) -> Boolean
?=? : (% , %) -> Boolean

```

These exports come from (p269) `OrderedSet()`:

```

hash : % -> SingleInteger
latex : % -> String
max : (% , %) -> %
min : (% , %) -> %
?<=? : (% , %) -> Boolean
?>? : (% , %) -> Boolean
?>=? : (% , %) -> Boolean
?~=? : (% , %) -> Boolean

```

These exports come from (p95) `RetractableTo(S:OrderedSet)`:

— category DVARCAT DifferentialVariableCategory —

```

)abbrev category DVARCAT DifferentialVariableCategory
++ Author: William Sit
++ Date Created: 19 July 1990
++ Date Last Updated: 13 September 1991
++ References: Ritt, J.F. "Differential Algebra" (Dover, 1950).
++ Description:
++ \spadtype{DifferentialVariableCategory} constructs the
++ set of derivatives of a given set of
++ (ordinary) differential indeterminates.
++ If x,...,y is an ordered set of differential indeterminates,
++ and the prime notation is used for differentiation, then
++ the set of derivatives (including
++ zero-th order) of the differential indeterminates is
++ x, \spad{x'}, \spad{x''}, ..., y, \spad{y'}, \spad{y''}, ...
++ (Note that in the interpreter, the n-th derivative of y is displayed as
++ y with a subscript n.) This set is
++ viewed as a set of algebraic indeterminates, totally ordered in a
++ way compatible with differentiation and the given order on the
++ differential indeterminates. Such a total order is called a
++ ranking of the differential indeterminates.
++
++ A domain in this category is needed to construct a differential

```

```

++ polynomial domain. Differential polynomials are ordered
++ by a ranking on the derivatives, and by an order (extending the
++ ranking) on
++ on the set of differential monomials. One may thus associate
++ a domain in this category with a ranking of the differential
++ indeterminates, just as one associates a domain in the category
++ \spadtype{OrderedAbelianMonoidSup} with an ordering of the set of
++ monomials in a set of algebraic indeterminates. The ranking
++ is specified through the binary relation \spadfun{<}.
++ For example, one may define
++ one derivative to be less than another by lexicographically comparing
++ first the \spadfun{order}, then the given order of the differential
++ indeterminates appearing in the derivatives. This is the default
++ implementation.
++
++ The notion of weight generalizes that of degree. A
++ polynomial domain may be made into a graded ring
++ if a weight function is given on the set of indeterminates,
++ Very often, a grading is the first step in ordering the set of
++ monomials. For differential polynomial domains, this
++ constructor provides a function \spadfun{weight}, which
++ allows the assignment of a non-negative number to each derivative of a
++ differential indeterminate. For example, one may define
++ the weight of a derivative to be simply its \spadfun{order}
++ (this is the default assignment).
++ This weight function can then be extended to the set of
++ all differential polynomials, providing a graded ring structure.

DifferentialVariableCategory(S:OrderedSet): Category ==
  Join(OrderedSet, RetractableTo S) with
    -- Examples:
    -- v:=makeVariable('s,5)
    makeVariable : (S, NonNegativeInteger) -> $
      ++ makeVariable(s, n) returns the n-th derivative of a
      ++ differential indeterminate s as an algebraic indeterminate.
    -- Example: makeVariable('s, 5)
    order : $ -> NonNegativeInteger
      ++ order(v) returns n if v is the n-th derivative of any
      ++ differential indeterminate.
    -- Example: order(v)
    variable : $ -> S
      ++ variable(v) returns s if v is any derivative of the differential
      ++ indeterminate s.
    -- Example: variable(v)
    -- default implementation using above primitives --

    weight : $ -> NonNegativeInteger
      ++ weight(v) returns the weight of the derivative v.
    -- Example: weight(v)
    differentiate : $ -> $

```

```

    ++ differentiate(v) returns the derivative of v.
    -- Example: differentiate(v)
differentiate : ($, NonNegativeInteger) -> $
    ++ differentiate(v, n) returns the n-th derivative of v.
    -- Example: differentiate(v,2)
coerce       : S -> $
    ++ coerce(s) returns s, viewed as the zero-th order derivative of s.
    -- Example: coerce('s); differentiate(%,5)
add
import NumberFormats

coerce (s:S):$ == makeVariable(s, 0)

differentiate v      == differentiate(v, 1)

differentiate(v, n) == makeVariable(variable v, n + order v)

retractIfCan v == (zero?(order v) => variable v; "failed")

v = u      == (variable v = variable u) and (order v = order u)

coerce(v:$):OutputForm ==
  a := variable(v)::OutputForm
  zero?(nn := order v) => a
  sub(a, outputForm nn)

retract v ==
  zero?(order v) => variable v
  error "Not retractable"

v < u ==
  -- the ranking below is orderly, and is the default --
  order v = order u => variable v < variable u
  order v < order u

weight v == order v
  -- the default weight is just the order

```

— DVARCAT.dotabb —

```

"DVARCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=DVARCAT"];
"DVARCAT" -> "ORDSET"
"DVARCAT" -> "RETRACT"

```

— DVARCAT.dotfull —

```

"DifferentialVariableCategory(a:OrderedSet)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=DVARCAT"];
"DifferentialVariableCategory(a:OrderedSet)" -> "OrderedSet()"
"DifferentialVariableCategory(a:OrderedSet)" -> "RetractableTo(OrderedSet)"

```

— DVARCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "DifferentialVariableCategory(a:OrderedSet)" [color=lightblue];
  "DifferentialVariableCategory(a:OrderedSet)" -> "OrderedSet()"
  "DifferentialVariableCategory(a:OrderedSet)" -> "RetractableTo(OrderedSet)"

  "RetractableTo(OrderedSet)" [color=seagreen];
  "RetractableTo(OrderedSet)" -> "RetractableTo(a:Type)"

  "RetractableTo(a:Type)" [color=lightblue];
  "RetractableTo(a:Type)" -> "Category"

  "OrderedSet()" [color=lightblue];
  "OrderedSet()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

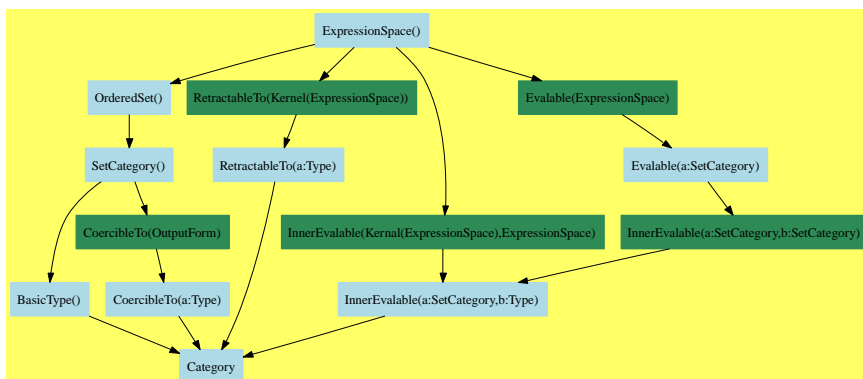
  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}

```

ExpressionSpace (ES)



— ExpressionSpace.input —

```

)set break resume
)sys rm -f ExpressionSpace.output
)spool ExpressionSpace.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ExpressionSpace
--R
--R ExpressionSpace is a category constructor
--R Abbreviation for ExpressionSpace is ES
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ES
--R
--R----- Operations -----
--R ?<? : (%,% ) -> Boolean      ?<=? : (%,% ) -> Boolean
--R ?=? : (%,% ) -> Boolean      ?>? : (%,% ) -> Boolean
--R ?>=? : (%,% ) -> Boolean     belong? : BasicOperator -> Boolean
--R box : List(% ) -> %         box : % -> %
--R coerce : Kernel(% ) -> %    coerce : % -> OutputForm
--R distribute : (%,% ) -> %    distribute : % -> %
--R elt : (BasicOperator,%,% ) -> % elt : (BasicOperator,% ) -> %
--R eval : (%,%,% ) -> %        eval : (% ,Equation(% )) -> %
--R eval : (% ,Kernel(% ),% ) -> % freeOf? : (% ,Symbol) -> Boolean
--R freeOf? : (%,% ) -> Boolean  hash : % -> SingleInteger
--R height : % -> NonNegativeInteger is? : (% ,Symbol) -> Boolean

```

```

--R kernel : (BasicOperator,%) -> %      kernels : % -> List(Kernel(%))
--R latex : % -> String                  max : (%,%) -> %
--R min : (%,%) -> %                     paren : List(%) -> %
--R paren : % -> %                       retract : % -> Kernel(%)
--R subst : (%,Equation(%)) -> %         tower : % -> List(Kernel(%))
--R ~=? : (%,%) -> Boolean
--R definingPolynomial : % -> % if $ has RING
--R elt : (BasicOperator,List(%)) -> %
--R elt : (BasicOperator,%,%,%,%) -> %
--R elt : (BasicOperator,%,%,%) -> %
--R eval : (%,BasicOperator,(% -> %)) -> %
--R eval : (%,BasicOperator,(List(%) -> %)) -> %
--R eval : (%,List(BasicOperator),List((List(%) -> %))) -> %
--R eval : (%,List(BasicOperator),List((% -> %))) -> %
--R eval : (%,Symbol,(% -> %)) -> %
--R eval : (%,Symbol,(List(%) -> %)) -> %
--R eval : (%,List(Symbol),List((List(%) -> %))) -> %
--R eval : (%,List(Symbol),List((% -> %))) -> %
--R eval : (%,List(%),List(%)) -> %
--R eval : (%,List(Equation(%))) -> %
--R eval : (%,List(Kernel(%)),List(%)) -> %
--R even? : % -> Boolean if $ has RETRACT(INT)
--R is? : (%,BasicOperator) -> Boolean
--R kernel : (BasicOperator,List(%)) -> %
--R mainKernel : % -> Union(Kernel(%),"failed")
--R map : ((% -> %),Kernel(%)) -> %
--R minPoly : Kernel(%) -> SparseUnivariatePolynomial(%) if $ has RING
--R odd? : % -> Boolean if $ has RETRACT(INT)
--R operator : BasicOperator -> BasicOperator
--R operators : % -> List(BasicOperator)
--R retractIfCan : % -> Union(Kernel(%),"failed")
--R subst : (%,List(Kernel(%)),List(%)) -> %
--R subst : (%,List(Equation(%))) -> %
--R
--E 1

)spool
)lisp (bye)

```

— ExpressionSpace.help —

=====
ExpressionSpace examples
=====

An expression space is a set which is closed under certain operators.

See Also:

o)show ExpressionSpace

See:

⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)

⇐ “Evalable” (EVALAB) [3](#) on page [129](#)

⇐ “InnerEvalable” (IEVALAB) [2](#) on page [56](#)

⇐ “OrderedSet” (ORDSET) [4](#) on page [269](#)

⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

Exports:

| | | | |
|------------|--------------|-----------|--------------------|
| belong? | box | coerce | definingPolynomial |
| distribute | elt | eval | even? |
| freeOf? | hash | height | is? |
| kernel | kernels | latex | mainKernel |
| map | max | min | minPoly |
| odd? | operator | operators | paren |
| retract | retractIfCan | subst | tower |
| ?<? | ?<=? | ?=? | ?>? |
| ?>=? | ?~=? | | |

These are directly exported but not implemented:

```
definingPolynomial : % -> % if $ has RING
eval : (%,List Symbol,List (List % -> %)) -> %
eval : (%,List Kernel %,List %) -> %
eval : (%,List %,List %) -> %
eval : (%,%,%) -> %
eval : (%,Equation %) -> %
eval : (%,Kernel %,%) -> %
kernels : % -> List Kernel %
minPoly : Kernel % -> SparseUnivariatePolynomial % if $ has RING
subst : (%,List Kernel %,List %) -> %
```

These are implemented by this category:

```
belong? : BasicOperator -> Boolean
box : List % -> %
box : % -> %
distribute : % -> %
distribute : (%,%) -> %
elt : (BasicOperator,%,%,%,%) -> %
elt : (BasicOperator,%,%,%) -> %
elt : (BasicOperator,%,%) -> %
```

```

elt : (BasicOperator,%) -> %
elt : (BasicOperator,List %) -> %
eval : (%,List Equation %) -> %
eval : (%,Symbol,(% -> %)) -> %
eval : (%,Symbol,(List % -> %)) -> %
eval : (%,BasicOperator,(% -> %)) -> %
eval : (%,BasicOperator,(List % -> %)) -> %
eval : (%,List BasicOperator,List (% -> %)) -> %
eval : (%,List Symbol,List (% -> %)) -> %
eval : (%,List BasicOperator,List (List % -> %)) -> %
even? : % -> Boolean if $ has RETRACT INT
freeOf? : (%,Symbol) -> Boolean
freeOf? : (%,%) -> Boolean
height : % -> NonNegativeInteger
is? : (%,BasicOperator) -> Boolean
is? : (%,Symbol) -> Boolean
kernel : (BasicOperator,%) -> %
kernel : (BasicOperator,List %) -> %
mainKernel : % -> Union(Kernel %,"failed")
map : ((% -> %),Kernel %) -> %
odd? : % -> Boolean if $ has RETRACT INT
operator : BasicOperator -> BasicOperator
operators : % -> List BasicOperator
paren : % -> %
paren : List % -> %
retract : % -> Kernel %
retractIfCan : % -> Union(Kernel %,"failed")
subst : (%,Equation %) -> %
subst : (%,List Equation %) -> %
tower : % -> List Kernel %

```

These exports come from (p269) `OrderedSet()`:

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
max : (%,%) -> %
min : (%,%) -> %
=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?<? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean
?<=? : (%,%) -> Boolean

```

These exports come from (p95) `RetractableTo(a:Type)`:

```

coerce : Kernel % -> %

```

These exports come from (p56) `InnerEvalable(a:SetCategory,b:Type)`:

These exports come from (p129) Evaluable(a:SetCategory):

— category ES ExpressionSpace —

```
)abbrev category ES ExpressionSpace
++ Category for domains on which operators can be applied
++ Author: Manuel Bronstein
++ Date Created: 22 March 1988
++ Date Last Updated: 27 May 1994
++ Description:
++ An expression space is a set which is closed under certain operators;

ExpressionSpace(): Category == Defn where
  N ==> NonNegativeInteger
  K ==> Kernel %
  OP ==> BasicOperator
  SY ==> Symbol
  PAREN ==> "%paren"::SY
  BOX ==> "%box"::SY
  DUMMYVAR ==> "%dummyVar"

Defn ==> Join(OrderedSet, RetractableTo K,
              InnerEvalable(K, %), Evalable %) with
  elt      : (OP, %) -> %
  ++ elt(op,x) or op(x) applies the unary operator op to x.
  elt      : (OP, %, %) -> %
  ++ elt(op,x,y) or op(x, y) applies the binary operator op to x and y.
  elt      : (OP, %, %, %) -> %
  ++ elt(op,x,y,z) or op(x, y, z) applies the ternary operator op
  ++ to x, y and z.
  elt      : (OP, %, %, %, %) -> %
  ++ elt(op,x,y,z,t) or op(x, y, z, t) applies the 4-ary operator op
  ++ to x, y, z and t.
  elt      : (OP, List %) -> %
  ++ elt(op,[x1,...,xn]) or op([x1,...,xn]) applies the n-ary operator
  ++ op to x1,...,xn.
  subst    : (%, Equation %) -> %
  ++ subst(f, k = g) replaces the kernel k by g formally in f.
  subst    : (%, List Equation %) -> %
  ++ subst(f, [k1 = g1,...,kn = gn]) replaces the kernels k1,...,kn
  ++ by g1,...,gn formally in f.
  subst    : (%, List K, List %) -> %
  ++ subst(f, [k1,...,kn], [g1,...,gn]) replaces the kernels k1,...,kn
  ++ by g1,...,gn formally in f.
  box      : % -> %
```

```

++ box(f) returns f with a 'box' around it that prevents f from
++ being evaluated when operators are applied to it. For example,
++ \spad{log(1)} returns 0, but \spad{log(box 1)}
++ returns the formal kernel log(1).
box      : List % -> %
++ box([f1,...,fn]) returns \spad{(f1,...,fn)} with a 'box'
++ around them that
++ prevents the fi from being evaluated when operators are applied to
++ them, and makes them applicable to a unary operator. For example,
++ \spad{atan(box [x, 2])} returns the formal kernel \spad{atan(x, 2)}.
paren    : % -> %
++ paren(f) returns (f). This prevents f from
++ being evaluated when operators are applied to it. For example,
++ \spad{log(1)} returns 0, but \spad{log(paren 1)} returns the
++ formal kernel log((1)).
paren    : List % -> %
++ paren([f1,...,fn]) returns \spad{(f1,...,fn)}. This
++ prevents the fi from being evaluated when operators are applied to
++ them, and makes them applicable to a unary operator. For example,
++ \spad{atan(paren [x, 2])} returns the formal
++ kernel \spad{atan((x, 2))}.
distribute : % -> %
++ distribute(f) expands all the kernels in f that are
++ formally enclosed by a \spadfunFrom{box}{ExpressionSpace}
++ or \spadfunFrom{paren}{ExpressionSpace} expression.
distribute : (% , %) -> %
++ distribute(f, g) expands all the kernels in f that contain g in their
++ arguments and that are formally
++ enclosed by a \spadfunFrom{box}{ExpressionSpace}
++ or a \spadfunFrom{paren}{ExpressionSpace} expression.
height    : % -> N
++ height(f) returns the highest nesting level appearing in f.
++ Constants have height 0. Symbols have height 1. For any
++ operator op and expressions f1,...,fn, \spad{op(f1,...,fn)} has
++ height equal to \spad{1 + max(height(f1),...,height(fn))}.
mainKernel : % -> Union(K, "failed")
++ mainKernel(f) returns a kernel of f with maximum nesting level, or
++ if f has no kernels (i.e. f is a constant).
kernels   : % -> List K
++ kernels(f) returns the list of all the top-level kernels
++ appearing in f, but not the ones appearing in the arguments
++ of the top-level kernels.
tower     : % -> List K
++ tower(f) returns all the kernels appearing in f, no matter
++ what their levels are.
operators : % -> List OP
++ operators(f) returns all the basic operators appearing in f,
++ no matter what their levels are.
operator  : OP -> OP
++ operator(op) returns a copy of op with the domain-dependent

```

```

    ++ properties appropriate for %.
belong?      : OP -> Boolean
    ++ belong?(op) tests if % accepts op as applicable to its
    ++ elements.
is?          : (%, OP)      -> Boolean
    ++ is?(x, op) tests if x is a kernel and is its operator is op.
is?          : (%, SY) -> Boolean
    ++ is?(x, s) tests if x is a kernel and is the name of its
    ++ operator is s.
kernel       : (OP, %) -> %
    ++ kernel(op, x) constructs op(x) without evaluating it.
kernel       : (OP, List %) -> %
    ++ kernel(op, [f1,...,fn]) constructs \spad{op(f1,...,fn)} without
    ++ evaluating it.
map          : (% -> %, K) -> %
    ++ map(f, k) returns \spad{op(f(x1),...,f(xn))} where
    ++ \spad{k = op(x1,...,xn)}.
freeOf?      : (%, %) -> Boolean
    ++ freeOf?(x, y) tests if x does not contain any occurrence of y,
    ++ where y is a single kernel.
freeOf?      : (%, SY) -> Boolean
    ++ freeOf?(x, s) tests if x does not contain any operator
    ++ whose name is s.
eval         : (%, List SY, List(% -> %)) -> %
    ++ eval(x, [s1,...,sm], [f1,...,fm]) replaces
    ++ every \spad{si(a)} in x by \spad{fi(a)} for any \spad{a}.
eval         : (%, List SY, List(List % -> %)) -> %
    ++ eval(x, [s1,...,sm], [f1,...,fm]) replaces
    ++ every \spad{si(a1,...,an)} in x by
    ++ \spad{fi(a1,...,an)} for any \spad{a1},..., \spad{an}.
eval         : (%, SY, List % -> %) -> %
    ++ eval(x, s, f) replaces every \spad{s(a1,...,am)} in x
    ++ by \spad{f(a1,...,am)} for any \spad{a1},..., \spad{am}.
eval         : (%, SY, % -> %) -> %
    ++ eval(x, s, f) replaces every \spad{s(a)} in x by \spad{f(a)}
    ++ for any \spad{a}.
eval         : (%, List OP, List(% -> %)) -> %
    ++ eval(x, [s1,...,sm], [f1,...,fm]) replaces
    ++ every \spad{si(a)} in x by \spad{fi(a)} for any \spad{a}.
eval         : (%, List OP, List(List % -> %)) -> %
    ++ eval(x, [s1,...,sm], [f1,...,fm]) replaces
    ++ every \spad{si(a1,...,an)} in x by
    ++ \spad{fi(a1,...,an)} for any \spad{a1},..., \spad{an}.
eval         : (%, OP, List % -> %) -> %
    ++ eval(x, s, f) replaces every \spad{s(a1,...,am)} in x
    ++ by \spad{f(a1,...,am)} for any \spad{a1},..., \spad{am}.
eval         : (%, OP, % -> %) -> %
    ++ eval(x, s, f) replaces every \spad{s(a)} in x by \spad{f(a)}
    ++ for any \spad{a}.
if % has Ring then

```



```

minPoly: K -> SparseUnivariatePolynomial %
  ++ minPoly(k) returns p such that \spad{p(k) = 0}.
definingPolynomial: % -> %
  ++ definingPolynomial(x) returns an expression p such that
  ++ \spad{p(x) = 0}.
if % has RetractableTo Integer then
  even?: % -> Boolean
  ++ even? x is true if x is an even integer.
  odd? : % -> Boolean
  ++ odd? x is true if x is an odd integer.

add

-- the 7 functions not provided are:
--   kernels    minPoly    definingPolynomial
--   coerce:K -> %   eval:(%, List K, List %) -> %
--   subst:(%, List K, List %) -> %
--   eval:(%, List Symbol, List(List % -> %)) -> %

allKernels: %      -> Set K
listk      : %      -> List K
allk       : List % -> Set K
unwrap     : (List K, %) -> %
okkernel   : (OP, List %) -> %
mkKerLists: List Equation % -> Record(lstk: List K, lstv:List %)

oppren := operator(PAREN)$CommonOperators()
opbox  := operator(BOX)$CommonOperators()

box(x:%)    == box [x]
paren(x:%)  == paren [x]
belong? op  == op = oppren or op = opbox
listk f     == parts allKernels f
tower f     == sort_! listk f
allk l      == reduce("union", [allKernels f for f in l], {})
operators f == [operator k for k in listk f]
height f    == reduce("max", [height k for k in kernels f], 0)
freeOf?(x:%, s:SY) == not member?(s, [name k for k in listk x])
distribute x == unwrap([k for k in listk x | is?(k, oppren)], x)
box(l:List %) == opbox l
paren(l:List %) == oppren l
freeOf?(x:%, k:%) == not member?(retract k, listk x)
kernel(op:OP, arg:%) == kernel(op, [arg])
elt(op:OP, x:%) == op [x]
elt(op:OP, x:%, y:%) == op [x, y]
elt(op:OP, x:%, y:%, z:%) == op [x, y, z]
elt(op:OP, x:%, y:%, z:%, t:%) == op [x, y, z, t]
eval(x:%, s:SY, f:List % -> %) == eval(x, [s], [f])
eval(x:%, s:OP, f:List % -> %) == eval(x, [name s], [f])
eval(x:%, s:SY, f:% -> %) ==

```

```

    eval(x, [s], [(y:List %):% +-> f(first y)])
eval(x:%, s:OP, f:% -> %) ==
    eval(x, [s], [(y:List %):% +-> f(first y)])
subst(x:%, e:Equation %) == subst(x, [e])

eval(x:%, ls:List OP, lf:List(% -> %)) ==
    eval(x, ls, [y +-> f(first y) for f in lf]$List(List % -> %))

eval(x:%, ls:List SY, lf:List(% -> %)) ==
    eval(x, ls, [y +-> f(first y) for f in lf]$List(List % -> %))

eval(x:%, ls:List OP, lf:List(List % -> %)) ==
    eval(x, [name s for s in ls]$List(SY), lf)

map(fn, k) ==
    (l := [fn x for x in argument k]$List(%)) = argument k => k::%
    (operator k) l

operator op ==
    is?(op, PAREN) => oppren
    is?(op, BOX) => opbox
    error "Unknown operator"

mainKernel x ==
    empty?(l := kernels x) => "failed"
    n := height(k := first l)
    for kk in rest l repeat
        if height(kk) > n then
            n := height kk
            k := kk
    k

-- takes all the kernels except for the dummy variables, which are second
-- arguments of rootOf's, integrals, sums and products which appear only in
-- their first arguments
allKernels f ==
    s := brace(l := kernels f)
    for k in l repeat
        t :=
            (u := property(operator k, DUMMYVAR)) case None =>
                arg := argument k
                s0 := remove_!(retract(second arg)@K, allKernels first arg)
                arg := rest rest arg
                n := (u::None) pretend N
                if n > 1 then arg := rest arg
                union(s0, allk arg)
            allk argument k
    s := union(s, t)
s

```

```

kernel(op:OP, args:List %) ==
  not belong? op => error "Unknown operator"
  okkernel(op, args)

okkernel(op, l) ==
  kernel(op, l, 1 + reduce("max", [height f for f in l], 0))$K :: %

elt(op:OP, args:List %) ==
  not belong? op => error "Unknown operator"
  ((u := arity op) case N) and (#args ^= u::N)
    => error "Wrong number of arguments"
  (v := evaluate(op,args)$BasicOperatorFunctions1(%)) case % => v::%
  okkernel(op, args)

retract f ==
  (k := mainKernel f) case "failed" => error "not a kernel"
  k::K::% ^= f => error "not a kernel"
  k::K

retractIfCan f ==
  (k := mainKernel f) case "failed" => "failed"
  k::K::% ^= f => "failed"
  k

is?(f:%, s:SY) ==
  (k := retractIfCan f) case "failed" => false
  is?(k::K, s)

is?(f:%, op:OP) ==
  (k := retractIfCan f) case "failed" => false
  is?(k::K, op)

unwrap(l, x) ==
  for k in reverse_! l repeat
    x := eval(x, k, first argument k)
  x

distribute(x, y) ==
  ky := retract y
  unwrap([k for k in listk x |
    is?(k, "%paren"::SY) and member?(ky, listk(k::%))], x)

-- in case of conflicting substitutions e.g. [x = a, x = b],
-- the first one prevails.
-- this is not part of the semantics of the function, but just
-- a feature of this implementation.
eval(f:%, leq:List Equation %) ==
  rec := mkKerLists leq
  eval(f, rec.lstk, rec.lstv)

```

```

subst(f:%, leq:List Equation %) ==
  rec := mkKerLists leq
  subst(f, rec.lstk, rec.lstv)

mkKerLists leq ==
  lk := empty()$List(K)
  lv := empty()$List(%)
  for eq in leq repeat
    (k := retractIfCan(lhs eq)@Union(K, "failed")) case "failed" =>
      error "left hand side must be a single kernel"
    if not member?(k::K, lk) then
      lk := concat(k::K, lk)
      lv := concat(rhs eq, lv)
  [lk, lv]

if % has RetractableTo Integer then
  intpred?: (% , Integer -> Boolean) -> Boolean

  even? x == intpred?(x, even?)
  odd? x == intpred?(x, odd?)

  intpred?(x, pred?) ==
    (u := retractIfCan(x)@Union(Integer, "failed")) case Integer
      and pred?(u::Integer)



---



— ES.dotabb —

"ES"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ES"];
"ES" -> "ORDSET"
"ES" -> "RETRACT"
"ES" -> "IEVALAB"
"ES" -> "EVALAB"



---



— ES.dotfull —

"ExpressionSpace()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ES"];
"ExpressionSpace()" -> "OrderedSet()"
"ExpressionSpace()" -> "RetractableTo(Kernel(ExpressionSpace))"
"ExpressionSpace()" ->
  "InnerEvalable(Kernal(ExpressionSpace),ExpressionSpace)"

```

```
"ExpressionSpace()" -> "Evaluable(ExpressionSpace)"
```

— ES.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ExpressionSpace()" [color=lightblue];
  "ExpressionSpace()" -> "OrderedSet()"
  "ExpressionSpace()" -> "RetractableTo(Kernel(ExpressionSpace))"
  "ExpressionSpace()" ->
    "InnerEvaluable(Kernal(ExpressionSpace),ExpressionSpace)"
  "ExpressionSpace()" -> "Evaluable(ExpressionSpace)"

  "Evaluable(ExpressionSpace)" [color=seagreen];
  "Evaluable(ExpressionSpace)" -> "Evaluable(a:SetCategory)"

  "Evaluable(a:SetCategory)" [color=lightblue];
  "Evaluable(a:SetCategory)" -> "InnerEvaluable(a:SetCategory,b:SetCategory)"

  "InnerEvaluable(Kernal(ExpressionSpace),ExpressionSpace)" [color=seagreen];
  "InnerEvaluable(Kernal(ExpressionSpace),ExpressionSpace)" ->
    "InnerEvaluable(a:SetCategory,b:Type)"

  "InnerEvaluable(a:SetCategory,b:SetCategory)" [color=seagreen];
  "InnerEvaluable(a:SetCategory,b:SetCategory)" ->
    "InnerEvaluable(a:SetCategory,b:Type)"

  "InnerEvaluable(a:SetCategory,b:Type)" [color=lightblue];
  "InnerEvaluable(a:SetCategory,b:Type)" -> "Category"

  "RetractableTo(Kernel(ExpressionSpace))" [color=seagreen];
  "RetractableTo(Kernel(ExpressionSpace))" -> "RetractableTo(a:Type)"

  "RetractableTo(a:Type)" [color=lightblue];
  "RetractableTo(a:Type)" -> "Category"

  "OrderedSet()" [color=lightblue];
  "OrderedSet()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"
```

```

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

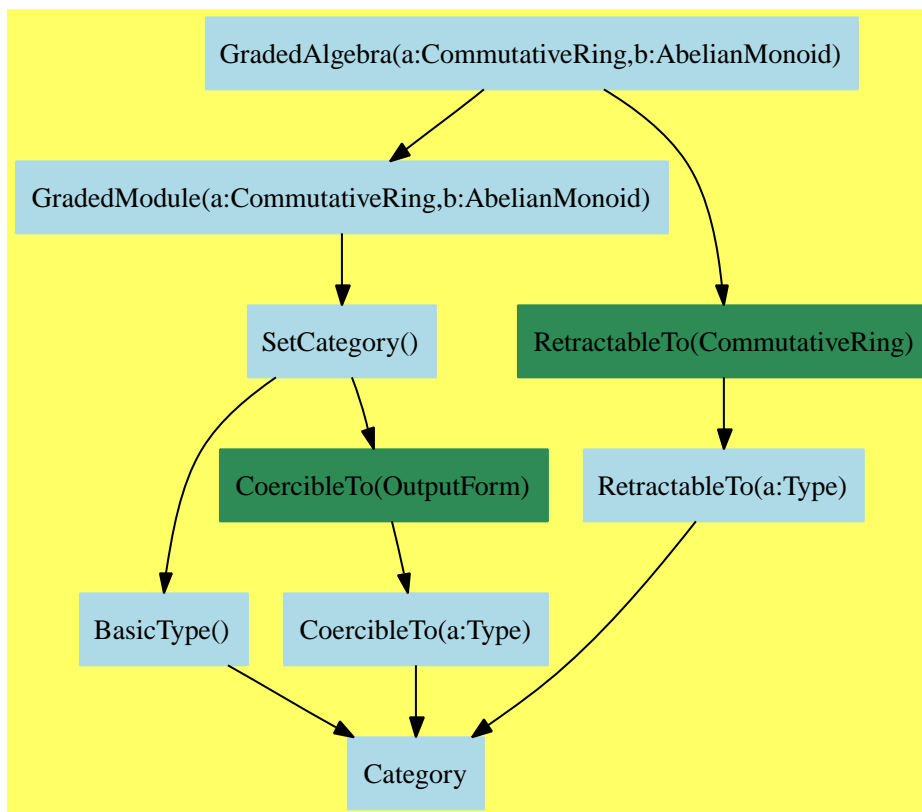
"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];
}

```

—————→

GradedAlgebra (GRALG)



— GradedAlgebra.input —

```

)set break resume
)sys rm -f GradedAlgebra.output
)spool GradedAlgebra.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show GradedAlgebra
--R GradedAlgebra(R: CommutativeRing,E: AbelianMonoid) is a category constructor
--R Abbreviation for GradedAlgebra is GRALG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for GRALG
--R
--R----- Operations -----
--R ?? : (R,% ) -> %           ?? : (R,% ) -> %
--R ?? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %               ?=? : (%,%) -> Boolean
--R 1 : () -> %               0 : () -> %
--R coerce : R -> %           coerce : % -> OutputForm
--R degree : % -> E           hash : % -> SingleInteger
--R latex : % -> String       product : (%,%) -> %
--R retract : % -> R          ?~=? : (%,%) -> Boolean
--R retractIfCan : % -> Union(R,"failed")
--R
--E 1

)spool
)lisp (bye)

```

— GradedAlgebra.help —

===== GradedAlgebra examples =====

GradedAlgebra(R,E) denotes "E-graded R-algebra". A graded algebra is a graded module together with a degree preserving R-linear map, called the product.

The name "product" is written out in full so inner and outer products with the same mapping type can be distinguished by name.

See Also:

o)show GradedAlgebra

See:

⇐ “GradedModule” (GRMOD) [4](#) on page [226](#)

⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

Exports:

| | | | | |
|-------|---------|---------|--------------|------|
| 0 | 1 | coerce | degree | hash |
| latex | product | retract | retractIfCan | ?~=? |
| ?*? | ?+? | ?-? | -? | ?=? |

These are directly exported but not implemented:

```
product : (%,% ) -> %
```

These are implemented by this category:

```
0 : () -> %
1 : () -> %
?*? : (% ,R) -> %
?*? : (R ,%) -> %
```

These exports come from (p[226](#)) GradedModule(R, E)
where R:CommutativeRing and E:AbelianMonoid:

```
coerce : % -> OutputForm
degree : % -> E
hash : % -> SingleInteger
latex : % -> String
?~=? : (% ,%) -> Boolean
?=? : (% ,%) -> Boolean
?-? : (% ,%) -> %
-? : % -> %
?+? : (% ,%) -> %
```

These exports come from (p[95](#)) RetractableTo(R:CommutativeRing):

```
coerce : R -> %
retract : % -> R
retractIfCan : % -> Union(R,"failed")
```

— category GRALG GradedAlgebra —

```
)abbrev category GRALG GradedAlgebra
```



```

++ Author: Stephen M. Watt
++ Date Created: May 20, 1991
++ Date Last Updated: May 20, 1991
++ References: Encyclopedic Dictionary of Mathematics, MIT Press, 1977
++ Description:
++ GradedAlgebra(R,E) denotes 'E-graded R-algebra'.
++ A graded algebra is a graded module together with a degree preserving
++ R-linear map, called the product.
++
++ The name 'product' is written out in full so inner and outer products
++ with the same mapping type can be distinguished by name.

```

```

GradedAlgebra(R: CommutativeRing, E: AbelianMonoid): Category ==
  Join(GradedModule(R, E),RetractableTo(R)) with

```

```

1: constant -> %
  ++ \spad{1} is the identity for \spad{product}.

product: (% , %) -> %
  ++ product(a,b) is the degree-preserving R-linear product:
  ++
  ++ \spad{degree product(a,b) = degree a + degree b}
  ++ \spad{product(a1+a2,b) = product(a1,b) + product(a2,b)}
  ++ \spad{product(a,b1+b2) = product(a,b1) + product(a,b2)}
  ++ \spad{product(r*a,b) = product(a,r*b) = r*product(a,b)}
  ++ \spad{product(a,product(b,c)) = product(product(a,b),c)}
add
if not (R is %) then

0: % == (0$R)::%

1: % == 1$R::%

(r: R)*(x: %) == product(r::%, x)

(x: %)*(r: R) == product(x, r::%)

```

— GRALG.dotabb —

```

"GRALG"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=GRALG" ];
"GRALG" -> "GRMOD"
"GRALG" -> "RETRACT"

```

— GRALG.dotfull —

```
"GradedAlgebra(a:CommutativeRing,b:AbelianMonoid)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=GRALG"];
"GradedAlgebra(a:CommutativeRing,b:AbelianMonoid)" ->
  "GradedModule(a:CommutativeRing,b:AbelianMonoid)"
"GradedAlgebra(a:CommutativeRing,b:AbelianMonoid)" ->
  "RetractableTo(CommutativeRing)"
```

— GRALG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "GradedAlgebra(a:CommutativeRing,b:AbelianMonoid)" [color=lightblue];
  "GradedAlgebra(a:CommutativeRing,b:AbelianMonoid)" ->
    "GradedModule(a:CommutativeRing,b:AbelianMonoid)"
  "GradedAlgebra(a:CommutativeRing,b:AbelianMonoid)" ->
    "RetractableTo(CommutativeRing)"

  "RetractableTo(CommutativeRing)" [color=seagreen];
  "RetractableTo(CommutativeRing)" -> "RetractableTo(a:Type)"

  "RetractableTo(a:Type)" [color=lightblue];
  "RetractableTo(a:Type)" -> "Category"

  "GradedModule(a:CommutativeRing,b:AbelianMonoid)" [color=lightblue];
  "GradedModule(a:CommutativeRing,b:AbelianMonoid)" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

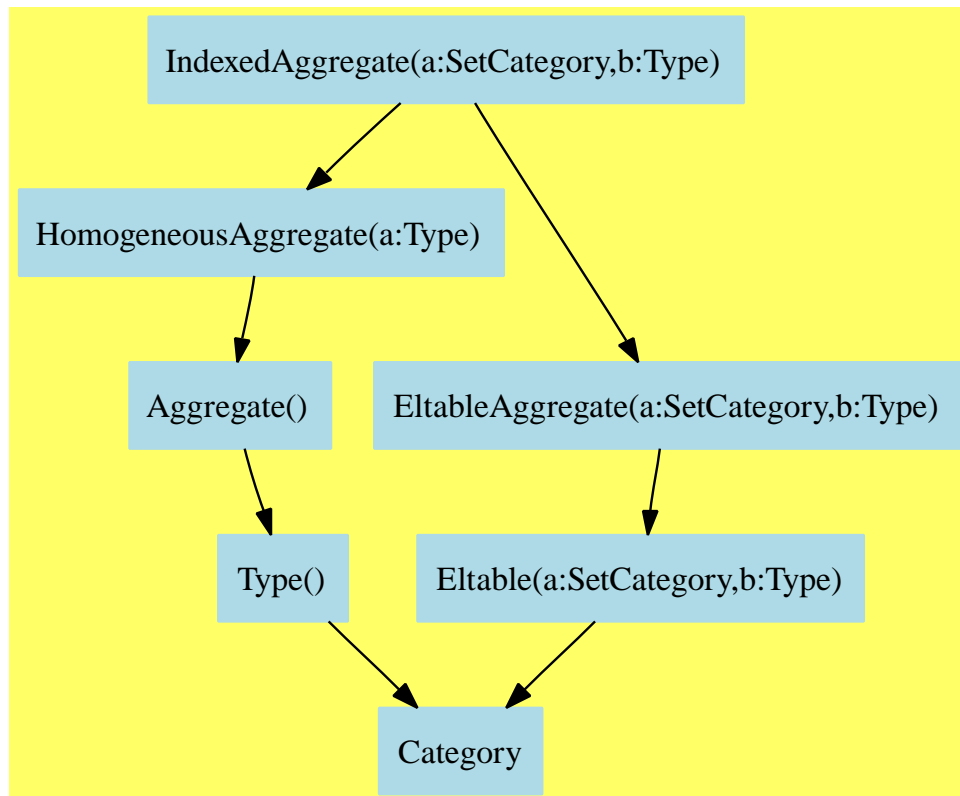
  "Category" [color=lightblue];
```

```

}

```

IndexedAggregate (IXAGG)



— IndexedAggregate.input —

```

)set break resume
)sys rm -f IndexedAggregate.output
)spool IndexedAggregate.output
)set message test on
)set message auto off
)clear all

```

--S 1 of 1

```

)show IndexedAggregate
--R
--R IndexedAggregate(Index: SetCategory,Entry: Type)  is a category constructor
--R Abbreviation for IndexedAggregate is IXAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for IXAGG
--R
--R----- Operations -----
--R copy : % -> %                                ?? : (% ,Index) -> Entry
--R elt : (% ,Index,Entry) -> Entry              empty : () -> %
--R empty? : % -> Boolean                        entries : % -> List(Entry)
--R eq? : (% ,%) -> Boolean                      index? : (Index ,%) -> Boolean
--R indices : % -> List(Index)                  map : ((Entry -> Entry) ,%) -> %
--R qelt : (% ,Index) -> Entry                  sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ==? : (% ,%) -> Boolean if Entry has SETCAT
--R any? : ((Entry -> Boolean) ,%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if Entry has SETCAT
--R count : (Entry ,%) -> NonNegativeInteger if Entry has SETCAT and $ has finiteAggregate
--R count : ((Entry -> Boolean) ,%) -> NonNegativeInteger if $ has finiteAggregate
--R entry? : (Entry ,%) -> Boolean if $ has finiteAggregate and Entry has SETCAT
--R eval : (% ,List(Entry) ,List(Entry)) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% ,Entry ,Entry) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% ,Equation(Entry)) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% ,List(Equation(Entry))) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R every? : ((Entry -> Boolean) ,%) -> Boolean if $ has finiteAggregate
--R fill! : (% ,Entry) -> % if $ has shallowlyMutable
--R first : % -> Entry if Index has ORDSET
--R hash : % -> SingleInteger if Entry has SETCAT
--R latex : % -> String if Entry has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((Entry -> Entry) ,%) -> % if $ has shallowlyMutable
--R maxIndex : % -> Index if Index has ORDSET
--R member? : (Entry ,%) -> Boolean if Entry has SETCAT and $ has finiteAggregate
--R members : % -> List(Entry) if $ has finiteAggregate
--R minIndex : % -> Index if Index has ORDSET
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(Entry) if $ has finiteAggregate
--R qsetelt! : (% ,Index,Entry) -> Entry if $ has shallowlyMutable
--R setelt : (% ,Index,Entry) -> Entry if $ has shallowlyMutable
--R size? : (% ,NonNegativeInteger) -> Boolean
--R swap! : (% ,Index,Index) -> Void if $ has shallowlyMutable
--R ~=? : (% ,%) -> Boolean if Entry has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— IndexedAggregate.help —

===== IndexedAggregate examples =====

An indexed aggregate is a many-to-one mapping of indices to entries. For example, a one-dimensional-array is an indexed aggregate where the index is an integer. Also, a table is an indexed aggregate where the indices and entries may have any type.

See Also:

o)show IndexedAggregate

See:

⇒ “DirectProductCategory” (DIRPCAT) [12](#) on page [1051](#)

⇒ “LinearAggregate” (LNAGG) [6](#) on page [458](#)

⇒ “TableAggregate” (TBAGG) [9](#) on page [852](#)

⇐ “EltableAggregate” (ELTAGG) [3](#) on page [125](#)

⇐ “HomogeneousAggregate” (HOAGG) [4](#) on page [233](#)

Exports:

| | | | | |
|--------|----------|---------|----------|----------|
| any? | coerce | copy | count | elt |
| empty | empty? | entries | entry? | eq? |
| eval | every? | fill! | first | hash |
| index? | indices | latex | less? | map |
| map! | maxIndex | member? | members | minIndex |
| more? | parts | qelt | qsetelt! | sample |
| setelt | size? | swap! | ?? | ?~=? |
| #? | ?=? | | | |

Attributes exported:

- nil

Attributes Used:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```
index? : (Index,%) -> Boolean
indices : % -> List Index
```

These are implemented by this category:

```
elt : (%,Index,Entry) -> Entry
entries : % -> List Entry
entry? : (Entry,%) -> Boolean
    if $ has finiteAggregate and Entry has SETCAT
fill! : (%,Entry) -> % if $ has shallowlyMutable
first : % -> Entry if Index has ORDSET
map : ((Entry -> Entry),%) -> %
map! : ((Entry -> Entry),%) -> % if $ has shallowlyMutable
maxIndex : % -> Index if Index has ORDSET
minIndex : % -> Index if Index has ORDSET
swap! : (%,Index,Index) -> Void if $ has shallowlyMutable
```

These exports come from (p233) HomogeneousAggregate(Entry:Type):

```
any? : ((Entry -> Boolean),%) -> Boolean
    if $ has finiteAggregate
coerce : % -> OutputForm if Entry has SETCAT
copy : % -> %
count : (Entry,%) -> NonNegativeInteger
    if Entry has SETCAT and $ has finiteAggregate
count : ((Entry -> Boolean),%) -> NonNegativeInteger
    if $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List Entry,List Entry) -> %
    if Entry has EVALAB Entry and Entry has SETCAT
eval : (%,Entry,Entry) -> %
    if Entry has EVALAB Entry and Entry has SETCAT
eval : (%,Equation Entry) -> %
    if Entry has EVALAB Entry and Entry has SETCAT
eval : (%,List Equation Entry) -> %
    if Entry has EVALAB Entry and Entry has SETCAT
every? : ((Entry -> Boolean),%) -> Boolean
    if $ has finiteAggregate
hash : % -> SingleInteger if Entry has SETCAT
latex : % -> String if Entry has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
member? : (Entry,%) -> Boolean
    if Entry has SETCAT and $ has finiteAggregate
members : % -> List Entry if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
```

```

parts : % -> List Entry if $ has finiteAggregate
sample : () -> %
size? : (% , NonNegativeInteger) -> Boolean
?~=? : (% , %) -> Boolean if Entry has SETCAT
#? : % -> NonNegativeInteger if $ has finiteAggregate
?=? : (% , %) -> Boolean if Entry has SETCAT

```

These exports come from (p125) EltableAggregate(Index:SetCategory,Entry:Type):

```

qelt : (% , Index) -> Entry
qsetelt! : (% , Index , Entry) -> Entry if $ has shallowlyMutable
setelt : (% , Index , Entry) -> Entry if $ has shallowlyMutable
?.? : (% , Index) -> Entry

```

— category IXAGG IndexedAggregate —

```

)abbrev category IXAGG IndexedAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ An indexed aggregate is a many-to-one mapping of indices to entries.
++ For example, a one-dimensional-array is an indexed aggregate where
++ the index is an integer. Also, a table is an indexed aggregate
++ where the indices and entries may have any type.

IndexedAggregate(Index: SetCategory, Entry: Type): Category ==
  Join(HomogeneousAggregate(Entry), EltableAggregate(Index, Entry)) with
    entries: % -> List Entry
      ++ entries(u) returns a list of all the entries of aggregate u
      ++ in no assumed order.
      -- to become entries: % -> Entry* and
      -- entries: % -> Iterator(Entry,Entry)
    index?: (Index,%) -> Boolean
      ++ index?(i,u) tests if i is an index of aggregate u.
    indices: % -> List Index
      ++ indices(u) returns a list of indices of aggregate u in no
      ++ particular order. to become indices:
      -- % -> Index* and indices: % -> Iterator(Index,Index).
  -- map: ((Entry,Entry)->Entry,% ,%,Entry) -> %
  -- ++ exists c = map(f,a,b,x), i:Index where
  -- ++ c.i = f(a(i,x),b(i,x)) | index?(i,a) or index?(i,b)
  if Entry has SetCategory and % has finiteAggregate then
    entry?: (Entry,%) -> Boolean
      ++ entry?(x,u) tests if x equals \axiom{u . i} for some index i.
  if Index has OrderedSet then
    maxIndex: % -> Index
      ++ maxIndex(u) returns the maximum index i of aggregate u.
      ++ Note that in general,

```

```

    ++ \axiom{maxIndex(u) = reduce(max,[i for i in indices u])};
    ++ if u is a list, \axiom{maxIndex(u) = #u}.
minIndex: % -> Index
    ++ minIndex(u) returns the minimum index i of aggregate u.
    ++ Note that in general,
    ++ \axiom{minIndex(a) = reduce(min,[i for i in indices a])};
    ++ for lists, \axiom{minIndex(a) = 1}.
first : % -> Entry
    ++ first(u) returns the first element x of u.
    ++ Note that for collections, \axiom{first([x,y,...,z]) = x}.
    ++ Error: if u is empty.

if % has shallowlyMutable then
    fill_!: (% ,Entry) -> %
        ++ fill!(u,x) replaces each entry in aggregate u by x.
        ++ The modified u is returned as value.
    swap_!: (% ,Index,Index) -> Void
        ++ swap!(u,i,j) interchanges elements i and j of aggregate u.
        ++ No meaningful value is returned.
add
elt(a, i, x) == (index?(i, a) => qelt(a, i); x)

if % has finiteAggregate then
    entries x == parts x
    if Entry has SetCategory then
        entry?(x, a) == member?(x, a)

if Index has OrderedSet then
    maxIndex a == "max"/indices(a)
    minIndex a == "min"/indices(a)
    first a == a minIndex a

if % has shallowlyMutable then
    map(f, a) == map_!(f, copy a)

    map_!(f, a) ==
        for i in indices a repeat qsetelt_!(a, i, f qelt(a, i))
        a

    fill_!(a, x) ==
        for i in indices a repeat qsetelt_!(a, i, x)
        a

    swap_!(a, i, j) ==
        t := a.i
        qsetelt_!(a, i, a.j)
        qsetelt_!(a, j, t)
        void

```

— IXAGG.dotabb —

```
"IXAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=IXAGG"];
"IXAGG" -> "HOAGG"
"IXAGG" -> "ELTAGG"
```

— IXAGG.dotfull —

```
"IndexedAggregate(a:SetCategory,b:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=IXAGG"];
"IndexedAggregate(a:SetCategory,b:Type)" ->
  "HomogeneousAggregate(a:Type)"
"IndexedAggregate(a:SetCategory,b:Type)" ->
  "EltableAggregate(a:SetCategory,b:Type)"

"IndexedAggregate(a:SetCategory,b:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=IXAGG"];
"IndexedAggregate(a:SetCategory,b:SetCategory)" ->
  "IndexedAggregate(a:SetCategory,b:Type)"

"IndexedAggregate(b:Integer,a:Type)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=IXAGG"];
"IndexedAggregate(b:Integer,a:Type)" ->
  "IndexedAggregate(a:SetCategory,b:Type)"
```

— IXAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "IndexedAggregate(a:SetCategory,b:Type)" [color=lightblue];
  "IndexedAggregate(a:SetCategory,b:Type)" ->
    "HomogeneousAggregate(a:Type)"
  "IndexedAggregate(a:SetCategory,b:Type)" ->
    "EltableAggregate(a:SetCategory,b:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "Aggregate()"
```

```
"EltableAggregate(a:SetCategory,b:Type)" [color=lightblue];
"EltableAggregate(a:SetCategory,b:Type)" -> "Eltable(a:SetCategory,b:Type)"

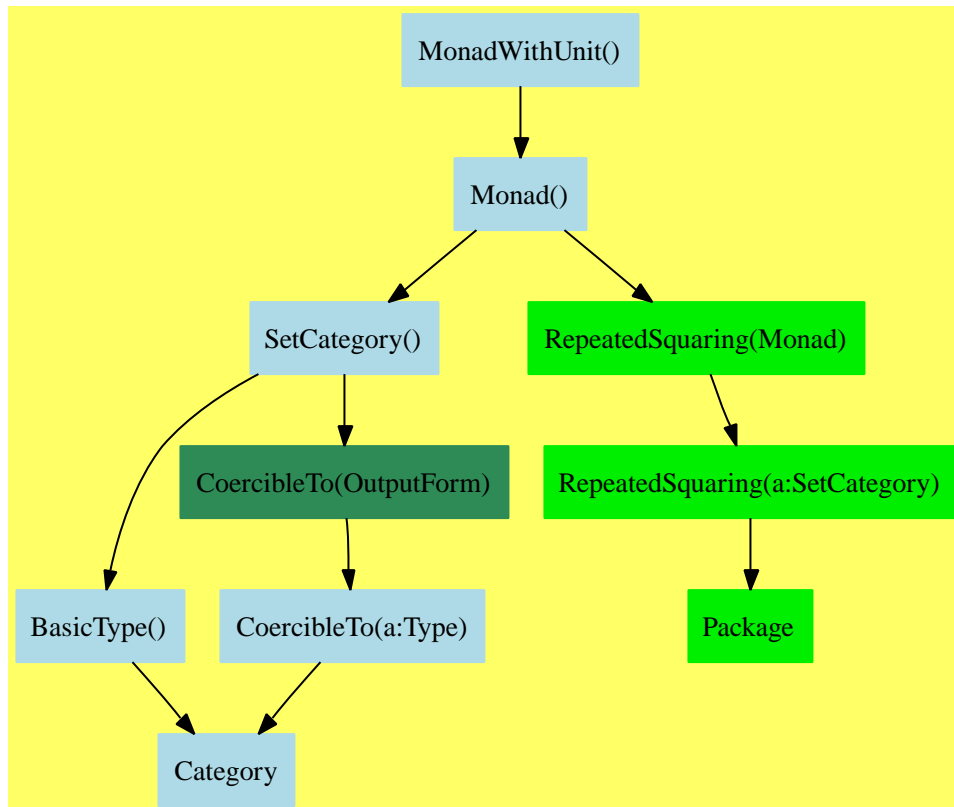
"Eltable(a:SetCategory,b:Type)" [color=lightblue];
"Eltable(a:SetCategory,b:Type)" -> "Category"

"Aggregate()" [color=lightblue];
"Aggregate()" -> "Type()"

"Type()" [color=lightblue];
"Type()" -> "Category"

"Category" [color=lightblue];
}
```

MonadWithUnit (MONADWU)



— MonadWithUnit.input —

```

)set break resume
)sys rm -f MonadWithUnit.output
)spool MonadWithUnit.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show MonadWithUnit
--R MonadWithUnit is a category constructor
--R Abbreviation for MonadWithUnit is MONADWU
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MONADWU
--R
--R----- Operations -----

```

```

--R ?? : (% , %) -> %
--R ==? : (% , %) -> Boolean
--R coerce : % -> OutputForm
--R latex : % -> String
--R recip : % -> Union(%, "failed")
--R ***? : (% , NonNegativeInteger) -> %
--R leftPower : (% , NonNegativeInteger) -> %
--R leftPower : (% , PositiveInteger) -> %
--R leftRecip : % -> Union(%, "failed")
--R rightPower : (% , NonNegativeInteger) -> %
--R rightPower : (% , PositiveInteger) -> %
--R rightRecip : % -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— MonadWithUnit.help —

=====

MonadWithUnit examples

=====

MonadWithUnit is the class of multiplicative monads with unit,
i.e. sets with a binary operation and a unit element.

Axioms:

```

leftIdentity("":(% , %)->%,1)      1*x=x
rightIdentity("":(% , %)->%,1)     x*1=x

```

Common Additional Axioms:

unitsKnown - if "recip" says "failed", it PROVES input wasn't a unit

See Also:

o)show MonadWithUnit

See:

⇒ “NonAssociativeRing” (NASRING) [9](#) on page [796](#)

⇐ “Monad” (MONAD) [4](#) on page [249](#)

Exports:

| | | | | |
|-------|-----------|-----------|------------|------------|
| 1 | coerce | hash | latex | one? |
| recip | leftPower | leftRecip | rightPower | rightRecip |
| ?*? | ?~=? | ?**? | ?=? | |

These are directly exported but not implemented:

```
1 : () -> %
leftRecip : % -> Union(%, "failed")
recip : % -> Union(%, "failed")
rightRecip : % -> Union(%, "failed")
```

These are implemented by this category:

```
leftPower : (%, NonNegativeInteger) -> %
one? : % -> Boolean
rightPower : (%, NonNegativeInteger) -> %
***? : (%, NonNegativeInteger) -> %
```

These exports come from (p249) `Monad()`:

```
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
leftPower : (%, PositiveInteger) -> %
rightPower : (%, PositiveInteger) -> %
***? : (%, PositiveInteger) -> %
?*? : (%, %) -> %
?~=? : (%, %) -> Boolean
?=? : (%, %) -> Boolean
```

— category MONADWU MonadWithUnit —

```
)abbrev category MONADWU MonadWithUnit
++ Authors: J. Grabmeier, R. Wisbauer
++ Date Created: 01 March 1991
++ Date Last Updated: 11 June 1991
++ Reference:
++ N. Jacobson: Structure and Representations of Jordan Algebras
++ AMS, Providence, 1968
++ Description:
++ MonadWithUnit is the class of multiplicative monads with unit,
++ that is, sets with a binary operation and a unit element.
++
++ Axioms\br
++ \tab{5}leftIdentity("":(%,%)->%,1) for example, 1*x=x\br
++ \tab{5}rightIdentity("":(%,%)->%,1) for example, x*1=x
++
++ Common Additional Axioms\br
++ \tab{5}unitsKnown - if "recip" says "failed", it PROVES input wasn't a unit
```

```

MonadWithUnit(): Category == Monad with

1: constant -> %
  ++ \spad{1} returns the unit element, denoted by 1.

one?: % -> Boolean
  ++ one?(a) tests whether \spad{a} is the unit 1.

rightPower: (% , NonNegativeInteger) -> %
  ++ rightPower(a,n) returns the \spad{n}-th right power of \spad{a},
  ++ that is, \spad{rightPower(a,n) := rightPower(a,n-1) * a} and
  ++ \spad{rightPower(a,0) := 1}.

leftPower: (% , NonNegativeInteger) -> %
  ++ leftPower(a,n) returns the \spad{n}-th left power of \spad{a},
  ++ that is, \spad{leftPower(a,n) := a * leftPower(a,n-1)} and
  ++ \spad{leftPower(a,0) := 1}.

"***": (% , NonNegativeInteger) -> %
  ++ \spad{a**n} returns the \spad{n}-th power of \spad{a},
  ++ defined by repeated squaring.

recip: % -> Union(% , "failed")
  ++ recip(a) returns an element, which is both a left and a right
  ++ inverse of \spad{a},
  ++ or \spad{"failed"} if such an element doesn't exist or cannot
  ++ be determined (see unitsKnown).

leftRecip: % -> Union(% , "failed")
  ++ leftRecip(a) returns an element, which is a left inverse of
  ++ \spad{a}, or \spad{"failed"} if such an element doesn't exist
  ++ or cannot be determined (see unitsKnown).

rightRecip: % -> Union(% , "failed")
  ++ rightRecip(a) returns an element, which is a right inverse of
  ++ \spad{a}, or \spad{"failed"} if such an element doesn't exist
  ++ or cannot be determined (see unitsKnown).

add

import RepeatedSquaring(%)

one? x == x = 1

x:% ** n:NonNegativeInteger ==
  zero? n => 1
  expt(x,n pretend PositiveInteger)

rightPower(a,n) ==

```

```

zero? n => 1
res := 1
for i in 1..n repeat res := res * a
res

leftPower(a,n) ==
zero? n => 1
res := 1
for i in 1..n repeat res := a * res
res

```

— MONADWU.dotabb —

```

"MONADWU"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=MONADWU" ];
"MONADWU" -> "MONAD"

```

— MONADWU.dotfull —

```

"MonadWithUnit()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=MONADWU" ];
"MonadWithUnit()" -> "Monad()"

```

— MONADWU.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "MonadWithUnit()" [color=lightblue];
  "MonadWithUnit()" -> "Monad()"

  "Monad()" [color=lightblue];
  "Monad()" -> "SetCategory()"
  "Monad()" -> "RepeatedSquaring(Monad)"

  "RepeatedSquaring(Monad)" [color="#00EE00"];
  "RepeatedSquaring(Monad)" -> "RepeatedSquaring(a:SetCategory)"

```

```

"RepeatedSquaring(a:SetCategory)" [color="#00EE00"];
"RepeatedSquaring(a:SetCategory)" -> "Package"

"Package" [color="#00EE00"];

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

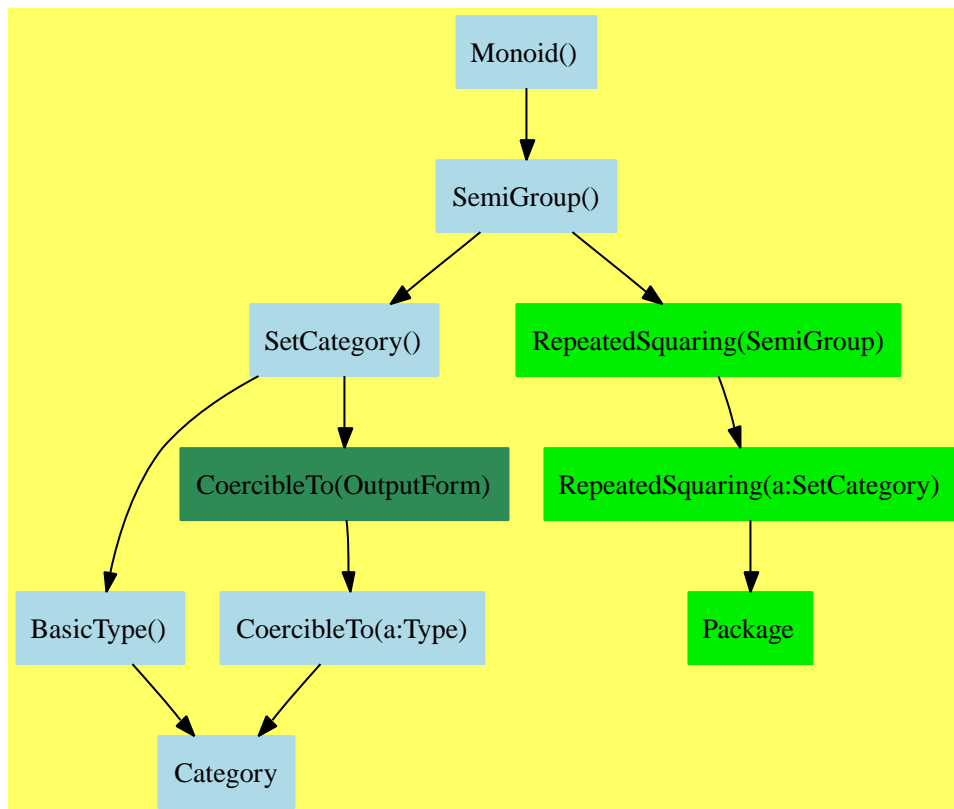
"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];

}

```

Monoid (MONOID)



— Monoid.input —

```

)set break resume
)sys rm -f Monoid.output
)spool Monoid.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show Monoid
--R Monoid is a category constructor
--R Abbreviation for Monoid is MONOID
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MONOID
--R
--R----- Operations -----

```

```

--R ?? : (%,% ) -> %
--R ==? : (%,% ) -> Boolean
--R ^? : (% ,PositiveInteger) -> %
--R hash : % -> SingleInteger
--R one? : % -> Boolean
--R sample : () -> %
--R ***? : (% ,NonNegativeInteger) -> %
--R ^? : (% ,NonNegativeInteger) -> %
--R
--E 1

```

```

)spool
)lisp (bye)

```

— Monoid.help —

=====

Monoid examples

=====

The class of multiplicative monoids, i.e. semigroups with a multiplicative identity element.

Axioms:

```

leftIdentity("":(%,% )->%,1)      1*x=x
rightIdentity("":(%,% )->%,1)     x*1=x

```

Conditional attributes:

unitsKnown - \spadfun{recip} only returns "failed" on non-units

See Also:

o)show Monoid

See:

⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)

⇒ “Group” (GROUP) [6](#) on page [452](#)

⇒ “OrderedMonoid” (ORDMON) [6](#) on page [516](#)

⇒ “OrderedRing” (ORDRING) [10](#) on page [933](#)

⇒ “Ring” (RING) [9](#) on page [826](#)

⇐ “SemiGroup” (SGROUP) [4](#) on page [292](#)

Exports:

```

1      coerce  hash  latex  one?
recip  sample  ??    ?=?   ?~=?
***?   ?^?

```

These are directly exported but not implemented:

```
1 : () -> %
```

These are implemented by this category:

```

one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
?^? : (%, NonNegativeInteger) -> %
***? : (%, NonNegativeInteger) -> %

```

These exports come from (p292) `SemiGroup()`:

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?? : (%, %) -> %
***? : (%, PositiveInteger) -> %
?^? : (%, PositiveInteger) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean

```

— category MONOID Monoid —

```

)abbrev category MONOID Monoid
++ Description:
++ The class of multiplicative monoids, i.e. semigroups with a
++ multiplicative identity element.
++
++ Axioms\br
++ \tab{5}\spad{leftIdentity("":(%,%)>%,1)}\tab{5}\spad{1*x=x}\br
++ \tab{5}\spad{rightIdentity("":(%,%)>%,1)}\tab{4}\spad{x*1=x}
++
++ Conditional attributes\br
++ \tab{5}unitsKnown - \spadfun{recip} only returns "failed" on non-units

Monoid(): Category == SemiGroup with
  1: constant -> %
    ++ 1 is the multiplicative identity.
  sample: constant -> %
    ++ sample yields a value of type %
  one?: % -> Boolean
    ++ one?(x) tests if x is equal to 1.
  "***": (%, NonNegativeInteger) -> %

```

```

    ++ x**n returns the repeated product
    ++ of x n times, i.e. exponentiation.
    "^" : (% , NonNegativeInteger) -> %
    ++ x^n returns the repeated product
    ++ of x n times, i.e. exponentiation.
    recip: % -> Union(% , "failed")
    ++ recip(x) tries to compute the multiplicative inverse for x
    ++ or "failed" if it cannot find the inverse (see unitsKnown).
add
import RepeatedSquaring(%)
_^(x:% , n:NonNegativeInteger):% == x ** n
one? x == x = 1
sample() == 1
recip x ==
  (x = 1) => x
  "failed"
x:% ** n:NonNegativeInteger ==
  zero? n => 1
  expt(x,n pretend PositiveInteger)

_____

— MONOID.dotabb —

"MONOID"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=MONOID" ];
"MONOID" -> "SGROUP"

_____

— MONOID.dotfull —

"Monoid()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=MONOID" ];
"Monoid()" -> "SemiGroup()"

_____

— MONOID.dotpic —

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

```

```

"Monoid()" [color=lightblue];
"Monoid()" -> "SemiGroup()"

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SetCategory()"
"SemiGroup()" -> "RepeatedSquaring(a:SemiGroup)"

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"RepeatedSquaring(a:SemiGroup)" [color="#00EE00"];
"RepeatedSquaring(a:SemiGroup)" -> "RepeatedSquaring(a:SetCategory)"

"RepeatedSquaring(a:SetCategory)" [color="#00EE00"];
"RepeatedSquaring(a:SetCategory)" -> "Package"

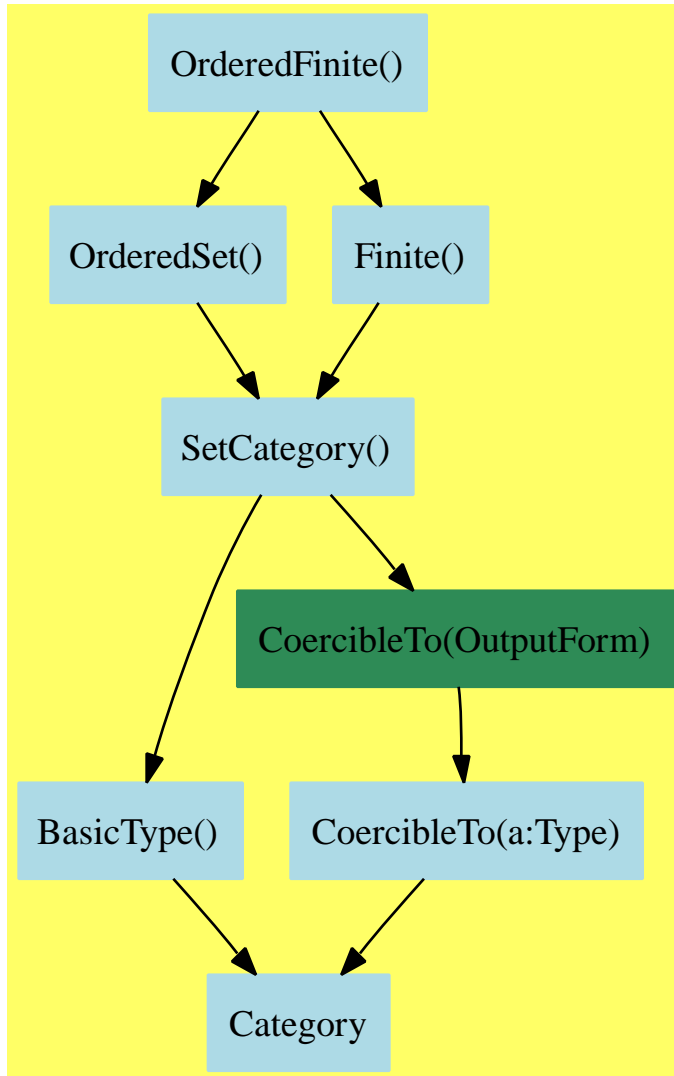
"Package" [color="#00EE00"];

"Category" [color=lightblue];

}

```

OrderedFinite (ORDFIN)



— OrderedFinite.input —

```

)set break resume
)sys rm -f OrderedFinite.output
)spool OrderedFinite.output
)set message test on
)set message auto off
)clear all
  
```

```

--S 1 of 1
)show OrderedFinite
--R OrderedFinite is a category constructor
--R Abbreviation for OrderedFinite is ORDFIN
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ORDFIN
--R
--R----- Operations -----
--R ?<? : (%,% ) -> Boolean          ?<=? : (%,% ) -> Boolean
--R ?=? : (%,% ) -> Boolean          ?>? : (%,% ) -> Boolean
--R ?>=? : (%,% ) -> Boolean        coerce : % -> OutputForm
--R enumerate : () -> List(%)       hash : % -> SingleInteger
--R index : PositiveInteger -> %    latex : % -> String
--R lookup : % -> PositiveInteger    max : (%,% ) -> %
--R min : (%,% ) -> %               random : () -> %
--R size : () -> NonNegativeInteger ?~=? : (%,% ) -> Boolean
--R
--E 1

)spool
)lisp (bye)

```

— OrderedFinite.help —

=====

OrderedFinite examples

=====

This is the category of Ordered finite sets.

See Also:

o)show OrderedFinite

See:

⇐ “Finite” (FINITE) [4](#) on page [218](#)

⇐ “OrderedSet” (ORDSET) [4](#) on page [269](#)

Exports:

| | | | | |
|--------|------|--------|-------|--------|
| coerce | hash | index | latex | lookup |
| max | min | random | size | ?~=? |
| ?<? | ?<=? | ?=? | ?>? | ?>=? |

These exports come from (p269) `OrderedSet()`:

```
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
max : (%,%) -> %
min : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?<? : (%,%) -> Boolean
?<=? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean
```

These exports come from (p218) `Finite()`:

```
index : PositiveInteger -> %
lookup : % -> PositiveInteger
random : () -> %
size : () -> NonNegativeInteger
```

— category ORDFIN OrderedFinite —

```
)abbrev category ORDFIN OrderedFinite
++ Description:
++ Ordered finite sets.
```

```
OrderedFinite(): Category == Join(OrderedSet, Finite)
```

—————

— ORDFIN.dotabb —

```
"ORDFIN"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ORDFIN" ];
"ORDFIN" -> "ORDSET"
"ORDFIN" -> "FINITE"
```

—————

— ORDFIN.dotfull —

```
"OrderedFinite()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ORDFIN" ];
"OrderedFinite()" -> "OrderedSet()"
"OrderedFinite()" -> "Finite()"
```

— ORDFIN.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrderedFinite()" [color=lightblue];
  "OrderedFinite()" -> "OrderedSet()"
  "OrderedFinite()" -> "Finite()"

  "Finite()" [color=lightblue];
  "Finite()" -> "SetCategory()"

  "OrderedSet()" [color=lightblue];
  "OrderedSet()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

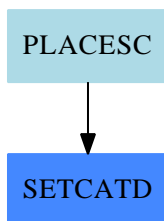
  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Category" [color=lightblue];
}

```

PlacesCategory (PLACESC)



— PlacesCategory.input —

```

)set break resume
)sys rm -f PlacesCategory.output
)spool PlacesCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PlacesCategory
--R
--R PlacesCategory(K: Field,PCS: LocalPowerSeriesCategory(t#1)) is a category constructor
--R Abbreviation for PlacesCategory is PLACESC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PLACESC
--R
--R----- Operations -----
--R ?? : (Integer,%) -> Divisor(%)      ?? : (%,%) -> Divisor(%)
--R -? : % -> Divisor(%)                ?-? : (%,%) -> Divisor(%)
--R ?? : (%,%) -> Boolean               coerce : % -> OutputForm
--R create : Symbol -> %                create : List(K) -> %
--R degree : % -> PositiveInteger        ?.? : (%,Integer) -> K
--R foundPlaces : () -> List(%)          hash : % -> SingleInteger
--R itsALeaf! : % -> Void                latex : % -> String
--R leaf? : % -> Boolean                 localParam : % -> List(PCS)
--R reduce : List(%) -> Divisor(%)       setParam! : (%,List(PCS)) -> Void
--R ?~=? : (%,%) -> Boolean
--R ?+? : (%,Divisor(%)) -> Divisor(%)
--R ?+? : (Divisor(%),%) -> Divisor(%)
--R ?-? : (%,Divisor(%)) -> Divisor(%)
--R ?-? : (Divisor(%),%) -> Divisor(%)
--R setDegree! : (%,PositiveInteger) -> Void
--R setFoundPlacesToEmpty : () -> List(%)
--R
--E 1
  
```

```
)spool
)lisp (bye)
```

— PlacesCategory.help —

```
=====
PlacesCategory examples
=====
```

This is part of the PAFF package, related to projective space.

See Also:

o)show PlacesCategory

See:

⇐ “SetCategoryWithDegree” (SETCATD) [4](#) on page [296](#)

Exports:

| | | | |
|-----------|------------|-----------------------|------------|
| -? | ?*? | ?+? | ?-? |
| ?.? | ?=? | ?~=? | coerce |
| create | degree | foundPlaces | hash |
| itsALeaf! | latex | leaf? | localParam |
| reduce | setDegree! | setFoundPlacesToEmpty | setParam! |

These are directly exported but not implemented:

```
-? : % -> Divisor %
?*? : (Integer,%) -> Divisor %
?+? : (%,%) -> Divisor %
?+? : (%,Divisor %) -> Divisor %
?+? : (Divisor %,%) -> Divisor %
?-? : (%,%) -> Divisor %
?-? : (%,Divisor %) -> Divisor %
?-? : (Divisor %,%) -> Divisor %
?.? : (%,Integer) -> K
create : List K -> %
create : Symbol -> %
foundPlaces : () -> List %
itsALeaf! : % -> Void
leaf? : % -> Boolean
localParam : % -> List PCS
reduce : List % -> Divisor %
```

```

setDegree! : (% , PositiveInteger) -> Void
setFoundPlacesToEmpty : () -> List %
setParam! : (% , List PCS) -> Void

```

These exports come from (p296) SetCategoryWithDegree

```

?=? : (% , %) -> Boolean
?~=? : (% , %) -> Boolean
coerce : % -> OutputForm
degree : % -> PositiveInteger
hash : % -> SingleInteger
latex : % -> String

```

— category PLACESC PlacesCategory —

```

)abbrev category PLACESC PlacesCategory
++ Author: Gaetan Hache
++ Date Created: 17 nov 1992
++ Date Last Updated: May 2010 by Tim Daly
++ Description:
++ This is part of the PAFF package, related to projective space.
PlacesCategory(K:Field,PCS:LocalPowerSeriesCategory(K)):Category
== SetCategoryWithDegree with

  "+": (% , %) -> Divisor(%)

  "+": (Divisor(%) , % ) -> Divisor(%)

  "+": (% , Divisor(%)) -> Divisor(%)

  "-": (% , %) -> Divisor(%)

  "-": (Divisor(%) , % ) -> Divisor(%)

  "-": (% , Divisor(%)) -> Divisor(%)

  "-": % -> Divisor(%)

  "*": (Integer , %) -> Divisor(%)

  reduce: List % -> Divisor(%)

  create: List K -> %

  create: Symbol -> %

  localParam: % -> List PCS
    ++ localParam(pl) returns the local parametrization associated
    ++ to the place pl.

```

```

setParam_!: (% ,List PCS) -> Void
  ++ setParam!(pl,ls) set the local parametrization of pl to ls.

setDegree_!: (% ,PositiveInteger) -> Void
  ++ setDegree!(pl,ls) set the degree.

leaf?: % -> Boolean
  ++ leaf?(pl) test if the place pl correspond to a leaf of a
  ++ desingularisation tree.

itsALeaf_!: % -> Void

foundPlaces: () -> List %
  ++ foundPlaces() returns the list of all "created" places up to now.

setFoundPlacesToEmpty: () -> List %
  ++ setFoundPlacesToEmpty() does what it says.
  ++ (this should not be used)!!!

elt: (% ,Integer) -> K
  ++ elt returns the value of a specified coordinates if the places
  ++ correspnd to a simple point

```

— PLACESC.dotabb —

```

"PLACESC" [color=lightblue,href="bookvol10.2.pdf#nameddest=PLACESC"];
"SETCATD" [color="#4488FF",href="bookvol10.2.pdf#nameddest=SETCATD"]
"PLACESC" -> "SETCATD"

```

— PLACESC.dotfull —

```

"PlacesCategory()" [color=lightblue,href="bookvol10.2.pdf#nameddest=PLACESC"];
"PlacesCategory()" -> "SetCategoryWithDegree()"

```

— PLACESC.dotpic —

```

digraph pic {
  fontsize=10;

```

```

bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"PlacesCategory()" [color=lightblue];
"PlacesCategory()" -> "SetCategoryWithDegree()"

"SetCategoryWithDegree()" [color=lightblue];
"SetCategoryWithDegree()" -> "BasicType()"
"SetCategoryWithDegree()" -> "CoercibleTo(OutputForm)"
"SetCategoryWithDegree()" -> "SetCategory()"

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

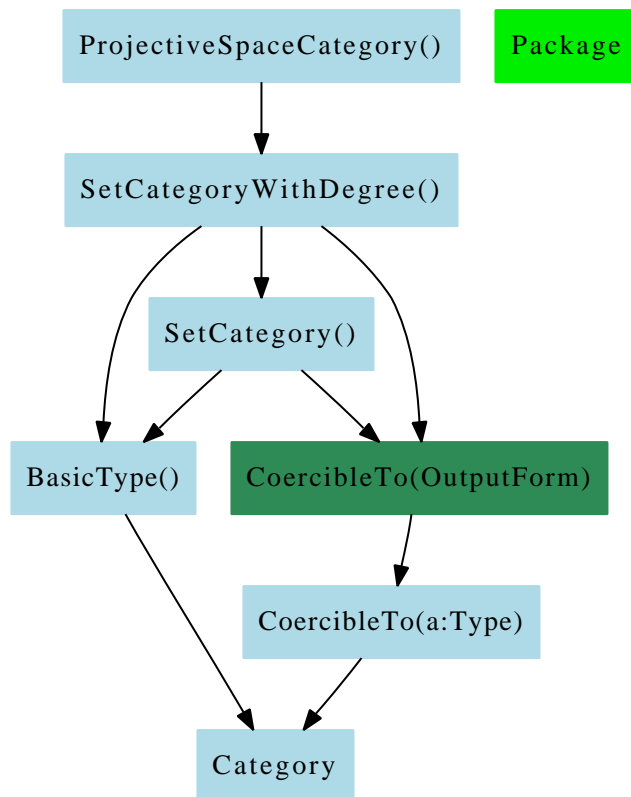
"Package" [color="#00EE00"];

"Category" [color=lightblue];

}

```

ProjectiveSpaceCategory (PRSPCAT)



— ProjectiveSpaceCategory.input —

```

)set break resume
)sys rm -f ProjectiveSpaceCategory.output
)spool ProjectiveSpaceCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ProjectiveSpaceCategory
--R
--R ProjectiveSpaceCategory(K: Field) is a category constructor
--R Abbreviation for ProjectiveSpaceCategory is PRSPCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PRSPCAT
--R

```

```

--R----- Operations -----
--R ?=? : (%,%) -> Boolean          coerce : List(K) -> %
--R coerce : % -> List(K)           coerce : % -> OutputForm
--R conjugate : % -> %              definingField : % -> K
--R degree : % -> PositiveInteger   ?? : (%,Integer) -> K
--R hash : % -> SingleInteger        homogenize : % -> %
--R homogenize : (%,Integer) -> %    lastNonNul : % -> Integer
--R lastNonNull : % -> Integer       latex : % -> String
--R list : % -> List(K)              orbit : % -> List(%)
--R pointValue : % -> List(K)        projectivePoint : List(K) -> %
--R rational? : % -> Boolean         setelt : (%,Integer,K) -> K
--R ?~=? : (%,%) -> Boolean
--R conjugate : (%,NonNegativeInteger) -> %
--R orbit : (%,NonNegativeInteger) -> List(%)
--R rational? : (%,NonNegativeInteger) -> Boolean
--R removeConjugate : List(%) -> List(%)
--R removeConjugate : (List(%),NonNegativeInteger) -> List(%)
--R
--E 1

)spool
)lisp (bye)

```

— ProjectiveSpaceCategory.help —

```

=====
ProjectiveSpaceCategory examples
=====

```

This is part of the PAFF package, related to projective space.

See Also:

o)show ProjectiveSpaceCategory

See:

← “SetCategoryWithDegree” (SETCATD) [4](#) on page [296](#)

Exports:

| | | | |
|-----------------|---------------|-----------------|------------|
| ?? | ?=? | ?=? | coerce |
| conjugate | definingField | degree | hash |
| homogenize | lastNonNul | lastNonNull | latex |
| list | orbit | orbit | pointValue |
| projectivePoint | rational? | removeConjugate | setelt |

These are directly exported but not implemented:

```

?..? : (%,Integer) -> K
coerce : % -> List K
coerce : List K -> %
conjugate : % -> %
conjugate : (% ,NonNegativeInteger) -> %
definingField : % -> K
homogenize : % -> %
homogenize : (% ,Integer) -> %
lastNonNul : % -> Integer
lastNonNull : % -> Integer
list : % -> List K
orbit : % -> List %
orbit : (% ,NonNegativeInteger) -> List %
pointValue : % -> List K
projectivePoint : List K -> %
rational? : % -> Boolean
rational? : (% ,NonNegativeInteger) -> Boolean
removeConjugate : (List % ,NonNegativeInteger) -> List %
removeConjugate : List % -> List %
setelt : (% ,Integer,K) -> K

```

These exports come from (p296) SetCategoryWithDegree

```

?=? : (% ,%) -> Boolean
?~=? : (% ,%) -> Boolean
coerce : % -> OutputForm
degree : % -> PositiveInteger
hash : % -> SingleInteger
latex : % -> String

```

— category PRSPCAT ProjectiveSpaceCategory —

```

)abbrev category PRSPCAT ProjectiveSpaceCategory
++ Author: Gaetan Hache
++ Date Created: 17 nov 1992
++ Date Last Updated: May 2010 by Tim Daly
++ Description:
++ This is part of the PAFF package, related to projective space.
ProjectiveSpaceCategory(K:Field):Category == Implementation where

LIST ==> List

```

```

INT ==> Integer
NNI ==> NonNegativeInteger

Implementation ==>
SetCategoryWithDegree with

lastNonNul: % -> INT

homogenize: (% ,INT) -> %
  ++ homogenize the point according to the coordinate specified
  ++ by the integer

projectivePoint: LIST(K) -> %
  ++ projectivePoint creates a projective point from a list

definingField: % -> K

coerce: % -> List(K)
  ++ coerce a a projective point list of K

coerce: LIST(K) -> %
  ++ coerce a list of K to a projective point.

orbit: % -> LIST %
  ++ orbit(p) returns the orbit of the point p according to the
  ++ characteristic of K, that is, for q= char K,
  ++ orbit(p) = \{ p, p**q, p**(q**2), p**(q**3), ..... \}

orbit: (% ,NNI) -> LIST %
  ++ orbit(p,n) returns the orbit of the point p according to n, that is
  ++ orbit(p,n) = \{ p, p**n, p**(n**2), p**(n**3), ..... \}

conjugate: (% ,NNI) -> %
  ++ conjugate(p,n) returns p**n, that is all the coordinates of p
  ++ to the power of n

conjugate: % -> %
  ++ conjugate(p) returns conjugate(p,n) where n is the
  ++ characteristic of the ground field.

removeConjugate: (LIST(%),NNI) -> LIST(%)
  ++ removeConjugate(lp,n) returns a list of points such that no points
  ++ in the list is the conjugate (according to n) of another point.

removeConjugate: LIST(%) -> LIST(%)
  ++ removeConjugate(lp) returns removeConjugate(lp,n)
  ++ where n is the characteristic of the ground field.

rational?: (% ,NNI) -> Boolean
  ++ rational?(p,n) test if the point is rational according to n.

```

```

rational?: % -> Boolean
  ++ rational?(p) test if the point is rational according to the
  ++ characteristic of the ground field.

homogenize: % -> %
  ++ homogenize(pt) the point according to the coordinate
  ++ which is the last non null.

lastNonNull: % -> INT
  ++ lastNonNull returns the integer corresponding to the last
  ++ non null coordinates.

list : % -> LIST(K)
  ++ list returns the list of the coordinates

elt: (% ,INT) -> K
  ++ elt returns the value of a specified coordinates

setelt: (% ,INT,K) -> K
  ++ setelt sets the value of a specified coordinates

pointValue: % -> LIST(K)
  ++ pointValue returns the coordinates of the point or of the point
  ++ of origin that represent an infinitely close point

```

— PRSPCAT.dotabb —

```

"PRSPCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PRSPCAT"];
"PRSPCAT" -> "SETCATD"

```

— PRSPCAT.dotfull —

```

"ProjectiveSpaceCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PRSPCAT"];
"ProjectiveSpaceCategory()" -> "SetCategoryWithDegree()"

```

— PRSPCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ProjectiveSpaceCategory()" [color=lightblue];
  "ProjectiveSpaceCategory()" -> "SetCategoryWithDegree()"

  "SetCategoryWithDegree()" [color=lightblue];
  "SetCategoryWithDegree()" -> "BasicType()"
  "SetCategoryWithDegree()" -> "CoercibleTo(OutputForm)"
  "SetCategoryWithDegree()" -> "SetCategory()"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

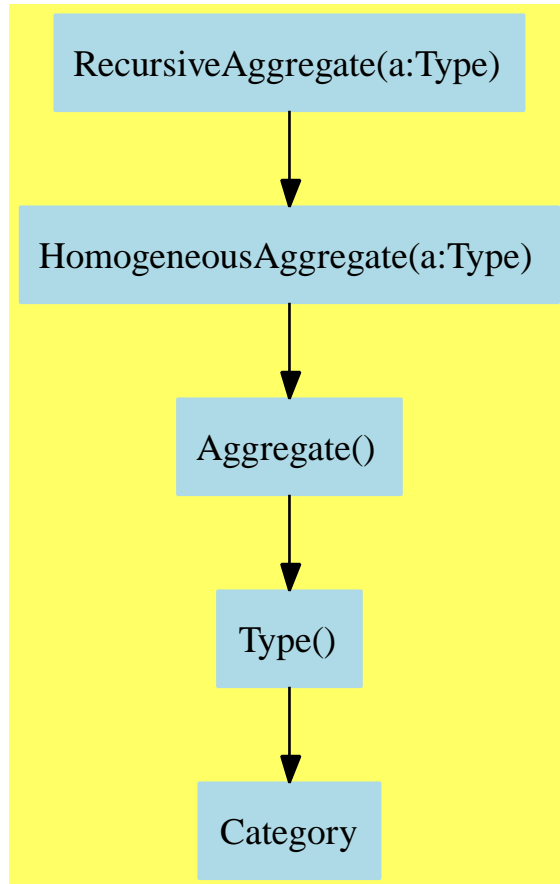
  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

  "Package" [color="#00EE00"];

  "Category" [color=lightblue];
}

```

RecursiveAggregate (RCAGG)



— RecursiveAggregate.input —

```

)set break resume
)sys rm -f RecursiveAggregate.output
)spool RecursiveAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RecursiveAggregate
--R
--R RecursiveAggregate(S: Type) is a category constructor
--R Abbreviation for RecursiveAggregate is RCAGG
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RCAGG
--R
--R----- Operations -----
--R children : % -> List(%)          copy : % -> %
--R cyclic? : % -> Boolean           distance : (%,%) -> Integer
--R ?.value : (%,value) -> S         empty : () -> %
--R empty? : % -> Boolean            eq? : (%,%) -> Boolean
--R leaf? : % -> Boolean             leaves : % -> List(S)
--R map : ((S -> S),%) -> %          nodes : % -> List(%)
--R sample : () -> %                value : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (%,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R child? : (%,%) -> Boolean if S has SETCAT
--R coerce : % -> OutputForm if S has SETCAT
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R node? : (%,%) -> Boolean if S has SETCAT
--R parts : % -> List(S) if $ has finiteAggregate
--R setchildren! : (%,List(%)) -> % if $ has shallowlyMutable
--R setelt : (%,value,S) -> S if $ has shallowlyMutable
--R setvalue! : (%,S) -> S if $ has shallowlyMutable
--R size? : (%,NonNegativeInteger) -> Boolean
--R ?~=? : (%,%) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— RecursiveAggregate.help —

```

=====
RecursiveAggregate examples
=====

```

A recursive aggregate over a type `S` is a model for a directed graph containing values of type `S`. Recursively, a recursive aggregate is a node consisting of a value from `S` and 0 or more children which are recursive aggregates. A node with no children is called a leaf node. A recursive aggregate may be cyclic for which some operations as noted may go into an infinite loop.

See Also:

o `)show RecursiveAggregate`

See:

⇒ “BinaryRecursiveAggregate” (BRAGG) [6](#) on page [426](#)

⇒ “DoublyLinkedAggregate” (DLAGG) [6](#) on page [446](#)

⇒ “UnaryRecursiveAggregate” (URAGG) [6](#) on page [560](#)

⇐ “HomogeneousAggregate” (HOAGG) [4](#) on page [233](#)

Exports:

| | | | | |
|----------------------|----------------------|---------------------------|---------------------|------------------------|
| <code>any?</code> | <code>child?</code> | <code>children</code> | <code>coerce</code> | <code>copy</code> |
| <code>count</code> | <code>cyclic?</code> | <code>distance</code> | <code>empty</code> | <code>empty?</code> |
| <code>eq?</code> | <code>eval</code> | <code>every?</code> | <code>hash</code> | <code>latex</code> |
| <code>leaf?</code> | <code>leaves</code> | <code>less?</code> | <code>map</code> | <code>map!</code> |
| <code>member?</code> | <code>members</code> | <code>more?</code> | <code>nodes</code> | <code>node?</code> |
| <code>parts</code> | <code>sample</code> | <code>setchildren!</code> | <code>setelt</code> | <code>setvalue!</code> |
| <code>size?</code> | <code>value</code> | <code>?.value</code> | <code>?~=?</code> | <code>#?</code> |
| <code>?=?</code> | | | | |

Attributes exported:

- `nil`

Attributes Used:

- `shallowlyMutable` is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the `shallowlyMutable` proper.

These are directly exported but not implemented:

```
children : % -> List %
cyclic?  : % -> Boolean
distance : (%,% ) -> Integer
nodes    : % -> List %
leaf?    : % -> Boolean
```

```

leaves : % -> List S
node? : (%,% ) -> Boolean if S has SETCAT
setchildren! : (% ,List % ) -> % if $ has shallowlyMutable
setvalue! : (% ,S) -> S if $ has shallowlyMutable
value : % -> S

```

These are implemented by this category:

```

child? : (%,% ) -> Boolean if S has SETCAT
setelt : (% ,value,S) -> S if $ has shallowlyMutable
?.value : (% ,value) -> S

```

These exports come from (p233) `HomogeneousAggregate(S:Type)`:

```

any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
coerce : % -> OutputForm if S has SETCAT
copy : % -> %
count : (S,% ) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,% ) -> Boolean
eval : (% ,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (% ,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (% ,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (% ,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
less? : (% ,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,% ) -> Boolean
      if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (% ,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
sample : () -> %
size? : (% ,NonNegativeInteger) -> Boolean
?~=?: (%,% ) -> Boolean if S has SETCAT
#?: % -> NonNegativeInteger if $ has finiteAggregate
?=: (%,% ) -> Boolean if S has SETCAT

```


— category RCAGG RecursiveAggregate —

```

)abbrev category RCAGG RecursiveAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A recursive aggregate over a type S is a model for a
++ a directed graph containing values of type S.
++ Recursively, a recursive aggregate is a node
++ consisting of a \spadfun{value} from S and 0 or more \spadfun{children}
++ which are recursive aggregates.
++ A node with no children is called a \spadfun{leaf} node.
++ A recursive aggregate may be cyclic for which some operations as noted
++ may go into an infinite loop.

RecursiveAggregate(S:Type): Category == HomogeneousAggregate(S) with
  children: % -> List %
    ++ children(u) returns a list of the children of aggregate u.
    -- should be % -> %* and also needs children: % -> Iterator(S,S)
  nodes: % -> List %
    ++ nodes(u) returns a list of all of the nodes of aggregate u.
    -- to become % -> %* and also nodes: % -> Iterator(S,S)
  leaf?: % -> Boolean
    ++ leaf?(u) tests if u is a terminal node.
  value: % -> S
    ++ value(u) returns the value of the node u.
  elt: (%,"value") -> S
    ++ elt(u,"value") (also written: \axiom{a. value}) is
    ++ equivalent to \axiom{value(a)}.
  cyclic?: % -> Boolean
    ++ cyclic?(u) tests if u has a cycle.
  leaves: % -> List S
    ++ leaves(t) returns the list of values in obtained by visiting the
    ++ nodes of tree \axiom{t} in left-to-right order.
  distance: (%,% ) -> Integer
    ++ distance(u,v) returns the path length (an integer) from node u to v.
  if S has SetCategory then
    child?: (%,% ) -> Boolean
      ++ child?(u,v) tests if node u is a child of node v.
    node?: (%,% ) -> Boolean
      ++ node?(u,v) tests if node u is contained in node v
      ++ (either as a child, a child of a child, etc.).
  if % has shallowlyMutable then
    setchildren_!: (% ,List % )->%
      ++ setchildren!(u,v) replaces the current children of node u
      ++ with the members of v in left-to-right order.
    setelt: (%,"value",S) -> S
      ++ setelt(a,"value",x) (also written \axiom{a . value := x})

```

```

    ++ is equivalent to \axiom{setvalue!(a,x)}
    setvalue_!: (%S) -> S
    ++ setvalue!(u,x) sets the value of node u to x.
add
  elt(x,"value") == value x
  if % has shallowlyMutable then
    setelt(x,"value",y) == setvalue_!(x,y)
  if S has SetCategory then
    child?(x,l) == member?(x,children(l))

    -----

    — RCAGG.dotabb —

    "RCAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=RCAGG"];
    "RCAGG" -> "HOAGG"

    -----

    — RCAGG.dotfull —

    "RecursiveAggregate(a:Type)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=RCAGG"];
    "RecursiveAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

    -----

    — RCAGG.dotpic —

    digraph pic {
      fontsize=10;
      bgcolor="#ECEA81";
      node [shape=box, color=white, style=filled];

      "RecursiveAggregate(a:Type)" [color=lightblue];
      "RecursiveAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

      "HomogeneousAggregate(a:Type)" [color=lightblue];
      "HomogeneousAggregate(a:Type)" -> "Aggregate()"

      "Aggregate()" [color=lightblue];
      "Aggregate()" -> "Type()"

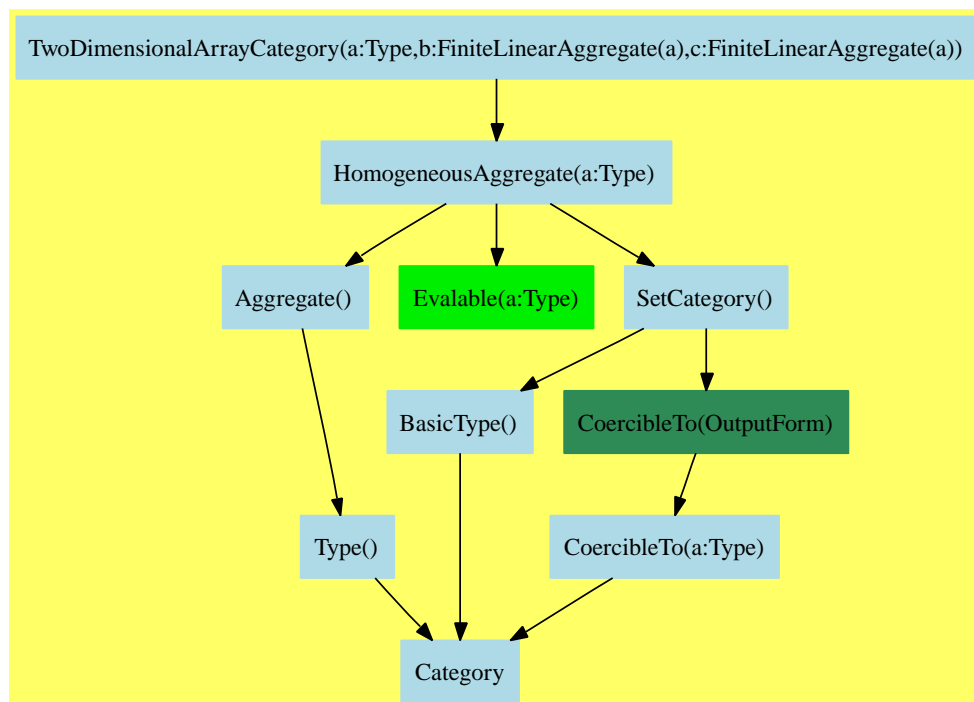
      "Type()" [color=lightblue];
      "Type()" -> "Category"

```

```
"Category" [color=lightblue];
}
```

—————→

TwoDimensionalArrayCategory (ARR2CAT)



TwoDimensionalArrayCategory is a general array category which allows different representations and indexing schemes. Rows and columns may be extracted with rows returned as objects of type Row and columns returned as objects of type Col. The index of the 'first' row may be obtained by calling the function 'minRowIndex'. The index of the 'first' column may be obtained by calling the function 'minColIndex'. The index of the first element of a 'Row' is the same as the index of the first column in an array and vice versa.

— TwoDimensionalArrayCategory.input —

```
)set break resume
)sys rm -f TwoDimensionalArrayCategory.output
```

```

)spool TwoDimensionalArrayCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show TwoDimensionalArrayCategory
--R
--R TwoDimensionalArrayCategory(R: Type, Row: FiniteLinearAggregate(t#1), Col: FiniteLinearAggregate(t#1)) is
--R Abbreviation for TwoDimensionalArrayCategory is ARR2CAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ARR2CAT
--R
--R----- Operations -----
--R column : (% , Integer) -> Col          copy : % -> %
--R elt : (% , Integer, Integer, R) -> R    elt : (% , Integer, Integer) -> R
--R empty : () -> %                        empty? : % -> Boolean
--R eq? : (% , %) -> Boolean               fill! : (% , R) -> %
--R map : (((R, R) -> R) , % , % , R) -> %  map : (((R, R) -> R) , % , %) -> %
--R map : ((R -> R) , %) -> %              map! : ((R -> R) , %) -> %
--R maxColIndex : % -> Integer             maxRowIndex : % -> Integer
--R minColIndex : % -> Integer             minRowIndex : % -> Integer
--R ncols : % -> NonNegativeInteger        nrows : % -> NonNegativeInteger
--R parts : % -> List(R)                   qelt : (% , Integer, Integer) -> R
--R row : (% , Integer) -> Row             sample : () -> %
--R setRow! : (% , Integer, Row) -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (% , %) -> Boolean if R has SETCAT
--R any? : ((R -> Boolean) , %) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if R has SETCAT
--R count : (R , %) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
--R count : ((R -> Boolean) , %) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (% , List(R) , List(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (% , R , R) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (% , Equation(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (% , List(Equation(R))) -> % if R has EVALAB(R) and R has SETCAT
--R every? : ((R -> Boolean) , %) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if R has SETCAT
--R latex : % -> String if R has SETCAT
--R less? : (% , NonNegativeInteger) -> Boolean
--R member? : (R , %) -> Boolean if R has SETCAT and $ has finiteAggregate
--R members : % -> List(R) if $ has finiteAggregate
--R more? : (% , NonNegativeInteger) -> Boolean
--R new : (NonNegativeInteger , NonNegativeInteger , R) -> %
--R qsetelt! : (% , Integer, Integer, R) -> R
--R setColumn! : (% , Integer, Col) -> %
--R setelt : (% , Integer, Integer, R) -> R
--R size? : (% , NonNegativeInteger) -> Boolean
--R ?~=? : (% , %) -> Boolean if R has SETCAT
--R

```

```
--E 1
```

```
)spool
)lisp (bye)
```

— TwoDimensionalArrayCategory.help —

```
=====
TwoDimensionalArrayCategory examples
=====
```

This is the category of two dimensional array categories and domains.

See Also:

o)show TwoDimensionalArrayCategory

See:

⇒ “MatrixCategory” (MATCAT) [6](#) on page [466](#)

⇐ “HomogeneousAggregate” (HOAGG) [4](#) on page [233](#)

Exports:

| | | | | |
|---------|-------------|-------------|-------------|----------|
| any? | column | coerce | copy | count |
| elt | empty | empty? | eq? | eval |
| every? | fill! | hash | latex | less? |
| map | map! | maxColIndex | maxRowIndex | member? |
| members | minColIndex | minRowIndex | more? | ncols |
| new | nrows | parts | qelt | qsetelt! |
| row | sample | setColumn! | setRow! | setelt |
| size? | #? | ?=? | ?~=? | |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

Attributes Used:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```
elt : (%,Integer,Integer) -> R
maxColIndex : % -> Integer
maxRowIndex : % -> Integer
minColIndex : % -> Integer
minRowIndex : % -> Integer
new : (NonNegativeInteger,NonNegativeInteger,R) -> %
ncols : % -> NonNegativeInteger
nrows : % -> NonNegativeInteger
qelt : (%,Integer,Integer) -> R
qsetelt! : (%,Integer,Integer,R) -> R
setelt : (%,Integer,Integer,R) -> R
```

These are implemented by this category:

```
any? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
coerce : % -> OutputForm if R has SETCAT
column : (%,Integer) -> Col
copy : % -> %
count : ((R -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
count : (R,%) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
elt : (%,Integer,Integer,R) -> R
every? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
fill! : (%,R) -> %
less? : (%,NonNegativeInteger) -> Boolean
map : ((R -> R),%) -> %
map : (((R,R) -> R),%,%) -> %
map : (((R,R) -> R),%,%,R) -> %
map! : ((R -> R),%) -> %
member? : (R,%) -> Boolean if R has SETCAT and $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List R
row : (%,Integer) -> Row
setColumn! : (%,Integer,Col) -> %
setRow! : (%,Integer,Row) -> %
size? : (%,NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
?=? : (%,%) -> Boolean if R has SETCAT
```

These exports come from (p233) `HomogeneousAggregate(R:Type)`

```
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
```

```

eval : (% , List R , List R) -> % if R has EVALAB R and R has SETCAT
eval : (% , R , R) -> % if R has EVALAB R and R has SETCAT
eval : (% , Equation R) -> % if R has EVALAB R and R has SETCAT
eval : (% , List Equation R) -> % if R has EVALAB R and R has SETCAT
hash : % -> SingleInteger if R has SETCAT
latex : % -> String if R has SETCAT
members : % -> List R if $ has finiteAggregate
sample : () -> %
?~=?: (% , %) -> Boolean if R has SETCAT

```

— category ARR2CAT TwoDimensionalArrayCategory —

```

)abbrev category ARR2CAT TwoDimensionalArrayCategory
++ Date Created: 27 October 1989
++ Date Last Updated: 27 June 1990
++ Keywords: array, data structure
++ Description:
++ Two dimensional array categories and domains

TwoDimensionalArrayCategory(R,Row,Col): Category == Definition where
R   : Type
Row : FiniteLinearAggregate R
Col : FiniteLinearAggregate R

Definition == HomogeneousAggregate(R) with

  shallowlyMutable
  ++ one may destructively alter arrays

  finiteAggregate
  ++ two-dimensional arrays are finite

--% Array creation

new: (NonNegativeInteger,NonNegativeInteger,R) -> %
++ new(m,n,r) is an m-by-n array all of whose entries are r
++
++X arr : ARRAY2 INT := new(5,4,0)

fill_!: (% , R) -> %
++ fill!(m,r) fills m with r's
++
++X arr : ARRAY2 INT := new(5,4,0)
++X fill!(arr,10)

--% Size inquiries

minRowIndex : % -> Integer
++ minRowIndex(m) returns the index of the 'first' row of the array m

```

```

++
++X arr : ARRAY2 INT := new(5,4,10)
++X minRowIndex(arr)

maxRowIndex : % -> Integer
++ maxRowIndex(m) returns the index of the 'last' row of the array m
++
++X arr : ARRAY2 INT := new(5,4,10)
++X maxRowIndex(arr)

minColIndex : % -> Integer
++ minColIndex(m) returns the index of the 'first' column of the array m
++
++X arr : ARRAY2 INT := new(5,4,10)
++X minColIndex(arr)

maxColIndex : % -> Integer
++ maxColIndex(m) returns the index of the 'last' column of the array m
++
++X arr : ARRAY2 INT := new(5,4,10)
++X maxColIndex(arr)

nrows : % -> NonNegativeInteger
++ nrows(m) returns the number of rows in the array m
++
++X arr : ARRAY2 INT := new(5,4,10)
++X nrows(arr)

ncols : % -> NonNegativeInteger
++ ncols(m) returns the number of columns in the array m
++
++X arr : ARRAY2 INT := new(5,4,10)
++X ncols(arr)

--% Part extractions

elt: (%,Integer,Integer) -> R
++ elt(m,i,j) returns the element in the ith row and jth
++ column of the array m
++ error check to determine if indices are in proper ranges
++
++X arr : ARRAY2 INT := new(5,4,10)
++X elt(arr,1,1)

qelt: (%,Integer,Integer) -> R
++ qelt(m,i,j) returns the element in the ith row and jth
++ column of the array m
++ NO error check to determine if indices are in proper ranges
++
++X arr : ARRAY2 INT := new(5,4,10)

```



```

++X qelt(arr,1,1)

elt: (%,Integer,Integer,R) -> R
++ elt(m,i,j,r) returns the element in the ith row and jth
++ column of the array m, if m has an ith row and a jth column,
++ and returns r otherwise
++
++X arr : ARRAY2 INT := new(5,4,10)
++X elt(arr,1,1,6)
++X elt(arr,1,10,6)

row: (%,Integer) -> Row
++ row(m,i) returns the ith row of m
++ error check to determine if index is in proper ranges
++
++X arr : ARRAY2 INT := new(5,4,10)
++X row(arr,1)

column: (%,Integer) -> Col
++ column(m,j) returns the jth column of m
++ error check to determine if index is in proper ranges
++
++X arr : ARRAY2 INT := new(5,4,10)
++X column(arr,1)

parts: % -> List R
++ parts(m) returns a list of the elements of m in row major order
++
++X arr : ARRAY2 INT := new(5,4,10)
++X parts(arr)

--% Part assignments

setelt: (%,Integer,Integer,R) -> R
-- will become setelt_!
++ setelt(m,i,j,r) sets the element in the ith row and jth
++ column of m to r
++ error check to determine if indices are in proper ranges
++
++X arr : ARRAY2 INT := new(5,4,0)
++X setelt(arr,1,1,17)

qsetelt_!: (%,Integer,Integer,R) -> R
++ qsetelt!(m,i,j,r) sets the element in the ith row and jth
++ column of m to r
++ NO error check to determine if indices are in proper ranges
++
++X arr : ARRAY2 INT := new(5,4,0)
++X qsetelt!(arr,1,1,17)

```

```

setRow_!: (%,Integer,Row) -> %
++ setRow!(m,i,v) sets to ith row of m to v
++
++X T1:=TwoDimensionalArray Integer
++X arr:T1:= new(5,4,0)
++X T2:=OneDimensionalArray Integer
++X arow:=construct([1,2,3,4]::List(INT))$T2
++X setRow!(arr,1,arow)$T1

setColumn_!: (%,Integer,Col) -> %
++ setColumn!(m,j,v) sets to jth column of m to v
++
++X T1:=TwoDimensionalArray Integer
++X arr:T1:= new(5,4,0)
++X T2:=OneDimensionalArray Integer
++X acol:=construct([1,2,3,4,5]::List(INT))$T2
++X setColumn!(arr,1,acol)$T1

--% Map and Zip

map: (R -> R,%) -> %
++ map(f,a) returns \spad{b}, where \spad{b(i,j) = f(a(i,j))}
++ for all \spad{i, j}
++
++X arr : ARRAY2 INT := new(5,4,10)
++X map(-,arr)
++X map((x +-> x + x),arr)

map_!: (R -> R,%) -> %
++ map!(f,a) assign \spad{a(i,j)} to \spad{f(a(i,j))}
++ for all \spad{i, j}
++X arr : ARRAY2 INT := new(5,4,10)
++X map!(-,arr)

map: ((R,R) -> R,%,% ) -> %
++ map(f,a,b) returns \spad{c}, where \spad{c(i,j) = f(a(i,j),b(i,j))}
++ for all \spad{i, j}
++
++X adder(a:Integer,b:Integer):Integer == a+b
++X arr : ARRAY2 INT := new(5,4,10)
++X map(adder,arr,arr)

map: ((R,R) -> R,%,% ,R) -> %
++ map(f,a,b,r) returns \spad{c}, where \spad{c(i,j) = f(a(i,j),b(i,j))}
++ when both \spad{a(i,j)} and \spad{b(i,j)} exist;
++ else \spad{c(i,j) = f(r, b(i,j))} when \spad{a(i,j)} does not exist;
++ else \spad{c(i,j) = f(a(i,j),r)} when \spad{b(i,j)} does not exist;
++ otherwise \spad{c(i,j) = f(r,r)}.
++
++X adder(a:Integer,b:Integer):Integer == a+b

```

```

++X arr1 : ARRAY2 INT := new(5,4,10)
++X arr2 : ARRAY2 INT := new(3,3,10)
++X map(adder,arr1,arr2,17)

add

--% Predicates

any?(f,m) ==
  for i in minRowIndex(m)..maxRowIndex(m) repeat
    for j in minColIndex(m)..maxColIndex(m) repeat
      f(qelt(m,i,j)) => return true
    false
  false

every?(f,m) ==
  for i in minRowIndex(m)..maxRowIndex(m) repeat
    for j in minColIndex(m)..maxColIndex(m) repeat
      not f(qelt(m,i,j)) => return false
    true
  true

size?(m,n) == nrow(m) * ncol(m) = n
less?(m,n) == nrow(m) * ncol(m) < n
more?(m,n) == nrow(m) * ncol(m) > n

--% Size inquiries

# m == nrow(m) * ncol(m)

--% Part extractions

elt(m,i,j,r) ==
  i < minRowIndex(m) or i > maxRowIndex(m) => r
  j < minColIndex(m) or j > maxColIndex(m) => r
  qelt(m,i,j)

count(f:R -> Boolean,m:%) ==
  num : NonNegativeInteger := 0
  for i in minRowIndex(m)..maxRowIndex(m) repeat
    for j in minColIndex(m)..maxColIndex(m) repeat
      if f(qelt(m,i,j)) then num := num + 1
    num

parts m ==
  entryList : List R := nil()
  for i in maxRowIndex(m)..minRowIndex(m) by -1 repeat
    for j in maxColIndex(m)..minColIndex(m) by -1 repeat
      entryList := concat(qelt(m,i,j),entryList)
  entryList

--% Creation

```

```

copy m ==
  ans := new(nrows m,ncols m,NIL$Lisp)
  for i in minRowIndex(m)..maxRowIndex(m) repeat
    for j in minColIndex(m)..maxColIndex(m) repeat
      qsetelt_!(ans,i,j,qelt(m,i,j))
  ans

fill_!(m,r) ==
  for i in minRowIndex(m)..maxRowIndex(m) repeat
    for j in minColIndex(m)..maxColIndex(m) repeat
      qsetelt_!(m,i,j,r)
  m

map(f,m) ==
  ans := new(nrows m,ncols m,NIL$Lisp)
  for i in minRowIndex(m)..maxRowIndex(m) repeat
    for j in minColIndex(m)..maxColIndex(m) repeat
      qsetelt_!(ans,i,j,f(qelt(m,i,j)))
  ans

map_!(f,m) ==
  for i in minRowIndex(m)..maxRowIndex(m) repeat
    for j in minColIndex(m)..maxColIndex(m) repeat
      qsetelt_!(m,i,j,f(qelt(m,i,j)))
  m

map(f,m,n) ==
  (nrows(m) ^= nrows(n)) or (ncols(m) ^= ncols(n)) =>
    error "map: arguments must have same dimensions"
  ans := new(nrows m,ncols m,NIL$Lisp)
  for i in minRowIndex(m)..maxRowIndex(m) repeat
    for j in minColIndex(m)..maxColIndex(m) repeat
      qsetelt_!(ans,i,j,f(qelt(m,i,j),qelt(n,i,j)))
  ans

map(f,m,n,r) ==
  maxRow := max(maxRowIndex m,maxRowIndex n)
  maxCol := max(maxColIndex m,maxColIndex n)
  ans := new(max(nrows m,nrows n),max(ncols m,ncols n),NIL$Lisp)
  for i in minRowIndex(m)..maxRow repeat
    for j in minColIndex(m)..maxCol repeat
      qsetelt_!(ans,i,j,f(elt(m,i,j,r),elt(n,i,j,r)))
  ans

setRow_!(m,i,v) ==
  i < minRowIndex(m) or i > maxRowIndex(m) =>
    error "setRow!: index out of range"
  for j in minColIndex(m)..maxColIndex(m) _
    for k in minIndex(v)..maxIndex(v) repeat

```

```

        qsetelt_!(m,i,j,v.k)
    m

setColumn_!(m,j,v) ==
    j < minColIndex(m) or j > maxColIndex(m) =>
        error "setColumn!: index out of range"
    for i in minRowIndex(m)..maxRowIndex(m) _
        for k in minIndex(v)..maxIndex(v) repeat
            qsetelt_!(m,i,j,v.k)
    m

if R has _= : (R,R) -> Boolean then

    m = n ==
        eq?(m,n) => true
        (nrows(m) ^= nrows(n)) or (ncols(m) ^= ncols(n)) => false
    for i in minRowIndex(m)..maxRowIndex(m) repeat
        for j in minColIndex(m)..maxColIndex(m) repeat
            not (qelt(m,i,j) = qelt(n,i,j)) => return false
    true

    member?(r,m) ==
        for i in minRowIndex(m)..maxRowIndex(m) repeat
            for j in minColIndex(m)..maxColIndex(m) repeat
                qelt(m,i,j) = r => return true
        false

    count(r:R,m:%) == count(x +-> x = r,m)

if Row has shallowlyMutable then

    row(m,i) ==
        i < minRowIndex(m) or i > maxRowIndex(m) =>
            error "row: index out of range"
        v : Row := new(ncols m,NIL$Lisp)
        for j in minColIndex(m)..maxColIndex(m) _
            for k in minIndex(v)..maxIndex(v) repeat
                qsetelt_!(v,k,qelt(m,i,j))
        v

if Col has shallowlyMutable then

    column(m,j) ==
        j < minColIndex(m) or j > maxColIndex(m) =>
            error "column: index out of range"
        v : Col := new(nrows m,NIL$Lisp)
        for i in minRowIndex(m)..maxRowIndex(m) _
            for k in minIndex(v)..maxIndex(v) repeat
                qsetelt_!(v,k,qelt(m,i,j))
        v

```

```

if R has CoercibleTo(OutputForm) then

  coerce(m:%) ==
    l : List List OutputForm
    l := [[qelt(m,i,j) :: OutputForm _
            for j in minColIndex(m)..maxColIndex(m)] _
            for i in minRowIndex(m)..maxRowIndex(m)]
  matrix l

_____

— ARR2CAT.dotabb —

"ARR2CAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ARR2CAT"];
"ARR2CAT" -> "HOAGG"

_____

— ARR2CAT.dotfull —

"TwoDimensionalArrayCategory(a:Type,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a))"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ARR2CAT"];
"TwoDimensionalArrayCategory(a:Type,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a))"
  -> "HomogeneousAggregate(a:Type)"

"TwoDimensionalArrayCategory(a:Type,d:IndexedOneDimensionalArray(a,b),e:IndexedOneDimensionalArray(a,c))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ARR2CAT"];
"TwoDimensionalArrayCategory(a:Type,d:IndexedOneDimensionalArray(a,b),e:IndexedOneDimensionalArray(a,c))"
  -> "TwoDimensionalArrayCategory(a:Type,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a))"

_____

— ARR2CAT.dotpic —

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "TwoDimensionalArrayCategory(a:Type,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a))"
    [color=lightblue];
  "TwoDimensionalArrayCategory(a:Type,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a))"
    -> "HomogeneousAggregate(a:Type)"

```

```

"HomogeneousAggregate(a:Type)" [color=lightblue];
"HomogeneousAggregate(a:Type)" -> "Aggregate()"
"HomogeneousAggregate(a:Type)" -> "Evaluable(a:Type)"
"HomogeneousAggregate(a:Type)" -> "SetCategory()"

"Evaluable(a:Type)" [color="#00EE00"];

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Aggregate()" [color=lightblue];
"Aggregate()" -> "Type()"

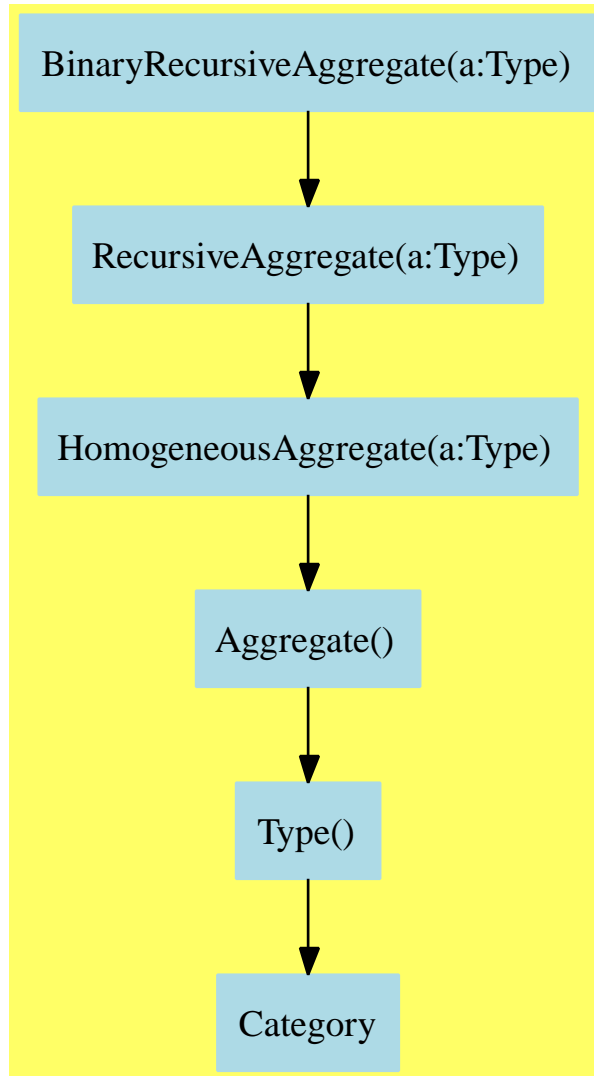
"Type()" [color=lightblue];
"Type()" -> "Category"

"Category" [color=lightblue];
}

```

Chapter 6

Category Layer 5

BinaryRecursiveAggregate (BRAGG)

— BinaryRecursiveAggregate.input —

```
)set break resume  
)sys rm -f BinaryRecursiveAggregate.output  
)spool BinaryRecursiveAggregate.output  
)set message test on  
)set message auto off  
)clear all
```

```

--S 1 of 1
)show BinaryRecursiveAggregate
--R
--R BinaryRecursiveAggregate(S: Type) is a category constructor
--R Abbreviation for BinaryRecursiveAggregate is BRAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for BRAGG
--R
--R----- Operations -----
--R children : % -> List(%)          copy : % -> %
--R cyclic? : % -> Boolean           distance : (%,%) -> Integer
--R ?.right : (%,right) -> %         ?.left : (%,left) -> %
--R ?.value : (%,value) -> S         empty : () -> %
--R empty? : % -> Boolean            eq? : (%,%) -> Boolean
--R leaf? : % -> Boolean             leaves : % -> List(S)
--R left : % -> %                    map : ((S -> S),%) -> %
--R nodes : % -> List(%)            right : % -> %
--R sample : () -> %                value : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?? : (%,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R child? : (%,%) -> Boolean if S has SETCAT
--R coerce : % -> OutputForm if S has SETCAT
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R node? : (%,%) -> Boolean if S has SETCAT
--R parts : % -> List(S) if $ has finiteAggregate
--R setchildren! : (%,List(%)) -> % if $ has shallowlyMutable
--R setelt : (%,right,%) -> % if $ has shallowlyMutable
--R setelt : (%,left,%) -> % if $ has shallowlyMutable
--R setelt : (%,value,S) -> S if $ has shallowlyMutable
--R setleft! : (%,%) -> % if $ has shallowlyMutable
--R setright! : (%,%) -> % if $ has shallowlyMutable
--R setvalue! : (%,S) -> S if $ has shallowlyMutable
--R size? : (%,NonNegativeInteger) -> Boolean
--R ?~=? : (%,%) -> Boolean if S has SETCAT
--R

```

```
--E 1
```

```
)spool
)lisp (bye)
```

— **BinaryRecursiveAggregate.help** —

```
=====
BinaryRecursiveAggregate examples
=====
```

A binary-recursive aggregate has 0, 1 or 2 children and serves as a model for a binary tree or a doubly-linked aggregate structure

See Also:

o)show BinaryRecursiveAggregate

See:

⇒ “BinaryTreeCategory” (BTCAT) [7](#) on page [579](#)

⇐ “RecursiveAggregate” (RCAGG) [5](#) on page [406](#)

Exports:

| | | | | |
|---------|----------|-----------|-----------|--------------|
| any? | children | child? | coerce | copy |
| count | cyclic? | distance | empty | empty? |
| eq? | eval | every? | hash | latex |
| leaf? | leaves | left | less? | map |
| map! | member? | members | more? | nodes |
| node? | parts | right | sample | setchildren! |
| setelt | setleft! | setright! | setvalue! | size? |
| value | #? | ?=? | ?~=? | ?..right |
| ?..left | ?..value | | | |

Attributes exported:

- **nil**

Attributes Used:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```

left : % -> %
right : % -> %
setelt : (%,right,%) -> % if $ has shallowlyMutable
setelt : (%,left,%) -> % if $ has shallowlyMutable
setleft! : (%,%) -> % if $ has shallowlyMutable
setright! : (%,%) -> % if $ has shallowlyMutable

```

These are implemented by this category:

```

children : % -> List %
coerce : % -> OutputForm if S has SETCAT
cyclic? : % -> Boolean
leaf? : % -> Boolean
leaves : % -> List S
member? : (S,%) -> Boolean
           if S has SETCAT and $ has finiteAggregate
nodes : % -> List %
node? : (%,%) -> Boolean if S has SETCAT
#? : % -> NonNegativeInteger if $ has finiteAggregate
==? : (%,%) -> Boolean if S has SETCAT
?.right : (%,right) -> %
?.left : (%,left) -> %

```

These exports come from (p406) RecursiveAggregate(S:Type)

```

any? : ((S -> Boolean),%) -> Boolean
           if $ has finiteAggregate
child? : (%,%) -> Boolean if S has SETCAT
copy : % -> %
count : (S,%) -> NonNegativeInteger
           if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
           if $ has finiteAggregate
distance : (%,%) -> Integer
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
           if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
           if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
           if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
           if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
hash : % -> SingleInteger if S has SETCAT

```

```

latex : % -> String if S has SETCAT
less? : (% , NonNegativeInteger) -> Boolean
map : ((S -> S) , %) -> %
map! : ((S -> S) , %) -> % if $ has shallowlyMutable
members : % -> List S if $ has finiteAggregate
more? : (% , NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
sample : () -> %
setchildren! : (% , List %) -> % if $ has shallowlyMutable
setelt : (% , value , S) -> S if $ has shallowlyMutable
setvalue! : (% , S) -> S if $ has shallowlyMutable
size? : (% , NonNegativeInteger) -> Boolean
value : % -> S
?~=? : (% , %) -> Boolean if S has SETCAT
?.value : (% , value) -> S

```

— category BRAGG BinaryRecursiveAggregate —

```

)abbrev category BRAGG BinaryRecursiveAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A binary-recursive aggregate has 0, 1 or 2 children and serves
++ as a model for a binary tree or a doubly-linked aggregate structure

```

```

BinaryRecursiveAggregate(S:Type):Category == RecursiveAggregate S with
-- needs preorder, inorder and postorder iterators
left: % -> %
++ left(u) returns the left child.
elt: (% , "left") -> %
++ elt(u, "left") (also written: \axiom{a . left}) is
++ equivalent to \axiom{left(a)}.
right: % -> %
++ right(a) returns the right child.
elt: (% , "right") -> %
++ elt(a, "right") (also written: \axiom{a . right})
++ is equivalent to \axiom{right(a)}.
if % has shallowlyMutable then
setelt: (% , "left" , %) -> %
++ setelt(a, "left", b) (also written \axiom{a . left := b}) is
++ equivalent to \axiom{setleft!(a,b)}.
setleft_!: (% , %) -> %
++ setleft!(a,b) sets the left child of \axiom{a} to be b.
setelt: (% , "right" , %) -> %
++ setelt(a, "right", b) (also written \axiom{b . right := b})
++ is equivalent to \axiom{setright!(a,b)}.
setright_!: (% , %) -> %
++ setright!(a,x) sets the right child of t to be x.

```

```

add
  cycleMax ==> 1000

  elt(x,"left") == left x
  elt(x,"right") == right x
  leaf? x == empty? x or empty? left x and empty? right x
  leaves t ==
    empty? t => empty()$List(S)
    leaf? t => [value t]
    concat(leaves left t,leaves right t)
  nodes x ==
    l := empty()$List(%)
    empty? x => l
    concat(nodes left x,concat([x],nodes right x))
  children x ==
    l := empty()$List(%)
    empty? x => l
    empty? left x => [right x]
    empty? right x => [left x]
    [left x, right x]
  if % has SetAggregate(S) and S has SetCategory then
    node?(u,v) ==
      empty? v => false
      u = v => true
      for y in children v repeat node?(u,y) => return true
      false
    x = y ==
      empty?(x) => empty?(y)
      empty?(y) => false
      value x = value y and left x = left y and right x = right y
    if % has finiteAggregate then
      member?(x,u) ==
        empty? u => false
        x = value u => true
        member?(x,left u) or member?(x,right u)

  if S has SetCategory then
    coerce(t:%): OutputForm ==
      empty? t => "[]"::OutputForm
      v := value(t):: OutputForm
      empty? left t =>
        empty? right t => v
        r := coerce(right t)@OutputForm
        bracket [".":OutputForm, v, r]
      l := coerce(left t)@OutputForm
      r :=
        empty? right t => ".":OutputForm
        coerce(right t)@OutputForm
      bracket [l, v, r]

```

```

if % has finiteAggregate then
  aggCount: (% , NonNegativeInteger) -> NonNegativeInteger
  #x == aggCount(x,0)
  aggCount(x,k) ==
    empty? x => 0
    k := k + 1
    k = cycleMax and cyclic? x => error "cyclic tree"
    for y in children x repeat k := aggCount(y,k)
  k

isCycle?: (% , List %) -> Boolean
eqMember?: (% , List %) -> Boolean
cyclic? x == not empty? x and isCycle?(x,empty()$(List %))
isCycle?(x,acc) ==
  empty? x => false
  eqMember?(x,acc) => true
  for y in children x | not empty? y repeat
    isCycle?(y,acc) => return true
  false
eqMember?(y,l) ==
  for x in l repeat eq?(x,y) => return true
  false
if % has shallowlyMutable then
  setelt(x,"left",b) == setleft_!(x,b)
  setelt(x,"right",b) == setright_!(x,b)

```

— BRAGG.dotabb —

```

"BRAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=BRAGG"];
"BRAGG" -> "RCAGG"

```

— BRAGG.dotfull —

```

"BinaryRecursiveAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=BRAGG"];
"BinaryRecursiveAggregate(a:Type)" -> "RecursiveAggregate(a:Type)"

"BinaryRecursiveAggregate(a:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=BRAGG"];
"BinaryRecursiveAggregate(a:SetCategory)" ->
  "BinaryRecursiveAggregate(a:Type)"

```

— BRAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "BinaryRecursiveAggregate(a:Type)" [color=lightblue];
  "BinaryRecursiveAggregate(a:Type)" -> "RecursiveAggregate(a:Type)"

  "RecursiveAggregate(a:Type)" [color=lightblue];
  "RecursiveAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "Aggregate()"

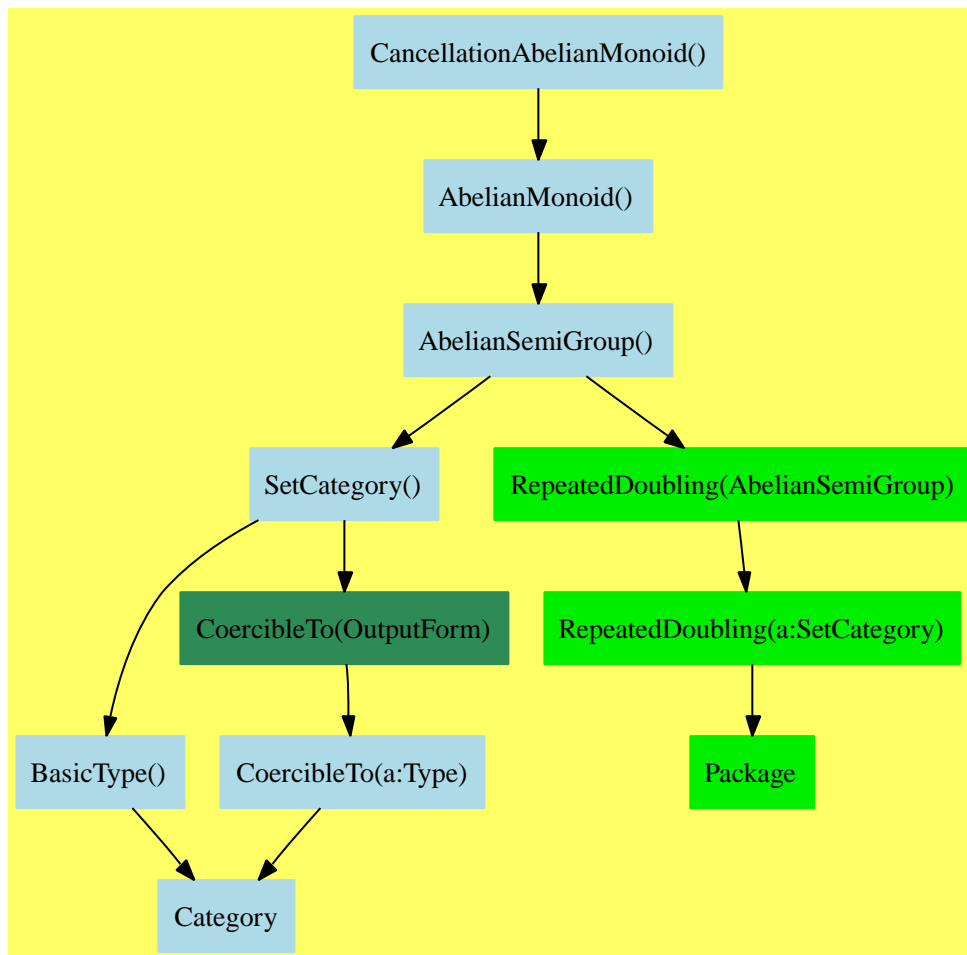
  "Aggregate()" [color=lightblue];
  "Aggregate()" -> "Type()"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "Category" [color=lightblue];
}

```

CancellationAbelianMonoid (CABMON)



— CancellationAbelianMonoid.input —

```

)set break resume
)sys rm -f CancellationAbelianMonoid.output
)spool CancellationAbelianMonoid.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show CancellationAbelianMonoid
--R CancellationAbelianMonoid is a category constructor

```

```

--R Abbreviation for CancellationAbelianMonoid is CABMON
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for CABMON
--R
--R----- Operations -----
--R ?? : (PositiveInteger,%) -> %      ?+? : (%,%) -> %
--R ?? : (%,%) -> Boolean              0 : () -> %
--R coerce : % -> OutputForm           hash : % -> SingleInteger
--R latex : % -> String                 sample : () -> %
--R zero? : % -> Boolean               ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— CancellationAbelianMonoid.help —

CancellationAbelianMonoid examples

This is an AbelianMonoid with the cancellation property, i.e.

$$a+b = a+c \Rightarrow b=c$$

This is formalised by the partial subtraction operator, which satisfies the Axiom

$$c = a+b \Leftrightarrow c-b = a$$

See Also:

- o)show CancellationAbelianMonoid

See:

\Rightarrow “AbelianGroup” (ABELGRP) [7](#) on page [574](#)
 \Rightarrow “FreeAbelianMonoidCategory” (FAMONC) [7](#) on page [617](#)
 \Rightarrow “OrderedCancellationAbelianMonoid” (OCAMON) [8](#) on page [751](#)
 \Leftarrow “AbelianMonoid” (ABELMON) [5](#) on page [321](#)

Exports:

```

0          coerce  hash  latex  sample
subtractIfCan  zero?  ?~=?  ?*?  ?+?
?=?

```

These are directly exported but not implemented:

```
subtractIfCan : (%,%) -> Union(%, "failed")
```

These exports come from (p321) `AbelianMonoid()`:

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
zero? : % -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?~=? : (%,%) -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean

```

— category CABMON CancellationAbelianMonoid —

```

)abbrev category CABMON CancellationAbelianMonoid
++ Description:
++ This is an \spadtype{AbelianMonoid} with the cancellation property, i.e.\br
++ \tab{5}\spad{ a+b = a+c => b=c }.\br
++ This is formalised by the partial subtraction operator,  

++ which satisfies the Axioms\br
++ \tab{5}\spad{c = a+b <=> c-b = a}

CancellationAbelianMonoid(): Category == AbelianMonoid with
  subtractIfCan: (%,%) -> Union(%, "failed")
  ++ subtractIfCan(x, y) returns an element z such that \spad{z+y=x}
  ++ or "failed" if no such element exists.

```

— CABMON.dotabb —

```

"CABMON"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=CABMON" ];
"CABMON" -> "ABELMON"

```

— CABMON.dotfull —

```
"CancellationAbelianMonoid()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CABMON"];
"CancellationAbelianMonoid()" -> "AbelianMonoid()"
```

— CABMON.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CancellationAbelianMonoid()" [color=lightblue];
  "CancellationAbelianMonoid()" -> "AbelianMonoid()"

  "AbelianMonoid()" [color=lightblue];
  "AbelianMonoid()" -> "AbelianSemiGroup()"

  "AbelianSemiGroup()" [color=lightblue];
  "AbelianSemiGroup()" -> "SetCategory()"
  "AbelianSemiGroup()" -> "RepeatedDoubling(AbelianSemiGroup)"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" ->
    "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

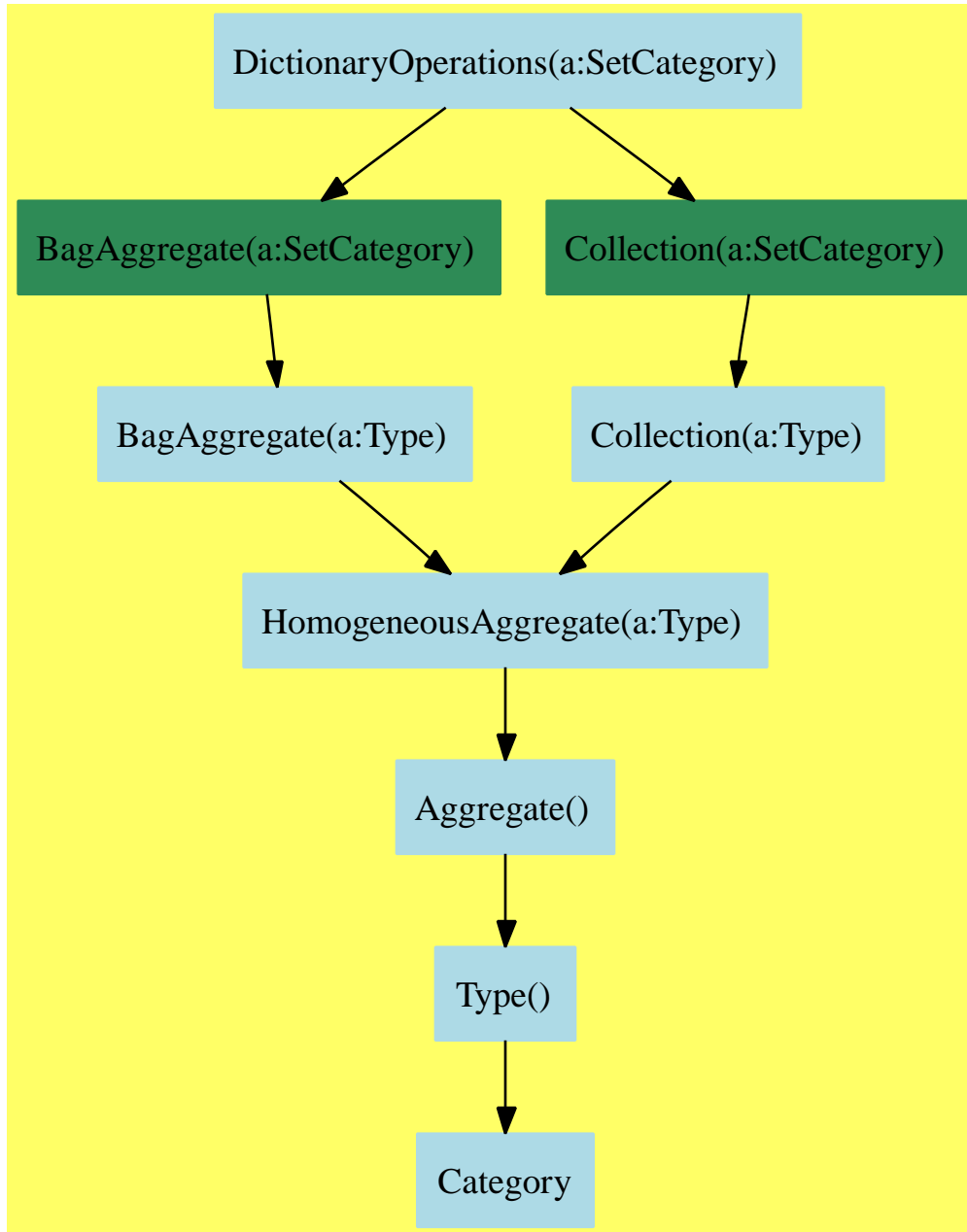
  "RepeatedDoubling(AbelianSemiGroup)" [color="#00EE00"];
  "RepeatedDoubling(AbelianSemiGroup)" -> "RepeatedDoubling(a:SetCategory)"

  "RepeatedDoubling(a:SetCategory)" [color="#00EE00"];
  "RepeatedDoubling(a:SetCategory)" -> "Package"

  "Package" [color="#00EE00"];
```

```
"Category" [color=lightblue];  
}
```

DictionaryOperations (DIOPS)



— DictionaryOperations.input —

```

)set break resume
)sys rm -f DictionaryOperations.output
)spool DictionaryOperations.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show DictionaryOperations
--R
--R DictionaryOperations(S: SetCategory) is a category constructor
--R Abbreviation for DictionaryOperations is DIOPS
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DIOPS
--R
--R----- Operations -----
--R bag : List(S) -> %                construct : List(S) -> %
--R copy : % -> %                    dictionary : List(S) -> %
--R dictionary : () -> %              empty : () -> %
--R empty? : % -> Boolean             eq? : (%,%) -> Boolean
--R extract! : % -> S                insert! : (S,%) -> %
--R inspect : % -> S                 map : ((S -> S),%) -> %
--R sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (%,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),%,S) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),%,S,S) -> S if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
--R remove! : ((S -> Boolean),%) -> % if $ has finiteAggregate

```

```

--R remove! : (S,%) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R select! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R ?~=? : (%,%) -> Boolean if S has SETCAT
--R
--E 1

```

```

)spool
)lisp (bye)

```

— DictionaryOperations.help —

```

=====
DictionaryOperations examples
=====

```

This category is a collection of operations common to both categories Dictionary and MultiDictionary.

See Also:

o)show DictionaryOperations

See:

⇒ “Dictionary” (DIAGG) [7](#) on page [586](#)
 ⇒ “MultiDictionary” (MDAGG) [7](#) on page [623](#)
 ⇐ “BagAggregate” (BGAGG) [5](#) on page [331](#)
 ⇐ “Collection” (CLAGG) [5](#) on page [341](#)

Exports:

| | | | | |
|--------|---------|------------|-----------|------------------|
| any? | bag | coerce | construct | convert |
| copy | count | dictionary | empty | empty? |
| eq? | eval | every? | extract! | find |
| hash | insert! | inspect | latex | less? |
| map | map! | member? | members | more? |
| parts | reduce | remove | remove! | removeDuplicates |
| sample | select | select! | size? | #? |
| ?=? | ?~=? | | | |

Attributes exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

Attributes Used:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.

These are directly exported but not implemented:

```
dictionary : List S -> %
remove! : ((S -> Boolean),%) -> % if $ has finiteAggregate
remove! : (S,%) -> % if $ has finiteAggregate
select! : ((S -> Boolean),%) -> % if $ has finiteAggregate
```

These are implemented by this category:

```
coerce : % -> OutputForm if S has SETCAT
construct : List S -> %
copy : % -> %
dictionary : () -> %
```

These exports come from (p331) BagAggregate(S:SetCategory):

```
any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
bag : List S -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
extract! : % -> S
hash : % -> SingleInteger if S has SETCAT
insert! : (S,%) -> %
inspect : % -> S
```

```

latex : % -> String if S has SETCAT
less? : (% , NonNegativeInteger) -> Boolean
map : ((S -> S), %) -> %
map! : ((S -> S), %) -> % if $ has shallowlyMutable
member? : (S, %) -> Boolean
    if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (% , NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
sample : () -> %
size? : (% , NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
?=? : (% , %) -> Boolean if S has SETCAT
?~=? : (% , %) -> Boolean if S has SETCAT

```

These exports come from (p341) Collection(S:SetCategory)

```

convert : % -> InputForm if S has KONVERT INFORM
find : ((S -> Boolean), %) -> Union(S, "failed")
reduce : (((S, S) -> S), %) -> S if $ has finiteAggregate
reduce : (((S, S) -> S), %, S) -> S if $ has finiteAggregate
reduce : (((S, S) -> S), %, S, S) -> S
    if S has SETCAT and $ has finiteAggregate
remove : ((S -> Boolean), %) -> % if $ has finiteAggregate
remove : (S, %) -> % if S has SETCAT and $ has finiteAggregate
removeDuplicates : % -> %
    if S has SETCAT and $ has finiteAggregate
select : ((S -> Boolean), %) -> % if $ has finiteAggregate

```

— category DIOPS DictionaryOperations —

```

)abbrev category DIOPS DictionaryOperations
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ This category is a collection of operations common to both
++ categories \spadtype{Dictionary} and \spadtype{MultiDictionary}

DictionaryOperations(S:SetCategory): Category ==
  Join(BagAggregate S, Collection(S)) with
    dictionary: () -> %
        ++ dictionary()$D creates an empty dictionary of type D.
    dictionary: List S -> %
        ++ dictionary([x,y,...,z]) creates a dictionary consisting of
        ++ entries \axiom{x,y,...,z}.
-- insert: (S, %) -> S                ++ insert an entry
-- member?: (S, %) -> Boolean          ++ search for an entry
-- remove_!: (S, %, NonNegativeInteger) -> %

```

```

-- ++ remove!(x,d,n) destructively changes dictionary d by removing
-- ++ up to n entries y such that \axiom{y = x}.
-- remove_!: (S->Boolean,%,NonNegativeInteger) -> %
-- ++ remove!(p,d,n) destructively changes dictionary d by removing
-- ++ up to n entries x such that \axiom{p(x)} is true.
if % has finiteAggregate then
  remove_!: (S,%) -> %
  ++ remove!(x,d) destructively changes dictionary d by removing
  ++ all entries y such that \axiom{y = x}.
  remove_!: (S->Boolean,%) -> %
  ++ remove!(p,d) destructively changes dictionary d by removing
  ++ all entries x such that \axiom{p(x)} is true.
  select_!: (S->Boolean,%) -> %
  ++ select!(p,d) destructively changes dictionary d by removing
  ++ all entries x such that \axiom{p(x)} is not true.
add
construct l == dictionary l
dictionary() == empty()
if % has finiteAggregate then
  copy d == dictionary parts d
  coerce(s:%):OutputForm ==
    prefix("dictionary"@String :: OutputForm,
          [x::OutputForm for x in parts s])

```

— DIOPS.dotabb —

```

"DIOPS" [color=lightblue,href="bookvol10.2.pdf#nameddest=DIOPS"];
"DIOPS" -> "BGAGG"
"DIOPS" -> "CLAGG"

```

— DIOPS.dotfull —

```

"DictionaryOperations(a:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=DIOPS"];
"DictionaryOperations(a:SetCategory)" -> "BagAggregate(a:SetCategory)"
"DictionaryOperations(a:SetCategory)" -> "Collection(a:SetCategory)"

```

— DIOPS.dotpic —

```

digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "DictionaryOperations(a:SetCategory)" [color=lightblue];
    "DictionaryOperations(a:SetCategory)" -> "BagAggregate(a:SetCategory)"
    "DictionaryOperations(a:SetCategory)" -> "Collection(a:SetCategory)"

    "BagAggregate(a:SetCategory)" [color=seagreen];
    "BagAggregate(a:SetCategory)" -> "BagAggregate(a:Type)"

    "BagAggregate(a:Type)" [color=lightblue];
    "BagAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

    "Collection(a:SetCategory)" [color=seagreen];
    "Collection(a:SetCategory)" -> "Collection(a:Type)"

    "Collection(a:Type)" [color=lightblue];
    "Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"

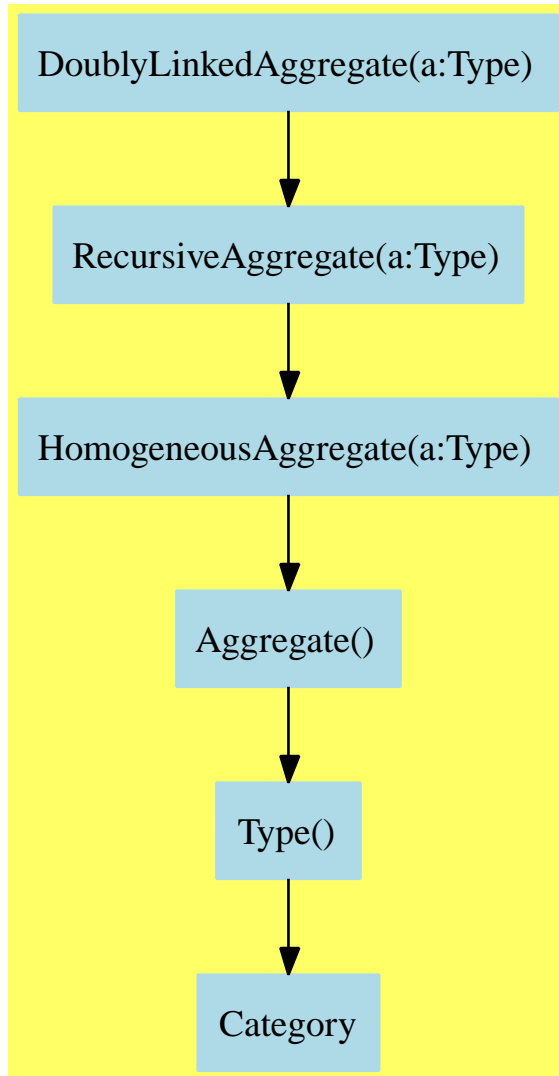
    "HomogeneousAggregate(a:Type)" [color=lightblue];
    "HomogeneousAggregate(a:Type)" -> "Aggregate()"

    "Aggregate()" [color=lightblue];
    "Aggregate()" -> "Type()"

    "Type()" [color=lightblue];
    "Type()" -> "Category"

    "Category" [color=lightblue];
}

```

DoublyLinkedAggregate (DLAGG)

— DoublyLinkedAggregate.input —

```
)set break resume  
)sys rm -f DoublyLinkedAggregate.output  
)spool DoublyLinkedAggregate.output  
)set message test on  
)set message auto off  
)clear all
```

```

--S 1 of 1
)show DoublyLinkedAggregate
--R
--R DoublyLinkedAggregate(S: Type) is a category constructor
--R Abbreviation for DoublyLinkedAggregate is DLAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DLAGG
--R
--R----- Operations -----
--R children : % -> List(%)          copy : % -> %
--R cyclic? : % -> Boolean           distance : (%,%) -> Integer
--R ?.value : (%,value) -> S         empty : () -> %
--R empty? : % -> Boolean            eq? : (%,%) -> Boolean
--R head : % -> %                   last : % -> S
--R leaf? : % -> Boolean             leaves : % -> List(S)
--R map : ((S -> S),%) -> %          next : % -> %
--R nodes : % -> List(%)            previous : % -> %
--R sample : () -> %                tail : % -> %
--R value : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ==? : (%,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R child? : (%,%) -> Boolean if S has SETCAT
--R coerce : % -> OutputForm if S has SETCAT
--R concat! : (%,%) -> % if $ has shallowlyMutable
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R node? : (%,%) -> Boolean if S has SETCAT
--R parts : % -> List(S) if $ has finiteAggregate
--R setchildren! : (%,List(%)) -> % if $ has shallowlyMutable
--R setelt : (%,value,S) -> S if $ has shallowlyMutable
--R setnext! : (%,%) -> % if $ has shallowlyMutable
--R setprevious! : (%,%) -> % if $ has shallowlyMutable
--R setvalue! : (%,S) -> S if $ has shallowlyMutable
--R size? : (%,NonNegativeInteger) -> Boolean
--R ~=? : (%,%) -> Boolean if S has SETCAT
--R

```

```
--E 1
```

```
)spool
)lisp (bye)
```

— **DoublyLinkedAggregate.help** —

```
=====
DoublyLinkedAggregate examples
=====
```

A doubly-linked aggregate serves as a model for a doubly-linked list, that is, a list which can has links to both next and previous nodes and thus can be efficiently traversed in both directions.

See Also:

o)show DoublyLinkedAggregate

See:

⇐ “RecursiveAggregate” (RCAGG) [5](#) on page [406](#)

Exports:

| | | | | |
|--------------|-----------|--------------|----------|----------|
| any? | children | child? | coerce | concat! |
| copy | count | cyclic? | distance | empty |
| empty? | eq? | eval | every? | hash |
| head | last | latex | leaf? | leaves |
| less? | map | map! | member? | members |
| more? | next | nodes | node? | parts |
| previous | sample | setchildren! | setelt | setnext! |
| setprevious! | setvalue! | size? | tail | value |
| #? | ?=? | ?~=? | ?.value | |

Attributes exported:

- **nil**

Attributes Used:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```
concat! : (%,%) -> % if $ has shallowlyMutable
head : % -> %
last : % -> S
next : % -> %
previous : % -> %
setnext! : (%,%) -> % if $ has shallowlyMutable
setprevious! : (%,%) -> % if $ has shallowlyMutable
tail : % -> %
```

These exports come from (p406) RecursiveAggregate(S:Type):

```
any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
children : % -> List %
child? : (%,%) -> Boolean if S has SETCAT
coerce : % -> OutputForm if S has SETCAT
copy : % -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
cyclic? : % -> Boolean
distance : (%,%) -> Integer
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
leaf? : % -> Boolean
leaves : % -> List S
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
      if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
nodes : % -> List %
node? : (%,%) -> Boolean if S has SETCAT
```



```

parts : % -> List S if $ has finiteAggregate
sample : () -> %
setchildren! : (%,List %) -> % if $ has shallowlyMutable
setelt : (%,value,S) -> S if $ has shallowlyMutable
setvalue! : (%,S) -> S if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
value : % -> S
#? : % -> NonNegativeInteger if $ has finiteAggregate
?? : (%,%) -> Boolean if S has SETCAT
?~=? : (%,%) -> Boolean if S has SETCAT
?.value : (%,value) -> S

```

— category DLAGG DoublyLinkedAggregate —

```

)abbrev category DLAGG DoublyLinkedAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A doubly-linked aggregate serves as a model for a doubly-linked
++ list, that is, a list which can has links to both next and previous
++ nodes and thus can be efficiently traversed in both directions.

DoublyLinkedAggregate(S:Type): Category == RecursiveAggregate S with
  last: % -> S
    ++ last(l) returns the last element of a doubly-linked aggregate l.
    ++ Error: if l is empty.
  head: % -> %
    ++ head(l) returns the first element of a doubly-linked aggregate l.
    ++ Error: if l is empty.
  tail: % -> %
    ++ tail(l) returns the doubly-linked aggregate l starting at
    ++ its second element.
    ++ Error: if l is empty.
  previous: % -> %
    ++ previous(l) returns the doubly-link list beginning with its previous
    ++ element.
    ++ Error: if l has no previous element.
    ++ Note that \axiom{next(previous(l)) = l}.
  next: % -> %
    ++ next(l) returns the doubly-linked aggregate beginning with its next
    ++ element.
    ++ Error: if l has no next element.
    ++ Note that \axiom{next(l) = rest(l)} and \axiom{previous(next(l)) = l}.
  if % has shallowlyMutable then
    concat_!: (%,%) -> %
      ++ concat!(u,v) destructively concatenates doubly-linked aggregate v
      ++ to the end of doubly-linked aggregate u.
    setprevious_!: (%,%) -> %

```

```

++ setprevious!(u,v) destructively sets the previous node of
++ doubly-linked aggregate u to v, returning v.
setnext_!: (%,% ) -> %
++ setnext!(u,v) destructively sets the next node of doubly-linked
++ aggregate u to v, returning v.

```

— DLAGG.dotabb —

```

"DLagg" [color=lightblue,href="bookvol10.2.pdf#nameddest=DLagg"];
"DLagg" -> "RCagg"

```

— DLAGG.dotfull —

```

"DoublyLinkedAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=DLagg"];
"DoublyLinkedAggregate(a:Type)" -> "RecursiveAggregate(a:Type)"

```

— DLAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "DoublyLinkedAggregate(a:Type)" [color=lightblue];
  "DoublyLinkedAggregate(a:Type)" -> "RecursiveAggregate(a:Type)"

  "RecursiveAggregate(a:Type)" [color=lightblue];
  "RecursiveAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "Aggregate()"

  "Aggregate()" [color=lightblue];
  "Aggregate()" -> "Type()"

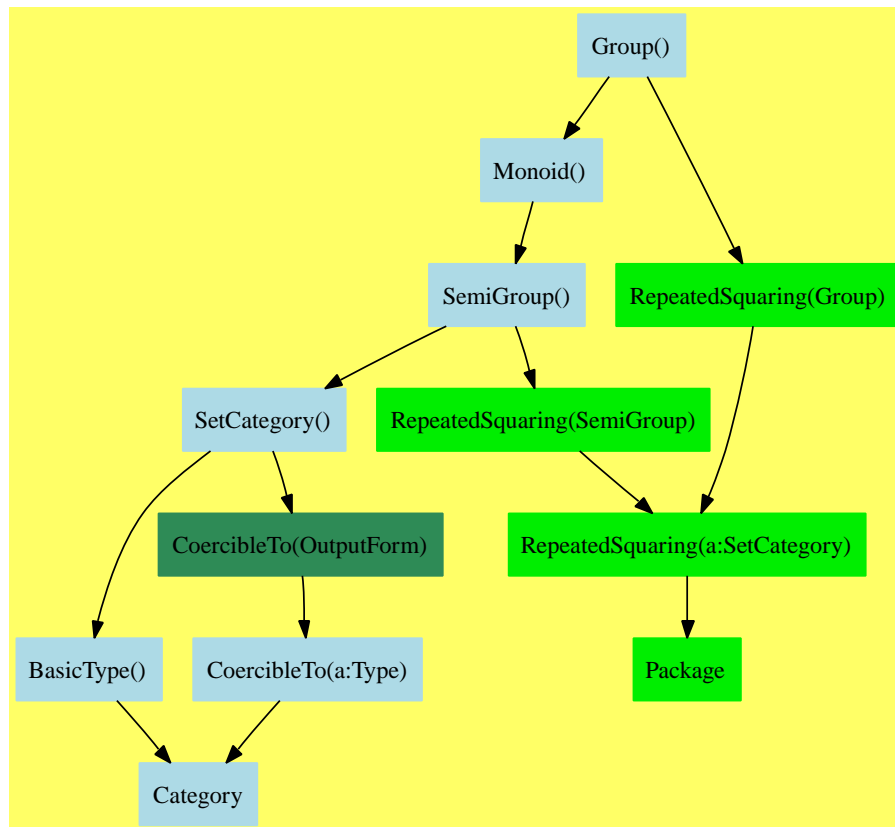
  "Type()" [color=lightblue];
  "Type()" -> "Category"
}

```

```
"Category" [color=lightblue];
}
```

→

Group (GROUP)



— Group.input —

```
)set break resume
)sys rm -f Group.output
)spool Group.output
)set message test on
)set message auto off
)clear all
```

```

--S 1 of 1
)show Group
--R Group is a category constructor
--R Abbreviation for Group is GROUP
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for GROUP
--R
--R----- Operations -----
--R ?? : (%,% ) -> %           ??? : (% ,Integer) -> %
--R ??? : (% ,PositiveInteger) -> %   ?/? : (% ,%) -> %
--R ?? : (% ,%) -> Boolean          1 : () -> %
--R ?? : (% ,Integer) -> %         ?? : (% ,PositiveInteger) -> %
--R coerce : % -> OutputForm       commutator : (% ,%) -> %
--R conjugate : (% ,%) -> %        hash : % -> SingleInteger
--R inv : % -> %                   latex : % -> String
--R one? : % -> Boolean            recip : % -> Union(% , "failed")
--R sample : () -> %              ?~=? : (% ,%) -> Boolean
--R ??? : (% ,NonNegativeInteger) -> %
--R ?? : (% ,NonNegativeInteger) -> %
--R
--E 1

)spool
)lisp (bye)

```

— Group.help —

=====
Group examples
=====

The class of multiplicative groups, i.e. monoids with multiplicative inverses.

Axioms:

```

leftInverse("":(% ,%) -> % ,inv)   inv(x)*x = 1
rightInverse("":(% ,%) -> % ,inv)  x*inv(x) = 1

```

See Also:

o)show Group

See:

⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)

⇒ “PermutationCategory” (PERMCAT) [7](#) on page [633](#)

⇐ “Monoid” (MONOID) [5](#) on page [386](#)

Exports:

```
1      coerce  commutator  conjugate  hash
inv    latex   one?       recip      sample
?~=?   ??      ***?      ?/?       ?=?
?^?
```

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation `recip` can only return “failed” if its argument is not a unit.

These are directly exported but not implemented:

```
inv : % -> %
```

These are implemented by this category:

```
commutator : (%,%) -> %
conjugate  : (%,%) -> %
recip      : % -> Union(%, "failed")
?/?       : (%,%) -> %
?^?       : (%, Integer) -> %
***?      : (%, Integer) -> %
```

These exports come from ([p386](#)) `Monoid()`:

```
1 : () -> %
coerce : % -> OutputForm
hash   : % -> SingleInteger
latex  : % -> String
one?   : % -> Boolean
sample : () -> %
?^?   : (%, NonNegativeInteger) -> %
?^?   : (%, PositiveInteger) -> %
***?  : (%, NonNegativeInteger) -> %
***?  : (%, PositiveInteger) -> %
??    : (%, %) -> %
?=?   : (%, %) -> Boolean
?~=?  : (%, %) -> Boolean
```

— category **GROUP Group** —

```
)abbrev category GROUP Group
++ Description:
```

```

++ The class of multiplicative groups, that is, monoids with
++ multiplicative inverses.
++
++ Axioms\br
++ \tab{5}\spad{leftInverse("":(%,%)->%,inv)}\tab{5}\spad{inv(x)*x = 1}\br
++ \tab{5}\spad{rightInverse("":(%,%)->%,inv)}\tab{4}\spad{x*inv(x) = 1}

```

```

Group(): Category == Monoid with
  inv: % -> %
    ++ inv(x) returns the inverse of x.
  "/": (%,% ) -> %
    ++ x/y is the same as x times the inverse of y.
  "**": (%,Integer) -> %
    ++ x**n returns x raised to the integer power n.
  "^": (%,Integer) -> %
    ++ x^n returns x raised to the integer power n.
  unitsKnown
    ++ unitsKnown asserts that recip only returns
    ++ "failed" for non-units.
  conjugate: (%,% ) -> %
    ++ conjugate(p,q) computes \spad{inv(q) * p * q}; this is
    ++ 'right action by conjugation'.
  commutator: (%,% ) -> %
    ++ commutator(p,q) computes \spad{inv(p) * inv(q) * p * q}.
add
  import RepeatedSquaring(%)
  x:% / y:% == x*inv(y)
  recip(x:% ) == inv(x)
  _^(x:% , n:Integer):% == x ** n
  x:% ** n:Integer ==
    zero? n => 1
    n<0 => expt(inv(x),(-n) pretend PositiveInteger)
    expt(x,n pretend PositiveInteger)
  conjugate(p,q) == inv(q) * p * q
  commutator(p,q) == inv(p) * inv(q) * p * q

```

— GROUP.dotabb —

```

"GROUP"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=GROUP"];
"GROUP" -> "MONOID"

```

— GROUP.dotfull —

```
"Group()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=GROUP"];
"Group()" -> "Monoid()"
```

— GROUP.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Group()" [color=lightblue];
  "Group()" -> "Monoid()"
  "Group()" -> "RepeatedSquaring(Group)"

  "Monoid()" [color=lightblue];
  "Monoid()" -> "SemiGroup()"

  "SemiGroup()" [color=lightblue];
  "SemiGroup()" -> "SetCategory()"
  "SemiGroup()" -> "RepeatedSquaring(SemiGroup)"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
  "CoercibleTo(a:Type)" -> "Category"

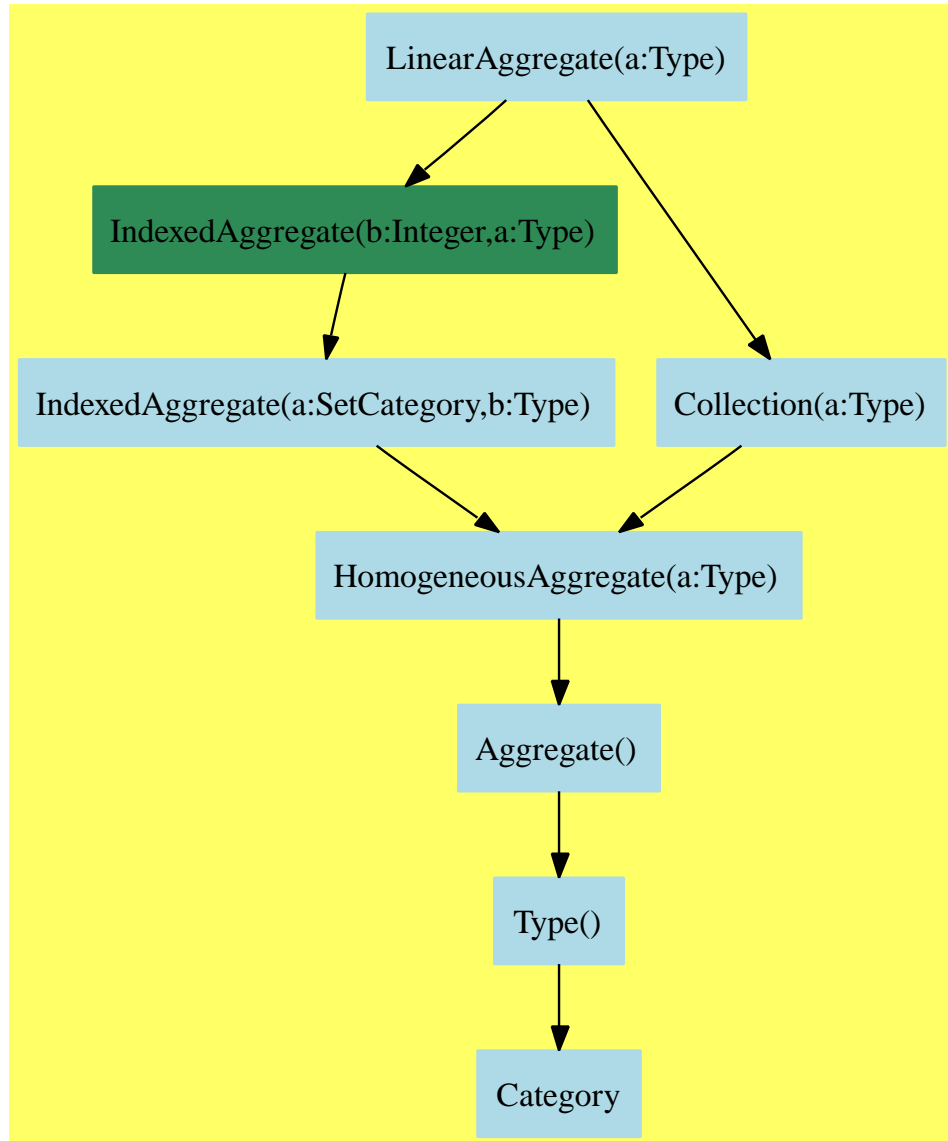
  "RepeatedSquaring(Group)" [color="#00EE00"];
  "RepeatedSquaring(Group)" -> "RepeatedSquaring(a:SetCategory)"

  "RepeatedSquaring(SemiGroup)" [color="#00EE00"];
  "RepeatedSquaring(SemiGroup)" -> "RepeatedSquaring(a:SetCategory)"

  "RepeatedSquaring(a:SetCategory)" [color="#00EE00"];
  "RepeatedSquaring(a:SetCategory)" -> "Package"

  "Package" [color="#00EE00];
```

```
"Category" [color=lightblue];  
}
```

LinearAggregate (LNAGG)

— LinearAggregate.input —

```

)set break resume
)sys rm -f LinearAggregate.output
)spool LinearAggregate.output
)set message test on

```

```

)set message auto off
)clear all

--S 1 of 1
)show LinearAggregate
--R
--R LinearAggregate(S: Type) is a category constructor
--R Abbreviation for LinearAggregate is LNAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LNAGG
--R
--R----- Operations -----
--R concat : List(%) -> %
--R concat : (S,%) -> %
--R construct : List(S) -> %
--R delete : (%,Integer) -> %
--R elt : (%,Integer,S) -> S
--R empty? : % -> Boolean
--R eq? : (%,%) -> Boolean
--R indices : % -> List(Integer)
--R insert : (S,%,Integer) -> %
--R map : ((S -> S),%) -> %
--R qelt : (%,Integer) -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (%,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R delete : (%,UniversalSegment(Integer)) -> %
--R ?? : (%,UniversalSegment(Integer)) -> %
--R entry? : (S,%) -> Boolean if $ has finiteAggregate and S has SETCAT
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (%,S) -> % if $ has shallowlyMutable
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R first : % -> S if Integer has ORDSET
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (%,NonNegativeInteger) -> Boolean

```

```

--R parts : % -> List(S) if $ has finiteAggregate
--R qsetelt! : (% , Integer, S) -> S if $ has shallowlyMutable
--R reduce : ((S, S) -> S), % -> S if $ has finiteAggregate
--R reduce : ((S, S) -> S), %, S -> S if $ has finiteAggregate
--R reduce : ((S, S) -> S), %, S, S -> S if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean), %) -> % if $ has finiteAggregate
--R remove : (S, %) -> % if S has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R select : ((S -> Boolean), %) -> % if $ has finiteAggregate
--R setelt : (% , UniversalSegment(Integer), S) -> S if $ has shallowlyMutable
--R setelt : (% , Integer, S) -> S if $ has shallowlyMutable
--R size? : (% , NonNegativeInteger) -> Boolean
--R swap! : (% , Integer, Integer) -> Void if $ has shallowlyMutable
--R ~=? : (% , %) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— LinearAggregate.help —

=====

LinearAggregate examples

=====

A linear aggregate is an aggregate whose elements are indexed by integers. Examples of linear aggregates are strings, lists, and arrays.

Most of the exported operations for linear aggregates are non-destructive but are not always efficient for a particular aggregate.

For example, concat of two lists needs only to copy its first argument, whereas concat of two arrays needs to copy both arguments. Most of the operations exported here apply to infinite objects (e.g. streams) as well to finite ones. For finite linear aggregates, see FiniteLinearAggregate.

See Also:

o)show LinearAggregate

See:

⇒ “ExtensibleLinearAggregate” (ELAGG) [7](#) on page [600](#)

⇒ “FiniteLinearAggregate” (FLAGG) [7](#) on page [608](#)

⇒ “StreamAggregate” (STAGG) [7](#) on page [639](#)

⇐ “Collection” (CLAGG) [5](#) on page [341](#)

⇐ “IndexedAggregate” (IXAGG) [5](#) on page [372](#)

Exports:

| | | | | |
|----------|---------|----------|------------------|---------|
| any? | coerce | concat | construct | convert |
| copy | count | delete | elt | empty |
| empty? | entries | entry? | eq? | eval |
| every? | fill! | find | first | hash |
| index? | indices | insert | latex | less? |
| map | map! | maxIndex | member? | members |
| minIndex | more? | new | parts | qelt |
| qsetelt! | reduce | remove | removeDuplicates | sample |
| setelt | size? | swap! | ?~=? | #? |
| ?=? | ?..? | | | |

Attributes exported:

- nil

Attributes Used:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```
concat : (%,%) -> %
concat : List % -> %
delete : (%,Integer) -> %
delete : (%,UniversalSegment Integer) -> %
insert : (%,%,Integer) -> %
map : (((S,S) -> S),%,%) -> %
new : (NonNegativeInteger,S) -> %
setelt : (%,UniversalSegment Integer,S) -> S
        if $ has shallowlyMutable
?..? : (%,UniversalSegment Integer) -> %
```

These are implemented by this category:

```
concat : (%,S) -> %
concat : (S,%) -> %
index? : (Integer,%) -> Boolean
indices : % -> List Integer
insert : (S,%,Integer) -> %
maxIndex : % -> Integer if Integer has ORDSET
```

These exports come from (p372) `IndexedAggregate(Integer,S:Type)`

```

any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
coerce : % -> OutputForm if S has SETCAT
copy : % -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
elt : (%,Integer,S) -> S
empty : () -> %
empty? : % -> Boolean
entries : % -> List S
entry? : (S,%) -> Boolean
      if $ has finiteAggregate and S has SETCAT
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
fill! : (%,S) -> % if $ has shallowlyMutable
first : % -> S if Integer has ORDSET
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
      if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
minIndex : % -> Integer if Integer has ORDSET
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
qelt : (%,Integer) -> S
qsetelt! : (%,Integer,S) -> S if $ has shallowlyMutable
sample : () -> %
setelt : (%,Integer,S) -> S if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable
#? : % -> NonNegativeInteger if $ has finiteAggregate
?.? : (%,Integer) -> S
?~=? : (%,%) -> Boolean if S has SETCAT
?=? : (%,%) -> Boolean if S has SETCAT

```

These exports come from (p341) `Collection(S:Type)`:

```
construct : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
find : ((S -> Boolean),%) -> Union(S,"failed")
reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S if $ has finiteAggregate
reduce : (((S,S) -> S),%,S,S) -> S
      if S has SETCAT and $ has finiteAggregate
remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
removeDuplicates : % -> %
      if S has SETCAT and $ has finiteAggregate
select : ((S -> Boolean),%) -> % if $ has finiteAggregate
```

— category LNAGG LinearAggregate —

```
)abbrev category LNAGG LinearAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A linear aggregate is an aggregate whose elements are indexed by integers.
++ Examples of linear aggregates are strings, lists, and
++ arrays.
++ Most of the exported operations for linear aggregates are non-destructive
++ but are not always efficient for a particular aggregate.
++ For example, \spadfun{concat} of two lists needs only to copy its first
++ argument, whereas \spadfun{concat} of two arrays needs to copy both
++ arguments. Most of the operations exported here apply to infinite
++ objects (e.g. streams) as well to finite ones.
++ For finite linear aggregates, see \spadtype{FiniteLinearAggregate}.
```

```
LinearAggregate(S:Type): Category ==
Join(IndexedAggregate(Integer, S), Collection(S)) with
new      : (NonNegativeInteger,S) -> %
      ++ new(n,x) returns \axiom{fill!(new n,x)}.
concat: (% ,S) -> %
      ++ concat(u,x) returns aggregate u with additional element x at the end.
      ++ Note that for lists, \axiom{concat(u,x) == concat(u,[x])}
concat: (S,% ) -> %
      ++ concat(x,u) returns aggregate u with additional element at the front.
      ++ Note that for lists: \axiom{concat(x,u) == concat([x],u)}.
concat: (% ,%) -> %
      ++ concat(u,v) returns an aggregate consisting of the elements of u
      ++ followed by the elements of v.
      ++ Note that if \axiom{w = concat(u,v)} then
      ++ \axiom{w.i = u.i for i in indices u}
      ++ and \axiom{w.(j + maxIndex u) = v.j for j in indices v}.
```

```

concat: List % -> %
  ++ concat(u), where u is a lists of aggregates \axiom{[a,b,...,c]},
  ++ returns a single aggregate consisting of the elements of \axiom{a}
  ++ followed by those
  ++ of b followed ... by the elements of c.
  ++ Note that \axiom{concat(a,b,...,c) = concat(a,concat(b,...,c))}.
map: ((S,S)->S,%,%) -> %
  ++ map(f,u,v) returns a new collection w with elements
  ++ \axiom{z = f(x,y)} for corresponding elements x and y from u and v.
  ++ Note that for linear aggregates, \axiom{w.i = f(u.i,v.i)}.
elt: (%,UniversalSegment(Integer)) -> %
  ++ elt(u,i..j) (also written: \axiom{a(i..j)}) returns the aggregate of
  ++ elements \axiom{u} for k from i to j in that order.
  ++ Note that in general, \axiom{a.s = [a.k for i in s]}.
delete: (%,Integer) -> %
  ++ delete(u,i) returns a copy of u with the \axiom{i}th
  ++ element deleted. Note that for lists,
  ++ \axiom{delete(a,i) == concat(a(0..i - 1),a(i + 1,...))}.
delete: (%,UniversalSegment(Integer)) -> %
  ++ delete(u,i..j) returns a copy of u with the \axiom{i}th through
  ++ \axiom{j}th element deleted.
  ++ Note that \axiom{delete(a,i..j) = concat(a(0..i-1),a(j+1...))}.
insert: (S,%,Integer) -> %
  ++ insert(x,u,i) returns a copy of u having x as its
  ++ \axiom{i}th element.
  ++ Note that \axiom{insert(x,a,k) = concat(concat(a(0..k-1),x),a(k...))}.
insert: (%,%,Integer) -> %
  ++ insert(v,u,k) returns a copy of u having v inserted beginning at the
  ++ \axiom{i}th element.
  ++ Note that \axiom{insert(v,u,k) = concat( u(0..k-1), v, u(k..) )}.
if % has shallowlyMutable then
  setelt: (%,UniversalSegment(Integer),S) -> S
    ++ setelt(u,i..j,x) (also written: \axiom{u(i..j) := x}) destructively
    ++ replaces each element in the segment \axiom{u(i..j)} by x.
    ++ The value x is returned.
    ++ Note that u is destructively change so
    ++ that \axiom{u.k := x for k in i..j};
    ++ its length remains unchanged.
add
indices a          == [i for i in minIndex a .. maxIndex a]
index?(i, a)       == i >= minIndex a and i <= maxIndex a
concat(a:%, x:S)    == concat(a, new(1, x))
concat(x:S, y:%)    == concat(new(1, x), y)
insert(x:S, a:%, i:Integer) == insert(new(1, x), a, i)
if % has finiteAggregate then
  maxIndex l == #l - 1 + minIndex l

--if % has shallowlyMutable then new(n, s) == fill_!(new n, s)

```

— LNAGG.dotabb —

```
"LNAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=LNAGG"];
"LNAGG" -> "IXAGG"
"LNAGG" -> "CLAGG"
```

— LNAGG.dotfull —

```
"LinearAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=LNAGG"];
"LinearAggregate(a:Type)" -> "IndexedAggregate(b:Integer,a:Type)"
"LinearAggregate(a:Type)" -> "Collection(a:Type)"
```

— LNAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "LinearAggregate(a:Type)" [color=lightblue];
  "LinearAggregate(a:Type)" -> "IndexedAggregate(b:Integer,a:Type)"
  "LinearAggregate(a:Type)" -> "Collection(a:Type)"

  "IndexedAggregate(b:Integer,a:Type)" [color=seagreen];
  "IndexedAggregate(b:Integer,a:Type)" ->
    "IndexedAggregate(a:SetCategory,b:Type)"

  "IndexedAggregate(a:SetCategory,b:Type)" [color=lightblue];
  "IndexedAggregate(a:SetCategory,b:Type)" ->
    "HomogeneousAggregate(a:Type)"

  "Collection(a:Type)" [color=lightblue];
  "Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "Aggregate()"

  "Aggregate()" [color=lightblue];
  "Aggregate()" -> "Type()"
```



```

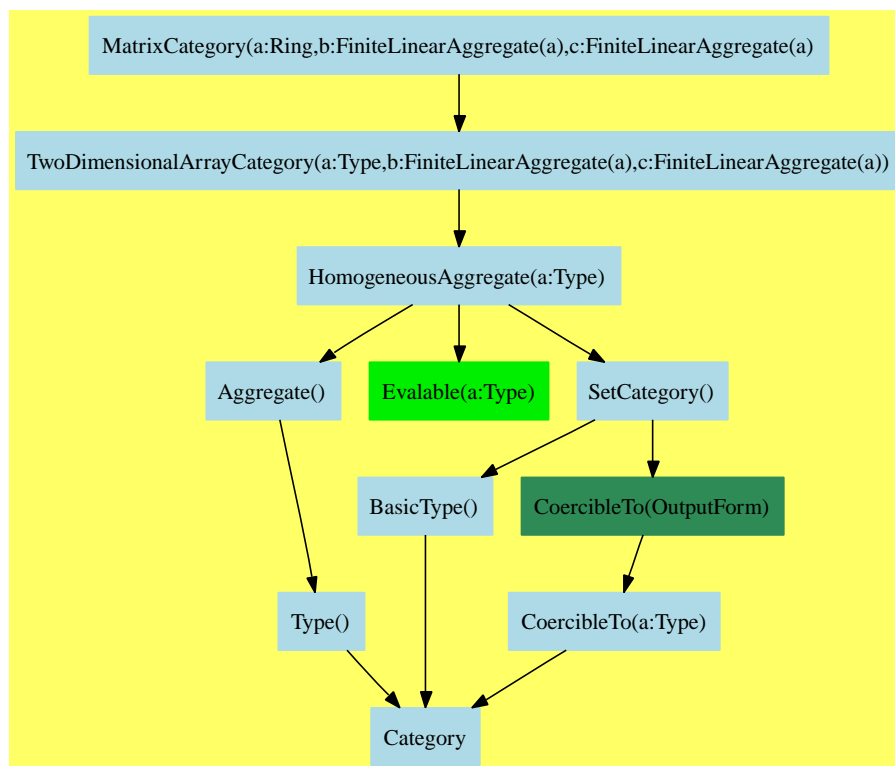
"Type()" [color=lightblue];
"Type()" -> "Category"

"Category" [color=lightblue];

}

```

MatrixCategory (MATCAT)



— MatrixCategory.input —

```

)set break resume
)sys rm -f MatrixCategory.output
)spool MatrixCategory.output
)set message test on

```

```
)set message auto off
)clear all
```

```
--S 1 of 59
square? matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R (1) true
--R
--E 1
```

Type: Boolean

```
--S 2 of 59
diagonal? matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R (2) false
--R
--E 2
```

Type: Boolean

```
--S 3 of 59
symmetric? matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R (3) false
--R
--E 3
```

Type: Boolean

```
--S 4 of 59
antisymmetric? matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R (4) false
--R
--E 4
```

Type: Boolean

```
--S 5 of 59
z:Matrix(INT):=zero(3,3)
--R
--R
--R      +0  0  0+
--R      |    |
--R (5) |0  0  0|
--R      |    |
--R      +0  0  0+
--R
--E 5
```

Type: Matrix(Integer)

```
--S 6 of 59
matrix [[1,2,3],[4,5,6],[7,8,9],[1,1,1]]
```

Type: Matrix(Integer)

Type: Matrix(Integer)

Type: Matrix(Integer)

Type: Matrix(Integer)

```

--S 10 of 59
coerce([1,2,3])@Matrix(INT)
--R
--R
--R      +1+
--R      | |
--R  (10) |2|
--R      | |
--R      +3+
--R
--R                                          Type: Matrix(Integer)
--E 10

--S 11 of 59
transpose([1,2,3])@Matrix(INT)
--R
--R
--R  (11)  [1  2  3]
--R
--R                                          Type: Matrix(Integer)
--E 11

--S 12 of 59
transpose matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R      +1  1   1   1   1  +
--R      |
--R      |1  2   3   4   5 |
--R      |
--R  (12) |1  4   9  16  25 |
--R      |
--R      |1  8  27  64 125|
--R      |
--R      +1 16  81 256 625+
--R
--R                                          Type: Matrix(Integer)
--E 12

--S 13 of 59
squareTop matrix [[j**i for i in 0..2] for j in 1..5]
--R
--R
--R      +1  1  1+
--R      |
--R  (13) |1  2  4|
--R      |
--R      +1  3  9+
--R
--R                                          Type: Matrix(Integer)
--E 13

--S 14 of 59
t1:=matrix [[j**i for i in 0..4] for j in 1..5]

```

```

--R
--R
--R      +1  1  1    1    1  +
--R      |
--R      |1  2  4    8   16 |
--R      |
--R      (14) |1  3  9   27  81 |
--R      |
--R      |1  4  16  64  256|
--R      |
--R      +1  5  25  125  625+
--R
--R                                          Type: Matrix(Integer)
--E 14

```

```

--S 15 of 59
horizConcat(t1,t1)
--R
--R
--R      +1  1  1    1    1  1  1  1  1  1  +
--R      |
--R      |1  2  4    8   16  1  2  4    8   16 |
--R      |
--R      (15) |1  3  9   27  81  1  3  9   27  81 |
--R      |
--R      |1  4  16  64  256  1  4  16  64  256|
--R      |
--R      +1  5  25  125  625  1  5  25  125  625+
--R
--R                                          Type: Matrix(Integer)
--E 15

```

```

--S 16 of 59
t2:=matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R      +1  1  1    1    1  +
--R      |
--R      |1  2  4    8   16 |
--R      |
--R      (16) |1  3  9   27  81 |
--R      |
--R      |1  4  16  64  256|
--R      |
--R      +1  5  25  125  625+
--R
--R                                          Type: Matrix(Integer)
--E 16

```

```

--S 17 of 59
vertConcat(t2,t2)
--R
--R

```

```

--R      +1  1  1    1    1 +
--R      |
--R      |1  2  4    8    16 |
--R      |
--R      |1  3  9    27   81 |
--R      |
--R      |1  4  16   64  256|
--R      |
--R      |1  5  25  125  625|
--R  (17) |
--R      |1  1  1    1    1 |
--R      |
--R      |1  2  4    8    16 |
--R      |
--R      |1  3  9    27   81 |
--R      |
--R      |1  4  16   64  256|
--R      |
--R      +1  5  25  125  625+
--R
--R                                          Type: Matrix(Integer)
--E 17

```

```

--S 18 of 59
t3:=matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R      +1  1  1    1    1 +
--R      |
--R      |1  2  4    8    16 |
--R      |
--R  (18) |1  3  9    27   81 |
--R      |
--R      |1  4  16   64  256|
--R      |
--R      +1  5  25  125  625+
--R
--R                                          Type: Matrix(Integer)
--E 18

```

```

--S 19 of 59
listOfLists t3
--R
--R
--R  (19)
--R  [[1,1,1,1,1],[1,2,4,8,16],[1,3,9,27,81],[1,4,16,64,256],[1,5,25,125,625]]
--R                                          Type: List(List(Integer))
--E 19

```

```

--S 20 of 59
t4:=matrix [[j**i for i in 0..4] for j in 1..5]
--R

```

```

--R
--R      +1  1  1    1    1  +
--R      |
--R      |1  2  4    8    16 |
--R      |
--R      (20) |1  3  9    27   81 |
--R      |
--R      |1  4  16   64   256|
--R      |
--R      +1  5  25   125  625+
--R
--R                                          Type: Matrix(Integer)
--E 20

```

```

--S 21 of 59
elt(t4,3,3)
--R
--R
--R      (21)  9
--R
--R                                          Type: PositiveInteger
--E 21

```

```

--S 22 of 59
t5:=matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R      +1  1  1    1    1  +
--R      |
--R      |1  2  4    8    16 |
--R      |
--R      (22) |1  3  9    27   81 |
--R      |
--R      |1  4  16   64   256|
--R      |
--R      +1  5  25   125  625+
--R
--R                                          Type: Matrix(Integer)
--E 22

```

```

--S 23 of 59
setelt(t5,3,3,10)
--R
--R
--R      (23)  10
--R
--R                                          Type: PositiveInteger
--E 23

```

```

--S 24 of 59
t6:=matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R      +1  1  1    1    1  +

```

```

--R      |
--R      |1  2  4   8  16 |
--R      |
--R      (24) |1  3  9  27  81 |
--R      |
--R      |1  4  16  64  256|
--R      |
--R      +1  5  25  125  625+
--R
--E 24

```

Type: Matrix(Integer)

```

--S 25 of 59
swapRows!(t6,2,4)
--R
--R
--R      +1  1  1   1   1 +
--R      |
--R      |1  4  16  64  256|
--R      |
--R      (25) |1  3  9  27  81 |
--R      |
--R      |1  2  4   8  16 |
--R      |
--R      +1  5  25  125  625+
--R
--E 25

```

Type: Matrix(Integer)

```

--S 26 of 59
t7:=matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R      +1  1  1   1   1 +
--R      |
--R      |1  2  4   8  16 |
--R      |
--R      (26) |1  3  9  27  81 |
--R      |
--R      |1  4  16  64  256|
--R      |
--R      +1  5  25  125  625+
--R
--E 26

```

Type: Matrix(Integer)

```

--S 27 of 59
swapColumns!(t7,2,4)
--R
--R
--R      +1  1  1   1   1 +
--R      |
--R      |1  8  4   2  16 |

```



```

--R      |
--R (27) |1  27   9   3  81 |
--R      |
--R      |1  64  16  4 256|
--R      |
--R      +1 125 25 5 625+
--R
--R                                          Type: Matrix(Integer)
--E 27

```

```

--S 28 of 59
t8:=matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R      +1  1  1   1   1  +
--R      |
--R      |1  2  4   8  16 |
--R      |
--R (28) |1  3  9  27  81 |
--R      |
--R      |1  4 16  64 256|
--R      |
--R      +1  5 25 125 625+
--R
--R                                          Type: Matrix(Integer)
--E 28

```

```

--S 29 of 59
subMatrix(t8,1,3,2,4)
--R
--R
--R      +1  1  1  +
--R      |
--R (29) |2  4  8 |
--R      |
--R      +3  9 27+
--R
--R                                          Type: Matrix(Integer)
--E 29

```

```

--S 30 of 59
t9:=matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R      +1  1  1   1   1  +
--R      |
--R      |1  2  4   8  16 |
--R      |
--R (30) |1  3  9  27  81 |
--R      |
--R      |1  4 16  64 256|
--R      |
--R      +1  5 25 125 625+

```


--S 34 of 59

t0-t0

--R

--R

--R +0 0 0 0 0+

--R | |

--R |0 0 0 0 0|

--R | |

--R (34) |0 0 0 0 0|

--R | |

--R |0 0 0 0 0|

--R | |

--R +0 0 0 0 0+

--R

--E 34

Type: Matrix(Integer)

--S 35 of 59

-t0

--R

--R

--R +- 1 - 1 - 1 - 1 - 1 +

--R | |

--R |- 1 - 2 - 4 - 8 - 16 |

--R | |

--R (35) |- 1 - 3 - 9 - 27 - 81 |

--R | |

--R |- 1 - 4 - 16 - 64 - 256 |

--R | |

--R +- 1 - 5 - 25 - 125 - 625+

--R

--E 35

Type: Matrix(Integer)

--S 36 of 59

t0*t0

--R

--R

--R + 5 15 55 225 979 +

--R | |

--R |31 129 573 2637 12405 |

--R | |

--R (36) |121 547 2551 12121 58315 |

--R | |

--R |341 1593 7585 36561 177745 |

--R | |

--R +781 3711 17871 86841 424731+

--R

--E 36

Type: Matrix(Integer)

--S 37 of 59

1/3*t0

```
--R
--R
--R      +1  1  1    1    1 +
--R      |- - -    -    - |
--R      |3  3  3    3    3 |
--R      |
--R      |1  2  4    8    16 |
--R      |- - -    -    -- |
--R      |3  3  3    3    3 |
--R      |
--R      |1
--R      (37) |- 1  3    9    27 |
--R      |3
--R      |
--R      |1  4  16  64  256|
--R      |- - -- --  ---|
--R      |3  3   3   3   3 |
--R      |
--R      |1  5  25  125  625|
--R      |- - -- ---  ---|
--R      +3  3   3   3   3 +
--R
--E 37
```

Type: Matrix(Fraction(Integer))

--S 38 of 59

m:=matrix [[j**i for i in 0..4] for j in 1..5]

```
--R
--R
--R      +1  1  1    1    1 +
--R      |
--R      |1  2  4    8    16 |
--R      |
--R      (38) |1  3  9    27    81 |
--R      |
--R      |1  4  16  64  256|
--R      |
--R      +1  5  25  125  625+
--R
--E 38
```

Type: Matrix(Integer)

--S 39 of 59

t0*1/3

```
--R
--R
--R      +1  1  1    1    1 +
--R      |- - -    -    - |
--R      |3  3  3    3    3 |
--R      |
--R      |1  2  4    8    16 |
```

```

--R      | - - - - -- |
--R      | 3 3 3 3 3 |
--R      |      |
--R      | 1      |
--R      (39) | - 1 3 9 27 |
--R      | 3      |
--R      |      |
--R      | 1 4 16 64 256 |
--R      | - - -- -- --- |
--R      | 3 3 3 3 3 |
--R      |      |
--R      | 1 5 25 125 625 |
--R      | - - -- --- --- |
--R      +3 3 3 3 3 +
--R
--E 39

```

Type: Matrix(Fraction(Integer))

```

--S 40 of 59
3*t0
--R
--R
--R      +3 3 3 3 3 +
--R      |      |
--R      | 3 6 12 24 48 |
--R      |      |
--R      (40) | 3 9 27 81 243 |
--R      |      |
--R      | 3 12 48 192 768 |
--R      |      |
--R      +3 15 75 375 1875+
--R
--E 40

```

Type: Matrix(Integer)

```

--S 41 of 59
c:=coerce([1,2,3,4,5])@Matrix(INT)
--R
--R
--R      +1+
--R      | |
--R      | 2 |
--R      | |
--R      (41) | 3 |
--R      | |
--R      | 4 |
--R      | |
--R      +5+
--R
--E 41

```

Type: Matrix(Integer)

```

--S 42 of 59

```

```

t0*c
--R
--R
--R      + 15 +
--R      |   |
--R      |129 |
--R      |   |
--R (42) |547 |
--R      |   |
--R      |1593|
--R      |   |
--R      +3711+
--R
--R                                          Type: Matrix(Integer)
--E 42

--S 43 of 59
r:=transpose([1,2,3,4,5])@Matrix(INT)
--R
--R
--R (43) [1 2 3 4 5]
--R
--R                                          Type: Matrix(Integer)
--E 43

--S 44 of 59
r*t0
--R
--R
--R (44) [15 55 225 979 4425]
--R
--R                                          Type: Matrix(Integer)
--E 44

--S 45 of 59
t0**3
--R
--R
--R      + 1279      5995      28635      138385      674175 +
--R      |          |          |          |          |
--R      |15775      74581      358021      1735927      8476705 |
--R      |          |          |          |          |
--R (45) |73655      348927      1677079      8138493      39765355 |
--R      |          |          |          |          |
--R      |223825      1061251      5103579      24775909      121090455|
--R      |          |          |          |          |
--R      +533935      2532835      12184195      59162185      289195879+
--R
--R                                          Type: Matrix(Integer)
--E 45

--S 46 of 59
t10:=matrix [[2**i for i in 2..4] for j in 1..5]
--R

```

```

--R
--R      +4  8  16+
--R      |      |
--R      |4  8  16|
--R      |      |
--R      (46) |4  8  16|
--R      |      |
--R      |4  8  16|
--R      |      |
--R      +4  8  16+
--R
--R                                          Type: Matrix(Integer)
--E 46

```

```

--S 47 of 59
exquo(t10,2)
--R
--R
--R      +2  4  8+
--R      |      |
--R      |2  4  8|
--R      |      |
--R      (47) |2  4  8|
--R      |      |
--R      |2  4  8|
--R      |      |
--R      +2  4  8+
--R
--R                                          Type: Union(Matrix(Integer),...)
--E 47

```

```

--S 48 of 59
t10/4
--R
--R
--R      +1  2  4+
--R      |      |
--R      |1  2  4|
--R      |      |
--R      (48) |1  2  4|
--R      |      |
--R      |1  2  4|
--R      |      |
--R      +1  2  4+
--R
--R                                          Type: Matrix(Fraction(Integer))
--E 48

```

```

--S 49 of 59
rowEchelon matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R      +1  0  0  0  0 +

```

[illegible]


```

--S 55 of 59
minordet matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R (55) 288
--R
--R                                         Type: PositiveInteger
--E 55

```

```

--S 56 of 59
pfaffian [[0,1,0,0],[-1,0,0,0],[0,0,0,1],[0,0,-1,0]]
--R
--R
--R (56) 1
--R
--R                                         Type: PositiveInteger
--E 56

```

```

--S 57 of 59
inverse matrix [[j**i for i in 0..4] for j in 1..5]
--R
--R
--R
--R      + 5      - 10      10      - 5      1      +
--R      |
--R      | 77      107      39      61      25|
--R      |- --      ---      - --      --      - --|
--R      | 12      6      2      6      12|
--R      |
--R      | 71      59      49      41      35 |
--R      | --      - --      --      - --      -- |
--R (57) | 24      6      4      6      24 |
--R      |
--R      | 7      13      11      5|
--R      |- --      --      - 3      --      - --|
--R      | 12      6      6      12|
--R      |
--R      | 1      1      1      1      1 |
--R      | --      - -      - -      - -      -- |
--R      + 24      6      4      6      24 +
--R
--R                                         Type: Union(Matrix(Fraction(Integer)),...)
--E 57

```

```

--S 58 of 59
(matrix [[j**i for i in 0..4] for j in 1..5]) ** 2
--R
--R
--R
--R      + 5      15      55      225      979      +
--R      |
--R      |31      129      573      2637      12405 |
--R      |
--R (58) |121      547      2551      12121      58315 |

```

```

--R      |
--R      |341  1593  7585   36561  177745|
--R      |
--R      +781  3711  17871  86841  424731+
--R
--R                                          Type: Matrix(Integer)
--E 58

```

```

--S 59 of 59

```

```

)show MatrixCategory

```

```

--R
--R MatrixCategory(R: Ring, Row: FiniteLinearAggregate(t#1), Col: FiniteLinearAggregate(t#1)) is a category
--R Abbreviation for MatrixCategory is MATCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MATCAT
--R
--R----- Operations -----
--R ??? : (Row, %) -> Row          ??? : (% , Col) -> Col
--R ??? : (Integer, %) -> %        ??? : (% , R) -> %
--R ??? : (R, %) -> %              ??? : (% , %) -> %
--R ?+? : (% , %) -> %            -? : % -> %
--R ?-? : (% , %) -> %            antisymmetric? : % -> Boolean
--R coerce : Col -> %              column : (% , Integer) -> Col
--R copy : % -> %                  diagonal? : % -> Boolean
--R diagonalMatrix : List(%) -> %  diagonalMatrix : List(R) -> %
--R elt : (% , Integer, Integer, R) -> R  elt : (% , Integer, Integer) -> R
--R empty : () -> %                empty? : % -> Boolean
--R eq? : (% , %) -> Boolean        fill! : (% , R) -> %
--R horizConcat : (% , %) -> %     listOfLists : % -> List(List(R))
--R map : (((R, R) -> R), % , % , R) -> %  map : (((R, R) -> R), % , %) -> %
--R map : ((R -> R), %) -> %        map! : ((R -> R), %) -> %
--R matrix : List(List(R)) -> %     maxColIndex : % -> Integer
--R maxRowIndex : % -> Integer      minColIndex : % -> Integer
--R minRowIndex : % -> Integer       ncols : % -> NonNegativeInteger
--R nrows : % -> NonNegativeInteger  parts : % -> List(R)
--R qelt : (% , Integer, Integer) -> R  row : (% , Integer) -> Row
--R sample : () -> %                setRow! : (% , Integer, Row) -> %
--R square? : % -> Boolean           squareTop : % -> %
--R symmetric? : % -> Boolean        transpose : % -> %
--R transpose : Row -> %            vertConcat : (% , %) -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ***? : (% , Integer) -> % if R has FIELD
--R ***? : (% , NonNegativeInteger) -> %
--R ?/? : (% , R) -> % if R has FIELD
--R ?? : (% , %) -> Boolean if R has SETCAT
--R any? : ((R -> Boolean), %) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if R has SETCAT
--R columnSpace : % -> List(Col) if R has EUCLDOM
--R count : (R, %) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
--R count : ((R -> Boolean), %) -> NonNegativeInteger if $ has finiteAggregate
--R determinant : % -> R if R has commutative(*)

```

```

--R elt : (% , List(Integer), List(Integer)) -> %
--R eval : (% , List(R), List(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (% , R, R) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (% , Equation(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (% , List(Equation(R))) -> % if R has EVALAB(R) and R has SETCAT
--R every? : ((R -> Boolean), %) -> Boolean if $ has finiteAggregate
--R exquo : (% , R) -> Union(%, "failed") if R has INTDOM
--R hash : % -> SingleInteger if R has SETCAT
--R inverse : % -> Union(%, "failed") if R has FIELD
--R latex : % -> String if R has SETCAT
--R less? : (% , NonNegativeInteger) -> Boolean
--R matrix : (NonNegativeInteger, NonNegativeInteger, ((Integer, Integer) -> R)) -> %
--R member? : (R, %) -> Boolean if R has SETCAT and $ has finiteAggregate
--R members : % -> List(R) if $ has finiteAggregate
--R minordet : % -> R if R has commutative(*)
--R more? : (% , NonNegativeInteger) -> Boolean
--R new : (NonNegativeInteger, NonNegativeInteger, R) -> %
--R nullSpace : % -> List(Col) if R has INTDOM
--R nullity : % -> NonNegativeInteger if R has INTDOM
--R pfaffian : % -> R if R has COMRING
--R qsetelt! : (% , Integer, Integer, R) -> R
--R rank : % -> NonNegativeInteger if R has INTDOM
--R rowEchelon : % -> % if R has EUCDOM
--R scalarMatrix : (NonNegativeInteger, R) -> %
--R setColumn! : (% , Integer, Col) -> %
--R setelt : (% , List(Integer), List(Integer), %) -> %
--R setelt : (% , Integer, Integer, R) -> R
--R setsubMatrix! : (% , Integer, Integer, %) -> %
--R size? : (% , NonNegativeInteger) -> Boolean
--R subMatrix : (% , Integer, Integer, Integer, Integer) -> %
--R swapColumns! : (% , Integer, Integer) -> %
--R swapRows! : (% , Integer, Integer) -> %
--R zero : (NonNegativeInteger, NonNegativeInteger) -> %
--R ?~=? : (% , %) -> Boolean if R has SETCAT
--R
--E 59

)spool
)lisp (bye)

```

— MatrixCategory.help —

```

=====
MatrixCategory examples
=====

```

MatrixCategory is a general matrix category which allows different representations and indexing schemes. Rows and columns may be extracted with rows returned as objects of type Row and columns returned as objects of type Col. A domain belonging to this category will be shallowly mutable. The index of the 'first' row may be obtained by calling the function minRowIndex. The index of the 'first' column may be obtained by calling the function minColIndex. The index of the first element of a Row is the same as the index of the first column in a matrix and vice versa.

Predicates:

square?(m) returns true if m is a square matrix
(if m has the same number of rows as columns) and false otherwise.

```
square matrix [[j**i for i in 0..4] for j in 1..5]
```

diagonal?(m) returns true if the matrix m is square and diagonal (i.e. all entries of m not on the diagonal are zero) and false otherwise.

```
diagonal? matrix [[j**i for i in 0..4] for j in 1..5]
```

symmetric?(m) returns true if the matrix m is square and symmetric (i.e. $\text{spad}\{m[i,j] = m[j,i]\}$ for all i and j) and false otherwise.

```
symmetric? matrix [[j**i for i in 0..4] for j in 1..5]
```

antisymmetric?(m) returns true if the matrix m is square and antisymmetric (i.e. $m[i,j] = -m[j,i]$ for all i and j) and false otherwise.

```
antisymmetric? matrix [[j**i for i in 0..4] for j in 1..5]
```

Creation

zero(m,n) returns an m-by-n zero matrix.

```
z:Matrix(INT):=zero(3,3)
```

matrix(l) converts the list of lists l to a matrix, where the list of lists is viewed as a list of the rows of the matrix.

```
matrix [[1,2,3],[4,5,6],[7,8,9],[1,1,1]]
```

scalarMatrix(n,r) returns an n-by-n matrix with r's on the diagonal and zeroes elsewhere.

```
z:Matrix(INT):=scalarMatrix(3,5)
```

`diagonalMatrix(1)` returns a diagonal matrix with the elements of 1 on the diagonal.

```
diagonalMatrix [1,2,3]
```

`diagonalMatrix([m1,...,mk])` creates a block diagonal matrix M with block matrices m_1, \dots, m_k down the diagonal, with 0 block matrices elsewhere.

More precisely: if $r_i := \text{nrows } m_i$, $c_i := \text{ncols } m_i$, then m is an $(r_1 + \dots + r_k)$ by $(c_1 + \dots + c_k)$ - matrix with entries $m.i.j = m_l.(i-r_1-\dots-r_{l-1}).(j-n_1-\dots-n_{l-1})$,
if $(r_1 + \dots + r_{l-1}) < i \leq r_1 + \dots + r_l$ and $(c_1 + \dots + c_{l-1}) < j \leq c_1 + \dots + c_l$,
 $m.i.j = 0$ otherwise.

```
diagonalMatrix [matrix [[1,2],[3,4]], matrix [[4,5],[6,7]]]
```

`coerce(col)` converts the column `col` to a column matrix.

```
coerce([1,2,3])@Matrix(INT)
```

`transpose(r)` converts the row `r` to a row matrix.

```
transpose([1,2,3])@Matrix(INT)
```

Creation of new matrices from old

`transpose(m)` returns the transpose of the matrix m .

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
transpose m
```

`squareTop(m)` returns an n -by- n matrix consisting of the first n rows of the m -by- n matrix m . Error: if $m < n$.

```
m:=matrix [[j**i for i in 0..2] for j in 1..5]
squareTop m
```

`horizConcat(x,y)` horizontally concatenates two matrices with an equal number of rows. The entries of y appear to the right of the entries of x . Error: if the matrices do not have the same number of rows.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
horizConcat(m,m)
```

`vertConcat(x,y)` vertically concatenates two matrices with an

equal number of columns. The entries of y appear below of the entries of x . Error: if the matrices do not have the same number of columns.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
vertConcat(m,m)
```

Part extractions/assignments

`listOfLists(m)` returns the rows of the matrix m as a list of lists

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
listOfLists m
```

`elt(x,rowList,colList)` returns an m -by- n matrix consisting of elements of x , where $m = \# \text{ rowList}$ and $n = \# \text{ colList}$

If $\text{rowList} = [i_{<1>}, i_{<2>}, \dots, i_{<m>}]$ and

$\text{colList} = [j_{<1>}, j_{<2>}, \dots, j_{<n>}]$,

then the (k,l) -th entry of `elt(x,rowList,colList)` is $x(i_{<k>}, j_{<l>})$.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
elt(m,3,3)
```

`setelt(x,rowList,colList,y)` destructively alters the matrix x .

If y is m -by- n ,

$\text{rowList} = [i_{<1>}, i_{<2>}, \dots, i_{<m>}]$ and

$\text{colList} = [j_{<1>}, j_{<2>}, \dots, j_{<n>}]$,

then $x(i_{<k>}, j_{<l>})$

is set to $y(k,l)$ for $k = 1, \dots, m$ and $l = 1, \dots, n$

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
setelt(m,3,3,10)
```

`swapRows!(m,i,j)` interchanges the i -th and j -th rows of m . This destructively alters the matrix.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
swapRows!(m,2,4)
```

`swapColumns!(m,i,j)` interchanges the i -th and j -th columns of m . This destructively alters the matrix.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
swapColumns!(m,2,4)
```

`subMatrix(x,i1,i2,j1,j2)` extracts the submatrix $[x(i,j)]$ where the index i ranges from $i1$ to $i2$ and the index j ranges from $j1$ to $j2$.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
```

```
subMatrix(m,1,3,2,4)
```

setsubMatrix(x,i1,j1,y) destructively alters the matrix x.
Here x(i,j) is set to y(i-i1+1,j-j1+1) for
i = i1,...,i1-1+nrows y and j = j1,...,j1-1+ncols y.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
setsubMatrix!(m,2,2,matrix [[3,3],[3,3]])
```

Arithmetic

x + y is the sum of the matrices x and y.
It is an error if the dimensions are incompatible.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
m+m
```

x - y is the difference of the matrices x and y.
It is an error if the dimensions are incompatible.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
m-m
```

-x returns the negative of the matrix x.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
-m
```

x * y is the product of the matrices x and y.
It is an error if the dimensions are incompatible.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
m*m
```

r*x is the left scalar multiple of the scalar r and the matrix x.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
1/3*m
```

x * r is the right scalar multiple of the scalar r and the matrix x.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
m*1/3
```

n * x is an integer multiple.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
3*m
```

$x * c$ is the product of the matrix x and the column vector c .
It is an error if the dimensions are incompatible.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
c:=coerce([1,2,3,4,5])@Matrix(INT)
m*c
```

$r * x$ is the product of the row vector r and the matrix x .
It is an error if the dimensions are incompatible.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
r:=transpose([1,2,3,4,5])@Matrix(INT)
r*m
```

$x ** n$ computes a non-negative integral power of the matrix x .
It is an error if the matrix is not square.

```
m:=matrix [[j**i for i in 0..4] for j in 1..5]
m**3
```

`exquo(m,r)` computes the exact quotient of the elements
of m by r , returning "failed" if this is not possible.

```
m:=matrix [[2**i for i in 2..4] for j in 1..5]
exquo(m,2)
```

m/r divides the elements of m by r , r must be non-zero.

```
m:=matrix [[2**i for i in 2..4] for j in 1..5]
m/4
```

Linear algebra

`rowEchelon(m)` returns the row echelon form of the matrix m .

```
rowEchelon matrix [[j**i for i in 0..4] for j in 1..5]
```

`columnSpace(m)` returns a sublist of columns of the matrix m

```
columnSpace matrix [[1,2,3],[4,5,6],[7,8,9],[1,1,1]]
```

`rank(m)` returns the rank of the matrix m .

```
rank matrix [[1,2,3],[4,5,6],[7,8,9]]
```

`nullity(m)` returns the nullity of the matrix m . This is
the dimension of the null space of the matrix m .

```
nullity matrix [[1,2,3],[4,5,6],[7,8,9]]
```


`nullSpace(m)` returns a basis for the null space of the matrix `m`.

```
nullSpace matrix [[1,2,3],[4,5,6],[7,8,9]]
```

`determinant(m)` returns the determinant of the matrix `m`.
It is an error if the matrix is not square.

```
determinant matrix [[j**i for i in 0..4] for j in 1..5]
```

`minordet(m)` computes the determinant of the matrix `m` using minors.
It is an error if the matrix is not square.

```
minordet matrix [[j**i for i in 0..4] for j in 1..5]
```

`pfaffian(m)` returns the Pfaffian of the matrix `m`.
It is an error if the matrix is not antisymmetric

```
pfaffian [[0,1,0,0],[-1,0,0,0],[0,0,0,1],[0,0,-1,0]]
```

`inverse(m)` returns the inverse of the matrix `m`.
If the matrix is not invertible, "failed" is returned.
It is an error if the matrix is not square.

```
inverse matrix [[j**i for i in 0..4] for j in 1..5]
```

`m**n` computes an integral power of the matrix `m`.
It is an error if matrix is not square or
if the matrix is square but not invertible.

```
(matrix [[j**i for i in 0..4] for j in 1..5]) ** 2
```

We define three categories for matrices

- `MatrixCategory` is the category of all matrices
- `RectangularMatrixCategory` is the category of all matrices of a given dimension
- `SquareMatrixCategory` inherits from `RectangularMatrixCategory`

The `Matrix` domain is the domain of all matrices.

All three domains share the same representation, inherited from `Matrix`. Most algorithms are only implemented for `Matrix` but implemented in separate packages.

- `MatrixLinearAlgebraFunctions` is the top-level package that calls the other packages
- `InnerMatrixLinearAlgebraFunctions` contains implementations that work over a `Field`

- `InnerMatrixQuotientFieldFunctions` contain implementations that work over a quotient field

Implementations that rely on the representation of matrices used in `Matrix` should be put into these packages.

See:

⇐ “`TwoDimensionalArrayCategory`” (`ARR2CAT`) [5](#) on page [412](#)

⇒ “`RectangularMatrixCategory`” (`RMATCAT`) [10](#) on page [954](#)

⇒ “`SquareMatrixCategory`” (`SMATCAT`) [12](#) on page [1131](#)

Exports:

| | | | | |
|-----------------------------|--------------------------|----------------------------|---------------------------|-----------------------------|
| <code>antisymmetric?</code> | <code>any?</code> | <code>coerce</code> | <code>column</code> | <code>columnSpace</code> |
| <code>copy</code> | <code>count</code> | <code>determinant</code> | <code>diagonal?</code> | <code>diagonalMatrix</code> |
| <code>elt</code> | <code>empty</code> | <code>empty?</code> | <code>eq?</code> | <code>eval</code> |
| <code>every?</code> | <code>exquo</code> | <code>fill!</code> | <code>hash</code> | <code>horizConcat</code> |
| <code>inverse</code> | <code>latex</code> | <code>less?</code> | <code>listOfLists</code> | <code>map</code> |
| <code>map!</code> | <code>matrix</code> | <code>maxColIndex</code> | <code>maxRowIndex</code> | <code>member?</code> |
| <code>members</code> | <code>minColIndex</code> | <code>minordet</code> | <code>minRowIndex</code> | <code>more?</code> |
| <code>ncols</code> | <code>new</code> | <code>nrows</code> | <code>nullSpace</code> | <code>nullity</code> |
| <code>parts</code> | <code>pfaffian</code> | <code>qelt</code> | <code>qsetelt!</code> | <code>rank</code> |
| <code>row</code> | <code>rowEchelon</code> | <code>sample</code> | <code>scalarMatrix</code> | <code>setColumn!</code> |
| <code>setelt</code> | <code>setRow!</code> | <code>setsubMatrix!</code> | <code>size?</code> | <code>square?</code> |
| <code>squareTop</code> | <code>subMatrix</code> | <code>swapColumns!</code> | <code>swapRows!</code> | <code>symmetric?</code> |
| <code>transpose</code> | <code>vertConcat</code> | <code>zero</code> | <code>#?</code> | <code>?**?</code> |
| <code>?/?</code> | <code>?=?</code> | <code>?~=?</code> | <code>?*?</code> | <code>?+?</code> |
| <code>-?</code> | <code>?-?</code> | | | |

Attributes Exported:

- **`finiteAggregate`** is true if it is an aggregate with a finite number of elements.
- **`shallowlyMutable`** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the `shallowlyMutable` proper.
- **`nil`**

These are directly exported but not implemented:

```
determinant : % -> R if R has commutative *
inverse : % -> Union(%, "failed") if R has FIELD
minordet : % -> R if R has commutative *
nullity : % -> NonNegativeInteger if R has INTDOM
nullSpace : % -> List Col if R has INTDOM
rowEchelon : % -> % if R has EUCDOM
rank : % -> NonNegativeInteger if R has INTDOM
```

These are implemented by this category:

```

antisymmetric? : % -> Boolean
coerce : Col -> %
columnSpace : % -> List Col if R has EUCLDOM
diagonal? : % -> Boolean
diagonalMatrix : List % -> %
diagonalMatrix : List R -> %
elt : (% , List Integer , List Integer) -> %
exquo : (% , R) -> Union(% , "failed") if R has INTDOM
horizConcat : (% , %) -> %
listOfLists : % -> List List R
pfaffian : % -> R if R has COMRING
matrix : List List R -> %
matrix : (NonNegativeInteger , NonNegativeInteger , (Integer , Integer) -> R) -> %
scalarMatrix : (NonNegativeInteger , R) -> %
setelt : (% , List Integer , List Integer , %) -> %
setsubMatrix! : (% , Integer , Integer , %) -> %
square? : % -> Boolean
squareTop : % -> %
subMatrix : (% , Integer , Integer , Integer , Integer) -> %
swapColumns! : (% , Integer , Integer) -> %
swapRows! : (% , Integer , Integer) -> %
symmetric? : % -> Boolean
transpose : Row -> %
transpose : % -> %
vertConcat : (% , %) -> %
zero : (NonNegativeInteger , NonNegativeInteger) -> %
?/? : (% , R) -> % if R has FIELD
?+? : (% , %) -> %
?-? : (% , %) -> %
-? : % -> %
?*? : (% , R) -> %
?*? : (R , %) -> %
?*? : (Integer , %) -> %
?*?? : (% , NonNegativeInteger) -> %
?*?? : (% , Integer) -> % if R has FIELD
?*? : (% , Col) -> Col
?*? : (Row , %) -> Row
?*? : (% , %) -> %

```

These exports come from (p412) TwoDimensionalArrayCategory(R,Row,Col)
 where R:Ring, Row:FiniteLinearAggregate(R),
 Col:FiniteLinearAggregate(R):

```

any? : ((R -> Boolean) , %) -> Boolean if $ has finiteAggregate
coerce : % -> OutputForm if R has SETCAT
column : (% , Integer) -> Col
copy : % -> %
count : (R , %) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate

```

```

count : ((R -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
elt : (%,Integer,Integer,R) -> R
elt : (%,Integer,Integer) -> R
empty : () -> %
empty? : % -> Boolean
eq? : (%,%)-> Boolean
eval : (%,List R,List R) -> % if R has EVALAB R and R has SETCAT
eval : (%R,R) -> % if R has EVALAB R and R has SETCAT
eval : (%Equation R) -> % if R has EVALAB R and R has SETCAT
eval : (%List Equation R) -> % if R has EVALAB R and R has SETCAT
every? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
fill! : (%R) -> %
hash : % -> SingleInteger if R has SETCAT
latex : % -> String if R has SETCAT
less? : (%NonNegativeInteger) -> Boolean
map : (((R,R) -> R),%,%,R) -> %
map : (((R,R) -> R),%,%) -> %
map : ((R -> R),%) -> %
map! : ((R -> R),%) -> %
maxColIndex : % -> Integer
maxRowIndex : % -> Integer
member? : (R,%) -> Boolean if R has SETCAT and $ has finiteAggregate
members : % -> List R if $ has finiteAggregate
minColIndex : % -> Integer
minRowIndex : % -> Integer
more? : (%NonNegativeInteger) -> Boolean
new : (NonNegativeInteger,NonNegativeInteger,R) -> %
ncols : % -> NonNegativeInteger
nrows : % -> NonNegativeInteger
parts : % -> List R
qelt : (%Integer,Integer) -> R
qsetelt! : (%Integer,Integer,R) -> R
row : (%Integer) -> Row
sample : () -> %
setColumn! : (%Integer,Col) -> %
setelt : (%Integer,Integer,R) -> R
setRow! : (%Integer,Row) -> %
size? : (%NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
?~=? : (%,%)-> Boolean if R has SETCAT
?=? : (%,%)-> Boolean if R has SETCAT

```

— category MATCAT MatrixCategory —

```

)abbrev category MATCAT MatrixCategory
++ Authors: Grabmeier, Gschnitzer, Williamson, Gabriel Dos Reis
++ Date Created: 1987
++ Date Last Updated: July 1990
++ Description:

```

```

++ \spadtype{MatrixCategory} is a general matrix category which allows
++ different representations and indexing schemes. Rows and
++ columns may be extracted with rows returned as objects of
++ type Row and columns returned as objects of type Col.
++ A domain belonging to this category will be shallowly mutable.
++ The index of the 'first' row may be obtained by calling the
++ function \spadfun{minRowIndex}. The index of the 'first' column may
++ be obtained by calling the function \spadfun{minColIndex}. The index of
++ the first element of a Row is the same as the index of the
++ first column in a matrix and vice versa.

MatrixCategory(R,Row,Col): Category == Definition where
  R : Ring
  Row : FiniteLinearAggregate R
  Col : FiniteLinearAggregate R

Definition ==> TwoDimensionalArrayCategory(R,Row,Col) with
  shallowlyMutable
  ++ One may destructively alter matrices

  finiteAggregate
  ++ matrices are finite

--% Predicates

square? : % -> Boolean
++square?(m) returns true if m is a square matrix
++ (if m has the same number of rows as columns) and false otherwise.
++
++X square matrix [[j**i for i in 0..4] for j in 1..5]

diagonal?: % -> Boolean
++diagonal?(m) returns true if the matrix m is square and
++ diagonal (that is, all entries of m not on the diagonal are zero) and
++ false otherwise.
++
++X diagonal? matrix [[j**i for i in 0..4] for j in 1..5]

symmetric?: % -> Boolean
++symmetric?(m) returns true if the matrix m is square and
++ symmetric (that is, \spad{m[i,j] = m[j,i]} for all i and j) and false
++ otherwise.
++
++X symmetric? matrix [[j**i for i in 0..4] for j in 1..5]

antisymmetric?: % -> Boolean
++antisymmetric?(m) returns true if the matrix m is square and
++ antisymmetric (that is, \spad{m[i,j] = -m[j,i]} for all i and j)
++ and false otherwise.
++

```

```

++X antisymmetric? matrix [[j**i for i in 0..4] for j in 1..5]

--% Creation

zero: (NonNegativeInteger,NonNegativeInteger) -> %
++zero(m,n) returns an m-by-n zero matrix.
++
++X z:Matrix(INT):=zero(3,3)

matrix: List List R -> %
++matrix(l) converts the list of lists l to a matrix, where the
++ list of lists is viewed as a list of the rows of the matrix.
++
++X matrix [[1,2,3],[4,5,6],[7,8,9],[1,1,1]]

matrix: (NonNegativeInteger,NonNegativeInteger,(Integer,Integer)->R) -> %
++matrix(n,m,f) constructs an \spad{n * m} matrix with
++ the \spad{(i,j)} entry equal to \spad{f(i,j)}
++
++X f(i:INT,j:INT):INT == i+j
++X matrix(3,4,f)

scalarMatrix: (NonNegativeInteger,R) -> %
++scalarMatrix(n,r) returns an n-by-n matrix with r's on the
++ diagonal and zeroes elsewhere.
++
++X z:Matrix(INT):=scalarMatrix(3,5)

diagonalMatrix: List R -> %
++diagonalMatrix(l) returns a diagonal matrix with the elements
++ of l on the diagonal.
++
++X diagonalMatrix [1,2,3]

diagonalMatrix: List % -> %
++diagonalMatrix([m1,...,mk]) creates a block diagonal matrix
++ M with block matrices m1,...,mk down the diagonal,
++ with 0 block matrices elsewhere.
++ More precisely: if \spad{ri := nrows mi}, \spad{ci := ncols mi},
++ then m is an (r1+..+rk) by (c1+..+ck) - matrix with entries
++ \spad{m.i.j = m1.(i-r1-..-r(l-1)).(j-n1-..-n(l-1))}, if
++ \spad{(r1+..+r(l-1)) < i <= r1+..+rl} and
++ \spad{(c1+..+c(l-1)) < i <= c1+..+cl},
++ \spad{m.i.j} = 0 otherwise.
++
++X diagonalMatrix [matrix [[1,2],[3,4]], matrix [[4,5],[6,7]]]

coerce: Col -> %
++coerce(col) converts the column col to a column matrix.

```

```

++
++X coerce([1,2,3])@Matrix(INT)

transpose: Row -> %
++transpose(r) converts the row r to a row matrix.
++
++X transpose([1,2,3])@Matrix(INT)

--% Creation of new matrices from old

transpose: % -> %
++transpose(m) returns the transpose of the matrix m.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X transpose m

squareTop: % -> %
++squareTop(m) returns an n-by-n matrix consisting of the first
++ n rows of the m-by-n matrix m. Error: if
++ \spad{m < n}.
++
++X m:=matrix [[j**i for i in 0..2] for j in 1..5]
++X squareTop m

horizConcat: (%,% ) -> %
++horizConcat(x,y) horizontally concatenates two matrices with
++ an equal number of rows. The entries of y appear to the right
++ of the entries of x. Error: if the matrices
++ do not have the same number of rows.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X horizConcat(m,m)

vertConcat: (%,% ) -> %
++vertConcat(x,y) vertically concatenates two matrices with an
++ equal number of columns. The entries of y appear below
++ of the entries of x. Error: if the matrices
++ do not have the same number of columns.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X vertConcat(m,m)

--% Part extractions/assignments

listOfLists: % -> List List R
++listOfLists(m) returns the rows of the matrix m as a list
++ of lists.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X listOfLists m

```

```

elt: (%,List Integer,List Integer) -> %
++elt(x,rowList,colList) returns an m-by-n matrix consisting
++ of elements of x, where \spad{m = # rowList} and \spad{n = # colList}
++ If \spad{rowList = [i<1>,i<2>,...,i<m>]} and \spad{colList =
++ [j<1>,j<2>,...,j<n>]}, then the \spad{(k,l)}th entry of
++ \spad{elt(x,rowList,colList)} is \spad{x(i<k>,j<l>)}.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X elt(m,3,3)

setelt: (%,List Integer,List Integer, %) -> %
++setelt(x,rowList,colList,y) destructively alters the matrix x.
++ If y is \spad{m}-by-\spad{n}, \spad{rowList = [i<1>,i<2>,...,i<m>]}
++ and \spad{colList = [j<1>,j<2>,...,j<n>]}, then \spad{x(i<k>,j<l>)}
++ is set to \spad{y(k,l)} for \spad{k = 1,...,m} and \spad{l = 1,...,n}
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X setelt(m,3,3,10)

swapRows_!: (%,Integer,Integer) -> %
++swapRows!(m,i,j) interchanges the \spad{i}th and \spad{j}th
++ rows of m. This destructively alters the matrix.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X swapRows!(m,2,4)

swapColumns_!: (%,Integer,Integer) -> %
++swapColumns!(m,i,j) interchanges the \spad{i}th and \spad{j}th
++ columns of m. This destructively alters the matrix.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X swapColumns!(m,2,4)

subMatrix: (%,Integer,Integer,Integer,Integer) -> %
++subMatrix(x,i1,i2,j1,j2) extracts the submatrix
++ \spad{[x(i,j)]} where the index i ranges from \spad{i1} to \spad{i2}
++ and the index j ranges from \spad{j1} to \spad{j2}.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X subMatrix(m,1,3,2,4)

setsubMatrix_!: (%,Integer,Integer,%) -> %
++setsubMatrix!(x,i1,j1,y) destructively alters the
++ matrix x. Here \spad{x(i,j)} is set to \spad{y(i-i1+1,j-j1+1)} for
++ \spad{i = i1,...,i1-1+nrows y} and \spad{j = j1,...,j1-1+ncols y}.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X setsubMatrix!(m,2,2,matrix [[3,3],[3,3]])

```


--% Arithmetic

```

"+" : (%,% ) -> %
++\spad{x + y} is the sum of the matrices x and y.
++ Error: if the dimensions are incompatible.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X m+m

 "-" : (%,% ) -> %
++\spad{x - y} is the difference of the matrices x and y.
++ Error: if the dimensions are incompatible.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X m-m

 "-" : %      -> %
++\spad{-x} returns the negative of the matrix x.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X -m

 "*" : (%,% ) -> %
++\spad{x * y} is the product of the matrices x and y.
++ Error: if the dimensions are incompatible.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X m*m

 "*" : (R,% ) -> %
++\spad{r*x} is the left scalar multiple of the scalar r and the
++ matrix x.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X 1/3*m

 "*" : (% ,R) -> %
++\spad{x * r} is the right scalar multiple of the scalar r and the
++ matrix x.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X m*1/3

 "*" : (Integer,% ) -> %
++\spad{n * x} is an integer multiple.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X 3*m

```

```

"*": (% , Col) -> Col
++\spad{x * c} is the product of the matrix x and the column vector c.
++ Error: if the dimensions are incompatible.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X c:=coerce([1,2,3,4,5])@Matrix(INT)
++X m*c

"*": (Row, %) -> Row
++\spad{r * x} is the product of the row vector r and the matrix x.
++ Error: if the dimensions are incompatible.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X r:=transpose([1,2,3,4,5])@Matrix(INT)
++X r*m

"**": (% , NonNegativeInteger) -> %
++\spad{x ** n} computes a non-negative integral power of the matrix x.
++ Error: if the matrix is not square.
++
++X m:=matrix [[j**i for i in 0..4] for j in 1..5]
++X m**3

if R has IntegralDomain then
"exquo": (% , R) -> Union(%, "failed")
++\spad{exquo(m,r)} computes the exact quotient of the elements
++ of m by r, returning \axiom{"failed"} if this is not possible.
++
++X m:=matrix [[2**i for i in 2..4] for j in 1..5]
++X exquo(m,2)

if R has Field then
"/": (% , R) -> %
++\spad{m/r} divides the elements of m by r. Error: if \spad{r = 0}.
++
++X m:=matrix [[2**i for i in 2..4] for j in 1..5]
++X m/4

--% Linear algebra

if R has EuclideanDomain then
rowEchelon: % -> %
++\spad{rowEchelon(m)} returns the row echelon form of the matrix m.
++
++X rowEchelon matrix [[j**i for i in 0..4] for j in 1..5]

columnSpace: % -> List Col
++\spad{columnSpace(m)} returns a sublist of columns of the matrix m
++ forming a basis of its column space
++

```

```

++X columnSpace matrix [[1,2,3],[4,5,6],[7,8,9],[1,1,1]]

if R has IntegralDomain then
rank: % -> NonNegativeInteger
++\spad{rank(m)} returns the rank of the matrix m.
++
++X rank matrix [[1,2,3],[4,5,6],[7,8,9]]

nullity: % -> NonNegativeInteger
++\spad{nullity(m)} returns the nullity of the matrix m. This is
++ the dimension of the null space of the matrix m.
++
++X nullity matrix [[1,2,3],[4,5,6],[7,8,9]]

nullSpace: % -> List Col
++\spad{nullSpace(m)} returns a basis for the null space of
++ the matrix m.
++
++X nullSpace matrix [[1,2,3],[4,5,6],[7,8,9]]

if R has commutative("*") then
determinant: % -> R
++\spad{determinant(m)} returns the determinant of the matrix m.
++ Error: if the matrix is not square.
++
++X determinant matrix [[j**i for i in 0..4] for j in 1..5]

minordet: % -> R
++\spad{minordet(m)} computes the determinant of the matrix m using
++ minors. Error: if the matrix is not square.
++
++X minordet matrix [[j**i for i in 0..4] for j in 1..5]

if R has CommutativeRing then
pfaffian: % -> R
++\spad{pfaffian(m)} returns the Pfaffian of the matrix m.
++ Error if the matrix is not antisymmetric
++
++X pfaffian [[0,1,0,0],[-1,0,0,0],[0,0,0,1],[0,0,-1,0]]

if R has Field then
inverse: % -> Union(%, "failed")
++\spad{inverse(m)} returns the inverse of the matrix m.
++ If the matrix is not invertible, "failed" is returned.
++ Error: if the matrix is not square.
++
++X inverse matrix [[j**i for i in 0..4] for j in 1..5]

"**: (% , Integer) -> %
++\spad{m**n} computes an integral power of the matrix m.
++ Error: if matrix is not square or if the matrix

```

```

    ++ is square but not invertible.
    ++
    ++X (matrix [[j**i for i in 0..4] for j in 1..5]) ** 2

add
  minr ==> minRowIndex
  maxr ==> maxRowIndex
  minc ==> minColIndex
  maxc ==> maxColIndex
  mini ==> minIndex
  maxi ==> maxIndex

--% Predicates

square? x == nRows x = nCols x

diagonal? x ==
  not square? x => false
  for i in minr x .. maxr x repeat
    for j in minc x .. maxc x | (j - minc x) ^= (i - minr x) repeat
      not zero? qelt(x, i, j) => return false
  true

symmetric? x ==
  (nRows := nRows x) ^= nCols x => false
  mr := minRowIndex x; mc := minColIndex x
  for i in 0..(nRows - 1) repeat
    for j in (i + 1)..(nRows - 1) repeat
      qelt(x, mr + i, mc + j) ^= qelt(x, mr + j, mc + i) => return false
  true

antisymmetric? x ==
  (nRows := nRows x) ^= nCols x => false
  mr := minRowIndex x; mc := minColIndex x
  for i in 0..(nRows - 1) repeat
    for j in i..(nRows - 1) repeat
      qelt(x, mr + i, mc + j) ^= -qelt(x, mr + j, mc + i) =>
        return false
  true

--% Creation of matrices

zero(rows,cols) == new(rows,cols,0)

matrix(l: List List R) ==
  null l => new(0,0,0)
  -- error check: this is a top level function
  rows : NonNegativeInteger := 1; cols := # first l
  cols = 0 => error "matrices with zero columns are not supported"
  for ll in rest l repeat

```

```

      cols ^= # ll => error "matrix: rows of different lengths"
      rows := rows + 1
      ans := new(rows,cols,0)
      for i in minr(ans)..maxr(ans) for ll in l repeat
        for j in minc(ans)..maxc(ans) for r in ll repeat
          qsetelt_!(ans,i,j,r)
      ans

matrix(n,m,f) ==
  mat := new(n,m,0)
  for i in minr mat..maxr mat repeat
    for j in minc mat..maxc mat repeat
      qsetelt!(mat,i,j,f(i,j))
  mat

scalarMatrix(n,r) ==
  ans := zero(n,n)
  for i in minr(ans)..maxr(ans) for j in minc(ans)..maxc(ans) repeat
    qsetelt_!(ans,i,j,r)
  ans

diagonalMatrix(l: List R) ==
  n := #l; ans := zero(n,n)
  for i in minr(ans)..maxr(ans) for j in minc(ans)..maxc(ans) _
    for r in l repeat qsetelt_!(ans,i,j,r)
  ans

diagonalMatrix(list: List %) ==
  rows : NonNegativeInteger := 0
  cols : NonNegativeInteger := 0
  for mat in list repeat
    rows := rows + nrows mat
    cols := cols + ncols mat
  ans := zero(rows,cols)
  loR := minr ans; loC := minc ans
  for mat in list repeat
    hiR := loR + nrows(mat) - 1; hiC := loC + nrows(mat) - 1
    for i in loR..hiR for k in minr(mat)..maxr(mat) repeat
      for j in loC..hiC for l in minc(mat)..maxc(mat) repeat
        qsetelt_!(ans,i,j,qelt(mat,k,l))
    loR := hiR + 1; loC := hiC + 1
  ans

coerce(v:Col) ==
  x := new(#v,1,0)
  one := minc(x)
  for i in minr(x)..maxr(x) for k in mini(v)..maxi(v) repeat
    qsetelt_!(x,i,one,qelt(v,k))
  x

```

```

transpose(v:Row) ==
  x := new(1,#v,0)
  one := minr(x)
  for j in minc(x)..maxc(x) for k in mini(v)..maxi(v) repeat
    qsetelt_!(x,one,j,qelt(v,k))
  x

transpose(x:%) ==
  ans := new(ncols x,nrows x,0)
  for i in minr(ans)..maxr(ans) repeat
    for j in minc(ans)..maxc(ans) repeat
      qsetelt_!(ans,i,j,qelt(x,j,i))
  ans

squareTop x ==
  nrows x < (cols := ncols x) =>
    error "squareTop: number of columns exceeds number of rows"
  ans := new(cols,cols,0)
  for i in minr(x)..(minr(x) + cols - 1) repeat
    for j in minc(x)..maxc(x) repeat
      qsetelt_!(ans,i,j,qelt(x,i,j))
  ans

horizConcat(x,y) ==
  (rows := nrows x) ~= nrows y =>
    error "HConcat: matrices must have same number of rows"
  ans := new(rows,(cols := ncols x) + ncols y,0)
  for i in minr(x)..maxr(x) repeat
    for j in minc(x)..maxc(x) repeat
      qsetelt_!(ans,i,j,qelt(x,i,j))
  for i in minr(y)..maxr(y) repeat
    for j in minc(y)..maxc(y) repeat
      qsetelt_!(ans,i,j + cols,qelt(y,i,j))
  ans

vertConcat(x,y) ==
  (cols := ncols x) ~= ncols y =>
    error "HConcat: matrices must have same number of columns"
  ans := new((rows := nrows x) + nrows y,cols,0)
  for i in minr(x)..maxr(x) repeat
    for j in minc(x)..maxc(x) repeat
      qsetelt_!(ans,i,j,qelt(x,i,j))
  for i in minr(y)..maxr(y) repeat
    for j in minc(y)..maxc(y) repeat
      qsetelt_!(ans,i + rows,j,qelt(y,i,j))
  ans

--% Part extraction/assignment

listOfLists x ==

```

```

ll : List List R := nil()
for i in maxr(x)..minr(x) by -1 repeat
  l : List R := nil()
  for j in maxc(x)..minc(x) by -1 repeat
    l := cons(qelt(x,i,j),l)
  ll := cons(l,ll)
ll

swapRows_!(x,i1,i2) ==
  (i1 < minr(x)) or (i1 > maxr(x)) or (i2 < minr(x)) or _
  (i2 > maxr(x)) => error "swapRows!: index out of range"
  i1 = i2 => x
  for j in minc(x)..maxc(x) repeat
    r := qelt(x,i1,j)
    qsetelt_!(x,i1,j,qelt(x,i2,j))
    qsetelt_!(x,i2,j,r)
  x

swapColumns_!(x,j1,j2) ==
  (j1 < minc(x)) or (j1 > maxc(x)) or (j2 < minc(x)) or _
  (j2 > maxc(x)) => error "swapColumns!: index out of range"
  j1 = j2 => x
  for i in minr(x)..maxr(x) repeat
    r := qelt(x,i,j1)
    qsetelt_!(x,i,j1,qelt(x,i,j2))
    qsetelt_!(x,i,j2,r)
  x

elt(x:%,rowList:List Integer,colList:List Integer) ==
  for ei in rowList repeat
    (ei < minr(x)) or (ei > maxr(x)) =>
      error "elt: index out of range"
  for ej in colList repeat
    (ej < minc(x)) or (ej > maxc(x)) =>
      error "elt: index out of range"
  y := new(# rowList,# colList,0)
  for ei in rowList for i in minr(y)..maxr(y) repeat
    for ej in colList for j in minc(y)..maxc(y) repeat
      qsetelt_!(y,i,j,qelt(x,ei,ej))
  y

setelt(x:%,rowList:List Integer,colList:List Integer,y:%) ==
  for ei in rowList repeat
    (ei < minr(x)) or (ei > maxr(x)) =>
      error "setelt: index out of range"
  for ej in colList repeat
    (ej < minc(x)) or (ej > maxc(x)) =>
      error "setelt: index out of range"
  ((# rowList) ^= (nrows y)) or ((# colList) ^= (ncols y)) =>
    error "setelt: matrix has bad dimensions"

```

```

    for ei in rowList for i in minr(y)..maxr(y) repeat
      for ej in colList for j in minc(y)..maxc(y) repeat
        qsetelt_!(x,ei,ej,qelt(y,i,j))
  y

subMatrix(x,i1,i2,j1,j2) ==
  (i2 < i1) => error "subMatrix: bad row indices"
  (j2 < j1) => error "subMatrix: bad column indices"
  (i1 < minr(x)) or (i2 > maxr(x)) =>
    error "subMatrix: index out of range"
  (j1 < minc(x)) or (j2 > maxc(x)) =>
    error "subMatrix: index out of range"
  rows := (i2 - i1 + 1) pretend NonNegativeInteger
  cols := (j2 - j1 + 1) pretend NonNegativeInteger
  y := new(rows,cols,0)
  for i in minr(y)..maxr(y) for k in i1..i2 repeat
    for j in minc(y)..maxc(y) for l in j1..j2 repeat
      qsetelt_!(y,i,j,qelt(x,k,l))
  y

setsubMatrix_!(x,i1,j1,y) ==
  i2 := i1 + nrows(y) - 1
  j2 := j1 + ncols(y) - 1
  (i1 < minr(x)) or (i2 > maxr(x)) =>
    error _
    "setsubMatrix!: inserted matrix too big, use subMatrix to restrict it"
  (j1 < minc(x)) or (j2 > maxc(x)) =>
    error _
    "setsubMatrix!: inserted matrix too big, use subMatrix to restrict it"
  for i in minr(y)..maxr(y) for k in i1..i2 repeat
    for j in minc(y)..maxc(y) for l in j1..j2 repeat
      qsetelt_!(x,k,l,qelt(y,i,j))
  x

--% Arithmetic

x + y ==
  ((r := nrows x) ^= nrows y) or ((c := ncols x) ^= ncols y) =>
    error "can't add matrices of different dimensions"
  ans := new(r,c,0)
  for i in minr(x)..maxr(x) repeat
    for j in minc(x)..maxc(x) repeat
      qsetelt_!(ans,i,j,qelt(x,i,j) + qelt(y,i,j))
  ans

x - y ==
  ((r := nrows x) ^= nrows y) or ((c := ncols x) ^= ncols y) =>
    error "can't subtract matrices of different dimensions"
  ans := new(r,c,0)
  for i in minr(x)..maxr(x) repeat

```



```

    for j in minc(x)..maxc(x) repeat
      qsetelt_!(ans,i,j,qelt(x,i,j) - qelt(y,i,j))
    ans

- x == map((r1:R):R +-> - r1,x)

a:R * x:% == map((r1:R):R +-> a * r1,x)

x:% * a:R == map((r1:R):R +-> r1 * a,x)

m:Integer * x:% == map((r1:R):R +-> m * r1,x)

x:% * y:% ==
  (ncols x ^= nrows y) =>
    error "can't multiply matrices of incompatible dimensions"
  ans := new(nrows x,ncols y,0)
  for i in minr(x)..maxr(x) repeat
    for j in minc(y)..maxc(y) repeat
      entry :=
        sum : R := 0
        for k in minr(y)..maxr(y) for l in minc(x)..maxc(x) repeat
          sum := sum + qelt(x,i,l) * qelt(y,k,j)
        sum
      qsetelt_!(ans,i,j,entry)
  ans

positivePower:(%,Integer) -> %
positivePower(x,n) ==
--   one? n => x
   (n = 1) => x
   odd? n => x * positivePower(x,n - 1)
   y := positivePower(x,n quo 2)
   y * y

x:% ** n:NonNegativeInteger ==
  not((nn:= nrows x) = ncols x) => error "***: matrix must be square"
  zero? n => scalarMatrix(nn,1)
  positivePower(x,n)

--if R has ConvertibleTo InputForm then
  --convert(x:%):InputForm ==
    --convert [convert("matrix":Symbol)@InputForm,
      --convert listOfLists x]$List(InputForm)

if Col has shallowlyMutable then

  x:% * v:Col ==
    ncols(x) ^= #v =>
      error "can't multiply matrix A and vector v if #cols A ^= #v"
    w : Col := new(nrows x,0)

```

```

for i in minr(x)..maxr(x) for k in mini(w)..maxi(w) repeat
  w.k :=
    sum : R := 0
    for j in minc(x)..maxc(x) for l in mini(v)..maxi(v) repeat
      sum := sum + qelt(x,i,j) * v(l)
    sum
  w

if Row has shallowlyMutable then

v:Row * x:% ==
  nrows(x) ^= #v =>
    error "can't multiply vector v and matrix A if #rows A ^= #v"
  w : Row := new(ncols x,0)
  for j in minc(x)..maxc(x) for k in mini(w)..maxi(w) repeat
    w.k :=
      sum : R := 0
      for i in minr(x)..maxr(x) for l in mini(v)..maxi(v) repeat
        sum := sum + qelt(x,i,j) * v(l)
      sum
    w

if R has EuclideanDomain then
  columnSpace M ==
    M2 := rowEchelon M
    basis: List Col := []
    n: Integer := ncols M
    m: Integer := nrows M
    indRow: Integer := 1
    for k in 1..n while indRow <= m repeat
      if not zero?(M2.(indRow,k)) then
        basis := cons(column(M,k),basis)
        indRow := indRow + 1
    reverse! basis

if R has CommutativeRing then
  skewSymmetricUnitMatrix(n:PositiveInteger):% ==
    matrix [(if i=j+1 and odd? j
              then -1
              else if i=j-1 and odd? i
              then 1
              else 0) for j in 1..n] for i in 1..n]

SUPR ==> SparseUnivariatePolynomial R

PfChar(A:%):SUPR ==
  n := nrows A
  (n = 2) => monomial(1$R,2)$SUPR + qelt(A,1,2)::SUPR
  M:=subMatrix(A,3,n,3,n)
  r:=subMatrix(A,1,1,3,n)

```

```

s:=subMatrix(A,3,n,2,2)
p:=PfChar(M)
d:=degree(p)$SUPR
B:=skewSymmetricUnitMatrix((n-2)::PositiveInteger)
C:=r*B
g:List R := [qelt(C*s,1,1), qelt(A,1,2), 1]
if d >= 4 then
  B:=M*B
  for i in 4..d by 2 repeat
    C:=C*B
    g:=cons(qelt(C*s,1,1),g)
  g:=reverse! g
res:SUPR := 0
for i in 0..d by 2 for j in 2..d+2 repeat
  c:=coefficient(p,i)
  for e in first(g,j) for k in 2..-d by -2 repeat
    res:=res+monomial(c*e,(k+i)::NonNegativeInteger)$SUPR
res

pfaffian a ==
  if antisymmetric? a
  then if odd? nrows a
    then 0
    else PfChar(a).0
  else
    error "pfaffian: only defined for antisymmetric square matrices"

if R has IntegralDomain then
  x exquo a ==
    ans := new(nrows x,ncols x,0)
    for i in minr(x)..maxr(x) repeat
      for j in minc(x)..maxc(x) repeat
        entry :=
          (r := (qelt(x,i,j) exquo a)) case "failed" =>
            return "failed"
        r :: R
      qsetelt_!(ans,i,j,entry)
    ans

if R has Field then
  x / r == map((r1:R):R +-> r1 / r,x)

x:% ** n:Integer ==
  not((nn:= nrows x) = ncols x) => error "***: matrix must be square"
  zero? n => scalarMatrix(nn,1)
  positive? n => positivePower(x,n)
  (xInv := inverse x) case "failed" =>
    error "***: matrix must be invertible"
  positivePower(xInv :: %, -n)

```

— MATCAT.dotabb —

```
"MATCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MATCAT"];
"MATCAT" -> "ARR2CAT"
```

— MATCAT.dotfull —

```
"MatrixCategory(a:Ring,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MATCAT"];
"MatrixCategory(a:Ring,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a)"
->
"TwoDimensionalArrayCategory(a:Type,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a))"
```

— MATCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "MatrixCategory(a:Ring,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a)"
    [color=lightblue];
  "MatrixCategory(a:Ring,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a)"
->
  "TwoDimensionalArrayCategory(a:Type,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a))"

  "TwoDimensionalArrayCategory(a:Type,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a))"
    [color=lightblue];
  "TwoDimensionalArrayCategory(a:Type,b:FiniteLinearAggregate(a),c:FiniteLinearAggregate(a))"
-> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "Aggregate()"
  "HomogeneousAggregate(a:Type)" -> "Evalable(a:Type)"
  "HomogeneousAggregate(a:Type)" -> "SetCategory()"

  "Evalable(a:Type)" [color="#00EE00"];

  "SetCategory()" [color=lightblue];
```

```
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

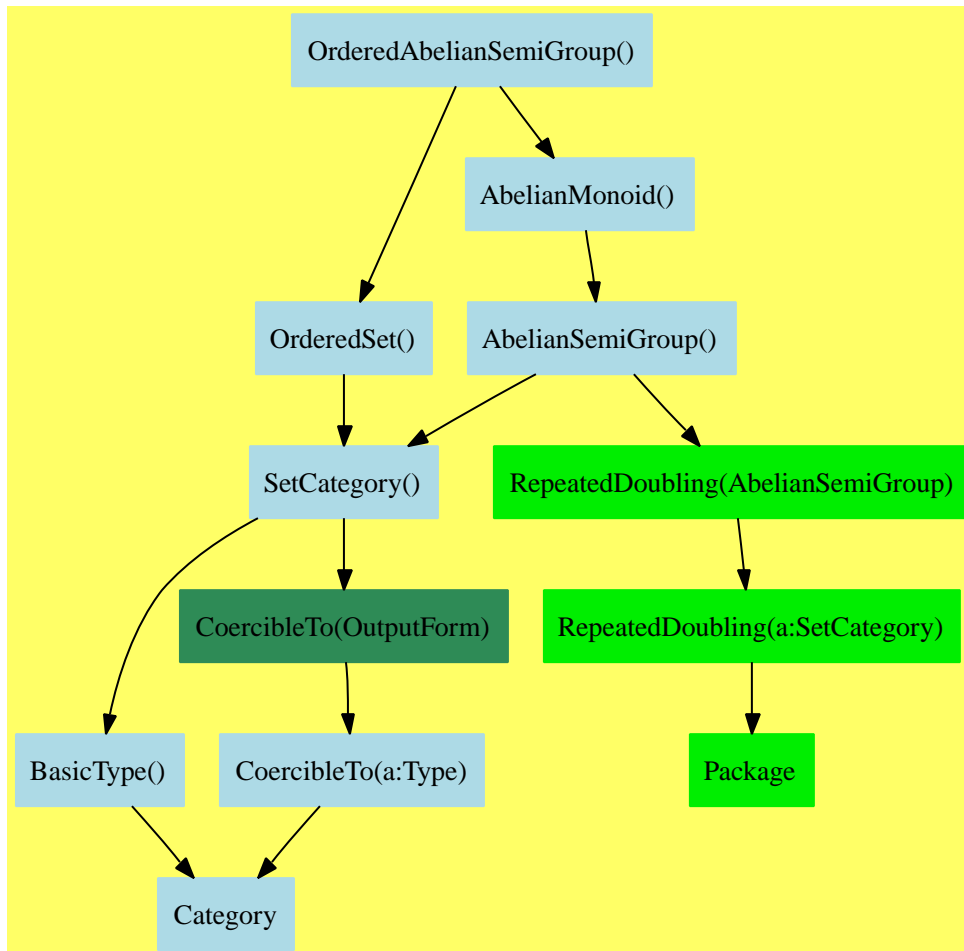
"Aggregate()" [color=lightblue];
"Aggregate()" -> "Type()"

"Type()" [color=lightblue];
"Type()" -> "Category"

"Category" [color=lightblue];

}
```

OrderedAbelianSemiGroup (OASGP)



— OrderedAbelianSemiGroup.input —

```

)set break resume
)sys rm -f OrderedAbelianSemiGroup.output
)spool OrderedAbelianSemiGroup.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrderedAbelianSemiGroup
--R OrderedAbelianSemiGroup is a category constructor

```

```

--R Abbreviation for OrderedAbelianSemiGroup is OASGP
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OASGP
--R
--R----- Operations -----
--R ?*? : (PositiveInteger,%) -> %      ?+? : (%,%) -> %
--R ?<? : (%,%) -> Boolean              ?<=? : (%,%) -> Boolean
--R ?=? : (%,%) -> Boolean              ?>? : (%,%) -> Boolean
--R ?>=? : (%,%) -> Boolean             0 : () -> %
--R coerce : % -> OutputForm            hash : % -> SingleInteger
--R latex : % -> String                  max : (%,%) -> %
--R min : (%,%) -> %                     sample : () -> %
--R zero? : % -> Boolean                 ?~=? : (%,%) -> Boolean
--R ?*? : (NonNegativeInteger,%) -> %
--R
--E 1

)spool
)lisp (bye)

```

— OrderedAbelianSemiGroup.help —

=====

OrderedAbelianSemiGroup examples

=====

Ordered sets which are also abelian semigroups, such that the addition preserves the ordering.

Axiom:

$$x < y \Rightarrow x+z < y+z$$

See Also:

o)show OrderedAbelianSemiGroup

See:

\Rightarrow “OrderedAbelianMonoid” (OAMON) [7](#) on page [629](#)

\Leftarrow “AbelianMonoid” (ABELMON) [5](#) on page [321](#)

\Leftarrow “OrderedSet” (ORDSET) [4](#) on page [269](#)

Exports:

```

0      coerce  hash  latex  max
min    sample  zero?  ?~=?  ?*?
?+?    ?<?    ?<=?  ?=?   ?>?
?>=?

```

These exports come from (p269) OrderedSet():

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
max : (%,% ) -> %
min : (%,% ) -> %
?<? : (%,% ) -> Boolean
?>? : (%,% ) -> Boolean
?<=? : (%,% ) -> Boolean
?>=? : (%,% ) -> Boolean
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean

```

These exports come from (p321) AbelianMonoid():

```

0 : () -> %
sample : () -> %
zero? : % -> Boolean
?*? : (NonNegativeInteger,% ) -> %
?*? : (PositiveInteger,% ) -> %
?+? : (%,% ) -> %

```

— category OASGP OrderedAbelianSemiGroup —

```

)abbrev category OASGP OrderedAbelianSemiGroup
++ Description:
++ Ordered sets which are also abelian semigroups, such that the addition
++ preserves the ordering.\br
++
++ Axiom\br
++ \tab{5} x < y => x+z < y+z

```

```
OrderedAbelianSemiGroup(): Category == Join(OrderedSet, AbelianMonoid)
```

— OASGP.dotabb —

```

"OASGP"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=OASGP" ];
"OASGP" -> "ORDSET"

```



```
"OASGP" -> "ABELMON"
```

— OASGP.dotfull —

```
"OrderedAbelianSemiGroup()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OASGP"];
"OrderedAbelianSemiGroup()" -> "OrderedSet()"
"OrderedAbelianSemiGroup()" -> "AbelianMonoid()"
```

— OASGP.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrderedAbelianSemiGroup()" [color=lightblue];
  "OrderedAbelianSemiGroup()" -> "OrderedSet()"
  "OrderedAbelianSemiGroup()" -> "AbelianMonoid()"

  "OrderedSet()" [color=lightblue];
  "OrderedSet()" -> "SetCategory()"

  "AbelianMonoid()" [color=lightblue];
  "AbelianMonoid()" -> "AbelianSemiGroup()"

  "AbelianSemiGroup()" [color=lightblue];
  "AbelianSemiGroup()" -> "SetCategory()"
  "AbelianSemiGroup()" -> "RepeatedDoubling(AbelianSemiGroup)"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

  "CoercibleTo(OutputForm)" [color=seagreen];
  "CoercibleTo(OutputForm)" ->
    "CoercibleTo(a:Type)"

  "CoercibleTo(a:Type)" [color=lightblue];
```

```
"CoercibleTo(a:Type)" -> "Category"

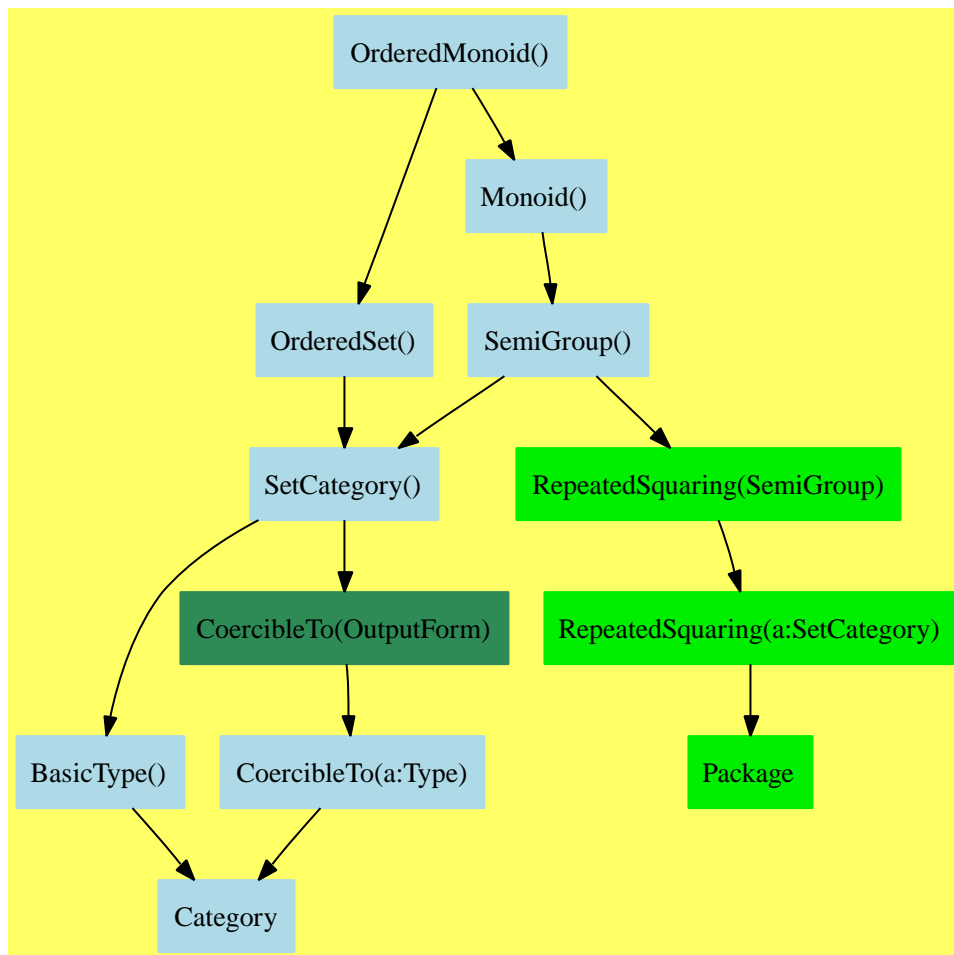
"RepeatedDoubling(AbelianSemiGroup)" [color="#00EE00"];
"RepeatedDoubling(AbelianSemiGroup)" -> "RepeatedDoubling(a:SetCategory)"

"RepeatedDoubling(a:SetCategory)" [color="#00EE00"];
"RepeatedDoubling(a:SetCategory)" -> "Package"

"Package" [color="#00EE00"];

"Category" [color=lightblue];
}
```

OrderedMonoid (ORDMON)



— OrderedMonoid.input —

```

)set break resume
)sys rm -f OrderedMonoid.output
)spool OrderedMonoid.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrderedMonoid
--R OrderedMonoid is a category constructor

```

```

--R Abbreviation for OrderedMonoid is ORDMON
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ORDMON
--R
--R----- Operations -----
--R ?? : (%,%) -> %                ??? : (%,PositiveInteger) -> %
--R ?<? : (%,%) -> Boolean          ?<=? : (%,%) -> Boolean
--R ?=? : (%,%) -> Boolean          ?>? : (%,%) -> Boolean
--R ?>=? : (%,%) -> Boolean         1 : () -> %
--R ??? : (%,PositiveInteger) -> %  coerce : % -> OutputForm
--R hash : % -> SingleInteger        latex : % -> String
--R max : (%,%) -> %                 min : (%,%) -> %
--R one? : % -> Boolean              recip : % -> Union(%, "failed")
--R sample : () -> %                 ?^=? : (%,%) -> Boolean
--R ?**? : (%,NonNegativeInteger) -> %
--R ?^? : (%,NonNegativeInteger) -> %
--R
--E 1

)spool
)lisp (bye)

```

— OrderedMonoid.help —

=====

OrderedMonoid examples

=====

Ordered sets which are also monoids, such that multiplication preserves the ordering.

Axioms:

$$x < y \Rightarrow x*z < y*z$$

$$x < y \Rightarrow z*x < z*y$$

See Also:

o)show OrderedMonoid

See:

⇐ “Monoid” (MONOID) [5](#) on page [386](#)

⇐ “OrderedSet” (ORDSET) [4](#) on page [269](#)

Exports:

| | | | | |
|------|--------|-------|--------|-----|
| 1 | coerce | hash | latex | max |
| min | one? | recip | sample | ?*? |
| ?**? | ?<? | ?<=? | ?=? | ?>? |
| ?>=? | ?~=? | ?^? | | |

These exports come from (p386) Monoid():

```

1 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
?*? : (%, %) -> %
?^? : (%, PositiveInteger) -> %
?~? : (%, NonNegativeInteger) -> %
?**? : (%, PositiveInteger) -> %
?*~? : (%, NonNegativeInteger) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean

```

These exports come from (p269) OrderedSet():

```

max : (%, %) -> %
min : (%, %) -> %
?<? : (%, %) -> Boolean
?<=? : (%, %) -> Boolean
?>? : (%, %) -> Boolean
?>=? : (%, %) -> Boolean

```

— category ORDMON OrderedMonoid —

```

)abbrev category ORDMON OrderedMonoid
++ Description:
++ Ordered sets which are also monoids, such that multiplication
++ preserves the ordering.
++
++ Axioms\br
++ \tab{5}\spad{x < y => x*z < y*z}\br
++ \tab{5}\spad{x < y => z*x < z*y}

```

```
OrderedMonoid(): Category == Join(OrderedSet, Monoid)
```

— ORDMON.dotabb —

```

"ORDMON"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ORDMON"];
"ORDMON" -> "ORDSET"
"ORDMON" -> "MONOID"

```

— ORDMON.dotfull —

```

"OrderedMonoid()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ORDMON"];
"OrderedMonoid()" -> "OrderedSet()"
"OrderedMonoid()" -> "Monoid()"

```

— ORDMON.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrderedMonoid()"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=ORDMON"];
  "OrderedMonoid()" -> "OrderedSet()"
  "OrderedMonoid()" -> "Monoid()"

  "OrderedSet()"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=ORDSET"];
  "OrderedSet()" -> "SetCategory()"

  "Monoid()" [color=lightblue];
  "Monoid()" -> "SemiGroup()"

  "SemiGroup()" [color=lightblue];
  "SemiGroup()" -> "SetCategory()"
  "SemiGroup()" -> "RepeatedSquaring(SemiGroup)"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

```

```

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"RepeatedSquaring(SemiGroup)" [color="#00EE00"];
"RepeatedSquaring(SemiGroup)" -> "RepeatedSquaring(a:SetCategory)"

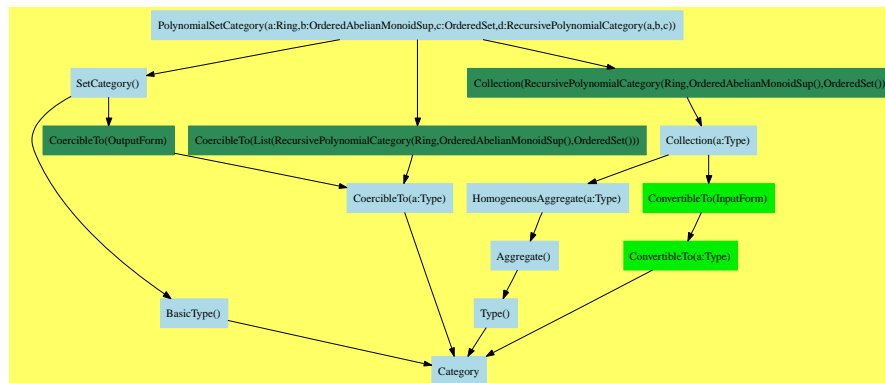
"RepeatedSquaring(a:SetCategory)" [color="#00EE00"];
"RepeatedSquaring(a:SetCategory)" -> "Package"

"Package" [color="#00EE00"];

"Category" [color=lightblue];
}

```

PolynomialSetCategory (PSETCAT)



— PolynomialSetCategory.input —

```

)set break resume
)sys rm -f PolynomialSetCategory.output
)spool PolynomialSetCategory.output
)set message test on
)set message auto off
)clear all

```

```

--S 1 of 1
)show PolynomialSetCategory
--R
--R PolynomialSetCategory(R: Ring,E: OrderedAbelianMonoidSup,VarSet: OrderedSet,P: RecursivePolynomialCategory)
--R Abbreviation for PolynomialSetCategory is PSETCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PSETCAT
--R
--R----- Operations -----
--R ?? : (%,% ) -> Boolean
--R coerce : % -> List(P)
--R collect : (% ,VarSet) -> %
--R collectUnder : (% ,VarSet) -> %
--R construct : List(P) -> %
--R copy : % -> %
--R empty : () -> %
--R empty? : % -> Boolean
--R eq? : (%,% ) -> Boolean
--R hash : % -> SingleInteger
--R latex : % -> String
--R mainVariables : % -> List(VarSet)
--R map : ((P -> P),%) -> %
--R mvar : % -> VarSet
--R retract : List(P) -> %
--R sample : () -> %
--R trivialIdeal? : % -> Boolean
--R variables : % -> List(VarSet)
--R ?~=? : (%,% ) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R any? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
--R convert : % -> InputForm if P has KONVERT(INFORM)
--R count : ((P -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R count : (P,%) -> NonNegativeInteger if P has SETCAT and $ has finiteAggregate
--R eval : (% ,List(Equation(P))) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% ,Equation(P)) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% ,P,P) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% ,List(P),List(P)) -> % if P has EVALAB(P) and P has SETCAT
--R every? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
--R find : ((P -> Boolean),%) -> Union(P,"failed")
--R headRemainder : (P,%) -> Record(num: P,den: R) if R has INTDOM
--R less? : (% ,NonNegativeInteger) -> Boolean
--R mainVariable? : (VarSet,%) -> Boolean
--R map! : ((P -> P),%) -> % if $ has shallowlyMutable
--R member? : (P,%) -> Boolean if P has SETCAT and $ has finiteAggregate
--R members : % -> List(P) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(P) if $ has finiteAggregate
--R reduce : (((P,P) -> P),%) -> P if $ has finiteAggregate
--R reduce : (((P,P) -> P),%,P) -> P if $ has finiteAggregate
--R reduce : (((P,P) -> P),%,P,P) -> P if P has SETCAT and $ has finiteAggregate
--R remainder : (P,%) -> Record(rnum: R,polnum: P,den: R) if R has INTDOM
--R remove : ((P -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (P,%) -> % if P has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
--R retractIfCan : List(P) -> Union(%, "failed")
--R rewriteIdealWithHeadRemainder : (List(P),%) -> List(P) if R has INTDOM
--R rewriteIdealWithRemainder : (List(P),%) -> List(P) if R has INTDOM

```



```

--R roughBase? : % -> Boolean if R has INTDOM
--R roughEqualIdeals? : (%,%) -> Boolean if R has INTDOM
--R roughSubIdeal? : (%,%) -> Boolean if R has INTDOM
--R roughUnitIdeal? : % -> Boolean if R has INTDOM
--R select : ((P -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R sort : (%,VarSet) -> Record(under: %,floor: %,upper: %)
--R triangular? : % -> Boolean if R has INTDOM
--R
--E 1

)spool
)lisp (bye)

```

— PolynomialSetCategory.help —

=====

PolynomialSetCategory examples

=====

A category for finite subsets of a polynomial ring. Such a set is only regarded as a set of polynomials and not identified to the ideal it generates. So two distinct sets may generate the same the ideal. Furthermore, for R being an integral domain, a set of polynomials may be viewed as a representation of the ideal it generates in the polynomial ring $(R)^{(-1)}P$, or the set of its zeros (described for instance by the radical of the previous ideal, or a split of the associated affine variety) and so on. So this category provides operations about those different notions.

See Also:

o)show PolynomialSetCategory

See:

⇒ “TriangularSetCategory” (TSETCAT) [7](#) on page [649](#)
 ⇐ “CoercibleTo” (KOERCE) [2](#) on page [33](#)
 ⇐ “Collection” (CLAGG) [5](#) on page [341](#)
 ⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

| | | |
|-----------------|-------------------------------|---------------------------|
| any? | coerce | collect |
| collectUnder | collectUpper | construct |
| convert | copy | count |
| empty | empty? | eq? |
| eval | every? | find |
| hash | headRemainder | latex |
| less? | mainVariables | mainVariable? |
| map | map! | member? |
| members | more? | mvar |
| parts | reduce | remainder |
| remove | removeDuplicates | retract |
| retractIfCan | rewriteIdealWithHeadRemainder | rewriteIdealWithRemainder |
| roughBase? | roughEqualIdeals? | roughSubIdeal? |
| roughUnitIdeal? | sample | select |
| size? | sort | triangular? |
| trivialIdeal? | variables | #? |
| ?~=? | ?=? | |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

These are directly exported but not implemented:

```
mvar : % -> VarSet
retract : List P -> %
retractIfCan : List P -> Union(%, "failed")
```

These are implemented by this category:

```
collect : (%, VarSet) -> %
collectUnder : (%, VarSet) -> %
collectUpper : (%, VarSet) -> %
headRemainder : (P, %) -> Record(num: P, den: R) if R has INTDOM
mainVariables : % -> List VarSet
mainVariable? : (VarSet, %) -> Boolean
remainder : (P, %) -> Record(rnum: R, polnum: P, den: R) if R has INTDOM
rewriteIdealWithHeadRemainder : (List P, %) -> List P if R has INTDOM
rewriteIdealWithRemainder : (List P, %) -> List P if R has INTDOM
roughBase? : % -> Boolean if R has INTDOM
roughEqualIdeals? : (%, %) -> Boolean if R has INTDOM
roughSubIdeal? : (%, %) -> Boolean if R has INTDOM
roughUnitIdeal? : % -> Boolean if R has INTDOM
sort : (%, VarSet) -> Record(under: %, floor: %, upper: %)
triangular? : % -> Boolean if R has INTDOM
trivialIdeal? : % -> Boolean
variables : % -> List VarSet
?=? : (%, %) -> Boolean
```

These exports come from (p162) SetCategory():

```
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?~=? : (%,% ) -> Boolean
```

These exports come from (p341) Collection(P)
 where P:RecursivePolynomialCategory(R,E,V)
 where R:Ring, E:OrderedAbelianMonoidSup, V:OrderedSet

```
any? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
construct : List P -> %
copy : % -> %
count : (P,%) -> NonNegativeInteger if P has SETCAT and $ has finiteAggregate
count : ((P -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,% ) -> Boolean
eval : (% ,List Equation P) -> % if P has EVALAB P and P has SETCAT
eval : (% ,Equation P) -> % if P has EVALAB P and P has SETCAT
eval : (% ,P,P) -> % if P has EVALAB P and P has SETCAT
eval : (% ,List P,List P) -> % if P has EVALAB P and P has SETCAT
every? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
find : ((P -> Boolean),%) -> Union(P,"failed")
less? : (% ,NonNegativeInteger) -> Boolean
map : ((P -> P),%) -> %
map! : ((P -> P),%) -> % if $ has shallowlyMutable
member? : (P,%) -> Boolean if P has SETCAT and $ has finiteAggregate
members : % -> List P if $ has finiteAggregate
more? : (% ,NonNegativeInteger) -> Boolean
parts : % -> List P if $ has finiteAggregate
reduce : (((P,P) -> P),%) -> P if $ has finiteAggregate
reduce : (((P,P) -> P),% ,P,P) -> P if P has SETCAT and $ has finiteAggregate
reduce : (((P,P) -> P),% ,P) -> P if $ has finiteAggregate
remove : (P,%) -> % if P has SETCAT and $ has finiteAggregate
remove : ((P -> Boolean),%) -> % if $ has finiteAggregate
removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
sample : () -> %
select : ((P -> Boolean),%) -> % if $ has finiteAggregate
size? : (% ,NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
```

These exports come from (p33) CoercibleTo(List(P))
 where P:RecursivePolynomialCategory(R,E,V)
 where R:Ring, E:OrderedAbelianMonoidSup, V:OrderedSet

```
coerce : % -> List P
convert : % -> InputForm if P has KONVERT INFORM
```

These exports come from (p1097) IntegralDomain():

— category PSETCAT PolynomialSetCategory —

```
)abbrev category PSETCAT PolynomialSetCategory
++ Author: Marc Moreno Maza
++ Date Created: 04/26/1994
++ Date Last Updated: 12/15/1998
++ Description:
++ A category for finite subsets of a polynomial ring.
++ Such a set is only regarded as a set of polynomials and not
++ identified to the ideal it generates. So two distinct sets may
++ generate the same the ideal. Furthermore, for \spad{R} being an
++ integral domain, a set of polynomials may be viewed as a representation
++ of the ideal it generates in the polynomial ring \spad{(R)^(-1) P},
++ or the set of its zeros (described for instance by the radical of the
++ previous ideal, or a split of the associated affine variety) and so on.
++ So this category provides operations about those different notions.

PolynomialSetCategory(R:Ring, E:OrderedAbelianMonoidSup, _
  VarSet:OrderedSet, P:RecursivePolynomialCategory(R,E,VarSet)): Category ==
  Join(SetCategory,Collection(P),CoercibleTo(List(P))) with
    finiteAggregate
    retractIfCan : List(P) -> Union($,"failed")
      ++ \axiom{retractIfCan(lp)} returns an element of the domain
      ++ whose elements are the members of \axiom{lp} if such an element
      ++ exists, otherwise \axiom{"failed"} is returned.
    retract : List(P) -> $
      ++ \axiom{retract(lp)} returns an element of the domain whose elements
      ++ are the members of \axiom{lp} if such an element exists, otherwise
      ++ an error is produced.
    mvar : $ -> VarSet
      ++ \axiom{mvar(ps)} returns the main variable of the non constant
      ++ polynomial with the greatest main variable, if any, else an
      ++ error is returned.
    variables : $ -> List VarSet
      ++ \axiom{variables(ps)} returns the decreasingly sorted list of the
      ++ variables which are variables of some polynomial in \axiom{ps}.
    mainVariables : $ -> List VarSet
      ++ \axiom{mainVariables(ps)} returns the decreasingly sorted list
      ++ of the variables which are main variables of some polynomial
      ++ in \axiom{ps}.
    mainVariable? : (VarSet,$) -> Boolean
      ++ \axiom{mainVariable?(v,ps)} returns true iff \axiom{v} is the
      ++ main variable of some polynomial in \axiom{ps}.
    collectUnder : ($,VarSet) -> $
      ++ \axiom{collectUnder(ps,v)} returns the set consisting of the
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    ++ polynomials of \axiom{ps} with main variable less than \axiom{v}.
collect : ($,VarSet) -> $
    ++ \axiom{collect(ps,v)} returns the set consisting of the
    ++ polynomials of \axiom{ps} with \axiom{v} as main variable.
collectUpper : ($,VarSet) -> $
    ++ \axiom{collectUpper(ps,v)} returns the set consisting of the
    ++ polynomials of \axiom{ps} with main variable greater
    ++ than \axiom{v}.
sort : ($,VarSet) -> Record(under:$,floor:$,upper:$)
    ++ \axiom{sort(v,ps)} returns \axiom{us,vs,ws} such that \axiom{us}
    ++ is \axiom{collectUnder(ps,v)}, \axiom{vs} is \axiom{collect(ps,v)}
    ++ and \axiom{ws} is \axiom{collectUpper(ps,v)}.
trivialIdeal?: $ -> Boolean
    ++ \axiom{trivialIdeal?(ps)} returns true iff \axiom{ps} does
    ++ not contain non-zero elements.
if R has IntegralDomain
then
    roughBase? : $ -> Boolean
        ++ \axiom{roughBase?(ps)} returns true iff for every pair
        ++ \axiom{{p,q}} of polynomials in \axiom{ps} their leading
        ++ monomials are relatively prime.
    roughSubIdeal? : ($,$) -> Boolean
        ++ \axiom{roughSubIdeal?(ps1,ps2)} returns true iff it can proved
        ++ that all polynomials in \axiom{ps1} lie in the ideal generated
        ++ by \axiom{ps2} in \axiom{\axiom{(R)^(-1) P}} without computing
        ++ Groebner bases.
    roughEqualIdeals? : ($,$) -> Boolean
        ++ \axiom{roughEqualIdeals?(ps1,ps2)} returns true iff it can
        ++ proved that \axiom{ps1} and \axiom{ps2} generate the same ideal
        ++ in \axiom{(R)^(-1) P} without computing Groebner bases.
    roughUnitIdeal? : $ -> Boolean
        ++ \axiom{roughUnitIdeal?(ps)} returns true iff \axiom{ps} contains
        ++ some non null element lying in the base ring \axiom{R}.
    headRemainder : (P,$) -> Record(num:P,den:R)
        ++ \axiom{headRemainder(a,ps)} returns \axiom{[b,r]} such that the
        ++ leading monomial of \axiom{b} is reduced in the sense of
        ++ Groebner bases w.r.t. \axiom{ps} and \axiom{r*a - b} lies in
        ++ the ideal generated by \axiom{ps}.
    remainder : (P,$) -> Record(rnum:R,polnum:P,den:R)
        ++ \axiom{remainder(a,ps)} returns \axiom{[c,b,r]} such that
        ++ \axiom{b} is fully reduced in the sense of Groebner bases
        ++ w.r.t. \axiom{ps}, \axiom{r*a - c*b} lies in the ideal
        ++ generated by \axiom{ps}. Furthermore, if \axiom{R} is a
        ++ gcd-domain, \axiom{b} is primitive.
    rewriteIdealWithHeadRemainder : (List(P),$) -> List(P)
        ++ \axiom{rewriteIdealWithHeadRemainder(lp,cs)} returns \axiom{lr}
        ++ such that the leading monomial of every polynomial in \axiom{lr}
        ++ is reduced in the sense of Groebner bases w.r.t. \axiom{cs}
        ++ and \axiom{(lp,cs)} and \axiom{(lr,cs)} generate the same
        ++ ideal in \axiom{(R)^(-1) P}.

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rewriteIdealWithRemainder : (List(P), $) -> List(P)
  ++ \axiom{rewriteIdealWithRemainder(lp,cs)} returns \axiom{lr}
  ++ such that every polynomial in \axiom{lr} is fully reduced in
  ++ the sense of Groebner bases w.r.t. \axiom{cs} and
  ++ \axiom{(lp,cs)} and \axiom{(lr,cs)} generate the same ideal
  ++ in \axiom{(R)^(-1) P}.
triangular? : $ -> Boolean
  ++ \axiom{triangular?(ps)} returns true iff \axiom{ps} is a
  ++ triangular set, i.e. two distinct polynomials have distinct
  ++ main variables and no constant lies in \axiom{ps}.

add

NNI ==> NonNegativeInteger
B ==> Boolean

elements: $ -> List(P)

elements(ps:$):List(P) ==
  lp : List(P) := members(ps)$

variables1(lp:List(P)):List VarSet ==
  lvars : List(List(VarSet)) := [variables(p)$P for p in lp]
  sort((z1:VarSet,z2:VarSet):Boolean +-> z1 > z2,
    removeDuplicates(concat(lvars)$List(VarSet)))

variables2(lp:List(P)):List VarSet ==
  lvars : List(VarSet) := [mvar(p)$P for p in lp]
  sort((z1:VarSet,z2:VarSet):Boolean +-> z1 > z2,
    removeDuplicates(lvars)$List(VarSet))

variables (ps:$) ==
  variables1(elements(ps))

mainVariables (ps:$) ==
  variables2(remove(ground?,elements(ps)))

mainVariable? (v,ps) ==
  lp : List(P) := remove(ground?,elements(ps))
  while (not empty? lp) and (not (mvar(first(lp)) = v)) repeat
    lp := rest lp
  (not empty? lp)

collectUnder (ps,v) ==
  lp : List P := elements(ps)
  lq : List P := []
  while (not empty? lp) repeat
    p := first lp
    lp := rest lp
    if (ground?(p)) or (mvar(p) < v)

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        then
            lq := cons(p,lq)
        construct(lq)$$

collectUpper (ps,v) ==
    lp : List P := elements(ps)
    lq : List P := []
    while (not empty? lp) repeat
        p := first lp
        lp := rest lp
        if (not ground?(p)) and (mvar(p) > v)
            then
                lq := cons(p,lq)
            construct(lq)$$

collect (ps,v) ==
    lp : List P := elements(ps)
    lq : List P := []
    while (not empty? lp) repeat
        p := first lp
        lp := rest lp
        if (not ground?(p)) and (mvar(p) = v)
            then
                lq := cons(p,lq)
            construct(lq)$$

sort (ps,v) ==
    lp : List P := elements(ps)
    us : List P := []
    vs : List P := []
    ws : List P := []
    while (not empty? lp) repeat
        p := first lp
        lp := rest lp
        if (ground?(p)) or (mvar(p) < v)
            then
                us := cons(p,us)
            else
                if (mvar(p) = v)
                    then
                        vs := cons(p,vs)
                    else
                        ws := cons(p,ws)
    [construct(us)$$,_
    construct(vs)$$,_
    construct(ws)$$$]Record(under:$,floor:$,upper:$)

ps1 = ps2 ==
    {p for p in elements(ps1)} =$(Set P) {p for p in elements(ps2)}

```

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exactQuo : (R,R) -> R

localInf? (p:P,q:P):B ==
  degree(p) <$E degree(q)

localTriangular? (lp:List(P)):B ==
  lp := remove(zero?, lp)
  empty? lp => true
  any? (ground?, lp) => false
  lp := sort((z1:P,z2:P):Boolean +-> mvar(z1)$P > mvar(z2)$P, lp)
  p,q : P
  p := first lp
  lp := rest lp
  while (not empty? lp) and (mvar(p) > mvar((q := first(lp)))) repeat
    p := q
    lp := rest lp
  empty? lp

triangular? ps ==
  localTriangular? elements ps

trivialIdeal? ps ==
  empty?(remove(zero?,elements(ps))$(List(P)))$(List(P))

if R has IntegralDomain
then

  roughUnitIdeal? ps ==
    any?(ground?,remove(zero?,elements(ps))$(List(P)))$(List P)

  relativelyPrimeLeadingMonomials? (p:P,q:P):B ==
    dp : E := degree(p)
    dq : E := degree(q)
    (sup(dp,dq)$E =$E dp +$E dq)@B

  roughBase? ps ==
    lp := remove(zero?,elements(ps))$(List(P))
    empty? lp => true
    rB? : B := true
    while (not empty? lp) and rB? repeat
      p := first lp
      lp := rest lp
      copylp := lp
      while (not empty? copylp) and rB? repeat
        rB? := relativelyPrimeLeadingMonomials?(p,first(copylp))
        copylp := rest copylp
    rB?

  roughSubIdeal?(ps1,ps2) ==
    lp: List(P) := rewriteIdealWithRemainder(elements(ps1),ps2)

```



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empty? (remove(zero?,lp))

roughEqualIdeals? (ps1,ps2) ==
  ps1 == ps2 => true
  roughSubIdeal?(ps1,ps2) and roughSubIdeal?(ps2,ps1)

if (R has GcdDomain) and (VarSet has ConvertibleTo (Symbol))
then

  LPR ==> List Polynomial R
  LS ==> List Symbol

  if R has EuclideanDomain
  then
    exactQuo(r:R,s:R):R ==
      r quo$R s
    else
      exactQuo(r:R,s:R):R ==
        (r exquo$R s)::R

  headRemainder (a,ps) ==
    lp1 : List(P) := remove(zero?, elements(ps))$(List(P))
    empty? lp1 => [a,1$R]
    any?(ground?,lp1) => [reductum(a),1$R]
    r : R := 1$R
    lp1 := sort(localInf?, reverse elements(ps))
    lp2 := lp1
    e : Union(E, "failed")
    while (not zero? a) and (not empty? lp2) repeat
      p := first lp2
      if ((e:= subtractIfCan(degree(a),degree(p))) case E)
      then
        g := gcd((lca := leadingCoefficient(a)),_
                  (lcp := leadingCoefficient(p)))$R
        (lca,lcp) := (exactQuo(lca,g),exactQuo(lcp,g))
        a := lcp * reductum(a) - monomial(lca, e::$E)$P * reductum(p)
        r := r * lcp
        lp2 := lp1
      else
        lp2 := rest lp2
    [a,r]

  makeIrreducible! (frac:Record(num:P,den:R)):Record(num:P,den:R) ==
    g := gcd(frac.den,frac.num)$P
    one? g => frac
    (g = 1) => frac
    frac.num := exactQuotient!(frac.num,g)
    frac.den := exactQuo(frac.den,g)
    frac

```

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remainder (a,ps) ==
  hRa := makeIrreducible! headRemainder (a,ps)
  a := hRa.num
  r : R := hRa.den
  zero? a => [1$R,a,r]
  b : P := monomial(1$R,degree(a))$P
  c : R := leadingCoefficient(a)
  while not zero?(a := reductum a) repeat
    hRa := makeIrreducible! headRemainder (a,ps)
    a := hRa.num
    r := r * hRa.den
    g := gcd(c,(lca := leadingCoefficient(a)))$R
    b := ((hRa.den) * exactQuo(c,g)) * b + _
          monomial(exactQuo(lca,g),degree(a))$P
    c := g
  [c,b,r]

rewriteIdealWithHeadRemainder(ps,cs) ==
  trivialIdeal? cs => ps
  roughUnitIdeal? cs => [0$P]
  ps := remove(zero?,ps)
  empty? ps => ps
  any?(ground?,ps) => [1$P]
  rs : List P := []
  while not empty? ps repeat
    p := first ps
    ps := rest ps
    p := (headRemainder(p,cs)).num
    if not zero? p
      then
        if ground? p
          then
            ps := []
            rs := [1$P]
          else
            primitivePart! p
            rs := cons(p,rs)
  removeDuplicates rs

rewriteIdealWithRemainder(ps,cs) ==
  trivialIdeal? cs => ps
  roughUnitIdeal? cs => [0$P]
  ps := remove(zero?,ps)
  empty? ps => ps
  any?(ground?,ps) => [1$P]
  rs : List P := []
  while not empty? ps repeat
    p := first ps
    ps := rest ps
    p := (remainder(p,cs)).polnum

```

```

    if not zero? p
    then
      if ground? p
      then
        ps := []
        rs := [1$P]
      else
        rs := cons(unitCanonical(p),rs)
    removeDuplicates rs

```

— PSETCAT.dotabb —

```

"PSETCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PSETCAT"];
"PSETCAT" -> "KOERCE"
"PSETCAT" -> "CLAGG"
"PSETCAT" -> "SETCAT"

```

— PSETCAT.dotfull —

```

"PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PSETCAT"];
"PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
-> "SetCategory()"
"PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
-> "Collection(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet()))"
"PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
-> "CoercibleTo(List(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet())))"

"PolynomialSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
[color=seagreen,href="bookvol10.2.pdf#nameddest=PSETCAT"];
"PolynomialSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
-> "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"

```

— PSETCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";

```

```

node [shape=box, color=white, style=filled];

"PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(a,b,c))"
  [color=lightblue];
"PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(a,b,c))"
  -> "SetCategory()"
"PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(a,b,c))"
  -> "Collection(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet()))"
"PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(a,b,c))"
  -> "CoercibleTo(List(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet())))"

"CoercibleTo(List(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet())))"
  [color=seagreen];
"CoercibleTo(List(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet())))"
  -> "CoercibleTo(a:Type)"

"Collection(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet()))" [color=seagreen];
"Collection(RecursivePolynomialCategory(Ring,OrderedAbelianMonoidSup(),OrderedSet()))"
  -> "Collection(a:Type)"

"Collection(a:Type)" [color=lightblue];
"Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"
"Collection(a:Type)" -> "ConvertibleTo(InputForm)"

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"HomogeneousAggregate(a:Type)" [color=lightblue];
"HomogeneousAggregate(a:Type)" -> "Aggregate()"

"Aggregate()" [color=lightblue];
"Aggregate()" -> "Type()"

"Type()" [color=lightblue];
"Type()" -> "Category"

"ConvertibleTo(InputForm)" [color="#00EE00"];
"ConvertibleTo(InputForm)" -> "ConvertibleTo(a:Type)"

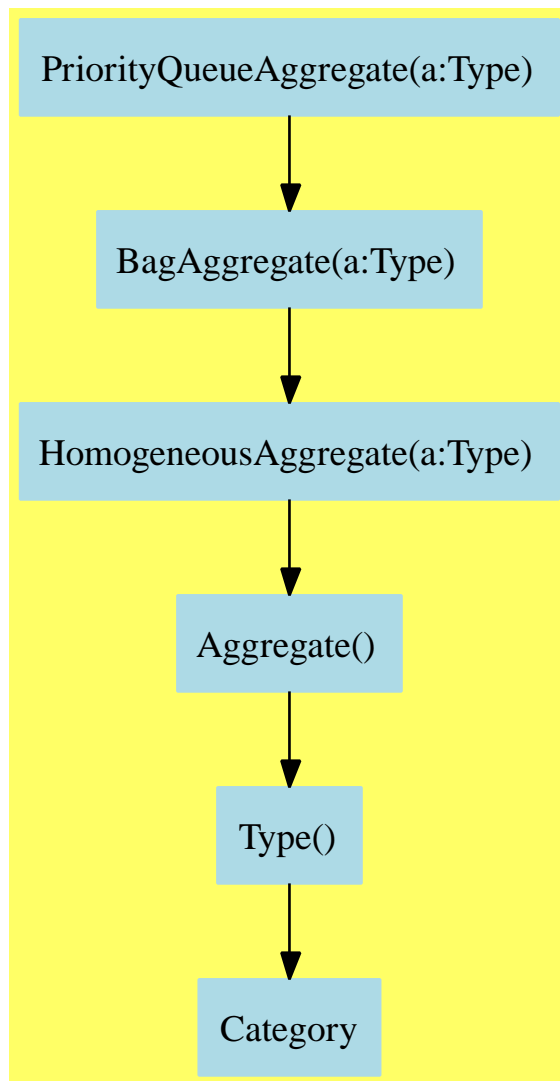
"ConvertibleTo(a:Type)" [color="#00EE00"];

```

```
"ConvertibleTo(a:Type)" -> "Category"  
  
"Category" [color=lightblue];  
}
```

—————

PriorityQueueAggregate (PRQAGG)



— PriorityQueueAggregate.input —

```

)set break resume
)sys rm -f PriorityQueueAggregate.output
)spool PriorityQueueAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PriorityQueueAggregate
--R
--R PriorityQueueAggregate(S: OrderedSet) is a category constructor
--R Abbreviation for PriorityQueueAggregate is PRQAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PRQAGG
--R
--R----- Operations -----
--R bag : List(S) -> %                copy : % -> %
--R empty : () -> %                  empty? : % -> Boolean
--R eq? : (%,% ) -> Boolean          extract! : % -> S
--R insert! : (S,% ) -> %            inspect : % -> S
--R map : ((S -> S),%) -> %          max : % -> S
--R merge : (%,% ) -> %              merge! : (%,% ) -> %
--R sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?? : (%,% ) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R count : (S,% ) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,% ) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R size? : (% ,NonNegativeInteger) -> Boolean
--R ?~=? : (%,% ) -> Boolean if S has SETCAT
--R

```

```
--E 1
```

```
)spool
)lisp (bye)
```

— **PriorityQueueAggregate.help** —

=====

PriorityQueueAggregate examples

=====

A priority queue is a bag of items from an ordered set where the item extracted is always the maximum element.

See Also:

o)show PriorityQueueAggregate

See:

⇒ “OrderedMultisetAggregate” (OMSAGG) [9](#) on page [819](#)

⇐ “BagAggregate” (BGAGG) [5](#) on page [331](#)

Exports:

| | | | | |
|----------|--------|---------|---------|---------|
| any? | bag | copy | coerce | count |
| empty | empty? | eq? | eval | every? |
| extract! | hash | insert! | inspect | latex |
| less? | map | map! | max | member? |
| members | merge | merge! | more? | parts |
| sample | size? | #? | ?=? | ?~=? |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```
max : % -> S
merge : (%,% ) -> %
merge! : (%,% ) -> %
```

These exports come from (p331) BagAggregate(S:OrderedSet):

```

any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
bag : List S -> %
coerce : % -> OutputForm if S has SETCAT
copy : % -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
extract! : % -> S
hash : % -> SingleInteger if S has SETCAT
insert! : (S,%) -> %
inspect : % -> S
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
      if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
sample : () -> %
size? : (%,NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
=? : (%,%) -> Boolean if S has SETCAT
?~=? : (%,%) -> Boolean if S has SETCAT

```

— category PRQAGG PriorityQueueAggregate —

```

)abbrev category PRQAGG PriorityQueueAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:

```


++ A priority queue is a bag of items from an ordered set where the item
 ++ extracted is always the maximum element.

```
PriorityQueueAggregate(S:OrderedSet): Category == BagAggregate S with
  finiteAggregate
  max: % -> S
    ++ max(q) returns the maximum element of priority queue q.
  merge: (%,% ) -> %
    ++ merge(q1,q2) returns combines priority queues q1 and q2 to return
    ++ a single priority queue q.
  merge_!: (%,% ) -> %
    ++ merge!(q,q1) destructively changes priority queue q to include the
    ++ values from priority queue q1.
```

— PRQAGG.dotabb —

```
"PRQAGG"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PRQAGG"];
"PRQAGG" -> "BGAGG"
```

— PRQAGG.dotfull —

```
"PriorityQueueAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PRQAGG"];
"PriorityQueueAggregate(a:Type)" -> "BagAggregate(a:Type)"

"PriorityQueueAggregate(a:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=PRQAGG"];
"PriorityQueueAggregate(a:SetCategory)" -> "PriorityQueueAggregate(a:Type)"

"PriorityQueueAggregate(a:OrderedSet)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=PRQAGG"];
"PriorityQueueAggregate(a:OrderedSet)" ->
  "PriorityQueueAggregate(a:SetCategory)"
```

— PRQAGG.dotpic —

```
digraph pic {
  fontsize=10;
```

```

bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"PriorityQueueAggregate(a:Type)" [color=lightblue];
"PriorityQueueAggregate(a:Type)" -> "BagAggregate(a:Type)"

"BagAggregate(a:Type)" [color=lightblue];
"BagAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

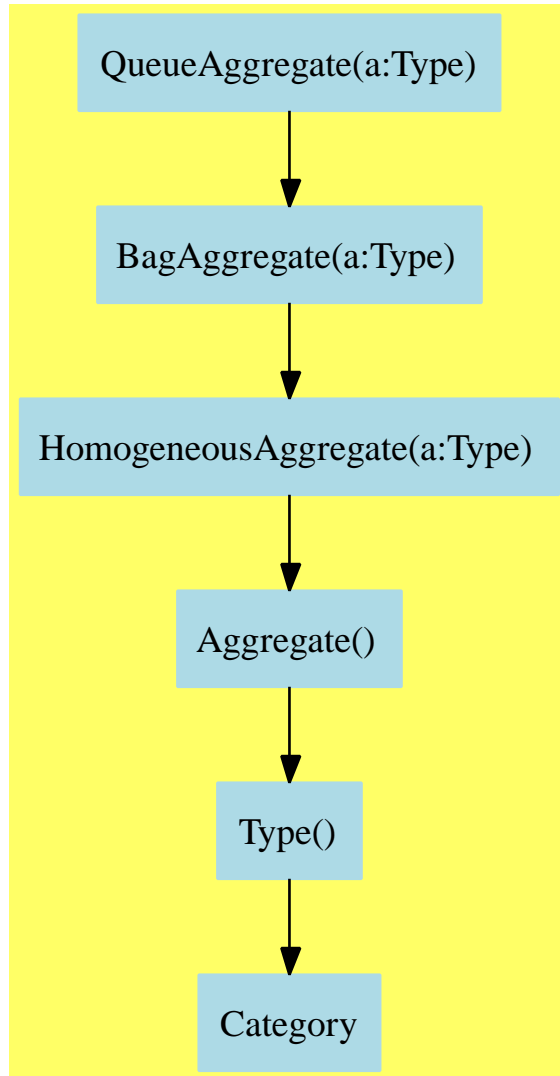
"HomogeneousAggregate(a:Type)" [color=lightblue];
"HomogeneousAggregate(a:Type)" -> "Aggregate()"

"Aggregate()" [color=lightblue];
"Aggregate()" -> "Type()"

"Type()" [color=lightblue];
"Type()" -> "Category"

"Category" [color=lightblue];
}

```

QueueAggregate (QUAGG)

— QueueAggregate.input —

```
)set break resume
)sys rm -f QueueAggregate.output
)spool QueueAggregate.output
)set message test on
)set message auto off
)clear all
```

```

--S 1 of 1
)show QueueAggregate
--R
--R QueueAggregate(S: Type) is a category constructor
--R Abbreviation for QueueAggregate is QUAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for QUAGG
--R
--R----- Operations -----
--R back : % -> S                                bag : List(S) -> %
--R copy : % -> %                                dequeue! : % -> S
--R empty : () -> %                               empty? : % -> Boolean
--R enqueue! : (S,% ) -> S                        eq? : (%,% ) -> Boolean
--R extract! : % -> S                             front : % -> S
--R insert! : (S,% ) -> %                         inspect : % -> S
--R length : % -> NonNegativeInteger              map : ((S -> S),%) -> %
--R rotate! : % -> %                             sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?? : (%,% ) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R count : (S,% ) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,% ) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R size? : (% ,NonNegativeInteger) -> Boolean
--R ~=? : (%,% ) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

```
=====
QueueAggregate examples
=====
```

A queue is a bag where the first item inserted is the first item extracted.

See Also:

```
o )show QueueAggregate
```

See:

⇒ “DequeueAggregate” (DQAGG) [7](#) on page [593](#)

⇐ “BagAggregate” (BGAGG) [5](#) on page [331](#)

Exports:

| | | | | |
|-------|----------|---------|----------|----------|
| any? | bag | back | coerce | copy |
| count | dequeue! | empty | empty? | enqueue! |
| eq? | eval | every? | extract! | front |
| hash | insert! | inspect | latex | length |
| less? | map | map! | member? | members |
| more? | parts | rotate! | sample | size? |
| #? | ?=? | ?~=? | | |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are implemented by this category:

```
back : % -> S
dequeue! : % -> S
enqueue! : (S,%) -> S
front : % -> S
length : % -> NonNegativeInteger
rotate! : % -> %
```

These exports come from (p[331](#)) BagAggregate(S:Type):

```
any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
bag : List S -> %
```

```

coerce : % -> OutputForm if S has SETCAT
copy : % -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
extract! : % -> S
hash : % -> SingleInteger if S has SETCAT
insert! : (S,%) -> %
inspect : % -> S
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
      if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
sample : () -> %
size? : (%,NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
=? : (%,%) -> Boolean if S has SETCAT
?~=? : (%,%) -> Boolean if S has SETCAT

```

— category QUAGG QueueAggregate —

```

)abbrev category QUAGG QueueAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A queue is a bag where the first item inserted is the first
++ item extracted.

```

```

QueueAggregate(S:Type): Category == BagAggregate S with
  finiteAggregate

```

```

enqueue_!: (S, %) -> S
  ++ enqueue!(x,q) inserts x into the queue q at the back end.
dequeue_!: % -> S
  ++ dequeue! s destructively extracts the first (top) element
  ++ from queue q. The element previously second in the queue becomes
  ++ the first element. Error: if q is empty.
rotate_!: % -> %
  ++ rotate! q rotates queue q so that the element at the front of
  ++ the queue goes to the back of the queue.
  ++ Note that rotate! q is equivalent to enqueue!(dequeue!(q)).
length: % -> NonNegativeInteger
  ++ length(q) returns the number of elements in the queue.
  ++ Note that \axiom{length(q) = #q}.
front: % -> S
  ++ front(q) returns the element at the front of the queue.
  ++ The queue q is unchanged by this operation.
  ++ Error: if q is empty.
back: % -> S
  ++ back(q) returns the element at the back of the queue.
  ++ The queue q is unchanged by this operation.
  ++ Error: if q is empty.

```

— QUAGG.dotabb —

```

"QUAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=QUAGG"];
"QUAGG" -> "BGAGG"

```

— QUAGG.dotfull —

```

"QueueAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=QUAGG"];
"QueueAggregate(a:Type)" -> "BagAggregate(a:Type)"

"QueueAggregate(a:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=QUAGG"];
"QueueAggregate(a:SetCategory)" -> "QueueAggregate(a:Type)"

```

— QUAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "QueueAggregate(a:Type)" [color=lightblue];
  "QueueAggregate(a:Type)" -> "BagAggregate(a:Type)"

  "BagAggregate(a:Type)" [color=lightblue];
  "BagAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "Aggregate()"

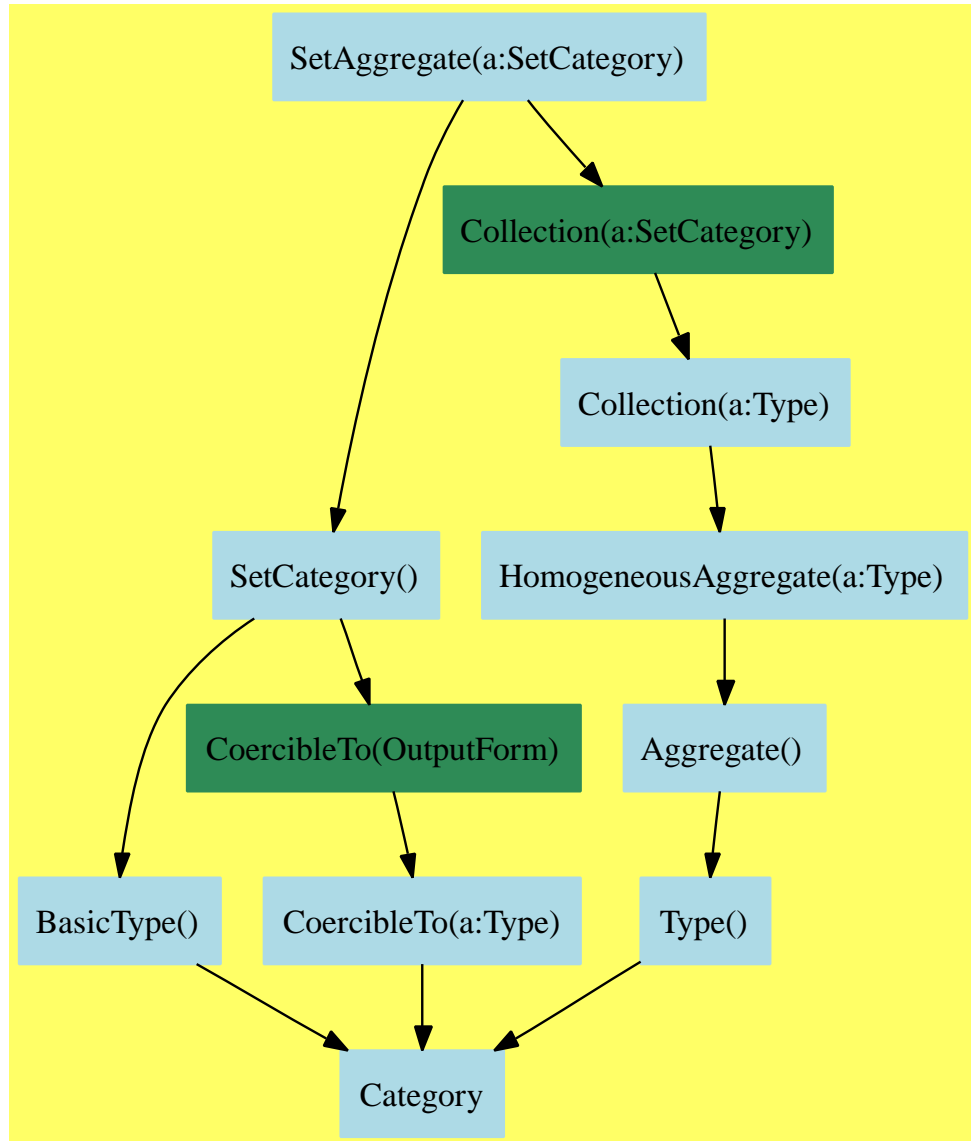
  "Aggregate()" [color=lightblue];
  "Aggregate()" -> "Type()"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "Category" [color=lightblue];
}

```

SetAggregate (SETAGG)



— SetAggregate.input —

```

)set break resume
)sys rm -f SetAggregate.output
)spool SetAggregate.output
)set message test on
  
```

```

)set message auto off
)clear all

--S 1 of 1
)show SetAggregate
--R
--R SetAggregate(S: SetCategory) is a category constructor
--R Abbreviation for SetAggregate is SETAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SETAGG
--R
--R----- Operations -----
--R ?<? : (%,%) -> Boolean           ?=? : (%,%) -> Boolean
--R brace : List(S) -> %              brace : () -> %
--R coerce : % -> OutputForm          construct : List(S) -> %
--R copy : % -> %                     difference : (%,S) -> %
--R difference : (%,%) -> %           empty : () -> %
--R empty? : % -> Boolean             eq? : (%,%) -> Boolean
--R hash : % -> SingleInteger         intersect : (%,%) -> %
--R latex : % -> String              map : ((S -> S),%) -> %
--R sample : () -> %                 set : List(S) -> %
--R set : () -> %                     subset? : (%,%) -> Boolean
--R union : (S,%) -> %                union : (%,S) -> %
--R union : (%,%) -> %                ?~=? : (%,%) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),%,S) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),%,S,S) -> S if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R symmetricDifference : (%,%) -> %

```

```
--R
--E 1

)spool
)lisp (bye)
```

— SetAggregate.help —

```
=====
SetAggregate examples
=====
```

A set category lists a collection of set-theoretic operations useful for both finite sets and multisets. Note however that finite sets are distinct from multisets. Although the operations defined for set categories are common to both, the relationship between the two cannot be described by inclusion or inheritance.

See Also:
o)show SetAggregate

See:

⇒ “FiniteSetAggregate” (FSAGG) [8](#) on page [675](#)
 ⇒ “MultisetAggregate” (MSETAGG) [8](#) on page [728](#)
 ⇐ “Collection” (CLAGG) [5](#) on page [341](#)
 ⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

Exports:

| | | | | |
|-----------|------------------|---------------------|-----------|---------|
| any? | brace | coerce | construct | convert |
| copy | count | difference | empty | empty? |
| eq? | eval | every? | find | hash |
| intersect | latex | less? | map | map! |
| member? | members | more? | parts | reduce |
| remove | removeDuplicates | sample | select | set |
| size? | subset? | symmetricDifference | union | #? |
| ?<? | ?=? | ?~=? | | |

Attributes Exported:

- **partiallyOrderedSet** is true if a set with $<$ which is transitive, but not($a < b$ or $a = b$) does not necessarily imply $b < a$.

- nil

These are directly exported but not implemented:

```
brace : List S -> %
brace : () -> %
difference : (%,%) -> %
intersect : (%,%) -> %
set : List S -> %
set : () -> %
subset? : (%,%) -> Boolean
union : (%,%) -> %
?<? : (%,%) -> Boolean
```

These are implemented by this category:

```
difference : (%,S) -> %
symmetricDifference : (%,%) -> %
union : (S,%) -> %
union : (%,S) -> %
```

These exports come from (p162) SetCategory():

```
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
```

These exports come from (p341) Collection(S:SetCategory):

```
any? : ((S -> Boolean),%) -> Boolean
  if $ has finiteAggregate
construct : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
copy : % -> %
count : ((S -> Boolean),%) -> NonNegativeInteger
  if $ has finiteAggregate
count : (S,%) -> NonNegativeInteger
  if S has SETCAT
  and $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List Equation S) -> %
  if S has EVALAB S
  and S has SETCAT
eval : (%,Equation S) -> %
  if S has EVALAB S
```

```

    and S has SETCAT
eval : (%,S,S) -> %
    if S has EVALAB S
    and S has SETCAT
eval : (%,List S,List S) -> %
    if S has EVALAB S
    and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean
    if $ has finiteAggregate
find : ((S -> Boolean),%) -> Union(S,"failed")
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
members : % -> List S if $ has finiteAggregate
member? : (S,%) -> Boolean
    if S has SETCAT and $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
reduce : (((S,S) -> S),%,S,S) -> S
    if S has SETCAT
    and $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S
    if $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S
    if $ has finiteAggregate
remove : ((S -> Boolean),%) -> %
    if $ has finiteAggregate
remove : (S,%) -> %
    if S has SETCAT
    and $ has finiteAggregate
removeDuplicates : % -> %
    if S has SETCAT
    and $ has finiteAggregate
sample : () -> %
select : ((S -> Boolean),%) -> %
    if $ has finiteAggregate
size? : (%,NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger
    if $ has finiteAggregate

```

— category SETAGG SetAggregate —

```

)abbrev category SETAGG SetAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: 14 Oct, 1993 by RSS
++ Description:
++ A set category lists a collection of set-theoretic operations
++ useful for both finite sets and multisets.

```

```

++ Note however that finite sets are distinct from multisets.
++ Although the operations defined for set categories are
++ common to both, the relationship between the two cannot
++ be described by inclusion or inheritance.

```

```

SetAggregate(S:SetCategory):
  Category == Join(SetCategory, Collection(S)) with
  partiallyOrderedSet
  "<"      : (%, %) -> Boolean
    ++ s < t returns true if all elements of set aggregate s are also
    ++ elements of set aggregate t.
  brace    : () -> %
    ++ brace()$D (otherwise written {}$D)
    ++ creates an empty set aggregate of type D.
    ++ This form is considered obsolete. Use \axiomFun{set} instead.
  brace    : List S -> %
    ++ brace([x,y,...,z])
    ++ creates a set aggregate containing items x,y,...,z.
    ++ This form is considered obsolete. Use \axiomFun{set} instead.
  set      : () -> %
    ++ set()$D creates an empty set aggregate of type D.
  set      : List S -> %
    ++ set([x,y,...,z]) creates a set aggregate containing items x,y,...,z.
  intersect: (%, %) -> %
    ++ intersect(u,v) returns the set aggregate w consisting of
    ++ elements common to both set aggregates u and v.
    ++ Note that equivalent to the notation (not currently supported)
    ++ {x for x in u | member?(x,v)}.
  difference : (%, %) -> %
    ++ difference(u,v) returns the set aggregate w consisting of
    ++ elements in set aggregate u but not in set aggregate v.
    ++ If u and v have no elements in common, \axiom{difference(u,v)}
    ++ returns a copy of u.
    ++ Note that equivalent to the notation (not currently supported)
    ++ \axiom{{x for x in u | not member?(x,v)}}.
  difference : (%, S) -> %
    ++ difference(u,x) returns the set aggregate u with element x removed.
    ++ If u does not contain x, a copy of u is returned.
    ++ Note that \axiom{difference(s, x) = difference(s, {x})}.
  symmetricDifference : (%, %) -> %
    ++ symmetricDifference(u,v) returns the set aggregate of elements x
    ++ which are members of set aggregate u or set aggregate v but
    ++ not both. If u and v have no elements in common,
    ++ \axiom{symmetricDifference(u,v)} returns a copy of u.
    ++ Note that \axiom{symmetricDifference(u,v) =
    ++ union(difference(u,v),difference(v,u))}
  subset?   : (%, %) -> Boolean
    ++ subset?(u,v) tests if u is a subset of v.
    ++ Note that equivalent to
    ++ \axiom{reduce(and,{member?(x,v) for x in u},true,false)}.

```

```

union      : (% , %) -> %
  ++ union(u,v) returns the set aggregate of elements which are members
  ++ of either set aggregate u or v.
union      : (% , S) -> %
  ++ union(u,x) returns the set aggregate u with the element x added.
  ++ If u already contains x, \axiom{union(u,x)} returns a copy of u.
union      : (S , %) -> %
  ++ union(x,u) returns the set aggregate u with the element x added.
  ++ If u already contains x, \axiom{union(x,u)} returns a copy of u.
add
symmetricDifference(x, y) == union(difference(x, y), difference(y, x))
union(s:%, x:S) == union(s, {x})
union(x:S, s:%) == union(s, {x})
difference(s:%, x:S) == difference(s, {x})

```

— SETAGG.dotabb —

```

"SETAGG"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SETAGG"];
"SETAGG" -> "SETCAT"
"SETAGG" -> "CLAGG"

```

— SETAGG.dotfull —

```

"SetAggregate(a:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SETAGG"];
"SetAggregate(a:SetCategory)" -> "SetCategory()"
"SetAggregate(a:SetCategory)" -> "Collection(a:SetCategory)"

```

— SETAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "SetAggregate(a:SetCategory)" [color=lightblue];
  "SetAggregate(a:SetCategory)" -> "SetCategory()"
  "SetAggregate(a:SetCategory)" -> "Collection(a:SetCategory)"

```

```

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Collection(a:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=CLAGG"];
"Collection(a:SetCategory)" -> "Collection(a:Type)"

"Collection(a:Type)" [color=lightblue];
"Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"

"HomogeneousAggregate(a:Type)" [color=lightblue];
"HomogeneousAggregate(a:Type)" -> "Aggregate()"

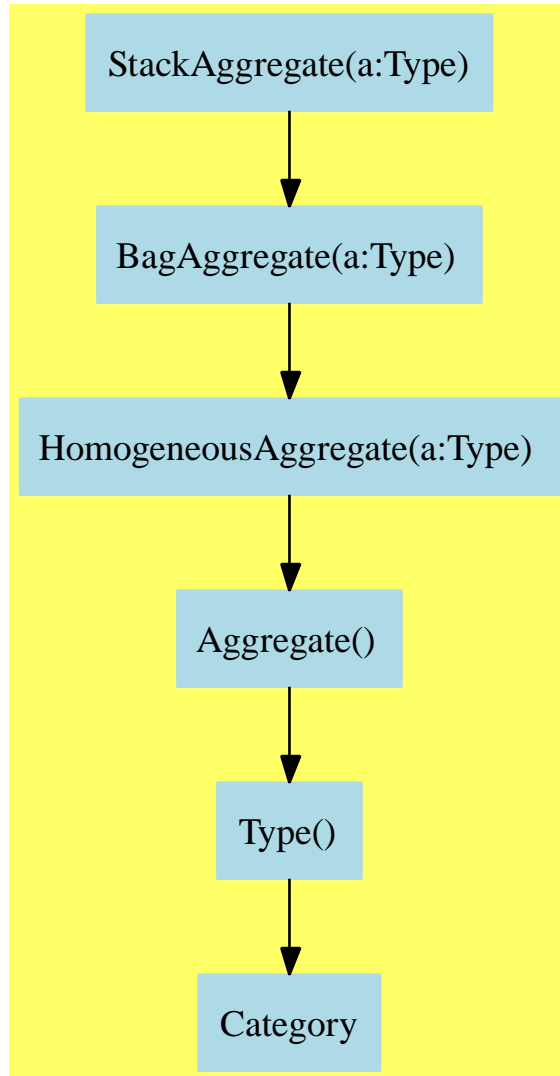
"Aggregate()" [color=lightblue];
"Aggregate()" -> "Type()"

"Type()" [color=lightblue];
"Type()" -> "Category"

"Category" [color=lightblue];

}

```

StackAggregate (SKAGG)

— StackAggregate.input —

```
)set break resume
)sys rm -f StackAggregate.output
)spool StackAggregate.output
)set message test on
)set message auto off
)clear all
```

```

--S 1 of 1
)show StackAggregate
--R
--R StackAggregate(S: Type) is a category constructor
--R Abbreviation for StackAggregate is SKAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SKAGG
--R
--R----- Operations -----
--R bag : List(S) -> %                copy : % -> %
--R depth : % -> NonNegativeInteger    empty : () -> %
--R empty? : % -> Boolean              eq? : (%,% ) -> Boolean
--R extract! : % -> S                 insert! : (S,% ) -> %
--R inspect : % -> S                  map : ((S -> S),%) -> %
--R pop! : % -> S                     push! : (S,% ) -> S
--R sample : () -> %                  top : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?? : (%,% ) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R count : (S,% ) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,% ) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R size? : (% ,NonNegativeInteger) -> Boolean
--R ?~=? : (%,% ) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— StackAggregate.help —

StackAggregate examples

=====

A stack is a bag where the last item inserted is the first item extracted.

See Also:

o)show StackAggregate

See:

⇒ “DequeAggregate” (DQAGG) [7](#) on page [593](#)

⇐ “BagAggregate” (BGAGG) [5](#) on page [331](#)

Exports:

| | | | | |
|---------|----------|--------|---------|---------|
| any? | bag | coerce | copy | count |
| depth | empty | empty? | eq? | eval |
| every? | extract! | hash | insert! | inspect |
| latex | less? | map | map! | member? |
| members | more? | parts | pop! | push! |
| sample | size? | top | #? | ?=? |
| ?~=? | | | | |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```
depth : % -> NonNegativeInteger
pop!  : % -> S
push! : (S,%) -> S
top   : % -> S
```

These exports come from (p331) BagAggregate(S:Type):

```
any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
bag  : List S -> %
coerce : % -> OutputForm if S has SETCAT
copy  : % -> %
count : (S,%) -> NonNegativeInteger
```

```

        if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
        if $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
        if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
        if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
        if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
        if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
extract! : % -> S
hash : % -> SingleInteger if S has SETCAT
insert! : (S,%) -> %
inspect : % -> S
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
        if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
sample : () -> %
size? : (%,NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
?? : (%,%) -> Boolean if S has SETCAT
?~=? : (%,%) -> Boolean if S has SETCAT

```

— category SKAGG StackAggregate —

```

)abbrev category SKAGG StackAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A stack is a bag where the last item inserted is the first item extracted.

```

```

StackAggregate(S:Type): Category == BagAggregate S with

```

```

    finiteAggregate

```

```

    push_!: (S,%) -> S

```

```

    ++push!(x,s) pushes x onto stack s, that is, destructively changing s

```

```

++ so as to have a new first (top) element x.
++ Afterwards, pop!(s) produces x and pop!(s) produces the original s.
++
++X a:Stack INT:= stack [1,2,3,4,5]
++X push! a
++X a

pop_!: % -> S
++pop!(s) returns the top element x, destructively removing x from s.
++ Note that Use \axiom{top(s)} to obtain x without removing it from s.
++ Error: if s is empty.
++
++X a:Stack INT:= stack [1,2,3,4,5]
++X pop! a
++X a

top: % -> S
++top(s) returns the top element x from s; s remains unchanged.
++ Note that Use \axiom{pop!(s)} to obtain x and remove it from s.
++
++X a:Stack INT:= stack [1,2,3,4,5]
++X top a

depth: % -> NonNegativeInteger
++depth(s) returns the number of elements of stack s.
++ Note that \axiom{depth(s) = #s}.
++
++X a:Stack INT:= stack [1,2,3,4,5]
++X depth a

-----

— SKAGG.dotabb —

"SKAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=SKAGG"];
"SKAGG" -> "BGAGG"

-----

— SKAGG.dotfull —

"StackAggregate(a:Type)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=SKAGG"];
"StackAggregate(a:Type)" -> "BagAggregate(a:Type)"

"StackAggregate(a:SetCategory)"
[color=seagreen,href="bookvol10.2.pdf#nameddest=SKAGG"];

```

```
"StackAggregate(a:SetCategory)" -> "StackAggregate(a:Type)"
```

— SKAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "StackAggregate(a:Type)" [color=lightblue];
  "StackAggregate(a:Type)" -> "BagAggregate(a:Type)"

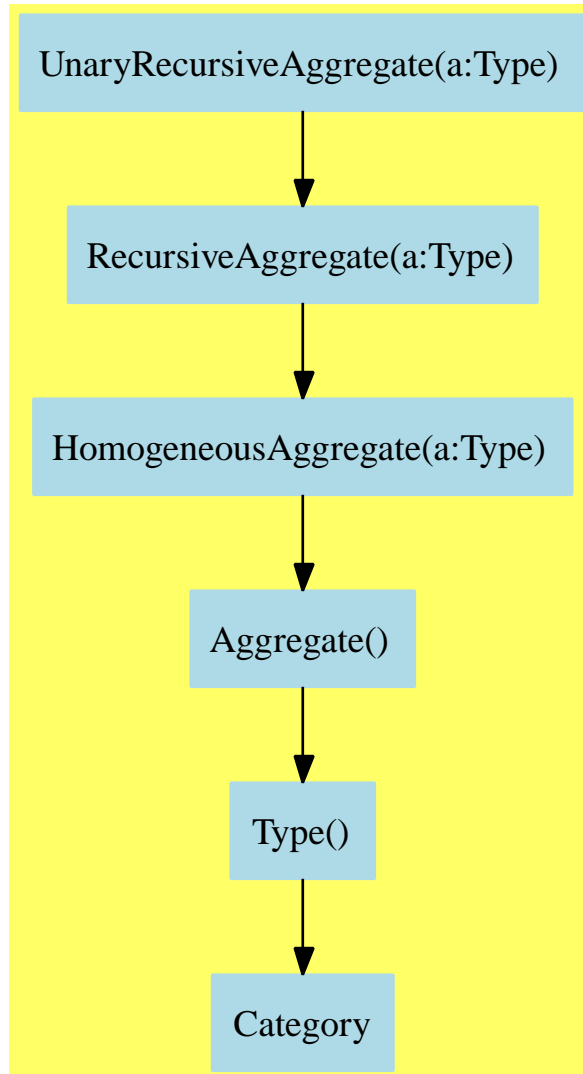
  "BagAggregate(a:Type)" [color=lightblue];
  "BagAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "Aggregate()"

  "Aggregate()" [color=lightblue];
  "Aggregate()" -> "Type()"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "Category" [color=lightblue];
}
```

UnaryRecursiveAggregate (URAGG)

— UnaryRecursiveAggregate.input —

```
)set break resume  
)sys rm -f UnaryRecursiveAggregate.output  
)spool UnaryRecursiveAggregate.output  
)set message test on  
)set message auto off  
)clear all
```

```

--S 1 of 1
)show UnaryRecursiveAggregate
--R
--R UnaryRecursiveAggregate(S: Type) is a category constructor
--R Abbreviation for UnaryRecursiveAggregate is URAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for URAGG
--R
--R----- Operations -----
--R children : % -> List(%)
--R concat : (%,% ) -> %
--R copy : % -> %
--R cycleEntry : % -> %
--R cycleTail : % -> %
--R cyclic? : % -> Boolean
--R distance : (%,% ) -> Integer
--R ?.last : (% ,last) -> S
--R ?.rest : (% ,rest) -> %
--R ?.first : (% ,first) -> S
--R ?.value : (% ,value) -> S
--R empty : () -> %
--R empty? : % -> Boolean
--R eq? : (%,% ) -> Boolean
--R first : % -> S
--R last : % -> S
--R leaf? : % -> Boolean
--R leaves : % -> List(S)
--R map : ((S -> S),%) -> %
--R nodes : % -> List(%)
--R rest : % -> %
--R sample : () -> %
--R second : % -> S
--R tail : % -> %
--R third : % -> S
--R value : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ==? : (%,% ) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R child? : (%,% ) -> Boolean if S has SETCAT
--R coerce : % -> OutputForm if S has SETCAT
--R concat! : (% ,S) -> % if $ has shallowlyMutable
--R concat! : (%,% ) -> % if $ has shallowlyMutable
--R count : (S,% ) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R cycleLength : % -> NonNegativeInteger
--R cycleSplit! : % -> % if $ has shallowlyMutable
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R first : (% ,NonNegativeInteger) -> %
--R hash : % -> SingleInteger if S has SETCAT
--R last : (% ,NonNegativeInteger) -> %
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,% ) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R node? : (%,% ) -> Boolean if S has SETCAT

```



```

--R parts : % -> List(S) if $ has finiteAggregate
--R rest : (% , NonNegativeInteger) -> %
--R setchildren! : (% , List(%)) -> % if $ has shallowlyMutable
--R setelt : (% , last, S) -> S if $ has shallowlyMutable
--R setelt : (% , rest, %) -> % if $ has shallowlyMutable
--R setelt : (% , first, S) -> S if $ has shallowlyMutable
--R setelt : (% , value, S) -> S if $ has shallowlyMutable
--R setfirst! : (% , S) -> S if $ has shallowlyMutable
--R setlast! : (% , S) -> S if $ has shallowlyMutable
--R setrest! : (% , %) -> % if $ has shallowlyMutable
--R setvalue! : (% , S) -> S if $ has shallowlyMutable
--R size? : (% , NonNegativeInteger) -> Boolean
--R split! : (% , Integer) -> % if $ has shallowlyMutable
--R ?=? : (% , %) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— UnaryRecursiveAggregate.help —

=====

UnaryRecursiveAggregate examples

=====

A unary-recursive aggregate is a one where nodes may have either 0 or 1 children. This aggregate models, though not precisely, a linked list possibly with a single cycle.

A node with one children models a non-empty list, with the value of the list designating the head, or first, of the list, and the child designating the tail, or rest, of the list. A node with no child then designates the empty list. Since these aggregates are recursive aggregates, they may be cyclic.

See Also:
o)show UnaryRecursiveAggregate

See:

⇒ “StreamAggregate” (STAGG) [7](#) on page [639](#)
⇐ “RecursiveAggregate” (RCAGG) [5](#) on page [406](#)

Exports:

| | | | | |
|-------------|-----------|--------------|------------|-------------|
| any? | children | child? | coerce | concat |
| concat! | copy | count | cycleEntry | cycleLength |
| cycleSplit! | cycleTail | cyclic? | distance | empty |
| empty? | eq? | eval | every? | first |
| hash | last | latex | leaf? | leaves |
| less? | map | map! | member? | members |
| more? | nodes | node? | parts | rest |
| sample | second | setchildren! | setelt | setfirst! |
| setlast! | setrest! | setvalue! | size? | split! |
| tail | third | value | #? | ?..last |
| ?..rest | ?..first | ?..value | ?..=? | ?~=? |

Attributes exported:

- **nil**

Attributes Used:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```
concat : (S,%) -> %
concat! : (%S) -> % if $ has shallowlyMutable
concat! : (%S) -> % if $ has shallowlyMutable
first : % -> S
first : (%NonNegativeInteger) -> %
rest : % -> %
setfirst! : (%S) -> S if $ has shallowlyMutable
```

These are implemented by this category:

```
children : % -> List %
concat : (%S) -> %
cycleEntry : % -> %
cycleLength : % -> NonNegativeInteger
cycleSplit! : % -> % if $ has shallowlyMutable
cycleTail : % -> %
cyclic? : % -> Boolean
last : % -> S
last : (%NonNegativeInteger) -> %
leaf? : % -> Boolean
less? : (%NonNegativeInteger) -> Boolean
```

```

more? : (%,NonNegativeInteger) -> Boolean
nodes : % -> List %
node? : (%,%) -> Boolean if S has SETCAT
rest : (%,NonNegativeInteger) -> %
second : % -> S
setchildren! : (%,List %) -> % if $ has shallowlyMutable
setelt : (%,first,S) -> S if $ has shallowlyMutable
setelt : (%,last,S) -> S if $ has shallowlyMutable
setelt : (%,rest,%) -> % if $ has shallowlyMutable
setlast! : (%,S) -> S if $ has shallowlyMutable
setvalue! : (%,S) -> S if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
split! : (%,Integer) -> % if $ has shallowlyMutable
tail : % -> %
third : % -> S
value : % -> S
#? : % -> NonNegativeInteger if $ has finiteAggregate
=? : (%,%) -> Boolean if S has SETCAT
?.first : (%,first) -> S
?.last : (%,last) -> S
?.rest : (%,rest) -> %

```

These exports come from (p406) `RecursiveAggregate(S:Type)`:

```

any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
child? : (%,%) -> Boolean if S has SETCAT
coerce : % -> OutputForm if S has SETCAT
copy : % -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
distance : (%,%) -> Integer
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
leaves : % -> List S
map : ((S -> S),%) -> %

```

```

map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
      if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
parts : % -> List S if $ has finiteAggregate
sample : () -> %
setelt : (%,value,S) -> S if $ has shallowlyMutable
setrest! : (%,%) -> % if $ has shallowlyMutable
?.value : (%,value) -> S
?~=? : (%,%) -> Boolean if S has SETCAT

```

— category URAGG UnaryRecursiveAggregate —

```

)abbrev category URAGG UnaryRecursiveAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A unary-recursive aggregate is a one where nodes may have either
++ 0 or 1 children.
++ This aggregate models, though not precisely, a linked
++ list possibly with a single cycle.
++ A node with one children models a non-empty list, with the
++ \spadfun{value} of the list designating the head, or \spadfun{first},
++ of the list, and the child designating the tail, or \spadfun{rest},
++ of the list. A node with no child then designates the empty list.
++ Since these aggregates are recursive aggregates, they may be cyclic.

```

```

UnaryRecursiveAggregate(S:Type): Category == RecursiveAggregate S with
  concat: (%,%) -> %
    ++ concat(u,v) returns an aggregate w consisting of the elements of u
    ++ followed by the elements of v.
    ++ Note that \axiom{v = rest(w,#a)}.
  concat: (S,%) -> %
    ++ concat(x,u) returns aggregate consisting of x followed by
    ++ the elements of u.
    ++ Note that if \axiom{v = concat(x,u)} then \axiom{x = first v}
    ++ and \axiom{u = rest v}.
  first: % -> S
    ++ first(u) returns the first element of u
    ++ (equivalently, the value at the current node).
  elt: (%, "first") -> S
    ++ elt(u, "first") (also written: \axiom{u . first})
    ++ is equivalent to first u.
  first: (%, NonNegativeInteger) -> %
    ++ first(u,n) returns a copy of the first n (\axiom{n >= 0})
    ++ elements of u.
  rest: % -> %
    ++ rest(u) returns an aggregate consisting of all but the first

```

```

++ element of u
++ (equivalently, the next node of u).
elt: (%,"rest") -> %
++ elt(%,"rest") (also written: \axiom{u.rest}) is
++ equivalent to \axiom{rest u}.
rest: (%,NonNegativeInteger) -> %
++ rest(u,n) returns the \axiom{n}th (n >= 0) node of u.
++ Note that \axiom{rest(u,0) = u}.
last: % -> S
++ last(u) return the last element of u.
++ Note that for lists, \axiom{last(u)=u . (maxIndex u)=u . (# u - 1)}.
elt: (%,"last") -> S
++ elt(u,"last") (also written: \axiom{u . last}) is equivalent
++ to last u.
last: (%,NonNegativeInteger) -> %
++ last(u,n) returns a copy of the last n (\axiom{n >= 0}) nodes of u.
++ Note that \axiom{last(u,n)} is a list of n elements.
tail: % -> %
++ tail(u) returns the last node of u.
++ Note that if u is \axiom{shallowlyMutable},
++ \axiom{setrest(tail(u),v) = concat(u,v)}.
second: % -> S
++ second(u) returns the second element of u.
++ Note that \axiom{second(u) = first(rest(u))}.
third: % -> S
++ third(u) returns the third element of u.
++ Note that \axiom{third(u) = first(rest(rest(u)))}.
cycleEntry: % -> %
++ cycleEntry(u) returns the head of a top-level cycle contained in
++ aggregate u, or \axiom{empty()} if none exists.
cycleLength: % -> NonNegativeInteger
++ cycleLength(u) returns the length of a top-level cycle
++ contained in aggregate u, or 0 if u has no such cycle.
cycleTail: % -> %
++ cycleTail(u) returns the last node in the cycle, or
++ empty if none exists.
if % has shallowlyMutable then
concat_!: (%,% ) -> %
++ concat!(u,v) destructively concatenates v to the end of u.
++ Note that \axiom{concat!(u,v) = setlast_!(u,v)}.
concat_!: (% ,S) -> %
++ concat!(u,x) destructively adds element x to the end of u.
++ Note that \axiom{concat!(a,x) = setlast!(a,[x])}.
cycleSplit_!: % -> %
++ cycleSplit!(u) splits the aggregate by dropping off the cycle.
++ The value returned is the cycle entry, or nil if none exists.
++ For example, if \axiom{w = concat(u,v)} is the cyclic list where
++ v is the head of the cycle, \axiom{cycleSplit!(w)} will drop v
++ off w thus destructively changing w to u, and returning v.
setfirst_!: (% ,S) -> S

```

```

    ++ setfirst!(u,x) destructively changes the first element of a to x.
setelt: (%,"first",S) -> S
    ++ setelt(u,"first",x) (also written: \axiom{u.first := x}) is
    ++ equivalent to \axiom{setfirst!(u,x)}.
setrest_!: (%,% ) -> %
    ++ setrest!(u,v) destructively changes the rest of u to v.
setelt: (%,"rest",%) -> %
    ++ setelt(u,"rest",v) (also written: \axiom{u.rest := v}) is
    ++ equivalent to \axiom{setrest!(u,v)}.
setlast_!: (% ,S) -> S
    ++ setlast!(u,x) destructively changes the last element of u to x.
setelt: (%,"last",S) -> S
    ++ setelt(u,"last",x) (also written: \axiom{u.last := b})
    ++ is equivalent to \axiom{setlast!(u,v)}.
split_!: (% ,Integer) -> %
    ++ split!(u,n) splits u into two aggregates: \axiom{v = rest(u,n)}
    ++ and \axiom{w = first(u,n)}, returning \axiom{v}.
    ++ Note that afterwards \axiom{rest(u,n)} returns \axiom{empty()}.
add
cycleMax ==> 1000

findCycle: % -> %

elt(x, "first") == first x
elt(x, "last") == last x
elt(x, "rest") == rest x
second x      == first rest x
third x       == first rest rest x
cyclic? x     == not empty? x and not empty? findCycle x
last x        == first tail x

nodes x ==
  l := empty()$List(%)
  while not empty? x repeat
    l := concat(x, l)
    x := rest x
  reverse_! l

children x ==
  l := empty()$List(%)
  empty? x => l
  concat(rest x,l)

leaf? x == empty? x

value x ==
  empty? x => error "value of empty object"
  first x

less?(l, n) ==

```

```

i := n::Integer
while i > 0 and not empty? l repeat (l := rest l; i := i - 1)
i > 0

more?(l, n) ==
i := n::Integer
while i > 0 and not empty? l repeat (l := rest l; i := i - 1)
zero?(i) and not empty? l

size?(l, n) ==
i := n::Integer
while not empty? l and i > 0 repeat (l := rest l; i := i - 1)
empty? l and zero? i

#x ==
for k in 0.. while not empty? x repeat
  k = cycleMax and cyclic? x => error "cyclic list"
  x := rest x
k

tail x ==
empty? x => error "empty list"
y := rest x
for k in 0.. while not empty? y repeat
  k = cycleMax and cyclic? x => error "cyclic list"
  y := rest(x := y)
x

findCycle x ==
y := rest x
while not empty? y repeat
  if eq?(x, y) then return x
  x := rest x
  y := rest y
if empty? y then return y
if eq?(x, y) then return y
y := rest y
y

cycleTail x ==
empty?(y := x := cycleEntry x) => x
z := rest x
while not eq?(x,z) repeat (y := z; z := rest z)
y

cycleEntry x ==
empty? x => x
empty?(y := findCycle x) => y
z := rest y
for l in 1.. while not eq?(y,z) repeat z := rest z

```

```

y := x
for k in 1..1 repeat y := rest y
while not eq?(x,y) repeat (x := rest x; y := rest y)
x

cycleLength x ==
empty? x => 0
empty?(x := findCycle x) => 0
y := rest x
for k in 1.. while not eq?(x,y) repeat y := rest y
k

rest(x, n) ==
for i in 1..n repeat
empty? x => error "Index out of range"
x := rest x
x

if % has finiteAggregate then
last(x, n) ==
n > (m := #x) => error "index out of range"
copy rest(x, (m - n)::NonNegativeInteger)

if S has SetCategory then
x = y ==
eq?(x, y) => true
for k in 0.. while not empty? x and not empty? y repeat
k = cycleMax and cyclic? x => error "cyclic list"
first x ^= first y => return false
x := rest x
y := rest y
empty? x and empty? y

node?(u, v) ==
for k in 0.. while not empty? v repeat
u = v => return true
k = cycleMax and cyclic? v => error "cyclic list"
v := rest v
u=v

if % has shallowlyMutable then
setelt(x, "first", a) == setfirst_!(x, a)
setelt(x, "last", a) == setlast_!(x, a)
setelt(x, "rest", a) == setrest_!(x, a)
concat(x:%, y:%) == concat_!(copy x, y)

setlast_!(x, s) ==
empty? x => error "setlast: empty list"
setfirst_!(tail x, s)
s

```



```

setchildren_!(u,lv) ==
  #lv=1 => setrest_!(u, first lv)
  error "wrong number of children specified"

setvalue_!(u,s) == setfirst_!(u,s)

split_!(p, n) ==
  n < 1 => error "index out of range"
  p := rest(p, (n - 1)::NonNegativeInteger)
  q := rest p
  setrest_!(p, empty())
  q

cycleSplit_! x ==
  empty?(y := cycleEntry x) or eq?(x, y) => y
  z := rest x
  while not eq?(z, y) repeat (x := z; z := rest z)
  setrest_!(x, empty())
  y

```

— URAGG.dotabb —

```

"URAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=URAGG"];
"URAGG" -> "RCAGG"

```

— URAGG.dotfull —

```

"UnaryRecursiveAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=URAGG"];
"UnaryRecursiveAggregate(a:Type)" -> "RecursiveAggregate(a:Type)"

```

— URAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

```

```
"UnaryRecursiveAggregate(a:Type)" [color=lightblue];
"UnaryRecursiveAggregate(a:Type)" -> "RecursiveAggregate(a:Type)"

"RecursiveAggregate(a:Type)" [color=lightblue];
"RecursiveAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

"HomogeneousAggregate(a:Type)" [color=lightblue];
"HomogeneousAggregate(a:Type)" -> "Aggregate()"

"Aggregate()" [color=lightblue];
"Aggregate()" -> "Type()"

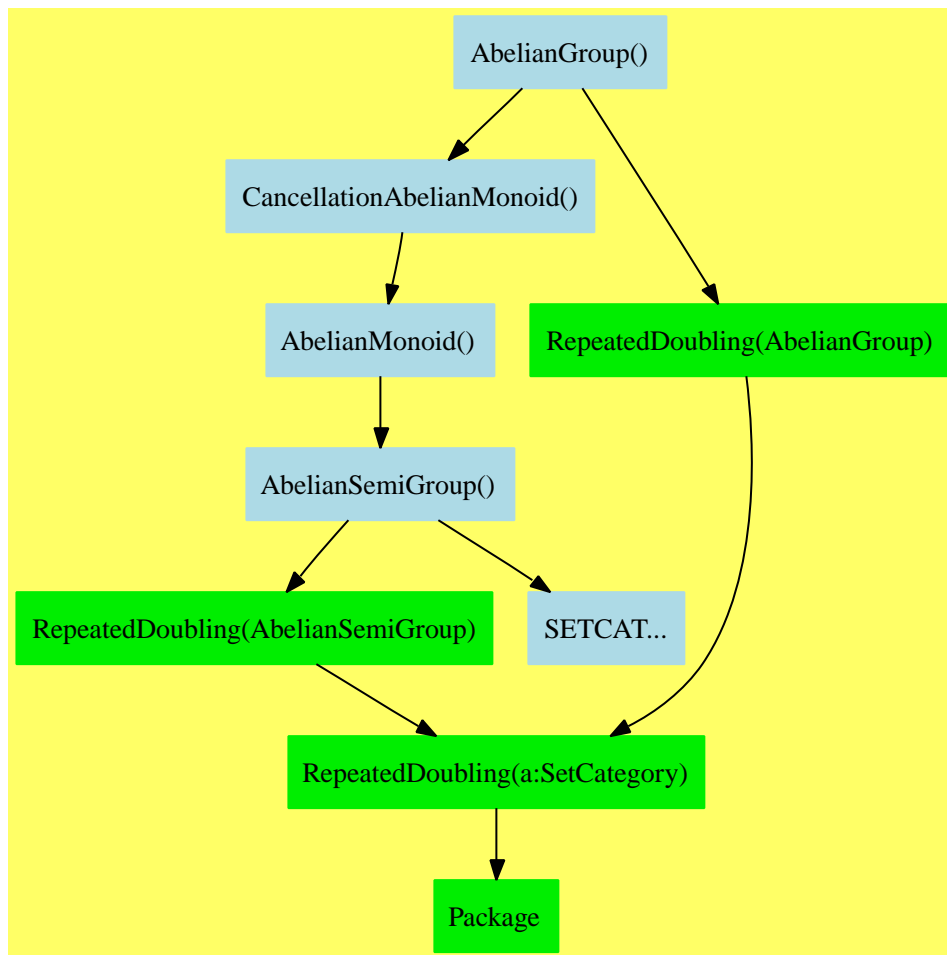
"Type()" [color=lightblue];
"Type()" -> "Category"

"Category" [color=lightblue];
}
```

Chapter 7

Category Layer 6

AbelianGroup (ABELGRP)



— AbelianGroup.input —

```

)set break resume
)sys rm -f AbelianGroup.output
)spool AbelianGroup.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show AbelianGroup
--R AbelianGroup is a category constructor

```

```

--R Abbreviation for AbelianGroup is ABELGRP
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ABELGRP
--R
--R----- Operations -----
--R ?? : (Integer,%) -> %           ?? : (PositiveInteger,%) -> %
--R ?+? : (%,%) -> %               ?-? : (%,%) -> %
--R -? : % -> %                     ?=? : (%,%) -> Boolean
--R 0 : () -> %                     coerce : % -> OutputForm
--R hash : % -> SingleInteger       latex : % -> String
--R sample : () -> %               zero? : % -> Boolean
--R ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

```

```

)spool
)lisp (bye)

```

— AbelianGroup.help —

=====

AbelianGroup examples

=====

The class of abelian groups, i.e. additive monoids where each element has an additive inverse.

Axioms:

$$\begin{aligned} -(-x) &= x \\ x+(-x) &= 0 \end{aligned}$$

See Also:

o)show AbelianGroup

See:

- ⇒ “FiniteDivisorCategory” (FDIVCAT) [8](#) on page [670](#)
- ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
- ⇒ “LeftModule” (LMODULE) [8](#) on page [710](#)
- ⇒ “NonAssociativeRng” (NARNG) [8](#) on page [734](#)
- ⇒ “OrderedAbelianGroup” (OAGROUP) [9](#) on page [811](#)
- ⇒ “RightModule” (RMODULE) [8](#) on page [771](#)

\Rightarrow “Rng” (RNG) 8 on page 775

\Leftarrow “CancellationAbelianMonoid” (CABMON) 6 on page 434

Exports:

```
0                coerce  hash   latex  sample
subtractIfCan    zero?    ?~=?   ?*?    ?+?
?-?              -?      ?=?
```

These are directly exported but not implemented:

```
-? : % -> %
```

These are implemented by this category:

```
subtractIfCan : (%,% ) -> Union(%, "failed")
?*? : (Integer,% ) -> %
?*? : (NonNegativeInteger,% ) -> %
?-? : (%,% ) -> %
```

These exports come from (p434) CancellationAbelianMonoid():

```
0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
zero? : % -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (PositiveInteger,% ) -> %
?+? : (%,% ) -> %
?=? : (%,% ) -> Boolean
```

— category ABELGRP AbelianGroup —

```
)abbrev category ABELGRP AbelianGroup
++ Description:
++ The class of abelian groups, i.e. additive monoids where
++ each element has an additive inverse.
++
++ Axioms\br
++ \tab{5}\spad{-(-x) = x}\br
++ \tab{5}\spad{x+(-x) = 0}
-- following domain must be compiled with subsumption disabled

AbelianGroup(): Category == CancellationAbelianMonoid with
  "-": % -> %
  ++ -x is the additive inverse of x.
  "-": (%,% ) -> %
```

```

++ x-y is the difference of x and y
++ i.e. \spad{x + (-y)}.
-- subsumes the partial subtraction from previous
"*": (Integer,%) -> %
++ n*x is the product of x by the integer n.
add
(x:% - y:%):% == x+(-y)
subtractIfCan(x:%, y:%):Union(%, "failed") == (x-y)::Union(%, "failed")
n:NonNegativeInteger * x:% == (n::Integer) * x
import RepeatedDoubling(%)
if not (% has Ring) then
  n:Integer * x:% ==
    zero? n => 0
    n>0 => double(n pretend PositiveInteger,x)
    double((-n) pretend PositiveInteger,-x)

-----

— ABELGRP.dotabb —

"ABELGRP"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ABELGRP"];
"ABELGRP" -> "CABMON"

-----

— ABELGRP.dotfull —

"AbelianGroup()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ABELGRP"];
"AbelianGroup()" -> "CancellationAbelianMonoid()"
"AbelianGroup()" -> "RepeatedDoubling(AbelianGroup)"

-----

— ABELGRP.dotpic —

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CancellationAbelianMonoid()"
  "AbelianGroup()" -> "RepeatedDoubling(AbelianGroup)"
}

```



```

"RepeatedDoubling(AbelianGroup)" [color="#00EE00"];
"RepeatedDoubling(AbelianGroup)" -> "RepeatedDoubling(a:SetCategory)"

"RepeatedDoubling(AbelianSemiGroup)" [color="#00EE00"];
"RepeatedDoubling(AbelianSemiGroup)" -> "RepeatedDoubling(a:SetCategory)"

"RepeatedDoubling(a:SetCategory)" [color="#00EE00"];
"RepeatedDoubling(a:SetCategory)" -> "Package"

"Package" [color="#00EE00"];

"CancellationAbelianMonoid()" [color=lightblue];
"CancellationAbelianMonoid()" -> "AbelianMonoid()"

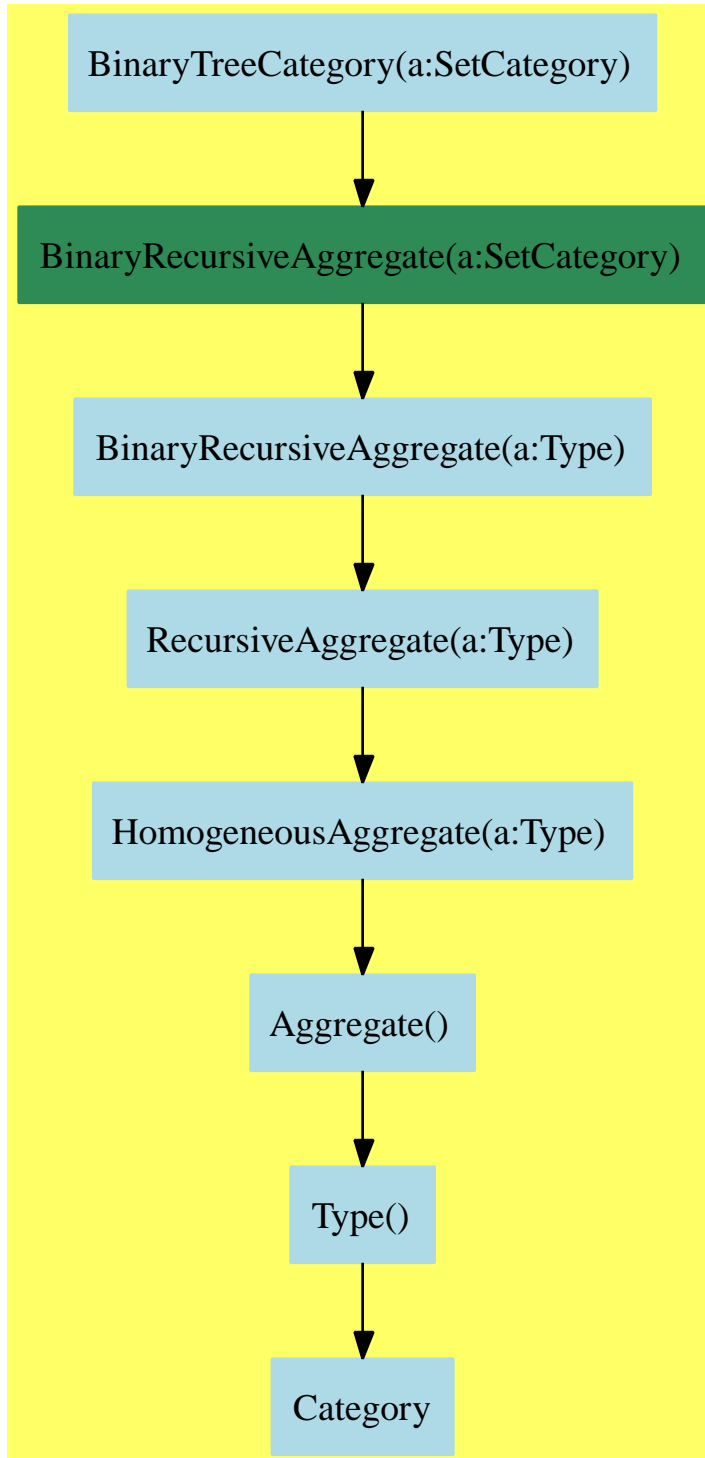
"AbelianMonoid()" [color=lightblue];
"AbelianMonoid()" -> "AbelianSemiGroup()"

"AbelianSemiGroup()" [color=lightblue];
"AbelianSemiGroup()" -> "SETCAT..."
"AbelianSemiGroup()" -> "RepeatedDoubling(AbelianSemiGroup)"

"SETCAT..." [color=lightblue];
}

```

BinaryTreeCategory (BTCAT)



— BinaryTreeCategory.input —

```

)set break resume
)sys rm -f BinaryTreeCategory.output
)spool BinaryTreeCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show BinaryTreeCategory
--R
--R BinaryTreeCategory(S: SetCategory) is a category constructor
--R Abbreviation for BinaryTreeCategory is BTCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for BTCAT
--R
--R----- Operations -----
--R children : % -> List(%)
--R cyclic? : % -> Boolean
--R ?.right : (% ,right) -> %
--R ?.value : (% ,value) -> S
--R empty? : % -> Boolean
--R leaf? : % -> Boolean
--R left : % -> %
--R node : (% ,S ,%) -> %
--R right : % -> %
--R value : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (% ,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean) ,%) -> Boolean if $ has finiteAggregate
--R child? : (% ,%) -> Boolean if S has SETCAT
--R coerce : % -> OutputForm if S has SETCAT
--R count : (S ,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean) ,%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (% ,List(S) ,List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S ,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean) ,%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S) ,%) -> % if $ has shallowlyMutable
--R member? : (S ,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean

```

```

--R node? : (%,% ) -> Boolean if S has SETCAT
--R parts : % -> List(S) if $ has finiteAggregate
--R setchildren! : (% ,List(%)) -> % if $ has shallowlyMutable
--R setelt : (% ,right,% ) -> % if $ has shallowlyMutable
--R setelt : (% ,left,% ) -> % if $ has shallowlyMutable
--R setelt : (% ,value,S) -> S if $ has shallowlyMutable
--R setleft! : (% ,% ) -> % if $ has shallowlyMutable
--R setright! : (% ,% ) -> % if $ has shallowlyMutable
--R setvalue! : (% ,S) -> S if $ has shallowlyMutable
--R size? : (% ,NonNegativeInteger) -> Boolean
--R ?~=? : (% ,% ) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— BinaryTreeCategory.help —

```

=====
BinaryTreeCategory examples
=====

```

BinaryTreeCategory(S) is the category of binary trees: a tree which is either empty or else is a node consisting of a value and a left and right, both binary trees.

See Also:

o)show BinaryTreeCategory

See:

⇐ “BinaryRecursiveAggregate” (BRAGG) [6](#) on page [426](#)

Exports:

| | | | | |
|--------------|---------|----------|-----------|-----------|
| any? | child? | children | coerce | copy |
| count | cyclic? | distance | empty | empty? |
| eq? | eval | every? | hash | latex |
| leaf? | leaves | less? | left | map |
| map! | member? | members | more? | node |
| node? | nodes | parts | right | sample |
| setchildren! | setelt | setleft! | setright! | setvalue! |
| size? | value | #? | ?=? | ?~=? |
| ?.right | ?.left | ?.value | | |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

These are directly exported but not implemented:

```
node : (% , S , %) -> %
```

These are implemented by this category:

```
copy : % -> %
map! : ((S -> S) , %) -> % if $ has shallowlyMutable
#? : % -> NonNegativeInteger if $ has finiteAggregate
```

These exports come from (p426) BinaryRecursiveAggregate(S:SetCategory):

```
any? : ((S -> Boolean) , %) -> Boolean if $ has finiteAggregate
child? : (% , %) -> Boolean if S has SETCAT
children : % -> List %
coerce : % -> OutputForm if S has SETCAT
count : (S , %) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean) , %) -> NonNegativeInteger if $ has finiteAggregate
cyclic? : % -> Boolean
distance : (% , %) -> Integer
empty : () -> %
empty? : % -> Boolean
eq? : (% , %) -> Boolean
eval : (% , List S , List S) -> % if S has EVALAB S and S has SETCAT
eval : (% , S , S) -> % if S has EVALAB S and S has SETCAT
eval : (% , Equation S) -> % if S has EVALAB S and S has SETCAT
eval : (% , List Equation S) -> % if S has EVALAB S and S has SETCAT
leaf? : % -> Boolean
leaves : % -> List S
```

```

left : % -> %
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
right : % -> %
sample : () -> %
setchildren! : (%,List %) -> % if $ has shallowlyMutable
setelt : (%,value,S) -> S if $ has shallowlyMutable
setelt : (%,right,%) -> % if $ has shallowlyMutable
setelt : (%,left,%) -> % if $ has shallowlyMutable
setleft! : (%,%) -> % if $ has shallowlyMutable
setright! : (%,%) -> % if $ has shallowlyMutable
setvalue! : (%,S) -> S if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
value : % -> S
?~=? : (%,%) -> Boolean if S has SETCAT
?.value : (%,value) -> S
?=? : (%,%) -> Boolean if S has SETCAT
?.right : (%,right) -> %
?.left : (%,left) -> %

```

— category BTCAT BinaryTreeCategory —

```

)abbrev category BTCAT BinaryTreeCategory
++ Author:W. H. Burge
++ Date Created:17 Feb 1992
++ Description:
++ \spadtype{BinaryTreeCategory(S)} is the category of
++ binary trees: a tree which is either empty or else is a
++ \spadfun{node} consisting of a value and a \spadfun{left} and
++ \spadfun{right}, both binary trees.

BinaryTreeCategory(S: SetCategory): Category == _
  BinaryRecursiveAggregate(S) with
  shallowlyMutable
  ++ Binary trees have updateable components
  finiteAggregate
  ++ Binary trees have a finite number of components
  node: (%,S,%) -> %
  ++ node(left,v,right) creates a binary tree with value \spad{v}, a binary
  ++ tree \spad{left}, and a binary tree \spad{right}.
  ++
add

```

```

cycleTreeMax ==> 5

copy t ==
  empty? t => empty()
  node(copy left t, value t, copy right t)

if % has shallowlyMutable then
  map_!(f,t) ==
    empty? t => t
    t.value := f(t.value)
    map_!(f,left t)
    map_!(f,right t)
    t

treeCount : (% , NonNegativeInteger) -> NonNegativeInteger

#t == treeCount(t,0)

treeCount(t,k) ==
  empty? t => k
  k := k + 1
  k = cycleTreeMax and cyclic? t => error "cyclic binary tree"
  k := treeCount(left t,k)
  treeCount(right t,k)

```

— BTCAT.dotabb —

```

"BTCAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=BTCAT" ];
"BTCAT" -> "BRAGG"

```

— BTCAT.dotfull —

```

"BinaryTreeCategory(a:SetCategory)"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=BTCAT" ];
"BinaryTreeCategory(a:SetCategory)" ->
  "BinaryRecursiveAggregate(a:SetCategory)"

```

— BTCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "BinaryTreeCategory(a:SetCategory)" [color=lightblue];
  "BinaryTreeCategory(a:SetCategory)" ->
    "BinaryRecursiveAggregate(a:SetCategory)"

  "BinaryRecursiveAggregate(a:SetCategory)"
    [color=seagreen,href="bookvol10.2.pdf#nameddest=BRAGG"];
  "BinaryRecursiveAggregate(a:SetCategory)" ->
    "BinaryRecursiveAggregate(a:Type)"

  "BinaryRecursiveAggregate(a:Type)" [color=lightblue];
  "BinaryRecursiveAggregate(a:Type)" -> "RecursiveAggregate(a:Type)"

  "RecursiveAggregate(a:Type)" [color=lightblue];
  "RecursiveAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "Aggregate()"

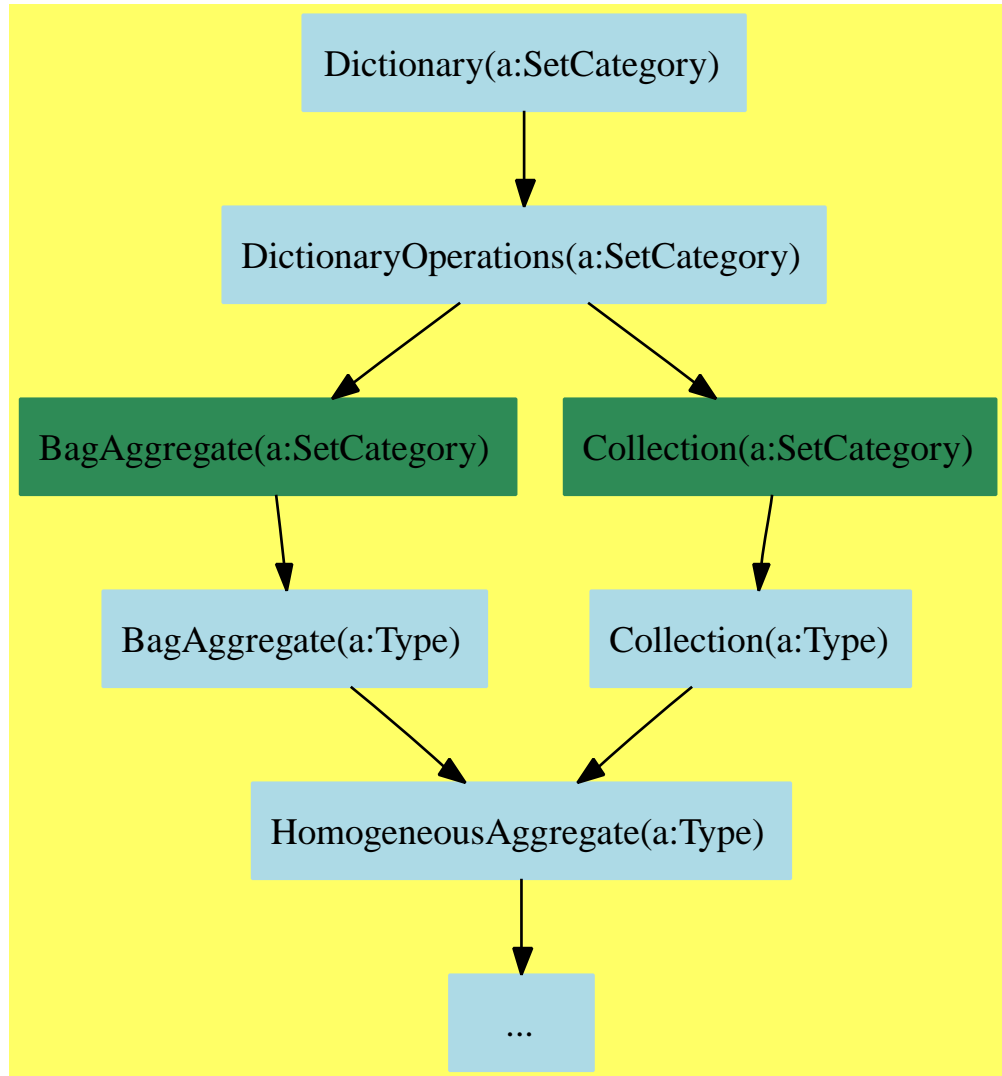
  "Aggregate()" [color=lightblue];
  "Aggregate()" -> "Type()"

  "Type()" [color=lightblue];
  "Type()" -> "Category"

  "Category" [color=lightblue];
}

```

Dictionary (DIAGG)



— Dictionary.input —

```

)set break resume
)sys rm -f Dictionary.output
)spool Dictionary.output
)set message test on
)set message auto off
)clear all
  
```

```

--S 1 of 1
)show Dictionary
--R
--R Dictionary(S: SetCategory) is a category constructor
--R Abbreviation for Dictionary is DIAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DIAGG
--R
--R----- Operations -----
--R bag : List(S) -> %                construct : List(S) -> %
--R copy : % -> %                    dictionary : List(S) -> %
--R dictionary : () -> %              empty : () -> %
--R empty? : % -> Boolean              eq? : (%,% ) -> Boolean
--R extract! : % -> S                 insert! : (S,% ) -> %
--R inspect : % -> S                  map : ((S -> S),%) -> %
--R sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (%,% ) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : (S,% ) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,% ) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),% ,S) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),% ,S,S) -> S if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (S,% ) -> % if S has SETCAT and $ has finiteAggregate
--R remove! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove! : (S,% ) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R select! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (% ,NonNegativeInteger) -> Boolean
--R ?~=? : (%,% ) -> Boolean if S has SETCAT

```

```
--R
--E 1

)spool
)lisp (bye)
```

— Dictionary.help —

=====

Dictionary examples

=====

A dictionary is an aggregate in which entries can be inserted, searched for and removed. Duplicates are thrown away on insertion. This category models the usual notion of dictionary which involves large amounts of data where copying is impractical.

Principal operations are thus destructive (non-copying) ones.

See Also:

o)show Dictionary

See:

⇒ “FiniteSetAggregate” (FSAGG) [8](#) on page [675](#)
 ⇒ “KeyedDictionary” (KDAGG) [8](#) on page [684](#)
 ⇐ “DictionaryOperations” (DIOPS) [6](#) on page [439](#)

Exports:

| | | | | |
|--------|---------|------------|-----------|------------------|
| any? | bag | coerce | construct | convert |
| copy | count | dictionary | empty | empty? |
| eq? | eval | every? | extract! | find |
| hash | insert! | inspect | latex | less? |
| map | map! | member? | members | more? |
| parts | reduce | remove | remove! | removeDuplicates |
| sample | select | select! | size? | #? |
| ?~=? | ?=? | | | |

Attributes exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

- `nil`

Attributes Used:

- **`finiteAggregate`** is true if it is an aggregate with a finite number of elements.

These are implemented by this category:

```
dictionary : List S -> %
select! : ((S -> Boolean),%) -> % if $ has finiteAggregate
?=? : (%,%) -> Boolean if S has SETCAT
remove! : ((S -> Boolean),%) -> % if $ has finiteAggregate
```

These exports come from (p439) DictionaryOperations(S:SetCategory):

```
any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
bag : List S -> %
coerce : % -> OutputForm if S has SETCAT
construct : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
copy : % -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
dictionary : () -> %
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
extract! : % -> S
find : ((S -> Boolean),%) -> Union(S,"failed")
hash : % -> SingleInteger if S has SETCAT
insert! : (S,%) -> %
inspect : % -> S
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
```

```

        if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (% , NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S if $ has finiteAggregate
reduce : (((S,S) -> S),%,S,S) -> S
        if S has SETCAT and $ has finiteAggregate
remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
remove! : (S,%) -> % if $ has finiteAggregate
removeDuplicates : % -> %
        if S has SETCAT and $ has finiteAggregate
sample : () -> %
select : ((S -> Boolean),%) -> % if $ has finiteAggregate
size? : (% , NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
?~=? : (% , %) -> Boolean if S has SETCAT

```

— category DIAGG Dictionary —

```

)abbrev category DIAGG Dictionary
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A dictionary is an aggregate in which entries can be inserted,
++ searched for and removed. Duplicates are thrown away on insertion.
++ This category models the usual notion of dictionary which involves
++ large amounts of data where copying is impractical.
++ Principal operations are thus destructive (non-copying) ones.

```

```

Dictionary(S:SetCategory): Category ==
DictionaryOperations S add
dictionary l ==
  d := dictionary()
  for x in l repeat insert_!(x, d)
  d

if % has finiteAggregate then
-- remove(f:S->Boolean,t:%) == remove_!(f, copy t)
-- select(f, t) == select_!(f, copy t)
select_!(f, t) == remove_!((x:S):Boolean +-> not f(x), t)

--extract_! d ==
--      empty? d => error "empty dictionary"
--      remove_!(x := first parts d, d, 1)
--      x

```

```

s = t ==
  eq?(s,t) => true
  #s ^= #t => false
  _and/[member?(x, t) for x in parts s]

remove_!(f:S->Boolean, t:%) ==
  for m in parts t repeat if f m then remove_!(m, t)
  t

```

— DIAGG.dotabb —

```

"DIAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=DIAGG"];
"DIAGG" -> "DIOPS"

```

— DIAGG.dotfull —

```

"Dictionary(a:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=DIAGG"];
"Dictionary(a:SetCategory)" -> "DictionaryOperations(a:SetCategory)"

"Dictionary(Record(a:SetCategory,b:SetCategory))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=DIAGG"];
"Dictionary(Record(a:SetCategory,b:SetCategory))" ->
  "Dictionary(a:SetCategory)"

```

— DIAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Dictionary(a:SetCategory)" [color=lightblue];
  "Dictionary(a:SetCategory)" -> "DictionaryOperations(a:SetCategory)"

  "DictionaryOperations(a:SetCategory)" [color=lightblue];
  "DictionaryOperations(a:SetCategory)" -> "BagAggregate(a:SetCategory)"
  "DictionaryOperations(a:SetCategory)" -> "Collection(a:SetCategory)"

```

```

"BagAggregate(a:SetCategory)" [color=seagreen];
"BagAggregate(a:SetCategory)" -> "BagAggregate(a:Type)"

"BagAggregate(a:Type)" [color=lightblue];
"BagAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

"Collection(a:SetCategory)" [color=seagreen];
"Collection(a:SetCategory)" -> "Collection(a:Type)"

"Collection(a:Type)" [color=lightblue];
"Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"

"HomogeneousAggregate(a:Type)" [color=lightblue];
"HomogeneousAggregate(a:Type)" -> "Aggregate()"

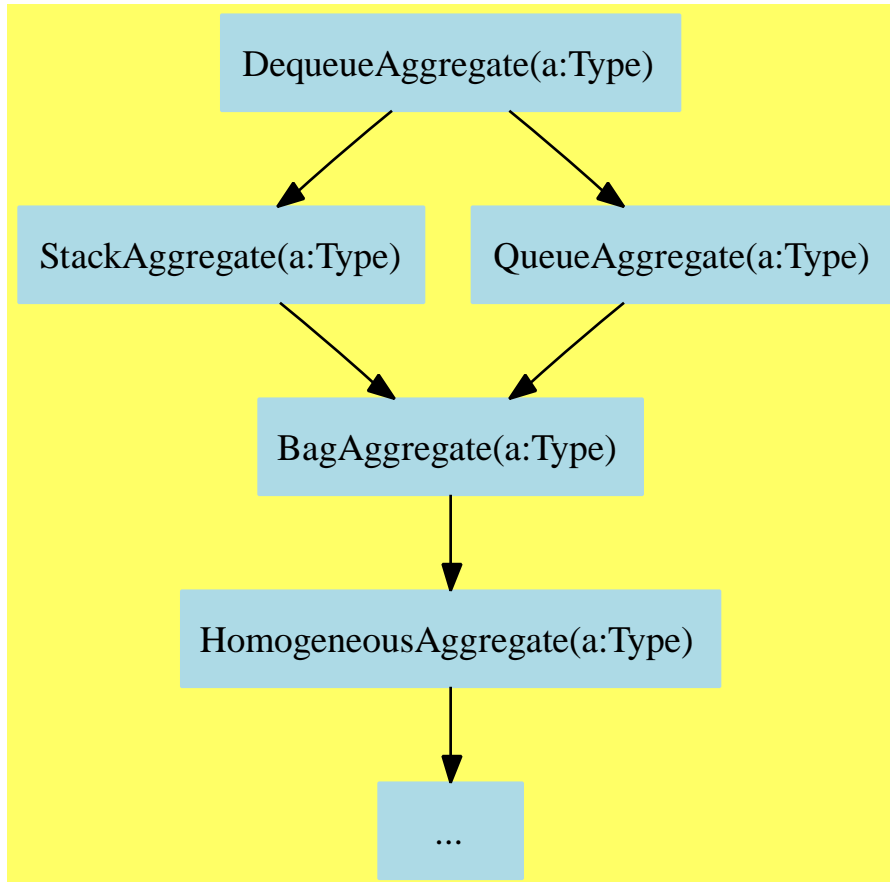
"Aggregate()" [color=lightblue];
"Aggregate()" -> "Type()"

"Type()" [color=lightblue];
"Type()" -> "Category"

"Category" [color=lightblue];
}

```

DequeAggregate (DQAGG)



— DequeueAggregate.input —

```

)set break resume
)sys rm -f DequeueAggregate.output
)spool DequeueAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show DequeueAggregate
--R
--R DequeueAggregate(S: Type) is a category constructor
--R Abbreviation for DequeueAggregate is DQAGG
--R This constructor is exposed in this frame.

```



```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DQAGG
--R
--R----- Operations -----
--R back : % -> S                                bag : List(S) -> %
--R bottom! : % -> S                              copy : % -> %
--R depth : % -> NonNegativeInteger              dequeue : List(S) -> %
--R dequeue : () -> %                             dequeue! : % -> S
--R empty : () -> %                               empty? : % -> Boolean
--R enqueue! : (S,%) -> S                         eq? : (%,%) -> Boolean
--R extract! : % -> S                             extractBottom! : % -> S
--R extractTop! : % -> S                         front : % -> S
--R height : % -> NonNegativeInteger             insert! : (S,%) -> %
--R insertBottom! : (S,%) -> S                   insertTop! : (S,%) -> S
--R inspect : % -> S                             length : % -> NonNegativeInteger
--R map : ((S -> S),%) -> %                       pop! : % -> S
--R push! : (S,%) -> S                           reverse! : % -> %
--R rotate! : % -> %                             sample : () -> %
--R top : % -> S                                  top! : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (%,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R ?~=? : (%,%) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

```
=====
DequeAggregate examples
=====
```

A dequeue is a doubly ended stack, that is, a bag where first items inserted are the first items extracted, at either the front or the back end of the data structure.

See Also:

o)show DequeueAggregate

See:

⇐ “QueueAggregate” (QUAGG) 6 on page 540

⇐ “StackAggregate” (SKAGG) 6 on page 554

Exports:

| | | | | |
|---------|----------|----------------|---------------|------------|
| any? | back | bag | bottom! | coerce |
| copy | count | depth | dequeue | dequeue! |
| empty | empty? | enqueue! | eq? | eval |
| every? | extract! | extractBottom! | extractTop! | front |
| hash | height | insert! | insertBottom! | insertTop! |
| inspect | latex | length | less? | map |
| map! | members | member? | more? | parts |
| pop! | push! | reverse! | rotate! | sample |
| size? | top | top! | #? | ?=? |
| ?~=? | | | | |

Attributes exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

These are directly exported but not implemented:

```
bottom! : % -> S
dequeue : () -> %
dequeue : List S -> %
extractBottom! : % -> S
extractTop! : % -> S
```

```

height : % -> NonNegativeInteger
insertBottom! : (S,%) -> S
insertTop! : (S,%) -> S
reverse! : % -> %
top! : % -> S

```

These exports come from (p554) StackAggregate(S:Type):

```

any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
bag : List S -> %
coerce : % -> OutputForm if S has SETCAT
copy : % -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
depth : % -> NonNegativeInteger
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
extract! : % -> S
hash : % -> SingleInteger if S has SETCAT
insert! : (S,%) -> %
inspect : % -> S
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
members : % -> List S if $ has finiteAggregate
member? : (S,%) -> Boolean
      if S has SETCAT and $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
pop! : % -> S
push! : (S,%) -> S
sample : () -> %
size? : (%,NonNegativeInteger) -> Boolean
top : % -> S
#? : % -> NonNegativeInteger if $ has finiteAggregate
=? : (%,%) -> Boolean if S has SETCAT

```

```
?~=? : (%,% ) -> Boolean if S has SETCAT
```

These exports come from (p540) QueueAggregate(S:Type):

```
back : % -> S
dequeue! : % -> S
enqueue! : (S,%) -> S
front : % -> S
length : % -> NonNegativeInteger
rotate! : % -> %
```

— category DQAGG DequeueAggregate —

```
)abbrev category DQAGG DequeueAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A dequeue is a doubly ended stack, that is, a bag where first items
++ inserted are the first items extracted, at either the front or
++ the back end of the data structure.

DequeueAggregate(S:Type):
Category == Join(StackAggregate S,QueueAggregate S) with
  dequeue: () -> %
    ++ dequeue()$D creates an empty dequeue of type D.
  dequeue: List S -> %
    ++ dequeue([x,y,...,z]) creates a dequeue with first (top or front)
    ++ element x, second element y,...,and last (bottom or back) element z.
  height: % -> NonNegativeInteger
    ++ height(d) returns the number of elements in dequeue d.
    ++ Note that \axiom{height(d) = # d}.
  top_!: % -> S
    ++ top!(d) returns the element at the top (front) of the dequeue.
  bottom_!: % -> S
    ++ bottom!(d) returns the element at the bottom (back) of the dequeue.
  insertTop_!: (S,%) -> S
    ++ insertTop!(x,d) destructively inserts x into the dequeue d, that is,
    ++ at the top (front) of the dequeue.
    ++ The element previously at the top of the dequeue becomes the
    ++ second in the dequeue, and so on.
  insertBottom_!: (S,%) -> S
    ++ insertBottom!(x,d) destructively inserts x into the dequeue d
    ++ at the bottom (back) of the dequeue.
  extractTop_!: % -> S
    ++ extractTop!(d) destructively extracts the top (front) element
    ++ from the dequeue d.
    ++ Error: if d is empty.
  extractBottom_!: % -> S
```

```

++ extractBottom!(d) destructively extracts the bottom (back) element
++ from the dequeue d.
++ Error: if d is empty.
reverse_!: % -> %
++ reverse!(d) destructively replaces d by its reverse dequeue, i.e.
++ the top (front) element is now the bottom (back) element, and so on.

```

— DQAGG.dotabb —

```

"DQAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=DQAGG"];
"DQAGG" -> "SKAGG"
"DQAGG" -> "QUAGG"

```

— DQAGG.dotfull —

```

"DequeueAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=DQAGG"];
"DequeueAggregate(a:Type)" -> "StackAggregate(a:Type)"
"DequeueAggregate(a:Type)" -> "QueueAggregate(a:Type)"

"DequeueAggregate(a:SetCategory)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=DQAGG"];
"DequeueAggregate(a:SetCategory)" -> "DequeueAggregate(a:Type)"

```

— DQAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "DequeueAggregate(a:Type)" [color=lightblue];
  "DequeueAggregate(a:Type)" -> "StackAggregate(a:Type)"
  "DequeueAggregate(a:Type)" -> "QueueAggregate(a:Type)"

  "StackAggregate(a:Type)" [color=lightblue];
  "StackAggregate(a:Type)" -> "BagAggregate(a:Type)"

  "QueueAggregate(a:Type)" [color=lightblue];

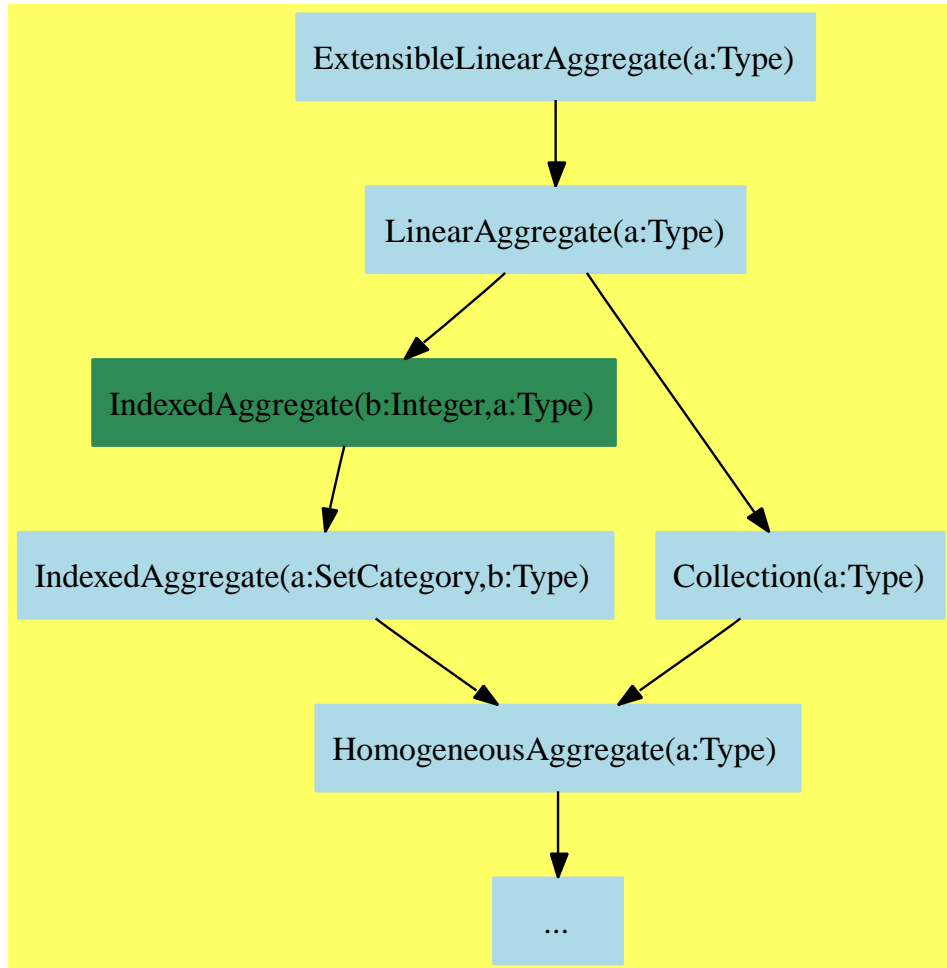
```

```
"QueueAggregate(a:Type)" -> "BagAggregate(a:Type)"

"BagAggregate(a:Type)" [color=lightblue];
"BagAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

"HomogeneousAggregate(a:Type)" [color=lightblue];
"HomogeneousAggregate(a:Type)" -> "...

"..." [color=lightblue];
}
```

ExtensibleLinearAggregate (ELAGG)

— ExtensibleLinearAggregate.input —

```

)set break resume
)sys rm -f ExtensibleLinearAggregate.output
)spool ExtensibleLinearAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ExtensibleLinearAggregate
--R

```

```

--R ExtensibleLinearAggregate(S: Type) is a category constructor
--R Abbreviation for ExtensibleLinearAggregate is ELAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ELAGG
--R
--R----- Operations -----
--R concat : List(%) -> %
--R concat : (S,%) -> %
--R concat! : (%,%) -> %
--R construct : List(S) -> %
--R delete : (%,Integer) -> %
--R ?.? : (%,Integer) -> S
--R empty : () -> %
--R entries : % -> List(S)
--R index? : (Integer,%) -> Boolean
--R insert : (%,%,Integer) -> %
--R insert! : (%,%,Integer) -> %
--R map : (((S,S) -> S),%,%) -> %
--R new : (NonNegativeInteger,S) -> %
--R sample : () -> %
--R #: % -> NonNegativeInteger if $ has finiteAggregate
--R ==? : (%,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R convert : % -> InputForm if S has CONVERT(INFORM)
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R delete : (%,UniversalSegment(Integer)) -> %
--R delete! : (%,UniversalSegment(Integer)) -> %
--R ?.? : (%,UniversalSegment(Integer)) -> %
--R entry? : (S,%) -> Boolean if $ has finiteAggregate and S has SETCAT
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (%,S) -> % if $ has shallowlyMutable
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R first : % -> S if Integer has ORDSET
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R merge! : (%,%) -> % if S has ORDSET
--R merge! : (((S,S) -> Boolean),%,%) -> %
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (%,NonNegativeInteger) -> Boolean

```



```

--R parts : % -> List(S) if $ has finiteAggregate
--R qsetelt! : (% , Integer, S) -> S if $ has shallowlyMutable
--R reduce : ((S, S) -> S), % -> S if $ has finiteAggregate
--R reduce : ((S, S) -> S), %, S -> S if $ has finiteAggregate
--R reduce : ((S, S) -> S), %, S, S -> S if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean), %) -> % if $ has finiteAggregate
--R remove : (S, %) -> % if S has SETCAT and $ has finiteAggregate
--R remove! : (S, %) -> % if S has SETCAT
--R remove! : ((S -> Boolean), %) -> %
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R removeDuplicates! : % -> % if S has SETCAT
--R select : ((S -> Boolean), %) -> % if $ has finiteAggregate
--R select! : ((S -> Boolean), %) -> %
--R setelt : (% , UniversalSegment(Integer), S) -> S if $ has shallowlyMutable
--R setelt : (% , Integer, S) -> S if $ has shallowlyMutable
--R size? : (% , NonNegativeInteger) -> Boolean
--R swap! : (% , Integer, Integer) -> Void if $ has shallowlyMutable
--R ?~=? : (% , %) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— ExtensibleLinearAggregate.help —

```

=====
ExtensibleLinearAggregate examples
=====

```

An extensible aggregate is one which allows insertion and deletion of entries. These aggregates are models of lists and streams which are represented by linked structures so as to make insertion, deletion, and concatenation efficient. However, access to elements of these extensible aggregates is generally slow since access is made from the end. See `FlexibleArray` for an exception.

See Also:

- o `)show ExtensibleLinearAggregate`
- o `)show FlexibleArray`

See:

⇒ “ListAggregate” (LSAGG) 8 on page 714

← “LinearAggregate” (LNAGG) 6 on page 458

Exports:

| | | | | |
|----------|---------|---------|------------------|-------------------|
| any? | coerce | concat | concat! | construct |
| copy | convert | count | delete | delete! |
| elt | empty | empty? | entries | entry? |
| eval | every? | eq? | fill! | find |
| first | hash | index? | indices | insert |
| insert! | latex | less? | map | map! |
| maxIndex | member? | members | merge! | minIndex |
| more? | new | parts | qelt | qsetelt! |
| reduce | remove | remove! | removeDuplicates | removeDuplicates! |
| sample | select | select! | setelt | size? |
| swap! | #? | ?=? | ?..? | ?^=? |

Attributes Exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

These are directly exported but not implemented:

```
concat! : (%,S) -> %
delete! : (%,Integer) -> %
delete! : (%,UniversalSegment Integer) -> %
insert! : (%,%,Integer) -> %
insert! : (S,%,Integer) -> %
merge! : (((S,S) -> Boolean),%,%) -> %
remove! : ((S -> Boolean),%) -> %
removeDuplicates! : % -> % if S has SETCAT
select! : ((S -> Boolean),%) -> %
```

These are implemented by this category:

```
concat : (%,%) -> %
concat : (%,S) -> %
concat! : (%,%) -> %
delete : (%,Integer) -> %
delete : (%,UniversalSegment Integer) -> %
insert : (%,%,Integer) -> %
insert : (S,%,Integer) -> %
merge! : (%,%) -> % if S has ORDSET
remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
remove! : (S,%) -> % if S has SETCAT
```

```

removeDuplicates : % -> %
    if S has SETCAT and $ has finiteAggregate
select : ((S -> Boolean),%) -> % if $ has finiteAggregate

```

These exports come from (p458) LinearAggregate(S:Type):

```

any? : ((S -> Boolean),%) -> Boolean
    if $ has finiteAggregate
coerce : % -> OutputForm if S has SETCAT
concat : List % -> %
concat : (S,%) -> %
construct : List S -> %
copy : % -> %
count : (S,%) -> NonNegativeInteger
    if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
    if $ has finiteAggregate
convert : % -> InputForm if S has KONVERT INFORM
elt : (%,Integer,S) -> S
empty : () -> %
empty? : % -> Boolean
entries : % -> List S
entry? : (S,%) -> Boolean
    if $ has finiteAggregate and S has SETCAT
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
    if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
    if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
    if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
    if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean
    if $ has finiteAggregate
index? : (Integer,%) -> Boolean
indices : % -> List Integer
fill! : (%,S) -> % if $ has shallowlyMutable
find : ((S -> Boolean),%) -> Union(S,"failed")
first : % -> S if Integer has ORDSET
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S,S) -> S),%,%) -> %
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
    if S has SETCAT and $ has finiteAggregate
maxIndex : % -> Integer if Integer has ORDSET
new : (NonNegativeInteger,S) -> %

```

```

members : % -> List S if $ has finiteAggregate
minIndex : % -> Integer if Integer has ORDSET
more? : (% , NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
qelt : (% , Integer) -> S
qsetelt! : (% , Integer, S) -> S
    if $ has shallowlyMutable
reduce : (((S, S) -> S), %) -> S
    if $ has finiteAggregate
reduce : (((S, S) -> S), %, S) -> S
    if $ has finiteAggregate
reduce : (((S, S) -> S), %, S, S) -> S
    if S has SETCAT and $ has finiteAggregate
sample : () -> %
setelt : (% , Integer, S) -> S if $ has shallowlyMutable
setelt : (% , UniversalSegment Integer, S) -> S
    if $ has shallowlyMutable
size? : (% , NonNegativeInteger) -> Boolean
swap! : (% , Integer, Integer) -> Void
    if $ has shallowlyMutable
#? : % -> NonNegativeInteger if $ has finiteAggregate
==? : (% , %) -> Boolean if S has SETCAT
?~=? : (% , %) -> Boolean if S has SETCAT
?.? : (% , Integer) -> S
?.? : (% , UniversalSegment Integer) -> %

```

— category ELAGG ExtensibleLinearAggregate —

```

)abbrev category ELAGG ExtensibleLinearAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ An extensible aggregate is one which allows insertion and deletion of
++ entries. These aggregates are models of lists and streams which are
++ represented by linked structures so as to make insertion, deletion, and
++ concatenation efficient. However, access to elements of these
++ extensible aggregates is generally slow since access is made from the end.
++ See \spadtype{FlexibleArray} for an exception.

```

```

ExtensibleLinearAggregate(S:Type):Category == LinearAggregate S with
shallowlyMutable
concat_!: (% , S) -> %
    ++ concat!(u,x) destructively adds element x to the end of u.
concat_!: (% , %) -> %
    ++ concat!(u,v) destructively appends v to the end of u.
    ++ v is unchanged
delete_!: (% , Integer) -> %
    ++ delete!(u,i) destructively deletes the \axiom{i}th element of u.

```

```

++
++E Data:=Record(age:Integer,gender:String)
++E a1:AssociationList(String,Data):=table()
++E a1."tim":=[55,"male"]$Data
++E delete!(a1,1)

delete_!: (% , UniversalSegment(Integer)) -> %
++ delete!(u,i..j) destructively deletes elements u.i through u.j.
remove_!: (S->Boolean,%) -> %
++ remove!(p,u) destructively removes all elements x of
++ u such that \axiom{p(x)} is true.
insert_!: (S,%,Integer) -> %
++ insert!(x,u,i) destructively inserts x into u at position i.
insert_!: (% ,%,Integer) -> %
++ insert!(v,u,i) destructively inserts aggregate v into u
++ at position i.
merge_!: ((S,S)->Boolean,%,%) -> %
++ merge!(p,u,v) destructively merges u and v using predicate p.
select_!: (S->Boolean,%) -> %
++ select!(p,u) destructively changes u by keeping only values
++ x such that \axiom{p(x)}.
if S has SetCategory then
  remove_!: (S,%) -> %
  ++ remove!(x,u) destructively removes all values x from u.
  removeDuplicates_!: % -> %
  ++ removeDuplicates!(u) destructively removes duplicates from u.
if S has OrderedSet then merge_!: (% ,%) -> %
  ++ merge!(u,v) destructively merges u and v in ascending order.
add
delete(x:%, i:Integer) == delete_!(copy x, i)
delete(x:%, i:UniversalSegment(Integer)) == delete_!(copy x, i)
remove(f:S -> Boolean, x:%) == remove_!(f, copy x)
insert(s:S, x:%, i:Integer) == insert_!(s, copy x, i)
insert(w:%, x:%, i:Integer) == insert_!(copy w, copy x, i)
select(f, x) == select_!(f, copy x)
concat(x:%, y:%) == concat_!(copy x, y)
concat(x:%, y:S) == concat_!(copy x, new(1, y))
concat_!(x:%, y:S) == concat_!(x, new(1, y))
if S has SetCategory then
  remove(s:S, x:%) == remove_!(s, copy x)
  remove_!(s:S, x:%) == remove_!(y +-> y = s, x)
  removeDuplicates(x:%) == removeDuplicates_!(copy x)

if S has OrderedSet then
  merge_!(x, y) == merge_!(<$S, x, y)

```

— ELAGG.dotabb —

```
"ELAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=ELAGG"];
"ELAGG" -> "LNAGG"
```

— ELAGG.dotfull —

```
"ExtensibleLinearAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ELAGG"];
"ExtensibleLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"
```

— ELAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ExtensibleLinearAggregate(a:Type)" [color=lightblue];
  "ExtensibleLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"

  "LinearAggregate(a:Type)" [color=lightblue];
  "LinearAggregate(a:Type)" -> "IndexedAggregate(b:Integer,a:Type)"
  "LinearAggregate(a:Type)" -> "Collection(a:Type)"

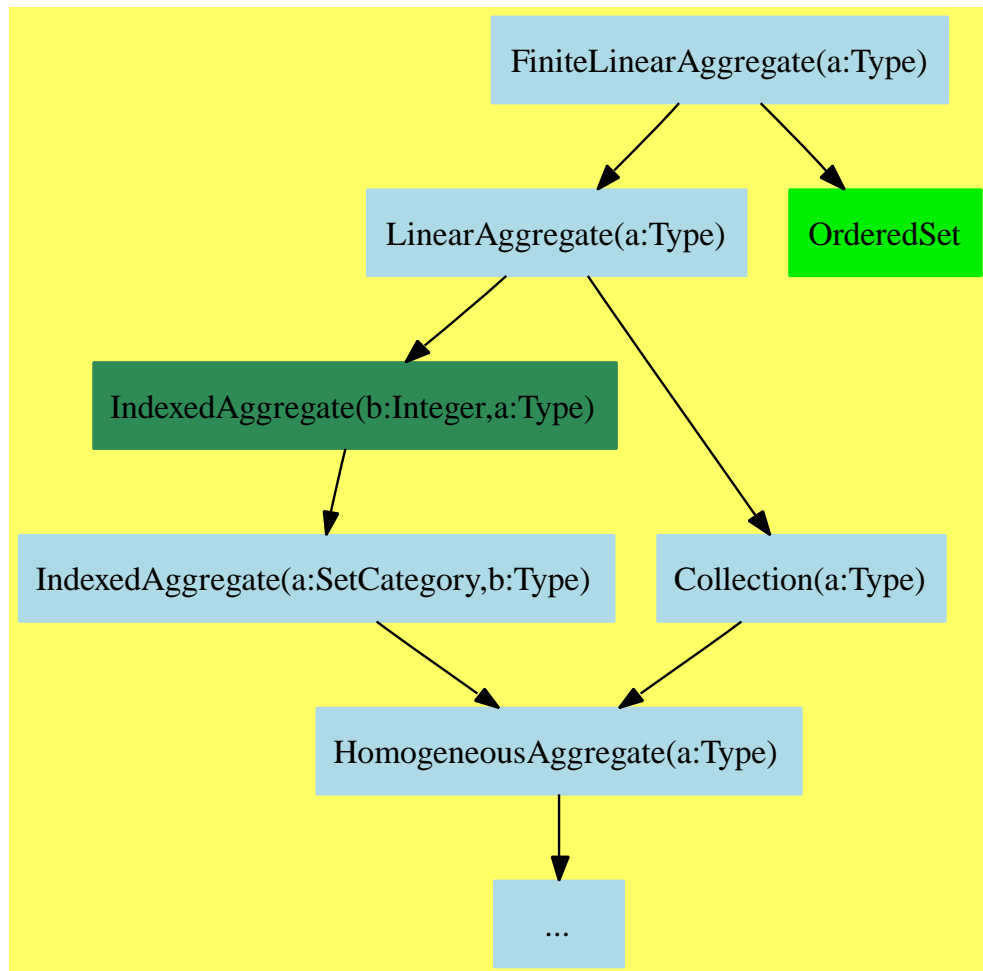
  "IndexedAggregate(b:Integer,a:Type)" [color=seagreen];
  "IndexedAggregate(b:Integer,a:Type)" ->
    "IndexedAggregate(a:SetCategory,b:Type)"

  "IndexedAggregate(a:SetCategory,b:Type)" [color=lightblue];
  "IndexedAggregate(a:SetCategory,b:Type)" ->
    "HomogeneousAggregate(a:Type)"

  "Collection(a:Type)" [color=lightblue];
  "Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "..."

  "..." [color=lightblue];
}
```

FiniteLinearAggregate (FLAGG)

— FiniteLinearAggregate.input —

```

)set break resume
)sys rm -f FiniteLinearAggregate.output
)spool FiniteLinearAggregate.output
)set message test on
)set message auto off
)clear all

```

```

--S 1 of 1
)show FiniteLinearAggregate
--R
--R FiniteLinearAggregate(S: Type) is a category constructor
--R Abbreviation for FiniteLinearAggregate is FLAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FLAGG
--R
--R----- Operations -----
--R concat : List(%) -> %          concat : (%,%) -> %
--R concat : (S,%) -> %          concat : (%,S) -> %
--R construct : List(S) -> %      copy : % -> %
--R delete : (%,Integer) -> %    ?? : (%,Integer) -> S
--R elt : (%,Integer,S) -> S     empty : () -> %
--R empty? : % -> Boolean        entries : % -> List(S)
--R eq? : (%,%) -> Boolean       index? : (Integer,%) -> Boolean
--R indices : % -> List(Integer) insert : (%,%,Integer) -> %
--R insert : (S,%,Integer) -> %  map : (((S,S) -> S),%,%) -> %
--R map : ((S -> S),%) -> %      new : (NonNegativeInteger,S) -> %
--R qelt : (%,Integer) -> S     reverse : % -> %
--R sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?<? : (%,%) -> Boolean if S has ORDSET
--R ?<=? : (%,%) -> Boolean if S has ORDSET
--R ?=? : (%,%) -> Boolean if S has SETCAT
--R ?>? : (%,%) -> Boolean if S has ORDSET
--R ?>=? : (%,%) -> Boolean if S has ORDSET
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R copyInto! : (%,%,Integer) -> % if $ has shallowlyMutable
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R delete : (%,UniversalSegment(Integer)) -> %
--R ?? : (%,UniversalSegment(Integer)) -> %
--R entry? : (S,%) -> Boolean if $ has finiteAggregate and S has SETCAT
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (%,S) -> % if $ has shallowlyMutable
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R first : % -> S if Integer has ORDSET
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R max : (%,%) -> % if S has ORDSET
--R maxIndex : % -> Integer if Integer has ORDSET

```



```

--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R merge : (%,% ) -> % if S has ORDSET
--R merge : (((S,S) -> Boolean),%,%) -> %
--R min : (%,% ) -> % if S has ORDSET
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R position : (S,% ,Integer) -> Integer if S has SETCAT
--R position : (S,% ) -> Integer if S has SETCAT
--R position : ((S -> Boolean),%) -> Integer
--R qsetelt! : (% ,Integer,S) -> S if $ has shallowlyMutable
--R reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),% ,S) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),% ,S,S) -> S if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (S,% ) -> % if S has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R reverse! : % -> % if $ has shallowlyMutable
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R setelt : (% ,UniversalSegment(Integer),S) -> S if $ has shallowlyMutable
--R setelt : (% ,Integer,S) -> S if $ has shallowlyMutable
--R size? : (% ,NonNegativeInteger) -> Boolean
--R sort : % -> % if S has ORDSET
--R sort : (((S,S) -> Boolean),%) -> %
--R sort! : % -> % if S has ORDSET and $ has shallowlyMutable
--R sort! : (((S,S) -> Boolean),%) -> % if $ has shallowlyMutable
--R sorted? : % -> Boolean if S has ORDSET
--R sorted? : (((S,S) -> Boolean),%) -> Boolean
--R swap! : (% ,Integer,Integer) -> Void if $ has shallowlyMutable
--R ~=? : (% ,%) -> Boolean if S has SETCAT
--R
--E 1

```

```

)spool
)lisp (bye)

```

— FiniteLinearAggregate.help —

```

=====
FiniteLinearAggregate examples
=====

```

A finite linear aggregate is a linear aggregate of finite length.
The finite property of the aggregate adds several exports to the
list of exports from LinearAggregate such as reverse, sort, and so on.

See Also:

o `)show FiniteLinearAggregate`

See:

⇒ “OneDimensionalArrayAggregate” (A1AGG) [8](#) on page [739](#)

⇒ “ListAggregate” (LSAGG) [8](#) on page [714](#)

⇐ “LinearAggregate” (LNAGG) [6](#) on page [458](#)

⇐ “OrderedSet” (ORDSET) [4](#) on page [269](#)

Exports:

| | | | | |
|----------|-----------|---------|------------------|----------|
| any? | coerce | concat | construct | convert |
| copy | copyInto! | count | delete | elt |
| empty | empty? | entries | entry? | eq? |
| eval | every? | fill! | find | first |
| hash | index? | indices | insert | latex |
| less? | map | map! | max | maxIndex |
| member? | members | merge | min | minIndex |
| more? | new | parts | position | qelt |
| qsetelt! | reduce | remove | removeDuplicates | reverse |
| reverse! | sample | select | setelt | size? |
| sort | sort! | sorted? | swap! | #? |
| ?.? | ?<? | ?<=? | ?=? | ?>? |
| ?>=? | ?~=? | | | |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

Attributes Used:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are directly exported but not implemented:

```
copyInto! : (%,%,Integer) -> %
           if $ has shallowlyMutable
merge : (((S,S) -> Boolean),%,%) -> %
sorted? : (((S,S) -> Boolean),%) -> Boolean
position : (S,%,Integer) -> Integer if S has SETCAT
```

```

position : ((S -> Boolean),%) -> Integer
reverse! : % -> % if $ has shallowlyMutable
sort! : (((S,S) -> Boolean),%) -> %
        if $ has shallowlyMutable

```

These are implemented by this category:

```

merge : (%,%) -> % if S has ORDSET
position : (S,%) -> Integer if S has SETCAT
reverse : % -> %
sort : % -> % if S has ORDSET
sort : (((S,S) -> Boolean),%) -> %
sorted? : % -> Boolean if S has ORDSET
sort! : % -> %
        if S has ORDSET and $ has shallowlyMutable

```

These exports come from (p458) LinearAggregate(S:Type):

```

any? : ((S -> Boolean),%) -> Boolean
        if $ has finiteAggregate
coerce : % -> OutputForm if S has SETCAT
concat : List % -> %
concat : (%,%) -> %
concat : (S,%) -> %
concat : (%,S) -> %
construct : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
copy : % -> %
count : (S,%) -> NonNegativeInteger
        if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
        if $ has finiteAggregate
delete : (%,UniversalSegment Integer) -> %
delete : (%,Integer) -> %
elt : (%,Integer,S) -> S
empty : () -> %
empty? : % -> Boolean
entries : % -> List S
entry? : (S,%) -> Boolean
        if $ has finiteAggregate and S has SETCAT
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
        if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
        if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
        if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
        if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean

```

```

        if $ has finiteAggregate
fill! : (% , S) -> % if $ has shallowlyMutable
find : ((S -> Boolean), %) -> Union(S, "failed")
first : % -> S if Integer has ORDSET
hash : % -> SingleInteger if S has SETCAT
index? : (Integer, %) -> Boolean
indices : % -> List Integer
insert : (S, %, Integer) -> %
insert : (% , %, Integer) -> %
latex : % -> String if S has SETCAT
less? : (% , NonNegativeInteger) -> Boolean
map : (((S, S) -> S), %, %) -> %
map : ((S -> S), %) -> %
map! : ((S -> S), %) -> % if $ has shallowlyMutable
maxIndex : % -> Integer if Integer has ORDSET
member? : (S, %) -> Boolean
        if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
minIndex : % -> Integer if Integer has ORDSET
more? : (% , NonNegativeInteger) -> Boolean
new : (NonNegativeInteger, S) -> %
parts : % -> List S if $ has finiteAggregate
qelt : (% , Integer) -> S
qsetelt! : (% , Integer, S) -> S
        if $ has shallowlyMutable
reduce : (((S, S) -> S), %) -> S
        if $ has finiteAggregate
reduce : (((S, S) -> S), %, S) -> S
        if $ has finiteAggregate
reduce : (((S, S) -> S), %, S, S) -> S
        if S has SETCAT and $ has finiteAggregate
remove : ((S -> Boolean), %) -> %
        if $ has finiteAggregate
remove : (S, %) -> %
        if S has SETCAT and $ has finiteAggregate
removeDuplicates : % -> %
        if S has SETCAT and $ has finiteAggregate
sample : () -> %
select : ((S -> Boolean), %) -> %
        if $ has finiteAggregate
setelt : (% , Integer, S) -> S
        if $ has shallowlyMutable
setelt : (% , UniversalSegment Integer, S) -> S
        if $ has shallowlyMutable
size? : (% , NonNegativeInteger) -> Boolean
swap! : (% , Integer, Integer) -> Void
        if $ has shallowlyMutable
#? : % -> NonNegativeInteger
        if $ has finiteAggregate
?.? : (% , Integer) -> S

```

```

?.? : (% , UniversalSegment Integer) -> %
?~=? : (% , %) -> Boolean if S has SETCAT
?=? : (% , %) -> Boolean if S has SETCAT

```

These exports come from (p269) OrderedSet:

```

max : (% , %) -> % if S has ORDSET
min : (% , %) -> % if S has ORDSET
?<? : (% , %) -> Boolean if S has ORDSET
?<=? : (% , %) -> Boolean if S has ORDSET
?>? : (% , %) -> Boolean if S has ORDSET
?>=? : (% , %) -> Boolean if S has ORDSET

```

— category FLAGG FiniteLinearAggregate —

```

)abbrev category FLAGG FiniteLinearAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A finite linear aggregate is a linear aggregate of finite length.
++ The finite property of the aggregate adds several exports to the
++ list of exports from \spadtype{LinearAggregate} such as
++ \spadfun{reverse}, \spadfun{sort}, and so on.

FiniteLinearAggregate(S:Type): Category == LinearAggregate S with
  finiteAggregate
  merge: ((S,S)->Boolean,% , %) -> %
    ++ merge(p,a,b) returns an aggregate c which merges \axiom{a} and b.
    ++ The result is produced by examining each element x of \axiom{a}
    ++ and y of b successively. If \axiom{p(x,y)} is true, then x is
    ++ inserted into the result; otherwise y is inserted. If x is
    ++ chosen, the next element of \axiom{a} is examined, and so on.
    ++ When all the elements of one aggregate are examined, the
    ++ remaining elements of the other are appended.
    ++ For example, \axiom{merge(<,[1,3],[2,7,5])} returns
    ++ \axiom{[1,2,3,7,5]}.
  reverse: % -> %
    ++ reverse(a) returns a copy of \axiom{a} with elements
    ++ in reverse order.
  sort: ((S,S)->Boolean,% ) -> %
    ++ sort(p,a) returns a copy of \axiom{a} sorted using total ordering
    ++ predicate p.
  sorted?: ((S,S)->Boolean,% ) -> Boolean
    ++ sorted?(p,a) tests if \axiom{a} is sorted according to predicate p.
  position: (S->Boolean, % ) -> Integer
    ++ position(p,a) returns the index i of the first x in \axiom{a}
    ++ such that \axiom{p(x)} is true, and \axiom{minIndex(a) - 1}
    ++ if there is no such x.

```

```

if S has SetCategory then
  position: (S, %) -> Integer
  ++ position(x,a) returns the index i of the first occurrence of
  ++ x in a, and \axiom{minIndex(a) - 1} if there is no such x.
  position: (S,%,Integer) -> Integer
  ++ position(x,a,n) returns the index i of the first occurrence of
  ++ x in \axiom{a} where \axiom{i >= n}, and \axiom{minIndex(a) - 1}
  ++ if no such x is found.
if S has OrderedSet then
  OrderedSet
  merge: (%,% ) -> %
  ++ merge(u,v) merges u and v in ascending order.
  ++ Note that \axiom{merge(u,v) = merge(<=,u,v)}.
  sort: % -> %
  ++ sort(u) returns an u with elements in ascending order.
  ++ Note that \axiom{sort(u) = sort(<=,u)}.
  sorted?: % -> Boolean
  ++ sorted?(u) tests if the elements of u are in ascending order.
if % has shallowlyMutable then
  copyInto!: (%,% ,Integer) -> %
  ++ copyInto!(u,v,i) returns aggregate u containing a copy of
  ++ v inserted at element i.
  reverse!: % -> %
  ++ reverse!(u) returns u with its elements in reverse order.
  sort_!: ((S,S)->Boolean,%) -> %
  ++ sort!(p,u) returns u with its elements ordered by p.
  if S has OrderedSet then sort_!: % -> %
  ++ sort!(u) returns u with its elements in ascending order.
add
  if S has SetCategory then
    position(x:S, t:%) == position(x, t, minIndex t)

  if S has OrderedSet then
--   sorted? l == sorted?(_<$S, l)
    sorted? l == sorted?((x,y) +-> x < y or x = y, l)
    merge(x, y) == merge(_<$S, x, y)
    sort l == sort(_<$S, l)

  if % has shallowlyMutable then
    reverse x == reverse_! copy x
    sort(f, l) == sort_!(f, copy l)

  if S has OrderedSet then
    sort_! l == sort_!(_<$S, l)

```

```
"FLAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=FLAGG"];
"FLAGG" -> "LNAGG"
```

— FLAGG.dotfull —

```
"FiniteLinearAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FLAGG"];
"FiniteLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"
```

— FLAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FiniteLinearAggregate(a:Type)" [color=lightblue];
  "FiniteLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"
  "FiniteLinearAggregate(a:Type)" -> "OrderedSet"

  "OrderedSet" [color="#00EE00"];

  "LinearAggregate(a:Type)" [color=lightblue];
  "LinearAggregate(a:Type)" -> "IndexedAggregate(b:Integer,a:Type)"
  "LinearAggregate(a:Type)" -> "Collection(a:Type)"

  "IndexedAggregate(b:Integer,a:Type)" [color=seagreen];
  "IndexedAggregate(b:Integer,a:Type)" ->
    "IndexedAggregate(a:SetCategory,b:Type)"

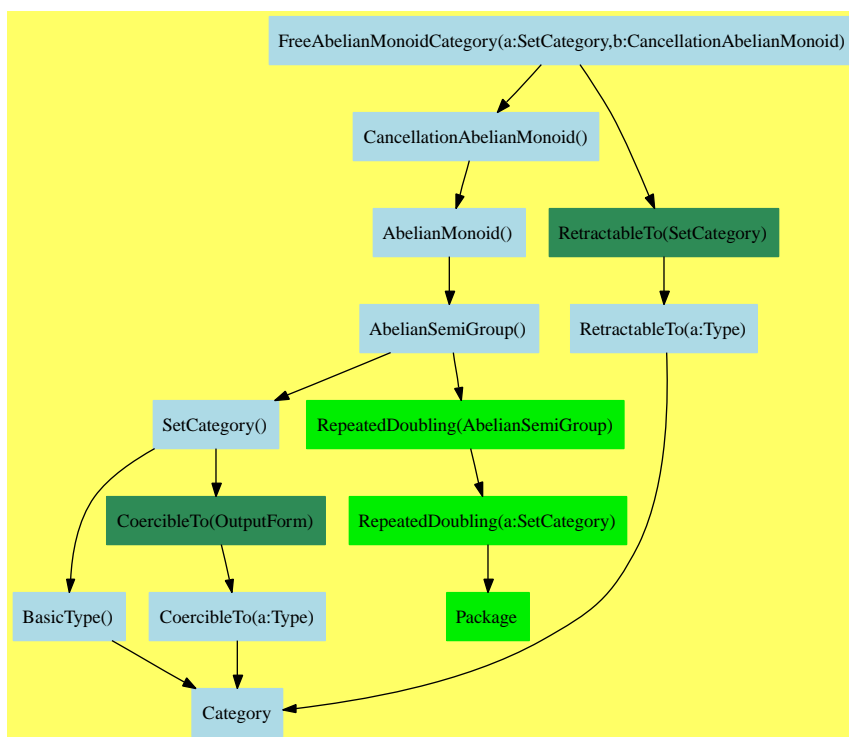
  "IndexedAggregate(a:SetCategory,b:Type)" [color=lightblue];
  "IndexedAggregate(a:SetCategory,b:Type)" ->
    "HomogeneousAggregate(a:Type)"

  "Collection(a:Type)" [color=lightblue];
  "Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "..."

  "..." [color=lightblue];
}
```

FreeAbelianMonoidCategory (FAMONC)



— FreeAbelianMonoidCategory.input —

```

)set break resume
)sys rm -f FreeAbelianMonoidCategory.output
)spool FreeAbelianMonoidCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FreeAbelianMonoidCategory
--R
--R FreeAbelianMonoidCategory(S: SetCategory,E: CancellationAbelianMonoid) is a category constructor
--R Abbreviation for FreeAbelianMonoidCategory is FAMONC
--R This constructor is exposed in this frame.

```



```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FAMONC
--R
--R----- Operations -----
--R ?? : (E,S) -> %           ?? : (PositiveInteger,%) -> %
--R ?? : (S,%) -> %           ?? : (%,%) -> %
--R ?? : (%,%) -> Boolean      0 : () -> %
--R coefficient : (S,%) -> E    coerce : S -> %
--R coerce : % -> OutputForm    hash : % -> SingleInteger
--R latex : % -> String         mapCoef : ((E -> E),%) -> %
--R mapGen : ((S -> S),%) -> %  nthCoef : (%,Integer) -> E
--R nthFactor : (%,Integer) -> S retract : % -> S
--R sample : () -> %           size : % -> NonNegativeInteger
--R zero? : % -> Boolean       ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R highCommonTerms : (%,%) -> % if E has OAMON
--R retractIfCan : % -> Union(S,"failed")
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R terms : % -> List(Record(gen: S,exp: E))
--R
--E 1

)spool
)lisp (bye)

```

— FreeAbelianMonoidCategory.help —

FreeAbelianMonoidCategory examples

A free abelian monoid on a set S is the monoid of finite sums of the form $\text{reduce}(+, [n_i * s_i])$ where the s_i 's are in S , and the n_i 's are in a given abelian monoid. The operation is commutative.

See Also:

o)show FreeAbelianMonoidCategory

See:

⇐ “CancellationAbelianMonoid” (CABMON) [6](#) on page [434](#)

⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

Exports:

| | | | | |
|---------|--------------|--------|---------|-----------------|
| 0 | coefficient | coerce | hash | highCommonTerms |
| latex | mapCoef | mapGen | nthCoef | nthFactor |
| retract | retractIfCan | sample | size | subtractIfCan |
| terms | zero? | ?*? | ?+? | ?=? |
| ?~=? | | | | |

These are directly exported but not implemented:

```

coefficient : (S,%) -> E
highCommonTerms : (%,%) -> % if E has OAMON
mapCoef : ((E -> E),%) -> %
mapGen : ((S -> S),%) -> %
nthCoef : (%,Integer) -> E
nthFactor : (%,Integer) -> S
size : % -> NonNegativeInteger
terms : % -> List Record(gen: S,exp: E)
?? : (S,%) -> %
?? : (E,S) -> %

```

These exports come from (p434) CancellationAbelianMonoid():

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?? : (PositiveInteger,%) -> %
?? : (%,%) -> %
?? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?? : (NonNegativeInteger,%) -> %

```

These exports come from (p95) RetractableTo(SetCategory):

```

coerce : S -> %
retract : % -> S
retractIfCan : % -> Union(S, "failed")

```

— category FAMONC FreeAbelianMonoidCategory —

```

)abbrev category FAMONC FreeAbelianMonoidCategory
++ Category for free abelian monoid on any set of generators
++ Author: Manuel Bronstein
++ Date Created: November 1989
++ Date Last Updated: 6 June 1991
++ Description:

```

++ A free abelian monoid on a set S is the monoid of finite sums of
 ++ the form $\text{\spad{reduce(+,[ni * si])}}$ where the si 's are in S , and the ni 's
 ++ are in a given abelian monoid. The operation is commutative.

```
FreeAbelianMonoidCategory(S: SetCategory, E:CancellationAbelianMonoid): _
  Category == Join(CancellationAbelianMonoid, RetractableTo S) with
    "+"      : (S, $) -> $
    ++ s + x returns the sum of s and x.
    "*"      : (E, S) -> $
    ++ e * s returns e times s.
    size     : $ -> NonNegativeInteger
    ++ size(x) returns the number of terms in x.
    ++ mapGen(f, a1\^e1 ... an\^en) returns
    ++ \spad{f(a1)\^e1 ... f(an)\^en}.
    terms    : $ -> List Record(gen: S, exp: E)
    ++ terms(e1 a1 + ... + en an) returns \spad{[[a1, e1],..., [an, en]]}.
    nthCoef  : ($, Integer) -> E
    ++ nthCoef(x, n) returns the coefficient of the nth term of x.
    nthFactor : ($, Integer) -> S
    ++ nthFactor(x, n) returns the factor of the nth term of x.
    coefficient: (S, $) -> E
    ++ coefficient(s, e1 a1 + ... + en an) returns ei such that
    ++ ai = s, or 0 if s is not one of the ai's.
    mapCoef  : (E -> E, $) -> $
    ++ mapCoef(f, e1 a1 +...+ en an) returns
    ++ \spad{f(e1) a1 +...+ f(en) an}.
    mapGen   : (S -> S, $) -> $
    ++ mapGen(f, e1 a1 +...+ en an) returns
    ++ \spad{e1 f(a1) +...+ en f(an)}.
    if E has OrderedAbelianMonoid then
      highCommonTerms: ($, $) -> $
      ++ highCommonTerms(e1 a1 + ... + en an, f1 b1 + ... + fm bm)
      ++ returns \spad{reduce(+,[max(ei, fi) ci])}
      ++ where ci ranges in the intersection
      ++ of \spad{{a1,...,an}} and \spad{{b1,...,bm}}.
```

— FAMONC.dotabb —

```
"FAMONC"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FAMONC"];
"FAMONC" -> "CABMON"
"FAMONC" -> "RETRACT"
```

— FAMONC.dotfull —

```

"FreeAbelianMonoidCategory(a:SetCategory,b:CancellationAbelianMonoid)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FAMONC"];
"FreeAbelianMonoidCategory(a:SetCategory,b:CancellationAbelianMonoid)" ->
  "CancellationAbelianMonoid()"
"FreeAbelianMonoidCategory(a:SetCategory,b:CancellationAbelianMonoid)" ->
  "RetractableTo(SetCategory)"

```

— FAMONC.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FreeAbelianMonoidCategory(a:SetCategory,b:CancellationAbelianMonoid)"
    [color=lightblue];
  "FreeAbelianMonoidCategory(a:SetCategory,b:CancellationAbelianMonoid)" ->
    "CancellationAbelianMonoid()"
  "FreeAbelianMonoidCategory(a:SetCategory,b:CancellationAbelianMonoid)" ->
    "RetractableTo(SetCategory)"

  "RetractableTo(SetCategory)" [color=seagreen];
  "RetractableTo(SetCategory)" -> "RetractableTo(a:Type)"

  "RetractableTo(a:Type)" [color=lightblue];
  "RetractableTo(a:Type)" -> "Category"

  "CancellationAbelianMonoid()" [color=lightblue];
  "CancellationAbelianMonoid()" -> "AbelianMonoid()"

  "AbelianMonoid()" [color=lightblue];
  "AbelianMonoid()" -> "AbelianSemiGroup()"

  "AbelianSemiGroup()" [color=lightblue];
  "AbelianSemiGroup()" -> "SetCategory()"
  "AbelianSemiGroup()" -> "RepeatedDoubling(AbelianSemiGroup)"

  "SetCategory()" [color=lightblue];
  "SetCategory()" -> "BasicType()"
  "SetCategory()" -> "CoercibleTo(OutputForm)"

  "BasicType()" [color=lightblue];
  "BasicType()" -> "Category"

```

```
"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" ->
  "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

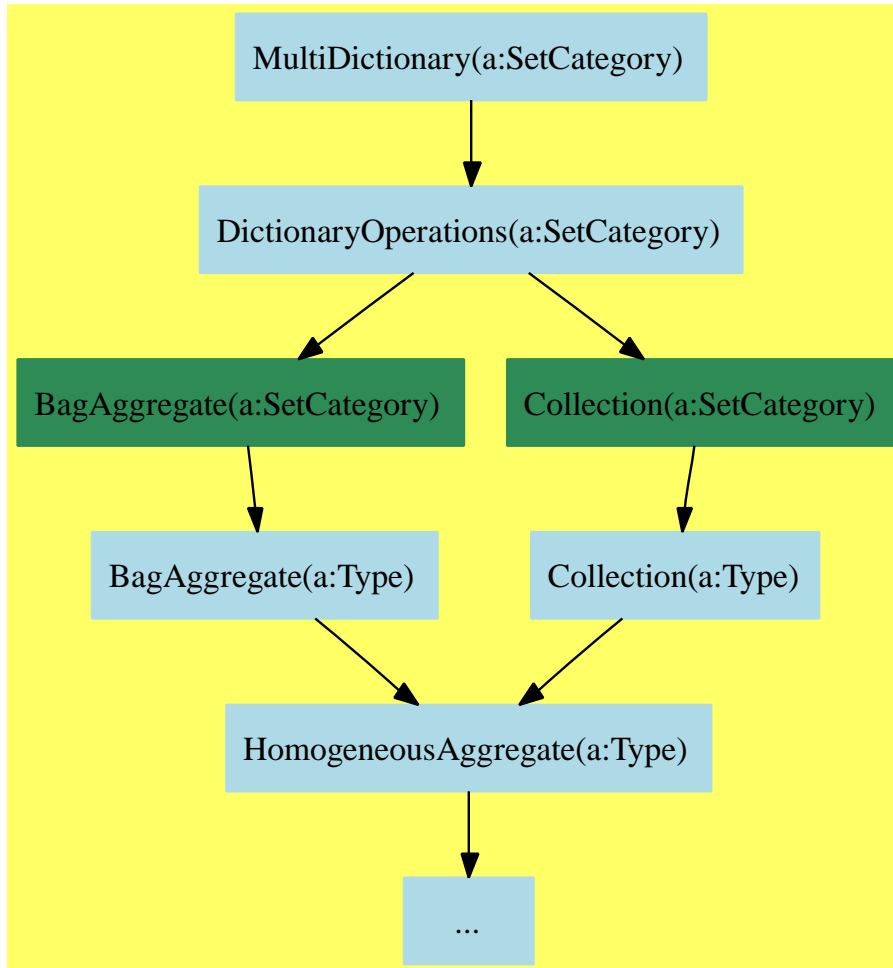
"RepeatedDoubling(AbelianSemiGroup)" [color="#00EE00"];
"RepeatedDoubling(AbelianSemiGroup)" -> "RepeatedDoubling(a:SetCategory)"

"RepeatedDoubling(a:SetCategory)" [color="#00EE00"];
"RepeatedDoubling(a:SetCategory)" -> "Package"

"Package" [color="#00EE00"];

"Category" [color=lightblue];
}
```

MultiDictionary (MDAGG)



— MultiDictionary.input —

```

)set break resume
)sys rm -f MultiDictionary.output
)spool MultiDictionary.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show MultiDictionary
--R

```

```

--R MultiDictionary(S: SetCategory) is a category constructor
--R Abbreviation for MultiDictionary is MDAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MDAGG
--R
--R----- Operations -----
--R bag : List(S) -> %                construct : List(S) -> %
--R copy : % -> %                    dictionary : List(S) -> %
--R dictionary : () -> %              empty : () -> %
--R empty? : % -> Boolean              eq? : (%,% ) -> Boolean
--R extract! : % -> S                  insert! : (S,% ) -> %
--R inspect : % -> S                  map : ((S -> S),%) -> %
--R removeDuplicates! : % -> %         sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (%,% ) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : (S,% ) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R duplicates : % -> List(Record(entry: S,count: NonNegativeInteger))
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R hash : % -> SingleInteger if S has SETCAT
--R insert! : (S,% ,NonNegativeInteger) -> %
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,% ) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),% ,S) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),% ,S,S) -> S if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (S,% ) -> % if S has SETCAT and $ has finiteAggregate
--R remove! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove! : (S,% ) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R select! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (% ,NonNegativeInteger) -> Boolean
--R ?~=? : (%,% ) -> Boolean if S has SETCAT
--R
--E 1

```

```
)spool
)lisp (bye)
```

— MultiDictionary.help —

=====

MultiDictionary examples

=====

A multi-dictionary is a dictionary which may contain duplicates.
 As for any dictionary, its size is assumed large so that
 copying (non-destructive) operations are generally to be avoided.

See Also:

o)show MultiDictionary

See:

⇒ “MultisetAggregate” (MSETAGG) [8](#) on page [728](#)

⇐ “DictionaryOperations” (DIOPS) [6](#) on page [439](#)

Exports:

| | | | | |
|------------------|-------------------|------------|------------|----------|
| any? | bag | coerce | construct | convert |
| copy | count | dictionary | duplicates | empty |
| empty? | eq? | eval | every? | extract! |
| find | hash | insert! | inspect | latex |
| less? | map | map! | member? | members |
| more? | parts | reduce | remove | remove! |
| removeDuplicates | removeDuplicates! | sample | select | select! |
| size? | #? | ?=? | ?~=? | |

Attributes exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

These are directly exported but not implemented:

```
insert! : (S,%,NonNegativeInteger) -> %
```



```

removeDuplicates! : % -> %
duplicates : % -> List Record(entry:S,count:NonNegativeInteger)

```

These exports come from (p439) DictionaryOperations(S:SetCategory):

```

any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
bag : List S -> %
coerce : % -> OutputForm if S has SETCAT
construct : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
copy : % -> %
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
dictionary : () -> %
dictionary : List S -> %
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
extract! : % -> S
find : ((S -> Boolean),%) -> Union(S,"failed")
hash : % -> SingleInteger if S has SETCAT
insert! : (S,%) -> %
inspect : % -> S
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
      if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S if $ has finiteAggregate
reduce : (((S,S) -> S),%,S,S) -> S
      if S has SETCAT and $ has finiteAggregate
remove : ((S -> Boolean),%) -> % if $ has finiteAggregate

```

```

remove : (S,%) -> %
      if S has SETCAT and $ has finiteAggregate
removeDuplicates : % -> %
      if S has SETCAT and $ has finiteAggregate
remove! : ((S -> Boolean),%) -> % if $ has finiteAggregate
remove! : (S,%) -> % if $ has finiteAggregate
select : ((S -> Boolean),%) -> % if $ has finiteAggregate
sample : () -> %
select! : ((S -> Boolean),%) -> % if $ has finiteAggregate
size? : (%,NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger
      if $ has finiteAggregate
?? : (%,%) -> Boolean if S has SETCAT
?~=? : (%,%) -> Boolean if S has SETCAT

```

— category MDAGG MultiDictionary —

```

)abbrev category MDAGG MultiDictionary
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A multi-dictionary is a dictionary which may contain duplicates.
++ As for any dictionary, its size is assumed large so that
++ copying (non-destructive) operations are generally to be avoided.

MultiDictionary(S:SetCategory): Category == DictionaryOperations S with
-- count: (S,%) -> NonNegativeInteger          ++ multiplicity count
  insert_!: (S,%,NonNegativeInteger) -> %
    ++ insert!(x,d,n) destructively inserts n copies of x into dictionary d.
-- remove_!: (S,%,NonNegativeInteger) -> %
--   ++ remove!(x,d,n) destructively removes (up to) n copies of x from
--   ++ dictionary d.
  removeDuplicates_!: % -> %
    ++ removeDuplicates!(d) destructively removes any duplicate values
    ++ in dictionary d.
  duplicates: % -> List Record(entry:S,count:NonNegativeInteger)
    ++ duplicates(d) returns a list of values which have duplicates in d
--   ++ duplicates(d) returns a list of          ++ duplicates iterator
-- to become duplicates: % -> Iterator(D,D)

```

— MDAGG.dotabb —

```

"MDAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=MDAGG"];
"MDAGG" -> "DIOPS"

```

— MDAGG.dotfull —

```
"MultiDictionary(a:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MDAGG"];
"MultiDictionary(a:SetCategory)" -> "DictionaryOperations(a:SetCategory)"
```

— MDAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "MultiDictionary(a:SetCategory)" [color=lightblue];
  "MultiDictionary(a:SetCategory)" -> "DictionaryOperations(a:SetCategory)"

  "DictionaryOperations(a:SetCategory)" [color=lightblue];
  "DictionaryOperations(a:SetCategory)" -> "BagAggregate(a:SetCategory)"
  "DictionaryOperations(a:SetCategory)" -> "Collection(a:SetCategory)"

  "BagAggregate(a:SetCategory)" [color=seagreen];
  "BagAggregate(a:SetCategory)" -> "BagAggregate(a:Type)"

  "BagAggregate(a:Type)" [color=lightblue];
  "BagAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

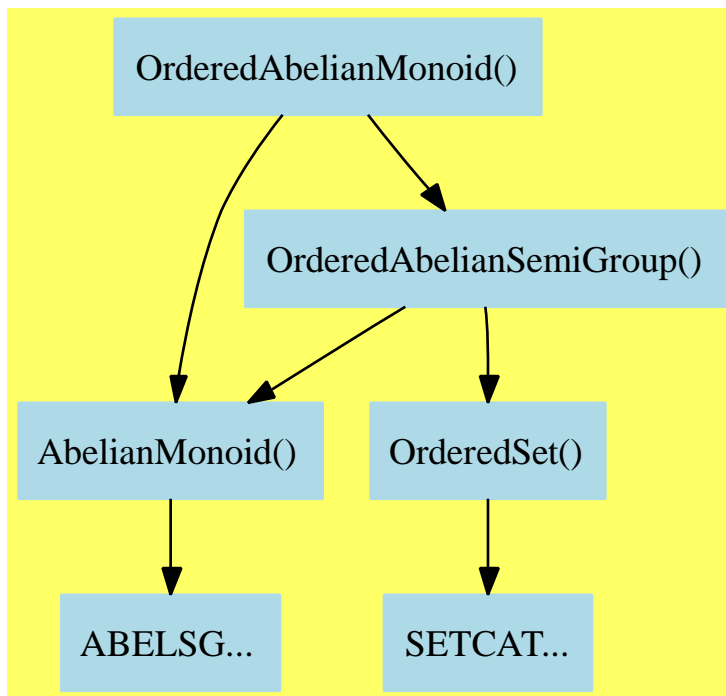
  "Collection(a:SetCategory)" [color=seagreen];
  "Collection(a:SetCategory)" -> "Collection(a:Type)"

  "Collection(a:Type)" [color=lightblue];
  "Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"

  "HomogeneousAggregate(a:Type)" [color=lightblue];
  "HomogeneousAggregate(a:Type)" -> "...";

  "... [color=lightblue];
}
```

OrderedAbelianMonoid (OAMON)



— OrderedAbelianMonoid.input —

```

)set break resume
)sys rm -f OrderedAbelianMonoid.output
)spool OrderedAbelianMonoid.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrderedAbelianMonoid
--R OrderedAbelianMonoid is a category constructor
--R Abbreviation for OrderedAbelianMonoid is OAMON
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OAMON
--R
--R----- Operations -----
--R ?? : (PositiveInteger,%) -> %      ?? : (%,%) -> %
--R ?? : (%,%) -> Boolean             ?<=? : (%,%) -> Boolean
--R ?? : (%,%) -> Boolean             ?>? : (%,%) -> Boolean
--R ?>=? : (%,%) -> Boolean           0 : () -> %

```

```

--R coerce : % -> OutputForm          hash : % -> SingleInteger
--R latex : % -> String                max : (%,% ) -> %
--R min : (%,% ) -> %                  sample : () -> %
--R zero? : % -> Boolean                ?~=? : (%,% ) -> Boolean
--R ?*? : (NonNegativeInteger,% ) -> %
--R
--E 1

```

```

)spool
)lisp (bye)

```

— OrderedAbelianMonoid.help —

```

=====
OrderedAbelianMonoid examples
=====

```

Ordered sets which are also abelian monoids, such that the addition preserves the ordering.

See Also:
o)show OrderedAbelianMonoid

See:

⇒ “OrderedCancellationAbelianMonoid” (OCAMON) [8](#) on page [751](#)
 ⇐ “AbelianMonoid” (ABELMON) [5](#) on page [321](#)
 ⇐ “OrderedAbelianSemiGroup” (OASGP) [6](#) on page [511](#)

Exports:

| | | | | |
|------|--------|-------|-------|------|
| 0 | coerce | hash | latex | max |
| min | sample | zero? | ?*? | ?+? |
| ?<? | ?<=? | ?=? | ?>? | ?>=? |
| ?~=? | | | | |

These exports come from ([p511](#)) OrderedAbelianSemiGroup():

```

coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
max : (%,% ) -> %
min : (%,% ) -> %
?<? : (%,% ) -> Boolean

```

```
?<=? : (%,%) -> Boolean
?= ? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
```

These exports come from (p321) `AbelianMonoid()`:

```
0 : () -> %
sample : () -> %
zero? : % -> Boolean
?*? : (PositiveInteger,%) -> %
?+? : (%,%) -> %
?*? : (NonNegativeInteger,%) -> %
```

— category OAMON OrderedAbelianMonoid —

```
)abbrev category OAMON OrderedAbelianMonoid
++ Description:
++ Ordered sets which are also abelian monoids, such that the addition
++ preserves the ordering.
```

```
OrderedAbelianMonoid(): Category ==
  Join(OrderedAbelianSemiGroup, AbelianMonoid)
```

— OAMON.dotabb —

```
"OAMON" [color=lightblue,href="bookvol10.2.pdf#nameddest=OAMON"];
"OAMON" -> "OASGP"
"OAMON" -> "ABELMON"
```

— OAMON.dotfull —

```
"OrderedAbelianMonoid()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OAMON"];
"OrderedAbelianMonoid()" -> "OrderedAbelianSemiGroup()"
"OrderedAbelianMonoid()" -> "AbelianMonoid()"
```

— OAMON.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrderedAbelianMonoid()" [color=lightblue];
  "OrderedAbelianMonoid()" -> "OrderedAbelianSemiGroup()"
  "OrderedAbelianMonoid()" -> "AbelianMonoid()"

  "OrderedAbelianSemiGroup()" [color=lightblue];
  "OrderedAbelianSemiGroup()" -> "OrderedSet()"
  "OrderedAbelianSemiGroup()" -> "AbelianMonoid()"

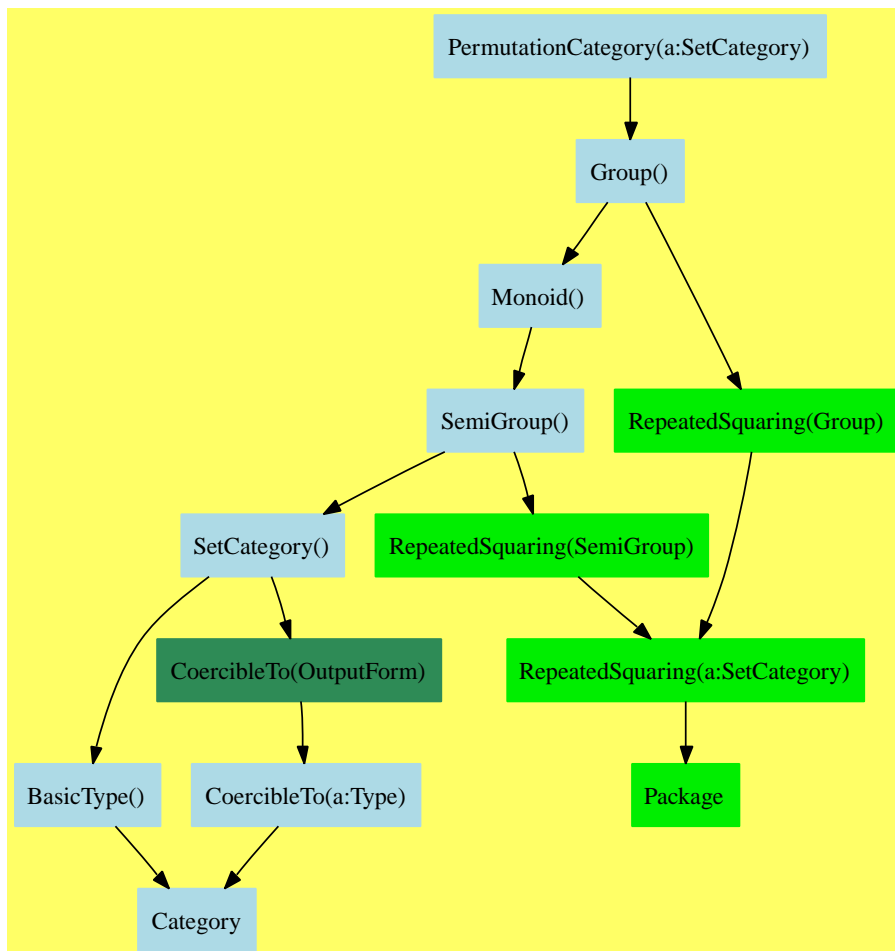
  "OrderedSet()" [color=lightblue];
  "OrderedSet()" -> "SETCAT..."

  "AbelianMonoid()" [color=lightblue];
  "AbelianMonoid()" -> "ABELSG..."

  "SETCAT..." [color=lightblue];
  "ABELSG..." [color=lightblue];
}

```

PermutationCategory (PERMCAT)



— PermutationCategory.input —

```

)set break resume
)sys rm -f PermutationCategory.output
)spool PermutationCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PermutationCategory
--R

```



```

--R PermutationCategory(S: SetCategory) is a category constructor
--R Abbreviation for PermutationCategory is PERMCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PERMCAT
--R
--R----- Operations -----
--R ?? : (%,%) -> %                ??? : (%,Integer) -> %
--R ??? : (%,PositiveInteger) -> %  ?/? : (%,%) -> %
--R ?<? : (%,%) -> Boolean          ?=? : (%,%) -> Boolean
--R 1 : () -> %                    ?? : (%,Integer) -> %
--R ?? : (%,PositiveInteger) -> %   coerce : % -> OutputForm
--R commutator : (%,%) -> %         conjugate : (%,%) -> %
--R cycle : List(S) -> %           cycles : List(List(S)) -> %
--R ?.? : (%,S) -> S               eval : (%,S) -> S
--R hash : % -> SingleInteger      inv : % -> %
--R latex : % -> String            one? : % -> Boolean
--R orbit : (%,S) -> Set(S)        recip : % -> Union(%, "failed")
--R sample : () -> %              ?~=? : (%,%) -> Boolean
--R ??? : (%,NonNegativeInteger) -> %
--R ?<=? : (%,%) -> Boolean if S has ORDSET or S has FINITE
--R ?>? : (%,%) -> Boolean if S has ORDSET or S has FINITE
--R ?>=? : (%,%) -> Boolean if S has ORDSET or S has FINITE
--R ?? : (%,NonNegativeInteger) -> %
--R max : (%,%) -> % if S has ORDSET or S has FINITE
--R min : (%,%) -> % if S has ORDSET or S has FINITE
--R
--E 1

)spool
)lisp (bye)

```

— PermutationCategory.help —

=====
PermutationCategory examples
=====

PermutationCategory provides a categorial environment for subgroups
of bijections of a set (i.e. permutations)

See Also:
o)show PermutationCategory

See:

⇐ “Group” (GROUP) 6 on page 452

Exports:

| | | | | |
|--------|--------|------------|-----------|-------|
| 1 | coerce | commutator | conjugate | cycle |
| cycles | eval | hash | inv | latex |
| max | min | one? | orbit | recip |
| sample | ?^? | ?..? | ?~=? | ?**? |
| ?<? | ?<=? | ?>? | ?>=? | ?*? |
| ?/? | ?=? | | | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.

These are directly exported but not implemented:

```
cycle : List S -> %
cycles : List List S -> %
eval : (%,S) -> S
orbit : (%,S) -> Set S
?<? : (%,%) -> Boolean
?..? : (%,S) -> S
```

These exports come from (p452) Group():

```
1 : () -> %
coerce : % -> OutputForm
commutator : (%,%) -> %
conjugate : (%,%) -> %
hash : % -> SingleInteger
inv : % -> %
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
?/? : (%,%) -> %
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
?^? : (%, Integer) -> %
?*? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
***? : (%, NonNegativeInteger) -> %
***? : (%, PositiveInteger) -> %
***? : (%, Integer) -> %
```

These exports come from (p269) OrderedSet():

```

max : (%,%) -> % if S has ORDSET or S has FINITE
min : (%,%) -> % if S has ORDSET or S has FINITE
?>? : (%,%) -> Boolean if S has ORDSET or S has FINITE
?<=? : (%,%) -> Boolean if S has ORDSET or S has FINITE
?>=? : (%,%) -> Boolean if S has ORDSET or S has FINITE

```

— category PERMCAT PermutationCategory —

```

)abbrev category PERMCAT PermutationCategory
++ Authors: Holger Gollan, Johannes Grabmeier, Gerhard Schneider
++ Date Created: 27 July 1989
++ Date Last Updated: 29 March 1990
++ Description:
++ PermutationCategory provides a categorial environment
++ for subgroups of bijections of a set (that is, permutations)

PermutationCategory(S:SetCategory): Category == Group with

  cycle   : List S      -> %
    ++ cycle(ls) coerces a cycle ls, that is, a list with not
    ++ repetitions to a permutation, which maps ls.i to
    ++ ls.i+1, indices modulo the length of the list.
    ++ Error: if repetitions occur.

  cycles  : List List S -> %
    ++ cycles(lls) coerces a list list of cycles lls
    ++ to a permutation, each cycle being a list with not
    ++ repetitions, is coerced to the permutation, which maps
    ++ ls.i to ls.i+1, indices modulo the length of the list,
    ++ then these permutations are multiplied.
    ++ Error: if repetitions occur in one cycle.

  eval    : (%,S)        -> S
    ++ eval(p, el) returns the image of el under the
    ++ permutation p.

  elt     : (%,S)        -> S
    ++ elt(p, el) returns the image of el under the
    ++ permutation p.

  orbit   : (%,S)        -> Set S
    ++ orbit(p, el) returns the orbit of el under the
    ++ permutation p, that is, the set which is given by applications of
    ++ the powers of p to el.

  "<" : (%,%)            -> Boolean
    ++ p < q is an order relation on permutations.
    ++ Note that this order is only total if and only if S is totally ordered
    ++ or S is finite.

```

```

if S has OrderedSet then OrderedSet

if S has Finite then OrderedSet

-----

— PERMCAT.dotabb —

"PERMCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PERMCAT"];
"PERMCAT" -> "GROUP"

-----

— PERMCAT.dotfull —

"PermutationCategory(a:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PERMCAT"];
"PermutationCategory(a:SetCategory)" -> "Group()"

-----

— PERMCAT.dotpic —

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PermutationCategory(a:SetCategory)" [color=lightblue];
  "PermutationCategory(a:SetCategory)" -> "Group()"

  "Group()" [color=lightblue];
  "Group()" -> "Monoid()"
  "Group()" -> "RepeatedSquaring(Group)"

  "Monoid()" [color=lightblue];
  "Monoid()" -> "SemiGroup()"

  "SemiGroup()" [color=lightblue];
  "SemiGroup()" -> "SetCategory()"
  "SemiGroup()" -> "RepeatedSquaring(SemiGroup)"

  "SetCategory()" [color=lightblue];

```

```

"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"RepeatedSquaring(Group)" [color="#00EE00"];
"RepeatedSquaring(Group)" -> "RepeatedSquaring(a:SetCategory)"

"RepeatedSquaring(SemiGroup)" [color="#00EE00"];
"RepeatedSquaring(SemiGroup)" -> "RepeatedSquaring(a:SetCategory)"

"RepeatedSquaring(a:SetCategory)" [color="#00EE00"];
"RepeatedSquaring(a:SetCategory)" -> "Package"

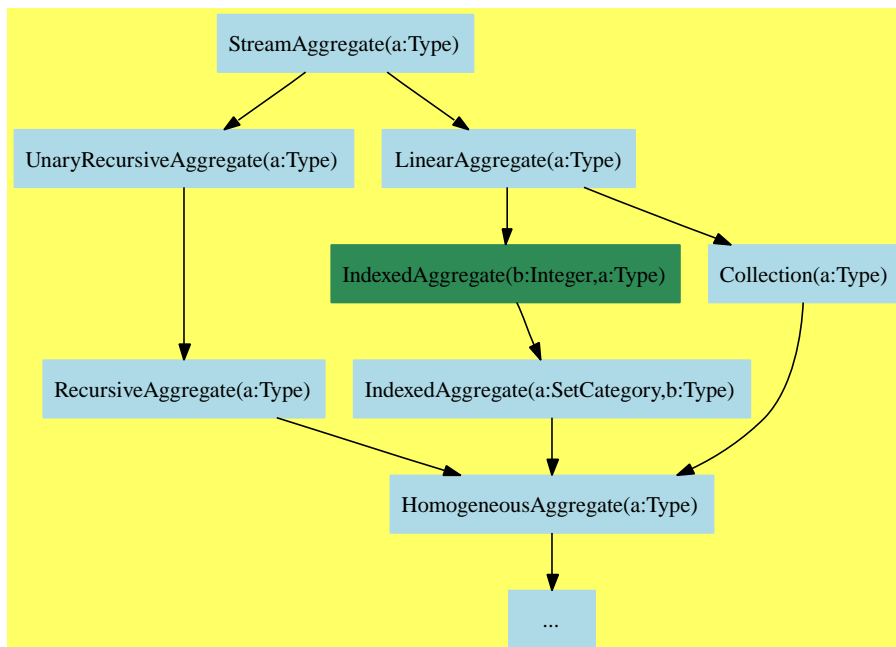
"Package" [color="#00EE00"];

"Category" [color=lightblue];

}

```

StreamAggregate (STAGG)



— StreamAggregate.input —

```

)set break resume
)sys rm -f StreamAggregate.output
)spool StreamAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show StreamAggregate
--R
--R StreamAggregate(S: Type) is a category constructor
--R Abbreviation for StreamAggregate is STAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for STAGG
--R
--R----- Operations -----
--R children : % -> List(%)
--R concat : List(%) -> %
--R concat : (%,%) -> %
--R copy : % -> %
--R cycleTail : % -> %
--R concat : (%,S) -> %
--R concat : (S,%) -> %
--R construct : List(S) -> %
--R cycleEntry : % -> %
--R cyclic? : % -> Boolean

```

```

--R delete : (%,Integer) -> %
--R elt : (%,Integer,S) -> S
--R ?.last : (% ,last) -> S
--R ?.first : (% ,first) -> S
--R empty : () -> %
--R entries : % -> List(S)
--R explicitlyFinite? : % -> Boolean
--R index? : (Integer,%) -> Boolean
--R insert : (S,%,Integer) -> %
--R last : % -> S
--R leaves : % -> List(S)
--R map : ((S -> S),%) -> %
--R nodes : % -> List(%)
--R qelt : (% ,Integer) -> S
--R sample : () -> %
--R tail : % -> %
--R value : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R !=? : (% ,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R child? : (% ,%) -> Boolean if S has SETCAT
--R coerce : % -> OutputForm if S has SETCAT
--R concat! : (% ,S) -> % if $ has shallowlyMutable
--R concat! : (% ,%) -> % if $ has shallowlyMutable
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R cycleLength : % -> NonNegativeInteger
--R cycleSplit! : % -> % if $ has shallowlyMutable
--R delete : (% ,UniversalSegment(Integer)) -> %
--R ?.? : (% ,UniversalSegment(Integer)) -> %
--R entry? : (S,%) -> Boolean if $ has finiteAggregate and S has SETCAT
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (% ,S) -> % if $ has shallowlyMutable
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R first : (% ,NonNegativeInteger) -> %
--R hash : % -> SingleInteger if S has SETCAT
--R last : (% ,NonNegativeInteger) -> %
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (% ,NonNegativeInteger) -> Boolean
distance : (% ,%) -> Integer
?.? : (% ,Integer) -> S
?.rest : (% ,rest) -> %
?.value : (% ,value) -> S
empty? : % -> Boolean
eq? : (% ,%) -> Boolean
first : % -> S
indices : % -> List(Integer)
insert : (% ,%,Integer) -> %
leaf? : % -> Boolean
map : ((S,S) -> S),%,%) -> %
new : (NonNegativeInteger,S) -> %
possiblyInfinite? : % -> Boolean
rest : % -> %
second : % -> S
third : % -> S

```

```

--R node? : (%,% ) -> Boolean if S has SETCAT
--R parts : % -> List(S) if $ has finiteAggregate
--R qsetelt! : (%,Integer,S) -> S if $ has shallowlyMutable
--R reduce : (((S,S) -> S),%,S,S) -> S if S has SETCAT and $ has finiteAggregate
--R reduce : (((S,S) -> S),%,S) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
--R remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R rest : (% ,NonNegativeInteger) -> %
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R setchildren! : (% ,List(%)) -> % if $ has shallowlyMutable
--R setelt : (% ,Integer,S) -> S if $ has shallowlyMutable
--R setelt : (% ,UniversalSegment(Integer),S) -> S if $ has shallowlyMutable
--R setelt : (% ,last,S) -> S if $ has shallowlyMutable
--R setelt : (% ,rest,%) -> % if $ has shallowlyMutable
--R setelt : (% ,first,S) -> S if $ has shallowlyMutable
--R setelt : (% ,value,S) -> S if $ has shallowlyMutable
--R setfirst! : (% ,S) -> S if $ has shallowlyMutable
--R setlast! : (% ,S) -> S if $ has shallowlyMutable
--R setrest! : (% ,%) -> % if $ has shallowlyMutable
--R setvalue! : (% ,S) -> S if $ has shallowlyMutable
--R size? : (% ,NonNegativeInteger) -> Boolean
--R split! : (% ,Integer) -> % if $ has shallowlyMutable
--R swap! : (% ,Integer,Integer) -> Void if $ has shallowlyMutable
--R ?~=? : (% ,%) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— StreamAggregate.help —

=====

StreamAggregate examples

=====

A stream aggregate is a linear aggregate which possibly has an infinite number of elements. A basic domain constructor which builds stream aggregates is Stream. From streams, a number of infinite structures such power series can be built. A stream aggregate may also be infinite since it may be cyclic. For example, see DecimalExpansion.

See Also:

- o)show StreamAggregate
- o)show DecimalExpansion

See:

- ⇒ “LazyStreamAggregate” (LZSTAGG) [8](#) on page [691](#)
 ⇐ “LinearAggregate” (LNAGG) [6](#) on page [458](#)
 ⇐ “UnaryRecursiveAggregate” (URAGG) [6](#) on page [560](#)

Exports:

| | | | | |
|-------------------|-------------|-------------|-----------|-------------------|
| any? | children | child? | coerce | concat |
| concat! | construct | convert | copy | count |
| cycleEntry | cycleLength | cycleSplit! | cycleTail | cyclic? |
| delete | distance | elt | empty | empty? |
| entries | entry? | eq? | eval | every? |
| explicitlyFinite? | fill! | find | first | hash |
| index? | indices | insert | last | latex |
| leaf? | leaves | less? | map | map! |
| maxIndex | member? | members | minIndex | more? |
| new | nodes | node? | parts | possiblyInfinite? |
| qelt | qsetelt! | reduce | remove | removeDuplicates |
| rest | sample | second | select | setchildren! |
| setelt | setfirst! | setlast! | setrest! | setvalue! |
| size? | split! | swap! | tail | third |
| value | #? | ?=? | ?.? | ?.first |
| ?.last | ?.rest | ?.value | ?~=? | |

Attributes exported:

- **nil**

Attributes Used:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.

These are implemented by this category:

```
concat : (%,%) -> %
concat : List % -> %
concat! : (%,%) -> % if $ has shallowlyMutable
fill! : (%,S) -> % if $ has shallowlyMutable
first : (%,NonNegativeInteger) -> %
explicitlyFinite? : % -> Boolean
map! : ((S -> S),%) -> % if $ has shallowlyMutable
```

```

possiblyInfinite? : % -> Boolean
setelt : (%,Integer,S) -> S if $ has shallowlyMutable
setelt : (%,UniversalSegment Integer,S) -> S
        if $ has shallowlyMutable
?..? : (%,Integer) -> S
?..? : (%,UniversalSegment Integer) -> %

```

These exports come from (p560) `UnaryRecursiveAggregate(S:Type)`:

```

any? : ((S -> Boolean),%) -> Boolean
        if $ has finiteAggregate
children : % -> List %
child? : (%,%) -> Boolean if S has SETCAT
coerce : % -> OutputForm if S has SETCAT
concat : (S,%) -> %
concat : (%,S) -> %
concat! : (%,S) -> % if $ has shallowlyMutable
copy : % -> %
count : (S,%) -> NonNegativeInteger
        if S has SETCAT
        and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
        if $ has finiteAggregate
cycleEntry : % -> %
cycleLength : % -> NonNegativeInteger
cycleSplit! : % -> % if $ has shallowlyMutable
cycleTail : % -> %
cyclic? : % -> Boolean
distance : (%,%) -> Integer
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
        if S has EVALAB S
        and S has SETCAT
eval : (%,S,S) -> %
        if S has EVALAB S
        and S has SETCAT
eval : (%,Equation S) -> %
        if S has EVALAB S
        and S has SETCAT
eval : (%,List Equation S) -> %
        if S has EVALAB S
        and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean
        if $ has finiteAggregate
first : % -> S
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
last : % -> S

```

```

last : (%,NonNegativeInteger) -> %
leaf? : % -> Boolean
leaves : % -> List S
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
member? : (S,%) -> Boolean
    if S has SETCAT
    and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
nodes : % -> List %
node? : (%,%) -> Boolean if S has SETCAT
parts : % -> List S if $ has finiteAggregate
rest : % -> %
rest : (%,NonNegativeInteger) -> %
sample : () -> %
second : % -> S
setchildren! : (%,List %) -> % if $ has shallowlyMutable
setelt : (%,first,S) -> S if $ has shallowlyMutable
setelt : (%,last,S) -> S if $ has shallowlyMutable
setelt : (%,rest,%) -> % if $ has shallowlyMutable
setelt : (%,value,S) -> S if $ has shallowlyMutable
setfirst! : (%,S) -> S if $ has shallowlyMutable
setlast! : (%,S) -> S if $ has shallowlyMutable
setrest! : (%,%) -> % if $ has shallowlyMutable
setvalue! : (%,S) -> S if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
split! : (%,Integer) -> % if $ has shallowlyMutable
tail : % -> %
third : % -> S
value : % -> S
#? : % -> NonNegativeInteger if $ has finiteAggregate
#=? : (%,%) -> Boolean if S has SETCAT
?.last : (%,last) -> S
?.rest : (%,rest) -> %
?.first : (%,first) -> S
?~=? : (%,%) -> Boolean if S has SETCAT
?.value : (%,value) -> S

```

These exports come from (p458) LinearAggregate(S:Type):

```

construct : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
delete : (%,Integer) -> %
delete : (%,UniversalSegment Integer) -> %
elt : (%,Integer,S) -> S
entry? : (S,%) -> Boolean
    if $ has finiteAggregate
    and S has SETCAT
entries : % -> List S

```

```

find : ((S -> Boolean),%) -> Union(S,"failed")
index? : (Integer,%) -> Boolean
indices : % -> List Integer
insert : (S,%,Integer) -> %
insert : (%,%,Integer) -> %
maxIndex : % -> Integer if Integer has ORDSET
map : (((S,S) -> S),%,%) -> %
minIndex : % -> Integer if Integer has ORDSET
new : (NonNegativeInteger,S) -> %
qelt : (%,Integer) -> S
qsetelt! : (%,Integer,S) -> S
          if $ has shallowlyMutable
reduce : (((S,S) -> S),%,S,S) -> S
          if S has SETCAT
          and $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S
          if $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S
          if $ has finiteAggregate
remove : (S,%) -> %
          if S has SETCAT
          and $ has finiteAggregate
remove : ((S -> Boolean),%) -> %
          if $ has finiteAggregate
removeDuplicates : % -> %
          if S has SETCAT
          and $ has finiteAggregate
select : ((S -> Boolean),%) -> %
          if $ has finiteAggregate
swap! : (%,Integer,Integer) -> Void
          if $ has shallowlyMutable

```

— category STAGG StreamAggregate —

```

)abbrev category STAGG StreamAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A stream aggregate is a linear aggregate which possibly has an infinite
++ number of elements. A basic domain constructor which builds stream
++ aggregates is \spadtype{Stream}. From streams, a number of infinite
++ structures such power series can be built. A stream aggregate may
++ also be infinite since it may be cyclic.
++ For example, see \spadtype{DecimalExpansion}.

```

```

StreamAggregate(S:Type): Category ==
  Join(UnaryRecursiveAggregate S, LinearAggregate S) with
    explicitlyFinite?: % -> Boolean

```

```

    ++ explicitlyFinite?(s) tests if the stream has a finite
    ++ number of elements, and false otherwise.
    ++ Note that for many datatypes,
    ++ \axiom{explicitlyFinite?(s) = not possiblyInfinite?(s)}.
possiblyInfinite?: % -> Boolean
    ++ possiblyInfinite?(s) tests if the stream s could possibly
    ++ have an infinite number of elements.
    ++ Note that for many datatypes,
    ++ \axiom{possiblyInfinite?(s) = not explicitlyFinite?(s)}.
add
c2: (% , %) -> S

explicitlyFinite? x == not cyclic? x
possiblyInfinite? x == cyclic? x
first(x, n)          == construct [c2(x, x := rest x) for i in 1..n]

c2(x, r) ==
  empty? x => error "Index out of range"
  first x

elt(x:%, i:Integer) ==
  i := i - minIndex x
  (i < 0) or empty?(x := rest(x, i::NonNegativeInteger)) => _
  error "index out of range"
  first x

elt(x:%, i:UniversalSegment(Integer)) ==
  l := lo(i) - minIndex x
  l < 0 => error "index out of range"
  not hasHi i => copy(rest(x, l::NonNegativeInteger))
  (h := hi(i) - minIndex x) < l => empty()
  first(rest(x, l::NonNegativeInteger), (h - l + 1)::NonNegativeInteger)

if % has shallowlyMutable then
  concat(x:%, y:%) == concat_!(copy x, y)

  concat l ==
    empty? l => empty()
    concat_!(copy first l, concat rest l)

  map_!(f, l) ==
    y := l
    while not empty? l repeat
      setfirst_!(l, f first l)
      l := rest l
    y

  fill_!(x, s) ==
    y := x
    while not empty? y repeat (setfirst_!(y, s); y := rest y)

```

```

x

setelt(x:%, i:Integer, s:S) ==
  i := i - minIndex x
  (i < 0) or empty?(x := rest(x,i::NonNegativeInteger)) => _
    error "index out of range"
  setfirst_!(x, s)

setelt(x:%, i:UniversalSegment(Integer), s:S) ==
  (l := lo(i) - minIndex x) < 0 => error "index out of range"
  h := if hasHi i then hi(i) - minIndex x else maxIndex x
  h < l => s
  y := rest(x, l::NonNegativeInteger)
  z := rest(y, (h - l + 1)::NonNegativeInteger)
  while not eq?(y, z) repeat (setfirst_!(y, s); y := rest y)
  s

concat_!(x:%, y:%) ==
  empty? x => y
  setrest_!(tail x, y)
x

```

— STAGG.dotabb —

```

"STAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=STAGG"];
"STAGG" -> "RCAGG"
"STAGG" -> "LNAGG"

```

— STAGG.dotfull —

```

"StreamAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=STAGG"];
"StreamAggregate(a:Type)" -> "UnaryRecursiveAggregate(a:Type)"
"StreamAggregate(a:Type)" -> "LinearAggregate(a:Type)"

```

— STAGG.dotpic —

```

digraph pic {
  fontsize=10;

```

```

bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"StreamAggregate(a:Type)" [color=lightblue];
"StreamAggregate(a:Type)" -> "UnaryRecursiveAggregate(a:Type)"
"StreamAggregate(a:Type)" -> "LinearAggregate(a:Type)"

"UnaryRecursiveAggregate(a:Type)" [color=lightblue];
"UnaryRecursiveAggregate(a:Type)" -> "RecursiveAggregate(a:Type)"

"RecursiveAggregate(a:Type)" [color=lightblue];
"RecursiveAggregate(a:Type)" -> "HomogeneousAggregate(a:Type)"

"LinearAggregate(a:Type)" [color=lightblue];
"LinearAggregate(a:Type)" -> "IndexedAggregate(b:Integer,a:Type)"
"LinearAggregate(a:Type)" -> "Collection(a:Type)"

"IndexedAggregate(b:Integer,a:Type)" [color=seagreen];
"IndexedAggregate(b:Integer,a:Type)" ->
  "IndexedAggregate(a:SetCategory,b:Type)"

"IndexedAggregate(a:SetCategory,b:Type)" [color=lightblue];
"IndexedAggregate(a:SetCategory,b:Type)" ->
  "HomogeneousAggregate(a:Type)"

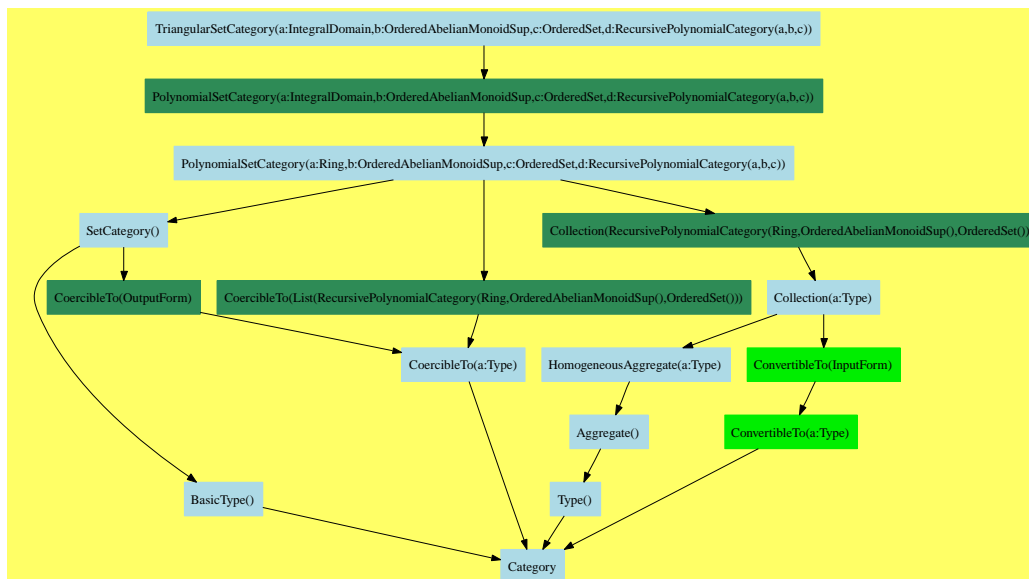
"Collection(a:Type)" [color=lightblue];
"Collection(a:Type)" -> "HomogeneousAggregate(a:Type)"

"HomogeneousAggregate(a:Type)" [color=lightblue];
"HomogeneousAggregate(a:Type)" -> "..."

"..." [color=lightblue];
}

```

TriangularSetCategory (TSETCAT)



— TriangularSetCategory.input —

```
)set break resume
)sys rm -f TriangularSetCategory.output
)spool TriangularSetCategory.output
)set message test on
)set message auto off
)clear all
```

```
--S 1 of 1
```

```
)show TriangularSetCategory
```

```
--R
```

```
--R TriangularSetCategory(R: IntegralDomain, E: OrderedAbelianMonoidSup, V: OrderedSet, P: RecursivePolynomial
```

```
--R Abbreviation for TriangularSetCategory is TSETCAT
```

```
--R This constructor is exposed in this frame.
```

```
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for TSETCAT
```

```
--R
```

```
--R----- Operations -----
```

```
--R ==? : (% , %) -> Boolean
```

```
algebraic? : (V, %) -> Boolean
```

```
--R algebraicVariables : % -> List(V)
```

```
coerce : % -> List(P)
```

```
--R coerce : % -> OutputForm
```

```
collect : (% , V) -> %
```

```
--R collectQuasiMonic : % -> %
```

```
collectUnder : (% , V) -> %
```

```
--R collectUpper : (% , V) -> %
```

```
construct : List(P) -> %
```

```
--R copy : % -> %
```

```
degree : % -> NonNegativeInteger
```

```
--R empty : () -> %
```

```
empty? : % -> Boolean
```



```

--R eq? : (%,% ) -> Boolean
--R first : % -> Union(P,"failed")
--R headReduce : (P,% ) -> P
--R headReduced? : (P,% ) -> Boolean
--R initiallyReduce : (P,% ) -> P
--R initials : % -> List(P)
--R latex : % -> String
--R mainVariables : % -> List(V)
--R mvar : % -> V
--R normalized? : (P,% ) -> Boolean
--R removeZero : (P,% ) -> P
--R retract : List(P) -> %
--R stronglyReduce : (P,% ) -> P
--R trivialIdeal? : % -> Boolean
--R zeroSetSplit : List(P) -> List(%)
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R any? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
--R autoReduced? : (%,((P,List(P)) -> Boolean)) -> Boolean
--R basicSet : (List(P),(P -> Boolean),((P,P) -> Boolean)) -> Union(Record(bas: %,top: List(P)),
--R basicSet : (List(P),((P,P) -> Boolean)) -> Union(Record(bas: %,top: List(P)),"failed")
--R coHeight : % -> NonNegativeInteger if V has FINITE
--R convert : % -> InputForm if P has KONVERT(INFORM)
--R count : ((P -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R count : (P,% ) -> NonNegativeInteger if P has SETCAT and $ has finiteAggregate
--R eval : (%,List(Equation(P))) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (%,Equation(P)) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (%,P,P) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (%,List(P),List(P)) -> % if P has EVALAB(P) and P has SETCAT
--R every? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
--R extendIfCan : (%,P) -> Union(%, "failed")
--R find : ((P -> Boolean),%) -> Union(P, "failed")
--R headRemainder : (P,% ) -> Record(num: P,den: R) if R has INTDOM
--R initiallyReduced? : (P,% ) -> Boolean
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((P -> P),%) -> % if $ has shallowlyMutable
--R member? : (P,% ) -> Boolean if P has SETCAT and $ has finiteAggregate
--R members : % -> List(P) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(P) if $ has finiteAggregate
--R quasiComponent : % -> Record(close: List(P),open: List(P))
--R reduce : (P,% ,((P,P) -> P),((P,P) -> Boolean)) -> P
--R reduce : ((P,P) -> P),%) -> P if $ has finiteAggregate
--R reduce : ((P,P) -> P),%,P) -> P if $ has finiteAggregate
--R reduce : ((P,P) -> P),%,P,P) -> P if P has SETCAT and $ has finiteAggregate
--R reduced? : (P,% ,((P,P) -> Boolean)) -> Boolean
--R remainder : (P,% ) -> Record(rnum: R,polnum: P,den: R) if R has INTDOM
--R remove : ((P -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (P,% ) -> % if P has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
--R retractIfCan : List(P) -> Union(%, "failed")
--R extend : (%,P) -> %
--R hash : % -> SingleInteger
--R headReduced? : % -> Boolean
--R infRittWu? : (%,%) -> Boolean
--R initiallyReduced? : % -> Boolean
--R last : % -> Union(P, "failed")
--R mainVariable? : (V,% ) -> Boolean
--R map : ((P -> P),%) -> %
--R normalized? : % -> Boolean
--R reduceByQuasiMonic : (P,% ) -> P
--R rest : % -> Union(%, "failed")
--R sample : () -> %
--R stronglyReduced? : % -> Boolean
--R variables : % -> List(V)
--R ~=? : (%,%) -> Boolean

```

```

--R rewriteIdealWithHeadRemainder : (List(P),%) -> List(P) if R has INTDOM
--R rewriteIdealWithRemainder : (List(P),%) -> List(P) if R has INTDOM
--R rewriteSetWithReduction : (List(P),%,((P,P) -> P),((P,P) -> Boolean)) -> List(P)
--R roughBase? : % -> Boolean if R has INTDOM
--R roughEqualIdeals? : (%,%) -> Boolean if R has INTDOM
--R roughSubIdeal? : (%,%) -> Boolean if R has INTDOM
--R roughUnitIdeal? : % -> Boolean if R has INTDOM
--R select : (%,V) -> Union(P,"failed")
--R select : ((P -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R sort : (%,V) -> Record(under: %,floor: %,upper: %)
--R stronglyReduced? : (P,%) -> Boolean
--R triangular? : % -> Boolean if R has INTDOM
--R zeroSetSplitIntoTriangularSystems : List(P) -> List(Record(close: %,open: List(P)))
--R
--E 1

)spool
)lisp (bye)

```

— TriangularSetCategory.help —

=====

TriangularSetCategory examples

=====

The category of triangular sets of multivariate polynomials with coefficients in an integral domain.

Let R be an integral domain and V a finite ordered set of variables,
 $X_1 < X_2 < \dots < X_n$

A set S of polynomials in $R[X_1, X_2, \dots, X_n]$ is triangular if no elements of S lies in R , and if two distinct elements of S have distinct main variables.

Note that the empty set is a triangular set. A triangular set is not necessarily a (lexicographical) Groebner basis and the notion of reduction related to triangular sets is based on the recursive view of polynomials. We recall this notion here. For details see

P. AUBRY, D. LAZARD and M. MORENO MAZA "On the Theories of Triangular Sets" Journal of Symbol. Comp.

A polynomial P is reduced with respect to a non-constant polynomial Q if the degree of P in the main variable of Q is less than the main degree of Q . A polynomial P is reduced with respect to a triangular set T if it is reduced with respect to every polynomial of T .

See Also:

o `)show TriangularSetCategory`

See:

⇒ “RegularTriangularSetCategory” (RSETCAT) 8 on page [755](#)

⇐ “PolynomialSetCategory” (PSETCAT) 6 on page [520](#)

Exports:

| | |
|-----------------------------------|-------------------------------|
| algebraic? | algebraicVariables |
| any? | autoReduced? |
| basicSet | coerce |
| coHeight | collect |
| collectQuasiMonic | collectUnder |
| collectUpper | construct |
| convert | copy |
| count | degree |
| empty | empty? |
| eq? | eval |
| every? | extend |
| extendIfCan | find |
| first | hash |
| headReduce | headReduced? |
| headRemainder | infRittWu? |
| initiallyReduce | initiallyReduced? |
| initials | last |
| latex | less? |
| mainVariable? | mainVariables |
| map | map! |
| member? | members |
| more? | mvar |
| normalized? | parts |
| quasiComponent | reduce |
| reduced? | reduceByQuasiMonic |
| remainder | remove |
| removeDuplicates | removeZero |
| rest | retract |
| retractIfCan | rewriteIdealWithHeadRemainder |
| rewriteIdealWithRemainder | rewriteSetWithReduction |
| roughBase? | roughEqualIdeals? |
| roughSubIdeal? | roughUnitIdeal? |
| sample | select |
| size? | sort |
| stronglyReduce | stronglyReduced? |
| triangular? | trivialIdeal? |
| variables | zeroSetSplit |
| zeroSetSplitIntoTriangularSystems | #? |
| ?=? | ?~=? |

Attributes Exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.

- **nil**

These are directly exported but not implemented:

```

extendIfCan : (% , P) -> Union(% , "failed")
zeroSetSplit : List P -> List %
zeroSetSplitIntoTriangularSystems :
  List P -> List Record(close: % , open: List P)

```

These are implemented by this category:

```

algebraic? : (V , %) -> Boolean
algebraicVariables : % -> List V
autoReduced? : (% , ((P , List P) -> Boolean)) -> Boolean
basicSet :
  (List P , (P -> Boolean) , ((P , P) -> Boolean)) ->
    Union(Record(bas: % , top: List P) , "failed")
basicSet : (List P , ((P , P) -> Boolean)) ->
  Union(Record(bas: % , top: List P) , "failed")
coerce : % -> List P
coHeight : % -> NonNegativeInteger if V has FINITE
collectQuasiMonic : % -> %
collectUnder : (% , V) -> %
collectUpper : (% , V) -> %
construct : List P -> %
convert : % -> InputForm if P has KONVERT INFORM
degree : % -> NonNegativeInteger
extend : (% , P) -> %
first : % -> Union(P , "failed")
headReduce : (P , %) -> P
headReduced? : % -> Boolean
headReduced? : (P , %) -> Boolean
infRittWu? : (% , %) -> Boolean
initiallyReduce : (P , %) -> P
initiallyReduced? : % -> Boolean
initiallyReduced? : (P , %) -> Boolean
initials : % -> List P
last : % -> Union(P , "failed")
mvar : % -> V
normalized? : % -> Boolean
normalized? : (P , %) -> Boolean
quasiComponent : % -> Record(close: List P , open: List P)
reduce : (P , % , ((P , P) -> P) , ((P , P) -> Boolean)) -> P
reduceByQuasiMonic : (P , %) -> P
reduced? : (P , % , ((P , P) -> Boolean)) -> Boolean
removeZero : (P , %) -> P
rest : % -> Union(% , "failed")
retractIfCan : List P -> Union(% , "failed")
rewriteSetWithReduction :
  (List P , % , ((P , P) -> P) , ((P , P) -> Boolean)) -> List P

```

```

select : (% , V) -> Union(P, "failed")
stronglyReduce : (P, %) -> P
stronglyReduced? : % -> Boolean
stronglyReduced? : (P, %) -> Boolean
?=? : (% , %) -> Boolean

```

These exports come from (p520) PolynomialSetCategory(R,E,V,P)
 where R:IntegralDomain, E:OrderedAbelianMonoidSup,
 V:OrderedSet, P:RecursivePolynomialCategory(R,E,V):

```

any? : ((P -> Boolean), %) -> Boolean if $ has finiteAggregate
coerce : % -> OutputForm
collect : (% , V) -> %
copy : % -> %
count : ((P -> Boolean), %) -> NonNegativeInteger
  if $ has finiteAggregate
count : (P, %) -> NonNegativeInteger
  if P has SETCAT and $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (% , %) -> Boolean
eval : (% , List Equation P) -> % if P has EVALAB P and P has SETCAT
eval : (% , Equation P) -> % if P has EVALAB P and P has SETCAT
eval : (% , P, P) -> % if P has EVALAB P and P has SETCAT
eval : (% , List P, List P) -> % if P has EVALAB P and P has SETCAT
every? : ((P -> Boolean), %) -> Boolean if $ has finiteAggregate
find : ((P -> Boolean), %) -> Union(P, "failed")
hash : % -> SingleInteger
headRemainder : (P, %) -> Record(num: P, den: R) if R has INTDOM
latex : % -> String
less? : (% , NonNegativeInteger) -> Boolean
mainVariable? : (V, %) -> Boolean
mainVariables : % -> List V
map : ((P -> P), %) -> %
map! : ((P -> P), %) -> % if $ has shallowlyMutable
member? : (P, %) -> Boolean
  if P has SETCAT and $ has finiteAggregate
members : % -> List P if $ has finiteAggregate
more? : (% , NonNegativeInteger) -> Boolean
parts : % -> List P if $ has finiteAggregate
reduce : (((P, P) -> P), %) -> P if $ has finiteAggregate
reduce : (((P, P) -> P), %, P) -> P if $ has finiteAggregate
reduce : (((P, P) -> P), %, P, P) -> P
  if P has SETCAT
  and $ has finiteAggregate
remainder : (P, %) -> Record(rnum: R, polnum: P, den: R)
  if R has INTDOM
remove : ((P -> Boolean), %) -> % if $ has finiteAggregate
remove : (P, %) -> % if P has SETCAT and $ has finiteAggregate
removeDuplicates : % -> %

```

```

    if P has SETCAT
    and $ has finiteAggregate
    retract : List P -> %
    rewriteIdealWithHeadRemainder : (List P,%) -> List P
    if R has INTDOM
    rewriteIdealWithRemainder : (List P,%) -> List P
    if R has INTDOM
    roughBase? : % -> Boolean if R has INTDOM
    roughEqualIdeals? : (%,%) -> Boolean if R has INTDOM
    roughSubIdeal? : (%,%) -> Boolean if R has INTDOM
    roughUnitIdeal? : % -> Boolean if R has INTDOM
    sample : () -> %
    select : ((P -> Boolean),%) -> % if $ has finiteAggregate
    size? : (%,NonNegativeInteger) -> Boolean
    sort : (%,V) -> Record(under: %,floor: %,upper: %)
    triangular? : % -> Boolean if R has INTDOM
    trivialIdeal? : % -> Boolean
    variables : % -> List V
    #? : % -> NonNegativeInteger if $ has finiteAggregate
    ~=?: (%,%) -> Boolean

```

— category TSETCAT TriangularSetCategory —

```

)abbrev category TSETCAT TriangularSetCategory
++ Author: Marc Moreno Maza (marc@nag.co.uk)
++ Date Created: 04/26/1994
++ Date Last Updated: 12/15/1998
++ References :
++ [1] P. AUBRY, D. LAZARD and M. MORENO MAZA "On the Theories
++      of Triangular Sets" Journal of Symbol. Comp. (to appear)
++ Description:
++ The category of triangular sets of multivariate polynomials
++ with coefficients in an integral domain.
++ Let \axiom{R} be an integral domain and \axiom{V} a finite ordered set of
++ variables, say \axiom{X1 < X2 < ... < Xn}.
++ A set \axiom{S} of polynomials in \axiom{R}[X1,X2,...,Xn] is triangular
++ if no elements of \axiom{S} lies in \axiom{R}, and if two distinct
++ elements of \axiom{S} have distinct main variables.
++ Note that the empty set is a triangular set. A triangular set is not
++ necessarily a (lexicographical) Groebner basis and the notion of
++ reduction related to triangular sets is based on the recursive view
++ of polynomials. We recall this notion here and refer to [1] for more
++ details.
++ A polynomial \axiom{P} is reduced w.r.t a non-constant polynomial
++ \axiom{Q} if the degree of \axiom{P} in the main variable of \axiom{Q}
++ is less than the main degree of \axiom{Q}.
++ A polynomial \axiom{P} is reduced w.r.t a triangular set \axiom{T}
++ if it is reduced w.r.t. every polynomial of \axiom{T}.

```

```

TriangularSetCategory(R: IntegralDomain, E: OrderedAbelianMonoidSup, _
V: OrderedSet, P: RecursivePolynomialCategory(R, E, V)):
    Category ==
PolynomialSetCategory(R, E, V, P) with
    finiteAggregate
    shallowlyMutable

infRittWu? : ($, $) -> Boolean
    ++ \axiom{infRittWu?(ts1, ts2)} returns true iff \axiom{ts2} has
    ++ higher rank than \axiom{ts1} in Wu Wen Tsun sense.
basicSet : (List P, ((P, P) -> Boolean)) -> _
    Union(Record(bas: $, top: List P), "failed")
    ++ \axiom{basicSet(ps, redOp?)} returns \axiom{[bs, ts]} where
    ++ \axiom{concat(bs, ts)} is \axiom{ps} and \axiom{bs}
    ++ is a basic set in Wu Wen Tsun sense of \axiom{ps} w.r.t
    ++ the reduction-test \axiom{redOp?}, if no non-zero constant
    ++ polynomial lie in \axiom{ps}, otherwise \axiom{"failed"} is returned.
basicSet : (List P, (P -> Boolean), ((P, P) -> Boolean)) -> _
    Union(Record(bas: $, top: List P), "failed")
    ++ \axiom{basicSet(ps, pred?, redOp?)} returns the same as
    ++ \axiom{basicSet(qs, redOp?)}
    ++ where \axiom{qs} consists of the polynomials of \axiom{ps}
    ++ satisfying property \axiom{pred?}.
initials : $ -> List P
    ++ \axiom{initials(ts)} returns the list of the non-constant initials
    ++ of the members of \axiom{ts}.
degree : $ -> NonNegativeInteger
    ++ \axiom{degree(ts)} returns the product of main degrees of the
    ++ members of \axiom{ts}.
quasiComponent : $ -> Record(close: List P, open: List P)
    ++ \axiom{quasiComponent(ts)} returns \axiom{[lp, lq]} where \axiom{lp}
    ++ is the list of the members of \axiom{ts} and \axiom{lq} is
    ++ \axiom{initials(ts)}.
normalized? : (P, $) -> Boolean
    ++ \axiom{normalized?(p, ts)} returns true iff \axiom{p} and all
    ++ its iterated initials have degree zero w.r.t. the main variables
    ++ of the polynomials of \axiom{ts}
normalized? : $ -> Boolean
    ++ \axiom{normalized?(ts)} returns true iff for every \axiom{p} in
    ++ \axiom{ts} we have \axiom{normalized?(p, us)} where \axiom{us}
    ++ is \axiom{collectUnder(ts, mvar(p))}.
reduced? : (P, $, ((P, P) -> Boolean)) -> Boolean
    ++ \axiom{reduced?(p, ts, redOp?)} returns true iff \axiom{p} is reduced
    ++ w.r.t. in the sense of the operation \axiom{redOp?}, that is if for
    ++ every \axiom{t} in \axiom{ts} \axiom{redOp?(p, t)} holds.
stronglyReduced? : (P, $) -> Boolean
    ++ \axiom{stronglyReduced?(p, ts)} returns true iff \axiom{p}
    ++ is reduced w.r.t. \axiom{ts}.
headReduced? : (P, $) -> Boolean
    ++ \axiom{headReduced?(p, ts)} returns true iff the head of \axiom{p} is

```



```

++ reduced w.r.t. \axiom{ts}.
initiallyReduced? : (P,$) -> Boolean
++ \axiom{initiallyReduced?(p,ts)} returns true iff \axiom{p} and all
++ its iterated initials are reduced w.r.t. to the elements of
++ \axiom{ts} with the same main variable.
autoReduced? : ($,((P,List(P)) -> Boolean)) -> Boolean
++ \axiom{autoReduced?(ts,redOp?) } returns true iff every element of
++ \axiom{ts} is reduced w.r.t to every other in the sense of
++ \axiom{redOp?}
stronglyReduced? : $ -> Boolean
++ \axiom{stronglyReduced?(ts)} returns true iff every element of
++ \axiom{ts} is reduced w.r.t to any other element of \axiom{ts}.
headReduced? : $ -> Boolean
++ headReduced?(ts) returns true iff the head of every element of
++ \axiom{ts} is reduced w.r.t to any other element of \axiom{ts}.
initiallyReduced? : $ -> Boolean
++ initiallyReduced?(ts) returns true iff for every element \axiom{p}
++ of \axiom{ts}. \axiom{p} and all its iterated initials are reduced
++ w.r.t. to the other elements of \axiom{ts} with the same main
++ variable.
reduce : (P,$,((P,P) -> P),((P,P) -> Boolean) ) -> P
++ \axiom{reduce(p,ts,redOp,redOp?) } returns a polynomial \axiom{r}
++ such that \axiom{redOp?(r,p)} holds for every \axiom{p} of
++ \axiom{ts} and there exists some product \axiom{h} of the initials
++ of the members of \axiom{ts} such that \axiom{h*p - r} lies in the
++ ideal generated by \axiom{ts}. The operation \axiom{redOp} must
++ satisfy the following conditions. For every \axiom{p} and \axiom{q}
++ we have \axiom{redOp?(redOp(p,q),q)} and there exists an integer
++ \axiom{e} and a polynomial \axiom{f} such that
++ \axiom{init(q)^e*p = f*q + redOp(p,q)}.
rewriteSetWithReduction : (List P,$,((P,P) -> P),((P,P) -> Boolean) ) ->_
List P
++ \axiom{rewriteSetWithReduction(lp,ts,redOp,redOp?) } returns a list
++ \axiom{lp} of polynomials such that
++ \axiom{[reduce(p,ts,redOp,redOp?) for p in lp]} and \axiom{lp}
++ have the same zeros inside the regular zero set of \axiom{ts}.
++ Moreover, for every polynomial \axiom{q} in \axiom{lp} and every
++ polynomial \axiom{t} in \axiom{ts}
++ \axiom{redOp?(q,t)} holds and there exists a polynomial \axiom{p}
++ in the ideal generated by \axiom{lp} and a product \axiom{h} of
++ \axiom{initials(ts)} such that \axiom{h*p - r} lies in the ideal
++ generated by \axiom{ts}.
++ The operation \axiom{redOp} must satisfy the following conditions.
++ For every \axiom{p} and \axiom{q} we have
++ \axiom{redOp?(redOp(p,q),q)}
++ and there exists an integer \axiom{e} and a polynomial \axiom{f}
++ such that \axiom{init(q)^e*p = f*q + redOp(p,q)}.
stronglyReduce : (P,$) -> P
++ \axiom{stronglyReduce(p,ts)} returns a polynomial \axiom{r} such that
++ \axiom{stronglyReduced?(r,ts)} holds and there exists some product

```

```

++ \axiom{h} of \axiom{initials(ts)}
++ such that \axiom{h*p - r} lies in the ideal generated by \axiom{ts}.
headReduce : (P,$) -> P
++ \axiom{headReduce(p,ts)} returns a polynomial \axiom{r} such that
++ \axiom{headReduce?(r,ts)} holds and there exists some product
++ \axiom{h} of \axiom{initials(ts)} such that \axiom{h*p - r} lies
++ in the ideal generated by \axiom{ts}.
initiallyReduce : (P,$) -> P
++ \axiom{initiallyReduce(p,ts)} returns a polynomial \axiom{r}
++ such that \axiom{initiallyReduced?(r,ts)}
++ holds and there exists some product \axiom{h} of \axiom{initials(ts)}
++ such that \axiom{h*p - r} lies in the ideal generated by \axiom{ts}.
removeZero: (P, $) -> P
++ \axiom{removeZero(p,ts)} returns \axiom{0} if \axiom{p} reduces
++ to \axiom{0} by pseudo-division w.r.t \axiom{ts} otherwise
++ returns a polynomial \axiom{q} computed from \axiom{p}
++ by removing any coefficient in \axiom{p} reducing to \axiom{0}.
collectQuasiMonic: $ -> $
++ \axiom{collectQuasiMonic(ts)} returns the subset of \axiom{ts}
++ consisting of the polynomials with initial in \axiom{R}.
reduceByQuasiMonic: (P, $) -> P
++ \axiom{reduceByQuasiMonic(p,ts)} returns the same as
++ \axiom{remainder(p,collectQuasiMonic(ts)).polnum}.
zeroSetSplit : List P -> List $
++ \axiom{zeroSetSplit(lp)} returns a list \axiom{lts} of triangular
++ sets such that the zero set of \axiom{lp} is the union of the
++ closures of the regular zero sets of the members of \axiom{lts}.
zeroSetSplitIntoTriangularSystems : List P -> _
List Record(close:$,open:List P)
++ \axiom{zeroSetSplitIntoTriangularSystems(lp)} returns a list of
++ triangular systems \axiom{[[ts1,qs1],...,[tsn,qsn]]} such that the
++ zero set of \axiom{lp} is the union of the closures of the
++ \axiom{W_i} where \axiom{W_i} consists of the zeros of \axiom{ts}
++ which do not cancel any polynomial in \axiom{qsi}.
first : $ -> Union(P,"failed")
++ \axiom{first(ts)} returns the polynomial of \axiom{ts} with
++ greatest main variable if \axiom{ts} is not empty, otherwise
++ returns \axiom{"failed"}.
last : $ -> Union(P,"failed")
++ \axiom{last(ts)} returns the polynomial of \axiom{ts} with
++ smallest main variable if \axiom{ts} is not empty, otherwise
++ returns \axiom{"failed"}.
rest : $ -> Union($,"failed")
++ \axiom{rest(ts)} returns the polynomials of \axiom{ts} with smaller
++ main variable than \axiom{mvar(ts)} if \axiom{ts} is not empty,
++ otherwise returns "failed"
algebraicVariables : $ -> List(V)
++ \axiom{algebraicVariables(ts)} returns the decreasingly sorted
++ list of the main variables of the polynomials of \axiom{ts}.
algebraic? : (V,$) -> Boolean

```

```

    ++ \axiom{algebraic?(v,ts)} returns true iff \axiom{v} is the
    ++ main variable of some polynomial in \axiom{ts}.
select : ($,V) -> Union(P,"failed")
    ++ \axiom{select(ts,v)} returns the polynomial of \axiom{ts} with
    ++ \axiom{v} as main variable, if any.
extendIfCan : ($,P) -> Union($,"failed")
    ++ \axiom{extendIfCan(ts,p)} returns a triangular set which encodes
    ++ the simple extension by \axiom{p} of the extension of the base
    ++ field defined by \axiom{ts}, according
    ++ to the properties of triangular sets of the current domain.
    ++ If the required properties do not hold then "failed" is returned.
    ++ This operation encodes in some sense the properties of the
    ++ triangular sets of the current category. Is is used to implement
    ++ the \axiom{construct} operation to guarantee that every triangular
    ++ set build from a list of polynomials has the required properties.
extend : ($,P) -> $
    ++ \axiom{extend(ts,p)} returns a triangular set which encodes the
    ++ simple extension by \axiom{p} of the extension of the base field
    ++ defined by \axiom{ts}, according to the properties of triangular
    ++ sets of the current category. If the required properties do not
    ++ hold an error is returned.
if V has Finite
then
    coHeight : $ -> NonNegativeInteger
    ++ \axiom{coHeight(ts)} returns \axiom{size()}\$V} minus \axiom{\#ts}.
add

GPS ==> GeneralPolynomialSet(R,E,V,P)
B ==> Boolean
RBT ==> Record(bas:$,top:List P)

ts:$ = us:$ ==
    empty?(ts)$ $ => empty?(us)$ $
    empty?(us)$ $ => false
    first(ts)::P = $P first(us)::P => rest(ts)::P = $ $ rest(us)::P
    false

infRittWu?(ts,us) ==
    empty?(us)$ $ => not empty?(ts)$ $
    empty?(ts)$ $ => false
    p : P := (last(ts))::P
    q : P := (last(us))::P
    infRittWu?(p,q)$P => true
    supRittWu?(p,q)$P => false
    v : V := mvar(p)
    infRittWu?(collectUpper(ts,v),collectUpper(us,v))$ $

reduced?(p,ts,redOp?) ==
    lp : List P := members(ts)
    while (not empty? lp) and (redOp?(p,first(lp))) repeat

```

```

    lp := rest lp
    empty? lp

basicSet(ps,redOp?) ==
  ps := remove(zero?,ps)
  any?(ground?,ps) => "failed"::Union(RBT,"failed")
  ps := sort(infRittWu?,ps)
  p,b : P
  bs := empty()$$
  ts : List P := []
  while not empty? ps repeat
    b := first(ps)
    bs := extend(bs,b)$$
    ps := rest ps
    while (not empty? ps) and _
      (not reduced?((p := first(ps)),bs,redOp?)) repeat
      ts := cons(p,ts)
      ps := rest ps
    ([bs,ts]$RBT)::Union(RBT,"failed")

basicSet(ps,pred?,redOp?) ==
  ps := remove(zero?,ps)
  any?(ground?,ps) => "failed"::Union(RBT,"failed")
  gps : List P := []
  bps : List P := []
  while not empty? ps repeat
    p := first ps
    ps := rest ps
    if pred?(p)
      then
        gps := cons(p,gps)
      else
        bps := cons(p,bps)
  gps := sort(infRittWu?,gps)
  p,b : P
  bs := empty()$$
  ts : List P := []
  while not empty? gps repeat
    b := first(gps)
    bs := extend(bs,b)$$
    gps := rest gps
    while (not empty? gps) and _
      (not reduced?((p := first(gps)),bs,redOp?)) repeat
      ts := cons(p,ts)
      gps := rest gps
  ts := sort(infRittWu?,concat(ts,bps))
  ([bs,ts]$RBT)::Union(RBT,"failed")

initials ts ==
  lip : List P := []

```

```

empty? ts => lip
lp := members(ts)
while not empty? lp repeat
  p := first(lp)
  if not ground?((ip := init(p)))
  then
    lip := cons(primPartElseUnitCanonical(ip),lip)
  lp := rest lp
removeDuplicates lip

degree ts ==
empty? ts => 0$NonNegativeInteger
lp := members ts
d : NonNegativeInteger := mdeg(first lp)
while not empty? (lp := rest lp) repeat
  d := d * mdeg(first lp)
d

quasiComponent ts ==
[members(ts),initials(ts)]

normalized?(p,ts) ==
normalized?(p,members(ts))$P

stronglyReduced? (p,ts) ==
reduced?(p,members(ts))$P

headReduced? (p,ts) ==
stronglyReduced?(head(p),ts)

initiallyReduced? (p,ts) ==
lp : List (P) := members(ts)
red : Boolean := true
while (not empty? lp) and (not ground?(p)$P) and red repeat
  while (not empty? lp) and (mvar(first(lp)) > mvar(p)) repeat
    lp := rest lp
  if (not empty? lp)
  then
    if (mvar(first(lp)) = mvar(p))
    then
      if reduced?(p,first(lp))
      then
        lp := rest lp
        p := init(p)
      else
        red := false
    else
      p := init(p)
red

```

```

reduce(p,ts,redOp,redOp?) ==
  (empty? ts) or (ground? p) => p
  ts0 := ts
  while (not empty? ts) and (not ground? p) repeat
    reductor := (first ts)::P
    ts := (rest ts)::P
    if not redOp?(p,reductor)
      then
        p := redOp(p,reductor)
        ts := ts0
  p

rewriteSetWithReduction(lp,ts,redOp,redOp?) ==
  trivialIdeal? ts => lp
  lp := remove(zero?,lp)
  empty? lp => lp
  any?(ground?,lp) => [1$P]
  rs : List P := []
  while not empty? lp repeat
    p := first lp
    lp := rest lp
    p := primPartElseUnitCanonical reduce(p,ts,redOp,redOp?)
    if not zero? p
      then
        if ground? p
          then
            lp := []
            rs := [1$P]
          else
            rs := cons(p,rs)
  removeDuplicates rs

stronglyReduce(p,ts) ==
  reduce (p,ts,lazyPrem,reduced?)

headReduce(p,ts) ==
  reduce (p,ts,headReduce,headReduced?)

initiallyReduce(p,ts) ==
  reduce (p,ts,initiallyReduce,initiallyReduced?)

removeZero(p,ts) ==
  (ground? p) or (empty? ts) => p
  v := mvar(p)
  ts_v_- := collectUnder(ts,v)
  if algebraic?(v,ts)
    then
      q := lazyPrem(p,select(ts,v)::P)
      zero? q => return q
      zero? removeZero(q,ts_v_-) => return 0

```

```

empty? ts_v_- => p
q: P := 0
while positive? degree(p,v) repeat
  q := removeZero(init(p),ts_v_-) * mainMonomial(p) + q
  p := tail(p)
q + removeZero(p,ts_v_-)

reduceByQuasiMonic(p, ts) ==
  (ground? p) or (empty? ts) => p
  remainder(p,collectQuasiMonic(ts)).polnum

autoReduced?(ts : $,redOp? : ((P,List(P)) -> Boolean)) ==
  empty? ts => true
  lp : List (P) := members(ts)
  p : P := first(lp)
  lp := rest lp
  while (not empty? lp) and redOp?(p,lp) repeat
    p := first lp
    lp := rest lp
  empty? lp

stronglyReduced? ts ==
  autoReduced? (ts, reduced?)

normalized? ts ==
  autoReduced? (ts,normalized?)

headReduced? ts ==
  autoReduced? (ts,headReduced?)

initiallyReduced? ts ==
  autoReduced? (ts,initiallyReduced?)

mvar ts ==
  empty? ts => error"Error from TSETCAT in mvar : #1 is empty"
  mvar((first(ts))::P)$P

first ts ==
  empty? ts => "failed"::Union(P,"failed")
  lp : List(P) := sort(supRittWu?,members(ts))$(List P)
  first(lp)::Union(P,"failed")

last ts ==
  empty? ts => "failed"::Union(P,"failed")
  lp : List(P) := sort(infRittWu?,members(ts))$(List P)
  first(lp)::Union(P,"failed")

rest ts ==
  empty? ts => "failed"::Union($,"failed")
  lp : List(P) := sort(supRittWu?,members(ts))$(List P)

```

```

    construct(rest(lp))::Union($,"failed")

coerce (ts:$) : List(P) ==
    sort(supRittWu?,members(ts))$(List P)

algebraicVariables ts ==
    [mvar(p) for p in members(ts)]

algebraic? (v,ts) ==
    member?(v,algebraicVariables(ts))

select (ts,v) ==
    lp : List (P) := sort(supRittWu?,members(ts))$(List P)
    while (not empty? lp) and (not (v = mvar(first lp))) repeat
        lp := rest lp
    empty? lp => "failed"::Union(P,"failed")
    (first lp)::Union(P,"failed")

collectQuasiMonic ts ==
    lp: List(P) := members(ts)
    newlp: List(P) := []
    while (not empty? lp) repeat
        if ground? init(first(lp)) then newlp := cons(first(lp),newlp)
        lp := rest lp
    construct(newlp)

collectUnder (ts,v) ==
    lp : List (P) := sort(supRittWu?,members(ts))$(List P)
    while (not empty? lp) and (not (v > mvar(first lp))) repeat
        lp := rest lp
    construct(lp)

collectUpper (ts,v) ==
    lp1 : List(P) := sort(supRittWu?,members(ts))$(List P)
    lp2 : List(P) := []
    while (not empty? lp1) and (mvar(first lp1) > v) repeat
        lp2 := cons(first(lp1),lp2)
        lp1 := rest lp1
    construct(reverse lp2)

construct(lp:List(P)) ==
    rif := retractIfCan(lp)@Union($,"failed")
    not (rif case $) => error"in construct : LP -> $ from TSETCAT : bad arg"
    rif::$

retractIfCan(lp:List(P)) ==
    empty? lp => (empty()$$)::Union($,"failed")
    lp := sort(supRittWu?,lp)
    rif := retractIfCan(rest(lp))@Union($,"failed")
    not (rif case $) => _

```



```

    error "in retractIfCan : LP -> ... from TSETCAT : bad arg"
    extendIfCan(rif::$,first(lp))@Union($,"failed")

extend(ts:$,p:P):$ ==
  eif := extendIfCan(ts,p)@Union($,"failed")
  not (eif case $) => error"in extend : ($,P) -> $ from TSETCAT : bad ars"
  eif::$

if V has Finite
then

  coHeight ts ==
    n := size()$V
    m := #(members ts)
    subtractIfCan(n,m)$NonNegativeInteger::NonNegativeInteger

_____

— TSETCAT.dotabb —

"TSETCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=TSETCAT"];
"TSETCAT" -> "PSETCAT"

_____

— TSETCAT.dotfull —

"TriangularSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialC
[color=lightblue,href="bookvol10.2.pdf#nameddest=TSETCAT"];
"TriangularSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolyno
-> "PolynomialSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursiveP

"TriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialC
[color=seagreen,href="bookvol10.2.pdf#nameddest=TSETCAT"];
"TriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialC
->
"TriangularSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolyno

_____

— TSETCAT.dotpic —

digraph pic {
  fontsize=10;

```

```

bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"TriangularSetCategory(a: IntegralDomain, b: OrderedAbelianMonoidSup, c: OrderedSet, d: RecursivePolynomialCategory)"
  [color=lightblue];
"TriangularSetCategory(a: IntegralDomain, b: OrderedAbelianMonoidSup, c: OrderedSet, d: RecursivePolynomialCategory)"
  -> "PolynomialSetCategory(a: IntegralDomain, b: OrderedAbelianMonoidSup, c: OrderedSet, d: RecursivePolynomialCategory)"

"PolynomialSetCategory(a: IntegralDomain, b: OrderedAbelianMonoidSup, c: OrderedSet, d: RecursivePolynomialCategory)"
  [color=seagreen];
"PolynomialSetCategory(a: IntegralDomain, b: OrderedAbelianMonoidSup, c: OrderedSet, d: RecursivePolynomialCategory)"
  -> "PolynomialSetCategory(a: Ring, b: OrderedAbelianMonoidSup, c: OrderedSet, d: RecursivePolynomialCategory(a, b, c))"

"PolynomialSetCategory(a: Ring, b: OrderedAbelianMonoidSup, c: OrderedSet, d: RecursivePolynomialCategory(a, b, c))"
  [color=lightblue];
"PolynomialSetCategory(a: Ring, b: OrderedAbelianMonoidSup, c: OrderedSet, d: RecursivePolynomialCategory(a, b, c))"
  -> "SetCategory()"
"PolynomialSetCategory(a: Ring, b: OrderedAbelianMonoidSup, c: OrderedSet, d: RecursivePolynomialCategory(a, b, c))"
  -> "Collection(RecursivePolynomialCategory(Ring, OrderedAbelianMonoidSup(), OrderedSet()))"
"PolynomialSetCategory(a: Ring, b: OrderedAbelianMonoidSup, c: OrderedSet, d: RecursivePolynomialCategory(a, b, c))"
  -> "CoercibleTo(List(RecursivePolynomialCategory(Ring, OrderedAbelianMonoidSup(), OrderedSet())))"

"CoercibleTo(List(RecursivePolynomialCategory(Ring, OrderedAbelianMonoidSup(), OrderedSet())))"
  [color=seagreen];
"CoercibleTo(List(RecursivePolynomialCategory(Ring, OrderedAbelianMonoidSup(), OrderedSet())))"
  -> "CoercibleTo(a: Type)"

"Collection(RecursivePolynomialCategory(Ring, OrderedAbelianMonoidSup(), OrderedSet()))" [color=seagreen];
"Collection(RecursivePolynomialCategory(Ring, OrderedAbelianMonoidSup(), OrderedSet()))"
  -> "Collection(a: Type)"

"Collection(a: Type)" [color=lightblue];
"Collection(a: Type)" -> "HomogeneousAggregate(a: Type)"
"Collection(a: Type)" -> "ConvertibleTo(InputForm)"

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a: Type)"

"CoercibleTo(a: Type)" [color=lightblue];
"CoercibleTo(a: Type)" -> "Category"

"HomogeneousAggregate(a: Type)" [color=lightblue];
"HomogeneousAggregate(a: Type)" -> "Aggregate()"

```

```
"Aggregate()" [color=lightblue];
"Aggregate()" -> "Type()"

"Type()" [color=lightblue];
"Type()" -> "Category"

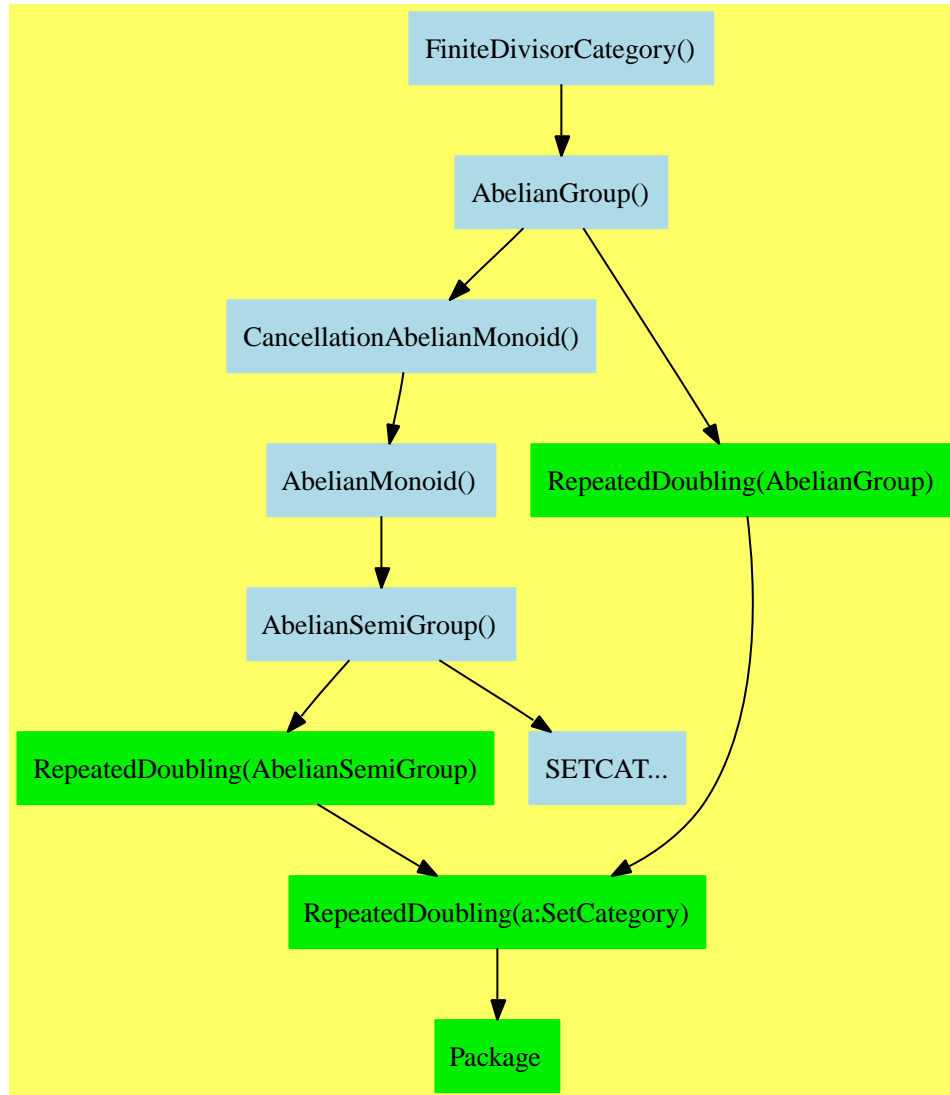
"ConvertibleTo(InputForm)" [color="#00EE00"];
"ConvertibleTo(InputForm)" -> "ConvertibleTo(a:Type)"

"ConvertibleTo(a:Type)" [color="#00EE00"];
"ConvertibleTo(a:Type)" -> "Category"

"Category" [color=lightblue];
}
```

Chapter 8

Category Layer 7

FiniteDivisorCategory (FDIVCAT)

— FiniteDivisorCategory.input —

```

)set break resume
)sys rm -f FiniteDivisorCategory.output
)spool FiniteDivisorCategory.output
)set message test on
)set message auto off

```

```

)clear all

--S 1 of 1
)show FiniteDivisorCategory
--R
--R FiniteDivisorCategory(F: Field,UP: UnivariatePolynomialCategory(t#1),UPUP: UnivariatePolynomialCategory
--R Abbreviation for FiniteDivisorCategory is FDIVCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FDIVCAT
--R
--R----- Operations -----
--R ?? : (Integer,%) -> %          ?? : (PositiveInteger,%) -> %
--R ?+? : (%,%) -> %              ?-? : (%,%) -> %
--R -? : % -> %                   ?=? : (%,%) -> Boolean
--R 0 : () -> %                   coerce : % -> OutputForm
--R divisor : (R,UP,UP,UP,F) -> %   divisor : (F,F,Integer) -> %
--R divisor : (F,F) -> %           divisor : R -> %
--R hash : % -> SingleInteger       latex : % -> String
--R principal? : % -> Boolean       reduce : % -> %
--R sample : () -> %               zero? : % -> Boolean
--R ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R decompose : % -> Record(id: FractionalIdeal(UP,Fraction(UP),UPUP,R),principalPart: R)
--R divisor : FractionalIdeal(UP,Fraction(UP),UPUP,R) -> %
--R generator : % -> Union(R,"failed")
--R ideal : % -> FractionalIdeal(UP,Fraction(UP),UPUP,R)
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— FiniteDivisorCategory.help —

FiniteDivisorCategory examples

This category describes finite rational divisors on a curve, that is finite formal sums $\sum (n * P)$ where the n 's are integers and the P 's are finite rational points on the curve.

See Also:

o)show FiniteDivisorCategory

See:

⇐ “AbelianGroup” (ABELGRP) 7 on page 574

Exports:

| | | | | |
|--------|---------------|-----------|------------|-----------|
| 0 | coerce | decompose | divisor | generator |
| hash | ideal | latex | principal? | reduce |
| sample | subtractIfCan | zero? | ?~=? | ?*? |
| ?+? | ?-? | -? | ?=? | |

These are directly exported but not implemented:

```

decompose : % ->
  Record(id: FractionalIdeal(UP,Fraction UP,UPUP,R),principalPart: R)
divisor : R -> %
divisor : FractionalIdeal(UP,Fraction UP,UPUP,R) -> %
divisor : (F,F) -> %
divisor : (F,F,Integer) -> %
divisor : (R,UP,UP,UP,F) -> %
generator : % -> Union(R,"failed")
ideal : % -> FractionalIdeal(UP,Fraction UP,UPUP,R)
reduce : % -> %

```

These are implemented by this category:

```

principal? : % -> Boolean

```

These exports come from (p574) AbelianGroup():

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
-? : % -> %
?-? : (%,%) -> %
?~=? : (%,%) -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?*? : (PositiveInteger,%) -> %
?*? : (Integer,%) -> %
?*? : (NonNegativeInteger,%) -> %

```

```

)abbrev category FDIVCAT FiniteDivisorCategory
++ Category for finite rational divisors on a curve
++ Author: Manuel Bronstein
++ Date Created: 19 May 1993
++ Date Last Updated: 19 May 1993
++ Description:
++ This category describes finite rational divisors on a curve, that
++ is finite formal sums  $\sum(n * P)$  where the n's are integers and the
++ P's are finite rational points on the curve.

FiniteDivisorCategory(F, UP, UPUP, R): Category == Result where
  F   : Field
  UP  : UnivariatePolynomialCategory F
  UPUP: UnivariatePolynomialCategory Fraction UP
  R   : FunctionFieldCategory(F, UP, UPUP)

ID ==> FractionalIdeal(UP, Fraction UP, UPUP, R)

Result ==> AbelianGroup with
  ideal      : % -> ID
    ++ ideal(D) returns the ideal corresponding to a divisor D.
  divisor    : ID -> %
    ++ divisor(I) makes a divisor D from an ideal I.
  divisor    : R -> %
    ++ divisor(g) returns the divisor of the function g.
  divisor    : (F, F) -> %
    ++ divisor(a, b) makes the divisor P: \spad{(x = a, y = b)}.
    ++ Error: if P is singular.
  divisor    : (F, F, Integer) -> %
    ++ divisor(a, b, n) makes the divisor
    ++ \spad{nP} where P: \spad{(x = a, y = b)}.
    ++ P is allowed to be singular if n is a multiple of the rank.
  decompose  : % -> Record(id:ID, principalPart: R)
    ++ decompose(d) returns \spad{[id, f]} where \spad{d = (id) + div(f)}.
  reduce     : % -> %
    ++ reduce(D) converts D to some reduced form (the reduced forms can
    ++ be different in different implementations).
  principal? : % -> Boolean
    ++ principal?(D) tests if the argument is the divisor of a function.
  generator  : % -> Union(R, "failed")
    ++ generator(d) returns f if \spad{(f) = d},
    ++ "failed" if d is not principal.
  divisor    : (R, UP, UP, UP, F) -> %
    ++ divisor(h, d, d', g, r) returns the sum of all the finite points
    ++ where \spad{h/d} has residue \spad{r}.
    ++ \spad{h} must be integral.
    ++ \spad{d} must be squarefree.
    ++ \spad{d'} is some derivative of \spad{d} (not necessarily dd/dx).
    ++ \spad{g = gcd(d,discriminant)} contains the ramified zeros of \spad{d}
add

```



```
principal? d == generator(d) case R
```

— **FDIVCAT.dotabb** —

```
"FDIVCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FDIVCAT"];
"FDIVCAT" -> "ABELGRP"
```

— **FDIVCAT.dotfull** —

```
"FiniteDivisorCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FDIVCAT"];
"FiniteDivisorCategory()" -> "AbelianGroup()"
```

— **FDIVCAT.dotpic** —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FiniteDivisorCategory()" [color=lightblue];
  "FiniteDivisorCategory()" -> "AbelianGroup()"

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CancellationAbelianMonoid()"
  "AbelianGroup()" -> "RepeatedDoubling(AbelianGroup)"

  "RepeatedDoubling(AbelianGroup)" [color="#00EE00"];
  "RepeatedDoubling(AbelianGroup)" -> "RepeatedDoubling(a:SetCategory)"

  "RepeatedDoubling(AbelianSemiGroup)" [color="#00EE00"];
  "RepeatedDoubling(AbelianSemiGroup)" -> "RepeatedDoubling(a:SetCategory)"

  "RepeatedDoubling(a:SetCategory)" [color="#00EE00"];
  "RepeatedDoubling(a:SetCategory)" -> "Package"

  "Package" [color="#00EE00];
```

```

"CancellationAbelianMonoid()" [color=lightblue];
"CancellationAbelianMonoid()" -> "AbelianMonoid()"

"AbelianMonoid()" [color=lightblue];
"AbelianMonoid()" -> "AbelianSemiGroup()"

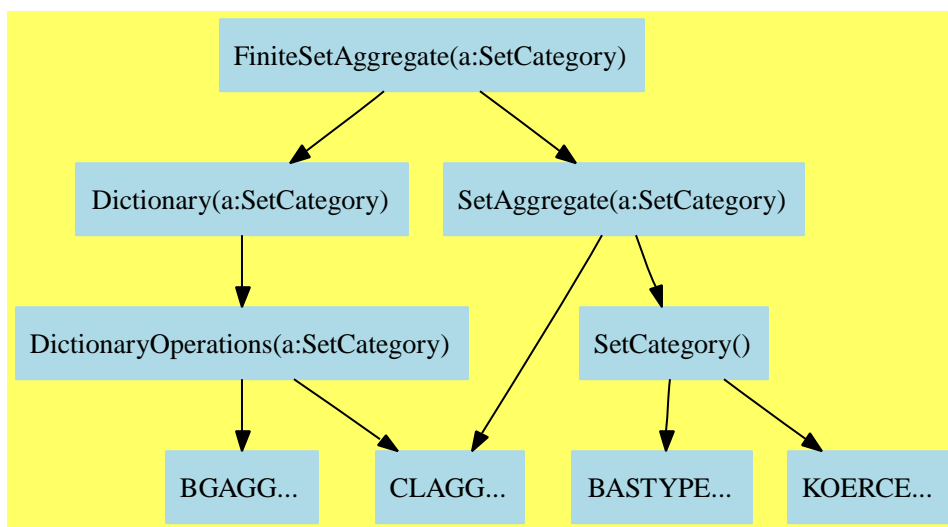
"AbelianSemiGroup()" [color=lightblue];
"AbelianSemiGroup()" -> "SETCAT..."
"AbelianSemiGroup()" -> "RepeatedDoubling(AbelianSemiGroup)"

"SETCAT..." [color=lightblue];
}

```

—————→

FiniteSetAggregate (FSAGG)



— FiniteSetAggregate.input —

```

)set break resume
)sys rm -f FiniteSetAggregate.output
)spool FiniteSetAggregate.output
)set message test on
)set message auto off
)clear all

```

```

--S 1 of 1
)show FiniteSetAggregate
--R FiniteSetAggregate(S: SetCategory) is a category constructor
--R Abbreviation for FiniteSetAggregate is FSAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FSAGG
--R
--R----- Operations -----
--R ?<? : (%,% ) -> Boolean          ?=? : (%,% ) -> Boolean
--R bag : List(S) -> %               brace : () -> %
--R brace : List(S) -> %             coerce : % -> OutputForm
--R construct : List(S) -> %         copy : % -> %
--R dictionary : List(S) -> %        dictionary : () -> %
--R difference : (%,% ) -> %         difference : (% ,S) -> %
--R empty : () -> %                 empty? : % -> Boolean
--R eq? : (%,% ) -> Boolean          extract! : % -> S
--R hash : % -> SingleInteger        insert! : (S,% ) -> %
--R inspect : % -> S                 intersect : (%,% ) -> %
--R latex : % -> String              map : ((S -> S),%) -> %
--R max : % -> S if S has ORDSET     min : % -> S if S has ORDSET
--R sample : () -> %                set : () -> %
--R set : List(S) -> %               subset? : (%,% ) -> Boolean
--R union : (%,% ) -> %              union : (% ,S) -> %
--R union : (S,% ) -> %              ?~=? : (%,% ) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R cardinality : % -> NonNegativeInteger
--R complement : % -> % if S has FINITE
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : (S,% ) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R enumerate : () -> List(%) if S has FINITE
--R eval : (% ,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R index : PositiveInteger -> % if S has FINITE
--R less? : (% ,NonNegativeInteger) -> Boolean
--R lookup : % -> PositiveInteger if S has FINITE
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,% ) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R random : () -> % if S has FINITE
--R reduce : ((S,S) -> S),%) -> S if $ has finiteAggregate
--R reduce : ((S,S) -> S),% ,S) -> S if $ has finiteAggregate
--R reduce : ((S,S) -> S),% ,S,S) -> S if S has SETCAT and $ has finiteAggregate

```

```

--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
--R remove! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove! : (S,%) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R select! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R size : () -> NonNegativeInteger if S has FINITE
--R size? : (%,NonNegativeInteger) -> Boolean
--R symmetricDifference : (%,%) -> %
--R universe : () -> % if S has FINITE
--R
--E 1

)spool
)lisp (bye)

```

— FiniteSetAggregate.help —

```

=====
FiniteSetAggregate examples
=====

```

A finite-set aggregate models the notion of a finite set, that is, a collection of elements characterized by membership, but not by order or multiplicity. See Set for an example.

See Also:

- o)show FiniteSetAggregate
- o)show Set

See:

⇐ “Dictionary” (DIAGG) [7](#) on page [586](#)
⇐ “SetAggregate” (SETAGG) [6](#) on page [546](#)

Exports:

| | | | | |
|------------|------------|---------------------|-------------|------------------|
| any? | bag | brace | cardinality | coerce |
| complement | construct | convert | copy | count |
| dictionary | difference | empty | empty? | eq? |
| eval | every? | extract! | find | hash |
| index | insert! | inspect | intersect | latex |
| less? | lookup | map | map! | max |
| member? | members | min | more? | parts |
| random | reduce | remove | remove! | removeDuplicates |
| sample | select | select! | set | size |
| size? | subset? | symmetricDifference | union | universe |
| #? | ?<? | ?=? | ?~=? | |

Attributes Exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **partiallyOrderedSet** is true if a set with $<$ which is transitive, but not($a < b$ or $a = b$) does not necessarily imply $b < a$.
- **nil**

These are implemented by this category:

```

brace : List S -> %
cardinality : % -> NonNegativeInteger
coerce : % -> OutputForm
complement : % -> % if S has FINITE
construct : List S -> %
count : (S,%) -> NonNegativeInteger
    if S has SETCAT and $ has finiteAggregate
difference : (%,% ) -> %
index : PositiveInteger -> % if S has FINITE
intersect : (%,% ) -> %
lookup : % -> PositiveInteger if S has FINITE
max : % -> S if S has ORDSET
min : % -> S if S has ORDSET
random : () -> % if S has FINITE
set : List S -> %
size : () -> NonNegativeInteger if S has FINITE
subset? : (%,% ) -> Boolean
symmetricDifference : (%,% ) -> %
union : (%,% ) -> %
universe : () -> % if S has FINITE
?<? : (%,% ) -> Boolean
?=? : (%,% ) -> Boolean

```

These exports come from (p586) Dictionary(S:SetCategory):

```

any? : ((S -> Boolean),%) -> Boolean
    if $ has finiteAggregate
bag : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
copy : % -> %
count : ((S -> Boolean),%) -> NonNegativeInteger
    if $ has finiteAggregate
dictionary : () -> %
dictionary : List S -> %
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
    if S has EVALAB S
    and S has SETCAT
eval : (%,S,S) -> %
    if S has EVALAB S
    and S has SETCAT
eval : (%,Equation S) -> %
    if S has EVALAB S
    and S has SETCAT
eval : (%,List Equation S) -> %
    if S has EVALAB S
    and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean
    if $ has finiteAggregate
extract! : % -> S
find : ((S -> Boolean),%) -> Union(S,"failed")
hash : % -> SingleInteger
insert! : (S,%) -> %
inspect : % -> S
latex : % -> String
less? : (%,NonNegativeInteger) -> Boolean
select! : ((S -> Boolean),%) -> %
    if $ has finiteAggregate
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> %
    if $ has shallowlyMutable
member? : (S,%) -> Boolean
    if S has SETCAT
    and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S
    if $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S
    if $ has finiteAggregate

```

```

reduce : ((S,S) -> S),%,S,S) -> S
  if S has SETCAT
  and $ has finiteAggregate
remove : ((S -> Boolean),%) -> %
  if $ has finiteAggregate
remove : (S,%) -> %
  if S has SETCAT
  and $ has finiteAggregate
remove! : ((S -> Boolean),%) -> %
  if $ has finiteAggregate
remove! : (S,%) -> % if $ has finiteAggregate
removeDuplicates : % -> %
  if S has SETCAT
  and $ has finiteAggregate
sample : () -> %
select : ((S -> Boolean),%) -> %
  if $ has finiteAggregate
size? : (%,NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
?~=? : (%,%) -> Boolean

```

These exports come from (p546) SetAggregate(S:SetCategory):

```

brace : () -> %
difference : (%,S) -> %
set : () -> %
union : (%,S) -> %
union : (S,%) -> %

```

— category FSAGG FiniteSetAggregate —

```

)abbrev category FSAGG FiniteSetAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: 14 Oct, 1993 by RSS
++ Description:
++ A finite-set aggregate models the notion of a finite set, that is,
++ a collection of elements characterized by membership, but not
++ by order or multiplicity.
++ See \spadtype{Set} for an example.

```

```

FiniteSetAggregate(S:SetCategory): Category ==
  Join(Dictionary S, SetAggregate S) with
    finiteAggregate
    cardinality: % -> NonNegativeInteger
      ++ cardinality(u) returns the number of elements of u.
      ++ Note that \axiom{cardinality(u) = #u}.
    if S has Finite then
      Finite

```

```

complement: % -> %
  ++ complement(u) returns the complement of the set u,
  ++ that is, the set of all values not in u.
universe: () -> %
  ++ universe()$D returns the universal set for finite set aggregate D.
if S has OrderedSet then
  max: % -> S
    ++ max(u) returns the largest element of aggregate u.
  min: % -> S
    ++ min(u) returns the smallest element of aggregate u.

add
s < t          == #s < #t and s = intersect(s,t)
s = t          == #s = #t and empty? difference(s,t)
brace l        == construct l
set            l == construct l
cardinality s  == #s
construct l     == (s := set(); for x in l repeat insert_!(x,s); s)
count(x:S, s:%) == (member?(x, s) => 1; 0)
subset?(s, t)  == #s <= #t and _and/[member?(x, t) for x in parts s]

coerce(s:%):OutputForm ==
  brace [x::OutputForm for x in parts s]$List(OutputForm)

intersect(s, t) ==
  i := {}
  for x in parts s | member?(x, t) repeat insert_!(x, i)
  i

difference(s:%, t:%) ==
  m := copy s
  for x in parts t repeat remove_!(x, m)
  m

symmetricDifference(s, t) ==
  d := copy s
  for x in parts t repeat
    if member?(x, s) then remove_!(x, d) else insert_!(x, d)
  d

union(s:%, t:%) ==
  u := copy s
  for x in parts t repeat insert_!(x, u)
  u

if S has Finite then
  universe() == {index(i::PositiveInteger) for i in 1..size()$S}
  complement s == difference(universe(), s)
  size() == 2 ** size()$S
  index i ==

```



```

    {index(j::PositiveInteger)$S for j in 1..size()$S | bit?(i-1,j-1)}
  random() ==
    index((random()$Integer rem (size()$% + 1))::PositiveInteger)

  lookup s ==
    n:PositiveInteger := 1
    for x in parts s repeat _
      n := n + 2 ** ((lookup(x) - 1)::NonNegativeInteger)
    n

  if S has OrderedSet then
    max s ==
      empty?(l := parts s) => error "Empty set"
      reduce("max", l)

    min s ==
      empty?(l := parts s) => error "Empty set"
      reduce("min", l)

    _____

    — FSAGG.dotabb —

    "FSAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=FSAGG"];
    "FSAGG" -> "DIAGG"
    "FSAGG" -> "SETAGG"

    _____

    — FSAGG.dotfull —

    "FiniteSetAggregate(a:SetCategory)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=FSAGG"];
    "FiniteSetAggregate(a:SetCategory)" -> "Dictionary(a:SetCategory)"
    "FiniteSetAggregate(a:SetCategory)" -> "SetAggregate(a:SetCategory)"

    _____

    — FSAGG.dotpic —

    digraph pic {
      fontsize=10;
      bgcolor="#ECEA81";
      node [shape=box, color=white, style=filled];

```

```

"FiniteSetAggregate(a:SetCategory)" [color=lightblue];
"FiniteSetAggregate(a:SetCategory)" -> "Dictionary(a:SetCategory)"
"FiniteSetAggregate(a:SetCategory)" -> "SetAggregate(a:SetCategory)"

"SetAggregate(a:SetCategory)" [color=lightblue];
"SetAggregate(a:SetCategory)" -> "SetCategory()"
"SetAggregate(a:SetCategory)" -> "CLAGG..."

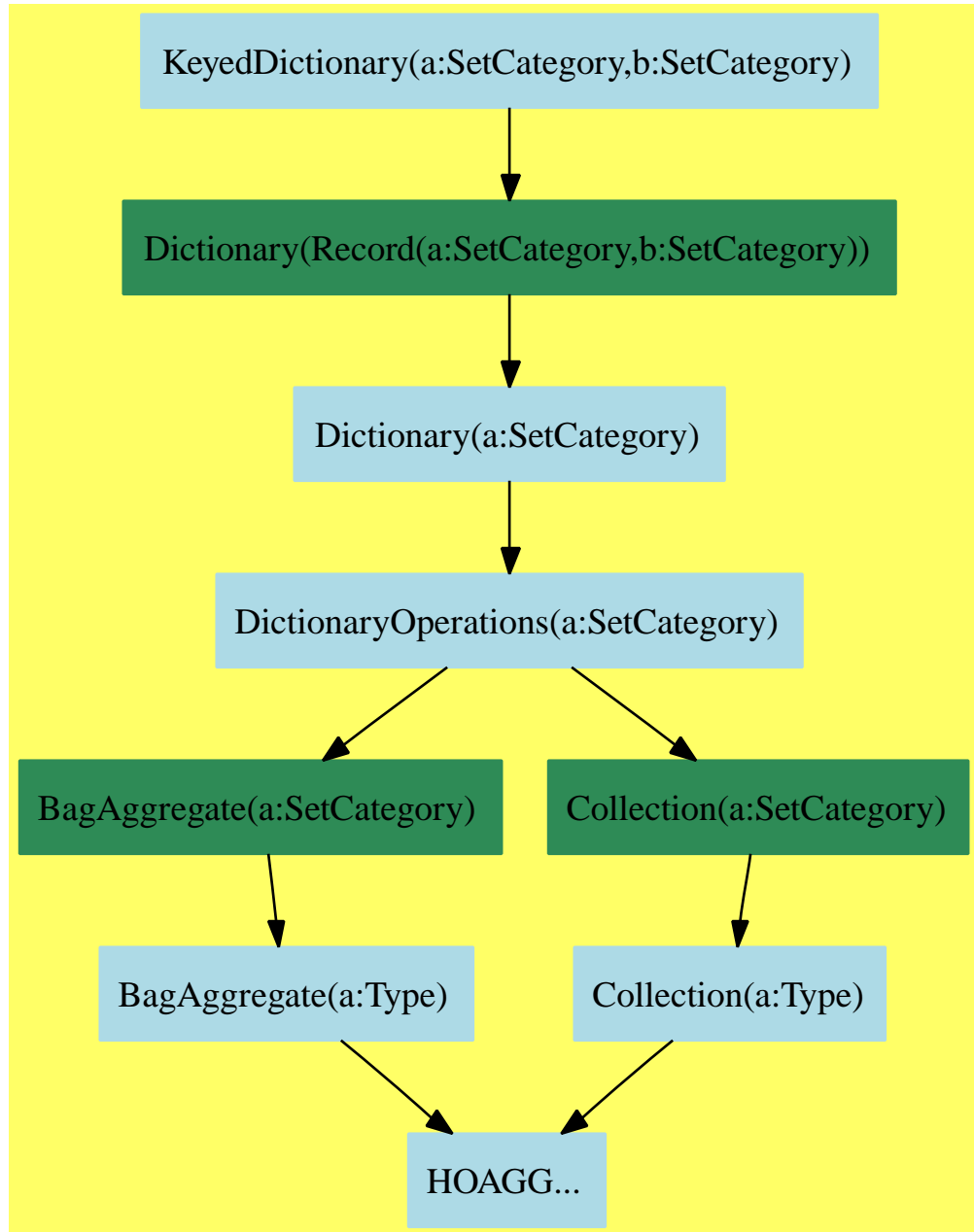
"SetCategory()" [color=lightblue];
"SetCategory()" -> "BASTYPE..."
"SetCategory()" -> "KOERCE..."

"Dictionary(a:SetCategory)" [color=lightblue];
"Dictionary(a:SetCategory)" -> "DictionaryOperations(a:SetCategory)"

"DictionaryOperations(a:SetCategory)" [color=lightblue];
"DictionaryOperations(a:SetCategory)" -> "BGAGG..."
"DictionaryOperations(a:SetCategory)" -> "CLAGG..."

"BGAGG..." [color=lightblue];
"CLAGG..." [color=lightblue];
"BASTYPE..." [color=lightblue];
"KOERCE..." [color=lightblue];
}

```

KeyedDictionary (KDAGG)

— KeyedDictionary.input —

```

)set break resume
)sys rm -f KeyedDictionary.output
)spool KeyedDictionary.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show KeyedDictionary
--R
--R KeyedDictionary(Key: SetCategory,Entry: SetCategory) is a category constructor
--R Abbreviation for KeyedDictionary is KDAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for KDAGG
--R
--R----- Operations -----
--R copy : % -> % dictionary : () -> %
--R empty : () -> % empty? : % -> Boolean
--R eq? : (%,% ) -> Boolean key? : (Key,% ) -> Boolean
--R keys : % -> List(Key) sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ==? : (%,% ) -> Boolean if Record(key: Key,entry: Entry) has SETCAT
--R any? : ((Record(key: Key,entry: Entry) -> Boolean),%) -> Boolean if $ has finiteAggregate
--R bag : List(Record(key: Key,entry: Entry)) -> %
--R coerce : % -> OutputForm if Record(key: Key,entry: Entry) has SETCAT
--R construct : List(Record(key: Key,entry: Entry)) -> %
--R convert : % -> InputForm if Record(key: Key,entry: Entry) has KONVERT(INFORM)
--R count : (Record(key: Key,entry: Entry),%) -> NonNegativeInteger if Record(key: Key,entry: Entry) has SETCAT
--R count : ((Record(key: Key,entry: Entry) -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R dictionary : List(Record(key: Key,entry: Entry)) -> %
--R eval : (% ,List(Record(key: Key,entry: Entry)),List(Record(key: Key,entry: Entry))) -> % if Record(key: Key,entry: Entry) has SETCAT
--R eval : (% ,Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> % if Record(key: Key,entry: Entry) has SETCAT
--R eval : (% ,Equation(Record(key: Key,entry: Entry))) -> % if Record(key: Key,entry: Entry) has EVALAB(Record(key: Key,entry: Entry))
--R eval : (% ,List(Equation(Record(key: Key,entry: Entry)))) -> % if Record(key: Key,entry: Entry) has EVALAB(Record(key: Key,entry: Entry))
--R every? : ((Record(key: Key,entry: Entry) -> Boolean),%) -> Boolean if $ has finiteAggregate
--R extract! : % -> Record(key: Key,entry: Entry)
--R find : ((Record(key: Key,entry: Entry) -> Boolean),%) -> Union(Record(key: Key,entry: Entry),"failed")
--R hash : % -> SingleInteger if Record(key: Key,entry: Entry) has SETCAT
--R insert! : (Record(key: Key,entry: Entry),%) -> %
--R inspect : % -> Record(key: Key,entry: Entry)
--R latex : % -> String if Record(key: Key,entry: Entry) has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map : ((Record(key: Key,entry: Entry) -> Record(key: Key,entry: Entry)),%) -> %
--R map! : ((Record(key: Key,entry: Entry) -> Record(key: Key,entry: Entry)),%) -> % if $ has shallowlyMutable
--R member? : (Record(key: Key,entry: Entry),%) -> Boolean if Record(key: Key,entry: Entry) has SETCAT and $ has finiteAggregate
--R members : % -> List(Record(key: Key,entry: Entry)) if $ has finiteAggregate
--R more? : (% ,NonNegativeInteger) -> Boolean
--R parts : % -> List(Record(key: Key,entry: Entry)) if $ has finiteAggregate
--R reduce : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,entry: Entry)),%) -> Record(key: Key,entry: Entry)
--R reduce : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,entry: Entry)),Record(key: Key,entry: Entry)) -> Record(key: Key,entry: Entry)

```

```

--R reduce : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,
--R remove : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (Record(key: Key,entry: Entry),%) -> % if Record(key: Key,entry: Entry) has SETCAT
--R remove! : (Key,%) -> Union(Entry,"failed")
--R remove! : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R remove! : (Record(key: Key,entry: Entry),%) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if Record(key: Key,entry: Entry) has SETCAT and $ has finiteAggregate
--R search : (Key,%) -> Union(Entry,"failed")
--R select : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R select! : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (% ,NonNegativeInteger) -> Boolean
--R ~=? : (% ,%) -> Boolean if Record(key: Key,entry: Entry) has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— **KeyedDictionary.help** —

=====

KeyedDictionary examples

=====

A keyed dictionary is a dictionary of key-entry pairs for which there is a unique entry for each key.

See Also:

o)show KeyedDictionary

See:

⇒ “TableAggregate” (TBAGG) [9](#) on page [852](#)

⇐ “Dictionary” (DIAGG) [7](#) on page [586](#)

Exports:

| | | | | |
|---------|------------------|------------|-----------|---------|
| any? | bag | coerce | construct | convert |
| copy | count | dictionary | empty | empty? |
| eq? | eval | every? | extract! | find |
| hash | insert! | inspect | key? | keys |
| latex | less? | map | map! | member? |
| members | more? | parts | reduce | remove |
| remove! | removeDuplicates | sample | search | select |
| select! | size? | #? | ?=? | ?~=? |

Attributes exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

Attributes Used:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.

These are directly exported but not implemented:

```
remove! : (Key,%) -> Union(Entry,"failed")
search  : (Key,%) -> Union(Entry,"failed")
```

These are implemented by this category:

```
key? : (Key,%) -> Boolean
member? : (Record(key: Key,entry: Entry),%) -> Boolean
    if Record(key: Key,entry: Entry) has SETCAT
    and $ has finiteAggregate
keys : % -> List Key
```

These exports come from (p586) Dictionary(R)
 where R=Record(a:SetCategory,b:SetCategory)
 and S=Record(key: Key,entry: Entry)

```
any? : ((S -> Boolean),%) -> Boolean
    if $ has finiteAggregate
bag : List S -> %
coerce : % -> OutputForm if S has SETCAT
construct : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
copy : % -> %
count : (S,%) -> NonNegativeInteger
    if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
    if $ has finiteAggregate
```

```

dictionary : () -> %
dictionary : List S -> %
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
extract! : % -> S
find : ((S -> Boolean),%) -> Union(S,"failed")
hash : % -> SingleInteger if S has SETCAT
insert! : (S,%) -> %
inspect : % -> S
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> %
      if $ has shallowlyMutable
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S
      if $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S
      if $ has finiteAggregate
reduce : (((S,S) -> S),%,S,S) -> S
      if S has SETCAT and $ has finiteAggregate
remove : ((S -> Boolean),%) -> %
      if $ has finiteAggregate
remove : (S,%) -> %
      if S has SETCAT and $ has finiteAggregate
remove! : ((S -> Boolean),%) -> %
      if $ has finiteAggregate
remove! : (S,%) -> % if $ has finiteAggregate
removeDuplicates : % -> %
      if S has SETCAT and $ has finiteAggregate
sample : () -> %
select : ((S -> Boolean),%) -> %
      if $ has finiteAggregate
select! : ((S -> Boolean),%) -> %
      if $ has finiteAggregate
size? : (%,NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger

```

```

    if $ has finiteAggregate
    ?=? : (%,%) -> Boolean if S has SETCAT
    ?~=? : (%,%) -> Boolean if S has SETCAT

```

— category KDAGG KeyedDictionary —

```

)abbrev category KDAGG KeyedDictionary
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A keyed dictionary is a dictionary of key-entry pairs for which there is
++ a unique entry for each key.

KeyedDictionary(Key:SetCategory, Entry:SetCategory): Category ==
  Dictionary Record(key:Key,entry:Entry) with
    key?: (Key, %) -> Boolean
      ++ key?(k,t) tests if k is a key in table t.
    keys: % -> List Key
      ++ keys(t) returns the list the keys in table t.
    -- to become keys: % -> Key* and keys: % -> Iterator(Entry,Entry)
    remove_!: (Key, %) -> Union(Entry,"failed")
      ++ remove!(k,t) searches the table t for the key k removing
      ++ (and return) the entry if there.
      ++ If t has no such key, \axiom{remove!(k,t)} returns "failed".
    search: (Key, %) -> Union(Entry,"failed")
      ++ search(k,t) searches the table t for the key k,
      ++ returning the entry stored in t for key k.
      ++ If t has no such key, \axiom{search(k,t)} returns "failed".
add
  key?(k, t) == search(k, t) case Entry

  member?(p, t) ==
    r := search(p.key, t)
    r case Entry and r::Entry = p.entry

  if % has finiteAggregate then
    keys t == [x.key for x in parts t]

```

— KDAGG.dotabb —

```

"KDAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=KDAGG"];
"KDAGG" -> "DIAGG"

```


— KDAGG.dotfull —

```
"KeyedDictionary(a:SetCategory,b:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=KDAGG"];
"KeyedDictionary(a:SetCategory,b:SetCategory)" ->
  "Dictionary(Record(a:SetCategory,b:SetCategory))"
```

— KDAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "KeyedDictionary(a:SetCategory,b:SetCategory)" [color=lightblue];
  "KeyedDictionary(a:SetCategory,b:SetCategory)" ->
    "Dictionary(Record(a:SetCategory,b:SetCategory))"

  "Dictionary(Record(a:SetCategory,b:SetCategory))" [color=seagreen];
  "Dictionary(Record(a:SetCategory,b:SetCategory))" ->
    "Dictionary(a:SetCategory)"

  "Dictionary(a:SetCategory)" [color=lightblue];
  "Dictionary(a:SetCategory)" -> "DictionaryOperations(a:SetCategory)"

  "DictionaryOperations(a:SetCategory)" [color=lightblue];
  "DictionaryOperations(a:SetCategory)" -> "BagAggregate(a:SetCategory)"
  "DictionaryOperations(a:SetCategory)" -> "Collection(a:SetCategory)"

  "BagAggregate(a:SetCategory)" [color=seagreen];
  "BagAggregate(a:SetCategory)" -> "BagAggregate(a:Type)"

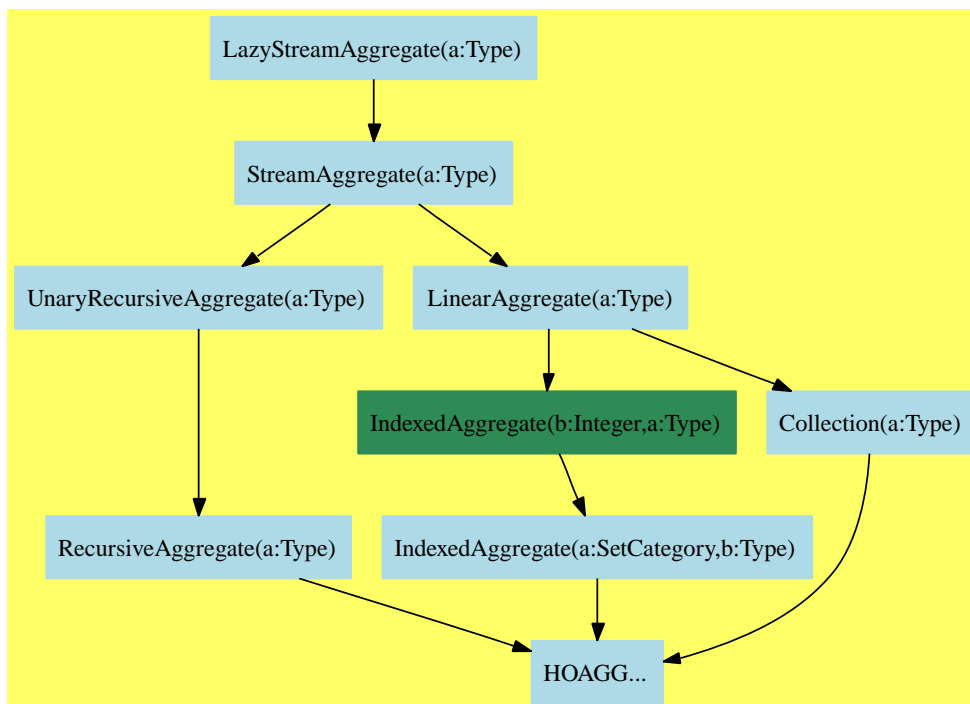
  "BagAggregate(a:Type)" [color=lightblue];
  "BagAggregate(a:Type)" -> "HOAGG..."

  "Collection(a:SetCategory)" [color=seagreen];
  "Collection(a:SetCategory)" -> "Collection(a:Type)"

  "Collection(a:Type)" [color=lightblue];
  "Collection(a:Type)" -> "HOAGG..."

  "HOAGG..." [color=lightblue];
}
```

LazyStreamAggregate (LZSTAGG)



— LazyStreamAggregate.input —

```

)set break resume
)sys rm -f LazyStreamAggregate.output
)spool LazyStreamAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show LazyStreamAggregate
--R
--R LazyStreamAggregate(S: Type) is a category constructor
--R Abbreviation for LazyStreamAggregate is LZSTAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LZSTAGG
--R
--R----- Operations -----

```

```

--R children : % -> List(%)
--R concat : (%,S) -> %
--R concat : (S,%) -> %
--R construct : List(S) -> %
--R cycleEntry : % -> %
--R cyclic? : % -> Boolean
--R distance : (%,%) -> Integer
--R ?.? : (%,Integer) -> S
--R ?.rest : (%,rest) -> %
--R ?.value : (%,value) -> S
--R empty? : % -> Boolean
--R eq? : (%,%) -> Boolean
--R explicitlyEmpty? : % -> Boolean
--R extend : (%,Integer) -> %
--R first : % -> S
--R indices : % -> List(Integer)
--R insert : (%,%,Integer) -> %
--R lazy? : % -> Boolean
--R leaf? : % -> Boolean
--R map : (((S,S) -> S),%,%) -> %
--R new : (NonNegativeInteger,S) -> %
--R possiblyInfinite? : % -> Boolean
--R remove : ((S -> Boolean),%) -> %
--R rst : % -> %
--R second : % -> S
--R tail : % -> %
--R value : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (%,%) -> Boolean if S has SETCAT
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R child? : (%,%) -> Boolean if S has SETCAT
--R coerce : % -> OutputForm if S has SETCAT
--R concat! : (%,S) -> % if $ has shallowlyMutable
--R concat! : (%,%) -> % if $ has shallowlyMutable
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R cycleLength : % -> NonNegativeInteger
--R cycleSplit! : % -> % if $ has shallowlyMutable
--R delete : (%,UniversalSegment(Integer)) -> %
--R ?.? : (%,UniversalSegment(Integer)) -> %
--R entry? : (S,%) -> Boolean if $ has finiteAggregate and S has SETCAT
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (%,S) -> % if $ has shallowlyMutable
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R first : (%,NonNegativeInteger) -> %
complete : % -> %
concat : List(%) -> %
concat : (%,%) -> %
copy : % -> %
cycleTail : % -> %
delete : (%,Integer) -> %
elt : (%,Integer,S) -> S
?.last : (%,last) -> S
?.first : (%,first) -> S
empty : () -> %
entries : % -> List(S)
explicitEntries? : % -> Boolean
explicitlyFinite? : % -> Boolean
first : % -> S
index? : (Integer,%) -> Boolean
insert : (S,%,Integer) -> %
last : % -> S
lazyEvaluate : % -> %
leaves : % -> List(S)
map : ((S -> S),%) -> %
nodes : % -> List(%)
qelt : (%,Integer) -> S
rest : % -> %
sample : () -> %
select : ((S -> Boolean),%) -> %
third : % -> S

```

```

--R hash : % -> SingleInteger if S has SETCAT
--R last : (% , NonNegativeInteger) -> %
--R latex : % -> String if S has SETCAT
--R less? : (% , NonNegativeInteger) -> Boolean
--R map! : ((S -> S) , %) -> % if $ has shallowlyMutable
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (S , %) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (% , NonNegativeInteger) -> Boolean
--R node? : (% , %) -> Boolean if S has SETCAT
--R numberOfComputedEntries : % -> NonNegativeInteger
--R parts : % -> List(S) if $ has finiteAggregate
--R qsetelt! : (% , Integer , S) -> S if $ has shallowlyMutable
--R reduce : (((S , S) -> S) , % , S , S) -> S if S has SETCAT and $ has finiteAggregate
--R reduce : (((S , S) -> S) , % , S) -> S if $ has finiteAggregate
--R reduce : (((S , S) -> S) , %) -> S if $ has finiteAggregate
--R remove : (S , %) -> % if S has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R rest : (% , NonNegativeInteger) -> %
--R setchildren! : (% , List(%)) -> % if $ has shallowlyMutable
--R setelt : (% , Integer , S) -> S if $ has shallowlyMutable
--R setelt : (% , UniversalSegment(Integer) , S) -> S if $ has shallowlyMutable
--R setelt : (% , last , S) -> S if $ has shallowlyMutable
--R setelt : (% , rest , %) -> % if $ has shallowlyMutable
--R setelt : (% , first , S) -> S if $ has shallowlyMutable
--R setelt : (% , value , S) -> S if $ has shallowlyMutable
--R setfirst! : (% , S) -> S if $ has shallowlyMutable
--R setlast! : (% , S) -> S if $ has shallowlyMutable
--R setrest! : (% , %) -> % if $ has shallowlyMutable
--R setvalue! : (% , S) -> S if $ has shallowlyMutable
--R size? : (% , NonNegativeInteger) -> Boolean
--R split! : (% , Integer) -> % if $ has shallowlyMutable
--R swap! : (% , Integer , Integer) -> Void if $ has shallowlyMutable
--R ?~=? : (% , %) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— LazyStreamAggregate.help —

```

=====
LazyStreamAggregate examples
=====

```

`LazyStreamAggregate` is the category of streams with lazy evaluation. It is understood that the function `'empty?'` will cause lazy evaluation if necessary to determine if there are entries. Functions which call `'empty?'`, e.g. `'first'` and `'rest'`, will also cause lazy evaluation if necessary.

See Also:

o `)show LazyStreamAggregate`

See:

← “StreamAggregate” (STAGG) 7 on page 639

Exports:

| | | | |
|-------------------------------|--------------------------------|--------------------------------|--------------------------------------|
| <code>any?</code> | <code>child?</code> | <code>children</code> | <code>coerce</code> |
| <code>complete</code> | <code>concat</code> | <code>concat!</code> | <code>construct</code> |
| <code>copy</code> | <code>convert</code> | <code>count</code> | <code>cycleEntry</code> |
| <code>cycleLength</code> | <code>cycleSplit!</code> | <code>cycleTail</code> | <code>cyclic?</code> |
| <code>delete</code> | <code>distance</code> | <code>elt</code> | <code>empty</code> |
| <code>empty?</code> | <code>entry?</code> | <code>entries</code> | <code>eq?</code> |
| <code>explicitEntries?</code> | <code>explicitlyEmpty?</code> | <code>explicitlyFinite?</code> | <code>extend</code> |
| <code>eval</code> | <code>every?</code> | <code>fill!</code> | <code>find</code> |
| <code>first</code> | <code>frst</code> | <code>hash</code> | <code>index?</code> |
| <code>indices</code> | <code>insert</code> | <code>last</code> | <code>latex</code> |
| <code>lazy?</code> | <code>lazyEvaluate</code> | <code>leaf?</code> | <code>leaves</code> |
| <code>less?</code> | <code>map</code> | <code>map!</code> | <code>maxIndex</code> |
| <code>member?</code> | <code>members</code> | <code>minIndex</code> | <code>more?</code> |
| <code>new</code> | <code>node?</code> | <code>nodes</code> | <code>numberOfComputedEntries</code> |
| <code>parts</code> | <code>possiblyInfinite?</code> | <code>qelt</code> | <code>qsetelt!</code> |
| <code>reduce</code> | <code>remove</code> | <code>removeDuplicates</code> | <code>rest</code> |
| <code>rst</code> | <code>sample</code> | <code>second</code> | <code>select</code> |
| <code>setchildren!</code> | <code>setelt</code> | <code>setfirst!</code> | <code>setlast!</code> |
| <code>setrest!</code> | <code>setvalue!</code> | <code>size?</code> | <code>split!</code> |
| <code>swap!</code> | <code>tail</code> | <code>third</code> | <code>value</code> |
| <code>#?</code> | <code>?=?</code> | <code>?.?</code> | <code>?.last</code> |
| <code>?.rest</code> | <code>?.first</code> | <code>?.value</code> | <code>?~=?</code> |

Attributes exported:

- `nil`

These are directly exported but not implemented:

```
explicitEntries? : % -> Boolean
```

```

explicitlyEmpty? : % -> Boolean
first : % -> S
lazy? : % -> Boolean
lazyEvaluate : % -> %
numberOfComputedEntries : % -> NonNegativeInteger
remove : ((S -> Boolean),%) -> %
rst : % -> %
select : ((S -> Boolean),%) -> %

```

These are implemented by this category:

```

any? : ((S -> Boolean),%) -> Boolean
  if $ has finiteAggregate
child? : (%,%) -> Boolean if S has SETCAT
children : % -> List %
complete : % -> %
construct : List S -> %
cycleEntry : % -> %
cycleLength : % -> NonNegativeInteger
cycleTail : % -> %
cyclic? : % -> Boolean
delete : (%,Integer) -> %
delete : (%,UniversalSegment Integer) -> %
distance : (%,%) -> Integer
elt : (%,Integer,S) -> S
entries : % -> List S
every? : ((S -> Boolean),%) -> Boolean
  if $ has finiteAggregate
explicitlyFinite? : % -> Boolean
extend : (%,Integer) -> %
first : (%,NonNegativeInteger) -> %
index? : (Integer,%) -> Boolean
indices : % -> List Integer
insert : (S,%,Integer) -> %
insert : (%,%,Integer) -> %
last : % -> S
last : (%,NonNegativeInteger) -> %
leaf? : % -> Boolean
less? : (%,NonNegativeInteger) -> Boolean
maxIndex : % -> Integer if Integer has ORDSET
minIndex : % -> Integer if Integer has ORDSET
more? : (%,NonNegativeInteger) -> Boolean
node? : (%,%) -> Boolean if S has SETCAT
nodes : % -> List %
possiblyInfinite? : % -> Boolean
rest : % -> %
rest : (%,NonNegativeInteger) -> %
value : % -> S
size? : (%,NonNegativeInteger) -> Boolean
tail : % -> %

```

```

#? : % -> NonNegativeInteger if $ has finiteAggregate
=? : (%,% ) -> Boolean if S has SETCAT
?.? : (% , UniversalSegment Integer) -> %
?.? : (% , Integer) -> S
?.first : (% , first) -> S
?.last : (% , last) -> S
?.rest : (% , rest) -> %

```

These exports come from (p639) `StreamAggregate(S:Type)`:

```

coerce : % -> OutputForm if S has SETCAT
concat : (%,% ) -> %
concat : (% , S) -> %
concat : (S , %) -> %
concat : List % -> %
concat! : (%,% ) -> % if $ has shallowlyMutable
concat! : (% , S) -> % if $ has shallowlyMutable
convert : % -> InputForm if S has KONVERT INFORM
copy : % -> %
count : (S , %) -> NonNegativeInteger
    if S has SETCAT
    and $ has finiteAggregate
count : ((S -> Boolean) , %) -> NonNegativeInteger
    if $ has finiteAggregate
cycleSplit! : % -> % if $ has shallowlyMutable
empty : () -> %
empty? : % -> Boolean
entry? : (S , %) -> Boolean
    if $ has finiteAggregate
    and S has SETCAT
eq? : (%,% ) -> Boolean
eval : (% , List S , List S) -> %
    if S has EVALAB S
    and S has SETCAT
eval : (% , S , S) -> %
    if S has EVALAB S
    and S has SETCAT
eval : (% , Equation S) -> %
    if S has EVALAB S
    and S has SETCAT
eval : (% , List Equation S) -> %
    if S has EVALAB S
    and S has SETCAT
fill! : (% , S) -> % if $ has shallowlyMutable
find : ((S -> Boolean) , %) -> Union(S , "failed")
first : % -> S
hash : % -> SingleInteger if S has SETCAT
latex : % -> String if S has SETCAT
leaves : % -> List S
map : ((S , S) -> S) , % , % -> %

```

```

map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
    if S has SETCAT
    and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
new : (NonNegativeInteger,S) -> %
parts : % -> List S if $ has finiteAggregate
qelt : (%,Integer) -> S
qsetelt! : (%,Integer,S) -> S if $ has shallowlyMutable
reduce : (((S,S) -> S),%,S,S) -> S
    if S has SETCAT
    and $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S if $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
removeDuplicates : % -> %
    if S has SETCAT
    and $ has finiteAggregate
sample : () -> %
second : % -> S
setchildren! : (%,List %) -> % if $ has shallowlyMutable
setelt : (%,Integer,S) -> S if $ has shallowlyMutable
setelt : (%,UniversalSegment Integer,S) -> S
    if $ has shallowlyMutable
setelt : (%,last,S) -> S if $ has shallowlyMutable
setelt : (%,rest,%) -> % if $ has shallowlyMutable
setelt : (%,first,S) -> S if $ has shallowlyMutable
setelt : (%,value,S) -> S if $ has shallowlyMutable
setfirst! : (%,S) -> S if $ has shallowlyMutable
setlast! : (%,S) -> S if $ has shallowlyMutable
setrest! : (%,%) -> % if $ has shallowlyMutable
setvalue! : (%,S) -> S if $ has shallowlyMutable
split! : (%,Integer) -> % if $ has shallowlyMutable
swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable
third : % -> S
?.value : (%,value) -> S
?~=? : (%,%) -> Boolean if S has SETCAT

```

— category LZSTAGG LazyStreamAggregate —

```

)abbrev category LZSTAGG LazyStreamAggregate
++ Author: Clifton J. Williamson
++ Date Created: 22 November 1989
++ Date Last Updated: 20 July 1990
++ Description:
++ LazyStreamAggregate is the category of streams with lazy
++ evaluation. It is understood that the function 'empty?' will
++ cause lazy evaluation if necessary to determine if there are

```


++ entries. Functions which call 'empty?', for example 'first' and 'rest',
 ++ will also cause lazy evaluation if necessary.

LazyStreamAggregate(S:Type): Category == StreamAggregate(S) with

```

remove: (S -> Boolean,%) -> %
  ++remove(f,st) returns a stream consisting of those elements of stream
  ++ st which do not satisfy the predicate f.
  ++ Note that \spad{remove(f,st) = [x for x in st | not f(x)]}.
  ++
  ++X m:=[i for i in 1..]
  ++X f(i:PositiveInteger):Boolean == even? i
  ++X remove(f,m)

select: (S -> Boolean,%) -> %
  ++select(f,st) returns a stream consisting of those elements of stream
  ++ st satisfying the predicate f.
  ++ Note that \spad{select(f,st) = [x for x in st | f(x)]}.
  ++
  ++X m:=[i for i in 0..]
  ++X select(x+>prime? x,m)

explicitEntries?: % -> Boolean
  ++explicitEntries?(s) returns true if the stream s has
  ++ explicitly computed entries, and false otherwise.
  ++
  ++X m:=[i for i in 0..]
  ++X explicitEntries? m

explicitlyEmpty?: % -> Boolean
  ++explicitlyEmpty?(s) returns true if the stream is an
  ++ (explicitly) empty stream.
  ++ Note that this is a null test which will not cause lazy evaluation.
  ++
  ++X m:=[i for i in 0..]
  ++X explicitlyEmpty? m

lazy?: % -> Boolean
  ++lazy?(s) returns true if the first node of the stream s
  ++ is a lazy evaluation mechanism which could produce an
  ++ additional entry to s.
  ++
  ++X m:=[i for i in 0..]
  ++X lazy? m

lazyEvaluate: % -> %
  ++lazyEvaluate(s) causes one lazy evaluation of stream s.
  ++ Caution: the first node must be a lazy evaluation mechanism
  ++ (satisfies \spad{lazy?(s) = true}) as there is no error check.
  ++ Note that a call to this function may

```

```

++ or may not produce an explicit first entry

first: % -> S
++first(s) returns the first element of stream s.
++ Caution: this function should only be called after a \spad{empty?}
++ test has been made since there no error check.
++
++X m:=[i for i in 0..]
++X first m

rst: % -> %
++rst(s) returns a pointer to the next node of stream s.
++ Caution: this function should only be called after a \spad{empty?}
++ test has been made since there no error check.
++
++X m:=[i for i in 0..]
++X rst m

numberOfComputedEntries: % -> NonNegativeInteger
++numberOfComputedEntries(st) returns the number of explicitly
++ computed entries of stream st which exist immediately prior to the
++ time this function is called.
++
++X m:=[i for i in 0..]
++X numberOfComputedEntries m

extend: (%,Integer) -> %
++extend(st,n) causes entries to be computed, if necessary,
++ so that 'st' will have at least 'n' explicit entries or so
++ that all entries of 'st' will be computed if 'st' is finite
++ with length <= n.
++
++X m:=[i for i in 0..]
++X numberOfComputedEntries m
++X extend(m,20)
++X numberOfComputedEntries m

complete: % -> %
++complete(st) causes all entries of 'st' to be computed.
++ this function should only be called on streams which are
++ known to be finite.
++
++X m:=[i for i in 1..]
++X n:=filterUntil(i+>i>100,m)
++X numberOfComputedEntries n
++X complete n
++X numberOfComputedEntries n

add

```

```

MIN ==> 1 -- minimal stream index

I  ==> Integer
NNI ==> NonNegativeInteger
L  ==> List
U  ==> UniversalSegment Integer

indexx?      : (Integer,%) -> Boolean
cycleElt     : % -> Union(%, "failed")
computeCycleLength : % -> NNI
computeCycleEntry  : (%,%) -> %

--% SETCAT functions

if S has SetCategory then

  x = y ==
    eq?(x,y) => true
    explicitlyFinite? x and explicitlyFinite? y =>
      entries x = entries y
    explicitEntries? x and explicitEntries? y =>
      first x = first y and EQ(rst x, rst y)$Lisp
    -- treat cyclic streams
    false

--% HOAGG functions

--null x == empty? x

less?(x,n) ==
  n = 0    => false
  empty? x => true
  less?(rst x, (n-1) :: NNI)

more?(x,n) ==
  empty? x => false
  n = 0    => true
  more?(rst x, (n-1) :: NNI)

size?(x,n) ==
  empty? x => n = 0
  size?(rst x, (n-1) :: NNI)

# x ==
  -- error if stream is not finite
  y := x
  for i in 0.. repeat
    explicitlyEmpty? y => return i
    lazy? y => error "#: infinite stream"
  y := rst y

```

```

    if odd? i then x := rst x
    eq?(x,y) => error "#: infinite stream"

--% CLAGG functions

any?(f,x) ==
  -- error message only when x is a stream with lazy
  -- evaluation and f(s) = false for all stream elements
  -- 's' which have been computed when the function is
  -- called
  y := x
  for i in 0.. repeat
    explicitlyEmpty? y => return false
    lazy? y => error "any?: infinite stream"
    f frst y => return true
    y := rst y
    if odd? i then x := rst x
    eq?(x,y) => return false

every?(f,x) ==
  -- error message only when x is a stream with lazy
  -- evaluation and f(s) = true for all stream elements
  -- 's' which have been computed when the function is
  -- called
  y := x
  for i in 0.. repeat
    explicitlyEmpty? y => return true
    lazy? y => error "every?: infinite stream"
    not f frst y => return false
    y := rst y
    if odd? i then x := rst x
    eq?(x,y) => return true

-- following ops count and member? are only exported if $ has finiteAggregate

-- count(f:S -> Boolean,x:%) ==
--   -- error if stream is not finite
--   count : NNI := 0
--   y := x
--   for i in 0.. repeat
--     explicitlyEmpty? y => return count
--     lazy? y => error "count: infinite stream"
--     if f frst y then count := count + 1
--     y := rst y
--     if odd? i then x := rst x
--     eq?(x,y) => error "count: infinite stream"

-- if S has SetCategory then

```

```

--      count(s:S,x:%) == count(#1 = s,x)
--      -- error if stream is not finite

--      member?(s,x) ==
--      -- error message only when x is a stream with lazy
--      -- evaluation and 's' is not among the stream elements
--      -- which have been computed when the function is called
--      y := x
--      for i in 0.. repeat
--      explicitlyEmpty? y => return false
--      lazy? y => error "member?: infinite stream"
--      first y = s => return true
--      y := rst y
--      if odd? i then x := rst x
--      eq?(x,y) => return false

entries x ==
-- returns a list of elements which have been computed
-- error if infinite
y := x
l : L S := empty()
for i in 0.. repeat
  explicitlyEmpty? y => return reverse_! l
  lazy? y => error "infinite stream"
  l := concat(first y,l)
  y := rst y
  if odd? i then x := rst x
  eq?(x,y) => error "infinite stream"

--% CNAGG functions

construct l ==
  empty? l => empty()
  concat(first l, construct rest l)

--entries x ==
-- returns a list of the stream elements
-- error if the stream is not finite
--members x

--% ELTAGG functions

elt(x:%,n:I) ==
  n < MIN or empty? x => error "elt: no such element"
  n = MIN => first x
  elt(rst x,n - 1)

elt(x:%,n:I,s:S) ==
  n < MIN or empty? x => s
  n = MIN => first x

```

```

    elt(rst x,n - 1)

--% IXAGG functions

-- following assumes % has finiteAggregate and S has SetCategory
-- entry?(s,x) ==
--   -- error message only when x is a stream with lazy
--   -- evaluation and 's' is not among the stream elements
--   -- which have been computed when the function is called
--   member?(s,x)

--entries x ==
--  error if the stream is not finite
--members x

indexx?(n,x) ==
  empty? x => false
  n = MIN => true
  indexx?(n-1,rst x)

index?(n,x) ==
  -- returns 'true' iff 'n' is the index of an entry which
  -- may or may not have been computed when the function is
  -- called
  -- additional entries are computed if necessary
  n < MIN => false
  indexx?(n,x)

indices x ==
  -- error if stream is not finite
  y := x
  l : L I := empty()
  for i in MIN.. repeat
    explicitlyEmpty? y => return reverse_! l
    lazy? y => error "indices: infinite stream"
    l := concat(i,l)
    y := rst y
    if odd? i then x := rst x
    eq?(x,y) => error "indices: infinite stream"

maxIndex x ==
  -- error if stream is not finite
  empty? x =>
    error "maxIndex: no maximal index for empty stream"
  y := rst x
  for i in MIN.. repeat
    explicitlyEmpty? y => return i
    lazy? y => error "maxIndex: infinite stream"
    y := rst y
    if odd? i then x := rst x

```

```

eq?(x,y) => error "maxIndex: infinite stream"

minIndex x ==
  empty? x => error "minIndex: no minimal index for empty stream"
  MIN

--% LNAGG functions

delete(x:%,n:I) ==
-- non-destructive
  not index?(n,x) => error "delete: index out of range"
  concat(first(x,(n - MIN) :: NNI), rest(x,(n - MIN + 1) :: NNI))

delete(x:%,seg:U) ==
  low := lo seg
  hasHi seg =>
    high := hi seg
    high < low => copy x
    (not index?(low,x)) or (not index?(high,x)) =>
      error "delete: index out of range"
    concat(first(x,(low - MIN) :: NNI),rest(x,(high - MIN + 1) :: NNI))
  not index?(low,x) => error "delete: index out of range"
  first(x,(low - MIN) :: NNI)

elt(x:%,seg:U) ==
  low := lo seg
  hasHi seg =>
    high := hi seg
    high < low => empty()
    (not index?(low,x)) or (not index?(high,x)) =>
      error "elt: index out of range"
    first(rest(x,(low - MIN) :: NNI),(high - low + 1) :: NNI)
  not index?(low,x) => error "elt: index out of range"
  rest(x,(low - MIN) :: NNI)

insert(s:S,x:%,n:I) ==
  not index?(n,x) => error "insert: index out of range"
  nn := (n - MIN) :: NNI
  concat([first(x,nn), concat(s, empty()), rest(x,nn)])

insert(y:%,x:%,n:I) ==
  not index?(n,x) => error "insert: index out of range"
  nn := (n - MIN) :: NNI
  concat([first(x,nn), y, rest(x,nn)])

--% RCAGG functions

cycleElt x == cycleElt(x)$CyclicStreamTools(S,%)

cyclic? x ==

```

```

cycleElt(x) case "failed" => false
true

if S has SetCategory then
  child?(x,y) ==
    empty? y => error "child: no children"
    x = rst y

children x ==
  empty? x => error "children: no children"
  [rst x]

distance(x,z) ==
  y := x
  for i in 0.. repeat
    eq?(y,z) => return i
    (explicitlyEmpty? y) or (lazy? y) =>
      error "distance: 2nd arg not a descendent of the 1st"
  y := rst y
  if odd? i then x := rst x
  eq?(x,y) =>
    error "distance: 2nd arg not a descendent of the 1st"

if S has SetCategory then
  node?(z,x) ==
    -- error message only when x is a stream with lazy
    -- evaluation and 'y' is not a node of 'x'
    -- which has been computed when the function is called
    y := x
    for i in 0.. repeat
      z = y => return true
      explicitlyEmpty? y => return false
      lazy? y => error "node?: infinite stream"
    y := rst y
    if odd? i then x := rst x
    eq?(x,y) => return false

nodes x ==
  y := x
  l : L % := []
  for i in 0.. repeat
    explicitlyEmpty? y => return reverse_! l
    lazy? y => error "nodes: infinite stream"
    l := concat(y,l)
    y := rst y
    if odd? i then x := rst x
    eq?(x,y) => error "nodes: infinite stream"
  l -- @#$$^& compiler

leaf? x == empty? rest x

```



```

value x == first x

--% URAGG functions

computeCycleLength cycElt ==
  computeCycleLength(cycElt)$CyclicStreamTools(S,%)

computeCycleEntry(x,cycElt) ==
  computeCycleEntry(x,cycElt)$CyclicStreamTools(S,%)

cycleEntry x ==
  cycElt := cycleElt x
  cycElt case "failed" =>
    error "cycleEntry: non-cyclic stream"
  computeCycleEntry(x,cycElt::%)

cycleLength x ==
  cycElt := cycleElt x
  cycElt case "failed" =>
    error "cycleLength: non-cyclic stream"
  computeCycleLength(cycElt::%)

cycleTail x ==
  cycElt := cycleElt x
  cycElt case "failed" =>
    error "cycleTail: non-cyclic stream"
  y := x := computeCycleEntry(x,cycElt::%)
  z := rst x
  repeat
    eq?(x,z) => return y
  y := z ; z := rst z

elt(x,"first") == first x

first(x,n) ==
-- former name: take
  n = 0 or empty? x => empty()
  concat(first x, first(rst x,(n-1) :: NNI))

rest x ==
  empty? x => error "Can't take the rest of an empty stream."
  rst x

elt(x,"rest") == rest x

rest(x,n) ==
-- former name: drop
  n = 0 or empty? x => x
  rest(rst x,(n-1) :: NNI)

```

```

last x ==
  -- error if stream is not finite
  empty? x => error "last: empty stream"
  y1 := x
  y2 := rst x
  for i in 0.. repeat
    explicitlyEmpty? y2 => return frst y1
    lazy? y2 => error "last: infinite stream"
    y1 := y2
    y2 := rst y2
    if odd? i then x := rst x
    eq?(x,y2) => error "last: infinite stream"

if % has finiteAggregate then -- # is only defined for finiteAggregates
last(x,n) ==
  possiblyInfinite? x => error "last: infinite stream"
  m := # x
  m < n => error "last: index out of range"
  copy rest(x,(m-n)::NNI)

elt(x,"last") == last x

tail x ==
  -- error if stream is not finite
  empty? x => error "tail: empty stream"
  y1 := x
  y2 := rst x
  for i in 0.. repeat
    explicitlyEmpty? y2 => return y1
    lazy? y2 => error "tail: infinite stream"
    y1 := y2
    y2 := rst y2
    if odd? i then x := rst x
    eq?(x,y2) => error "tail: infinite stream"

--% STAGG functions

possiblyInfinite? x ==
  y := x
  for i in 0.. repeat
    explicitlyEmpty? y => return false
    lazy? y => return true
    if odd? i then x := rst x
    y := rst y
    eq?(x,y) => return true

explicitlyFinite? x == not possiblyInfinite? x

--% LZSTAGG functions

```

```

extend(x,n) ==
  y := x
  for i in 1..n while not empty? y repeat y := rst y
  x

complete x ==
  y := x
  while not empty? y repeat y := rst y
  x

```

— LZSTAGG.dotabb —

```

"LZSTAGG"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=LZSTAGG" ];
"LZSTAGG" -> "STAGG"

```

— LZSTAGG.dotfull —

```

"LazyStreamAggregate(a:Type)"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=LZSTAGG" ];
"LazyStreamAggregate(a:Type)" -> "StreamAggregate(a:Type)"

```

— LZSTAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "LazyStreamAggregate(a:Type)" [color=lightblue];
  "LazyStreamAggregate(a:Type)" -> "StreamAggregate(a:Type)"

  "StreamAggregate(a:Type)" [color=lightblue];
  "StreamAggregate(a:Type)" -> "UnaryRecursiveAggregate(a:Type)"
  "StreamAggregate(a:Type)" -> "LinearAggregate(a:Type)"

  "UnaryRecursiveAggregate(a:Type)" [color=lightblue];
  "UnaryRecursiveAggregate(a:Type)" -> "RecursiveAggregate(a:Type)"

```

```

"RecursiveAggregate(a:Type)" [color=lightblue];
"RecursiveAggregate(a:Type)" -> "HOAGG..."

"LinearAggregate(a:Type)" [color=lightblue];
"LinearAggregate(a:Type)" -> "IndexedAggregate(b:Integer,a:Type)"
"LinearAggregate(a:Type)" -> "Collection(a:Type)"

"IndexedAggregate(b:Integer,a:Type)" [color=seagreen];
"IndexedAggregate(b:Integer,a:Type)" ->
    "IndexedAggregate(a:SetCategory,b:Type)"

"IndexedAggregate(a:SetCategory,b:Type)" [color=lightblue];
"IndexedAggregate(a:SetCategory,b:Type)" -> "HOAGG..."

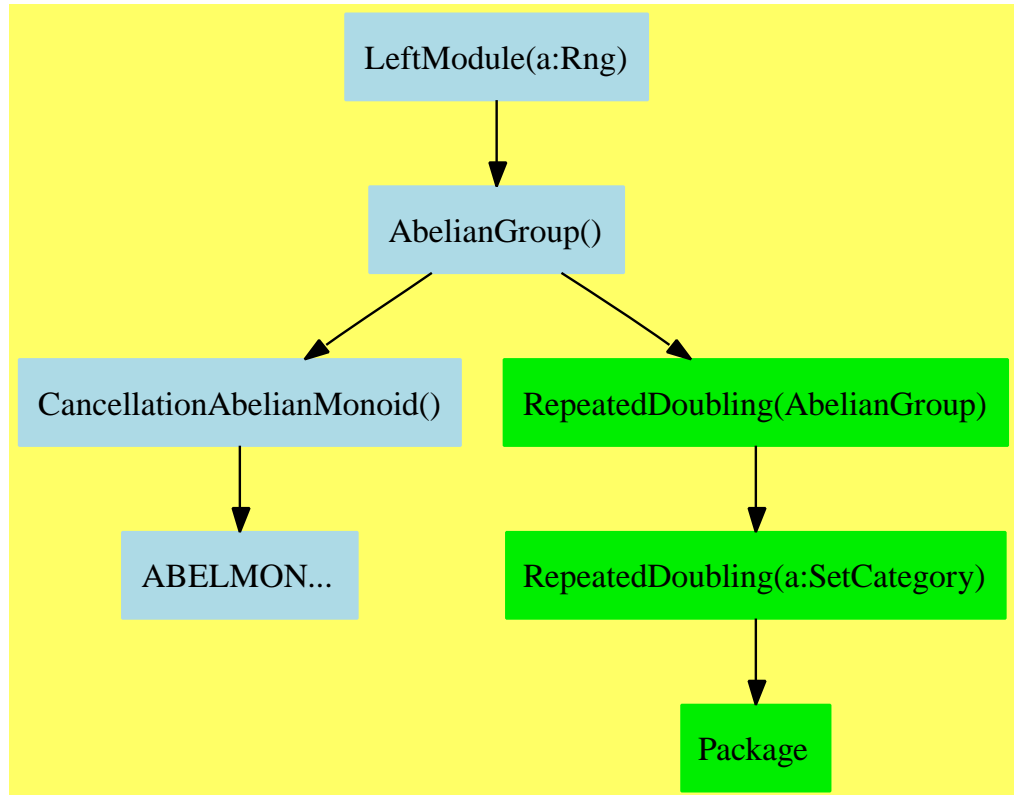
"Collection(a:Type)" [color=lightblue];
"Collection(a:Type)" -> "HOAGG..."

"HOAGG..." [color=lightblue];

}

```

LeftModule (LMODULE)



— LeftModule.input —

```

)set break resume
)sys rm -f LeftModule.output
)spool LeftModule.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show LeftModule
--R
--R LeftModule(R: Rng) is a category constructor
--R Abbreviation for LeftModule is LMODULE
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LMODULE
--R
--R----- Operations -----

```

```

--R ?? : (R,%) -> %
--R ?? : (PositiveInteger,%) -> %
--R ?? : (%,%) -> %
--R ?? : (%,%) -> Boolean
--R coerce : % -> OutputForm
--R latex : % -> String
--R zero? : % -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

```

```

)spool
)lisp (bye)

```

— LeftModule.help —

```

LeftModule examples

```

The category of left modules over an rng (ring not necessarily with unit). This is an abelian group which supports left multiplication by elements of the rng.

See Also:
o)show LeftModule

See:

⇒ “BiModule” (BMODULE) [9](#) on page [782](#)
 ⇒ “LeftAlgebra” (LALG) [10](#) on page [918](#)
 ⇒ “Ring” (RING) [9](#) on page [826](#)
 ⇐ “AbelianGroup” (ABELGRP) [7](#) on page [574](#)

Exports:

| | | | | |
|---------------|--------|------|-------|--------|
| 0 | coerce | hash | latex | sample |
| subtractIfCan | zero? | ?~=? | ?? | ?+? |
| ?-? | -? | ?=? | | |

These are directly exported but not implemented:

```

?? : (R,%) -> %

```

These exports come from (p574) `AbelianGroup()`:

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%,%) -> Boolean
?? : (%,%) -> Boolean
?+? : (%,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?*? : (Integer,%) -> %
?-? : (%,%) -> %
-? : % -> %

```

— category LMODULE LeftModule —

```

)abbrev category LMODULE LeftModule
++ Description:
++ The category of left modules over an rng (ring not necessarily with unit).
++ This is an abelian group which supports left multiplication by elements of
++ the rng.
++
++ Axioms\br
++ \tab{5}\spad{ (a*b)*x = a*(b*x) }\br
++ \tab{5}\spad{ (a+b)*x = (a*x)+(b*x) }\br
++ \tab{5}\spad{ a*(x+y) = (a*x)+(a*y) }

LeftModule(R:Rng):Category == AbelianGroup with
  "(": (R,%) -> %
  ++ r*x returns the left multiplication of the module element x
  ++ by the ring element r.

```

— LMODULE.dotabb —

```

"LMODULE"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=LMODULE" ];
"LMODULE" -> "ABELGRP"

```

— LMODULE.dotfull —

```
"LeftModule(a:Rng)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=LMODULE"];
"LeftModule(a:Rng)" -> "AbelianGroup()"

"LeftModule(a:Ring)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=LMODULE"];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"
```

— LMODULE.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "LeftModule(a:Rng)" [color=lightblue];
  "LeftModule(a:Rng)" -> "AbelianGroup()"

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CancellationAbelianMonoid()"
  "AbelianGroup()" -> "RepeatedDoubling(AbelianGroup)"

  "RepeatedDoubling(AbelianGroup)" [color="#00EE00"];
  "RepeatedDoubling(AbelianGroup)" -> "RepeatedDoubling(a:SetCategory)"

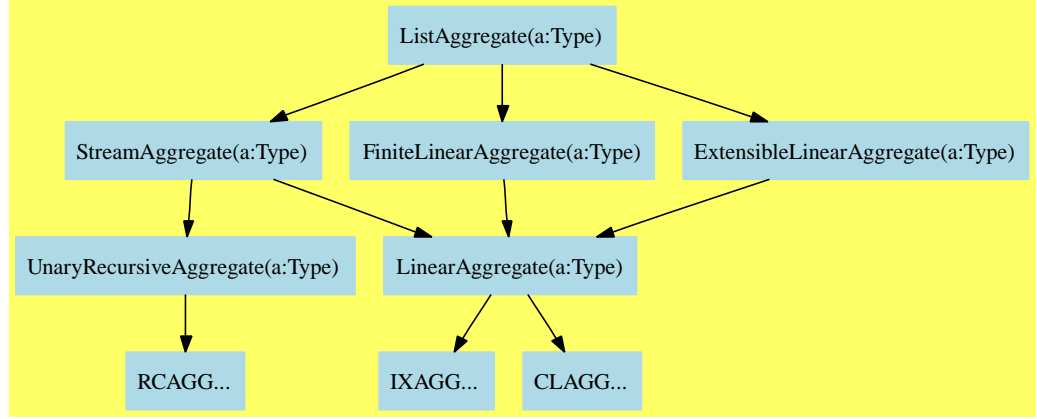
  "RepeatedDoubling(a:SetCategory)" [color="#00EE00"];
  "RepeatedDoubling(a:SetCategory)" -> "Package"

  "Package" [color="#00EE00"];

  "CancellationAbelianMonoid()" [color=lightblue];
  "CancellationAbelianMonoid()" -> "ABELMON..."

  "ABELMON..." [color=lightblue];
}
```

ListAggregate (LSAGG)



— ListAggregate.input —

```

)set break resume
)sys rm -f ListAggregate.output
)spool ListAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ListAggregate
--R
--R ListAggregate(S: Type) is a category constructor
--R Abbreviation for ListAggregate is LSAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LSAGG
--R
--R----- Operations -----
--R children : % -> List(%)
--R concat : List(%) -> %
--R concat : (%,%) -> %
--R concat! : (%,%) -> %
--R copy : % -> %
--R cycleTail : % -> %
--R delete : (%,Integer) -> %
--R distance : (%,%) -> Integer
--R ?.? : (%,Integer) -> S
--R ?.rest : (%,rest) -> %
--R ?.value : (%,value) -> S
--R empty? : % -> Boolean
--R eq? : (%,%) -> Boolean
--R concat : (%,S) -> %
--R concat : (S,%) -> %
--R concat! : (%,S) -> %
--R construct : List(S) -> %
--R cycleEntry : % -> %
--R cyclic? : % -> Boolean
--R delete! : (%,Integer) -> %
--R elt : (%,Integer,S) -> S
--R ?.last : (%,last) -> S
--R ?.first : (%,first) -> S
--R empty : () -> %
--R entries : % -> List(S)
--R explicitlyFinite? : % -> Boolean

```

```

--R first : % -> S
--R indices : % -> List(Integer)
--R insert : (%,% ,Integer) -> %
--R insert! : (%,% ,Integer) -> %
--R leaf? : % -> Boolean
--R list : S -> %
--R map : ((S -> S),%) -> %
--R nodes : % -> List(%)
--R qelt : (% ,Integer) -> S
--R reverse : % -> %
--R second : % -> S
--R third : % -> S
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?<? : (% ,%) -> Boolean if S has ORDSET
--R ?<=? : (% ,%) -> Boolean if S has ORDSET
--R ?=? : (% ,%) -> Boolean if S has SETCAT
--R ?>? : (% ,%) -> Boolean if S has ORDSET
--R ?>=? : (% ,%) -> Boolean if S has ORDSET
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R child? : (% ,%) -> Boolean if S has SETCAT
--R coerce : % -> OutputForm if S has SETCAT
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R copyInto! : (%,% ,Integer) -> % if $ has shallowlyMutable
--R count : (S ,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R cycleLength : % -> NonNegativeInteger
--R cycleSplit! : % -> % if $ has shallowlyMutable
--R delete : (% ,UniversalSegment(Integer)) -> %
--R delete! : (% ,UniversalSegment(Integer)) -> %
--R ?.? : (% ,UniversalSegment(Integer)) -> %
--R entry? : (S ,%) -> Boolean if $ has finiteAggregate and S has SETCAT
--R eval : (% ,List(S) ,List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,S ,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (% ,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (% ,S) -> % if $ has shallowlyMutable
--R find : ((S -> Boolean),%) -> Union(S , "failed")
--R first : (% ,NonNegativeInteger) -> %
--R hash : % -> SingleInteger if S has SETCAT
--R last : (% ,NonNegativeInteger) -> %
--R latex : % -> String if S has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R max : (% ,%) -> % if S has ORDSET
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (S ,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R merge : ((S ,S) -> Boolean),% ,%) -> %
--R merge : (% ,%) -> % if S has ORDSET
--R index? : (Integer ,%) -> Boolean
--R insert : (S ,% ,Integer) -> %
--R insert! : (S ,% ,Integer) -> %
--R last : % -> S
--R leaves : % -> List(S)
--R map : (((S ,S) -> S),% ,%) -> %
--R new : (NonNegativeInteger ,S) -> %
--R possiblyInfinite? : % -> Boolean
--R rest : % -> %
--R sample : () -> %
--R tail : % -> %
--R value : % -> S

```

```

--R merge! : (((S,S) -> Boolean),%,%) -> %
--R merge! : (%,%) -> % if S has ORDSET
--R min : (%,%) -> % if S has ORDSET
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (%,NonNegativeInteger) -> Boolean
--R node? : (%,%) -> Boolean if S has SETCAT
--R parts : % -> List(S) if $ has finiteAggregate
--R position : ((S -> Boolean),%) -> Integer
--R position : (S,%) -> Integer if S has SETCAT
--R position : (S,%,Integer) -> Integer if S has SETCAT
--R qsetelt! : (%,Integer,S) -> S if $ has shallowlyMutable
--R reduce : (((S,S) -> S),%,S,S) -> S if S has SETCAT and $ has finiteAggregate
--R reduce : (((S,S) -> S),%,S) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),%,%) -> S if $ has finiteAggregate
--R remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove! : ((S -> Boolean),%) -> %
--R remove! : (S,%) -> % if S has SETCAT
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R removeDuplicates! : % -> % if S has SETCAT
--R rest : (%,NonNegativeInteger) -> %
--R reverse! : % -> % if $ has shallowlyMutable
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R select! : ((S -> Boolean),%) -> %
--R setchildren! : (%,List(%)) -> % if $ has shallowlyMutable
--R setelt : (%,Integer,S) -> S if $ has shallowlyMutable
--R setelt : (%,UniversalSegment(Integer),S) -> S if $ has shallowlyMutable
--R setelt : (%,last,S) -> S if $ has shallowlyMutable
--R setelt : (%,rest,%) -> % if $ has shallowlyMutable
--R setelt : (%,first,S) -> S if $ has shallowlyMutable
--R setelt : (%,value,S) -> S if $ has shallowlyMutable
--R setfirst! : (%,S) -> S if $ has shallowlyMutable
--R setlast! : (%,S) -> S if $ has shallowlyMutable
--R setrest! : (%,%) -> % if $ has shallowlyMutable
--R setvalue! : (%,S) -> S if $ has shallowlyMutable
--R size? : (%,NonNegativeInteger) -> Boolean
--R sort : (((S,S) -> Boolean),%) -> %
--R sort : % -> % if S has ORDSET
--R sort! : (((S,S) -> Boolean),%) -> % if $ has shallowlyMutable
--R sort! : % -> % if S has ORDSET and $ has shallowlyMutable
--R sorted? : (((S,S) -> Boolean),%) -> Boolean
--R sorted? : % -> Boolean if S has ORDSET
--R split! : (%,Integer) -> % if $ has shallowlyMutable
--R swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable
--R ?~=? : (%,%) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— ListAggregate.help —

```
=====
ListAggregate examples
=====
```

A list aggregate is a model for a linked list data structure. A linked list is a versatile data structure. Insertion and deletion are efficient and searching is a linear operation.

See Also:

o)show ListAggregate

See:

⇒ “AssociationListAggregate” (ALAGG) [10](#) on page [873](#)

⇐ “ExtensibleLinearAggregate” (ELAGG) [7](#) on page [600](#)

⇐ “FiniteLinearAggregate” (FLAGG) [7](#) on page [608](#)

Exports:

| | | | |
|------------------|-------------------|-------------------|-------------------|
| any? | children | child? | coerce |
| concat | concat! | construct | convert |
| copy | copyInto! | count | cycleEntry |
| cycleLength | cycleSplit! | cycleTail | cyclic? |
| delete | delete! | distance | elt |
| empty | empty? | entries | entry? |
| eq? | eval | every? | explicitlyFinite? |
| fill! | find | first | hash |
| index? | indices | insert | insert! |
| last | latex | leaf? | leaves |
| less? | list | map | map! |
| max | maxIndex | member? | members |
| merge | merge! | min | minIndex |
| more? | new | nodes | node? |
| parts | position | possiblyInfinite? | qelt |
| qsetelt! | reduce | remove | remove! |
| removeDuplicates | removeDuplicates! | rest | reverse |
| reverse! | sample | second | select |
| select! | setchildren! | setelt | setfirst! |
| setlast! | setrest! | setvalue! | size? |
| sort | sort! | sorted? | split! |
| swap! | tail | third | value |
| #? | ?.? | ?.last | ?.rest |
| ?.first | ?.value | ?<? | ?<=? |
| ?=? | ?>? | ?>=? | ?~=? |

Attributes exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

These are implemented by this category:

```

copy : % -> %
copyInto! : (%,%,Integer) -> % if $ has shallowlyMutable
delete! : (%,Integer) -> %
delete! : (%,UniversalSegment Integer) -> %
find : ((S -> Boolean),%) -> Union(S,"failed")
insert! : (S,%,Integer) -> %
insert! : (%,%,Integer) -> %
list : S -> %
map : (((S,S) -> S),%,%) -> %
merge : (((S,S) -> Boolean),%,%) -> %

```

```

merge! : (((S,S) -> Boolean),%,%) -> %
new : (NonNegativeInteger,S) -> %
position : ((S -> Boolean),%) -> Integer
position : (S,%,Integer) -> Integer if S has SETCAT
reduce : (((S,S) -> S),%,S) -> S
        if $ has finiteAggregate
reduce : (((S,S) -> S),%,S,S) -> S
        if S has SETCAT
        and $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S
        if $ has finiteAggregate
remove! : ((S -> Boolean),%) -> %
removeDuplicates! : % -> % if S has SETCAT
reverse! : % -> % if $ has shallowlyMutable
select : ((S -> Boolean),%) -> %
        if $ has finiteAggregate
sort! : (((S,S) -> Boolean),%) -> %
        if $ has shallowlyMutable
sorted? : (((S,S) -> Boolean),%) -> Boolean
?<? : (%,%) -> Boolean if S has ORDSET

```

These exports come from (p639) StreamAggregate(S:Type):

```

any? : ((S -> Boolean),%) -> Boolean
        if $ has finiteAggregate
children : % -> List %
child? : (%,%) -> Boolean if S has SETCAT
coerce : % -> OutputForm if S has SETCAT
concat : (%,S) -> %
concat : List % -> %
concat : (S,%) -> %
concat : (%,%) -> %
concat! : (%,S) -> %
concat! : (%,%) -> %
construct : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
count : (S,%) -> NonNegativeInteger
        if S has SETCAT
        and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
        if $ has finiteAggregate
cycleEntry : % -> %
cycleLength : % -> NonNegativeInteger
cycleSplit! : % -> % if $ has shallowlyMutable
cycleTail : % -> %
cyclic? : % -> Boolean
delete : (%,UniversalSegment Integer) -> %
delete : (%,Integer) -> %
distance : (%,%) -> Integer
elt : (%,Integer,S) -> S

```

```

empty : () -> %
empty? : % -> Boolean
entry? : (S,%) -> Boolean
          if $ has finiteAggregate
          and S has SETCAT
entries : % -> List S
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
          if S has EVALAB S
          and S has SETCAT
eval : (%,S,S) -> %
          if S has EVALAB S
          and S has SETCAT
eval : (%,Equation S) -> %
          if S has EVALAB S
          and S has SETCAT
eval : (%,List Equation S) -> %
          if S has EVALAB S
          and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean
          if $ has finiteAggregate
explicitlyFinite? : % -> Boolean
fill! : (%,S) -> % if $ has shallowlyMutable
first : % -> S
first : (%,NonNegativeInteger) -> %
hash : % -> SingleInteger if S has SETCAT
index? : (Integer,%) -> Boolean
indices : % -> List Integer
insert : (S,%,Integer) -> %
insert : (%,%,Integer) -> %
last : % -> S
last : (%,NonNegativeInteger) -> %
latex : % -> String if S has SETCAT
leaf? : % -> Boolean
leaves : % -> List S
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
maxIndex : % -> Integer if Integer has ORDSET
member? : (S,%) -> Boolean
          if S has SETCAT
          and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
minIndex : % -> Integer if Integer has ORDSET
more? : (%,NonNegativeInteger) -> Boolean
nodes : % -> List %
node? : (%,%) -> Boolean if S has SETCAT
parts : % -> List S if $ has finiteAggregate
possiblyInfinite? : % -> Boolean
qelt : (%,Integer) -> S

```

```

qsetelt! : (%,Integer,S) -> S if $ has shallowlyMutable
remove : (S,%) -> %
    if S has SETCAT
    and $ has finiteAggregate
remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
removeDuplicates : % -> %
    if S has SETCAT
    and $ has finiteAggregate
rest : % -> %
rest : (%,NonNegativeInteger) -> %
sample : () -> %
second : % -> S
setchildren! : (%,List %) -> % if $ has shallowlyMutable
setelt : (%,Integer,S) -> S if $ has shallowlyMutable
setelt : (%,UniversalSegment Integer,S) -> S
    if $ has shallowlyMutable
setelt : (%,last,S) -> S if $ has shallowlyMutable
setelt : (%,rest,%) -> % if $ has shallowlyMutable
setelt : (%,first,S) -> S if $ has shallowlyMutable
setelt : (%,value,S) -> S if $ has shallowlyMutable
setfirst! : (%,S) -> S if $ has shallowlyMutable
setlast! : (%,S) -> S if $ has shallowlyMutable
setrest! : (%,%) -> % if $ has shallowlyMutable
setvalue! : (%,S) -> S if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
split! : (%,Integer) -> % if $ has shallowlyMutable
swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable
tail : % -> %
third : % -> S
value : % -> S
#? : % -> NonNegativeInteger if $ has finiteAggregate
?.last : (%,last) -> S
?.rest : (%,rest) -> %
?.first : (%,first) -> S
?.value : (%,value) -> S
?.? : (%,Integer) -> S
?.? : (%,UniversalSegment Integer) -> %
?? : (%,%) -> Boolean if S has SETCAT
?~=? : (%,%) -> Boolean if S has SETCAT

```

These exports come from (p608) FiniteLinearAggregate(S:Type)

```

max : (%,%) -> % if S has ORDSET
merge : (%,%) -> % if S has ORDSET
min : (%,%) -> % if S has ORDSET
position : (S,%) -> Integer if S has SETCAT
reverse : % -> %
sort : (((S,S) -> Boolean),%) -> %
sort : % -> % if S has ORDSET
sort! : % -> % if S has ORDSET and $ has shallowlyMutable

```



```

sorted? : % -> Boolean if S has ORDSET
?<=? : (%,% ) -> Boolean if S has ORDSET
?>? : (%,% ) -> Boolean if S has ORDSET
?>=? : (%,% ) -> Boolean if S has ORDSET

```

These exports come from (p600) ExtensibleLinearAggregate(S:Type):

```

merge! : (%,% ) -> % if S has ORDSET
remove! : (S,% ) -> % if S has SETCAT
select! : ((S -> Boolean),%) -> %

```

— category LSAGG ListAggregate —

```

)abbrev category LSAGG ListAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A list aggregate is a model for a linked list data structure.
++ A linked list is a versatile
++ data structure. Insertion and deletion are efficient and
++ searching is a linear operation.

ListAggregate(S:Type): Category == Join(StreamAggregate S,
  FiniteLinearAggregate S, ExtensibleLinearAggregate S) with
  list: S -> %
  ++ list(x) returns the list of one element x.
add
  cycleMax ==> 1000

  mergeSort: ((S, S) -> Boolean, %, Integer) -> %

  sort_!(f, l) == mergeSort(f, l, #l)
  list x == concat(x, empty())
  reduce(f, x) ==
    empty? x => _
    error "reducing over an empty list needs the 3 argument form"
    reduce(f, rest x, first x)
  merge(f, p, q) == merge_!(f, copy p, copy q)

  select_!(f, x) ==
    while not empty? x and not f first x repeat x := rest x
    empty? x => x
    y := x
    z := rest y
    while not empty? z repeat
      if f first z then (y := z; z := rest z)
      else (z := rest z; setrest_!(y, z))
    x

```

```

merge_!(f, p, q) ==
  empty? p => q
  empty? q => p
  eq?(p, q) => error "cannot merge a list into itself"
  if f(first p, first q)
    then (r := t := p; p := rest p)
    else (r := t := q; q := rest q)
  while not empty? p and not empty? q repeat
    if f(first p, first q)
      then (setrest_!(t, p); t := p; p := rest p)
      else (setrest_!(t, q); t := q; q := rest q)
  setrest_!(t, if empty? p then q else p)
  r

insert_!(s:S, x:%, i:Integer) ==
  i < (m := minIndex x) => error "index out of range"
  i = m => concat(s, x)
  y := rest(x, (i - 1 - m)::NonNegativeInteger)
  z := rest y
  setrest_!(y, concat(s, z))
  x

insert_!(w:%, x:%, i:Integer) ==
  i < (m := minIndex x) => error "index out of range"
  i = m => concat_!(w, x)
  y := rest(x, (i - 1 - m)::NonNegativeInteger)
  z := rest y
  setrest_!(y, w)
  concat_!(y, z)
  x

remove_!(f:S -> Boolean, x:%) ==
  while not empty? x and f first x repeat x := rest x
  empty? x => x
  p := x
  q := rest x
  while not empty? q repeat
    if f first q then q := setrest_!(p, rest q)
    else (p := q; q := rest q)
  x

delete_!(x:%, i:Integer) ==
  i < (m := minIndex x) => error "index out of range"
  i = m => rest x
  y := rest(x, (i - 1 - m)::NonNegativeInteger)
  setrest_!(y, rest(y, 2))
  x

delete_!(x:%, i:UniversalSegment(Integer)) ==

```

```

(l := lo i) < (m := minIndex x) => error "index out of range"
h := if hasHi i then hi i else maxIndex x
h < l => x
l = m => rest(x, (h + 1 - m)::NonNegativeInteger)
t := rest(x, (l - 1 - m)::NonNegativeInteger)
setrest_!(t, rest(t, (h - l + 2)::NonNegativeInteger))
x

find(f, x) ==
  while not empty? x and not f first x repeat x := rest x
  empty? x => "failed"
  first x

position(f:S -> Boolean, x:%) ==
  for k in minIndex(x).. while not empty? x and not f first x repeat
    x := rest x
  empty? x => minIndex(x) - 1
  k

mergeSort(f, p, n) ==
  if n = 2 and f(first rest p, first p) then p := reverse_! p
  n < 3 => p
  l := (n quo 2)::NonNegativeInteger
  q := split_!(p, l)
  p := mergeSort(f, p, l)
  q := mergeSort(f, q, n - l)
  merge_!(f, p, q)

sorted?(f, l) ==
  empty? l => true
  p := rest l
  while not empty? p repeat
    not f(first l, first p) => return false
  p := rest(l := p)
  true

reduce(f, x, i) ==
  r := i
  while not empty? x repeat (r := f(r, first x); x := rest x)
  r

if S has SetCategory then
  reduce(f, x, i,a) ==
    r := i
    while not empty? x and r ^= a repeat
      r := f(r, first x)
      x := rest x
    r

new(n, s) ==

```

```

l := empty()
for k in 1..n repeat l := concat(s, l)
l

map(f, x, y) ==
  z := empty()
  while not empty? x and not empty? y repeat
    z := concat(f(first x, first y), z)
    x := rest x
    y := rest y
  reverse_! z

-- map(f, x, y, d) ==
--   z := empty()
--   while not empty? x and not empty? y repeat
--     z := concat(f(first x, first y), z)
--     x := rest x
--     y := rest y
--   z := reverseInPlace z
--   if not empty? x then
--     z := concat_!(z, map(f(#1, d), x))
--   if not empty? y then
--     z := concat_!(z, map(f(d, #1), y))
--   z

reverse_! x ==
  empty? x => x
  empty?(y := rest x) => x
  setrest_!(x, empty())
  while not empty? y repeat
    z := rest y
    setrest_!(y, x)
    x := y
    y := z
  x

copy x ==
  y := empty()
  for k in 0.. while not empty? x repeat
    k = cycleMax and cyclic? x => error "cyclic list"
    y := concat(first x, y)
    x := rest x
  reverse_! y

copyInto_!(y, x, s) ==
  s < (m := minIndex y) => error "index out of range"
  z := rest(y, (s - m)::NonNegativeInteger)
  while not empty? z and not empty? x repeat
    setfirst_!(z, first x)
    x := rest x

```

```

      z := rest z
    y

if S has SetCategory then
  position(w, x, s) ==
    s < (m := minIndex x) => error "index out of range"
    x := rest(x, (s - m)::NonNegativeInteger)
    for k in s.. while not empty? x and w ^!= first x repeat
      x := rest x
    empty? x => minIndex x - 1
  k

removeDuplicates_! l ==
  p := 1
  while not empty? p repeat
    p := setrest_!(p, remove_!((x:S):Boolean +-> x = first p, rest p))
  l

if S has OrderedSet then
  x < y ==
    while not empty? x and not empty? y repeat
      first x ^!= first y => return(first x < first y)
      x := rest x
      y := rest y
    empty? x => not empty? y
  false

```

— LSAGG.dotabb —

```

"LSAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=LSAGG"];
"LSAGG" -> "FLAGG"
"LSAGG" -> "ELAGG"

```

— LSAGG.dotfull —

```

"ListAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=LSAGG"];
"ListAggregate(a:Type)" -> "StreamAggregate(a:Type)"
"ListAggregate(a:Type)" -> "FiniteLinearAggregate(a:Type)"
"ListAggregate(a:Type)" -> "ExtensibleLinearAggregate(a:Type)"

"ListAggregate(Record(a:SetCategory,b:SetCategory))"

```

```
[color=seagreen,href="bookvol10.2.pdf#nameddest=LSAGG"];
"ListAggregate(Record(a:SetCategory,b:SetCategory))" ->
  "ListAggregate(a:Type)"
```

— LSAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ListAggregate(a:Type)" [color=lightblue];
  "ListAggregate(a:Type)" -> "StreamAggregate(a:Type)"
  "ListAggregate(a:Type)" -> "FiniteLinearAggregate(a:Type)"
  "ListAggregate(a:Type)" -> "ExtensibleLinearAggregate(a:Type)"

  "StreamAggregate(a:Type)" [color=lightblue];
  "StreamAggregate(a:Type)" -> "UnaryRecursiveAggregate(a:Type)"
  "StreamAggregate(a:Type)" -> "LinearAggregate(a:Type)"

  "FiniteLinearAggregate(a:Type)" [color=lightblue];
  "FiniteLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"

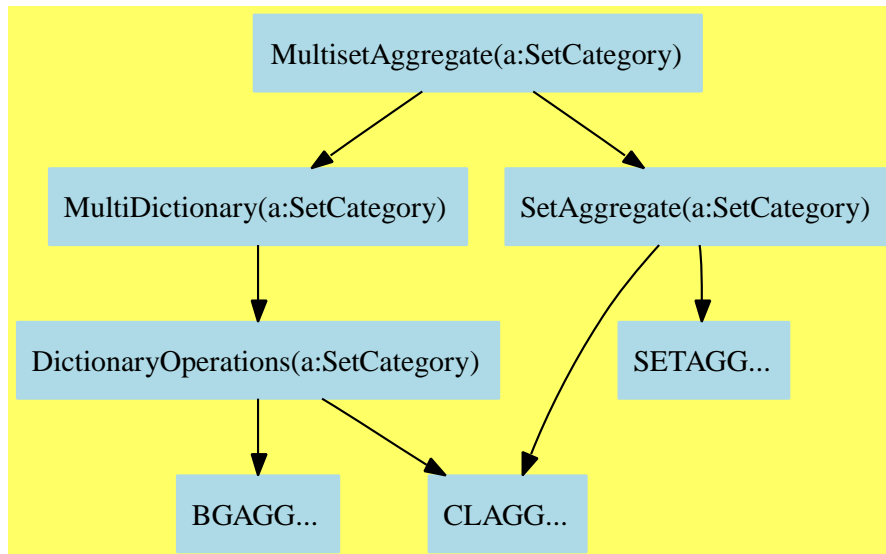
  "ExtensibleLinearAggregate(a:Type)" [color=lightblue];
  "ExtensibleLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"

  "UnaryRecursiveAggregate(a:Type)" [color=lightblue];
  "UnaryRecursiveAggregate(a:Type)" -> "RCAGG..."

  "LinearAggregate(a:Type)" [color=lightblue];
  "LinearAggregate(a:Type)" -> "IXAGG..."
  "LinearAggregate(a:Type)" -> "CLAGG..."

  "CLAGG..." [color=lightblue];
  "IXAGG..." [color=lightblue];
  "RCAGG..." [color=lightblue];
}
```

MultisetAggregate (MSETAGG)



— MultisetAggregate.input —

```

)set break resume
)sys rm -f MultisetAggregate.output
)spool MultisetAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show MultisetAggregate
--R
--R MultisetAggregate(S: SetCategory) is a category constructor
--R Abbreviation for MultisetAggregate is MSETAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MSETAGG
--R
--R----- Operations -----
--R ?<? : (%,%) -> Boolean           ?=? : (%,%) -> Boolean
--R bag : List(S) -> %               brace : () -> %
--R brace : List(S) -> %             coerce : % -> OutputForm
--R construct : List(S) -> %         copy : % -> %
--R dictionary : List(S) -> %       dictionary : () -> %
--R difference : (%,%) -> %         difference : (%,S) -> %
--R empty : () -> %                empty? : % -> Boolean
--R eq? : (%,%) -> Boolean          extract! : % -> S

```

```

--R hash : % -> SingleInteger          insert! : (S,%) -> %
--R inspect : % -> S                  intersect : (%,%) -> %
--R latex : % -> String              map : ((S -> S),%) -> %
--R removeDuplicates! : % -> %        sample : () -> %
--R set : () -> %                     set : List(S) -> %
--R subset? : (%,%) -> Boolean        union : (%,%) -> %
--R union : (%,S) -> %                union : (S,%) -> %
--R ~=? : (%,%) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R duplicates : % -> List(Record(entry: S,count: NonNegativeInteger))
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R insert! : (S,%,NonNegativeInteger) -> %
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R reduce : (((S,S) -> S),%) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),%,S) -> S if $ has finiteAggregate
--R reduce : (((S,S) -> S),%,S,S) -> S if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
--R remove! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove! : (S,%) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R select! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R symmetricDifference : (%,%) -> %
--R
--E 1

)spool
)lisp (bye)

```


=====

MultisetAggregate examples

=====

A multi-set aggregate is a set which keeps track of the multiplicity of its elements.

See Also:

o)show MultisetAggregate

See:

⇒ “OrderedMultisetAggregate” (OMSAGG) [9](#) on page [819](#)

⇐ “MultiDictionary” (MDAGG) [7](#) on page [623](#)

⇐ “SetAggregate” (SETAGG) [6](#) on page [546](#)

Exports:

| | | | |
|------------|---------------------|-------------------|---------|
| any? | bag | brace | coerce |
| construct | convert | copy | count |
| dictionary | difference | duplicates | empty |
| empty? | eq? | eval | every? |
| extract! | find | hash | insert! |
| inspect | intersect | latex | less? |
| map | map! | member? | members |
| more? | parts | reduce | remove |
| remove! | removeDuplicates | removeDuplicates! | sample |
| select | select! | set | size? |
| subset? | symmetricDifference | union | #? |
| ?~=? | ?<? | ?=? | |

Attributes exported:

- **partiallyOrderedSet** is true if a set with $<$ which is transitive, but not($a < b$ or $a = b$) does not necessarily imply $b < a$.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

These exports come from (p[623](#)) MultiDictionary(S:SetCategory):

```
any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
bag : List S -> %
```

```

coerce : % -> OutputForm
construct : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
copy : % -> %
count : (S,%) -> NonNegativeInteger
    if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
    if $ has finiteAggregate
dictionary : List S -> %
dictionary : () -> %
duplicates : % ->
    List Record(entry: S,count: NonNegativeInteger)
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> % if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> % if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> % if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> % if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
extract! : % -> S
find : ((S -> Boolean),%) -> Union(S,"failed")
hash : % -> SingleInteger
insert! : (S,%) -> %
insert! : (S,%,NonNegativeInteger) -> %
inspect : % -> S
latex : % -> String
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
    if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S
    if $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S
    if $ has finiteAggregate
reduce : (((S,S) -> S),%,S,S) -> S
    if S has SETCAT and $ has finiteAggregate
remove : ((S -> Boolean),%) -> %
    if $ has finiteAggregate
remove : (S,%) -> %
    if S has SETCAT and $ has finiteAggregate
removeDuplicates : % -> %
    if S has SETCAT and $ has finiteAggregate
removeDuplicates! : % -> %
remove! : ((S -> Boolean),%) -> %
    if $ has finiteAggregate

```

```

remove! : (S,%) -> % if $ has finiteAggregate
select : ((S -> Boolean),%) -> %
    if $ has finiteAggregate
select! : ((S -> Boolean),%) -> %
    if $ has finiteAggregate
size? : (%,NonNegativeInteger) -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
?~=? : (%,%) -> Boolean
?=? : (%,%) -> Boolean

```

These exports come from (p546) SetAggregate(S:SetCategory):

```

brace : () -> %
brace : List S -> %
difference : (%,S) -> %
intersect : (%,%) -> %
sample : () -> %
set : () -> %
set : List S -> %
subset? : (%,%) -> Boolean
symmetricDifference : (%,%) -> %
union : (%,S) -> %
union : (S,%) -> %
union : (%,%) -> %
?<? : (%,%) -> Boolean

```

— category MSETAGG MultisetAggregate —

```

)abbrev category MSETAGG MultisetAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A multi-set aggregate is a set which keeps track of the multiplicity
++ of its elements.

```

```

MultisetAggregate(S:SetCategory):
    Category == Join(MultiDictionary S, SetAggregate S)

```

— MSETAGG.dotabb —

```

"MSETAGG"
[color=lightblue,href="bookvol10.2.pdf#nameddest=MSETAGG"];
"MSETAGG" -> "MDAGG"
"MSETAGG" -> "SETAGG"

```

— MSETAGG.dotfull —

```
"MultisetAggregate(a:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MSETAGG"];
"MultisetAggregate(a:SetCategory)" -> "MultiDictionary(a:SetCategory)"
"MultisetAggregate(a:SetCategory)" -> "SetAggregate(a:SetCategory)"
```

— MSETAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "MultisetAggregate(a:SetCategory)" [color=lightblue];
  "MultisetAggregate(a:SetCategory)" -> "MultiDictionary(a:SetCategory)"
  "MultisetAggregate(a:SetCategory)" -> "SetAggregate(a:SetCategory)"

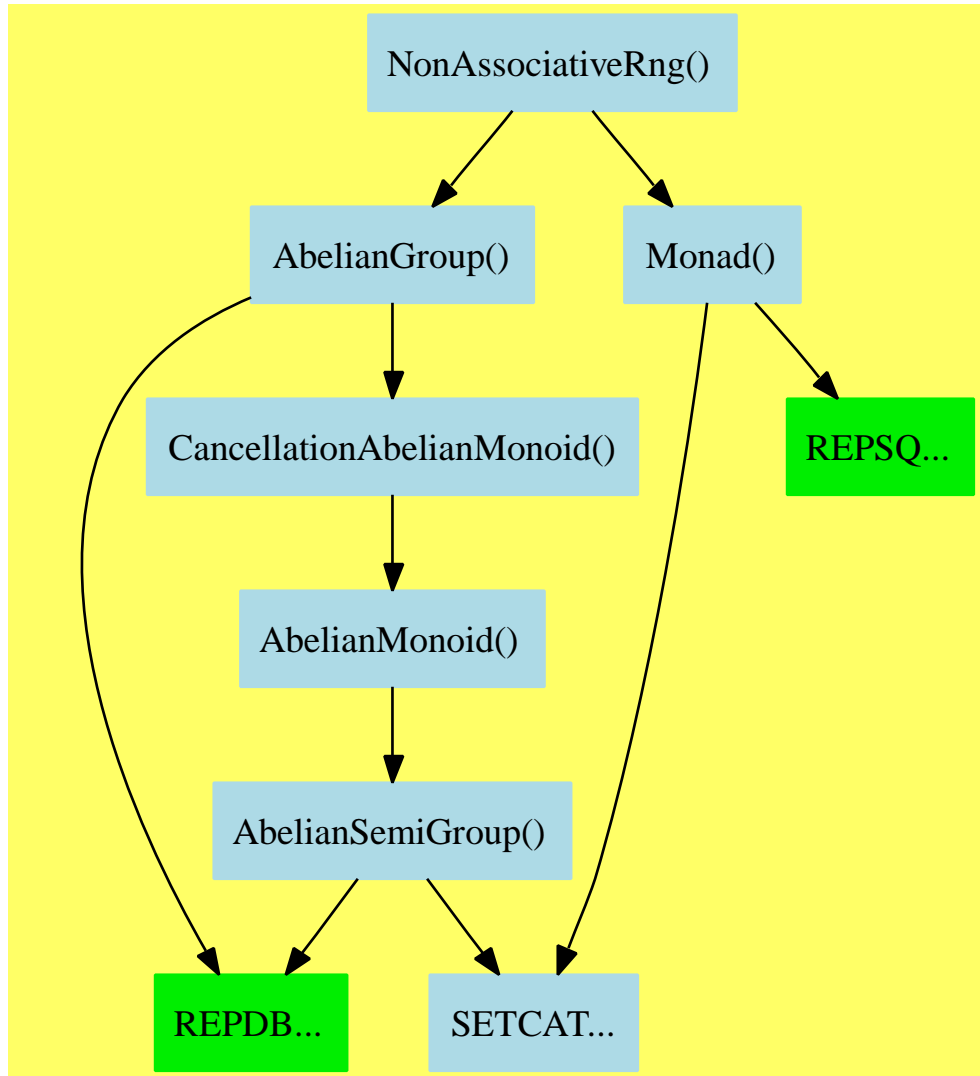
  "MultiDictionary(a:SetCategory)" [color=lightblue];
  "MultiDictionary(a:SetCategory)" -> "DictionaryOperations(a:SetCategory)"

  "SetAggregate(a:SetCategory)" [color=lightblue];
  "SetAggregate(a:SetCategory)" -> "SETAGG..."
  "SetAggregate(a:SetCategory)" -> "CLAGG..."

  "DictionaryOperations(a:SetCategory)" [color=lightblue];
  "DictionaryOperations(a:SetCategory)" -> "BGAGG..."
  "DictionaryOperations(a:SetCategory)" -> "CLAGG..."

  "BGAGG..." [color=lightblue];
  "CLAGG..." [color=lightblue];
  "SETAGG..." [color=lightblue];
}
```

NonAssociativeRng (NARNG)



— NonAssociativeRng.input —

```

)set break resume
)sys rm -f NonAssociativeRng.output
)spool NonAssociativeRng.output
)set message test on
)set message auto off
)clear all
  
```

```

--S 1 of 1
)show NonAssociativeRng
--R NonAssociativeRng is a category constructor
--R Abbreviation for NonAssociativeRng is NARNG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for NARNG
--R
--R----- Operations -----
--R ?? : (%,% ) -> %           ?? : (Integer,% ) -> %
--R ?? : (PositiveInteger,% ) -> %   ??? : (% ,PositiveInteger) -> %
--R +? : (%,% ) -> %           ?-? : (%,% ) -> %
--R -? : % -> %               ?=? : (%,% ) -> Boolean
--R 0 : () -> %               antiCommutator : (%,% ) -> %
--R associator : (%,%,% ) -> %     coerce : % -> OutputForm
--R commutator : (%,% ) -> %       hash : % -> SingleInteger
--R latex : % -> String           sample : () -> %
--R zero? : % -> Boolean          ?~=? : (%,% ) -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R leftPower : (% ,PositiveInteger) -> %
--R rightPower : (% ,PositiveInteger) -> %
--R subtractIfCan : (%,% ) -> Union(% ,"failed")
--R
--E 1

)spool
)lisp (bye)

```

— NonAssociativeRng.help —

=====

NonAssociativeRng examples

=====

NonAssociativeRng is a basic ring-type structure, not necessarily commutative or associative, and not necessarily with unit.

Axioms:

$$\begin{aligned}
 x*(y+z) &= x*y + x*z \\
 (x+y)*z &= x*z + y*z
 \end{aligned}$$

Common Additional Axioms

$$\text{noZeroDivisors} \quad ab = 0 \Rightarrow a=0 \text{ or } b=0$$

See Also:

o)show NonAssociativeRng

See:

⇒ “NonAssociativeAlgebra” (NAALG) [11](#) on page [1032](#)
 ⇒ “NonAssociativeRing” (NASRING) [9](#) on page [796](#)
 ⇐ “AbelianGroup” (ABELGRP) [7](#) on page [574](#)
 ⇐ “Monad” (MONAD) [4](#) on page [249](#)

Exports:

| | | | | |
|---------------|----------------|------------|------------|------------|
| 0 | antiCommutator | associator | coerce | commutator |
| hash | latex | leftPower | rightPower | sample |
| subtractIfCan | zero? | ?*? | ?**? | ?+? |
| ?-? | -? | ?=? | ?~=? | |

These are implemented by this category:

```
antiCommutator : (%,% ) -> %
associator : (%,% ,%) -> %
commutator : (%,% ) -> %
```

These exports come from ([p574](#)) AbelianGroup():

```
0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,% ) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (PositiveInteger,% ) -> %
?+? : (%,% ) -> %
?=? : (%,% ) -> Boolean
?*? : (Integer,% ) -> %
?*? : (NonNegativeInteger,% ) -> %
?-? : (%,% ) -> %
-? : % -> %
```

These exports come from ([p249](#)) Monad():

```
leftPower : (% , PositiveInteger) -> %
rightPower : (% , PositiveInteger) -> %
?*? : (%,% ) -> %
?*?? : (% , PositiveInteger) -> %
```

— category NARNG NonAssociativeRng —

```

)abbrev category NARNG NonAssociativeRng
++ Author: J. Grabmeier, R. Wisbauer
++ Date Created: 01 March 1991
++ Date Last Updated: 03 July 1991
++ Reference:
++ R.D. Schafer: An Introduction to Nonassociative Algebras
++ Academic Press, New York, 1966
++ Description:
++ NonAssociativeRng is a basic ring-type structure, not necessarily
++ commutative or associative, and not necessarily with unit.\br
++ Axioms\br
++ \tab{5}x*(y+z) = x*y + x*z\br
++ \tab{5}(x+y)*z = x*z + y*z\br
++
++ Common Additional Axioms\br
++ \tab{5}noZeroDivisors\tab{5} ab = 0 => a=0 or b=0

```

```

NonAssociativeRng(): Category == Join(AbelianGroup,Monad) with
  associator: (%,%,% ) -> %
    ++ associator(a,b,c) returns \spad{(a*b)*c-a*(b*c)}.
  commutator: (%,% ) -> %
    ++ commutator(a,b) returns \spad{a*b-b*a}.
  antiCommutator: (%,% ) -> %
    ++ antiCommutator(a,b) returns \spad{a*b+b*a}.
add
  associator(x,y,z) == (x*y)*z - x*(y*z)
  commutator(x,y) == x*y - y*x
  antiCommutator(x,y) == x*y + y*x

```

— NARNG.dotabb —

```

"NARNG"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=NARNG" ];
"NARNG" -> "ABELGRP"
"NARNG" -> "MONAD"

```

— NARNG.dotfull —

```

"NonAssociativeRng()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=NARNG" ];
"NonAssociativeRng()" -> "AbelianGroup()"
"NonAssociativeRng()" -> "Monad()"

```

— NARNG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "NonAssociativeRng()" [color=lightblue];
  "NonAssociativeRng()" -> "AbelianGroup()"
  "NonAssociativeRng()" -> "Monad()"

  "Monad()" [color=lightblue];
  "Monad()" -> "SETCAT..."
  "Monad()" -> "REPSQ..."

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CancellationAbelianMonoid()"
  "AbelianGroup()" -> "REPDB..."

  "CancellationAbelianMonoid()" [color=lightblue];
  "CancellationAbelianMonoid()" -> "AbelianMonoid()"

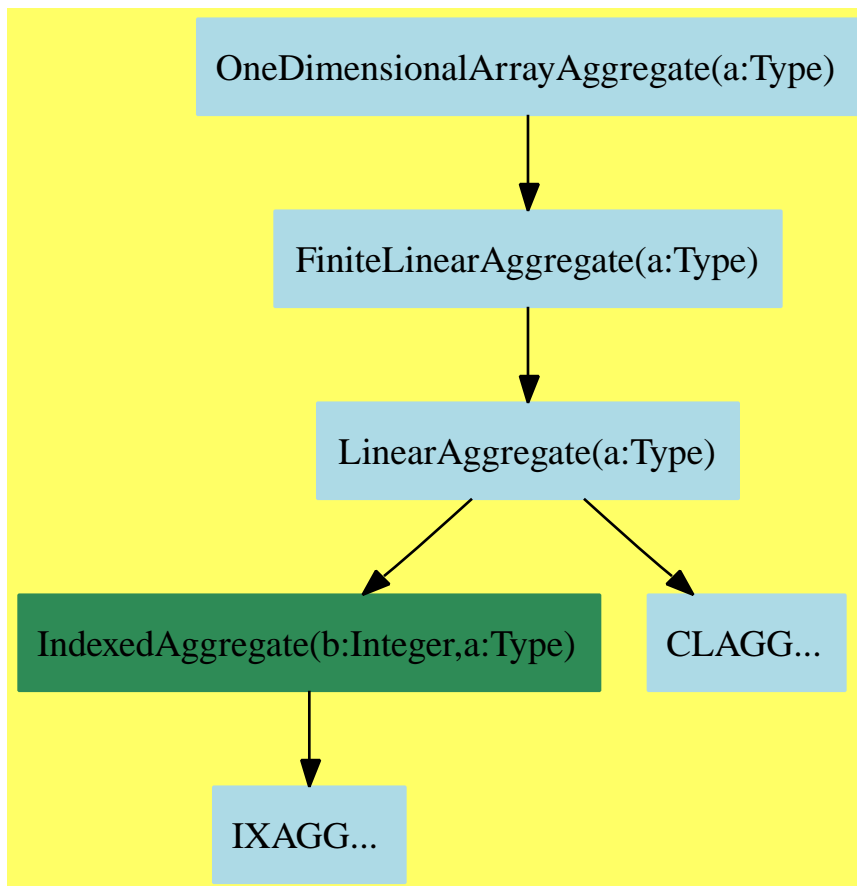
  "AbelianMonoid()" [color=lightblue];
  "AbelianMonoid()" -> "AbelianSemiGroup()"

  "AbelianSemiGroup()" [color=lightblue];
  "AbelianSemiGroup()" -> "SETCAT..."
  "AbelianSemiGroup()" -> "REPDB..."

  "REPDB..." [color="#00EE00"];
  "REPSQ..." [color="#00EE00"];
  "SETCAT..." [color=lightblue];
}

```

OneDimensionalArrayAggregate (A1AGG)



— OneDimensionalArrayAggregate.input —

```

)set break resume
)sys rm -f OneDimensionalArrayAggregate.output
)spool OneDimensionalArrayAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OneDimensionalArrayAggregate
--R
--R OneDimensionalArrayAggregate(S: Type) is a category constructor
--R Abbreviation for OneDimensionalArrayAggregate is A1AGG
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for A1AGG
--R
--R----- Operations -----
--R concat : List(%) -> %                concat : (%,%) -> %
--R concat : (S,%) -> %                  concat : (%,S) -> %
--R construct : List(S) -> %             copy : % -> %
--R delete : (%,Integer) -> %            ?.? : (%,Integer) -> S
--R elt : (%,Integer,S) -> S             empty : () -> %
--R empty? : % -> Boolean                entries : % -> List(S)
--R eq? : (%,%) -> Boolean               index? : (Integer,%) -> Boolean
--R indices : % -> List(Integer)         insert : (%,%,Integer) -> %
--R insert : (S,%,Integer) -> %         map : ((S,S) -> S),%,%) -> %
--R map : ((S -> S),%) -> %             new : (NonNegativeInteger,S) -> %
--R qelt : (%,Integer) -> S             reverse : % -> %
--R sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?<? : (%,%) -> Boolean if S has ORDSET
--R ?<=? : (%,%) -> Boolean if S has ORDSET
--R ?=? : (%,%) -> Boolean if S has SETCAT
--R ?>? : (%,%) -> Boolean if S has ORDSET
--R ?>=? : (%,%) -> Boolean if S has ORDSET
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if S has SETCAT
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R copyInto! : (%,%,Integer) -> % if $ has shallowlyMutable
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R delete : (%,UniversalSegment(Integer)) -> %
--R ?.? : (%,UniversalSegment(Integer)) -> %
--R entry? : (S,%) -> Boolean if $ has finiteAggregate and S has SETCAT
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (%,S) -> % if $ has shallowlyMutable
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R first : % -> S if Integer has ORDSET
--R hash : % -> SingleInteger if S has SETCAT
--R latex : % -> String if S has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R max : (%,%) -> % if S has ORDSET
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R merge : (%,%) -> % if S has ORDSET
--R merge : (((S,S) -> Boolean),%,%) -> %
--R min : (%,%) -> % if S has ORDSET
--R minIndex : % -> Integer if Integer has ORDSET

```

```

--R more? : (% , NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R position : (S , % , Integer) -> Integer if S has SETCAT
--R position : (S , %) -> Integer if S has SETCAT
--R position : ((S -> Boolean) , %) -> Integer
--R qsetelt! : (% , Integer , S) -> S if $ has shallowlyMutable
--R reduce : (((S , S) -> S) , %) -> S if $ has finiteAggregate
--R reduce : (((S , S) -> S) , % , S) -> S if $ has finiteAggregate
--R reduce : (((S , S) -> S) , % , S , S) -> S if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean) , %) -> % if $ has finiteAggregate
--R remove : (S , %) -> % if S has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R reverse! : % -> % if $ has shallowlyMutable
--R select : ((S -> Boolean) , %) -> % if $ has finiteAggregate
--R setelt : (% , UniversalSegment(Integer) , S) -> S if $ has shallowlyMutable
--R setelt : (% , Integer , S) -> S if $ has shallowlyMutable
--R size? : (% , NonNegativeInteger) -> Boolean
--R sort : % -> % if S has ORDSET
--R sort : (((S , S) -> Boolean) , %) -> %
--R sort! : % -> % if S has ORDSET and $ has shallowlyMutable
--R sort! : (((S , S) -> Boolean) , %) -> % if $ has shallowlyMutable
--R sorted? : % -> Boolean if S has ORDSET
--R sorted? : (((S , S) -> Boolean) , %) -> Boolean
--R swap! : (% , Integer , Integer) -> Void if $ has shallowlyMutable
--R ~=?: (% , %) -> Boolean if S has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— OneDimensionalArrayAggregate.help —

OneDimensionalArrayAggregate examples

One-dimensional-array aggregates serves as models for one-dimensional arrays. Categorically, these aggregates are finite linear aggregates with the shallowlyMutable property, that is, any component of the array may be changed without affecting the identity of the overall array. Array data structures are typically represented by a fixed area in storage and cannot efficiently grow or shrink on demand as can list structures (see however FlexibleArray for a data structure which is a cross between a list and an array).

Iteration over, and access to, elements of arrays is extremely fast

(and often can be optimized to open-code).

Insertion and deletion however is generally slow since an entirely new data structure must be created for the result.

See Also:

- o `)show OneDimensionalArrayAggregate`
- o `)show FlexibleArray`

See:

- ⇒ “BitAggregate” (BTAGG) [9](#) on page [787](#)
- ⇒ “StringAggregate” (SRAGG) [9](#) on page [841](#)
- ⇒ “VectorCategory” (VECTCAT) [9](#) on page [863](#)
- ⇐ “FiniteLinearAggregate” (FLAGG) [7](#) on page [608](#)

Exports:

| | | | | |
|-----------------------|------------------------|----------------------|-------------------------------|-----------------------|
| <code>any?</code> | <code>coerce</code> | <code>concat</code> | <code>construct</code> | <code>convert</code> |
| <code>copy</code> | <code>copyInto!</code> | <code>count</code> | <code>delete</code> | <code>elt</code> |
| <code>empty</code> | <code>empty?</code> | <code>entries</code> | <code>entry?</code> | <code>eq?</code> |
| <code>eval</code> | <code>every?</code> | <code>fill!</code> | <code>find</code> | <code>first</code> |
| <code>hash</code> | <code>index?</code> | <code>indices</code> | <code>insert</code> | <code>latex</code> |
| <code>less?</code> | <code>map</code> | <code>map!</code> | <code>max</code> | <code>maxIndex</code> |
| <code>member?</code> | <code>members</code> | <code>merge</code> | <code>min</code> | <code>minIndex</code> |
| <code>more?</code> | <code>new</code> | <code>parts</code> | <code>position</code> | <code>qelt</code> |
| <code>qsetelt!</code> | <code>reduce</code> | <code>remove</code> | <code>removeDuplicates</code> | <code>reverse</code> |
| <code>reverse!</code> | <code>sample</code> | <code>select</code> | <code>setelt</code> | <code>size?</code> |
| <code>sort</code> | <code>sort!</code> | <code>sorted?</code> | <code>swap!</code> | <code>#?</code> |
| <code>?..?</code> | <code>?<?</code> | <code>?<=?</code> | <code>?~=?</code> | <code>?=?</code> |
| <code>?>?</code> | <code>?>=?</code> | | | |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

These are implemented by this category:

```
any? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
```

```

coerce : % -> OutputForm if S has SETCAT
concat : (%,%) -> %
concat : List % -> %
construct : List S -> %
copy : % -> %
copyInto! : (%,%,Integer) -> % if $ has shallowlyMutable
count : ((S -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
delete : (%,UniversalSegment Integer) -> %
delete : (%,Integer) -> %
every? : ((S -> Boolean),%) -> Boolean
      if $ has finiteAggregate
find : ((S -> Boolean),%) -> Union(S,"failed")
insert : (%,%,Integer) -> %
map : ((S,S) -> S),%,%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
merge : ((S,S) -> Boolean),%,%) -> %
parts : % -> List S if $ has finiteAggregate
position : ((S -> Boolean),%) -> Integer
position : (S,%,Integer) -> Integer
      if S has SETCAT
reduce : (((S,S) -> S),%) -> S
      if $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S
      if $ has finiteAggregate
reduce : (((S,S) -> S),%,S,S) -> S
      if S has SETCAT and $ has finiteAggregate
reverse! : % -> % if $ has shallowlyMutable
setelt : (%,UniversalSegment Integer,S) -> S
      if $ has shallowlyMutable
sort! : (((S,S) -> Boolean),%) -> %
      if $ has shallowlyMutable
sorted? : (((S,S) -> Boolean),%) -> Boolean
?.? : (%,UniversalSegment Integer) -> %
?=? : (%,%) -> Boolean if S has SETCAT
?<? : (%,%) -> Boolean if S has ORDSET

```

These exports come from (p608) FiniteLinearAggregate(S:Type):

```

concat : (S,%) -> %
concat : (%,S) -> %
convert : % -> InputForm if S has KONVERT INFORM
count : (S,%) -> NonNegativeInteger
      if S has SETCAT and $ has finiteAggregate
elt : (%,Integer,S) -> S
empty : () -> %
empty? : % -> Boolean
entries : % -> List S
entry? : (S,%) -> Boolean
      if $ has finiteAggregate and S has SETCAT

```

```

eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
      if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
      if S has EVALAB S and S has SETCAT
fill! : (%,S) -> % if $ has shallowlyMutable
first : % -> S if Integer has ORDSET
hash : % -> SingleInteger if S has SETCAT
index? : (Integer,%) -> Boolean
indices : % -> List Integer
insert : (S,%,Integer) -> %
latex : % -> String if S has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
max : (%,%) -> % if S has ORDSET
maxIndex : % -> Integer if Integer has ORDSET
member? : (S,%) -> Boolean
      if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
merge : (%,%) -> % if S has ORDSET
min : (%,%) -> % if S has ORDSET
minIndex : % -> Integer if Integer has ORDSET
more? : (%,NonNegativeInteger) -> Boolean
new : (NonNegativeInteger,S) -> %
position : (S,%) -> Integer if S has SETCAT
qelt : (%,Integer) -> S
qsetelt! : (%,Integer,S) -> S
      if $ has shallowlyMutable
remove : ((S -> Boolean),%) -> %
      if $ has finiteAggregate
remove : (S,%) -> %
      if S has SETCAT and $ has finiteAggregate
removeDuplicates : % -> %
      if S has SETCAT and $ has finiteAggregate
reverse : % -> %
sample : () -> %
select : ((S -> Boolean),%) -> %
      if $ has finiteAggregate
setelt : (%,Integer,S) -> S if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
sort : % -> % if S has ORDSET
sort : ((S,S) -> Boolean),% -> %
sort! : % -> %
      if S has ORDSET and $ has shallowlyMutable
sorted? : % -> Boolean if S has ORDSET
swap! : (%,Integer,Integer) -> Void

```

```

        if $ has shallowlyMutable
#? : % -> NonNegativeInteger if $ has finiteAggregate
?.? : (%,Integer) -> S
?~=? : (%,% ) -> Boolean if S has SETCAT
?>? : (%,% ) -> Boolean if S has ORDSET
?>=? : (%,% ) -> Boolean if S has ORDSET
?<=? : (%,% ) -> Boolean if S has ORDSET

```

— category A1AGG OneDimensionalArrayAggregate —

```

)abbrev category A1AGG OneDimensionalArrayAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Basic Operations:
++ Related Constructors:
++ Also See:
++ AMS Classifications:
++ Keywords:
++ References:
++ Description:
++ One-dimensional-array aggregates serves as models for one-dimensional
++ arrays. Categorically, these aggregates are finite linear aggregates
++ with the \spadatt{shallowlyMutable} property, that is, any component of
++ the array may be changed without affecting the
++ identity of the overall array.
++ Array data structures are typically represented by a fixed area in
++ storage and cannot efficiently grow or shrink on demand as can list
++ structures (see however \spadtype{FlexibleArray} for a data structure
++ which is a cross between a list and an array).
++ Iteration over, and access to, elements of arrays is extremely fast
++ (and often can be optimized to open-code).
++ Insertion and deletion however is generally slow since an entirely new
++ data structure must be created for the result.

```

```

OneDimensionalArrayAggregate(S:Type): Category ==
  FiniteLinearAggregate S with shallowlyMutable
add
  parts x          == [qelt(x, i) for i in minIndex x .. maxIndex x]
  sort_!(f, a) == quickSort(f, a)$FiniteLinearAggregateSort(S, %)

  any?(f, a) ==
    for i in minIndex a .. maxIndex a repeat
      f qelt(a, i) => return true
    false

  every?(f, a) ==
    for i in minIndex a .. maxIndex a repeat
      not(f qelt(a, i)) => return false

```



```

true

position(f:S -> Boolean, a:%) ==
  for i in minIndex a .. maxIndex a repeat
    f qelt(a, i) => return i
  minIndex(a) - 1

find(f, a) ==
  for i in minIndex a .. maxIndex a repeat
    f qelt(a, i) => return qelt(a, i)
  "failed"

count(f:S->Boolean, a:%) ==
  n:NonNegativeInteger := 0
  for i in minIndex a .. maxIndex a repeat
    if f(qelt(a, i)) then n := n+1
  n

map_!(f, a) ==
  for i in minIndex a .. maxIndex a repeat
    qsetelt_!(a, i, f qelt(a, i))
  a

setelt(a:%, s:UniversalSegment(Integer), x:S) ==
  l := lo s; h := if hasHi s then hi s else maxIndex a
  l < minIndex a or h > maxIndex a => error "index out of range"
  for k in l..h repeat qsetelt_!(a, k, x)
  x

reduce(f, a) ==
  empty? a => error "cannot reduce an empty aggregate"
  r := qelt(a, m := minIndex a)
  for k in m+1 .. maxIndex a repeat r := f(r, qelt(a, k))
  r

reduce(f, a, identity) ==
  for k in minIndex a .. maxIndex a repeat
    identity := f(identity, qelt(a, k))
  identity

if S has SetCategory then
  reduce(f, a, identity, absorber) ==
    for k in minIndex a .. maxIndex a while identity ^= absorber
      repeat identity := f(identity, qelt(a, k))
    identity

-- this is necessary since new has disappeared.
stupidnew: (NonNegativeInteger, %, %) -> %
stupidget: List % -> S
-- a and b are not both empty if n > 0

```

```

stupidnew(n, a, b) ==
  zero? n => empty()
  new(n, (empty? a => qelt(b, minIndex b); qelt(a, minIndex a)))
-- at least one element of l must be non-empty
stupidget l ==
  for a in l repeat
    not empty? a => return first a
  error "Should not happen"

map(f, a, b) ==
  m := max(minIndex a, minIndex b)
  n := min(maxIndex a, maxIndex b)
  l := max(0, n - m + 1)::NonNegativeInteger
  c := stupidnew(l, a, b)
  for i in minIndex(c).. for j in m..n repeat
    qsetelt_!(c, i, f(qelt(a, j), qelt(b, j)))
  c

-- map(f, a, b, x) ==
--   m := min(minIndex a, minIndex b)
--   n := max(maxIndex a, maxIndex b)
--   l := (n - m + 1)::NonNegativeInteger
--   c := new l
--   for i in minIndex(c).. for j in m..n repeat
--     qsetelt_!(c, i, f(a(j, x), b(j, x)))
--   c

merge(f, a, b) ==
  r := stupidnew(#a + #b, a, b)
  i := minIndex a
  m := maxIndex a
  j := minIndex b
  n := maxIndex b
  for k in minIndex(r).. while i <= m and j <= n repeat
    if f(qelt(a, i), qelt(b, j)) then
      qsetelt_!(r, k, qelt(a, i))
      i := i+1
    else
      qsetelt_!(r, k, qelt(b, j))
      j := j+1
  for k in k.. for i in i..m repeat qsetelt_!(r, k, elt(a, i))
  for k in k.. for j in j..n repeat qsetelt_!(r, k, elt(b, j))
  r

elt(a:%, s:UniversalSegment(Integer)) ==
  l := lo s
  h := if hasHi s then hi s else maxIndex a
  l < minIndex a or h > maxIndex a => error "index out of range"
  r := stupidnew(max(0, h - l + 1)::NonNegativeInteger, a, a)
  for k in minIndex r.. for i in l..h repeat

```

```

    qsetelt_!(r, k, qelt(a, i))
  r

insert(a:%, b:%, i:Integer) ==
  m := minIndex b
  n := maxIndex b
  i < m or i > n => error "index out of range"
  y := stupidnew(#a + #b, a, b)
  for k in minIndex y.. for j in m..i-1 repeat
    qsetelt_!(y, k, qelt(b, j))
  for k in k.. for j in minIndex a .. maxIndex a repeat
    qsetelt_!(y, k, qelt(a, j))
  for k in k.. for j in i..n repeat qsetelt_!(y, k, qelt(b, j))
  y

copy x ==
  y := stupidnew(#x, x, x)
  for i in minIndex x .. maxIndex x for j in minIndex y .. repeat
    qsetelt_!(y, j, qelt(x, i))
  y

copyInto_(y, x, s) ==
  s < minIndex y or s + #x > maxIndex y + 1 =>
    error "index out of range"
  for i in minIndex x .. maxIndex x for j in s.. repeat
    qsetelt_!(y, j, qelt(x, i))
  y

construct l ==
--  a := new(#l)
  empty? l => empty()
  a := new(#l, first l)
  for i in minIndex(a).. for x in l repeat qsetelt_!(a, i, x)
  a

delete(a:%, s:UniversalSegment(Integer)) ==
  l := lo s; h := if hasHi s then hi s else maxIndex a
  l < minIndex a or h > maxIndex a => error "index out of range"
  h < l => copy a
  r := stupidnew((#a - h + l - 1)::NonNegativeInteger, a, a)
  for k in minIndex(r).. for i in minIndex a..l-1 repeat
    qsetelt_!(r, k, qelt(a, i))
  for k in k.. for i in h+1 .. maxIndex a repeat
    qsetelt_!(r, k, qelt(a, i))
  r

delete(x:%, i:Integer) ==
  i < minIndex x or i > maxIndex x => error "index out of range"
  y := stupidnew((#x - 1)::NonNegativeInteger, x, x)
  for i in minIndex(y).. for j in minIndex x..i-1 repeat

```

```

    qsetelt_!(y, i, qelt(x, j))
  for i in i .. for j in i+1 .. maxIndex x repeat
    qsetelt_!(y, i, qelt(x, j))
  y

reverse_! x ==
  m := minIndex x
  n := maxIndex x
  for i in 0..((n-m) quo 2) repeat swap_!(x, m+i, n-i)
  x

concat l ==
  empty? l => empty()
  n := _+/#a for a in l]
  i := minIndex(r := new(n, stupidget l))
  for a in l repeat
    copyInto_!(r, a, i)
    i := i + #a
  r

sorted?(f, a) ==
  for i in minIndex(a)..maxIndex(a)-1 repeat
    not f(qelt(a, i), qelt(a, i + 1)) => return false
  true

concat(x:%, y:%) ==
  z := stupidnew(#x + #y, x, y)
  copyInto_!(z, x, i := minIndex z)
  copyInto_!(z, y, i + #x)
  z

if S has SetCategory then
  x = y ==
    #x ^= #y => false
    for i in minIndex x .. maxIndex x repeat
      not(qelt(x, i) = qelt(y, i)) => return false
    true

coerce(r:%):OutputForm ==
  bracket commaSeparate
    [qelt(r, k)::OutputForm for k in minIndex r .. maxIndex r]

position(x:S, t:%, s:Integer) ==
  n := maxIndex t
  s < minIndex t or s > n => error "index out of range"
  for k in s..n repeat
    qelt(t, k) = x => return k
  minIndex(t) - 1

if S has OrderedSet then

```

```

a < b ==
  for i in minIndex a .. maxIndex a
    for j in minIndex b .. maxIndex b repeat
      qelt(a, i) ^= qelt(b, j) => return a.i < b.j
#a < #b

```

— A1AGG.dotabb —

```

"A1AGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=A1AGG"];
"A1AGG" -> "FLAGG"

```

— A1AGG.dotfull —

```

"OneDimensionalArrayAggregate(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=A1AGG"];
"OneDimensionalArrayAggregate(a:Type)" ->
  "FiniteLinearAggregate(a:Type)"

"OneDimensionalArrayAggregate(Character)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=A1AGG"];
"OneDimensionalArrayAggregate(Character)" ->
  "OneDimensionalArrayAggregate(a:Type)"

"OneDimensionalArrayAggregate(Boolean)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=A1AGG"];
"OneDimensionalArrayAggregate(Boolean)" ->
  "OneDimensionalArrayAggregate(a:Type)"

```

— A1AGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OneDimensionalArrayAggregate(a:Type)" [color=lightblue];
  "OneDimensionalArrayAggregate(a:Type)" ->
    "FiniteLinearAggregate(a:Type)"

```

```

"FiniteLinearAggregate(a:Type)" [color=lightblue];
"FiniteLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"

"LinearAggregate(a:Type)" [color=lightblue];
"LinearAggregate(a:Type)" -> "IndexedAggregate(b:Integer,a:Type)"
"LinearAggregate(a:Type)" -> "CLAGG..."

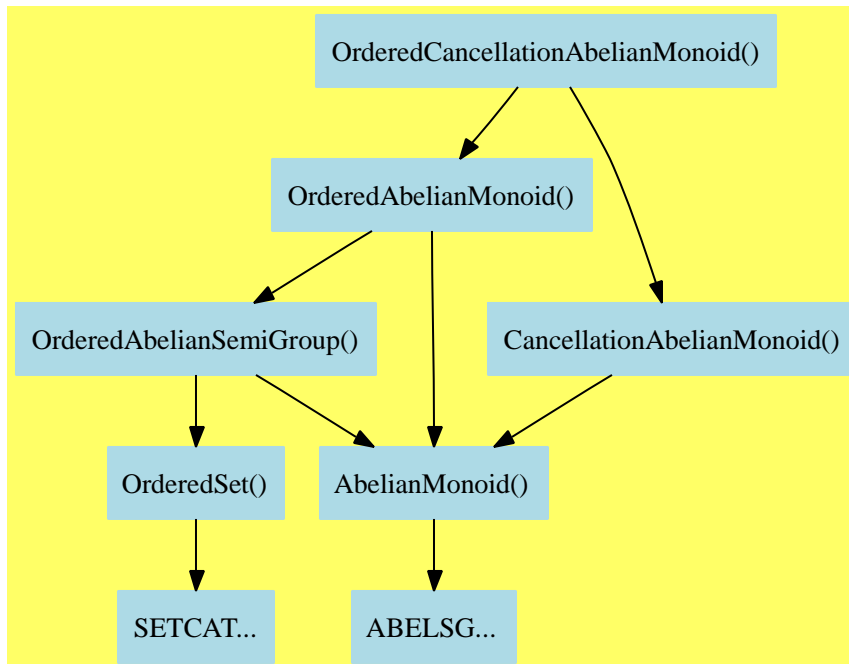
"IndexedAggregate(b:Integer,a:Type)" [color=seagreen];
"IndexedAggregate(b:Integer,a:Type)" -> "IXAGG..."

"CLAGG..." [color=lightblue];
"IXAGG..." [color=lightblue];
}

```

—————→

OrderedCancellationAbelianMonoid (OCAMON)



— OrderedCancellationAbelianMonoid.input —

```

)set break resume
)sys rm -f OrderedCancellationAbelianMonoid.output
)spool OrderedCancellationAbelianMonoid.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrderedCancellationAbelianMonoid
--R OrderedCancellationAbelianMonoid is a category constructor
--R Abbreviation for OrderedCancellationAbelianMonoid is OCAMON
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OCAMON
--R
--R----- Operations -----
--R ?? : (PositiveInteger,%) -> %      ?+? : (%,%) -> %
--R ?<? : (%,%) -> Boolean             ?<=? : (%,%) -> Boolean
--R ?=? : (%,%) -> Boolean             ?>? : (%,%) -> Boolean
--R ?>=? : (%,%) -> Boolean            0 : () -> %
--R coerce : % -> OutputForm           hash : % -> SingleInteger
--R latex : % -> String                 max : (%,%) -> %
--R min : (%,%) -> %                   sample : () -> %
--R zero? : % -> Boolean                ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— OrderedCancellationAbelianMonoid.help —

=====

OrderedCancellationAbelianMonoid examples

=====

Ordered sets which are also abelian cancellation monoids, such that the addition preserves the ordering.

See Also:

o)show OrderedCancellationAbelianMonoid

See:

\Rightarrow “OrderedAbelianGroup” (OAGROUP) [9](#) on page [811](#)
 \Rightarrow “OrderedAbelianMonoidSup” (OAMONS) [9](#) on page [815](#)
 \Leftarrow “CancellationAbelianMonoid” (CABMON) [6](#) on page [434](#)
 \Leftarrow “OrderedAbelianMonoid” (OAMON) [7](#) on page [629](#)

Exports:

| | | | | |
|-----|--------|---------------|-------|------|
| 0 | coerce | hash | latex | max |
| min | sample | subtractIfCan | zero? | ?~=? |
| ?*? | ?+? | ?<? | ?<=? | ?=? |
| ?>? | ?>=? | | | |

These exports come from (p[629](#)) OrderedAbelianMonoid():

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
max : (%,%) -> %
min : (%,%) -> %
sample : () -> %
zero? : % -> Boolean
?<? : (%,%) -> Boolean
?<=? : (%,%) -> Boolean
?=? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?+? : (%,%) -> %

```

These exports come from (p[434](#)) CancellationAbelianMonoid():

```

subtractIfCan : (%,%) -> Union(%, "failed")

```

— category OCAMON OrderedCancellationAbelianMonoid —

```

)abbrev category OCAMON OrderedCancellationAbelianMonoid
++ Description:
++ Ordered sets which are also abelian cancellation monoids,
++ such that the addition preserves the ordering.

OrderedCancellationAbelianMonoid(): Category ==
  Join(OrderedAbelianMonoid, CancellationAbelianMonoid)

```

— OCAMON.dotabb —

```
"OCAMON"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OCAMON"];
"OCAMON" -> "OAMON"
"OCAMON" -> "CABMON"
```

— OCAMON.dotfull —

```
"OrderedCancellationAbelianMonoid()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OCAMON"];
"OrderedCancellationAbelianMonoid()" -> "OrderedAbelianMonoid()"
"OrderedCancellationAbelianMonoid()" -> "CancellationAbelianMonoid()"
```

— OCAMON.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrderedCancellationAbelianMonoid()" [color=lightblue];
  "OrderedCancellationAbelianMonoid()" -> "OrderedAbelianMonoid()"
  "OrderedCancellationAbelianMonoid()" -> "CancellationAbelianMonoid()"

  "OrderedAbelianMonoid()" [color=lightblue];
  "OrderedAbelianMonoid()" -> "OrderedAbelianSemiGroup()"
  "OrderedAbelianMonoid()" -> "AbelianMonoid()"

  "OrderedAbelianSemiGroup()" [color=lightblue];
  "OrderedAbelianSemiGroup()" -> "OrderedSet()"
  "OrderedAbelianSemiGroup()" -> "AbelianMonoid()"

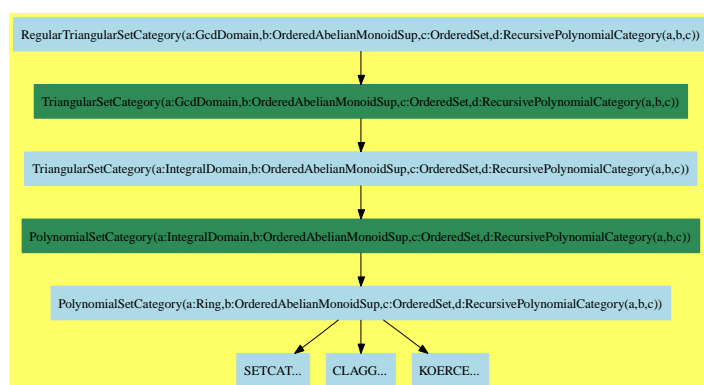
  "OrderedSet()" [color=lightblue];
  "OrderedSet()" -> "SETCAT..."

  "CancellationAbelianMonoid()" [color=lightblue];
  "CancellationAbelianMonoid()" -> "AbelianMonoid()"

  "AbelianMonoid()" [color=lightblue];
  "AbelianMonoid()" -> "ABELSG..."
```

```
"SETCAT..." [color=lightblue];
"ABELSG..." [color=lightblue];
}
```

RegularTriangularSetCategory (RSETCAT)



— RegularTriangularSetCategory.input —

```
)set break resume
)sys rm -f RegularTriangularSetCategory.output
)spool RegularTriangularSetCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RegularTriangularSetCategory
--R
--R RegularTriangularSetCategory(R: GcdDomain,E: OrderedAbelianMonoidSup,V: OrderedSet,P: RecursivePolynomialCategory(a,b,c))
--R Abbreviation for RegularTriangularSetCategory is RSETCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RSETCAT
--R
--R----- Operations -----
--R ?? : (%,% ) -> Boolean      algebraic? : (V,%) -> Boolean
--R algebraicVariables : % -> List(V)    augment : (List(P),%) -> List(%)
--R augment : (P,List(%)) -> List(%)    augment : (P,%) -> List(%)
```

```

--R coerce : % -> List(P)
--R collect : (% , V) -> %
--R collectUnder : (% , V) -> %
--R construct : List(P) -> %
--R degree : % -> NonNegativeInteger
--R empty? : % -> Boolean
--R extend : (List(P), %) -> List(%)
--R extend : (P, %) -> List(%)
--R first : % -> Union(P, "failed")
--R headReduce : (P, %) -> P
--R headReduced? : (P, %) -> Boolean
--R initiallyReduce : (P, %) -> P
--R initials : % -> List(P)
--R intersect : (P, %) -> List(%)
--R invertibleSet : (P, %) -> List(%)
--R latex : % -> String
--R mainVariables : % -> List(V)
--R mvar : % -> V
--R normalized? : (P, %) -> Boolean
--R reduceByQuasiMonic : (P, %) -> P
--R rest : % -> Union(%, "failed")
--R sample : () -> %
--R stronglyReduced? : % -> Boolean
--R variables : % -> List(V)
--R ?^=? : (% , %) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R algebraicCoefficients? : (P, %) -> Boolean
--R any? : ((P -> Boolean), %) -> Boolean if $ has finiteAggregate
--R augment : (List(P), List(%)) -> List(%)
--R autoReduced? : (% , ((P, List(P)) -> Boolean)) -> Boolean
--R basicSet : (List(P), (P -> Boolean), ((P, P) -> Boolean)) -> Union(Record(bas: %, top: List(P)),
--R basicSet : (List(P), ((P, P) -> Boolean)) -> Union(Record(bas: %, top: List(P)), "failed")
--R coHeight : % -> NonNegativeInteger if V has FINITE
--R convert : % -> InputForm if P has KONVERT(INFORM)
--R count : ((P -> Boolean), %) -> NonNegativeInteger if $ has finiteAggregate
--R count : (P, %) -> NonNegativeInteger if P has SETCAT and $ has finiteAggregate
--R eval : (% , List(Equation(P))) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% , Equation(P)) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% , P, P) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% , List(P), List(P)) -> % if P has EVALAB(P) and P has SETCAT
--R every? : ((P -> Boolean), %) -> Boolean if $ has finiteAggregate
--R extend : (List(P), List(%)) -> List(%)
--R extendIfCan : (% , P) -> Union(%, "failed")
--R find : ((P -> Boolean), %) -> Union(P, "failed")
--R headRemainder : (P, %) -> Record(num: P, den: R) if R has INTDOM
--R initiallyReduced? : (P, %) -> Boolean
--R internalAugment : (List(P), %) -> %
--R intersect : (P, List(%)) -> List(%)
--R intersect : (List(P), List(%)) -> List(%)
--R intersect : (List(P), %) -> List(%)

coerce : % -> OutputForm
collectQuasiMonic : % -> %
collectUpper : (% , V) -> %
copy : % -> %
empty : () -> %
eq? : (% , %) -> Boolean
extend : (P, List(%)) -> List(%)
extend : (% , P) -> %
hash : % -> SingleInteger
headReduced? : % -> Boolean
infRittWu? : (% , %) -> Boolean
initiallyReduced? : % -> Boolean
internalAugment : (P, %) -> %
invertible? : (P, %) -> Boolean
last : % -> Union(P, "failed")
mainVariable? : (V, %) -> Boolean
map : ((P -> P), %) -> %
normalized? : % -> Boolean
purelyAlgebraic? : % -> Boolean
removeZero : (P, %) -> P
retract : List(P) -> %
stronglyReduce : (P, %) -> P
trivialIdeal? : % -> Boolean
zeroSetSplit : List(P) -> List(%)

```

```

--R invertible? : (P,%) -> List(Record(val: Boolean,tower: %))
--R invertibleElseSplit? : (P,%) -> Union(Boolean,List(%))
--R lastSubResultant : (P,P,%) -> List(Record(val: P,tower: %))
--R lastSubResultantElseSplit : (P,P,%) -> Union(P,List(%))
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((P -> P),%) -> % if $ has shallowlyMutable
--R member? : (P,%) -> Boolean if P has SETCAT and $ has finiteAggregate
--R members : % -> List(P) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(P) if $ has finiteAggregate
--R purelyAlgebraic? : (P,%) -> Boolean
--R purelyAlgebraicLeadingMonomial? : (P,%) -> Boolean
--R purelyTranscendental? : (P,%) -> Boolean
--R quasiComponent : % -> Record(close: List(P),open: List(P))
--R reduce : (P,%,((P,P) -> P),((P,P) -> Boolean)) -> P
--R reduce : (((P,P) -> P),%) -> P if $ has finiteAggregate
--R reduce : (((P,P) -> P),%,P) -> P if $ has finiteAggregate
--R reduce : (((P,P) -> P),%,P,P) -> P if P has SETCAT and $ has finiteAggregate
--R reduced? : (P,%,((P,P) -> Boolean)) -> Boolean
--R remainder : (P,%) -> Record(rnum: R,polnum: P,den: R) if R has INTDOM
--R remove : ((P -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (P,%) -> % if P has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
--R retractIfCan : List(P) -> Union(%, "failed")
--R rewriteIdealWithHeadRemainder : (List(P),%) -> List(P) if R has INTDOM
--R rewriteIdealWithRemainder : (List(P),%) -> List(P) if R has INTDOM
--R rewriteSetWithReduction : (List(P),%,((P,P) -> P),((P,P) -> Boolean)) -> List(P)
--R roughBase? : % -> Boolean if R has INTDOM
--R roughEqualIdeals? : (%,%) -> Boolean if R has INTDOM
--R roughSubIdeal? : (%,%) -> Boolean if R has INTDOM
--R roughUnitIdeal? : % -> Boolean if R has INTDOM
--R select : (%,V) -> Union(P, "failed")
--R select : ((P -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R sort : (%,V) -> Record(under: %,floor: %,upper: %)
--R squareFreePart : (P,%) -> List(Record(val: P,tower: %))
--R stronglyReduced? : (P,%) -> Boolean
--R triangular? : % -> Boolean if R has INTDOM
--R zeroSetSplit : (List(P),Boolean) -> List(%)
--R zeroSetSplitIntoTriangularSystems : List(P) -> List(Record(close: %,open: List(P)))
--R
--E 1

```

```

)spool
)lisp (bye)

```

=====

RegularTriangularSetCategory examples

=====

The category of regular triangular sets was introduced under the name regular chains in M. KALKBRENER "Three contributions to elimination theory".

In P. AUBRY, D. LAZARD and M. MORENO MAZA "On the Theories of Triangular Sets" it is proved that extensions of a field are equivalent notions.

In the following definitions, all polynomials and ideals are taken from the polynomial ring $k[x_1, \dots, x_n]$ where k is the fraction field of R .

The triangular set $[t_1, \dots, t_m]$ is regular iff for every i the initial of t_{i+1} is invertible in the tower of simple extensions associated with $[t_1, \dots, t_i]$.

A family $[T_1, \dots, T_s]$ of regular triangular sets is a split of Kalkbrener of a given ideal I iff the radical of I is equal to the intersection of the radical ideals generated by the saturated ideals of the $[T_1, \dots, T_i]$.

A family $[T_1, \dots, T_s]$ of regular triangular sets is a split of Kalkbrener of a given triangular set T iff it is a split of Kalkbrener of the saturated ideal of T . Let K be an algebraic closure of k .

Assume that V is finite with cardinality n and let A be the affine space K^n .

For a regular triangular set T let denote by $W(T)$ the set of regular zeros of T . A family $[T_1, \dots, T_s]$ of regular triangular sets is a split of Lazard of a given subset S of A iff the union of the $W(T_i)$ contains S and is contained in the closure of S (w.r.t. Zariski topology).

A family $[T_1, \dots, T_s]$ of regular triangular sets is a split of Lazard of a given triangular set T if it is a split of Lazard of $W(T)$. Note that if $[T_1, \dots, T_s]$ is a split of Lazard of T then it is also a split of Kalkbrener of T . The converse is false.

This category provides operations related to both kinds of splits, the former being related to ideals decomposition whereas the latter deals with varieties decomposition. See the example illustrating the RegularTriangularSet constructor for more explanations about decompositions by means of regular triangular sets.

See Also:

o)show RegularTriangularSetCategory

See:

⇒ “NormalizedTriangularSetCategory” (NTSCAT) [9](#) on page [801](#)

⇒ “SquareFreeRegularTriangularSetCategory” (SFRTCAT) [9](#) on page [831](#)

⇐ “TriangularSetCategory” (TSETCAT) [7](#) on page [649](#)

Exports:

| | | |
|---------------------------|---------------------------------|-----------------------------------|
| algebraicCoefficients? | algebraicVariables | any? |
| augment | autoReduced? | basicSet |
| coerce | coHeight | collect |
| collectQuasiMonic | collectUnder | collectUpper |
| construct | convert | copy |
| count | degree | empty |
| empty? | eq? | eval |
| every? | extend | extendIfCan |
| find | first | hash |
| headReduce | headReduced? | headRemainder |
| infRittWu? | initiallyReduce | initiallyReduced? |
| initials | internalAugment | intersect |
| invertible? | invertibleElseSplit? | invertibleSet |
| last | lastSubResultant | lastSubResultantElseSplit |
| less? | latex | mainVariable? |
| mainVariables | map | map! |
| member? | members | more? |
| mvar | normalized? | parts |
| purelyAlgebraic? | purelyAlgebraicLeadingMonomial? | purelyTranscendental? |
| quasiComponent | reduce | reduceByQuasiMonic |
| reduced? | remainder | remove |
| removeDuplicates | removeZero | rest |
| retract | retractIfCan | rewriteIdealWithHeadRemainder |
| rewriteIdealWithRemainder | rewriteSetWithReduction | roughBase? |
| roughEqualIdeals? | roughSubIdeal? | roughUnitIdeal? |
| sample | select | size? |
| sort | squareFreePart | stronglyReduce |
| stronglyReduced? | triangular? | trivialIdeal? |
| variables | zeroSetSplit | zeroSetSplitIntoTriangularSystems |
| #? | ?=? | ?~=? |

Attributes Exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

These are directly exported but not implemented:

```

augment : (P,%) -> List %
extend : (P,%) -> List %
internalAugment : (P,%) -> %
internalAugment : (List P,%) -> %
intersect : (P,%) -> List %
invertibleElseSplit? : (P,%) -> Union(Boolean,List %)
invertible? : (P,%) -> List Record(val: Boolean,tower: %)
invertible? : (P,%) -> Boolean
invertibleSet : (P,%) -> List %
lastSubResultant : (P,P,%) -> List Record(val: P,tower: %)
lastSubResultantElseSplit : (P,P,%) -> Union(P,List %)
squareFreePart : (P,%) -> List Record(val: P,tower: %)
zeroSetSplit : (List P,Boolean) -> List %

```

These are implemented by this category:

```

algebraicCoefficients? : (P,%) -> Boolean
augment : (P,List %) -> List %
augment : (List P,%) -> List %
augment : (List P,List %) -> List %
extend : (P,List %) -> List %
extend : (List P,%) -> List %
extend : (List P,List %) -> List %
intersect : (List P,List %) -> List %
intersect : (List P,%) -> List %
intersect : (P,List %) -> List %
purelyAlgebraic? : % -> Boolean
purelyAlgebraic? : (P,%) -> Boolean
purelyAlgebraicLeadingMonomial? : (P,%) -> Boolean
purelyTranscendental? : (P,%) -> Boolean

```

These exports come from (p649) `TriangularSetCategory(R,E,V,P)` where `R:GcdDomain`, `E:OrderedAbelianMonoidSup`, `V:OrderedSet`, `P:RecursivePolynomialCategory(R,E,V)`:

```

algebraic? : (V,%) -> Boolean
algebraicVariables : % -> List V
any? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
autoReduced? : (%,((P,List P) -> Boolean)) -> Boolean
basicSet :
  (List P,((P,P) -> Boolean)) ->
    Union(Record(bas: %,top: List P),"failed")
basicSet :
  (List P,(P -> Boolean),((P,P) -> Boolean)) ->
    Union(Record(bas: %,top: List P),"failed")
coerce : % -> List P
coerce : % -> OutputForm

```

```

coHeight : % -> NonNegativeInteger if V has FINITE
collect : (% , V) -> %
collectQuasiMonic : % -> %
collectUnder : (% , V) -> %
collectUpper : (% , V) -> %
construct : List P -> %
convert : % -> InputForm if P has KONVERT INFORM
copy : % -> %
count : ((P -> Boolean), %) -> NonNegativeInteger
  if $ has finiteAggregate
count : (P, %) -> NonNegativeInteger
  if P has SETCAT
  and $ has finiteAggregate
degree : % -> NonNegativeInteger
empty : () -> %
empty? : % -> Boolean
eq? : (% , %) -> Boolean
eval : (% , List Equation P) -> % if P has EVALAB P and P has SETCAT
eval : (% , Equation P) -> % if P has EVALAB P and P has SETCAT
eval : (% , P, P) -> % if P has EVALAB P and P has SETCAT
eval : (% , List P, List P) -> % if P has EVALAB P and P has SETCAT
every? : ((P -> Boolean), %) -> Boolean if $ has finiteAggregate
extend : (% , P) -> %
extendIfCan : (% , P) -> Union(%, "failed")
find : ((P -> Boolean), %) -> Union(P, "failed")
first : % -> Union(P, "failed")
hash : % -> SingleInteger
headReduce : (P, %) -> P
headReduced? : % -> Boolean
headReduced? : (P, %) -> Boolean
headRemainder : (P, %) -> Record(num: P, den: R) if R has INTDOM
infRittWu? : (% , %) -> Boolean
initiallyReduce : (P, %) -> P
initiallyReduced? : % -> Boolean
initiallyReduced? : (P, %) -> Boolean
initials : % -> List P
last : % -> Union(P, "failed")
latex : % -> String
less? : (% , NonNegativeInteger) -> Boolean
mainVariable? : (V, %) -> Boolean
mainVariables : % -> List V
map : ((P -> P), %) -> %
map! : ((P -> P), %) -> % if $ has shallowlyMutable
member? : (P, %) -> Boolean if P has SETCAT and $ has finiteAggregate
members : % -> List P if $ has finiteAggregate
more? : (% , NonNegativeInteger) -> Boolean
mvar : % -> V
normalized? : % -> Boolean
normalized? : (P, %) -> Boolean
parts : % -> List P if $ has finiteAggregate

```



```

quasiComponent : % -> Record(close: List P, open: List P)
reduce : (((P,P) -> P), %) -> P if $ has finiteAggregate
reduce : (((P,P) -> P), %, P) -> P if $ has finiteAggregate
reduce : (((P,P) -> P), %, P, P) -> P
  if P has SETCAT
  and $ has finiteAggregate
reduce : (P, %, ((P,P) -> P), ((P,P) -> Boolean)) -> P
reduceByQuasiMonic : (P, %) -> P
reduced? : (P, %, ((P,P) -> Boolean)) -> Boolean
remainder : (P, %) -> Record(rnum: R, polnum: P, den: R) if R has INTDOM
remove : ((P -> Boolean), %) -> % if $ has finiteAggregate
remove : (P, %) -> % if P has SETCAT and $ has finiteAggregate
removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
removeZero : (P, %) -> P
rest : % -> Union(%, "failed")
retract : List P -> %
rewriteIdealWithHeadRemainder : (List P, %) -> List P if R has INTDOM
rewriteIdealWithRemainder : (List P, %) -> List P if R has INTDOM
retractIfCan : List P -> Union(%, "failed")
rewriteSetWithReduction :
  (List P, %, ((P,P) -> P), ((P,P) -> Boolean)) -> List P
roughBase? : % -> Boolean if R has INTDOM
roughEqualIdeals? : (%, %) -> Boolean if R has INTDOM
roughSubIdeal? : (%, %) -> Boolean if R has INTDOM
roughUnitIdeal? : % -> Boolean if R has INTDOM
sample : () -> %
select : ((P -> Boolean), %) -> % if $ has finiteAggregate
select : (%, V) -> Union(P, "failed")
size? : (%, NonNegativeInteger) -> Boolean
sort : (%, V) -> Record(under: %, floor: %, upper: %)
stronglyReduce : (P, %) -> P
stronglyReduced? : (P, %) -> Boolean
stronglyReduced? : % -> Boolean
triangular? : % -> Boolean if R has INTDOM
trivialIdeal? : % -> Boolean
variables : % -> List V
zeroSetSplit : List P -> List %
zeroSetSplitIntoTriangularSystems :
  List P -> List Record(close: %, open: List P)
#? : % -> NonNegativeInteger if $ has finiteAggregate
?~=? : (%, %) -> Boolean
?=? : (%, %) -> Boolean

```

— category RSETCAT RegularTriangularSetCategory —

```

)abbrev category RSETCAT RegularTriangularSetCategory
++ Author: Marc Moreno Maza
++ Date Created: 09/03/1998
++ Date Last Updated: 12/15/1998

```

```

++ References :
++ [1] M. KALKBRENER "Three contributions to elimination theory"
++     Phd Thesis, University of Linz, Austria, 1991.
++ [2] M. KALKBRENER "Algorithmic properties of polynomial rings"
++     Journal of Symbol. Comp. 1998
++ [3] P. AUBRY, D. LAZARD and M. MORENO MAZA "On the Theories
++     of Triangular Sets" Journal of Symbol. Comp. (to appear)
++ [4] M. MORENO MAZA "A new algorithm for computing triangular
++     decomposition of algebraic varieties" NAG Tech. Rep. 4/98.
++ Description:
++ The category of regular triangular sets, introduced under
++ the name regular chains in [1] (and other papers).
++ In [3] it is proved that regular triangular sets and towers of simple
++ extensions of a field are equivalent notions.
++ In the following definitions, all polynomials and ideals
++ are taken from the polynomial ring  $\text{spad}\{k[x_1, \dots, x_n]\}$  where  $\text{spad}\{k\}$ 
++ is the fraction field of  $\text{spad}\{R\}$ .
++ The triangular set  $\text{spad}\{[t_1, \dots, t_m]\}$  is regular
++ iff for every  $\text{spad}\{i\}$  the initial of  $\text{spad}\{t_{i+1}\}$  is invertible
++ in the tower of simple extensions associated with  $\text{spad}\{[t_1, \dots, t_i]\}$ .
++ A family  $\text{spad}\{[T_1, \dots, T_s]\}$  of regular triangular sets
++ is a split of Kalkbrener of a given ideal  $\text{spad}\{I\}$ 
++ iff the radical of  $\text{spad}\{I\}$  is equal to the intersection
++ of the radical ideals generated by the saturated ideals
++ of the  $\text{spad}\{[T_1, \dots, T_i]\}$ .
++ A family  $\text{spad}\{[T_1, \dots, T_s]\}$  of regular triangular sets
++ is a split of Kalkbrener of a given triangular set  $\text{spad}\{T\}$ 
++ iff it is a split of Kalkbrener of the saturated ideal of  $\text{spad}\{T\}$ .
++ Let  $\text{spad}\{K\}$  be an algebraic closure of  $\text{spad}\{k\}$ .
++ Assume that  $\text{spad}\{V\}$  is finite with cardinality
++  $\text{spad}\{n\}$  and let  $\text{spad}\{A\}$  be the affine space  $\text{spad}\{K^n\}$ .
++ For a regular triangular set  $\text{spad}\{T\}$  let denote by  $\text{spad}\{W(T)\}$  the
++ set of regular zeros of  $\text{spad}\{T\}$ .
++ A family  $\text{spad}\{[T_1, \dots, T_s]\}$  of regular triangular sets
++ is a split of Lazard of a given subset  $\text{spad}\{S\}$  of  $\text{spad}\{A\}$ 
++ iff the union of the  $\text{spad}\{W(T_i)\}$  contains  $\text{spad}\{S\}$  and
++ is contained in the closure of  $\text{spad}\{S\}$  (w.r.t. Zariski topology).
++ A family  $\text{spad}\{[T_1, \dots, T_s]\}$  of regular triangular sets
++ is a split of Lazard of a given triangular set  $\text{spad}\{T\}$ 
++ if it is a split of Lazard of  $\text{spad}\{W(T)\}$ .
++ Note that if  $\text{spad}\{[T_1, \dots, T_s]\}$  is a split of Lazard of
++  $\text{spad}\{T\}$  then it is also a split of Kalkbrener of  $\text{spad}\{T\}$ .
++ The converse is false.
++ This category provides operations related to both kinds of
++ splits, the former being related to ideals decomposition whereas
++ the latter deals with varieties decomposition.
++ See the example illustrating the RegularTriangularSet constructor for more
++ explanations about decompositions by means of regular triangular sets.

RegularTriangularSetCategory(R:GcdDomain, E:OrderedAbelianMonoidSup, _

```

```

V:OrderedSet,P:RecursivePolynomialCategory(R,E,V)):
  Category ==
TriangularSetCategory(R,E,V,P) with
  purelyAlgebraic?: (P,$) -> Boolean
    ++ \spad{purelyAlgebraic?(p,ts)} returns \spad{true} iff every
    ++ variable of \spad{p} is algebraic w.r.t. \spad{ts}.
  purelyTranscendental? : (P,$) -> Boolean
    ++ \spad{purelyTranscendental?(p,ts)} returns \spad{true} iff every
    ++ variable of \spad{p} is not algebraic w.r.t. \spad{ts}
  algebraicCoefficients? : (P,$) -> Boolean
    ++ \spad{algebraicCoefficients?(p,ts)} returns \spad{true} iff every
    ++ variable of \spad{p} which is not the main one of \spad{p}
    ++ is algebraic w.r.t. \spad{ts}.
  purelyAlgebraic?: $ -> Boolean
    ++ \spad{purelyAlgebraic?(ts)} returns true iff for every algebraic
    ++ variable \spad{v} of \spad{ts} we have
    ++ \spad{algebraicCoefficients?(t_v,ts_v_-)} where \spad{ts_v}
    ++ is select from TriangularSetCategory(ts,v) and
    ++ \spad{ts_v_-} is
    ++ collectUnder from TriangularSetCategory(ts,v).
  purelyAlgebraicLeadingMonomial?: (P, $) -> Boolean
    ++ \spad{purelyAlgebraicLeadingMonomial?(p,ts)} returns true iff
    ++ the main variable of any non-constant iterated initial
    ++ of \spad{p} is algebraic w.r.t. \spad{ts}.
  invertibleElseSplit? : (P,$) -> Union(Boolean,List $)
    ++ \spad{invertibleElseSplit?(p,ts)} returns \spad{true} (resp.
    ++ \spad{false}) if \spad{p} is invertible in the tower
    ++ associated with \spad{ts} or returns a split of Kalkbrener
    ++ of \spad{ts}.
  invertible? : (P,$) -> List Record(val : Boolean, tower : $)
    ++ \spad{invertible?(p,ts)} returns \spad{lbwt} where \spad{lbwt.i}
    ++ is the result of \spad{invertibleElseSplit?(p,lbwt.i.tower)} and
    ++ the list of the \spad{(lqrwt.i).tower} is a split of Kalkbrener of
    ++ \spad{ts}.
  invertible?: (P,$) -> Boolean
    ++ \spad{invertible?(p,ts)} returns true iff \spad{p} is invertible
    ++ in the tower associated with \spad{ts}.
  invertibleSet: (P,$) -> List $
    ++ \spad{invertibleSet(p,ts)} returns a split of Kalkbrener of the
    ++ quotient ideal of the ideal \spad{axiom{I}} by \spad{p} where \spad{I} is
    ++ the radical of saturated of \spad{ts}.
  lastSubResultantElseSplit: (P, P, $) -> Union(P,List $)
    ++ \spad{lastSubResultantElseSplit(p1,p2,ts)} returns either
    ++ \spad{g} a quasi-monic gcd of \spad{p1} and \spad{p2} w.r.t.
    ++ the \spad{ts} or a split of Kalkbrener of \spad{ts}.
    ++ This assumes that \spad{p1} and \spad{p2} have the same main
    ++ variable and that this variable is greater than any variable
    ++ occurring in \spad{ts}.
  lastSubResultant: (P, P, $) -> List Record(val : P, tower : $)
    ++ \spad{lastSubResultant(p1,p2,ts)} returns \spad{lpwt} such that

```

```

++ \spad{lpwt.i.val} is a quasi-monic gcd of \spad{p1} and \spad{p2}
++ w.r.t. \spad{lpwt.i.tower}, for every \spad{i}, and such
++ that the list of the \spad{lpwt.i.tower} is a split of Kalkbrener of
++ \spad{ts}. Moreover, if \spad{p1} and \spad{p2} do not
++ have a non-trivial gcd w.r.t. \spad{lpwt.i.tower} then
++ \spad{lpwt.i.val} is the resultant of these polynomials w.r.t.
++ \spad{lpwt.i.tower}. This assumes that \spad{p1} and \spad{p2} have
++ the same main variable and that this variable is greater than any
++ variable occurring in \spad{ts}.
squareFreePart: (P,$) -> List Record(val : P, tower : $)
++ \spad{squareFreePart(p,ts)} returns \spad{lpwt} such that
++ \spad{lpwt.i.val} is a square-free polynomial
++ w.r.t. \spad{lpwt.i.tower}, this polynomial being associated with
++ \spad{p} modulo \spad{lpwt.i.tower}, for every \spad{i}. Moreover,
++ the list of the \spad{lpwt.i.tower} is a split
++ of Kalkbrener of \spad{ts}.
++ WARNING: This assumes that \spad{p} is a non-constant polynomial
++ such that if \spad{p} is added to \spad{ts}, then the resulting set
++ is a regular triangular set.
intersect: (P,$) -> List $
++ \spad{intersect(p,ts)} returns the same as
++ \spad{intersect([p],ts)}
intersect: (List P, $) -> List $
++ \spad{intersect(lp,ts)} returns \spad{lts} a split of Lazard
++ of the intersection of the affine variety associated
++ with \spad{lp} and the regular zero set of \spad{ts}.
intersect: (List P, List $) -> List $
++ \spad{intersect(lp,lts)} returns the same as
++ \spad{concat([intersect(lp,ts) for ts in lts])}
intersect: (P, List $) -> List $
++ \spad{intersect(p,lts)} returns the same as
++ \spad{intersect([p],lts)}
augment: (P,$) -> List $
++ \spad{augment(p,ts)} assumes that \spad{p} is a non-constant
++ polynomial whose main variable is greater than any variable
++ of \spad{ts}. This operation assumes also that if \spad{p} is
++ added to \spad{ts} the resulting set, say \spad{ts+p}, is a
++ regular triangular set. Then it returns a split of Kalkbrener
++ of \spad{ts+p}. This may not be \spad{ts+p} itself, if for
++ instance \spad{ts+p} is required to be square-free.
augment: (P,List $) -> List $
++ \spad{augment(p,lts)} returns the same as
++ \spad{concat([augment(p,ts) for ts in lts])}
augment: (List P,$) -> List $
++ \spad{augment(lp,ts)} returns \spad{ts} if \spad{empty? lp},
++ \spad{augment(p,ts)} if \spad{lp = [p]}, otherwise
++ \spad{augment(first lp, augment(rest lp, ts))}
augment: (List P,List $) -> List $
++ \spad{augment(lp,lts)} returns the same as
++ \spad{concat([augment(lp,ts) for ts in lts])}

```

```

internalAugment: (P, $) -> $
  ++ \spad{internalAugment(p,ts)} assumes that \spad{augment(p,ts)}
  ++ returns a singleton and returns it.
internalAugment: (List P, $) -> $
  ++ \spad{internalAugment(lp,ts)} returns \spad{ts} if \spad{lp}
  ++ is empty otherwise returns
  ++ \spad{internalAugment(rest lp, internalAugment(first lp, ts))}
extend: (P,$) -> List $
  ++ \spad{extend(p,ts)} assumes that \spad{p} is a non-constant
  ++ polynomial whose main variable is greater than any variable
  ++ of \spad{ts}. Then it returns a split of Kalkbrener
  ++ of \spad{ts+p}. This may not be \spad{ts+p} itself, if for
  ++ instance \spad{ts+p} is not a regular triangular set.
extend: (P, List $) -> List $
  ++ \spad{extend(p,lts)} returns the same as
  ++ \spad{concat([extend(p,ts) for ts in lts])}
extend: (List P,$) -> List $
  ++ \spad{extend(lp,ts)} returns \spad{ts} if \spad{empty? lp}
  ++ \spad{extend(p,ts)} if \spad{lp = [p]} else
  ++ \spad{extend(first lp, extend(rest lp, ts))}
extend: (List P,List $) -> List $
  ++ \spad{extend(lp,lts)} returns the same as
  ++ \spad{concat([extend(lp,ts) for ts in lts])}
zeroSetSplit: (List P, Boolean) -> List $
  ++ \spad{zeroSetSplit(lp,clos?)} returns \spad{lts} a split of
  ++ Kalkbrener of the radical ideal associated with \spad{lp}.
  ++ If \spad{clos?} is false, it is also a decomposition of the
  ++ variety associated with \spad{lp} into the regular zero set of the
  ++ \spad{ts} in \spad{lts} (or, in other words, a split of Lazard of
  ++ this variety). See the example illustrating the
  ++ \spad{type{RegularTriangularSet}} constructor for more explanations
  ++ about decompositions by means of regular triangular sets.

```

add

```

NNI ==> NonNegativeInteger
INT ==> Integer
LP ==> List P
PWT ==> Record(val : P, tower : $)
LpWT ==> Record(val : (List P), tower : $)
Split ==> List $
pack ==> PolynomialSetUtilitiesPackage(R,E,V,P)

purelyAlgebraic?(p: P, ts: $): Boolean ==
  ground? p => true
  not algebraic?(mvar(p),ts) => false
  algebraicCoefficients?(p,ts)

purelyTranscendental?(p:P,ts:$): Boolean ==
  empty? ts => true

```

```

lv : List V := variables(p)$P
while (not empty? lv) and (not algebraic?(first(lv),ts)) repeat _
  lv := rest lv
empty? lv

purelyAlgebraicLeadingMonomial?(p: P, ts: $): Boolean ==
  ground? p => true
  algebraic?(mvar(p),ts) and purelyAlgebraicLeadingMonomial?(init(p), ts)

algebraicCoefficients?(p:P,ts:$): Boolean ==
  ground? p => true
  (not ground? init(p)) and not (algebraic?(mvar(init(p)),ts)) => false
  algebraicCoefficients?(init(p),ts) =>
    ground? tail(p) => true
    mvar(tail(p)) = mvar(p) =>
      algebraicCoefficients?(tail(p),ts)
    algebraic?(mvar(tail(p)),ts) =>
      algebraicCoefficients?(tail(p),ts)
    false
  false

if V has Finite
then
  purelyAlgebraic?(ts: $): Boolean ==
    empty? ts => true
    size()$V = #ts => true
    lp: LP := sort(infRittWu?,members(ts))
    i: NonNegativeInteger := size()$V
    for p in lp repeat
      v: V := mvar(p)
      (i = (lookup(v)$V)::NNI) =>
        i := subtractIfCan(i,1)::NNI
      univariate?(p)$pack =>
        i := subtractIfCan(i,1)::NNI
      not algebraicCoefficients?(p,collectUnder(ts,v)) =>
        return false
      i := subtractIfCan(i,1)::NNI
    true
else

  purelyAlgebraic?(ts: $): Boolean ==
    empty? ts => true
    v: V := mvar(ts)
    p: P := select(ts,v)::P
    ts := collectUnder(ts,v)
    empty? ts => univariate?(p)$pack
    not purelyAlgebraic?(ts) => false
    algebraicCoefficients?(p,ts)

```

```

augment(p:P,lts:List $) ==
  toSave: Split := []
  while not empty? lts repeat
    ts := first lts
    lts := rest lts
    toSave := concat(augment(p,ts),toSave)
  toSave

augment(lp:LP,ts:$) ==
  toSave: Split := [ts]
  empty? lp => toSave
  lp := sort(infRittWu?,lp)
  while not empty? lp repeat
    p := first lp
    lp := rest lp
    toSave := augment(p,toSave)
  toSave

augment(lp:LP,lts:List $) ==
  empty? lp => lts
  toSave: Split := []
  while not empty? lts repeat
    ts := first lts
    lts := rest lts
    toSave := concat(augment(lp,ts),toSave)
  toSave

extend(p:P,lts:List $) ==
  toSave : Split := []
  while not empty? lts repeat
    ts := first lts
    lts := rest lts
    toSave := concat(extend(p,ts),toSave)
  toSave

extend(lp:LP,ts:$) ==
  toSave: Split := [ts]
  empty? lp => toSave
  lp := sort(infRittWu?,lp)
  while not empty? lp repeat
    p := first lp
    lp := rest lp
    toSave := extend(p,toSave)
  toSave

extend(lp:LP,lts:List $) ==
  empty? lp => lts
  toSave: Split := []
  while not empty? lts repeat
    ts := first lts

```

```

    lts := rest lts
    toSave := concat(extend(lp,ts),toSave)
  toSave

intersect(lp:LP,lts:List $): List $ ==
  -- A VERY GENERAL default algorithm
  (empty? lp) or (empty? lts) => lts
  lp := [primitivePart(p) for p in lp]
  lp := removeDuplicates lp
  lp := remove(zero?,lp)
  any?(ground?,lp) => []
  toSee: List LpWT := [[lp,ts]$LpWT for ts in lts]
  toSave: List $ := []
  lp: LP
  p: P
  ts: $
  lus: List $
  while (not empty? toSee) repeat
    lpwt := first toSee; toSee := rest toSee
    lp := lpwt.val; ts := lpwt.tower
    empty? lp => toSave := cons(ts, toSave)
    p := first lp; lp := rest lp
    lus := intersect(p,ts)
    toSee := concat([[lp,us]$LpWT for us in lus], toSee)
  toSave

intersect(lp: LP,ts: $): List $ ==
  intersect(lp,[ts])

intersect(p: P,lts: List $): List $ ==
  intersect([p],lts)

```

— RSETCAT.dotabb —

```

"RSETCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=RSETCAT"];
"RSETCAT" -> "TSETCAT"

```

— RSETCAT.dotfull —

```

"RegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=RSETCAT"];

```



```

"RegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePoly
->
"TriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialC

```

— RSETCAT.dotpic —

```

digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "RegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePoly
    [color=lightblue];
    "RegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePoly
    ->
    "TriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialC

    "TriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialC
    [color=seagreen];
    "TriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialC
    ->
    "TriangularSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolyno
    "TriangularSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolyno
    [color=lightblue];
    "TriangularSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolyno
    -> "PolynomialSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursiveP

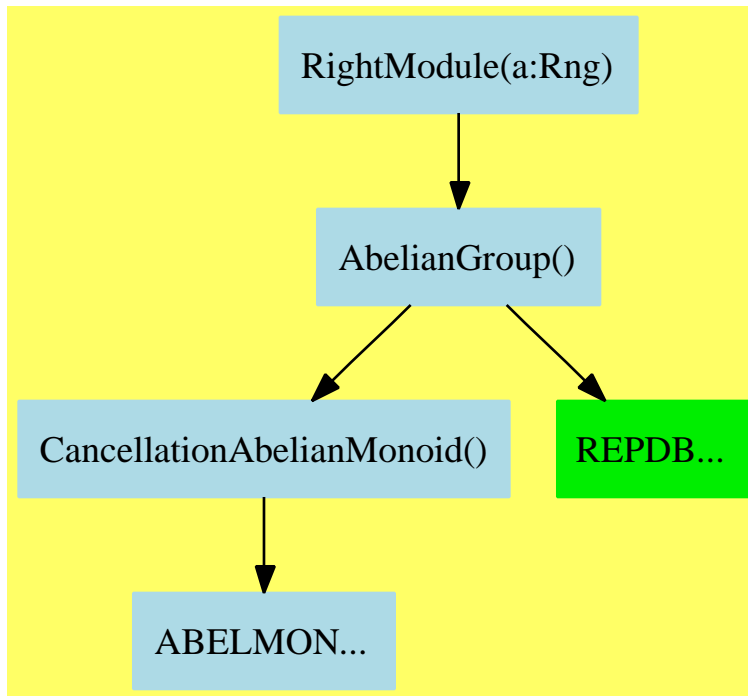
    "PolynomialSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolyno
    [color=seagreen];
    "PolynomialSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolyno
    -> "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialC

    "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCatego
    [color=lightblue];
    "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCatego
    -> "SETCAT..."
    "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCatego
    -> "CLAGG..."
    "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCatego
    -> "KOERCE..."

    "SETCAT..." [color=lightblue];
    "KOERCE..." [color=lightblue];
    "CLAGG..." [color=lightblue];
}

```

RightModule (RMODULE)



— RightModule.input —

```

)set break resume
)sys rm -f RightModule.output
)spool RightModule.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RightModule
--R
--R RightModule(R: Rng) is a category constructor
--R Abbreviation for RightModule is RMODULE
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RMODULE
--R

```

```

--R----- Operations -----
--R ?? : (% , R) -> %           ?? : (Integer, %) -> %
--R ?? : (PositiveInteger, %) -> %   ?+? : (% , %) -> %
--R ?-? : (% , %) -> %           -? : % -> %
--R ?? : (% , %) -> Boolean       0 : () -> %
--R coerce : % -> OutputForm      hash : % -> SingleInteger
--R latex : % -> String           sample : () -> %
--R zero? : % -> Boolean          ?~=? : (% , %) -> Boolean
--R ?? : (NonNegativeInteger, %) -> %
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— RightModule.help —

```

=====
RightModule examples
=====

```

The category of right modules over an rng (ring not necessarily with unit). This is an abelian group which supports right multiplication by elements of the rng.

Axioms:

```

x*(a*b) = (x*a)*b
x*(a+b) = (x*a)+(x*b)
(x+y)*x = (x*a)+(y*a)

```

See Also:

o)show RightModule

See:

⇒ “BiModule” (BMODULE) [9](#) on page [782](#)

⇐ “AbelianGroup” (ABELGRP) [7](#) on page [574](#)

Exports:

| | | | | |
|---------------|--------|------|-------|--------|
| 0 | coerce | hash | latex | sample |
| subtractIfCan | zero? | ?~=? | ?? | ?+? |
| ?-? | -? | ?=? | | |

These are directly exported but not implemented:

```
?? : (% , R) -> %
```

These exports come from (p574) `AbelianGroup()`:

```
0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (% , %) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (% , %) -> Boolean
?? : (PositiveInteger, %) -> %
?+? : (% , %) -> %
?=?: (% , %) -> Boolean
?? : (NonNegativeInteger, %) -> %
?? : (Integer, %) -> %
?-? : (% , %) -> %
-? : % -> %
```

— category RMODULE RightModule —

```
)abbrev category RMODULE RightModule
++ Description:
++ The category of right modules over an rng (ring not necessarily
++ with unit). This is an abelian group which supports right
++ multiplication by elements of the rng.
++
++ Axioms\br
++ \tab{5}\spad{x*(a*b) = (x*a)*b}\br
++ \tab{5}\spad{x*(a+b) = (x*a)+(x*b)}\br
++ \tab{5}\spad{(x+y)*x = (x*a)+(y*a)}
```

RightModule(R:Rng):Category == AbelianGroup with

```
"*": (% , R) -> %
++ x*r returns the right multiplication of the module element x
++ by the ring element r.
```

—————

— RMODULE.dotabb —

```
"RMODULE"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=RMODULE" ];
"RMODULE" -> "ABELGRP"
```

— RMODULE.dotfull —

```
"RightModule(a:Rng)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RMODULE"];
"RightModule(a:Rng)" -> "AbelianGroup()"

"RightModule(a:Ring)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=RMODULE"];
"RightModule(a:Ring)" -> "RightModule(a:Rng)"
```

— RMODULE.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

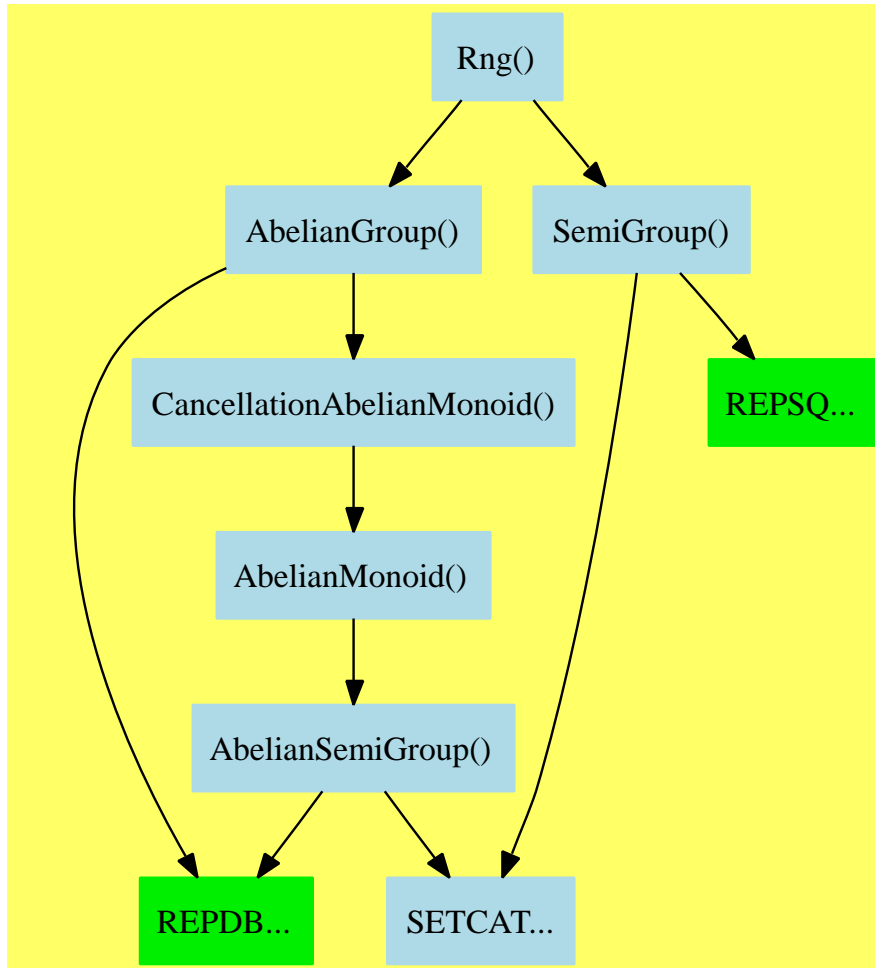
  "RightModule(a:Rng)" [color=lightblue];
  "RightModule(a:Rng)" -> "AbelianGroup()"

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CancellationAbelianMonoid()"
  "AbelianGroup()" -> "REPDB..."

  "CancellationAbelianMonoid()" [color=lightblue];
  "CancellationAbelianMonoid()" -> "ABELMON..."

  "ABELMON..." [color=lightblue];
  "REPDB..." [color="#00EE00"];
}
```

Rng (RNG)



Rng is a Ring that does not necessarily have a unit.

— Rng.input —

```

)set break resume
)sys rm -f Rng.output
)spool Rng.output
)set message test on
)set message auto off
)clear all

```

--S 1 of 1

```

)show Rng
--R Rng is a category constructor
--R Abbreviation for Rng is RNG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RNG
--R
--R----- Operations -----
--R ?? : (%,%) -> %                ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %  ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %                ?-? : (%,%) -> %
--R -? : % -> %                     ?? : (%,%) -> Boolean
--R 0 : () -> %                     ?^? : (%,PositiveInteger) -> %
--R coerce : % -> OutputForm        hash : % -> SingleInteger
--R latex : % -> String              sample : () -> %
--R zero? : % -> Boolean             ?~? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— Rng.help —

=====

Rng examples

=====

The category of associative rings, not necessarily commutative, and not necessarily with a 1. This is a combination of an abelian group and a semigroup, with multiplication distributing over addition.

Axioms:

$$\begin{aligned}
 x*(y+z) &= x*y + x*z \\
 (x+y)*z &= x*z + y*z
 \end{aligned}$$

Conditional attributes:

$$\text{noZeroDivisors} \quad ab = 0 \Rightarrow a=0 \text{ or } b=0$$

See Also:

o)show Rng

See:

⇒ “Ring” (RING) 9 on page 826

⇐ “AbelianGroup” (ABELGRP) 7 on page 574

⇐ “SemiGroup” (SGROUP) 4 on page 292

Exports:

| | | | | |
|-------|---------------|------|-------|--------|
| 0 | coerce | hash | latex | sample |
| zero? | subtractIfCan | ?*? | ?**? | ?+? |
| ?-? | -? | ?=? | ?^=? | ?^? |

These exports come from (p574) AbelianGroup():

```
0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?^=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?**? : (PositiveInteger,%) -> %
?*? : (Integer,%) -> %
?-? : (%,%) -> %
-? : % -> %
```

These exports come from (p292) SemiGroup():

```
?*? : (%,%) -> %
?**? : (%, PositiveInteger) -> %
?^? : (%, PositiveInteger) -> %
```

— category RNG Rng —

```
)abbrev category RNG Rng
++ Description:
++ The category of associative rings, not necessarily commutative, and not
++ necessarily with a 1. This is a combination of an abelian group
++ and a semigroup, with multiplication distributing over addition.
++
++ Axioms\br
++ \tab{5}\spad{ x*(y+z) = x*y + x*z }\br
++ \tab{5}\spad{ (x+y)*z = x*z + y*z }
++
++ Conditional attributes\br
++ \tab{5}noZeroDivisors\tab{5}\spad{ ab = 0 => a=0 or b=0}
```



```
Rng(): Category == Join(AbelianGroup,SemiGroup)
```

— RNG.dotabb —

```
"Rng" [color=lightblue,href="bookvol10.2.pdf#nameddest=RNG"];
"RNG" -> "ABELGRP"
"RNG" -> "SGROUP"
```

— RNG.dotfull —

```
"Rng()" [color=lightblue,href="bookvol10.2.pdf#nameddest=RNG"];
"Rng()" -> "AbelianGroup()"
"Rng()" -> "SemiGroup()"
```

— RNG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Rng()" [color=lightblue];
  "Rng()" -> "AbelianGroup()"
  "Rng()" -> "SemiGroup()"

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CancellationAbelianMonoid()"
  "AbelianGroup()" -> "REPDB..."

  "CancellationAbelianMonoid()" [color=lightblue];
  "CancellationAbelianMonoid()" -> "AbelianMonoid()"

  "AbelianMonoid()" [color=lightblue];
  "AbelianMonoid()" -> "AbelianSemiGroup()"

  "AbelianSemiGroup()" [color=lightblue];
  "AbelianSemiGroup()" -> "SETCAT..."
  "AbelianSemiGroup()" -> "REPDB..."
```

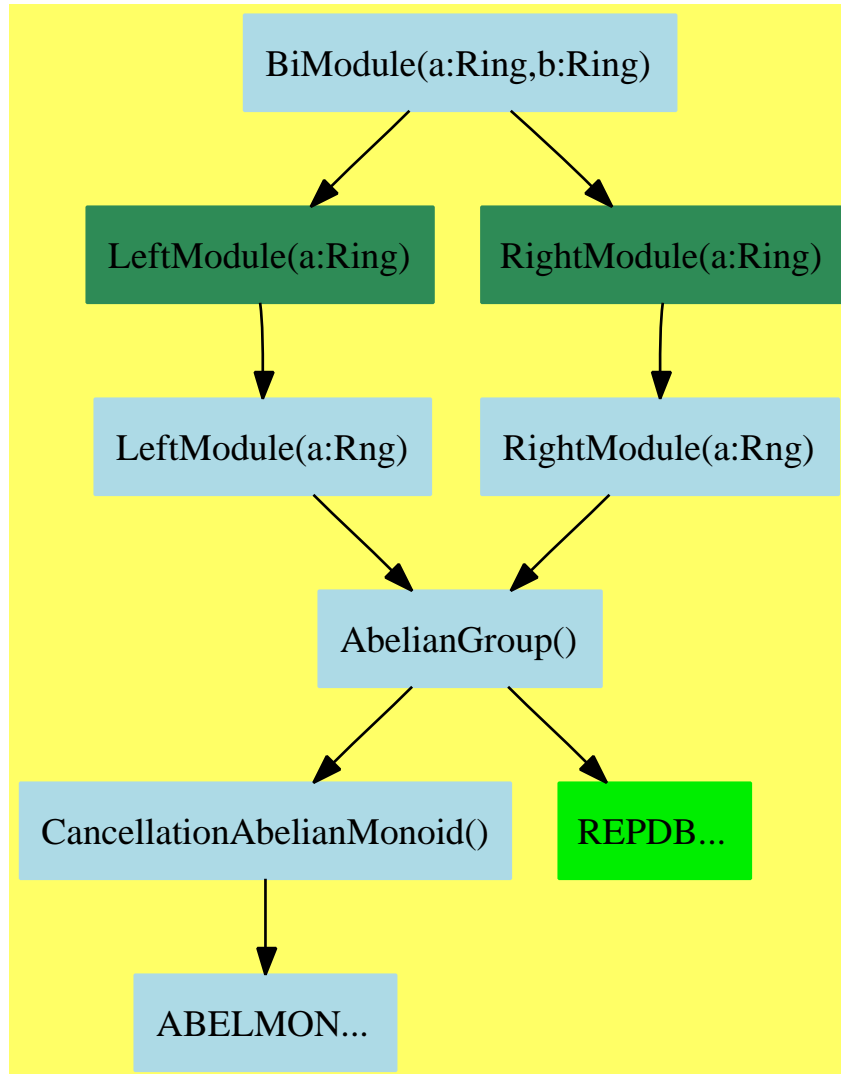
```
"SemiGroup()" [color=lightblue];  
"SemiGroup()" -> "SETCAT..."  
"SemiGroup()" -> "REPSQ..."  
  
"REPDB..." [color="#00EE00"];  
"REPSQ..." [color="#00EE00"];  
"SETCAT..." [color=lightblue];  
}
```

—————→

Chapter 9

Category Layer 8

BiModule (BMODULE)



— BiModule.input —

```

)set break resume
)sys rm -f BiModule.output
)spool BiModule.output
)set message test on
)set message auto off
)clear all

```

```

--S 1 of 1
)show BiModule
--R BiModule(R: Ring,S: Ring) is a category constructor
--R Abbreviation for BiModule is BMODULE
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for BMODULE
--R
--R----- Operations -----
--R ?? : (%,S) -> %           ?? : (R,%) -> %
--R ?? : (Integer,%) -> %     ?? : (PositiveInteger,%) -> %
--R +? : (%,%) -> %          ?-? : (%,%) -> %
--R -? : % -> %              ?=? : (%,%) -> Boolean
--R 0 : () -> %              coerce : % -> OutputForm
--R hash : % -> SingleInteger latex : % -> String
--R sample : () -> %          zero? : % -> Boolean
--R ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

```

```

)spool
)lisp (bye)

```

— BiModule.help —

=====

BiModule examples

=====

A BiModule is both a left and right module with respect to potentially different rings.

Axiom:

$$r*(x*s) = (r*x)*s$$

See Also:

o)show BiModule

See:

⇒ “AbelianMonoidRing” (AMR) [13](#) on page [1151](#)

⇒ “CommutativeRing” (COMRING) [10](#) on page [896](#)

\Rightarrow “DirectProductCategory” (DIRPCAT) [12](#) on page [1051](#)
 \Rightarrow “EntireRing” (ENTIRER) [10](#) on page [907](#)
 \Rightarrow “FreeModuleCat” (FMCAT) [10](#) on page [912](#)
 \Rightarrow “Module” (MODULE) [10](#) on page [928](#)
 \Rightarrow “MonogenicLinearOperator” (MLO) [12](#) on page [1103](#)
 \Rightarrow “RectangularMatrixCategory” (RMATCAT) [10](#) on page [954](#)
 \Rightarrow “SquareMatrixCategory” (SMATCAT) [12](#) on page [1131](#)
 \Rightarrow “UnivariateSkewPolynomialCategory” (OREPCAT) [10](#) on page [982](#)
 \Rightarrow “XAlgebra” (XALG) [10](#) on page [994](#)
 \Leftarrow “LeftModule” (LMODULE) [8](#) on page [710](#)
 \Leftarrow “RightModule” (RMODULE) [8](#) on page [771](#)

Exports:

| | | | | |
|---------------|--------|------|-------|--------|
| 0 | coerce | hash | latex | sample |
| subtractIfCan | zero? | ?~=? | ?*? | ?+? |
| ?-? | -? | ?=? | | |

Attributes Exported:

- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These exports come from ([p710](#)) LeftModule(R:Ring):

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,% ) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (R,% ) -> %
?=? : (%,% ) -> Boolean
?+? : (%,% ) -> %
?*? : (PositiveInteger,% ) -> %
?*? : (NonNegativeInteger,% ) -> %
?*? : (Integer,% ) -> %
?-? : (%,% ) -> %
-? : % -> %

```

These exports come from ([p771](#)) RightModule(S:Ring):

```

?*? : (% , S) -> %

```

```

)abbrev category BMODULE BiModule
++ Description:
++ A \spadtype{BiModule} is both a left and right module with respect
++ to potentially different rings.
++
++ Axiom\br
++ \tab{5}\spad{r*(x*s) = (r*x)*s}

```

```

BiModule(R:Ring,S:Ring):Category ==
  Join(LeftModule(R),RightModule(S)) with
    leftUnitary
      ++ \spad{1 * x = x}
    rightUnitary
      ++ \spad{x * 1 = x}

```

— BMODULE.dotabb —

```

"BiModule"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=BMODULE"];
"BiModule" -> "LModule"
"BiModule" -> "RModule"

```

— BMODULE.dotfull —

```

"BiModule(a:Ring,b:Ring)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=BMODULE"];
"BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
"BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

"BiModule(a:CommutativeRing,b:CommutativeRing)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=BMODULE"];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BiModule(a:Ring,b:Ring)"

"BiModule(a:Ring,b:OrderedAbelianMonoid)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=BMODULE"];
"BiModule(a:Ring,b:OrderedAbelianMonoid)" -> "BiModule(a:Ring,b:Ring)"

```

— BMODULE.dotpic —


```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "BiModule(a:Ring,b:Ring)" [color=lightblue];
  "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
  "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

  "RightModule(a:Ring)" [color=seagreen];
  "RightModule(a:Ring)" -> "RightModule(a:Rng)"

  "RightModule(a:Rng)" [color=lightblue];
  "RightModule(a:Rng)" -> "AbelianGroup()"

  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

  "LeftModule(a:Rng)" [color=lightblue];
  "LeftModule(a:Rng)" -> "AbelianGroup()"

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CancellationAbelianMonoid()"
  "AbelianGroup()" -> "REPDB..."

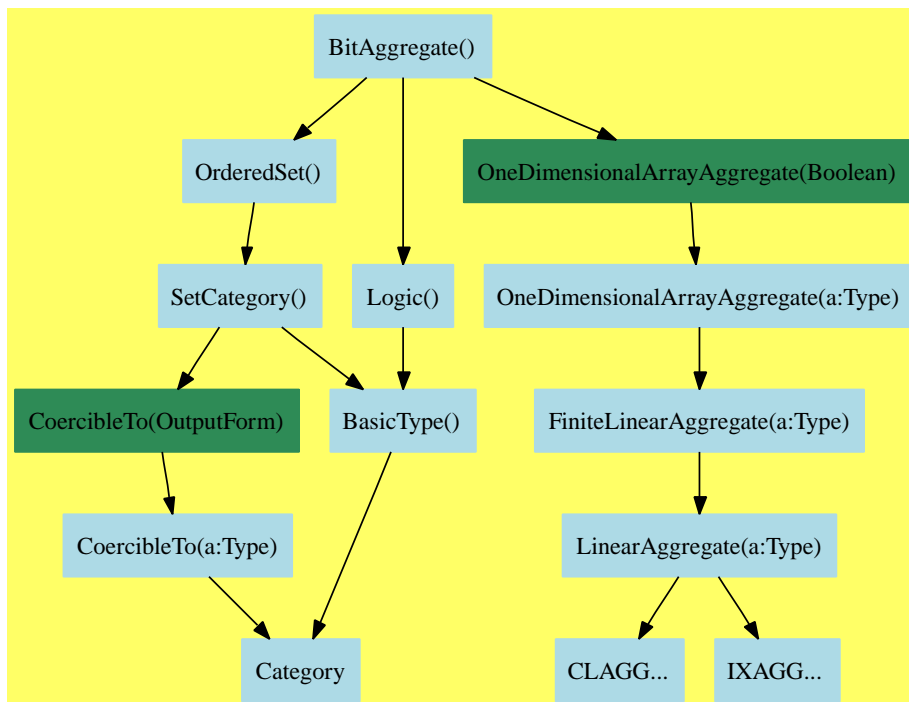
  "CancellationAbelianMonoid()" [color=lightblue];
  "CancellationAbelianMonoid()" -> "ABELMON..."

  "ABELMON..." [color=lightblue];
  "REPDB..." [color="#00EE00"];
}

```

—————→

BitAggregate (BTAGG)



— BitAggregate.input —

```

)set break resume
)sys rm -f BitAggregate.output
)spool BitAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show BitAggregate
--R
--R BitAggregate is a category constructor
--R Abbreviation for BitAggregate is BTAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for BTAGG
--R
--R----- Operations -----
--R ?/\? : (% ,%) -> %
--R ?<=? : (% ,%) -> Boolean
--R ?>=? : (% ,%) -> Boolean
--R ?/? : (% ,%) -> Boolean
--R ?<=? : (% ,%) -> Boolean
--R ?>=? : (% ,%) -> Boolean

```

```

--R ?\/? : (% , %) -> %
--R ?and? : (% , %) -> %
--R concat : (% , Boolean) -> %
--R concat : (% , %) -> %
--R construct : List(Boolean) -> %
--R delete : (% , Integer) -> %
--R empty : () -> %
--R entries : % -> List(Boolean)
--R hash : % -> SingleInteger
--R indices : % -> List(Integer)
--R latex : % -> String
--R min : (% , %) -> %
--R nor : (% , %) -> %
--R ?or? : (% , %) -> %
--R reverse : % -> %
--R xor : (% , %) -> %
--R ?~=? : (% , %) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R any? : ((Boolean -> Boolean), %) -> Boolean if $ has finiteAggregate
--R convert : % -> InputForm if Boolean has KONVERT(INFORM)
--R copyInto! : (% , %, Integer) -> % if $ has shallowlyMutable
--R count : ((Boolean -> Boolean), %) -> NonNegativeInteger if $ has finiteAggregate
--R count : (Boolean, %) -> NonNegativeInteger if Boolean has SETCAT and $ has finiteAggregate
--R delete : (% , UniversalSegment(Integer)) -> %
--R elt : (% , Integer, Boolean) -> Boolean
--R ?.? : (% , UniversalSegment(Integer)) -> %
--R entry? : (Boolean, %) -> Boolean if $ has finiteAggregate and Boolean has SETCAT
--R eval : (% , List(Equation(Boolean))) -> % if Boolean has EVALAB(BOOLEAN) and Boolean has SETCAT
--R eval : (% , Equation(Boolean)) -> % if Boolean has EVALAB(BOOLEAN) and Boolean has SETCAT
--R eval : (% , Boolean, Boolean) -> % if Boolean has EVALAB(BOOLEAN) and Boolean has SETCAT
--R eval : (% , List(Boolean), List(Boolean)) -> % if Boolean has EVALAB(BOOLEAN) and Boolean has SETCAT
--R every? : ((Boolean -> Boolean), %) -> Boolean if $ has finiteAggregate
--R fill! : (% , Boolean) -> % if $ has shallowlyMutable
--R find : ((Boolean -> Boolean), %) -> Union(Boolean, "failed")
--R first : % -> Boolean if Integer has ORDSET
--R insert : (Boolean, %, Integer) -> %
--R less? : (% , NonNegativeInteger) -> Boolean
--R map : ((Boolean -> Boolean), %) -> %
--R map : (((Boolean, Boolean) -> Boolean), %, %) -> %
--R map! : ((Boolean -> Boolean), %) -> % if $ has shallowlyMutable
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (Boolean, %) -> Boolean if Boolean has SETCAT and $ has finiteAggregate
--R members : % -> List(Boolean) if $ has finiteAggregate
--R merge : (((Boolean, Boolean) -> Boolean), %, %) -> %
--R merge : (% , %) -> % if Boolean has ORDSET
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (% , NonNegativeInteger) -> Boolean
--R new : (NonNegativeInteger, Boolean) -> %
--R parts : % -> List(Boolean) if $ has finiteAggregate
--R position : ((Boolean -> Boolean), %) -> Integer
~? : % -> %
coerce : % -> OutputForm
concat : (Boolean, %) -> %
concat : List(%) -> %
copy : % -> %
?.? : (% , Integer) -> Boolean
empty? : % -> Boolean
eq? : (% , %) -> Boolean
index? : (Integer, %) -> Boolean
insert : (% , %, Integer) -> %
max : (% , %) -> %
nand : (% , %) -> %
not? : % -> %
qelt : (% , Integer) -> Boolean
sample : () -> %
~? : % -> %

```

```

--R position : (Boolean,%) -> Integer if Boolean has SETCAT
--R position : (Boolean,%,Integer) -> Integer if Boolean has SETCAT
--R qsetelt! : (%,Integer,Boolean) -> Boolean if $ has shallowlyMutable
--R reduce : (((Boolean,Boolean) -> Boolean),%,Boolean,Boolean) -> Boolean if Boolean has SETCAT and $ has :
--R reduce : (((Boolean,Boolean) -> Boolean),%,Boolean) -> Boolean if $ has finiteAggregate
--R reduce : (((Boolean,Boolean) -> Boolean),%) -> Boolean if $ has finiteAggregate
--R remove : (Boolean,%) -> % if Boolean has SETCAT and $ has finiteAggregate
--R remove : ((Boolean -> Boolean),%) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if Boolean has SETCAT and $ has finiteAggregate
--R reverse! : % -> % if $ has shallowlyMutable
--R select : ((Boolean -> Boolean),%) -> % if $ has finiteAggregate
--R setelt : (%,Integer,Boolean) -> Boolean if $ has shallowlyMutable
--R setelt : (%,UniversalSegment(Integer),Boolean) -> Boolean if $ has shallowlyMutable
--R size? : (%,NonNegativeInteger) -> Boolean
--R sort : (((Boolean,Boolean) -> Boolean),%) -> %
--R sort : % -> % if Boolean has ORDSET
--R sort! : (((Boolean,Boolean) -> Boolean),%) -> % if $ has shallowlyMutable
--R sort! : % -> % if Boolean has ORDSET and $ has shallowlyMutable
--R sorted? : (((Boolean,Boolean) -> Boolean),%) -> Boolean
--R sorted? : % -> Boolean if Boolean has ORDSET
--R swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable
--R
--E 1

)spool
)lisp (bye)

```

— BitAggregate.help —

```

=====
BitAggregate examples
=====

```

The bit aggregate category models aggregates representing large quantities of Boolean data.

See Also:

o)show BitAggregate

See:

⇐ “Logic” (LOGIC) [3](#) on page [145](#)

⇐ “OneDimensionalArrayAggregate” (A1AGG) [8](#) on page [739](#)

⇐ “OrderedSet” (ORDSET) [4](#) on page [269](#)

Exports:

| | | | | |
|---------|------------------|---------|-----------|----------|
| any? | coerce | concat | construct | convert |
| copy | copyInto! | count | delete | elt |
| empty | empty? | entry? | entries | eq? |
| eval | every? | fill! | find | first |
| hash | index? | indices | insert | latex |
| less? | map | map! | max | maxIndex |
| member? | members | merge | min | minIndex |
| more? | nand | new | nor | not? |
| parts | position | qelt | qsetelt! | reduce |
| remove | removeDuplicates | reverse | reverse! | sample |
| select | setelt | size? | sort | sort! |
| sorted? | swap! | xor | #? | ?/\? |
| ?<? | ?<=? | ?=? | ?>? | ?>=? |
| ?\/? | ^? | ?and? | ?..? | ?or? |
| ~? | ?~=? | | | |

Attributes exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

These are directly exported but not implemented:

```
?and? : (%,% ) -> %
?or?  : (%,% ) -> %
xor    : (%,% ) -> %
```

These are implemented by this category:

```
not? : % -> %
^?   : % -> %
~?   : % -> %
?/\? : (%,% ) -> %
?\/? : (%,% ) -> %
nand : (%,% ) -> %
nor  : (%,% ) -> %
```

These exports come from (p269) `OrderedSet()`:

```
coerce : % -> OutputForm
hash    : % -> SingleInteger
```

```

latex : % -> String
max : (%,%) -> %
min : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?<? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?<=? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean

```

TPDHERE: Note that none of the exports of Logic are needed. Perhaps this can be eliminated.

These exports come from (p739) OneDimensionalArrayAggregate(Boolean):

```

any? : ((Boolean -> Boolean),%) -> Boolean
  if $ has finiteAggregate
concat : (%,%) -> %
concat : List % -> %
concat : (%,Boolean) -> %
concat : (Boolean,%) -> %
construct : List Boolean -> %
convert : % -> InputForm
  if Boolean has KONVERT INFORM
copy : % -> %
copyInto! : (%,%,Integer) -> %
  if $ has shallowlyMutable
count : (Boolean,%) -> NonNegativeInteger
  if Boolean has SETCAT and $ has finiteAggregate
count : ((Boolean -> Boolean),%) -> NonNegativeInteger
  if $ has finiteAggregate
delete : (%,UniversalSegment Integer) -> %
delete : (%,Integer) -> %
elt : (%,Integer,Boolean) -> Boolean
empty : () -> %
empty? : % -> Boolean
entry? : (Boolean,%) -> Boolean
  if $ has finiteAggregate and Boolean has SETCAT
entries : % -> List Boolean
eq? : (%,%) -> Boolean
eval : (%,List Equation Boolean) -> %
  if Boolean has EVALAB BOOLEAN and Boolean has SETCAT
eval : (%,Equation Boolean) -> %
  if Boolean has EVALAB BOOLEAN and Boolean has SETCAT
eval : (%,Boolean,Boolean) -> %
  if Boolean has EVALAB BOOLEAN and Boolean has SETCAT
eval : (%,List Boolean,List Boolean) -> %
  if Boolean has EVALAB BOOLEAN and Boolean has SETCAT
every? : ((Boolean -> Boolean),%) -> Boolean
  if $ has finiteAggregate

```

```

fill! : (% , Boolean) -> %
    if $ has shallowlyMutable
find : ((Boolean -> Boolean), %) -> Union(Boolean, "failed")
first : % -> Boolean if Integer has ORDSET
index? : (Integer, %) -> Boolean
indices : % -> List Integer
insert : (Boolean, %, Integer) -> %
insert : (% , %, Integer) -> %
less? : (% , NonNegativeInteger) -> Boolean
map : ((Boolean -> Boolean), %) -> %
map : (((Boolean, Boolean) -> Boolean), %, %) -> %
map! : ((Boolean -> Boolean), %) -> %
    if $ has shallowlyMutable
maxIndex : % -> Integer if Integer has ORDSET
member? : (Boolean, %) -> Boolean
    if Boolean has SETCAT and $ has finiteAggregate
members : % -> List Boolean if $ has finiteAggregate
merge : (% , %) -> % if Boolean has ORDSET
minIndex : % -> Integer if Integer has ORDSET
more? : (% , NonNegativeInteger) -> Boolean
new : (NonNegativeInteger, Boolean) -> %
merge : (((Boolean, Boolean) -> Boolean), %, %) -> %
parts : % -> List Boolean if $ has finiteAggregate
position : ((Boolean -> Boolean), %) -> Integer
position : (Boolean, %, Integer) -> Integer
    if Boolean has SETCAT
position : (Boolean, %) -> Integer
    if Boolean has SETCAT
qelt : (% , Integer) -> Boolean
qsetelt! : (% , Integer, Boolean) -> Boolean
    if $ has shallowlyMutable
reverse : % -> %
reduce : (((Boolean, Boolean) -> Boolean), %) -> Boolean
    if $ has finiteAggregate
reduce : (((Boolean, Boolean) -> Boolean), %, Boolean) -> Boolean
    if $ has finiteAggregate
reduce :
    (((Boolean, Boolean) -> Boolean), %, Boolean, Boolean) -> Boolean
    if Boolean has SETCAT and $ has finiteAggregate
remove : (Boolean, %) -> %
    if Boolean has SETCAT and $ has finiteAggregate
remove : ((Boolean -> Boolean), %) -> %
    if $ has finiteAggregate
removeDuplicates : % -> %
    if Boolean has SETCAT and $ has finiteAggregate
reverse! : % -> % if $ has shallowlyMutable
sample : () -> %
setelt : (% , UniversalSegment Integer, Boolean) -> Boolean
    if $ has shallowlyMutable
select : ((Boolean -> Boolean), %) -> %

```

```

    if $ has finiteAggregate
setelt : (%,Integer,Boolean) -> Boolean
    if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
sort : ((Boolean,Boolean) -> Boolean,%) -> %
sort : % -> % if Boolean has ORDSET
sort! : % -> %
    if Boolean has ORDSET and $ has shallowlyMutable
sort! : ((Boolean,Boolean) -> Boolean,%) -> %
    if $ has shallowlyMutable
sorted? : % -> Boolean if Boolean has ORDSET
sorted? : ((Boolean,Boolean) -> Boolean,%) -> Boolean
swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable
?.? : (%,UniversalSegment Integer) -> %
#? : % -> NonNegativeInteger if $ has finiteAggregate
?.? : (%,Integer) -> Boolean

```

— category BTAGG BitAggregate —

```

)abbrev category BTAGG BitAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ The bit aggregate category models aggregates representing large
++ quantities of Boolean data.

```

```

BitAggregate(): Category ==
Join(OrderedSet, Logic, OneDimensionalArrayAggregate Boolean) with
  "not": % -> %
    ++ not(b) returns the logical not of bit aggregate
    ++ \axiom{b}.
  "^" : % -> %
    ++ ^ b returns the logical not of bit aggregate
    ++ \axiom{b}.
  nand : (%, %) -> %
    ++ nand(a,b) returns the logical nand of bit aggregates
    ++ \axiom{a} and \axiom{b}.
  nor : (%, %) -> %
    ++ nor(a,b) returns the logical nor of bit aggregates
    ++ \axiom{a} and \axiom{b}.
  _and : (%, %) -> %
    ++ a and b returns the logical and of bit aggregates
    ++ \axiom{a} and \axiom{b}.
  _or : (%, %) -> %
    ++ a or b returns the logical or of bit aggregates
    ++ \axiom{a} and \axiom{b}.
  xor : (%, %) -> %
    ++ xor(a,b) returns the logical exclusive-or of bit aggregates

```



```
++ \axiom{a} and \axiom{b}.
```

```
add
  not v      == map(_not, v)
  _^ v       == map(_not, v)
  _~(v)      == map(_~, v)
  _/_\ (v, u) == map(_/_\, v, u)
  _\_/(v, u) == map(_\_/, v, u)
  nand(v, u) == map(nand, v, u)
  nor(v, u)  == map(nor, v, u)
```

— BTAGG.dotabb —

```
"BTAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=BTAGG"];
"BTAGG" -> "ORDSET"
"BTAGG" -> "LOGIC"
"BTAGG" -> "A1AGG"
```

— BTAGG.dotfull —

```
"BitAggregate()"
[ color=lightblue,href="bookvol10.2.pdf#nameddest=BTAGG"];
"BitAggregate()" -> "OrderedSet()"
"BitAggregate()" -> "Logic()"
"BitAggregate()" -> "OneDimensionalArrayAggregate(Boolean)"
```

— BTAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "BitAggregate()" [color=lightblue];
  "BitAggregate()" -> "OrderedSet()"
  "BitAggregate()" -> "Logic()"
  "BitAggregate()" -> "OneDimensionalArrayAggregate(Boolean)"

  "OneDimensionalArrayAggregate(Boolean)"
```

```

[color=seagreen,href="bookvol10.2.pdf#nameddest=A1AGG"];
"OneDimensionalArrayAggregate(Boolean)" ->
  "OneDimensionalArrayAggregate(a:Type)"

"OneDimensionalArrayAggregate(a:Type)" [color=lightblue];
"OneDimensionalArrayAggregate(a:Type)" ->
  "FiniteLinearAggregate(a:Type)"

"FiniteLinearAggregate(a:Type)" [color=lightblue];
"FiniteLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"

"LinearAggregate(a:Type)" [color=lightblue];
"LinearAggregate(a:Type)" -> "IXAGG..."
"LinearAggregate(a:Type)" -> "CLAGG..."

"OrderedSet()" [color=lightblue];
"OrderedSet()" -> "SetCategory()"

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"Logic()" [color=lightblue];
"Logic()" -> "BasicType()"

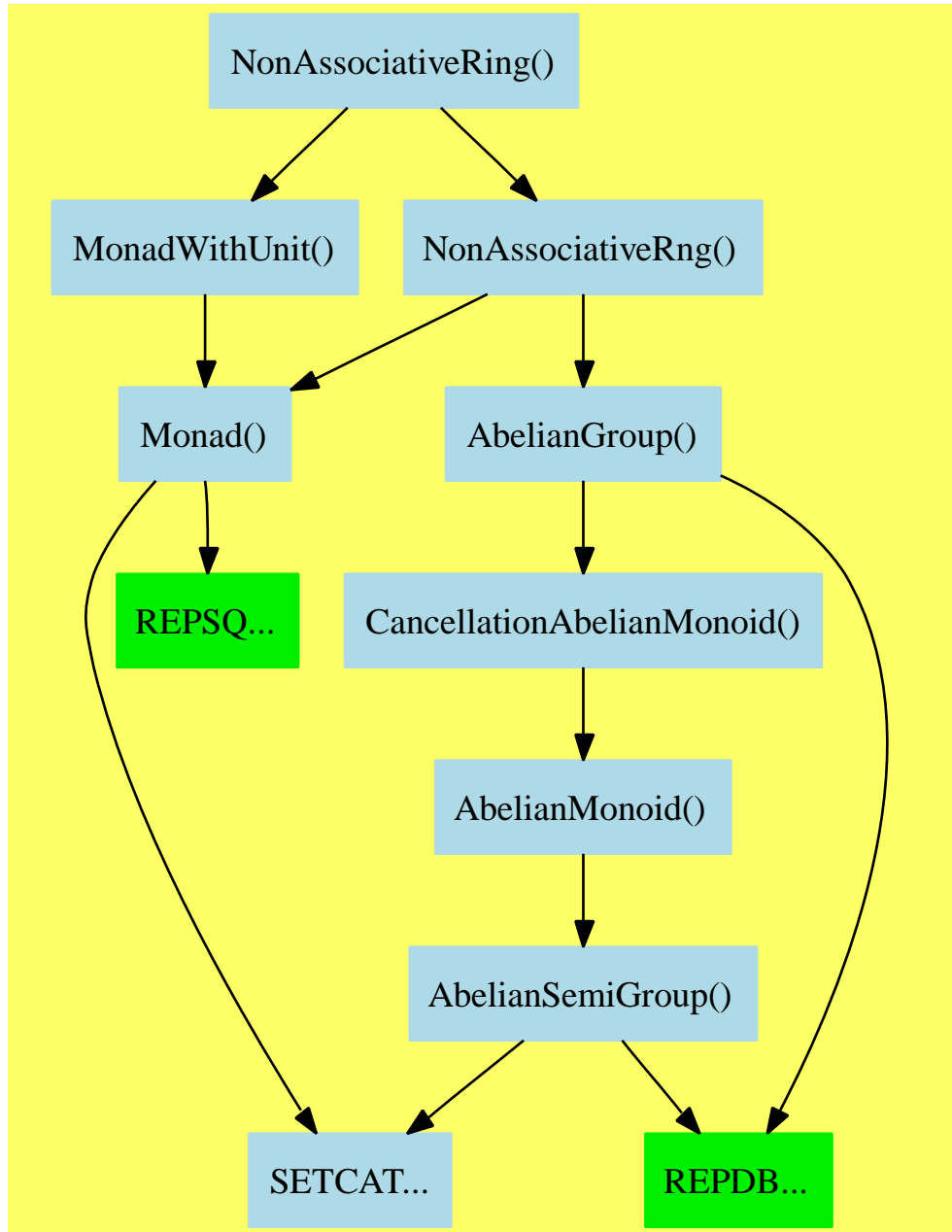
"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"Category" [color=lightblue];

"CLAGG..." [color=lightblue];
"IXAGG..." [color=lightblue];
}

```

NonAssociativeRing (NASRING)



— NonAssociativeRing.input —

```

)set break resume
)sys rm -f NonAssociativeRing.output
)spool NonAssociativeRing.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show NonAssociativeRing
--R NonAssociativeRing is a category constructor
--R Abbreviation for NonAssociativeRing is NASRING
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for NASRING
--R
--R----- Operations -----
--R ??? : (%,%) -> %           ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %               ?=? : (%,%) -> Boolean
--R 1 : () -> %               0 : () -> %
--R antiCommutator : (%,%) -> %   associator : (%,%,%) -> %
--R coerce : Integer -> %       coerce : % -> OutputForm
--R commutator : (%,%) -> %     hash : % -> SingleInteger
--R latex : % -> String        one? : % -> Boolean
--R recip : % -> Union(%, "failed") sample : () -> %
--R zero? : % -> Boolean       ?~=? : (%,%) -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R leftPower : (%,NonNegativeInteger) -> %
--R leftPower : (%,PositiveInteger) -> %
--R leftRecip : % -> Union(%, "failed")
--R rightPower : (%,NonNegativeInteger) -> %
--R rightPower : (%,PositiveInteger) -> %
--R rightRecip : % -> Union(%, "failed")
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— NonAssociativeRing.help —

```

=====
NonAssociativeRing examples
=====

```

A `NonAssociativeRing` is a non associative rng which has a unit,
the multiplication is not necessarily commutative or associative.

See Also:

o `)show NonAssociativeRing`

See:

⇐ “`MonadWithUnit`” (`MONADWU`) [5](#) on page [380](#)

⇐ “`NonAssociativeRng`” (`NARNG`) [8](#) on page [734](#)

Exports:

| | | | | |
|------------------------|----------------------------|-----------------------------|-------------------------|-----------------------------|
| <code>0</code> | <code>1</code> | <code>antiCommutator</code> | <code>associator</code> | <code>characteristic</code> |
| <code>coerce</code> | <code>commutator</code> | <code>hash</code> | <code>latex</code> | <code>leftPower</code> |
| <code>leftRecip</code> | <code>one?</code> | <code>recip</code> | <code>rightPower</code> | <code>rightRecip</code> |
| <code>sample</code> | <code>subtractIfCan</code> | <code>zero?</code> | <code>?*?</code> | <code>?~=?</code> |
| <code>?**?</code> | <code>?+?</code> | <code>?-?</code> | <code>-?</code> | <code>?=?</code> |

These are directly exported but not implemented:

```
characteristic : () -> NonNegativeInteger
```

These are implemented by this category:

```
coerce : Integer -> %
```

These exports come from ([p734](#)) `NonAssociativeRng()`:

```
0 : () -> %
antiCommutator : (%,%) -> %
associator : (%,%,%) -> %
coerce : % -> OutputForm
commutator : (%,%) -> %
hash : % -> SingleInteger
latex : % -> String
leftPower : (%,PositiveInteger) -> %
rightPower : (%,PositiveInteger) -> %
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%,%) -> Boolean
?*? : (PositiveInteger,%) -> %
?*? : (%,%) -> %
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
```

```

?? : (Integer,%) -> %
?? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%,PositiveInteger) -> %

```

These exports come from (p380) `MonadWithUnit()`:

```

1 : () -> %
leftPower : (%,NonNegativeInteger) -> %
leftRecip : % -> Union(%, "failed")
one? : % -> Boolean
recip : % -> Union(%, "failed")
rightPower : (%,NonNegativeInteger) -> %
rightRecip : % -> Union(%, "failed")
***? : (%,NonNegativeInteger) -> %

```

— category NASRING NonAssociativeRing —

```

)abbrev category NASRING NonAssociativeRing
++ Author: J. Grabmeier, R. Wisbauer
++ Date Created: 01 March 1991
++ Date Last Updated: 11 June 1991
++ Reference:
++ R.D. Schafer: An Introduction to Nonassociative Algebras
++ Academic Press, New York, 1966
++ Description:
++ A NonAssociativeRing is a non associative rng which has a unit,
++ the multiplication is not necessarily commutative or associative.

NonAssociativeRing(): Category == Join(NonAssociativeRng,MonadWithUnit) with
  characteristic: -> NonNegativeInteger
  ++ characteristic() returns the characteristic of the ring.
  --we can not make this a constant, since some domains are mutable
  coerce: Integer -> %
  ++ coerce(n) coerces the integer n to an element of the ring.
add
  n:Integer
  coerce(n) == n * 1$%

```

— NASRING.dotabb —

```

"NASRING"
[color=lightblue,href="bookvol10.2.pdf#nameddest=NASRING"];
"NASRING" -> "MONADWU"

```

```
"NASRING" -> "NARNG"
```

— NASRING.dotfull —

```
"NonAssociativeRing()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=NASRING"];
"NonAssociativeRing()" -> "NonAssociativeRng()"
"NonAssociativeRing()" -> "MonadWithUnit()"
```

— NASRING.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "NonAssociativeRing()"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=NASRING"];
  "NonAssociativeRing()" -> "NonAssociativeRng()"
  "NonAssociativeRing()" -> "MonadWithUnit()"

  "MonadWithUnit()" [color=lightblue];
  "MonadWithUnit()" -> "Monad()"

  "NonAssociativeRng()" [color=lightblue];
  "NonAssociativeRng()" -> "AbelianGroup()"
  "NonAssociativeRng()" -> "Monad()"

  "Monad()" [color=lightblue];
  "Monad()" -> "SETCAT..."
  "Monad()" -> "REPSQ..."

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CancellationAbelianMonoid()"
  "AbelianGroup()" -> "REPDB..."

  "CancellationAbelianMonoid()" [color=lightblue];
  "CancellationAbelianMonoid()" -> "AbelianMonoid()"

  "AbelianMonoid()" [color=lightblue];
  "AbelianMonoid()" -> "AbelianSemiGroup()"
```

```

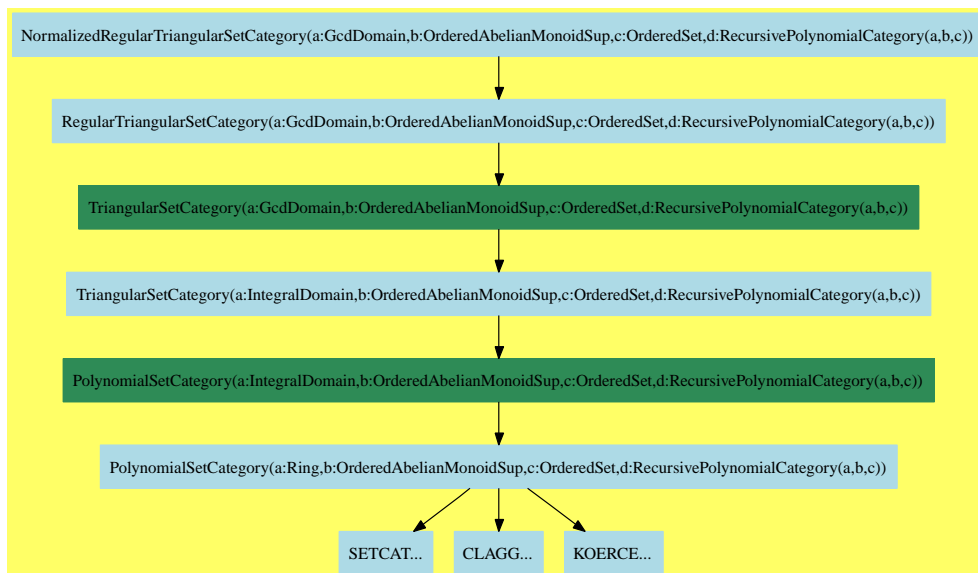
"AbelianSemiGroup()" [color=lightblue];
"AbelianSemiGroup()" -> "SETCAT..."
"AbelianSemiGroup()" -> "REPDB..."

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
}

```

—————→

NormalizedTriangularSetCategory (NTSCAT)



— NormalizedTriangularSetCategory.input —

```

)set break resume
)sys rm -f NormalizedTriangularSetCategory.output
)spool NormalizedTriangularSetCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show NormalizedTriangularSetCategory

```



```

--R
--R NormalizedTriangularSetCategory(R: GcdDomain,E: OrderedAbelianMonoidSup,V: OrderedSet,P: Rec
--R Abbreviation for NormalizedTriangularSetCategory is NTSCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for NTSCAT
--R
--R----- Operations -----
--R ?=? : (% ,%) -> Boolean
--R algebraicVariables : % -> List(V)
--R augment : (P,List(%)) -> List(%)
--R coerce : % -> List(P)
--R collect : (% ,V) -> %
--R collectUnder : (% ,V) -> %
--R construct : List(P) -> %
--R degree : % -> NonNegativeInteger
--R empty? : % -> Boolean
--R extend : (List(P),%) -> List(%)
--R extend : (P,%) -> List(%)
--R first : % -> Union(P,"failed")
--R headReduce : (P,%) -> P
--R headReduced? : (P,%) -> Boolean
--R initiallyReduce : (P,%) -> P
--R initials : % -> List(P)
--R intersect : (P,%) -> List(%)
--R invertibleSet : (P,%) -> List(%)
--R latex : % -> String
--R mainVariables : % -> List(V)
--R mvar : % -> V
--R normalized? : (P,%) -> Boolean
--R reduceByQuasiMonic : (P,%) -> P
--R rest : % -> Union(%, "failed")
--R sample : () -> %
--R stronglyReduced? : % -> Boolean
--R variables : % -> List(V)
--R ?~=? : (% ,%) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R algebraicCoefficients? : (P,%) -> Boolean
--R any? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
--R augment : (List(P),List(%)) -> List(%)
--R autoReduced? : (% ,((P,List(P)) -> Boolean)) -> Boolean
--R basicSet : (List(P),(P -> Boolean),((P,P) -> Boolean)) -> Union(Record(bas: %,top: List(P)),
--R basicSet : (List(P),((P,P) -> Boolean)) -> Union(Record(bas: %,top: List(P)),"failed")
--R coHeight : % -> NonNegativeInteger if V has FINITE
--R convert : % -> InputForm if P has KONVERT(INFORM)
--R count : ((P -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R count : (P,%) -> NonNegativeInteger if P has SETCAT and $ has finiteAggregate
--R eval : (% ,List(Equation(P))) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% ,Equation(P)) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% ,P,P) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% ,List(P),List(P)) -> % if P has EVALAB(P) and P has SETCAT
--R algebraic? : (V,%) -> Boolean
--R augment : (List(P),%) -> List(%)
--R augment : (P,%) -> List(%)
--R coerce : % -> OutputForm
--R collectQuasiMonic : % -> %
--R collectUpper : (% ,V) -> %
--R copy : % -> %
--R empty : () -> %
--R eq? : (% ,%) -> Boolean
--R extend : (P,List(%)) -> List(%)
--R extend : (% ,P) -> %
--R hash : % -> SingleInteger
--R headReduced? : % -> Boolean
--R infRittWu? : (% ,%) -> Boolean
--R initiallyReduced? : % -> Boolean
--R internalAugment : (P,%) -> %
--R invertible? : (P,%) -> Boolean
--R last : % -> Union(P,"failed")
--R mainVariable? : (V,%) -> Boolean
--R map : ((P -> P),%) -> %
--R normalized? : % -> Boolean
--R purelyAlgebraic? : % -> Boolean
--R removeZero : (P,%) -> P
--R retract : List(P) -> %
--R stronglyReduce : (P,%) -> P
--R trivialIdeal? : % -> Boolean
--R zeroSetSplit : List(P) -> List(%)

```

```

--R every? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
--R extend : (List(P),List(%)) -> List(%)
--R extendIfCan : (%,P) -> Union(%, "failed")
--R find : ((P -> Boolean),%) -> Union(P, "failed")
--R headRemainder : (P,%) -> Record(num: P,den: R) if R has INTDOM
--R initiallyReduced? : (P,%) -> Boolean
--R internalAugment : (List(P),%) -> %
--R intersect : (P,List(%)) -> List(%)
--R intersect : (List(P),List(%)) -> List(%)
--R intersect : (List(P),%) -> List(%)
--R invertible? : (P,%) -> List(Record(val: Boolean,tower: %))
--R invertibleElseSplit? : (P,%) -> Union(Boolean,List(%))
--R lastSubResultant : (P,P,%) -> List(Record(val: P,tower: %))
--R lastSubResultantElseSplit : (P,P,%) -> Union(P,List(%))
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((P -> P),%) -> % if $ has shallowlyMutable
--R member? : (P,%) -> Boolean if P has SETCAT and $ has finiteAggregate
--R members : % -> List(P) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(P) if $ has finiteAggregate
--R purelyAlgebraic? : (P,%) -> Boolean
--R purelyAlgebraicLeadingMonomial? : (P,%) -> Boolean
--R purelyTranscendental? : (P,%) -> Boolean
--R quasiComponent : % -> Record(close: List(P),open: List(P))
--R reduce : (P,%,((P,P) -> P),((P,P) -> Boolean)) -> P
--R reduce : (((P,P) -> P),%) -> P if $ has finiteAggregate
--R reduce : (((P,P) -> P),%,P) -> P if $ has finiteAggregate
--R reduce : (((P,P) -> P),%,P,P) -> P if P has SETCAT and $ has finiteAggregate
--R reduced? : (P,%,((P,P) -> Boolean)) -> Boolean
--R remainder : (P,%) -> Record(rnum: R,polnum: P,den: R) if R has INTDOM
--R remove : ((P -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (P,%) -> % if P has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
--R retractIfCan : List(P) -> Union(%, "failed")
--R rewriteIdealWithHeadRemainder : (List(P),%) -> List(P) if R has INTDOM
--R rewriteIdealWithRemainder : (List(P),%) -> List(P) if R has INTDOM
--R rewriteSetWithReduction : (List(P),%,((P,P) -> P),((P,P) -> Boolean)) -> List(P)
--R roughBase? : % -> Boolean if R has INTDOM
--R roughEqualIdeals? : (%,%) -> Boolean if R has INTDOM
--R roughSubIdeal? : (%,%) -> Boolean if R has INTDOM
--R roughUnitIdeal? : % -> Boolean if R has INTDOM
--R select : (%,V) -> Union(P, "failed")
--R select : ((P -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R sort : (%,V) -> Record(under: %,floor: %,upper: %)
--R squareFreePart : (P,%) -> List(Record(val: P,tower: %))
--R stronglyReduced? : (P,%) -> Boolean
--R triangular? : % -> Boolean if R has INTDOM
--R zeroSetSplit : (List(P),Boolean) -> List(%)
--R zeroSetSplitIntoTriangularSystems : List(P) -> List(Record(close: %,open: List(P)))

```

```
--R
--E 1
```

```
)spool
)lisp (bye)
```

— NormalizedTriangularSetCategory.help —

```
=====
NormalizedTriangularSetCategory examples
=====
```

The category of normalized triangular sets. A triangular set `ts` is said normalized if for every algebraic variable `v` of `ts` the polynomial `select(ts,v)` is normalized w.r.t. every polynomial in `collectUnder(ts,v)`.

A polynomial `p` is said normalized w.r.t. a non-constant polynomial `q` if `p` is constant or `degree(p,mdeg(q)) = 0` and `init(p)` is normalized w.r.t. `q`. One of the important features of normalized triangular sets is that they are regular sets.

See Also:

o `)show NormalizedTriangularSetCategory`

See:

⇒ “SquareFreeNormalizedTriangularSetCategory” (SNTSCAT) [10](#) on page [963](#)

⇐ “RegularTriangularSetCategory” (RSETCAT) [8](#) on page [755](#)

Exports:

| | |
|---------------------------------|-----------------------------------|
| algebraic? | algebraicCoefficients? |
| algebraicVariables | any? |
| augment | autoReduced? |
| basicSet | coerce |
| coHeight | collect |
| collectQuasiMonic | collectUnder |
| collectUpper | construct |
| copy | convert |
| count | degree |
| empty | empty? |
| eq? | eval |
| every? | extend |
| extendIfCan | find |
| first | hash |
| headReduce | headReduced? |
| headRemainder | inFRittWu? |
| initiallyReduce | initiallyReduced? |
| initials | internalAugment |
| intersect | invertible? |
| invertibleElseSplit? | invertibleSet |
| last | lastSubResultant |
| lastSubResultantElseSplit | latex |
| less? | mainVariable? |
| mainVariables | map |
| map! | member? |
| members | more? |
| mvar | normalized? |
| parts | purelyAlgebraic? |
| purelyAlgebraicLeadingMonomial? | purelyTranscendental? |
| quasiComponent | reduce |
| reduceByQuasiMonic | reduced? |
| remainder | remove |
| removeDuplicates | removeZero |
| rest | retract |
| retractIfCan | rewriteIdealWithHeadRemainder |
| rewriteIdealWithRemainder | rewriteSetWithReduction |
| roughBase? | roughEqualIdeals? |
| roughSubIdeal? | roughUnitIdeal? |
| sample | select |
| size? | sort |
| squareFreePart | stronglyReduce |
| stronglyReduced? | triangular? |
| trivialIdeal? | variables |
| zeroSetSplit | zeroSetSplitIntoTriangularSystems |
| #? | ?=? |
| ?~=? | |

Attributes Exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

These exports come from (p755) `RegularTriangularSetCategory(R,E,V,P)` where `R:GcdDomain`, `E:OrderedAbelianMonoidSup`, `V:OrderedSet`, `P:RecursivePolynomialCategory(R,E,V)`:

```

algebraic? : (V,%) -> Boolean
algebraicCoefficients? : (P,%) -> Boolean
algebraicVariables : % -> List V
any? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
augment : (List P,List %) -> List %
augment : (List P,%) -> List %
augment : (P,List %) -> List %
augment : (P,%) -> List %
autoReduced? : (%,(P,List P) -> Boolean)) -> Boolean
basicSet :
  (List P,(P -> Boolean),((P,P) -> Boolean)) ->
    Union(Record(bas: %,top: List P),"failed")
basicSet :
  (List P,((P,P) -> Boolean)) ->
    Union(Record(bas: %,top: List P),"failed")
coerce : % -> List P
coerce : % -> OutputForm
coHeight : % -> NonNegativeInteger if V has FINITE
collect : (% ,V) -> %
collectQuasiMonic : % -> %
collectUnder : (% ,V) -> %
collectUpper : (% ,V) -> %
construct : List P -> %
copy : % -> %
convert : % -> InputForm if P has KONVERT INFORM
count : ((P -> Boolean),%) -> NonNegativeInteger
  if $ has finiteAggregate
count : (P,%) -> NonNegativeInteger
  if P has SETCAT
  and $ has finiteAggregate
degree : % -> NonNegativeInteger
empty : () -> %
empty? : % -> Boolean
eq? : (% ,%) -> Boolean
eval : (% ,List Equation P) -> % if P has EVALAB P and P has SETCAT
eval : (% ,Equation P) -> % if P has EVALAB P and P has SETCAT

```

```

eval : (%,P,P) -> % if P has EVALAB P and P has SETCAT
eval : (%,List P,List P) -> % if P has EVALAB P and P has SETCAT
every? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
extend : (List P,List %) -> List %
extend : (List P,%) -> List %
extend : (P,List %) -> List %
extend : (P,%) -> List %
extend : (%,P) -> %
extendIfCan : (%,P) -> Union(%, "failed")
find : ((P -> Boolean),%) -> Union(P, "failed")
first : % -> Union(P, "failed")
hash : % -> SingleInteger
headReduce : (P,%) -> P
headReduced? : % -> Boolean
headReduced? : (P,%) -> Boolean
headRemainder : (P,%) -> Record(num: P,den: R) if R has INTDOM
infRittWu? : (%,%) -> Boolean
initiallyReduce : (P,%) -> P
initiallyReduced? : % -> Boolean
initiallyReduced? : (P,%) -> Boolean
initials : % -> List P
internalAugment : (P,%) -> %
internalAugment : (List P,%) -> %
intersect : (P,List %) -> List %
intersect : (List P,%) -> List %
intersect : (P,%) -> List %
intersect : (List P,List %) -> List %
invertible? : (P,%) -> Boolean
invertible? : (P,%) -> List Record(val: Boolean,tower: %)
invertibleElseSplit? : (P,%) -> Union(Boolean,List %)
invertibleSet : (P,%) -> List %
last : % -> Union(P, "failed")
lastSubResultant : (P,P,%) -> List Record(val: P,tower: %)
lastSubResultantElseSplit : (P,P,%) -> Union(P,List %)
latex : % -> String
less? : (%,NonNegativeInteger) -> Boolean
mainVariable? : (V,%) -> Boolean
mainVariables : % -> List V
map : ((P -> P),%) -> %
map! : ((P -> P),%) -> % if $ has shallowlyMutable
member? : (P,%) -> Boolean if P has SETCAT and $ has finiteAggregate
members : % -> List P if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
mvar : % -> V
normalized? : % -> Boolean
normalized? : (P,%) -> Boolean
parts : % -> List P if $ has finiteAggregate
purelyAlgebraic? : (P,%) -> Boolean
purelyAlgebraic? : % -> Boolean
purelyAlgebraicLeadingMonomial? : (P,%) -> Boolean

```

```

purelyTranscendental? : (P,%) -> Boolean
quasiComponent : % -> Record(close: List P,open: List P)
reduce : (P,%,(P,P) -> P),(P,P) -> Boolean -> P
reduce : ((P,P) -> P),% -> P if $ has finiteAggregate
reduce : ((P,P) -> P),%,P -> P if $ has finiteAggregate
reduce : ((P,P) -> P),%,P,P -> P
  if P has SETCAT
  and $ has finiteAggregate
reduceByQuasiMonic : (P,%) -> P
reduced? : (P,%,(P,P) -> Boolean) -> Boolean
remainder : (P,%) -> Record(rnum: R,polnum: P,den: R)
  if R has INTDOM
remove : ((P -> Boolean),%) -> % if $ has finiteAggregate
remove : (P,%) -> % if P has SETCAT and $ has finiteAggregate
removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
removeZero : (P,%) -> P
rest : % -> Union(%, "failed")
retract : List P -> %
retractIfCan : List P -> Union(%, "failed")
rewriteIdealWithHeadRemainder : (List P,%) -> List P if R has INTDOM
rewriteIdealWithRemainder : (List P,%) -> List P if R has INTDOM
rewriteSetWithReduction :
  (List P,%,(P,P) -> P),(P,P) -> Boolean -> List P
roughBase? : % -> Boolean if R has INTDOM
roughEqualIdeals? : (%,%) -> Boolean if R has INTDOM
roughSubIdeal? : (%,%) -> Boolean if R has INTDOM
roughUnitIdeal? : % -> Boolean if R has INTDOM
sample : () -> %
select : (%,V) -> Union(P, "failed")
select : ((P -> Boolean),%) -> % if $ has finiteAggregate
size? : (%,NonNegativeInteger) -> Boolean
sort : (%,V) -> Record(under: %,floor: %,upper: %)
squareFreePart : (P,%) -> List Record(val: P,tower: %)
stronglyReduce : (P,%) -> P
stronglyReduced? : (P,%) -> Boolean
stronglyReduced? : % -> Boolean
triangular? : % -> Boolean if R has INTDOM
trivialIdeal? : % -> Boolean
variables : % -> List V
zeroSetSplit : List P -> List %
zeroSetSplit : (List P,Boolean) -> List %
zeroSetSplitIntoTriangularSystems :
  List P -> List Record(close: %,open: List P)
#? : % -> NonNegativeInteger if $ has finiteAggregate
#=? : (%,%) -> Boolean
#~=? : (%,%) -> Boolean

```

— category NTSCAT NormalizedTriangularSetCategory —

```

)abbrev category NTSCAT NormalizedTriangularSetCategory
++ Author: Marc Moreno Maza
++ Date Created: 10/07/1998
++ Date Last Updated: 12/12/1998
++ References :
++ [1] D. LAZARD "A new method for solving algebraic systems of
++       positive dimension" Discr. App. Math. 33:147-160,1991
++ [2] P. AUBRY, D. LAZARD and M. MORENO MAZA "On the Theories
++       of Triangular Sets" Journal of Symbol. Comp. (to appear)
++ [3] M. MORENO MAZA and R. RIOBOO "Computations of gcd over
++       algebraic towers of simple extensions" In proceedings of AAEC11
++       Paris, 1995.
++ [4] M. MORENO MAZA "Calculs de pgcd au-dessus des tours
++       d'extensions simples et resolution des systemes d'equations
++       algebriques" These, Universite P.etM. Curie, Paris, 1997.
++ Description:
++ The category of normalized triangular sets. A triangular
++ set ts is said normalized if for every algebraic
++ variable v of ts the polynomial select(ts,v)
++ is normalized w.r.t. every polynomial in collectUnder(ts,v).
++ A polynomial p is said normalized w.r.t. a non-constant
++ polynomial q if p is constant or degree(p,mdeg(q)) = 0
++ and init(p) is normalized w.r.t. q. One of the important
++ features of normalized triangular sets is that they are regular sets.

```

```

NormalizedTriangularSetCategory(R:GcdDomain,E:OrderedAbelianMonoidSup,
  V:OrderedSet,P:RecursivePolynomialCategory(R,E,V)):
  Category == RegularTriangularSetCategory(R,E,V,P)

```

— NTSCAT.dotabb —

```

"NTSCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=NTSCAT"];
"NTSCAT" -> "RSETCAT"

```

— NTSCAT.dotfull —

```

"NormalizedRegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P)):
  [color=lightblue,href="bookvol10.2.pdf#nameddest=NTSCAT"];
"NormalizedRegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P)):
  ->
"RegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P)):

```

— NTSCAT.dotpic —

```

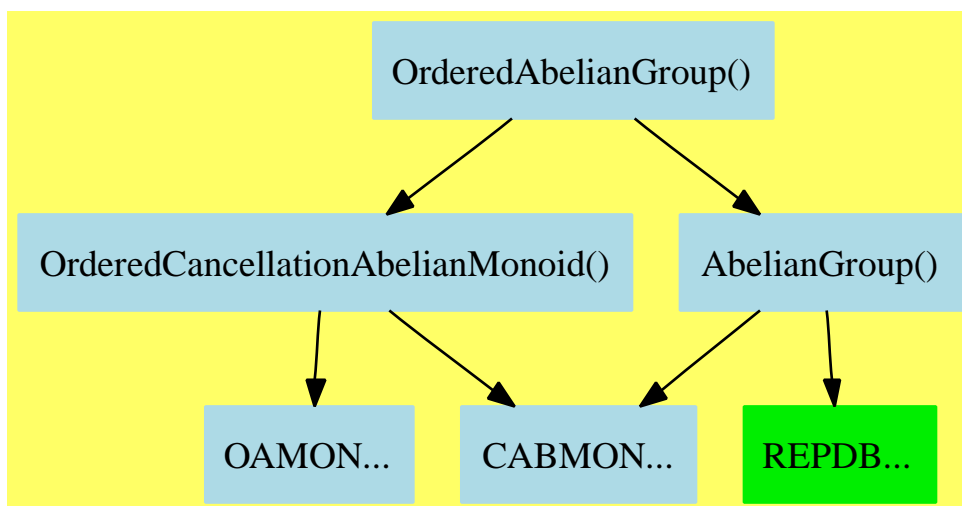
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "NormalizedRegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    [color=lightblue];
  "NormalizedRegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    ->
  "RegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    [color=lightblue];
  "RegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    ->
  "TriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    [color=seagreen];
  "TriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    ->
  "TriangularSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    [color=lightblue];
  "TriangularSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    -> "PolynomialSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    [color=seagreen];
  "PolynomialSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    -> "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    [color=lightblue];
  "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    -> "SETCAT..."
  "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    -> "CLAGG..."
  "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory)"
    -> "KOERCE..."

  "SETCAT..." [color=lightblue];
  "KOERCE..." [color=lightblue];
  "CLAGG..." [color=lightblue];
}

```

OrderedAbelianGroup (OAGROUP)



— OrderedAbelianGroup.input —

```

)set break resume
)sys rm -f OrderedAbelianGroup.output
)spool OrderedAbelianGroup.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrderedAbelianGroup
--R OrderedAbelianGroup is a category constructor
--R Abbreviation for OrderedAbelianGroup is OAGROUP
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OAGROUP
--R
--R----- Operations -----
--R ?? : (Integer,%) -> %           ??? : (PositiveInteger,%) -> %
--R ?+? : (%,%) -> %               -? : % -> %
--R ?-? : (%,%) -> %               ?<? : (%,%) -> Boolean
--R ?<=? : (%,%) -> Boolean         ?=? : (%,%) -> Boolean

```

```

--R ?>? : (%,% ) -> Boolean
--R 0 : () -> %
--R hash : % -> SingleInteger
--R max : (%,% ) -> %
--R sample : () -> %
--R ?~=? : (%,% ) -> Boolean
--R ?*? : (NonNegativeInteger,% ) -> %
--R subtractIfCan : (%,% ) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— OrderedAbelianGroup.help —

OrderedAbelianGroup examples

Ordered sets which are also abelian groups, such that the addition preserves the ordering.

See Also:

o)show OrderedAbelianGroup

See:

⇒ “OrderedRing” (ORDRING) [10](#) on page [933](#)

⇐ “AbelianGroup” (ABELGRP) [7](#) on page [574](#)

⇐ “OrderedCancellationAbelianMonoid” (OCAMON) [8](#) on page [751](#)

Exports:

| | | | | |
|------|--------|---------------|-------|------|
| 0 | coerce | hash | latex | max |
| min | sample | subtractIfCan | zero? | ?~=? |
| ?*? | ?+? | -? | ?-? | ?<? |
| ?<=? | ?=? | ?>? | ?>=? | |

These exports come from (p[751](#)) OrderedCancellationAbelianMonoid():

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger

```

```

latex : % -> String
max : (%,%) -> %
min : (%,%) -> %
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?<? : (%,%) -> Boolean
?<=? : (%,%) -> Boolean
?=? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?+? : (%,%) -> %

```

These exports come from (p574) `AbelianGroup()`:

```

-? : % -> %
?*? : (Integer,%) -> %
?-? : (%,%) -> %

```

— category **OAGROUP** `OrderedAbelianGroup` —

```

)abbrev category OAGROUP OrderedAbelianGroup
++ Description:
++ Ordered sets which are also abelian groups, such that the
++ addition preserves the ordering.

```

```

OrderedAbelianGroup(): Category ==
  Join(OrderedCancellationAbelianMonoid, AbelianGroup)

```

— **OAGROUP**.dotabb —

```

"OAGROUP"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OAGROUP"];
"OAGROUP" -> "OCAMON"
"OAGROUP" -> "ABELGRP"

```

— **OAGROUP**.dotfull —

```

"OrderedAbelianGroup()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OAGROUP"];
"OrderedAbelianGroup()" -> "OrderedCancellationAbelianMonoid()"
"OrderedAbelianGroup()" -> "AbelianGroup()"

```

— OAGROUP.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrderedAbelianGroup()" [color=lightblue];
  "OrderedAbelianGroup()" -> "OrderedCancellationAbelianMonoid()"
  "OrderedAbelianGroup()" -> "AbelianGroup()"

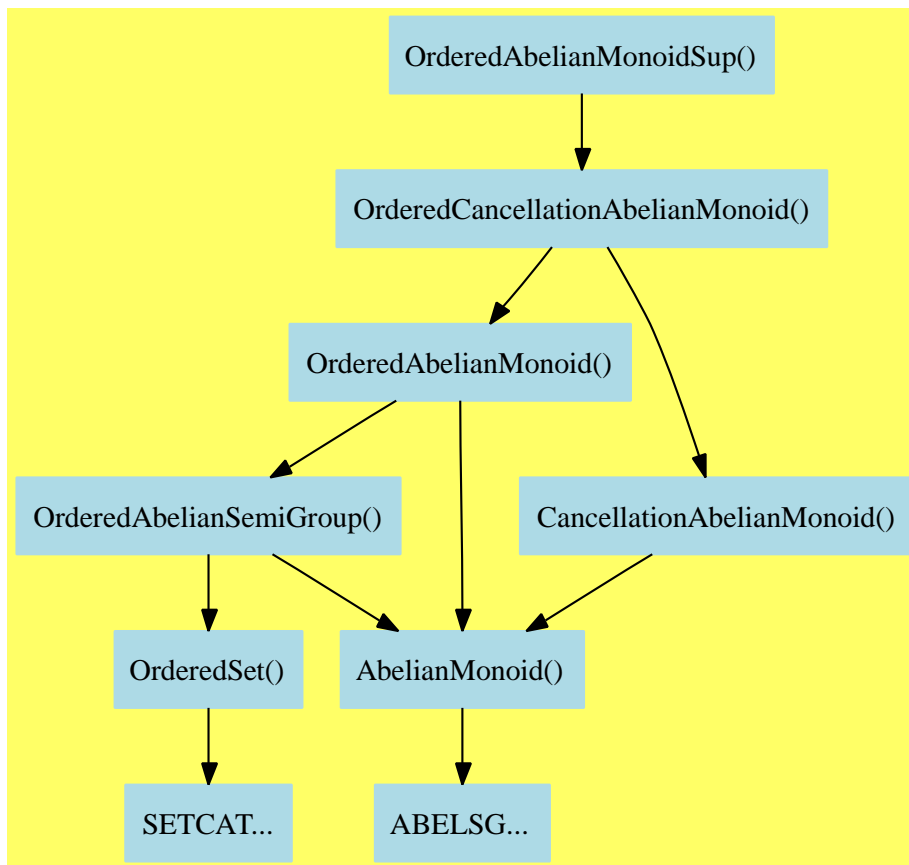
  "OrderedCancellationAbelianMonoid()" [color=lightblue];
  "OrderedCancellationAbelianMonoid()" -> "OAMON..."
  "OrderedCancellationAbelianMonoid()" -> "CABMON..."

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CABMON..."
  "AbelianGroup()" -> "REPDB..."

  "REPDB..." [color="#00EE00"];
  "OAMON..." [color=lightblue];
  "CABMON..." [color=lightblue];
}

```

OrderedAbelianMonoidSup (OAMONS)



— OrderedAbelianMonoidSup.input —

```

)set break resume
)sys rm -f OrderedAbelianMonoidSup.output
)spool OrderedAbelianMonoidSup.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrderedAbelianMonoidSup
--R OrderedAbelianMonoidSup is a category constructor
--R Abbreviation for OrderedAbelianMonoidSup is OAMONS
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OAMONS

```

```

--R
--R----- Operations -----
--R ?? : (PositiveInteger,%) -> %      ?+? : (%,%) -> %
--R ?<? : (%,%) -> Boolean              ?<=? : (%,%) -> Boolean
--R ?=? : (%,%) -> Boolean              ?>? : (%,%) -> Boolean
--R ?>=? : (%,%) -> Boolean            0 : () -> %
--R coerce : % -> OutputForm           hash : % -> SingleInteger
--R latex : % -> String                 max : (%,%) -> %
--R min : (%,%) -> %                   sample : () -> %
--R sup : (%,%) -> %                   zero? : % -> Boolean
--R ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— OrderedAbelianMonoidSup.help —

```

=====
OrderedAbelianMonoidSup examples
=====

```

This domain is an OrderedAbelianMonoid with a sup operation added. The purpose of the sup operator in this domain is to act as a supremum with respect to the partial order imposed by ‘-’, rather than with respect to the total > order (since that is "max").

Axioms:

```

sup(a,b)-a ~="failed"
sup(a,b)-b ~="failed"
x-a ~="failed" and x-b ~="failed" => x >= sup(a,b)

```

See Also:

```

o )show OrderedAbelianMonoidSup

```

See:

⇐ “DirectProductCategory” (DIRPCAT) [12](#) on page [1051](#)
⇐ “OrderedCancellationAbelianMonoid” (OCAMON) [8](#) on page [751](#)

Exports:

```

0      coerce  hash      latex  max
min    sample  subtractIfCan  sup   zero?
?~=?   ??      ?<=?      ?+?   ?<?
?=?    ?>?     ?>=?

```

These are directly exported but not implemented:

```
sup : (%,%) -> %
```

These exports come from (p751) `OrderedCancellationAbelianMonoid()`:

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
max : (%,%) -> %
min : (%,%) -> %
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?+? : (%,%) -> %
?<? : (%,%) -> Boolean
?<=? : (%,%) -> Boolean
?=? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean

```

— category OAMONS OrderedAbelianMonoidSup —

```

)abbrev category OAMONS OrderedAbelianMonoidSup
++ Description:
++ This domain is an OrderedAbelianMonoid with a sup
++ operation added. The purpose of the sup operator
++ in this domain is to act as a supremum with respect to the
++ partial order imposed by '-', rather than with respect to
++ the total > order (since that is "max").
++
++ Axioms\br
++ \tab{5}sup(a,b)-a \~~= "failed"\br
++ \tab{5}sup(a,b)-b \~~= "failed"\br
++ \tab{5}x-a \~~= "failed" and x-b \~~= "failed" => x >= sup(a,b)\br

OrderedAbelianMonoidSup(): Category == OrderedCancellationAbelianMonoid with
  sup: (%,%) -> %
    ++ sup(x,y) returns the least element from which both

```


++ x and y can be subtracted.

— OAMONS.dotabb —

```
"OAMONS"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OAMONS"];
"OAMONS" -> "OCAMON"
```

— OAMONS.dotfull —

```
"OrderedAbelianMonoidSup()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OAMONS"];
"OrderedAbelianMonoidSup()" -> "OrderedCancellationAbelianMonoid()"
```

— OAMONS.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrderedAbelianMonoidSup()" [color=lightblue];
  "OrderedAbelianMonoidSup()" -> "OrderedCancellationAbelianMonoid()"

  "OrderedCancellationAbelianMonoid()" [color=lightblue];
  "OrderedCancellationAbelianMonoid()" -> "OrderedAbelianMonoid()"
  "OrderedCancellationAbelianMonoid()" -> "CancellationAbelianMonoid()"

  "OrderedAbelianMonoid()" [color=lightblue];
  "OrderedAbelianMonoid()" -> "OrderedAbelianSemiGroup()"
  "OrderedAbelianMonoid()" -> "AbelianMonoid()"

  "OrderedAbelianSemiGroup()" [color=lightblue];
  "OrderedAbelianSemiGroup()" -> "OrderedSet()"
  "OrderedAbelianSemiGroup()" -> "AbelianMonoid()"

  "OrderedSet()" [color=lightblue];
  "OrderedSet()" -> "SETCAT..."
```

```

"CancellationAbelianMonoid()" [color=lightblue];
"CancellationAbelianMonoid()" -> "AbelianMonoid()"

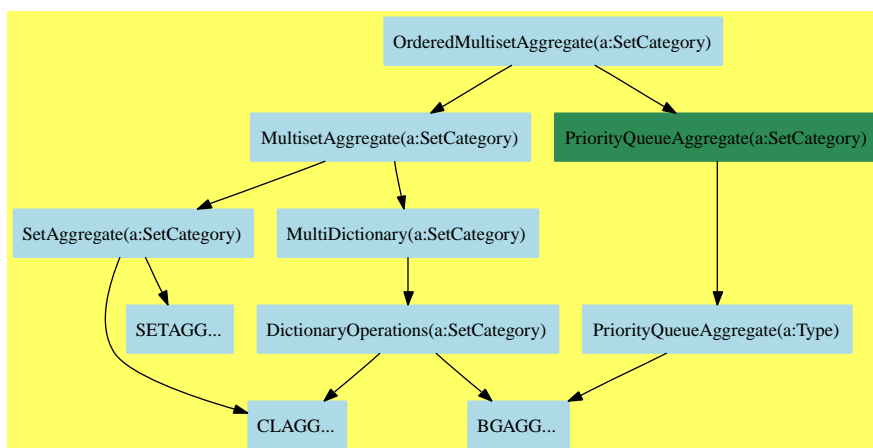
"AbelianMonoid()" [color=lightblue];
"AbelianMonoid()" -> "ABELSG..."

"SETCAT..." [color=lightblue];
"ABELSG..." [color=lightblue];
}

```

—————→

OrderedMultisetAggregate (OMSAGG)



— OrderedMultisetAggregate.input —

```

)set break resume
)sys rm -f OrderedMultisetAggregate.output
)spool OrderedMultisetAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrderedMultisetAggregate
--R
--R OrderedMultisetAggregate(S: OrderedSet) is a category constructor
--R Abbreviation for OrderedMultisetAggregate is OMSAGG

```

```

--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OMSAGG
--R
--R----- Operations -----
--R ?? : (%,%) -> Boolean           ?=? : (%,%) -> Boolean
--R bag : List(S) -> %              brace : () -> %
--R brace : List(S) -> %            coerce : % -> OutputForm
--R construct : List(S) -> %        copy : % -> %
--R dictionary : List(S) -> %       dictionary : () -> %
--R difference : (%,%) -> %         difference : (%,S) -> %
--R empty : () -> %                empty? : % -> Boolean
--R eq? : (%,%) -> Boolean          extract! : % -> S
--R hash : % -> SingleInteger       insert! : (S,%) -> %
--R inspect : % -> S               intersect : (%,%) -> %
--R latex : % -> String            map : ((S -> S),%) -> %
--R max : % -> S                   merge : (%,%) -> %
--R merge! : (%,%) -> %            min : % -> S
--R removeDuplicates! : % -> %      sample : () -> %
--R set : () -> %                  set : List(S) -> %
--R subset? : (%,%) -> Boolean      union : (%,%) -> %
--R union : (%,S) -> %             union : (S,%) -> %
--R ?~=? : (%,%) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R count : (S,%) -> NonNegativeInteger if S has SETCAT and $ has finiteAggregate
--R count : ((S -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R duplicates : % -> List(Record(entry: S,count: NonNegativeInteger))
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,S,S) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,Equation(S)) -> % if S has EVALAB(S) and S has SETCAT
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S) and S has SETCAT
--R every? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
--R find : ((S -> Boolean),%) -> Union(S,"failed")
--R insert! : (S,%,NonNegativeInteger) -> %
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((S -> S),%) -> % if $ has shallowlyMutable
--R member? : (S,%) -> Boolean if S has SETCAT and $ has finiteAggregate
--R members : % -> List(S) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(S) if $ has finiteAggregate
--R reduce : ((S,S) -> S),%) -> S if $ has finiteAggregate
--R reduce : ((S,S) -> S),%,S) -> S if $ has finiteAggregate
--R reduce : ((S,S) -> S),%,S,S) -> S if S has SETCAT and $ has finiteAggregate
--R remove : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (S,%) -> % if S has SETCAT and $ has finiteAggregate
--R remove! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R remove! : (S,%) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if S has SETCAT and $ has finiteAggregate
--R select : ((S -> Boolean),%) -> % if $ has finiteAggregate

```

```

--R select! : ((S -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R symmetricDifference : (%,%) -> %
--R
--E 1

)spool
)lisp (bye)

```

— OrderedMultisetAggregate.help —

OrderedMultisetAggregate examples

An ordered-multiset aggregate is a multiset built over an ordered set S so that the relative sizes of its entries can be assessed. These aggregates serve as models for priority queues.

See Also:

o)show OrderedMultisetAggregate

See:

⇐ “MultisetAggregate” (MSETAGG) 8 on page 728

⇐ “PriorityQueueAggregate” (PRQAGG) 6 on page 534

Exports:

| | | | |
|------------|---------------------|-------------------|---------|
| any? | bag | brace | coerce |
| construct | convert | copy | count |
| dictionary | difference | empty | empty? |
| eq? | duplicates | eval | every? |
| extract! | find | hash | insert! |
| inspect | intersect | latex | less? |
| map | map! | max | member? |
| members | merge | merge! | min |
| more? | parts | reduce | remove |
| remove! | removeDuplicates | removeDuplicates! | sample |
| select | select! | set | size? |
| subset? | symmetricDifference | union | #? |
| ?<? | ?=? | ?~? | |

Attributes exported:

- **partiallyOrderedSet** is true if a set with $<$ which is transitive, but not($a < b$ or $a = b$) does not necessarily imply $b < a$.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

These are directly exported but not implemented:

```
min : % -> S
```

These exports come from (p728) MultisetAggregate(S:OrderedSet):

```
any? : ((S -> Boolean),%) -> Boolean if $ has finiteAggregate
bag : List S -> %
brace : () -> %
brace : List S -> %
coerce : % -> OutputForm
construct : List S -> %
convert : % -> InputForm if S has KONVERT INFORM
copy : % -> %
count : (S,%) -> NonNegativeInteger
    if S has SETCAT and $ has finiteAggregate
count : ((S -> Boolean),%) -> NonNegativeInteger
    if $ has finiteAggregate
dictionary : List S -> %
dictionary : () -> %
difference : (%,S) -> %
difference : (%,%) -> %
duplicates : % ->
    List Record(entry: S,count: NonNegativeInteger)
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List S,List S) -> %
    if S has EVALAB S and S has SETCAT
eval : (%,S,S) -> %
    if S has EVALAB S and S has SETCAT
eval : (%,Equation S) -> %
    if S has EVALAB S and S has SETCAT
eval : (%,List Equation S) -> %
    if S has EVALAB S and S has SETCAT
every? : ((S -> Boolean),%) -> Boolean
    if $ has finiteAggregate
extract! : % -> S
find : ((S -> Boolean),%) -> Union(S,"failed")
```

```

hash : % -> SingleInteger
insert! : (S,%) -> %
insert! : (S,%,NonNegativeInteger) -> %
inspect : % -> S
intersect : (%,%) -> %
latex : % -> String
less? : (%,NonNegativeInteger) -> Boolean
map : ((S -> S),%) -> %
map! : ((S -> S),%) -> % if $ has shallowlyMutable
member? : (S,%) -> Boolean
  if S has SETCAT and $ has finiteAggregate
members : % -> List S if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List S if $ has finiteAggregate
reduce : (((S,S) -> S),%) -> S
  if $ has finiteAggregate
reduce : (((S,S) -> S),%,S) -> S
  if $ has finiteAggregate
reduce : (((S,S) -> S),%,S,S) -> S
  if S has SETCAT and $ has finiteAggregate
remove : ((S -> Boolean),%) -> %
  if $ has finiteAggregate
remove : (S,%) -> %
  if S has SETCAT and $ has finiteAggregate
remove! : ((S -> Boolean),%) -> %
  if $ has finiteAggregate
remove! : (S,%) -> %
  if $ has finiteAggregate
removeDuplicates : % -> %
  if S has SETCAT and $ has finiteAggregate
removeDuplicates! : % -> %
sample : () -> %
select : ((S -> Boolean),%) -> % if $ has finiteAggregate
select! : ((S -> Boolean),%) -> % if $ has finiteAggregate
set : () -> %
set : List S -> %
size? : (%,NonNegativeInteger) -> Boolean
subset? : (%,%) -> Boolean
symmetricDifference : (%,%) -> %
union : (%,%) -> %
union : (%,S) -> %
union : (S,%) -> %
#? : % -> NonNegativeInteger if $ has finiteAggregate
?~=? : (%,%) -> Boolean
?=? : (%,%) -> Boolean
?<? : (%,%) -> Boolean

```

These exports come from (p534) PriorityQueueAggregate(S:OrderedSet):

```

max : % -> S

```

```
merge : (%,%) -> %
merge! : (%,%) -> %
```

— category OMSAGG OrderedMultisetAggregate —

```
)abbrev category OMSAGG OrderedMultisetAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ An ordered-multiset aggregate is a multiset built over an ordered set S
++ so that the relative sizes of its entries can be assessed.
++ These aggregates serve as models for priority queues.

OrderedMultisetAggregate(S:OrderedSet): Category ==
  Join(MultisetAggregate S,PriorityQueueAggregate S) with
  -- max: % -> S                ++ smallest entry in the set
  -- duplicates: % -> List Record(entry:S,count:NonNegativeInteger)
  ++ to become an in order iterator
  -- parts: % -> List S          ++ in order iterator
  min: % -> S
  ++ min(u) returns the smallest entry in the multiset aggregate u.
```

— OMSAGG.dotabb —

```
"OMSAGG"
[color=lightblue,href="bookvol10.2.pdf#nameddest=OMSAGG"];
"OMSAGG" -> "MSETAGG"
"OMSAGG" -> "PRQAGG"
```

— OMSAGG.dotfull —

```
"OrderedMultisetAggregate(a:SetCategory)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=OMSAGG"];
"OrderedMultisetAggregate(a:SetCategory)" ->
  "MultisetAggregate(a:SetCategory)"
"OrderedMultisetAggregate(a:SetCategory)" ->
  "PriorityQueueAggregate(a:SetCategory)"
```

— OMSAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrderedMultisetAggregate(a:SetCategory)" [color=lightblue];
  "OrderedMultisetAggregate(a:SetCategory)" ->
    "MultisetAggregate(a:SetCategory)"
  "OrderedMultisetAggregate(a:SetCategory)" ->
    "PriorityQueueAggregate(a:SetCategory)"

  "MultisetAggregate(a:SetCategory)" [color=lightblue];
  "MultisetAggregate(a:SetCategory)" -> "MultiDictionary(a:SetCategory)"
  "MultisetAggregate(a:SetCategory)" -> "SetAggregate(a:SetCategory)"

  "MultiDictionary(a:SetCategory)" [color=lightblue];
  "MultiDictionary(a:SetCategory)" -> "DictionaryOperations(a:SetCategory)"

  "SetAggregate(a:SetCategory)" [color=lightblue];
  "SetAggregate(a:SetCategory)" -> "SETAGG..."
  "SetAggregate(a:SetCategory)" -> "CLAGG..."

  "DictionaryOperations(a:SetCategory)" [color=lightblue];
  "DictionaryOperations(a:SetCategory)" -> "BGAGG..."
  "DictionaryOperations(a:SetCategory)" -> "CLAGG..."

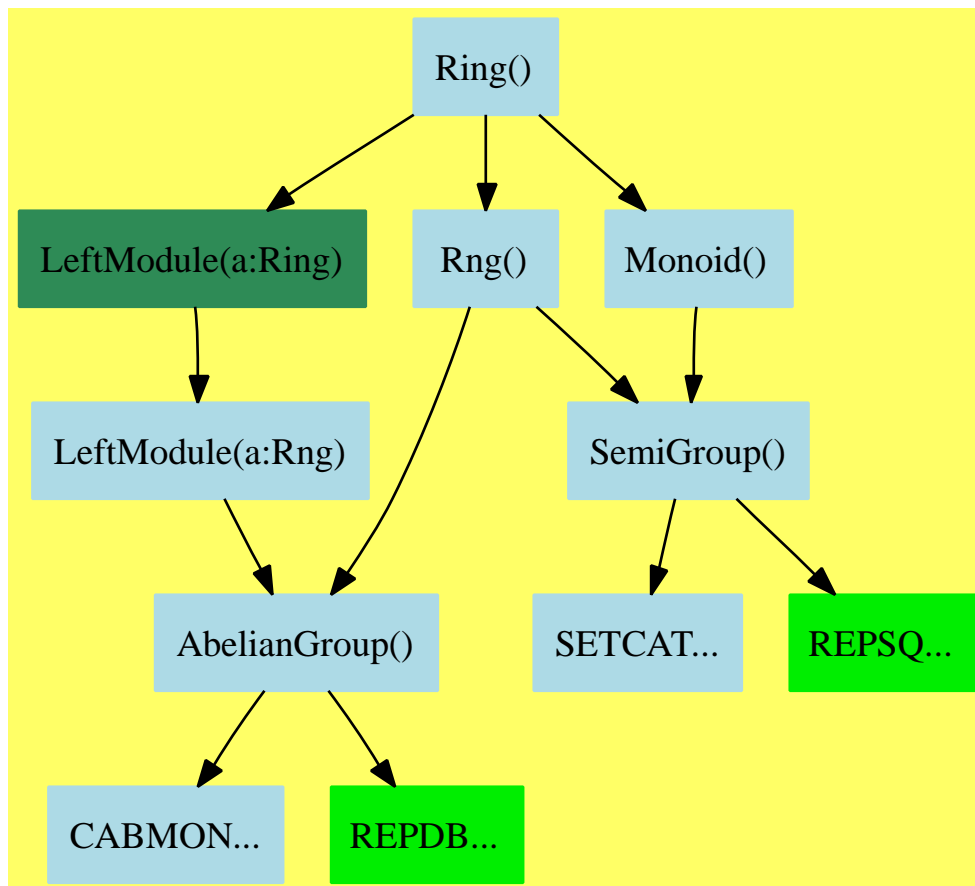
  "PriorityQueueAggregate(a:SetCategory)" [color=seagreen];
  "PriorityQueueAggregate(a:SetCategory)" -> "PriorityQueueAggregate(a:Type)"

  "PriorityQueueAggregate(a:Type)" [color=lightblue];
  "PriorityQueueAggregate(a:Type)" -> "BGAGG..."

  "BGAGG..." [color=lightblue];
  "CLAGG..." [color=lightblue];
  "SETAGG..." [color=lightblue];
}

```

Ring (RING)



— Ring.input —

```

)set break resume
)sys rm -f Ring.output
)spool Ring.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show Ring
--R Ring is a category constructor
--R Abbreviation for Ring is RING
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RING

```

```

--R
--R----- Operations -----
--R ??? : (%,% ) -> %           ??? : (Integer,% ) -> %
--R ??? : (PositiveInteger,% ) -> %   ??? : (% ,PositiveInteger) -> %
--R ?+? : (%,% ) -> %           ?-? : (%,% ) -> %
--R -? : % -> %                 ?? : (%,% ) -> Boolean
--R 1 : () -> %                 0 : () -> %
--R ?? : (% ,PositiveInteger) -> %   coerce : Integer -> %
--R coerce : % -> OutputForm         hash : % -> SingleInteger
--R latex : % -> String             one? : % -> Boolean
--R recip : % -> Union(% ,"failed")  sample : () -> %
--R zero? : % -> Boolean            ?~=? : (%,% ) -> Boolean
--R ??? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ?? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R subtractIfCan : (%,% ) -> Union(% ,"failed")
--R
--E 1

)spool
)lisp (bye)

```

— Ring.help —

=====
Ring examples
=====

The category of rings with unity, always associative, but not necessarily commutative.

See Also:

o)show Ring

See:

- ⇒ “Algebra” (ALGEBRA) [11](#) on page [999](#)
- ⇒ “AbelianMonoidRing” (AMR) [13](#) on page [1151](#)
- ⇒ “CharacteristicNonZero” (CHARNZ) [10](#) on page [887](#)
- ⇒ “CharacteristicZero” (CHARZ) [10](#) on page [892](#)
- ⇒ “CommutativeRing” (COMRING) [10](#) on page [896](#)
- ⇒ “DifferentialExtension” (DIFEXT) [11](#) on page [1005](#)
- ⇒ “DifferentialRing” (DIFRING) [10](#) on page [902](#)

⇒ “EntireRing” (ENTIRER) [10](#) on page [907](#)
 ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
 ⇒ “LeftAlgebra” (LALG) [10](#) on page [918](#)
 ⇒ “LinearlyExplicitRingOver” (LINEXP) [10](#) on page [923](#)
 ⇒ “MonogenicLinearOperator” (MLO) [12](#) on page [1103](#)
 ⇒ “OrderedRing” (ORDRING) [10](#) on page [933](#)
 ⇒ “PartialDifferentialRing” (PDRING) [10](#) on page [939](#)
 ⇒ “UnivariateSkewPolynomialCategory” (OREPCAT) [10](#) on page [982](#)
 ⇒ “XAlgebra” (XALG) [10](#) on page [994](#)
 ⇒ “XFreeAlgebra” (XFALG) [11](#) on page [1042](#)
 ⇐ “LeftModule” (LMODULE) [8](#) on page [710](#)
 ⇐ “Monoid” (MONOID) [5](#) on page [386](#)
 ⇐ “Rng” (RNG) [8](#) on page [775](#)

Exports:

| | | | | |
|-------|------|----------------|--------|---------------|
| 1 | 0 | characteristic | coerce | hash |
| latex | one? | recip | sample | subtractIfCan |
| zero? | ?~=? | ?*? | ?**? | ?^? |
| ?+? | ?-? | -? | ?=? | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation `recip` can only return “failed” if its argument is not a unit.

These are directly exported but not implemented:

```
characteristic : () -> NonNegativeInteger
```

These are implemented by this category:

```
coerce : Integer -> %
```

These exports come from (p[775](#)) `Rng()`:

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %

```

```

?? : (Integer,%) -> %
?? : (%,%) -> %
?? : (%,%) -> %
-? : % -> %
??* : (%,PositiveInteger) -> %
??^ : (%,PositiveInteger) -> %

```

These exports come from (p386) Monoid():

```

1 : () -> %
one? : % -> Boolean
recip : % -> Union(%, "failed")
??* : (%,NonNegativeInteger) -> %
??^ : (%,NonNegativeInteger) -> %

```

— category RING Ring —

```

)abbrev category RING Ring
++ Description:
++ The category of rings with unity, always associative, but
++ not necessarily commutative.

Ring(): Category == Join(Rng, Monoid, LeftModule(%)) with
  characteristic: () -> NonNegativeInteger
    ++ characteristic() returns the characteristic of the ring
    ++ this is the smallest positive integer n such that
    ++ \spad{n*x=0} for all x in the ring, or zero if no such n
    ++ exists.
    --We can not make this a constant, since some domains are mutable
  coerce: Integer -> %
    ++ coerce(i) converts the integer i to a member of the given domain.
-- recip: % -> Union(%, "failed") -- inherited from Monoid
  unitsKnown
    ++ recip truly yields
    ++ reciprocal or "failed" if not a unit.
    ++ Note that \spad{recip(0) = "failed"}.
  add
    n: Integer
    coerce(n) == n * 1$%

```

— RING.dotabb —

```

"RING"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=RING" ];
"RING" -> "RNG"

```

```
"RING" -> "MONOID"
"RING" -> "LMODULE"
```

— RING.dotfull —

```
"Ring()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RING"];
"Ring()" -> "Rng()"
"Ring()" -> "Monoid()"
"Ring()" -> "LeftModule(a:Ring)"
```

— RING.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Ring()" [color=lightblue];
  "Ring()" -> "Rng()"
  "Ring()" -> "Monoid()"
  "Ring()" -> "LeftModule(a:Ring)"

  "Rng()" [color=lightblue];
  "Rng()" -> "AbelianGroup()"
  "Rng()" -> "SemiGroup()"

  "Monoid()" [color=lightblue];
  "Monoid()" -> "SemiGroup()"

  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

  "LeftModule(a:Rng)" [color=lightblue];
  "LeftModule(a:Rng)" -> "AbelianGroup()"

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CABMON..."
  "AbelianGroup()" -> "REPDB..."

  "SemiGroup()" [color=lightblue];
  "SemiGroup()" -> "SETCAT..."
```

```

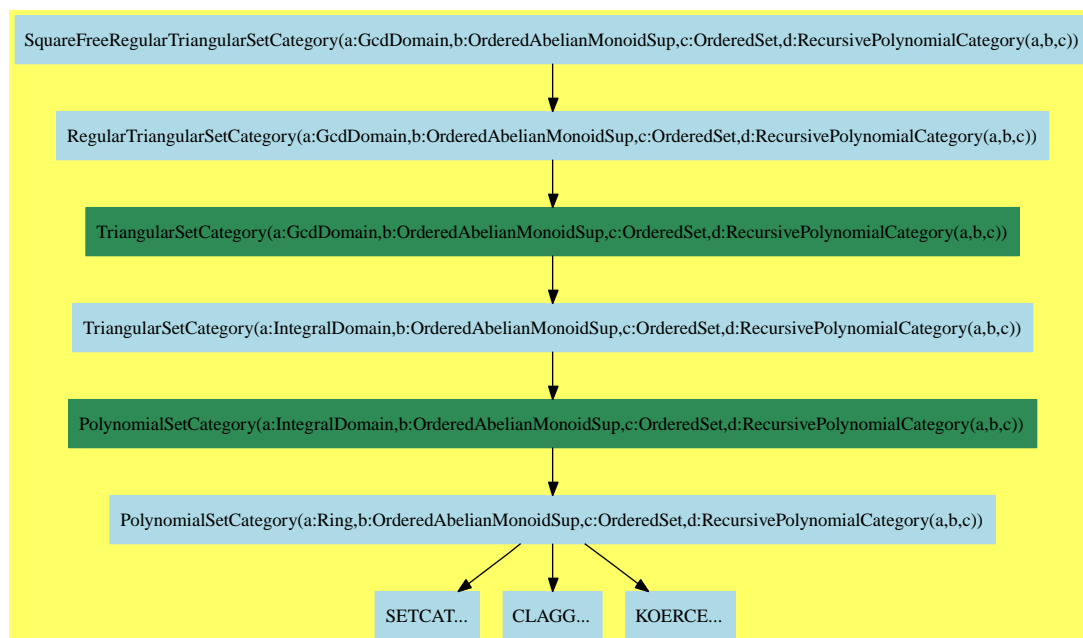
"SemiGroup()" -> "REPSQ..."

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"CABMON..." [color=lightblue];
}

```

—————→

SquareFreeRegularTriangularSetCategory (SFRTCAT)



— SquareFreeRegularTriangularSetCategory.input —

```

)set break resume
)sys rm -f SquareFreeRegularTriangularSetCategory.output
)spool SquareFreeRegularTriangularSetCategory.output
)set message test on
)set message auto off
)clear all

```

--S 1 of 1

```

)show SquareFreeRegularTriangularSetCategory
--R
--R SquareFreeRegularTriangularSetCategory(R: GcdDomain,E: OrderedAbelianMonoidSup,V: OrderedSet
--R Abbreviation for SquareFreeRegularTriangularSetCategory is SFRTCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SFRTCAT
--R
--R----- Operations -----
--R ?=? : (%,% ) -> Boolean
--R algebraicVariables : % -> List(V)
--R augment : (P,List(%)) -> List(V)
--R coerce : % -> List(P)
--R collect : (% ,V) -> %
--R collectUnder : (% ,V) -> %
--R construct : List(P) -> %
--R degree : % -> NonNegativeInteger
--R empty? : % -> Boolean
--R extend : (List(P),%) -> List(V)
--R extend : (P,%) -> List(V)
--R first : % -> Union(P,"failed")
--R headReduce : (P,%) -> P
--R headReduced? : (P,%) -> Boolean
--R initiallyReduce : (P,%) -> P
--R initials : % -> List(P)
--R intersect : (P,%) -> List(V)
--R invertibleSet : (P,%) -> List(V)
--R latex : % -> String
--R mainVariables : % -> List(V)
--R mvar : % -> V
--R normalized? : (P,%) -> Boolean
--R reduceByQuasiMonic : (P,%) -> P
--R rest : % -> Union(%,"failed")
--R sample : () -> %
--R stronglyReduced? : % -> Boolean
--R variables : % -> List(V)
--R ?^=? : (%,% ) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R algebraicCoefficients? : (P,%) -> Boolean
--R any? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
--R augment : (List(P),List(%)) -> List(V)
--R autoReduced? : (% ,((P,List(P)) -> Boolean)) -> Boolean
--R basicSet : (List(P),(P -> Boolean),((P,P) -> Boolean)) -> Union(Record(bas: %,top: List(P)),
--R basicSet : (List(P),((P,P) -> Boolean)) -> Union(Record(bas: %,top: List(P)),"failed")
--R coHeight : % -> NonNegativeInteger if V has FINITE
--R convert : % -> InputForm if P has KONVERT(INFORM)
--R count : ((P -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R count : (P,%) -> NonNegativeInteger if P has SETCAT and $ has finiteAggregate
--R eval : (% ,List(Equation(P))) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% ,Equation(P)) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (% ,P,P) -> % if P has EVALAB(P) and P has SETCAT

```

```

--R eval : (% , List(P), List(P)) -> % if P has EVALAB(P) and P has SETCAT
--R every? : ((P -> Boolean), %) -> Boolean if $ has finiteAggregate
--R extend : (List(P), List(%)) -> List(%)
--R extendIfCan : (% , P) -> Union(%, "failed")
--R find : ((P -> Boolean), %) -> Union(P, "failed")
--R headRemainder : (P, %) -> Record(num: P, den: R) if R has INTDOM
--R initiallyReduced? : (P, %) -> Boolean
--R internalAugment : (List(P), %) -> %
--R intersect : (P, List(%)) -> List(%)
--R intersect : (List(P), List(%)) -> List(%)
--R intersect : (List(P), %) -> List(%)
--R invertible? : (P, %) -> List(Record(val: Boolean, tower: %))
--R invertibleElseSplit? : (P, %) -> Union(Boolean, List(%))
--R lastSubResultant : (P, P, %) -> List(Record(val: P, tower: %))
--R lastSubResultantElseSplit : (P, P, %) -> Union(P, List(%))
--R less? : (% , NonNegativeInteger) -> Boolean
--R map! : ((P -> P), %) -> % if $ has shallowlyMutable
--R member? : (P, %) -> Boolean if P has SETCAT and $ has finiteAggregate
--R members : % -> List(P) if $ has finiteAggregate
--R more? : (% , NonNegativeInteger) -> Boolean
--R parts : % -> List(P) if $ has finiteAggregate
--R purelyAlgebraic? : (P, %) -> Boolean
--R purelyAlgebraicLeadingMonomial? : (P, %) -> Boolean
--R purelyTranscendental? : (P, %) -> Boolean
--R quasiComponent : % -> Record(close: List(P), open: List(P))
--R reduce : (P, %, ((P, P) -> P), ((P, P) -> Boolean)) -> P
--R reduce : (((P, P) -> P), %) -> P if $ has finiteAggregate
--R reduce : (((P, P) -> P), %, P) -> P if $ has finiteAggregate
--R reduce : (((P, P) -> P), %, P, P) -> P if P has SETCAT and $ has finiteAggregate
--R reduced? : (P, %, ((P, P) -> Boolean)) -> Boolean
--R remainder : (P, %) -> Record(rnum: R, polnum: P, den: R) if R has INTDOM
--R remove : ((P -> Boolean), %) -> % if $ has finiteAggregate
--R remove : (P, %) -> % if P has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
--R retractIfCan : List(P) -> Union(%, "failed")
--R rewriteIdealWithHeadRemainder : (List(P), %) -> List(P) if R has INTDOM
--R rewriteIdealWithRemainder : (List(P), %) -> List(P) if R has INTDOM
--R rewriteSetWithReduction : (List(P), %, ((P, P) -> P), ((P, P) -> Boolean)) -> List(P)
--R roughBase? : % -> Boolean if R has INTDOM
--R roughEqualIdeals? : (% , %) -> Boolean if R has INTDOM
--R roughSubIdeal? : (% , %) -> Boolean if R has INTDOM
--R roughUnitIdeal? : % -> Boolean if R has INTDOM
--R select : (% , V) -> Union(P, "failed")
--R select : ((P -> Boolean), %) -> % if $ has finiteAggregate
--R size? : (% , NonNegativeInteger) -> Boolean
--R sort : (% , V) -> Record(under: %, floor: %, upper: %)
--R squareFreePart : (P, %) -> List(Record(val: P, tower: %))
--R stronglyReduced? : (P, %) -> Boolean
--R triangular? : % -> Boolean if R has INTDOM
--R zeroSetSplit : (List(P), Boolean) -> List(%)

```



```
--R zeroSetSplitIntoTriangularSystems : List(P) -> List(Record(close: %,open: List(P)))
--R
--E 1

)spool
)lisp (bye)
```

— SquareFreeRegularTriangularSetCategory.help —

```
=====
SquareFreeRegularTriangularSetCategory examples
=====
```

The category of square-free regular triangular sets. A regular triangular set ts is square-free if the gcd of any polynomial p in ts and $\text{differentiate}(p, \text{mvar}(p))$ w.r.t. $\text{collectUnder}(ts, \text{mvar}(p))$ has degree zero w.r.t. $\text{mvar}(p)$. Thus any square-free regular set defines a tower of square-free simple extensions.

See Also:

o)show SquareFreeRegularTriangularSetCategory

See:

⇒ “SquareFreeNormalizedTriangularSetCategory” (SNTSCAT) [10](#) on page [963](#)

⇐ “RegularTriangularSetCategory” (RSETCAT) [8](#) on page [755](#)

Exports:

| | |
|---------------------------------|-----------------------------------|
| algebraic? | algebraicCoefficients? |
| algebraicVariables | any? |
| augment | autoReduced? |
| basicSet | coerce |
| coHeight | collect |
| collectQuasiMonic | collectUnder |
| collectUpper | construct |
| copy | convert |
| count | degree |
| empty | empty? |
| eq? | eval |
| every? | extend |
| extendIfCan | find |
| first | hash |
| headReduce | headReduced? |
| headRemainder | inFRittWu? |
| initiallyReduce | initiallyReduced? |
| initials | internalAugment |
| intersect | invertible? |
| invertibleElseSplit? | invertibleSet |
| last | lastSubResultant |
| lastSubResultantElseSplit | latex |
| less? | mainVariable? |
| mainVariables | map |
| map! | member? |
| members | more? |
| mvar | normalized? |
| parts | purelyAlgebraic? |
| purelyAlgebraicLeadingMonomial? | purelyTranscendental? |
| quasiComponent | reduce |
| reduceByQuasiMonic | reduced? |
| remainder | remove |
| removeDuplicates | removeZero |
| rest | retract |
| retractIfCan | rewriteIdealWithHeadRemainder |
| rewriteIdealWithRemainder | rewriteSetWithReduction |
| roughBase? | roughEqualIdeals? |
| roughSubIdeal? | roughUnitIdeal? |
| sample | select |
| size? | sort |
| squareFreePart | stronglyReduce |
| stronglyReduced? | triangular? |
| trivialIdeal? | variables |
| zeroSetSplit | zeroSetSplitIntoTriangularSystems |
| #? | ?=? |
| ?~=? | |

Attributes Exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

These exports come from (p755) `RegularTriangularSetCategory(R,E,V,P)` where `R:GcdDomain`, `E:OrderedAbelianMonoidSup`, `V:OrderedSet`, `P:RecursivePolynomialCategory(R,E,V)`:

```

algebraic? : (V,%) -> Boolean
algebraicCoefficients? : (P,%) -> Boolean
algebraicVariables : % -> List V
any? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
augment : (List P,List %) -> List %
augment : (List P,%) -> List %
augment : (P,List %) -> List %
augment : (P,%) -> List %
autoReduced? : (%,((P,List P) -> Boolean)) -> Boolean
basicSet :
  (List P,(P -> Boolean),((P,P) -> Boolean)) ->
    Union(Record(bas: %,top: List P),"failed")
basicSet :
  (List P,((P,P) -> Boolean)) ->
    Union(Record(bas: %,top: List P),"failed")
coerce : % -> List P
coerce : % -> OutputForm
coHeight : % -> NonNegativeInteger if V has FINITE
collect : (%,V) -> %
collectQuasiMonic : % -> %
collectUnder : (%,V) -> %
collectUpper : (%,V) -> %
construct : List P -> %
convert : % -> InputForm if P has KONVERT INFORM
copy : % -> %
count : ((P -> Boolean),%) -> NonNegativeInteger
  if $ has finiteAggregate
count : (P,%) -> NonNegativeInteger
  if P has SETCAT
  and $ has finiteAggregate
degree : % -> NonNegativeInteger
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List Equation P) -> % if P has EVALAB P and P has SETCAT
eval : (%,Equation P) -> % if P has EVALAB P and P has SETCAT

```

```

eval : (%,P,P) -> % if P has EVALAB P and P has SETCAT
eval : (%,List P,List P) -> % if P has EVALAB P and P has SETCAT
every? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
extend : (List P,List %) -> List %
extend : (List P,%) -> List %
extend : (P,List %) -> List %
extend : (P,%) -> List %
extend : (%,P) -> %
extendIfCan : (%,P) -> Union(%, "failed")
find : ((P -> Boolean),%) -> Union(P, "failed")
first : % -> Union(P, "failed")
hash : % -> SingleInteger
headReduce : (P,%) -> P
headReduced? : % -> Boolean
headReduced? : (P,%) -> Boolean
headRemainder : (P,%) -> Record(num: P,den: R) if R has INTDOM
infRittWu? : (%,%) -> Boolean
initiallyReduce : (P,%) -> P
initiallyReduced? : % -> Boolean
initiallyReduced? : (P,%) -> Boolean
initials : % -> List P
internalAugment : (P,%) -> %
internalAugment : (List P,%) -> %
intersect : (P,List %) -> List %
intersect : (List P,%) -> List %
intersect : (P,%) -> List %
intersect : (List P,List %) -> List %
invertible? : (P,%) -> Boolean
invertible? : (P,%) -> List Record(val: Boolean,tower: %)
invertibleElseSplit? : (P,%) -> Union(Boolean,List %)
invertibleSet : (P,%) -> List %
last : % -> Union(P, "failed")
lastSubResultant : (P,P,%) -> List Record(val: P,tower: %)
lastSubResultantElseSplit : (P,P,%) -> Union(P,List %)
latex : % -> String
less? : (%,NonNegativeInteger) -> Boolean
mainVariable? : (V,%) -> Boolean
mainVariables : % -> List V
map : ((P -> P),%) -> %
map! : ((P -> P),%) -> % if $ has shallowlyMutable
member? : (P,%) -> Boolean if P has SETCAT and $ has finiteAggregate
members : % -> List P if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
mvar : % -> V
normalized? : % -> Boolean
normalized? : (P,%) -> Boolean
parts : % -> List P if $ has finiteAggregate
purelyAlgebraic? : (P,%) -> Boolean
purelyAlgebraic? : % -> Boolean
purelyAlgebraicLeadingMonomial? : (P,%) -> Boolean

```

```

purelyTranscendental? : (P,%) -> Boolean
quasiComponent : % -> Record(close: List P,open: List P)
reduce : (P,%,(P,P) -> P),(P,P) -> Boolean -> P
reduce : ((P,P) -> P),% -> P if $ has finiteAggregate
reduce : ((P,P) -> P),%,P -> P if $ has finiteAggregate
reduce : ((P,P) -> P),%,P,P -> P
  if P has SETCAT
  and $ has finiteAggregate
reduceByQuasiMonic : (P,%) -> P
reduced? : (P,%,(P,P) -> Boolean) -> Boolean
remainder : (P,%) -> Record(rnum: R, polnum: P, den: R)
  if R has INTDOM
remove : ((P -> Boolean),%) -> % if $ has finiteAggregate
remove : (P,%) -> % if P has SETCAT and $ has finiteAggregate
removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
removeZero : (P,%) -> P
rest : % -> Union(%,"failed")
retract : List P -> %
retractIfCan : List P -> Union(%,"failed")
rewriteIdealWithHeadRemainder : (List P,%) -> List P if R has INTDOM
rewriteIdealWithRemainder : (List P,%) -> List P if R has INTDOM
rewriteSetWithReduction :
  (List P,%,(P,P) -> P),(P,P) -> Boolean -> List P
roughBase? : % -> Boolean if R has INTDOM
roughEqualIdeals? : (%,%) -> Boolean if R has INTDOM
roughSubIdeal? : (%,%) -> Boolean if R has INTDOM
roughUnitIdeal? : % -> Boolean if R has INTDOM
sample : () -> %
select : (% ,V) -> Union(P,"failed")
select : ((P -> Boolean),%) -> % if $ has finiteAggregate
size? : (% ,NonNegativeInteger) -> Boolean
sort : (% ,V) -> Record(under: %, floor: %, upper: %)
squareFreePart : (P,%) -> List Record(val: P, tower: %)
stronglyReduce : (P,%) -> P
stronglyReduced? : (P,%) -> Boolean
stronglyReduced? : % -> Boolean
triangular? : % -> Boolean if R has INTDOM
trivialIdeal? : % -> Boolean
variables : % -> List V
zeroSetSplit : List P -> List %
zeroSetSplit : (List P, Boolean) -> List %
zeroSetSplitIntoTriangularSystems :
  List P -> List Record(close: %, open: List P)
#? : % -> NonNegativeInteger if $ has finiteAggregate
?? : (% ,%) -> Boolean
?~? : (% ,%) -> Boolean

```

```

)abbrev category SFRTCAT SquareFreeRegularTriangularSetCategory
++ Author: Marc Moreno Maza
++ Date Created: 09/03/1996
++ Date Last Updated: 09/10/1998
++ References :
++ [1] D. LAZARD "A new method for solving algebraic systems of
++       positive dimension" Discr. App. Math. 33:147-160,1991
++ [2] M. KALKBRENER "Algorithmic properties of polynomial rings"
++       Habilitation Thesis, ETZH, Zurich, 1995.
++ [3] M. MORENO MAZA "A new algorithm for computing triangular
++       decomposition of algebraic varieties" NAG Tech. Rep. 4/98.
++ Description:
++ The category of square-free regular triangular sets.
++ A regular triangular set \spad{ts} is square-free if
++ the gcd of any polynomial \spad{p} in \spad{ts} and
++ differentiate(p,mvar(p)) w.r.t. collectUnder(ts,mvar(p))
++ has degree zero w.r.t. \spad{mvar(p)}. Thus any square-free regular
++ set defines a tower of square-free simple extensions.

SquareFreeRegularTriangularSetCategory(R:GcdDomain,E:OrderedAbelianMonoidSup,
  V:OrderedSet,P:RecursivePolynomialCategory(R,E,V)):
  Category ==
    RegularTriangularSetCategory(R,E,V,P)

```

— SFRTCAT.dotabb —

```

"SFRTCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SFRTCAT"];
"SFRTCAT" -> "RSETCAT"

```

— SFRTCAT.dotfull —

```

"SquareFreeRegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P))
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SFRTCAT"];
"SquareFreeRegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P))
->
"RegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P))

```

— SFRTCAT.dotpic —

```

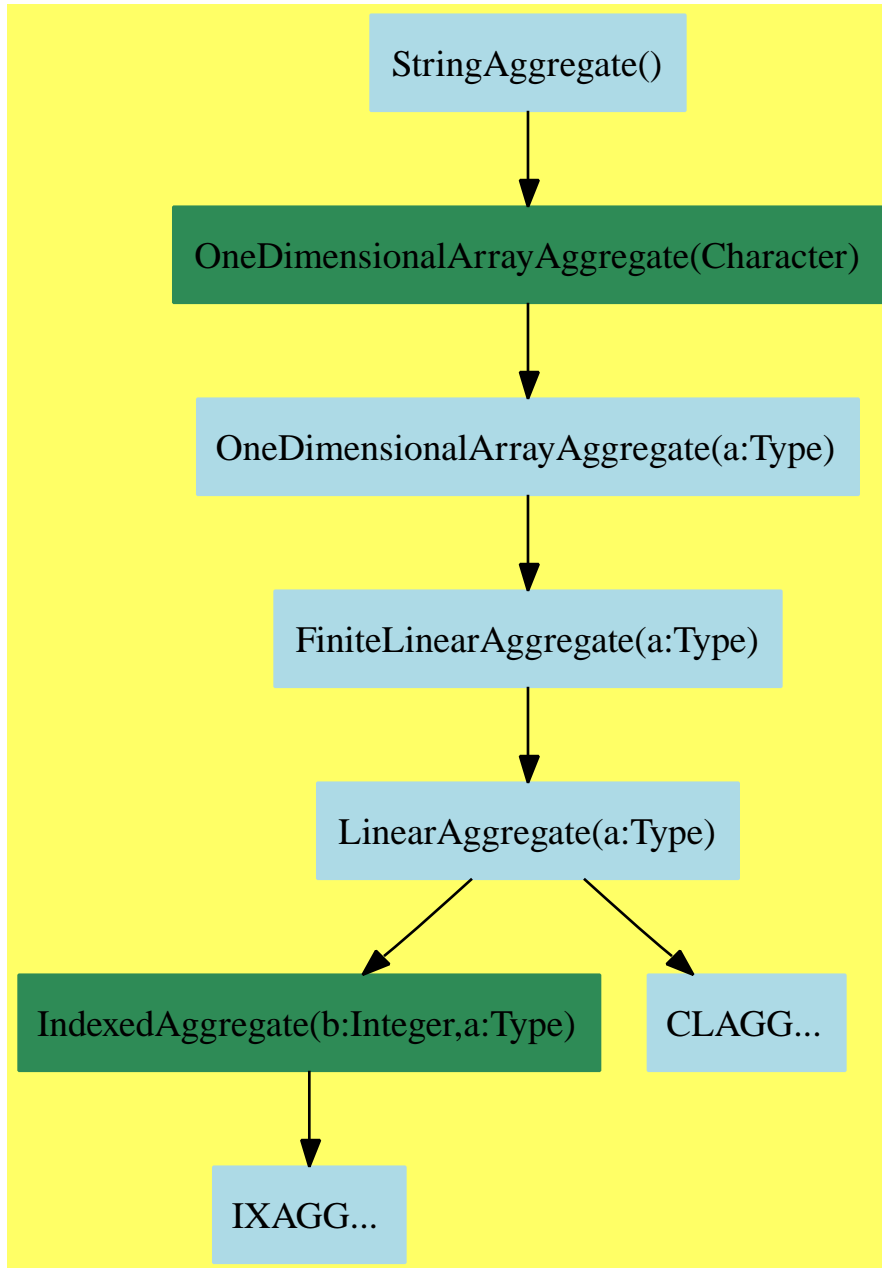
digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "SquareFreeRegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    [color=lightblue];
    "SquareFreeRegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    ->
    "RegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    [color=lightblue];
    "RegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    ->
    "TriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    [color=seagreen];
    "TriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    ->
    "TriangularSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    [color=lightblue];
    "TriangularSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    -> "PolynomialSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    [color=seagreen];
    "PolynomialSetCategory(a:IntegralDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    -> "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    [color=lightblue];
    "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    -> "SETCAT..."
    "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    -> "CLAGG..."
    "PolynomialSetCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialSetCategory)"
    -> "KOERCE..."

    "SETCAT..." [color=lightblue];
    "KOERCE..." [color=lightblue];
    "CLAGG..." [color=lightblue];
}

```

StringAggregate (SRAGG)



— StringAggregate.input —


```

)set break resume
)sys rm -f StringAggregate.output
)spool StringAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show StringAggregate
--R
--R StringAggregate is a category constructor
--R Abbreviation for StringAggregate is SRAGG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SRAGG
--R
--R----- Operations -----
--R coerce : Character -> %
--R concat : (%,% ) -> %
--R concat : (% ,Character) -> %
--R copy : % -> %
--R ?.? : (%,% ) -> %
--R empty : () -> %
--R entries : % -> List(Character)
--R index? : (Integer,% ) -> Boolean
--R insert : (% ,%,Integer) -> %
--R lowerCase : % -> %
--R prefix? : (%,% ) -> Boolean
--R reverse : % -> %
--R sample : () -> %
--R suffix? : (%,% ) -> Boolean
--R trim : (% ,Character) -> %
--R upperCase! : % -> %
--R concat : List(%) -> %
--R concat : (Character,% ) -> %
--R construct : List(Character) -> %
--R delete : (% ,Integer) -> %
--R ?.? : (% ,Integer) -> Character
--R empty? : % -> Boolean
--R eq? : (%,% ) -> Boolean
--R indices : % -> List(Integer)
--R leftTrim : (% ,Character) -> %
--R lowerCase! : % -> %
--R qelt : (% ,Integer) -> Character
--R rightTrim : (% ,Character) -> %
--R split : (% ,Character) -> List(%)
--R trim : (% ,CharacterClass) -> %
--R upperCase : % -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?<? : (%,% ) -> Boolean if Character has ORDSET
--R ?<=? : (%,% ) -> Boolean if Character has ORDSET
--R ?=? : (%,% ) -> Boolean if Character has SETCAT
--R ?>? : (%,% ) -> Boolean if Character has ORDSET
--R ?>=? : (%,% ) -> Boolean if Character has ORDSET
--R any? : ((Character -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if Character has SETCAT
--R convert : % -> InputForm if Character has KONVERT(INFORM)
--R copyInto! : (% ,%,Integer) -> % if $ has shallowlyMutable
--R count : (Character,% ) -> NonNegativeInteger if Character has SETCAT and $ has finiteAggregate
--R count : ((Character -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R delete : (% ,UniversalSegment(Integer)) -> %
--R ?.? : (% ,UniversalSegment(Integer)) -> %
--R elt : (% ,Integer,Character) -> Character
--R entry? : (Character,% ) -> Boolean if $ has finiteAggregate and Character has SETCAT
--R eval : (% ,List(Character),List(Character)) -> % if Character has EVALAB(CHAR) and Character
--R eval : (% ,Character,Character) -> % if Character has EVALAB(CHAR) and Character has SETCAT

```

```

--R eval : (% ,Equation(Character)) -> % if Character has EVALAB(Char) and Character has SETCAT
--R eval : (% ,List(Equation(Character))) -> % if Character has EVALAB(Char) and Character has SETCAT
--R every? : ((Character -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (% ,Character) -> % if $ has shallowlyMutable
--R find : ((Character -> Boolean),%) -> Union(Character,"failed")
--R first : % -> Character if Integer has ORDSET
--R hash : % -> SingleInteger if Character has SETCAT
--R insert : (Character,%,Integer) -> %
--R latex : % -> String if Character has SETCAT
--R leftTrim : (% ,CharacterClass) -> %
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map : (((Character,Character) -> Character),%,%) -> %
--R map : ((Character -> Character),%) -> %
--R map! : ((Character -> Character),%) -> % if $ has shallowlyMutable
--R match : (% ,%,Character) -> NonNegativeInteger
--R match? : (% ,%,Character) -> Boolean
--R max : (% ,%) -> % if Character has ORDSET
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (Character,%) -> Boolean if Character has SETCAT and $ has finiteAggregate
--R members : % -> List(Character) if $ has finiteAggregate
--R merge : (% ,%) -> % if Character has ORDSET
--R merge : (((Character,Character) -> Boolean),%,%) -> %
--R min : (% ,%) -> % if Character has ORDSET
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (% ,NonNegativeInteger) -> Boolean
--R new : (NonNegativeInteger,Character) -> %
--R parts : % -> List(Character) if $ has finiteAggregate
--R position : (CharacterClass,%,Integer) -> Integer
--R position : (% ,%,Integer) -> Integer
--R position : (Character,%,Integer) -> Integer if Character has SETCAT
--R position : (Character,%) -> Integer if Character has SETCAT
--R position : ((Character -> Boolean),%) -> Integer
--R qsetelt! : (% ,Integer,Character) -> Character if $ has shallowlyMutable
--R reduce : (((Character,Character) -> Character),%) -> Character if $ has finiteAggregate
--R reduce : (((Character,Character) -> Character),%,Character) -> Character if $ has finiteAggregate
--R reduce : (((Character,Character) -> Character),%,Character,Character) -> Character if Character has SETCAT
--R remove : ((Character -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (Character,%) -> % if Character has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if Character has SETCAT and $ has finiteAggregate
--R replace : (% ,UniversalSegment(Integer),%) -> %
--R reverse! : % -> % if $ has shallowlyMutable
--R rightTrim : (% ,CharacterClass) -> %
--R select : ((Character -> Boolean),%) -> % if $ has finiteAggregate
--R setelt : (% ,UniversalSegment(Integer),Character) -> Character if $ has shallowlyMutable
--R setelt : (% ,Integer,Character) -> Character if $ has shallowlyMutable
--R size? : (% ,NonNegativeInteger) -> Boolean
--R sort : % -> % if Character has ORDSET
--R sort : (((Character,Character) -> Boolean),%) -> %
--R sort! : % -> % if Character has ORDSET and $ has shallowlyMutable
--R sort! : (((Character,Character) -> Boolean),%) -> % if $ has shallowlyMutable

```

```

--R sorted? : % -> Boolean if Character has ORDSET
--R sorted? : (((Character,Character) -> Boolean),%) -> Boolean
--R split : (% ,CharacterClass) -> List(%)
--R substring? : (% ,%,Integer) -> Boolean
--R swap! : (% ,Integer,Integer) -> Void if $ has shallowlyMutable
--R ~=? : (% ,%) -> Boolean if Character has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— StringAggregate.help —

```

=====
StringAggregate examples
=====

```

A string aggregate is a category for strings, that is, one dimensional arrays of characters.

See Also:

o)show StringAggregate

See:

⇒ “StringCategory” (STRICAT) [10](#) on page [972](#)

⇐ “OneDimensionalArrayAggregate” (A1AGG) [8](#) on page [739](#)

Exports:

| | | | | |
|-----------|------------|-----------|------------|------------------|
| any? | coerce | concat | construct | copy |
| convert | copyInto! | count | delete | elt |
| empty | empty? | entries | entry? | eval |
| every? | eq? | fill! | find | first |
| hash | index? | indices | insert | latex |
| leftTrim | less? | lowerCase | lowerCase! | map |
| map! | match | match? | max | maxIndex |
| member? | members | merge | min | minIndex |
| more? | new | parts | position | prefix? |
| qelt | qsetelt! | reduce | remove | removeDuplicates |
| replace | reverse | reverse! | rightTrim | sample |
| setelt | size? | sort | sort! | sorted? |
| split | substring? | suffix? | swap! | trim |
| upperCase | upperCase! | #? | ?~=? | ?.? |
| ?<? | ?<=? | ?=? | ?>? | ?>=? |

Attributes exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

These are directly exported but not implemented:

```

leftTrim : (%,Character) -> %
leftTrim : (%,CharacterClass) -> %
lowerCase! : % -> %
match : (%,%,Character) -> NonNegativeInteger
match? : (%,%,Character) -> Boolean
position : (CharacterClass,%,Integer) -> Integer
position : (%,%,Integer) -> Integer
replace : (%,UniversalSegment Integer,%) -> %
rightTrim : (%,Character) -> %
rightTrim : (%,CharacterClass) -> %
split : (%,Character) -> List %
split : (%,CharacterClass) -> List %
substring? : (%,%,Integer) -> Boolean
suffix? : (%,%) -> Boolean
upperCase! : % -> %

```

These are implemented by this category:

```

coerce : Character -> %
lowerCase : % -> %
prefix? : (%,%) -> Boolean

```

```

trim : (% , CharacterClass) -> %
trim : (% , Character) -> %
upperCase : % -> %
?.? : (% , %) -> %

```

These exports come from (p739) `OneDimensionalArrayAggregate(Character)`:

```

any? : ((Character -> Boolean), %) -> Boolean
      if $ has finiteAggregate
coerce : % -> OutputForm if Character has SETCAT
concat : List % -> %
concat : (% , %) -> %
concat : (Character , %) -> %
concat : (% , Character) -> %
construct : List Character -> %
convert : % -> InputForm
      if Character has KONVERT INFORM
copy : % -> %
copyInto! : (% , % , Integer) -> %
      if $ has shallowlyMutable
count : (Character , %) -> NonNegativeInteger
      if Character has SETCAT
      and $ has finiteAggregate
count : ((Character -> Boolean), %) -> NonNegativeInteger
      if $ has finiteAggregate
delete : (% , Integer) -> %
delete : (% , UniversalSegment Integer) -> %
elt : (% , Integer , Character) -> Character
empty : () -> %
empty? : % -> Boolean
entries : % -> List Character
entry? : (Character , %) -> Boolean
      if $ has finiteAggregate
      and Character has SETCAT
eq? : (% , %) -> Boolean
eval : (% , List Character , List Character) -> %
      if Character has EVALAB CHAR
      and Character has SETCAT
eval : (% , Character , Character) -> %
      if Character has EVALAB CHAR
      and Character has SETCAT
eval : (% , Equation Character) -> %
      if Character has EVALAB CHAR
      and Character has SETCAT
eval : (% , List Equation Character) -> %
      if Character has EVALAB CHAR
      and Character has SETCAT
every? : ((Character -> Boolean), %) -> Boolean
      if $ has finiteAggregate
fill! : (% , Character) -> %

```

```

        if $ has shallowlyMutable
find : ((Character -> Boolean),%) -> Union(Character,"failed")
first : % -> Character
        if Integer has ORDSET
hash : % -> SingleInteger
        if Character has SETCAT
index? : (Integer,%) -> Boolean
indices : % -> List Integer
insert : (Character,%,Integer) -> %
insert : (%,%,Integer) -> %
latex : % -> String if Character has SETCAT
less? : (%,NonNegativeInteger) -> Boolean
map : ((Character -> Character),%) -> %
map : (((Character,Character) -> Character),%,%) -> %
map! : ((Character -> Character),%) -> %
        if $ has shallowlyMutable
max : (%,%) -> % if Character has ORDSET
maxIndex : % -> Integer if Integer has ORDSET
member? : (Character,%) -> Boolean
        if Character has SETCAT
        and $ has finiteAggregate
members : % -> List Character
        if $ has finiteAggregate
merge : (%,%) -> % if Character has ORDSET
merge : (((Character,Character) -> Boolean),%,%) -> %
min : (%,%) -> % if Character has ORDSET
minIndex : % -> Integer if Integer has ORDSET
more? : (%,NonNegativeInteger) -> Boolean
new : (NonNegativeInteger,Character) -> %
parts : % -> List Character if $ has finiteAggregate
position : (Character,%) -> Integer
        if Character has SETCAT
position : ((Character -> Boolean),%) -> Integer
position : (Character,%,Integer) -> Integer
        if Character has SETCAT
qelt : (%,Integer) -> Character
qsetelt! : (%,Integer,Character) -> Character
        if $ has shallowlyMutable
reduce : (((Character,Character) -> Character),%) -> Character
        if $ has finiteAggregate
reduce :
    (((Character,Character) -> Character),%,Character) -> Character
        if $ has finiteAggregate
reduce :
    (((Character,Character) -> Character),%,Character,Character)
        -> Character
        if Character has SETCAT and $ has finiteAggregate
remove : ((Character -> Boolean),%) -> %
        if $ has finiteAggregate
remove : (Character,%) -> %

```

```

        if Character has SETCAT
        and $ has finiteAggregate
removeDuplicates : % -> %
        if Character has SETCAT
        and $ has finiteAggregate
reverse : % -> %
reverse! : % -> % if $ has shallowlyMutable
sample : () -> %
select : ((Character -> Boolean),%) -> %
        if $ has finiteAggregate
setelt : (% , UniversalSegment Integer, Character) -> Character
        if $ has shallowlyMutable
sort! : (((Character, Character) -> Boolean),%) -> %
        if $ has shallowlyMutable
sorted? : (((Character, Character) -> Boolean),%) -> Boolean
setelt : (% , Integer, Character) -> Character
        if $ has shallowlyMutable
size? : (% , NonNegativeInteger) -> Boolean
sort : % -> % if Character has ORDSET
sort : (((Character, Character) -> Boolean),%) -> %
sort! : % -> %
        if Character has ORDSET
        and $ has shallowlyMutable
sorted? : % -> Boolean if Character has ORDSET
swap! : (% , Integer, Integer) -> Void
        if $ has shallowlyMutable
#? : % -> NonNegativeInteger if $ has finiteAggregate
?~=? : (% , %) -> Boolean if Character has SETCAT
?.? : (% , UniversalSegment Integer) -> %
?.? : (% , Integer) -> Character
?<? : (% , %) -> Boolean if Character has ORDSET
?<=? : (% , %) -> Boolean if Character has ORDSET
?=? : (% , %) -> Boolean if Character has SETCAT
?>? : (% , %) -> Boolean if Character has ORDSET
?>=? : (% , %) -> Boolean if Character has ORDSET

```

— category SRAGG StringAggregate —

```

)abbrev category SRAGG StringAggregate
++ Author: Stephen Watt and Michael Monagan.
++ revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A string aggregate is a category for strings, that is,
++ one dimensional arrays of characters.

StringAggregate: Category == OneDimensionalArrayAggregate Character with
lowerCase          : % -> %

```

```

    ++ lowerCase(s) returns the string with all characters in lower case.
lowerCase_!: % -> %
    ++ lowerCase!(s) destructively replaces the alphabetic characters
    ++ in s by lower case.
upperCase      : % -> %
    ++ upperCase(s) returns the string with all characters in upper case.
upperCase_!: % -> %
    ++ upperCase!(s) destructively replaces the alphabetic characters
    ++ in s by upper case characters.
prefix?        : (% , %) -> Boolean
    ++ prefix?(s,t) tests if the string s is the initial substring of t.
    ++ Note that \axiom{prefix?(s,t) ==
    ++   reduce(and,[s.i = t.i for i in 0..maxIndex s])}.
suffix?        : (% , %) -> Boolean
    ++ suffix?(s,t) tests if the string s is the final substring of t.
    ++ Note that \axiom{suffix?(s,t) ==
    ++   reduce(and,[s.i = t.(n - m + i) for i in 0..maxIndex s])}
    ++ where m and n denote the maxIndex of s and t respectively.
substring?: (% , % , Integer) -> Boolean
    ++ substring?(s,t,i) tests if s is a substring of t beginning at
    ++ index i.
    ++ Note that \axiom{substring?(s,t,0) = prefix?(s,t)}.
match: (% , % , Character) -> NonNegativeInteger
    ++ match(p,s,wc) tests if pattern \axiom{p} matches subject \axiom{s}
    ++ where \axiom{wc} is a wild card character. If no match occurs,
    ++ the index \axiom{0} is returned; otherwise, the value returned
    ++ is the first index of the first character in the subject matching
    ++ the subject (excluding that matched by an initial wild-card).
    ++ For example, \axiom{match("to*", "yorktown", "*")} returns \axiom{5}
    ++ indicating a successful match starting at index \axiom{5} of
    ++ \axiom{"yorktown"}.
match?: (% , % , Character) -> Boolean
    ++ match?(s,t,c) tests if s matches t except perhaps for
    ++ multiple and consecutive occurrences of character c.
    ++ Typically c is the blank character.
replace        : (% , UniversalSegment(Integer), %) -> %
    ++ replace(s,i..j,t) replaces the substring \axiom{s(i..j)}
    ++ of s by string t.
position       : (% , % , Integer) -> Integer
    ++ position(s,t,i) returns the position j of the substring s in
    ++ string t, where \axiom{j >= i} is required.
position       : (CharacterClass, % , Integer) -> Integer
    ++ position(cc,t,i) returns the position \axiom{j >= i} in t of
    ++ the first character belonging to cc.
coerce        : Character -> %
    ++ coerce(c) returns c as a string s with the character c.
split: (% , Character) -> List %
    ++ split(s,c) returns a list of substrings delimited by character c.
split: (% , CharacterClass) -> List %
    ++ split(s,cc) returns a list of substrings delimited by

```



```

++ characters in cc.
trim: (% , Character) -> %
++ trim(s,c) returns s with all characters c deleted from right
++ and left ends.
++ For example, \axiom{trim(" abc ", char " ")} returns \axiom{"abc"}.
trim: (% , CharacterClass) -> %
++ trim(s,cc) returns s with all characters in cc deleted from right
++ and left ends.
++ For example, \axiom{trim("(abc)", charClass "()")}
++ returns \axiom{"abc"}.
leftTrim: (% , Character) -> %
++ leftTrim(s,c) returns s with all leading characters c deleted.
++ For example, \axiom{leftTrim(" abc ", char " ")}
++ returns \axiom{"abc "}.
leftTrim: (% , CharacterClass) -> %
++ leftTrim(s,cc) returns s with all leading characters in cc deleted.
++ For example, \axiom{leftTrim("(abc)", charClass "()")}
++ returns \axiom{"abc"}.
rightTrim: (% , Character) -> %
++ rightTrim(s,c) returns s with all trailing occurrences of c deleted.
++ For example, \axiom{rightTrim(" abc ", char " ")}
++ returns \axiom{" abc"}.
rightTrim: (% , CharacterClass) -> %
++ rightTrim(s,cc) returns s with all trailing occurrences of
++ characters in cc deleted.
++ For example, \axiom{rightTrim("(abc)", charClass "()")}
++ returns \axiom{"(abc)".
elt: (% , %) -> %
++ elt(s,t) returns the concatenation of s and t. It is provided to
++ allow juxtaposition of strings to work as concatenation.
++ For example, \axiom{"smoo" "shed"} returns \axiom{"smooshed"}.
add
trim(s: % , c: Character) == leftTrim(rightTrim(s, c), c)
trim(s: % , cc: CharacterClass) == leftTrim(rightTrim(s, cc), cc)
lowerCase s == lowerCase_! copy s
upperCase s == upperCase_! copy s
prefix?(s, t) == substring?(s, t, minIndex t)
coerce(c: Character): % == new(1, c)
elt(s: %, t: %): % == concat(s,t)$%

```

— SRAGG.dotabb —

"SRAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=SRAGG"];
"SRAGG" -> "A1AGG"

— SRAGG.dotfull —

```
"StringAggregate()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SRAGG"];
"StringAggregate()" -> "OneDimensionalArrayAggregate(Character)"
```

— SRAGG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "StringAggregate()" [color=lightblue];
  "StringAggregate()" -> "OneDimensionalArrayAggregate(Character)"

  "OneDimensionalArrayAggregate(Character)" [color=seagreen];
  "OneDimensionalArrayAggregate(Character)" ->
    "OneDimensionalArrayAggregate(a:Type)"

  "OneDimensionalArrayAggregate(a:Type)" [color=lightblue];
  "OneDimensionalArrayAggregate(a:Type)" ->
    "FiniteLinearAggregate(a:Type)"

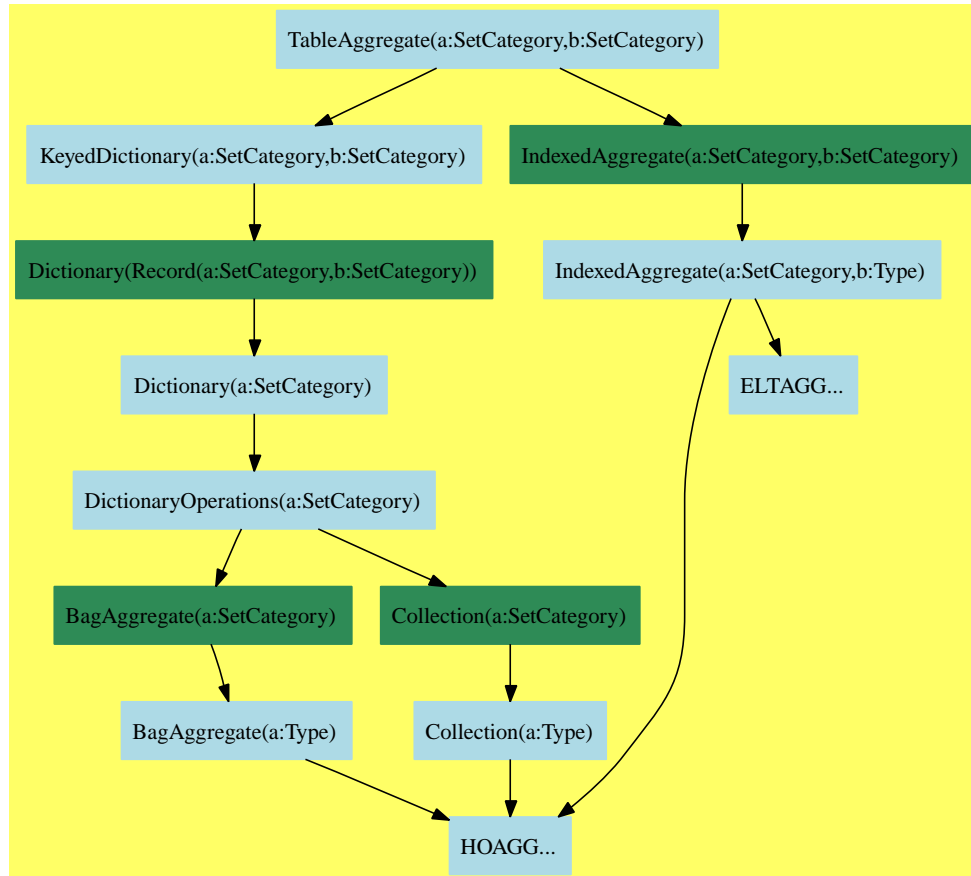
  "FiniteLinearAggregate(a:Type)" [color=lightblue];
  "FiniteLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"

  "LinearAggregate(a:Type)" [color=lightblue];
  "LinearAggregate(a:Type)" -> "IndexedAggregate(b:Integer,a:Type)"
  "LinearAggregate(a:Type)" -> "CLAGG..."

  "IndexedAggregate(b:Integer,a:Type)" [color=seagreen];
  "IndexedAggregate(b:Integer,a:Type)" -> "IXAGG..."

  "CLAGG..." [color=lightblue];
  "IXAGG..." [color=lightblue];
}
```

TableAggregate (TBAGG)



— TableAggregate.input —

```

)set break resume
)sys rm -f TableAggregate.output
)spool TableAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show TableAggregate
--R
--R TableAggregate(Key: SetCategory,Entry: SetCategory) is a category constructor
--R Abbreviation for TableAggregate is TBAGG
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for TBAGG
--R
--R----- Operations -----
--R copy : % -> % dictionary : () -> %
--R elt : (% ,Key,Entry) -> Entry ?..? : (% ,Key) -> Entry
--R empty : () -> % empty? : % -> Boolean
--R entries : % -> List(Entry) eq? : (% ,%) -> Boolean
--R index? : (Key,% ) -> Boolean indices : % -> List(Key)
--R key? : (Key,% ) -> Boolean keys : % -> List(Key)
--R map : ((Entry -> Entry),%) -> % qelt : (% ,Key) -> Entry
--R sample : () -> % setelt : (% ,Key,Entry) -> Entry
--R table : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?=? : (% ,%) -> Boolean if Entry has SETCAT or Record(key: Key,entry: Entry) has SETCAT
--R any? : ((Entry -> Boolean),%) -> Boolean if $ has finiteAggregate
--R any? : ((Record(key: Key,entry: Entry) -> Boolean),%) -> Boolean if $ has finiteAggregate
--R bag : List(Record(key: Key,entry: Entry)) -> %
--R coerce : % -> OutputForm if Entry has SETCAT or Record(key: Key,entry: Entry) has SETCAT
--R construct : List(Record(key: Key,entry: Entry)) -> %
--R convert : % -> InputForm if Record(key: Key,entry: Entry) has KONVERT(INFORM)
--R count : ((Entry -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R count : (Entry,% ) -> NonNegativeInteger if Entry has SETCAT and $ has finiteAggregate
--R count : (Record(key: Key,entry: Entry),%) -> NonNegativeInteger if Record(key: Key,entry: Entry) has SETCAT
--R count : ((Record(key: Key,entry: Entry) -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R dictionary : List(Record(key: Key,entry: Entry)) -> %
--R entry? : (Entry,% ) -> Boolean if $ has finiteAggregate and Entry has SETCAT
--R eval : (% ,List(Equation(Entry))) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% ,Equation(Entry)) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% ,Entry,Entry) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% ,List(Entry),List(Entry)) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% ,List(Record(key: Key,entry: Entry)),List(Record(key: Key,entry: Entry))) -> % if Record(key: Key,entry: Entry) has SETCAT
--R eval : (% ,Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> % if Record(key: Key,entry: Entry) has SETCAT
--R eval : (% ,Equation(Record(key: Key,entry: Entry))) -> % if Record(key: Key,entry: Entry) has EVALAB(Record(key: Key,entry: Entry))
--R eval : (% ,List(Equation(Record(key: Key,entry: Entry)))) -> % if Record(key: Key,entry: Entry) has EVALAB(Record(key: Key,entry: Entry))
--R every? : ((Entry -> Boolean),%) -> Boolean if $ has finiteAggregate
--R every? : ((Record(key: Key,entry: Entry) -> Boolean),%) -> Boolean if $ has finiteAggregate
--R extract! : % -> Record(key: Key,entry: Entry)
--R fill! : (% ,Entry) -> % if $ has shallowlyMutable
--R find : ((Record(key: Key,entry: Entry) -> Boolean),%) -> Union(Record(key: Key,entry: Entry),"failed")
--R first : % -> Entry if Key has ORDSET
--R hash : % -> SingleInteger if Entry has SETCAT or Record(key: Key,entry: Entry) has SETCAT
--R insert! : (Record(key: Key,entry: Entry),%) -> %
--R inspect : % -> Record(key: Key,entry: Entry)
--R latex : % -> String if Entry has SETCAT or Record(key: Key,entry: Entry) has SETCAT
--R less? : (% ,NonNegativeInteger) -> Boolean
--R map : (((Entry,Entry) -> Entry),%,%) -> %
--R map : ((Record(key: Key,entry: Entry) -> Record(key: Key,entry: Entry)),%) -> %
--R map! : ((Entry -> Entry),%) -> % if $ has shallowlyMutable
--R map! : ((Record(key: Key,entry: Entry) -> Record(key: Key,entry: Entry)),%) -> % if $ has shallowlyMutable
--R maxIndex : % -> Key if Key has ORDSET

```

```

--R member? : (Entry,%) -> Boolean if Entry has SETCAT and $ has finiteAggregate
--R member? : (Record(key: Key,entry: Entry),%) -> Boolean if Record(key: Key,entry: Entry) has
--R members : % -> List(Entry) if $ has finiteAggregate
--R members : % -> List(Record(key: Key,entry: Entry)) if $ has finiteAggregate
--R minIndex : % -> Key if Key has ORDSET
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(Entry) if $ has finiteAggregate
--R parts : % -> List(Record(key: Key,entry: Entry)) if $ has finiteAggregate
--R qsetelt! : (%,Key,Entry) -> Entry if $ has shallowlyMutable
--R reduce : ((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,
--R reduce : ((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,
--R reduce : ((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,
--R remove : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (Record(key: Key,entry: Entry),%) -> % if Record(key: Key,entry: Entry) has SETCAT
--R remove! : (Key,%) -> Union(Entry,"failed")
--R remove! : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R remove! : (Record(key: Key,entry: Entry),%) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if Record(key: Key,entry: Entry) has SETCAT and $ has finiteAggregate
--R search : (Key,%) -> Union(Entry,"failed")
--R select : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R select! : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R swap! : (%,Key,Key) -> Void if $ has shallowlyMutable
--R table : List(Record(key: Key,entry: Entry)) -> %
--R ~=? : (%,%) -> Boolean if Entry has SETCAT or Record(key: Key,entry: Entry) has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— TableAggregate.help —

=====

TableAggregate examples

=====

A table aggregate is a model of a table, i.e. a discrete many-to-one mapping from keys to entries.

See Also:

- o)show TableAggregate

See:

⇒ “AssociationListAggregate” (ALAGG) [10](#) on page [873](#)

⇐ “IndexedAggregate” (IXAGG) [5](#) on page [372](#)

⇐ “KeyedDictionary” (KDAGG) [8](#) on page [684](#)

Exports:

| | | | | |
|--------|----------|------------------|-----------|----------|
| any? | bag | coerce | construct | convert |
| copy | count | dictionary | elt | empty |
| empty? | entries | entry? | eq? | eval |
| every? | extract! | fill! | find | first |
| hash | index? | indices | insert! | inspect |
| key? | keys | latex | less? | map |
| map! | maxIndex | member? | members | minIndex |
| more? | parts | qelt | qsetelt! | reduce |
| remove | remove! | removeDuplicates | sample | search |
| select | select! | setelt | size? | swap! |
| table | #? | ?=? | ?.? | ?~=? |

Attributes exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **nil**

Attributes Used:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.

These are directly exported but not implemented:

```
setelt : (% ,Key,Entry) -> Entry
```

These are implemented by this category:

```
any? : ((Entry -> Boolean),%) -> Boolean
  if $ has finiteAggregate
coerce : % -> OutputForm
  if Entry has SETCAT
    or Record(key: Key,entry: Entry) has SETCAT
count : ((Entry -> Boolean),%) -> NonNegativeInteger
  if $ has finiteAggregate
elt : (% ,Key,Entry) -> Entry
entries : % -> List Entry
every? : ((Entry -> Boolean),%) -> Boolean
  if $ has finiteAggregate
extract! : % -> Record(key: Key,entry: Entry)
```

```

find :
  ((Record(key: Key,entry: Entry) -> Boolean),%)
  -> Union(Record(key: Key,entry: Entry),"failed")
index? : (Key,%) -> Boolean
indices : % -> List Key
insert! : (Record(key: Key,entry: Entry),%) -> %
inspect : % -> Record(key: Key,entry: Entry)
map : ((Entry,Entry) -> Entry),%,%) -> %
map : ((Record(key: Key,entry: Entry)
      -> Record(key: Key,entry: Entry)),%) -> %
map! : ((Entry -> Entry),%) -> % if $ has shallowlyMutable
map! :
  ((Record(key: Key,entry: Entry)
    -> Record(key: Key,entry: Entry)),%)
    -> % if $ has shallowlyMutable
parts : % -> List Entry if $ has finiteAggregate
parts : % -> List Record(key: Key,entry: Entry)
      if $ has finiteAggregate
remove! : (Key,%) -> Union(Entry,"failed")
table : () -> %
table : List Record(key: Key,entry: Entry) -> %
?.? : (%,Key) -> Entry
?=? : (%,%) -> Boolean
      if Entry has SETCAT
      or Record(key: Key,entry: Entry) has SETCAT

```

These exports come from (p684) `KeyedDictionary(Key,Entry)`
 where `Key:SetCategory` and `Entry:SetCategory`
 and `RecKE=Record(key: Key,entry: Entry)`:

```

any? : ((RecKE -> Boolean),%) -> Boolean
      if $ has finiteAggregate
bag : List RecKE -> %
construct : List RecKE -> %
convert : % -> InputForm if RecKE has KONVERT INFORM
copy : % -> %
count : (Entry,%) -> NonNegativeInteger
      if Entry has SETCAT
      and $ has finiteAggregate
count : ((RecKE -> Boolean),%) -> NonNegativeInteger
      if $ has finiteAggregate
dictionary : () -> %
dictionary : List RecKE -> %
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List RecKE,List RecKE) -> %
      if RecKE has EVALAB RecKE
      and RecKE has SETCAT
eval : (%,RecKE,RecKE) -> %

```

```

        if RecKE has EVALAB RecKE
        and RecKE has SETCAT
eval : (% ,Equation RecKE) -> %
        if RecKE has EVALAB RecKE
        and RecKE has SETCAT
eval : (% ,List Equation RecKE) -> %
        if RecKE has EVALAB RecKE
        and RecKE has SETCAT
every? : ((RecKE -> Boolean),%) -> Boolean
        if $ has finiteAggregate
key? : (Key,%) -> Boolean
keys : % -> List Key
hash : % -> SingleInteger
        if Entry has SETCAT
        or RecKE has SETCAT
latex : % -> String
        if Entry has SETCAT
        or RecKE has SETCAT
less? : (% ,NonNegativeInteger) -> Boolean
member? : (RecKE,%) -> Boolean
        if RecKE has SETCAT
        and $ has finiteAggregate
members : % -> List RecKE if $ has finiteAggregate
more? : (% ,NonNegativeInteger) -> Boolean
reduce :
    (((RecKE,RecKE) -> RecKE),%) -> RecKE
        if $ has finiteAggregate
reduce :
    (((RecKE,RecKE)->RecKE),%,RecKE) -> RecKE
        if $ has finiteAggregate
reduce :
    (((RecKE,RecKE)->RecKE),%,RecKE,RecKE)
    -> RecKE
        if RecKE has SETCAT
        and $ has finiteAggregate
remove : ((RecKE -> Boolean),%) -> %
        if $ has finiteAggregate
remove : (RecKE,%) -> %
        if RecKE has SETCAT
        and $ has finiteAggregate
remove! : ((RecKE -> Boolean),%) -> %
        if $ has finiteAggregate
remove! : (RecKE,%) -> % if $ has finiteAggregate
removeDuplicates : % -> %
        if RecKE has SETCAT
        and $ has finiteAggregate
sample : () -> %
search : (Key,%) -> Union(Entry,"failed")
select : ((RecKE -> Boolean),%) -> %
        if $ has finiteAggregate

```



```

select! : ((RecKE -> Boolean),%) -> %
    if $ has finiteAggregate
#? : % -> NonNegativeInteger if $ has finiteAggregate
?~=? : (%,%) -> Boolean
    if Entry has SETCAT
    or RecKE has SETCAT

```

These exports come from (p372) IndexedAggregate(Key,Entry))
 where Key:SetCategory and Entry:SetCategory
 and RecKE=Record(key: Key,entry: Entry):

```

count : (RecKE,%) -> NonNegativeInteger
    if RecKE has SETCAT
    and $ has finiteAggregate
entry? : (Entry,%) -> Boolean
    if $ has finiteAggregate
    and Entry has SETCAT
eval : (%,List Equation Entry) -> %
    if Entry has EVALAB Entry
    and Entry has SETCAT
eval : (%,Equation Entry) -> %
    if Entry has EVALAB Entry
    and Entry has SETCAT
eval : (%,Entry,Entry) -> %
    if Entry has EVALAB Entry
    and Entry has SETCAT
eval : (%,List Entry,List Entry) -> %
    if Entry has EVALAB Entry
    and Entry has SETCAT
fill! : (%,Entry) -> % if $ has shallowlyMutable
first : % -> Entry if Key has ORDSET
map : ((Entry -> Entry),%) -> %
maxIndex : % -> Key if Key has ORDSET
member? : (Entry,%) -> Boolean
    if Entry has SETCAT
    and $ has finiteAggregate
members : % -> List Entry if $ has finiteAggregate
minIndex : % -> Key if Key has ORDSET
qelt : (%,Key) -> Entry
qsetelt! : (%,Key,Entry) -> Entry if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
swap! : (%,Key,Key) -> Void if $ has shallowlyMutable

```

— category TBAGG TableAggregate —

```

)abbrev category TBAGG TableAggregate
++ Author: Michael Monagan, Stephen Watt;
++ revised by Manuel Bronstein and Richard Jenks

```

```

++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ A table aggregate is a model of a table, that is, a discrete many-to-one
++ mapping from keys to entries.

TableAggregate(Key:SetCategory, Entry:SetCategory): Category ==
  Join(KeyedDictionary(Key,Entry),IndexedAggregate(Key,Entry)) with

  setelt: (%,Key,Entry) -> Entry          -- setelt_! later
  ++ setelt(t,k,e) (also written \axiom{t.k := e}) is equivalent
  ++ to \axiom{(insert([k,e],t); e)}.

table: () -> %
  ++table()$T creates an empty table of type T.
  ++
  ++E Data:=Record(age:Integer,gender:String)
  ++E a1:AssociationList(String,Data):=table()
  ++E a1."tim" := [55,"male"]$Data

table: List Record(key:Key,entry:Entry) -> %
  ++ table([x,y,...,z]) creates a table consisting of entries
  ++ \axiom{x,y,...,z}.

-- to become table: Record(key:Key,entry:Entry)* -> %

map: ((Entry, Entry) -> Entry, %, %) -> %
  ++ map(fn,t1,t2) creates a new table t from given tables t1 and t2 with
  ++ elements fn(x,y) where x and y are corresponding elements from t1
  ++ and t2 respectively.

add
  table()          == empty()
  table l          == dictionary l
-- empty()         == dictionary()

insert_!(p, t)     == (t(p.key) := p.entry; t)
indices t          == keys t

coerce(t:%):OutputForm ==
  prefix("table":OutputForm,
    [k:OutputForm = (t.k)::OutputForm for k in keys t])

elt(t, k) ==
  (r := search(k, t)) case Entry => r::Entry
  error "key not in table"

elt(t, k, e) ==
  (r := search(k, t)) case Entry => r::Entry
  e

```

```

map_!(f, t) ==
  for k in keys t repeat t.k := f t.k
  t

map(f:(Entry, Entry) -> Entry, s:%, t:%) ==
  z := table()
  for k in keys s | key?(k, t) repeat z.k := f(s.k, t.k)
  z

-- map(f, s, t, x) ==
--   z := table()
--   for k in keys s repeat z.k := f(s.k, t(k, x))
--   for k in keys t | not key?(k, s) repeat z.k := f(t.k, x)
--   z

if % has finiteAggregate then
  parts(t:%):List Record(key:Key,entry:Entry) ==
    [[k, t.k] for k in keys t]
  parts(t:%):List Entry == [t.k for k in keys t]
  entries(t:%):List Entry == parts(t)

s:% = t:% ==
  eq?(s,t) => true
  #s ^= #t => false
  for k in keys s repeat
    (e := search(k, t)) _
    case "failed" or (e::Entry) ^= s.k => return false
  true

map(f: Record(key:Key,entry:Entry)->Record(key:Key,entry:Entry),t:%):%==
  z := table()
  for k in keys t repeat
    ke: Record(key:Key,entry:Entry) := f [k, t.k]
    z ke.key := ke.entry
  z
map_!(f:Record(key:Key,entry:Entry)->Record(key:Key,entry:Entry),t:%):%_
==
  lke: List Record(key:Key,entry:Entry) := nil()
  for k in keys t repeat
    lke := cons(f [k, remove_!(k,t)::Entry], lke)
  for ke in lke repeat
    t ke.key := ke.entry
  t

inspect(t: %): Record(key:Key,entry:Entry) ==
  ks := keys t
  empty? ks => error "Cannot extract from an empty aggregate"
  [first ks, t first ks]

find(f: Record(key:Key,entry:Entry)->Boolean, t:%):_

```

```

    Union(Record(key:Key,entry:Entry), "failed") ==
    for ke in parts(t)@List(Record(key:Key,entry:Entry)) _
        repeat if f ke then return ke
    "failed"

index?(k: Key, t: %): Boolean ==
    search(k,t) case Entry

remove_!(x:Record(key:Key,entry:Entry), t:%) ==
    if member?(x, t) then remove_!(x.key, t)
    t
extract_!(t: %): Record(key:Key,entry:Entry) ==
    k: Record(key:Key,entry:Entry) := inspect t
    remove_!(k.key, t)
    k

any?(f: Entry->Boolean, t: %): Boolean ==
    for k in keys t | f t k repeat return true
    false
every?(f: Entry->Boolean, t: %): Boolean ==
    for k in keys t | not f t k repeat return false
    true
count(f: Entry->Boolean, t: %): NonNegativeInteger ==
    tally: NonNegativeInteger := 0
    for k in keys t | f t k repeat tally := tally + 1
    tally

```

— TBAGG.dotabb —

```

"TBAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=TBAGG"];
"TBAGG" -> "KDAGG"
"TBAGG" -> "IXAGG"

```

— TBAGG.dotfull —

```

"TableAggregate(a:SetCategory,b:SetCategory)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=TBAGG"];
"TableAggregate(a:SetCategory,b:SetCategory)" ->
    "KeyedDictionary(a:SetCategory,b:SetCategory)"
"TableAggregate(a:SetCategory,b:SetCategory)" ->
    "IndexedAggregate(a:SetCategory,b:SetCategory)"

```

— TBAGG.dotpic —

```

digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "TableAggregate(a:SetCategory,b:SetCategory)" [color=lightblue];
    "TableAggregate(a:SetCategory,b:SetCategory)" ->
        "KeyedDictionary(a:SetCategory,b:SetCategory)"
    "TableAggregate(a:SetCategory,b:SetCategory)" ->
        "IndexedAggregate(a:SetCategory,b:SetCategory)"

    "IndexedAggregate(a:SetCategory,b:SetCategory)" [color=seagreen];
    "IndexedAggregate(a:SetCategory,b:SetCategory)" ->
        "IndexedAggregate(a:SetCategory,b:Type)"

    "IndexedAggregate(a:SetCategory,b:Type)" [color=lightblue];
    "IndexedAggregate(a:SetCategory,b:Type)" -> "HOAGG..."
    "IndexedAggregate(a:SetCategory,b:Type)" -> "ELTAGG..."

    "KeyedDictionary(a:SetCategory,b:SetCategory)" [color=lightblue];
    "KeyedDictionary(a:SetCategory,b:SetCategory)" ->
        "Dictionary(Record(a:SetCategory,b:SetCategory))"

    "Dictionary(Record(a:SetCategory,b:SetCategory))" [color=seagreen];
    "Dictionary(Record(a:SetCategory,b:SetCategory))" ->
        "Dictionary(a:SetCategory)"

    "Dictionary(a:SetCategory)" [color=lightblue];
    "Dictionary(a:SetCategory)" -> "DictionaryOperations(a:SetCategory)"

    "DictionaryOperations(a:SetCategory)" [color=lightblue];
    "DictionaryOperations(a:SetCategory)" -> "BagAggregate(a:SetCategory)"
    "DictionaryOperations(a:SetCategory)" -> "Collection(a:SetCategory)"

    "BagAggregate(a:SetCategory)" [color=seagreen];
    "BagAggregate(a:SetCategory)" -> "BagAggregate(a:Type)"

    "BagAggregate(a:Type)" [color=lightblue];
    "BagAggregate(a:Type)" -> "HOAGG..."

    "Collection(a:SetCategory)" [color=seagreen];
    "Collection(a:SetCategory)" -> "Collection(a:Type)"

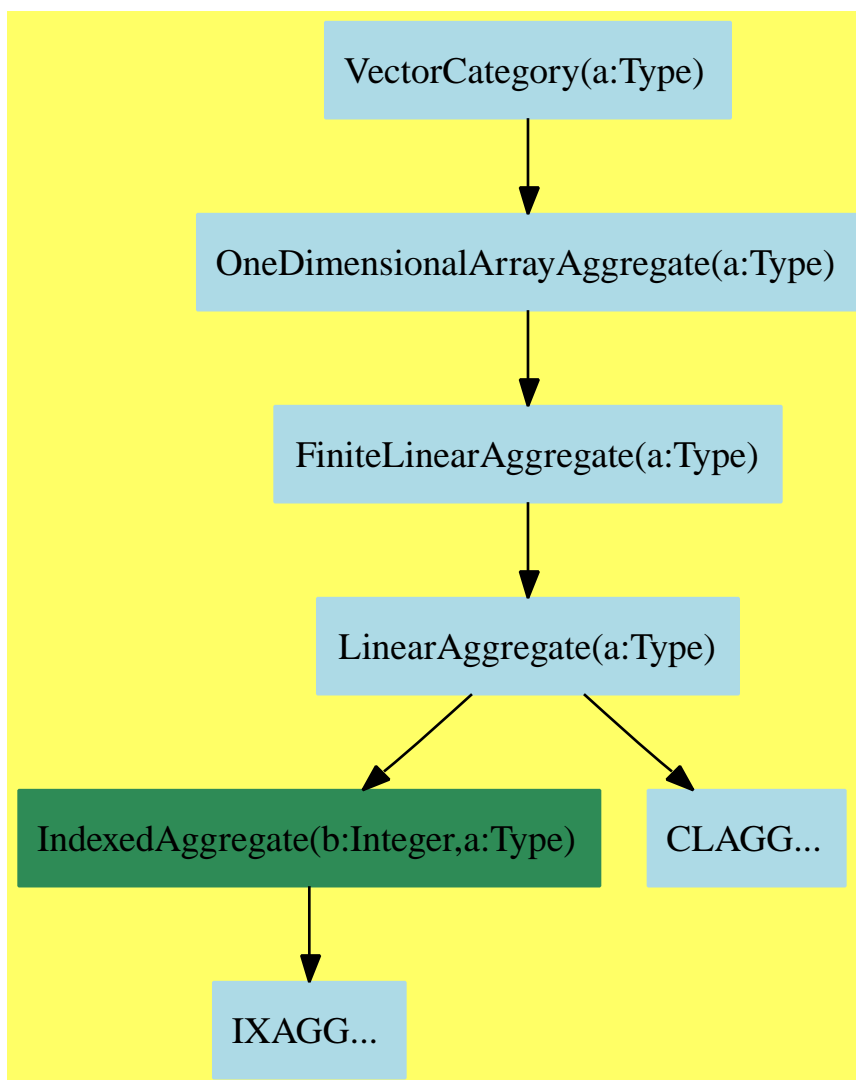
    "Collection(a:Type)" [color=lightblue];
    "Collection(a:Type)" -> "HOAGG..."

```

```
"ELTAGG..." [color=lightblue];  
"HOAGG..." [color=lightblue];  
}
```

—————→

VectorCategory (VECTCAT)



— VectorCategory.input —

```

)set break resume
)sys rm -f VectorCategory.output
)spool VectorCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show VectorCategory
--R
--R VectorCategory(R: Type) is a category constructor
--R Abbreviation for VectorCategory is VECTCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for VECTCAT
--R
--R----- Operations -----
--R -? : % -> % if R has ABELGRP          concat : List(%) -> %
--R concat : (%,%) -> %                  concat : (R,%) -> %
--R concat : (%,R) -> %                  construct : List(R) -> %
--R copy : % -> %                        delete : (%,Integer) -> %
--R ?? : (%,Integer) -> R                elt : (%,Integer,R) -> R
--R empty : () -> %                     empty? : % -> Boolean
--R entries : % -> List(R)               eq? : (%,%) -> Boolean
--R index? : (Integer,%) -> Boolean       indices : % -> List(Integer)
--R insert : (%,%,Integer) -> %          insert : (R,%,Integer) -> %
--R map : ((R,R) -> R),%,%) -> %         map : ((R -> R),%) -> %
--R new : (NonNegativeInteger,R) -> %    qelt : (%,Integer) -> R
--R reverse : % -> %                     sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?? : (%,R) -> % if R has MONOID
--R ?? : (R,%) -> % if R has MONOID
--R ?? : (Integer,%) -> % if R has ABELGRP
--R ?+? : (%,%) -> % if R has ABELSG
--R ?-? : (%,%) -> % if R has ABELGRP
--R ?<? : (%,%) -> Boolean if R has ORDSET
--R ?<=? : (%,%) -> Boolean if R has ORDSET
--R ?=? : (%,%) -> Boolean if R has SETCAT
--R ?>? : (%,%) -> Boolean if R has ORDSET
--R ?>=? : (%,%) -> Boolean if R has ORDSET
--R any? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if R has SETCAT
--R convert : % -> InputForm if R has KONVERT(INFORM)
--R copyInto! : (%,%,Integer) -> % if $ has shallowlyMutable
--R count : (R,%) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
--R count : ((R -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R cross : (%,%) -> % if R has RING
--R delete : (%,UniversalSegment(Integer)) -> %

```

```

--R dot : (%,%) -> R if R has RING
--R ?.? : (%,UniversalSegment(Integer)) -> %
--R entry? : (R,%) -> Boolean if $ has finiteAggregate and R has SETCAT
--R eval : (%,List(R),List(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,R,R) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,Equation(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,List(Equation(R))) -> % if R has EVALAB(R) and R has SETCAT
--R every? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (%,R) -> % if $ has shallowlyMutable
--R find : ((R -> Boolean),%) -> Union(R,"failed")
--R first : % -> R if Integer has ORDSET
--R hash : % -> SingleInteger if R has SETCAT
--R latex : % -> String if R has SETCAT
--R length : % -> R if R has RING and R has RADCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R magnitude : % -> R if R has RING and R has RADCAT
--R map! : ((R -> R),%) -> % if $ has shallowlyMutable
--R max : (%,%) -> % if R has ORDSET
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (R,%) -> Boolean if R has SETCAT and $ has finiteAggregate
--R members : % -> List(R) if $ has finiteAggregate
--R merge : (%,%) -> % if R has ORDSET
--R merge : ((R,R) -> Boolean),%,%) -> %
--R min : (%,%) -> % if R has ORDSET
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (%,NonNegativeInteger) -> Boolean
--R outerProduct : (%,%) -> Matrix(R) if R has RING
--R parts : % -> List(R) if $ has finiteAggregate
--R position : (R,%,Integer) -> Integer if R has SETCAT
--R position : (R,%) -> Integer if R has SETCAT
--R position : ((R -> Boolean),%) -> Integer
--R qsetelt! : (%,Integer,R) -> R if $ has shallowlyMutable
--R reduce : ((R,R) -> R),%) -> R if $ has finiteAggregate
--R reduce : ((R,R) -> R),%,R) -> R if $ has finiteAggregate
--R reduce : ((R,R) -> R),%,R,R) -> R if R has SETCAT and $ has finiteAggregate
--R remove : ((R -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (R,%) -> % if R has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if R has SETCAT and $ has finiteAggregate
--R reverse! : % -> % if $ has shallowlyMutable
--R select : ((R -> Boolean),%) -> % if $ has finiteAggregate
--R setelt : (%,UniversalSegment(Integer),R) -> R if $ has shallowlyMutable
--R setelt : (%,Integer,R) -> R if $ has shallowlyMutable
--R size? : (%,NonNegativeInteger) -> Boolean
--R sort : % -> % if R has ORDSET
--R sort : ((R,R) -> Boolean),%) -> %
--R sort! : % -> % if R has ORDSET and $ has shallowlyMutable
--R sort! : ((R,R) -> Boolean),%) -> % if $ has shallowlyMutable
--R sorted? : % -> Boolean if R has ORDSET
--R sorted? : ((R,R) -> Boolean),%) -> Boolean
--R swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable

```



```

--R zero : NonNegativeInteger -> % if R has ABELMON
--R ?~=? : (%,% ) -> Boolean if R has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— VectorCategory.help —

=====

VectorCategory examples

=====

VectorCategory represents the type of vector like objects, i.e. finite sequences indexed by some finite segment of the integers. The operations available on vectors depend on the structure of the underlying components. Many operations from the component domain are defined for vectors componentwise. It can be assumed that extraction or updating components can be done in constant time.

See Also:

- o)show VectorCategory

See:

⇒ “PointCategory” (PTCAT) [10](#) on page [946](#)
 ⇐ “OneDimensionalArrayAggregate” (A1AGG) [8](#) on page [739](#)

Exports:

| | | | | |
|----------|--------------|---------|------------------|-----------|
| any? | coerce | concat | construct | convert |
| copy | copyInto! | count | cross | delete |
| dot | entry? | elt | empty | empty? |
| entries | eq? | eval | every? | fill! |
| find | first | hash | index? | indices |
| insert | latex | length | less? | magnitude |
| map | map! | max | maxIndex | member? |
| members | merge | min | minIndex | more? |
| new | outerProduct | parts | position | qelt |
| qsetelt! | reduce | remove | removeDuplicates | reverse |
| reverse! | sample | select | setelt | size? |
| sort | sort! | sorted? | swap! | zero |
| #? | ?* | ?+? | ?-? | ?<? |
| ?<=? | ?=? | ?>? | ?>=? | -? |
| ?..? | ?~=? | | | |

Attributes Exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.

These are implemented by this category:

```

cross : (%,% ) -> % if R has RING
dot : (%,% ) -> R if R has RING
length : % -> R if R has RING and R has RADCAT
magnitude : % -> R if R has RING and R has RADCAT
outerProduct : (%,% ) -> Matrix R if R has RING
zero : NonNegativeInteger -> % if R has ABELMON
?*? : (Integer,% ) -> % if R has ABELGRP
?*? : (% ,R) -> % if R has MONOID
?*? : (R,% ) -> % if R has MONOID
?-? : (% ,% ) -> % if R has ABELGRP
-? : % -> % if R has ABELGRP
?+? : (% ,% ) -> % if R has ABELSG

```

These exports come from (p739) `OneDimensionalArrayAggregate(R:Type)`:

```

any? : ((R -> Boolean),% ) -> Boolean if $ has finiteAggregate
coerce : % -> OutputForm if R has SETCAT
concat : (R,% ) -> %
concat : (% ,R) -> %
concat : List % -> %
concat : (% ,% ) -> %
construct : List R -> %
convert : % -> InputForm if R has KONVERT INFORM

```

```

copy : % -> %
copyInto! : (%,%,Integer) -> % if $ has shallowlyMutable
count : ((R -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
count : (R,%) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
delete : (%,Integer) -> %
delete : (%UniversalSegment Integer) -> %
elt : (%Integer,R) -> R
empty : () -> %
empty? : % -> Boolean
entries : % -> List R
entry? : (R,%) -> Boolean if $ has finiteAggregate and R has SETCAT
eq? : (%,%)-> Boolean
eval : (%List R,List R) -> % if R has EVALAB R and R has SETCAT
eval : (%R,R) -> % if R has EVALAB R and R has SETCAT
eval : (%Equation R) -> % if R has EVALAB R and R has SETCAT
eval : (%List Equation R) -> % if R has EVALAB R and R has SETCAT
every? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
fill! : (%R) -> % if $ has shallowlyMutable
find : ((R -> Boolean),%) -> Union(R,"failed")
first : % -> R if Integer has ORDSET
hash : % -> SingleInteger if R has SETCAT
index? : (Integer,%) -> Boolean
indices : % -> List Integer
insert : (%,%Integer) -> %
insert : (R,%Integer) -> %
latex : % -> String if R has SETCAT
less? : (%NonNegativeInteger) -> Boolean
map : ((R -> R),%) -> %
map : (((R,R) -> R),%,%) -> %
map! : ((R -> R),%) -> % if $ has shallowlyMutable
max : (%,%)-> % if R has ORDSET
maxIndex : % -> Integer if Integer has ORDSET
member? : (R,%) -> Boolean if R has SETCAT and $ has finiteAggregate
members : % -> List R if $ has finiteAggregate
merge : (%,%)-> % if R has ORDSET
merge : (((R,R) -> Boolean),%,%) -> %
min : (%,%)-> % if R has ORDSET
minIndex : % -> Integer if Integer has ORDSET
more? : (%NonNegativeInteger) -> Boolean
new : (NonNegativeInteger,R) -> %
parts : % -> List R if $ has finiteAggregate
position : (R,%) -> Integer if R has SETCAT
position : ((R -> Boolean),%) -> Integer
position : (R,%Integer) -> Integer if R has SETCAT
qelt : (%Integer) -> R
qsetelt! : (%Integer,R) -> R if $ has shallowlyMutable
reduce : (((R,R) -> R),%,%) -> R if $ has finiteAggregate
reduce : (((R,R) -> R),%,R) -> R if $ has finiteAggregate
reduce : (((R,R) -> R),%,R,R) -> R if R has SETCAT and $ has finiteAggregate
remove : ((R -> Boolean),%) -> % if $ has finiteAggregate

```

```

remove : (R,%) -> % if R has SETCAT and $ has finiteAggregate
removeDuplicates : % -> % if R has SETCAT and $ has finiteAggregate
reverse : % -> %
reverse! : % -> % if $ has shallowlyMutable
sample : () -> %
select : ((R -> Boolean),%) -> % if $ has finiteAggregate
setelt : (%,Integer,R) -> R if $ has shallowlyMutable
setelt : (%,UniversalSegment Integer,R) -> R if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
sort : % -> % if R has ORDSET
sort : ((R,R) -> Boolean),% -> %
sort! : % -> % if R has ORDSET and $ has shallowlyMutable
sort! : ((R,R) -> Boolean),% -> % if $ has shallowlyMutable
sorted? : % -> Boolean if R has ORDSET
sorted? : ((R,R) -> Boolean),% -> Boolean
swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable
#? : % -> NonNegativeInteger if $ has finiteAggregate
?.? : (%,Integer) -> R
?.? : (%,UniversalSegment Integer) -> %
?? : (%,%) -> Boolean if R has SETCAT
?<? : (%,%) -> Boolean if R has ORDSET
?<=? : (%,%) -> Boolean if R has ORDSET
?>? : (%,%) -> Boolean if R has ORDSET
?>=? : (%,%) -> Boolean if R has ORDSET
?~=? : (%,%) -> Boolean if R has SETCAT

```

— category VECTCAT VectorCategory —

```

)abbrev category VECTCAT VectorCategory
++ Description:
++ \spadtype{VectorCategory} represents the type of vector like objects,
++ that is, finite sequences indexed by some finite segment of the
++ integers. The operations available on vectors depend on the structure
++ of the underlying components. Many operations from the component domain
++ are defined for vectors componentwise. It can be assumed that extraction or
++ updating components can be done in constant time.

```

```

VectorCategory(R:Type): Category == OneDimensionalArrayAggregate R with

```

```

  if R has AbelianSemiGroup then

```

```

    _+ : (%, %) -> %
    ++ x + y returns the component-wise sum of the vectors x and y.
    ++ Error: if x and y are not of the same length.

```

```

  if R has AbelianMonoid then

```

```

    zero: NonNegativeInteger -> %
    ++ zero(n) creates a zero vector of length n.

```

```

if R has AbelianGroup then

  _- : % -> %
  ++ -x negates all components of the vector x.

  _- : (% , %) -> %
  ++ x - y returns the component-wise difference of the vectors x and y.
  ++ Error: if x and y are not of the same length.

  _* : (Integer, %) -> %
  ++ n * y multiplies each component of the vector y by the integer n.

if R has Monoid then

  _* : (R, %) -> %
  ++ r * y multiplies the element r times each component of the vector y.

  _* : (% , R) -> %
  ++ y * r multiplies each component of the vector y by the element r.

if R has Ring then

  dot: (% , %) -> R
  ++ dot(x,y) computes the inner product of the two vectors x and y.
  ++ Error: if x and y are not of the same length.

  outerProduct: (% , %) -> Matrix R
  ++ outerProduct(u,v) constructs the matrix whose (i,j)'th element is
  ++ u(i)*v(j).

  cross: (% , %) -> %
  ++ cross(u,v) constructs the cross product of u and v.
  ++ Error: if u and v are not of length 3.

if R has RadicalCategory and R has Ring then

  length: % -> R
  ++ length(v) computes the sqrt(dot(v,v)), that is, the magnitude

  magnitude: % -> R
  ++ magnitude(v) computes the sqrt(dot(v,v)), that is, the length
add

if R has AbelianSemiGroup then

  u + v ==
  (n := #u) ^= #v => error "Vectors must be of the same length"
  map(_+ , u, v)

```

```

if R has AbelianMonoid then

  zero n == new(n, 0)

if R has AbelianGroup then

  - u          == map(x +-> -x, u)

  n:Integer * u:% == map(x +-> n * x, u)

  u - v        == u + (-v)

if R has Monoid then

  u:% * r:R      == map(x +-> x * r, u)

  r:R * u:%      == map(x +-> r * x, u)

if R has Ring then

  dot(u, v) ==
    #u ^= #v => error "Vectors must be of the same length"
    _+/[qelt(u, i) * qelt(v, i) for i in minIndex u .. maxIndex u]

  outerProduct(u, v) ==
    matrix [[qelt(u, i) * qelt(v, j) for i in minIndex u .. maxIndex u] _
            for j in minIndex v .. maxIndex v]

  cross(u, v) ==
    #u ^= 3 or #v ^= 3 => error "Vectors must be of length 3"
    construct [qelt(u, 2)*qelt(v, 3) - qelt(u, 3)*qelt(v, 2) , _
              qelt(u, 3)*qelt(v, 1) - qelt(u, 1)*qelt(v, 3) , _
              qelt(u, 1)*qelt(v, 2) - qelt(u, 2)*qelt(v, 1) ]

if R has RadicalCategory and R has Ring then

  length p ==
    sqrt(dot(p,p))

  magnitude p ==
    sqrt(dot(p,p))

  _____

  — VECTCAT.dotabb —

"VECTCAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=VECTCAT" ];

```

"VECTCAT" -> "A1AGG"

— VECTCAT.dotfull —

```
"VectorCategory(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=VECTCAT"];
"VectorCategory(a:Type)" -> "OneDimensionalArrayAggregate(a:Type)"

"VectorCategory(a:Ring)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=VECTCAT"];
"VectorCategory(a:Ring)" -> "VectorCategory(a:Type)"
```

— VECTCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "VectorCategory(a:Type)" [color=lightblue];
  "VectorCategory(a:Type)" -> "OneDimensionalArrayAggregate(a:Type)"

  "OneDimensionalArrayAggregate(a:Type)" [color=lightblue];
  "OneDimensionalArrayAggregate(a:Type)" ->
    "FiniteLinearAggregate(a:Type)"

  "FiniteLinearAggregate(a:Type)" [color=lightblue];
  "FiniteLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"

  "LinearAggregate(a:Type)" [color=lightblue];
  "LinearAggregate(a:Type)" -> "IndexedAggregate(b:Integer,a:Type)"
  "LinearAggregate(a:Type)" -> "CLAGG..."

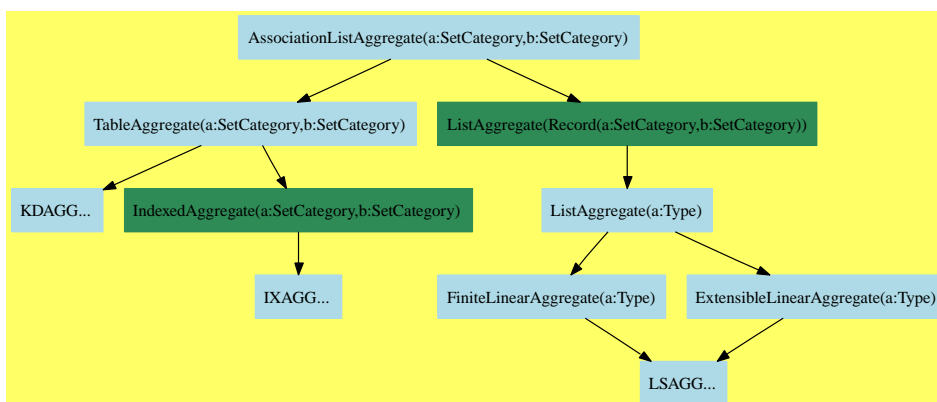
  "IndexedAggregate(b:Integer,a:Type)" [color=seagreen];
  "IndexedAggregate(b:Integer,a:Type)" -> "IXAGG..."

  "CLAGG..." [color=lightblue];
  "IXAGG..." [color=lightblue];
}
```

Chapter 10

Category Layer 9

AssociationListAggregate (ALAGG)



— AssociationListAggregate.input —

```
)set break resume
)sys rm -f AssociationListAggregate.output
)spool AssociationListAggregate.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show AssociationListAggregate
--R
--R AssociationListAggregate(Key: SetCategory,Entry: SetCategory) is a category constructor
--R Abbreviation for AssociationListAggregate is ALAGG
```



```

--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ALAGG
--R
--R----- Operations -----
--R children : % -> List(%)
--R concat : List(%) -> %
--R copy : % -> %
--R cycleTail : % -> %
--R delete : (%,Integer) -> %
--R dictionary : () -> %
--R ?.rest : (%,rest) -> %
--R ?? : (%,Key) -> Entry
--R empty? : % -> Boolean
--R eq? : (%,%) -> Boolean
--R index? : (Integer,%) -> Boolean
--R indices : % -> List(Integer)
--R insert : (%,%,Integer) -> %
--R key? : (Key,%) -> Boolean
--R leaf? : % -> Boolean
--R nodes : % -> List(%)
--R qelt : (%,Key) -> Entry
--R reverse : % -> %
--R setelt : (%,Key,Entry) -> Entry
--R tail : % -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?<? : (%,%) -> Boolean if Record(key: Key,entry: Entry) has ORDSET
--R ?<=? : (%,%) -> Boolean if Record(key: Key,entry: Entry) has ORDSET
--R ?=? : (%,%) -> Boolean if Record(key: Key,entry: Entry) has SETCAT or Entry has SETCAT or Re
--R ?>? : (%,%) -> Boolean if Record(key: Key,entry: Entry) has ORDSET
--R ?>=? : (%,%) -> Boolean if Record(key: Key,entry: Entry) has ORDSET
--R any? : ((Record(key: Key,entry: Entry) -> Boolean),%) -> Boolean if $ has finiteAggregate
--R any? : ((Entry -> Boolean),%) -> Boolean if $ has finiteAggregate
--R any? : ((Record(key: Key,entry: Entry) -> Boolean),%) -> Boolean if $ has finiteAggregate
--R assoc : (Key,%) -> Union(Record(key: Key,entry: Entry),"failed")
--R bag : List(Record(key: Key,entry: Entry)) -> %
--R child? : (%,%) -> Boolean if Record(key: Key,entry: Entry) has SETCAT
--R coerce : % -> OutputForm if Record(key: Key,entry: Entry) has SETCAT or Entry has SETCAT or
--R concat : (Record(key: Key,entry: Entry),%) -> %
--R concat : (%,Record(key: Key,entry: Entry)) -> %
--R concat! : (%,Record(key: Key,entry: Entry)) -> %
--R construct : List(Record(key: Key,entry: Entry)) -> %
--R construct : List(Record(key: Key,entry: Entry)) -> %
--R convert : % -> InputForm if Record(key: Key,entry: Entry) has KONVERT(INFORM) or Record(key:
--R copyInto! : (%,%,Integer) -> % if $ has shallowlyMutable
--R count : ((Record(key: Key,entry: Entry) -> Boolean),%) -> NonNegativeInteger if $ has finite
--R count : (Record(key: Key,entry: Entry),%) -> NonNegativeInteger if Record(key: Key,entry: En
--R count : ((Entry -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R count : (Entry,%) -> NonNegativeInteger if Entry has SETCAT and $ has finiteAggregate
--R count : (Record(key: Key,entry: Entry),%) -> NonNegativeInteger if Record(key: Key,entry: En
--R count : ((Record(key: Key,entry: Entry) -> Boolean),%) -> NonNegativeInteger if $ has finite

```

```

--R cycleLength : % -> NonNegativeInteger
--R cycleSplit! : % -> % if $ has shallowlyMutable
--R delete : (% , UniversalSegment(Integer)) -> %
--R delete! : (% , UniversalSegment(Integer)) -> %
--R dictionary : List(Record(key: Key, entry: Entry)) -> %
--R ?.value : (% , value) -> Record(key: Key, entry: Entry)
--R ?.first : (% , first) -> Record(key: Key, entry: Entry)
--R ?.last : (% , last) -> Record(key: Key, entry: Entry)
--R ?.? : (% , UniversalSegment(Integer)) -> %
--R ?.? : (% , Integer) -> Record(key: Key, entry: Entry)
--R elt : (% , Integer, Record(key: Key, entry: Entry)) -> Record(key: Key, entry: Entry)
--R entries : % -> List(Record(key: Key, entry: Entry))
--R entry? : (Record(key: Key, entry: Entry), %) -> Boolean if $ has finiteAggregate and Record(key: Key, entry: Entry)
--R entry? : (Entry, %) -> Boolean if $ has finiteAggregate and Entry has SETCAT
--R eval : (% , List(Equation(Record(key: Key, entry: Entry)))) -> % if Record(key: Key, entry: Entry) has EVALAB(Record(key: Key, entry: Entry))
--R eval : (% , Equation(Record(key: Key, entry: Entry))) -> % if Record(key: Key, entry: Entry) has EVALAB(Record(key: Key, entry: Entry))
--R eval : (% , Record(key: Key, entry: Entry), Record(key: Key, entry: Entry)) -> % if Record(key: Key, entry: Entry) has EVALAB(Record(key: Key, entry: Entry))
--R eval : (% , List(Record(key: Key, entry: Entry)), List(Record(key: Key, entry: Entry))) -> % if Record(key: Key, entry: Entry) has EVALAB(Record(key: Key, entry: Entry))
--R eval : (% , List(Equation(Entry))) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% , Equation(Entry)) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% , Entry, Entry) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% , List(Entry), List(Entry)) -> % if Entry has EVALAB(Entry) and Entry has SETCAT
--R eval : (% , List(Record(key: Key, entry: Entry)), List(Record(key: Key, entry: Entry))) -> % if Record(key: Key, entry: Entry) has EVALAB(Record(key: Key, entry: Entry))
--R eval : (% , Record(key: Key, entry: Entry), Record(key: Key, entry: Entry)) -> % if Record(key: Key, entry: Entry) has EVALAB(Record(key: Key, entry: Entry))
--R eval : (% , Equation(Record(key: Key, entry: Entry))) -> % if Record(key: Key, entry: Entry) has EVALAB(Record(key: Key, entry: Entry))
--R eval : (% , List(Equation(Record(key: Key, entry: Entry)))) -> % if Record(key: Key, entry: Entry) has EVALAB(Record(key: Key, entry: Entry))
--R every? : ((Record(key: Key, entry: Entry) -> Boolean), %) -> Boolean if $ has finiteAggregate
--R every? : ((Entry -> Boolean), %) -> Boolean if $ has finiteAggregate
--R every? : ((Record(key: Key, entry: Entry) -> Boolean), %) -> Boolean if $ has finiteAggregate
--R extract! : % -> Record(key: Key, entry: Entry)
--R fill! : (% , Record(key: Key, entry: Entry)) -> % if $ has shallowlyMutable
--R fill! : (% , Entry) -> % if $ has shallowlyMutable
--R find : ((Record(key: Key, entry: Entry) -> Boolean), %) -> Union(Record(key: Key, entry: Entry), "failed")
--R find : ((Record(key: Key, entry: Entry) -> Boolean), %) -> Union(Record(key: Key, entry: Entry), "failed")
--R first : % -> Record(key: Key, entry: Entry)
--R first : (% , NonNegativeInteger) -> %
--R first : % -> Entry if Key has ORDSET
--R hash : % -> SingleInteger if Record(key: Key, entry: Entry) has SETCAT or Entry has SETCAT or Record(key: Key, entry: Entry) has SETCAT
--R insert : (Record(key: Key, entry: Entry), % , Integer) -> %
--R insert! : (Record(key: Key, entry: Entry), % , Integer) -> %
--R insert! : (Record(key: Key, entry: Entry), %) -> %
--R inspect : % -> Record(key: Key, entry: Entry)
--R last : % -> Record(key: Key, entry: Entry)
--R last : (% , NonNegativeInteger) -> %
--R latex : % -> String if Record(key: Key, entry: Entry) has SETCAT or Entry has SETCAT or Record(key: Key, entry: Entry) has SETCAT
--R leaves : % -> List(Record(key: Key, entry: Entry))
--R less? : (% , NonNegativeInteger) -> Boolean
--R list : Record(key: Key, entry: Entry) -> %
--R map : ((Record(key: Key, entry: Entry) -> Record(key: Key, entry: Entry)), %) -> %
--R map : (((Record(key: Key, entry: Entry), Record(key: Key, entry: Entry)) -> Record(key: Key, entry: Entry)), %) -> %

```

```

--R map : (((Entry,Entry) -> Entry),%,%) -> %
--R map : ((Record(key: Key,entry: Entry) -> Record(key: Key,entry: Entry)),%) -> %
--R map! : ((Record(key: Key,entry: Entry) -> Record(key: Key,entry: Entry)),%) -> % if $ has shallowlyMutable
--R map! : ((Entry -> Entry),%) -> % if $ has shallowlyMutable
--R map! : ((Record(key: Key,entry: Entry) -> Record(key: Key,entry: Entry)),%) -> % if $ has shallowlyMutable
--R max : (%,%) -> % if Record(key: Key,entry: Entry) has ORDSET
--R maxIndex : % -> Integer if Integer has ORDSET
--R maxIndex : % -> Key if Key has ORDSET
--R member? : (Record(key: Key,entry: Entry),%) -> Boolean if Record(key: Key,entry: Entry) has SETCAT
--R member? : (Entry,%) -> Boolean if Entry has SETCAT and $ has finiteAggregate
--R member? : (Record(key: Key,entry: Entry),%) -> Boolean if Record(key: Key,entry: Entry) has SETCAT
--R members : % -> List(Record(key: Key,entry: Entry)) if $ has finiteAggregate
--R members : % -> List(Entry) if $ has finiteAggregate
--R members : % -> List(Record(key: Key,entry: Entry)) if $ has finiteAggregate
--R merge : (%,%) -> % if Record(key: Key,entry: Entry) has ORDSET
--R merge : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Boolean),%,%) -> %
--R merge! : (%,%) -> % if Record(key: Key,entry: Entry) has ORDSET
--R merge! : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Boolean),%,%) -> %
--R min : (%,%) -> % if Record(key: Key,entry: Entry) has ORDSET
--R minIndex : % -> Integer if Integer has ORDSET
--R minIndex : % -> Key if Key has ORDSET
--R more? : (%,NonNegativeInteger) -> Boolean
--R new : (NonNegativeInteger,Record(key: Key,entry: Entry)) -> %
--R node? : (%,%) -> Boolean if Record(key: Key,entry: Entry) has SETCAT
--R parts : % -> List(Record(key: Key,entry: Entry)) if $ has finiteAggregate
--R parts : % -> List(Entry) if $ has finiteAggregate
--R parts : % -> List(Record(key: Key,entry: Entry)) if $ has finiteAggregate
--R position : (Record(key: Key,entry: Entry),%,Integer) -> Integer if Record(key: Key,entry: Entry) has SETCAT
--R position : (Record(key: Key,entry: Entry),%) -> Integer if Record(key: Key,entry: Entry) has SETCAT
--R position : ((Record(key: Key,entry: Entry) -> Boolean),%) -> Integer
--R qelt : (%,Integer) -> Record(key: Key,entry: Entry)
--R qsetelt! : (%,Integer,Record(key: Key,entry: Entry)) -> Record(key: Key,entry: Entry) if $ has shallowlyMutable
--R qsetelt! : (%,Key,Entry) -> Entry if $ has shallowlyMutable
--R reduce : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,entry: Entry)),%,%) -> %
--R reduce : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,entry: Entry)),%,%) -> %
--R reduce : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,entry: Entry)),%,%) -> %
--R reduce : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,entry: Entry)),%,%) -> %
--R reduce : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,entry: Entry)),%,%) -> %
--R reduce : (((Record(key: Key,entry: Entry),Record(key: Key,entry: Entry)) -> Record(key: Key,entry: Entry)),%,%) -> %
--R remove : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (Record(key: Key,entry: Entry),%) -> % if Record(key: Key,entry: Entry) has SETCAT
--R remove : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (Record(key: Key,entry: Entry),%) -> % if Record(key: Key,entry: Entry) has SETCAT
--R remove! : (Record(key: Key,entry: Entry),%) -> % if Record(key: Key,entry: Entry) has SETCAT
--R remove! : ((Record(key: Key,entry: Entry) -> Boolean),%) -> %
--R remove! : (Key,%) -> Union(Entry,"failed")
--R remove! : ((Record(key: Key,entry: Entry) -> Boolean),%) -> % if $ has finiteAggregate
--R remove! : (Record(key: Key,entry: Entry),%) -> % if $ has finiteAggregate
--R removeDuplicates : % -> % if Record(key: Key,entry: Entry) has SETCAT and $ has finiteAggregate
--R removeDuplicates! : % -> % if Record(key: Key,entry: Entry) has SETCAT

```

```

--R rest : (% , NonNegativeInteger) -> %
--R reverse! : % -> % if $ has shallowlyMutable
--R search : (Key, %) -> Union(Entry, "failed")
--R second : % -> Record(key: Key, entry: Entry)
--R select : ((Record(key: Key, entry: Entry) -> Boolean), %) -> % if $ has finiteAggregate
--R select : ((Record(key: Key, entry: Entry) -> Boolean), %) -> % if $ has finiteAggregate
--R select! : ((Record(key: Key, entry: Entry) -> Boolean), %) -> %
--R select! : ((Record(key: Key, entry: Entry) -> Boolean), %) -> % if $ has finiteAggregate
--R setchildren! : (% , List(%)) -> % if $ has shallowlyMutable
--R setelt : (% , value, Record(key: Key, entry: Entry)) -> Record(key: Key, entry: Entry) if $ has shallowlyMutable
--R setelt : (% , first, Record(key: Key, entry: Entry)) -> Record(key: Key, entry: Entry) if $ has shallowlyMutable
--R setelt : (% , rest, %) -> % if $ has shallowlyMutable
--R setelt : (% , last, Record(key: Key, entry: Entry)) -> Record(key: Key, entry: Entry) if $ has shallowlyMutable
--R setelt : (% , UniversalSegment(Integer), Record(key: Key, entry: Entry)) -> Record(key: Key, entry: Entry) if $ has shallowlyMutable
--R setelt : (% , Integer, Record(key: Key, entry: Entry)) -> Record(key: Key, entry: Entry) if $ has shallowlyMutable
--R setfirst! : (% , Record(key: Key, entry: Entry)) -> Record(key: Key, entry: Entry) if $ has shallowlyMutable
--R setlast! : (% , Record(key: Key, entry: Entry)) -> Record(key: Key, entry: Entry) if $ has shallowlyMutable
--R setrest! : (% , %) -> % if $ has shallowlyMutable
--R setvalue! : (% , Record(key: Key, entry: Entry)) -> Record(key: Key, entry: Entry) if $ has shallowlyMutable
--R size? : (% , NonNegativeInteger) -> Boolean
--R sort : % -> % if Record(key: Key, entry: Entry) has ORDSET
--R sort : (((Record(key: Key, entry: Entry), Record(key: Key, entry: Entry)) -> Boolean), %) -> %
--R sort! : % -> % if Record(key: Key, entry: Entry) has ORDSET and $ has shallowlyMutable
--R sort! : (((Record(key: Key, entry: Entry), Record(key: Key, entry: Entry)) -> Boolean), %) -> % if $ has shallowlyMutable
--R sorted? : % -> Boolean if Record(key: Key, entry: Entry) has ORDSET
--R sorted? : (((Record(key: Key, entry: Entry), Record(key: Key, entry: Entry)) -> Boolean), %) -> Boolean
--R split! : (% , Integer) -> % if $ has shallowlyMutable
--R swap! : (% , Integer, Integer) -> Void if $ has shallowlyMutable
--R swap! : (% , Key, Key) -> Void if $ has shallowlyMutable
--R table : List(Record(key: Key, entry: Entry)) -> %
--R third : % -> Record(key: Key, entry: Entry)
--R value : % -> Record(key: Key, entry: Entry)
--R ?~=? : (% , %) -> Boolean if Record(key: Key, entry: Entry) has SETCAT or Entry has SETCAT or Record(key: Key, entry: Entry) has SETCAT
--R
--E 1

)spool
)lisp (bye)

```

— AssociationListAggregate.help —

AssociationListAggregate examples

An association list is a list of key entry pairs which may be viewed as a table. It is a poor mans version of a table; searching for a key

is a linear operation.

See Also:

o)show AssociationListAggregate

See:

⇐ “ListAggregate” (LSAGG) [8](#) on page [714](#)

⇐ “TableAggregate” (TBAGG) [9](#) on page [852](#)

Exports:

| | | | |
|-------------------|-------------------|-------------------|------------------|
| any? | assoc | bag | children |
| child? | coerce | concat | concat! |
| construct | convert | copy | copyInto! |
| count | cycleEntry | cycleLength | cycleSplit! |
| cycleTail | cyclic? | delete | delete! |
| dictionary | distance | elt | empty |
| empty? | entries | entry? | eq? |
| eval | every? | explicitlyFinite? | extract! |
| fill! | find | first | hash |
| index? | indices | insert | insert! |
| inspect | key? | keys | last |
| latex | leaf? | leaves | less? |
| list | map | map! | max |
| maxIndex | member? | members | merge |
| merge! | min | minIndex | more? |
| new | nodes | node? | parts |
| position | possiblyInfinite? | qelt | qsetelt! |
| reduce | remove | remove! | removeDuplicates |
| removeDuplicates! | rest | reverse | reverse! |
| sample | search | second | select |
| select! | setchildren! | setelt | setfirst! |
| setlast! | setrest! | setvalue! | size? |
| sort | sort! | sorted? | split! |
| swap! | table | tail | third |
| value | #? | ?<? | ?<=? |
| ?=? | ?>? | ?>=? | ?~=? |
| ?.rest | ?.value | ?.first | ?.last |
| ?.? | | | |

Attributes exported:

- **shallowlyMutable** is true if its values have immediate components that are update-able (mutable). Note that the properties of any component domain are irrelevant to

the shallowlyMutable proper.

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

These are directly exported but not implemented:

```
assoc : (Key,% ) -> Union(Record(key: Key,entry: Entry),"failed")
```

These exports come from (p852) TableAggregate(Key, Entry)
 where Key:SetCategory and Entry:SetCategory
 and RecKE = Record(key: Key,entry: Entry)

```
any? : ((RecKE -> Boolean),%) -> Boolean
      if $ has finiteAggregate
any? : ((Entry -> Boolean),%) -> Boolean
      if $ has finiteAggregate
any? : ((RecKE -> Boolean),%) -> Boolean
      if $ has finiteAggregate
bag : List RecKE -> %
construct : List RecKE -> %
convert : % -> InputForm
          if RecKE has KONVERT INFORM
          or RecKE has KONVERT INFORM
copy : % -> %
count :
  ((RecKE -> Boolean),%) -> NonNegativeInteger
  if $ has finiteAggregate
count : (RecKE,% ) -> NonNegativeInteger
  if RecKE has SETCAT
  and $ has finiteAggregate
count : ((Entry -> Boolean),%) -> NonNegativeInteger
  if $ has finiteAggregate
count : (Entry,% ) -> NonNegativeInteger
  if Entry has SETCAT
  and $ has finiteAggregate
count : (RecKE,% ) -> NonNegativeInteger
  if RecKE has SETCAT
  and $ has finiteAggregate
count :
  ((RecKE -> Boolean),%) -> NonNegativeInteger
  if $ has finiteAggregate
dictionary : () -> %
dictionary : List RecKE -> %
elt : (% ,Key,Entry) -> Entry
elt : (% ,Integer,RecKE) -> RecKE
empty : () -> %
empty? : % -> Boolean
entries : % -> List Entry
```

```

entry? : (Entry,%) -> Boolean
    if $ has finiteAggregate
    and Entry has SETCAT
eq? : (%,%) -> Boolean
eval : (%,List Equation RecKE) -> %
    if RecKE has EVALAB RecKE
    and RecKE has SETCAT
eval : (%,Equation RecKE) -> %
    if RecKE has EVALAB RecKE
    and RecKE has SETCAT
eval : (%,RecKE,RecKE) -> %
    if RecKE has EVALAB RecKE
    and RecKE has SETCAT
eval : (%,List RecKE,List RecKE) -> %
    if RecKE has EVALAB RecKE
    and RecKE has SETCAT
eval : (%,List Equation Entry) -> %
    if Entry has EVALAB Entry
    and Entry has SETCAT
eval : (%,Equation Entry) -> %
    if Entry has EVALAB Entry
    and Entry has SETCAT
eval : (%,Entry,Entry) -> %
    if Entry has EVALAB Entry
    and Entry has SETCAT
eval : (%,List Entry,List Entry) -> %
    if Entry has EVALAB Entry
    and Entry has SETCAT
eval : (%,List RecKE,List RecKE) -> %
    if RecKE has EVALAB RecKE
    and RecKE has SETCAT
eval : (%,RecKE,RecKE) -> %
    if RecKE has EVALAB RecKE
    and RecKE has SETCAT
eval : (%,Equation RecKE) -> %
    if RecKE has EVALAB RecKE
    and RecKE has SETCAT
eval : (%,List Equation RecKE) -> %
    if RecKE has EVALAB RecKE
    and RecKE has SETCAT
every? : ((RecKE -> Boolean),%) -> Boolean
    if $ has finiteAggregate
every? : ((Entry -> Boolean),%) -> Boolean
    if $ has finiteAggregate
extract! : % -> RecKE
fill! : (%,Entry) -> % if $ has shallowlyMutable
find : ((RecKE -> Boolean),%) -> Union(RecKE,"failed")
first : % -> Entry if Key has ORDSET
hash : % -> SingleInteger
    if RecKE has SETCAT

```

```

        or Entry has SETCAT
        or RecKE has SETCAT
index? : (Key,%) -> Boolean
indices : % -> List Key
insert! : (RecKE,%) -> %
inspect : % -> RecKE
key? : (Key,%) -> Boolean
keys : % -> List Key
latex : % -> String
        if RecKE has SETCAT
        or Entry has SETCAT
        or RecKE has SETCAT
less? : (% , NonNegativeInteger) -> Boolean
map : ((Entry -> Entry),%) -> %
map : ((RecKE -> RecKE),%) -> %
map : (((Entry,Entry) -> Entry),%,%) -> %
map! : ((RecKE -> RecKE),%) -> %
        if $ has shallowlyMutable
map! : ((Entry -> Entry),%) -> % if $ has shallowlyMutable
map! : ((RecKE -> RecKE),%) -> %
        if $ has shallowlyMutable
maxIndex : % -> Key if Key has ORDSET
member? : (RecKE,%) -> Boolean
        if RecKE has SETCAT
        and $ has finiteAggregate
member? : (Entry,%) -> Boolean
        if Entry has SETCAT
        and $ has finiteAggregate
members : % -> List RecKE if $ has finiteAggregate
members : % -> List Entry if $ has finiteAggregate
members : % -> List RecKE if $ has finiteAggregate
minIndex : % -> Key if Key has ORDSET
more? : (% , NonNegativeInteger) -> Boolean
parts : % -> List Entry if $ has finiteAggregate
parts : % -> List RecKE if $ has finiteAggregate
qelt : (% , Key) -> Entry
qsetelt! : (% , Key, Entry) -> Entry if $ has shallowlyMutable
reduce :
    (((RecKE,RecKE) -> RecKE),%)
    -> RecKE
        if $ has finiteAggregate
reduce :
    (((RecKE,RecKE) -> RecKE),%,RecKE)
    -> RecKE
        if $ has finiteAggregate
reduce :
    (((RecKE,RecKE) -> RecKE),%,RecKE,RecKE)
    -> RecKE
        if RecKE has SETCAT
        and $ has finiteAggregate

```



```

remove : ((RecKE -> Boolean),%) -> % if $ has finiteAggregate
remove : (RecKE,%) -> %
      if RecKE has SETCAT
      and $ has finiteAggregate
remove! : (Key,%) -> Union(Entry,"failed")
remove! : (RecKE,%) -> % if RecKE has SETCAT
remove! : (RecKE,%) -> % if $ has finiteAggregate
removeDuplicates : % -> %
      if RecKE has SETCAT
      and $ has finiteAggregate
      or RecKE has SETCAT
      and $ has finiteAggregate
sample : () -> %
search : (Key,%) -> Union(Entry,"failed")
select : ((RecKE -> Boolean),%) -> %
      if $ has finiteAggregate
select! : ((RecKE -> Boolean),%) -> %
      if $ has finiteAggregate
setelt : (%,Key,Entry) -> Entry
size? : (%,NonNegativeInteger) -> Boolean
swap! : (%,Key,Key) -> Void if $ has shallowlyMutable
table : () -> %
table : List RecKE -> %
?~=? : (%,%) -> Boolean
      if RecKE has SETCAT
      or Entry has SETCAT
      or RecKE has SETCAT
??.? : (%,Key) -> Entry

```

These exports come from (p714) ListAggregate(a)
 where a is Record(key:Key,entry:Entry)
 and RecKE=Record(key: Key,entry: Entry)

```

children : % -> List %
child? : (%,%) -> Boolean if RecKE has SETCAT
coerce : % -> OutputForm
      if RecKE has SETCAT
      or Entry has SETCAT
      or RecKE has SETCAT
concat : (%,%) -> %
concat : List % -> %
concat : (RecKE,%) -> %
concat : (%,RecKE) -> %
concat! : (%,%) -> %
concat! : (%,RecKE) -> %
copyInto! : (%,%,Integer) -> % if $ has shallowlyMutable
cycleEntry : % -> %
cycleLength : % -> NonNegativeInteger
cycleSplit! : % -> % if $ has shallowlyMutable
cycleTail : % -> %

```

```

cyclic? : % -> Boolean
delete : (%,Integer) -> %
delete! : (%,Integer) -> %
delete : (%,UniversalSegment Integer) -> %
delete! : (%,UniversalSegment Integer) -> %
distance : (%,% ) -> Integer
entries : % -> List RecKE
entry? : (RecKE,%) -> Boolean
    if $ has finiteAggregate
    and RecKE has SETCAT
explicitlyFinite? : % -> Boolean
fill! : (% ,RecKE) -> % if $ has shallowlyMutable
first : % -> RecKE
first : (% ,NonNegativeInteger) -> %
index? : (Integer,%) -> Boolean
indices : % -> List Integer
insert : (% ,%,Integer) -> %
insert : (RecKE,%,Integer) -> %
insert! : (% ,%,Integer) -> %
insert! : (RecKE,%,Integer) -> %
last : % -> RecKE
last : (% ,NonNegativeInteger) -> %
leaf? : % -> Boolean
leaves : % -> List RecKE
list : RecKE -> %
map : (((RecKE,RecKE) -> RecKE),%,%) -> %
max : (% ,%) -> % if RecKE has ORDSET
maxIndex : % -> Integer if Integer has ORDSET
merge : (% ,%) -> % if RecKE has ORDSET
merge : (((RecKE,RecKE) -> Boolean),%,%) -> %
merge! : (% ,%) -> % if RecKE has ORDSET
merge! : (((RecKE,RecKE) -> Boolean),%,%) -> %
min : (% ,%) -> % if RecKE has ORDSET
minIndex : % -> Integer if Integer has ORDSET
new : (NonNegativeInteger,RecKE) -> %
nodes : % -> List %
node? : (% ,%) -> Boolean if RecKE has SETCAT
position : (RecKE,%,Integer) -> Integer
    if RecKE has SETCAT
position : (RecKE,%) -> Integer
    if RecKE has SETCAT
position : ((RecKE -> Boolean),%) -> Integer
possiblyInfinite? : % -> Boolean
qelt : (% ,Integer) -> RecKE
qsetelt! : (% ,Integer,RecKE) -> RecKE
    if $ has shallowlyMutable
remove! : ((RecKE -> Boolean),%) -> %
remove! : ((RecKE -> Boolean),%) -> %
    if $ has finiteAggregate
removeDuplicates! : % -> % if RecKE has SETCAT

```

```

rest : % -> %
rest : (%,NonNegativeInteger) -> %
reverse : % -> %
reverse! : % -> % if $ has shallowlyMutable
second : % -> RecKE
select! : ((RecKE -> Boolean),%) -> %
setchildren! : (%,List %) -> % if $ has shallowlyMutable
setelt : (%,value,RecKE) -> RecKE
        if $ has shallowlyMutable
setelt : (%,first,RecKE) -> RecKE
        if $ has shallowlyMutable
setelt : (%,rest,%) -> % if $ has shallowlyMutable
setelt : (%,last,RecKE) -> RecKE
        if $ has shallowlyMutable
setelt : (%,UniversalSegment Integer,RecKE) -> RecKE
        if $ has shallowlyMutable
setelt : (%,Integer,RecKE) -> RecKE
        if $ has shallowlyMutable
setfirst! : (%,RecKE) -> RecKE
        if $ has shallowlyMutable
setlast! : (%,RecKE) -> RecKE
        if $ has shallowlyMutable
setrest! : (%,%) -> % if $ has shallowlyMutable
setvalue! : (%,RecKE) -> RecKE
        if $ has shallowlyMutable
sort : % -> % if RecKE has ORDSET
sort : ((RecKE,RecKE) -> Boolean,%) -> %
sort! : % -> %
        if RecKE has ORDSET
        and $ has shallowlyMutable
sort! : ((RecKE,RecKE) -> Boolean,%) -> %
        if $ has shallowlyMutable
sorted? : % -> Boolean if RecKE has ORDSET
sorted? : ((RecKE,RecKE) -> Boolean,%) -> Boolean
split! : (%,Integer) -> % if $ has shallowlyMutable
swap! : (%,Integer,Integer) -> Void
        if $ has shallowlyMutable
tail : % -> %
third : % -> RecKE
value : % -> RecKE
#? : % -> NonNegativeInteger if $ has finiteAggregate
?<? : (%,%) -> Boolean if RecKE has ORDSET
?<=? : (%,%) -> Boolean if RecKE has ORDSET
?=? : (%,%) -> Boolean
        if RecKE has SETCAT
        or Entry has SETCAT
        or RecKE has SETCAT
?>? : (%,%) -> Boolean if RecKE has ORDSET
?>=? : (%,%) -> Boolean if RecKE has ORDSET
?.value : (%,value) -> RecKE

```

```
?.first : (% ,first) -> RecKE
?.last  : (% ,last)  -> RecKE
?.rest  : (% ,rest)  -> %
?.? : (% ,UniversalSegment Integer) -> %
?.? : (% ,Integer) -> RecKE
```

— category ALAGG AssociationListAggregate —

```
)abbrev category ALAGG AssociationListAggregate
++ Author: Michael Monagan; revised by Manuel Bronstein and Richard Jenks
++ Date Created: August 87 through August 88
++ Date Last Updated: April 1991
++ Description:
++ An association list is a list of key entry pairs which may be viewed
++ as a table.           It is a poor mans version of a table:
++ searching for a key is a linear operation.
```

```
AssociationListAggregate(Key:SetCategory,Entry:SetCategory): Category ==
  Join(TableAggregate(Key, Entry), _
    ListAggregate Record(key:Key,entry:Entry)) with
  assoc: (Key, %) -> Union(Record(key:Key,entry:Entry), "failed")
  ++ assoc(k,u) returns the element x in association list u stored
  ++ with key k, or "failed" if u has no key k.
```

— ALAGG.dotabb —

```
"ALAGG" [color=lightblue,href="bookvol10.2.pdf#nameddest=ALAGG"];
"ALAGG" -> "TBAGG"
"ALAGG" -> "LSAGG"
```

— ALAGG.dotfull —

```
"AssociationListAggregate(a:SetCategory,b:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ALAGG"];
"AssociationListAggregate(a:SetCategory,b:SetCategory)" ->
  "TableAggregate(a:SetCategory,b:SetCategory)"
"AssociationListAggregate(a:SetCategory,b:SetCategory)" ->
  "ListAggregate(Record(a:SetCategory,b:SetCategory))"
```

— ALAGG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "AssociationListAggregate(a:SetCategory,b:SetCategory)" [color=lightblue];
  "AssociationListAggregate(a:SetCategory,b:SetCategory)" ->
    "TableAggregate(a:SetCategory,b:SetCategory)"
  "AssociationListAggregate(a:SetCategory,b:SetCategory)" ->
    "ListAggregate(Record(a:SetCategory,b:SetCategory))"

  "TableAggregate(a:SetCategory,b:SetCategory)" [color=lightblue];
  "TableAggregate(a:SetCategory,b:SetCategory)" -> "KDAGG..."
  "TableAggregate(a:SetCategory,b:SetCategory)" ->
    "IndexedAggregate(a:SetCategory,b:SetCategory)"

  "IndexedAggregate(a:SetCategory,b:SetCategory)" [color=seagreen];
  "IndexedAggregate(a:SetCategory,b:SetCategory)" -> "IXAGG..."

  "ListAggregate(Record(a:SetCategory,b:SetCategory))" [color=seagreen];
  "ListAggregate(Record(a:SetCategory,b:SetCategory))" ->
    "ListAggregate(a:Type)"

  "ListAggregate(a:Type)" [color=lightblue];
  "ListAggregate(a:Type)" -> "FiniteLinearAggregate(a:Type)"
  "ListAggregate(a:Type)" -> "ExtensibleLinearAggregate(a:Type)"

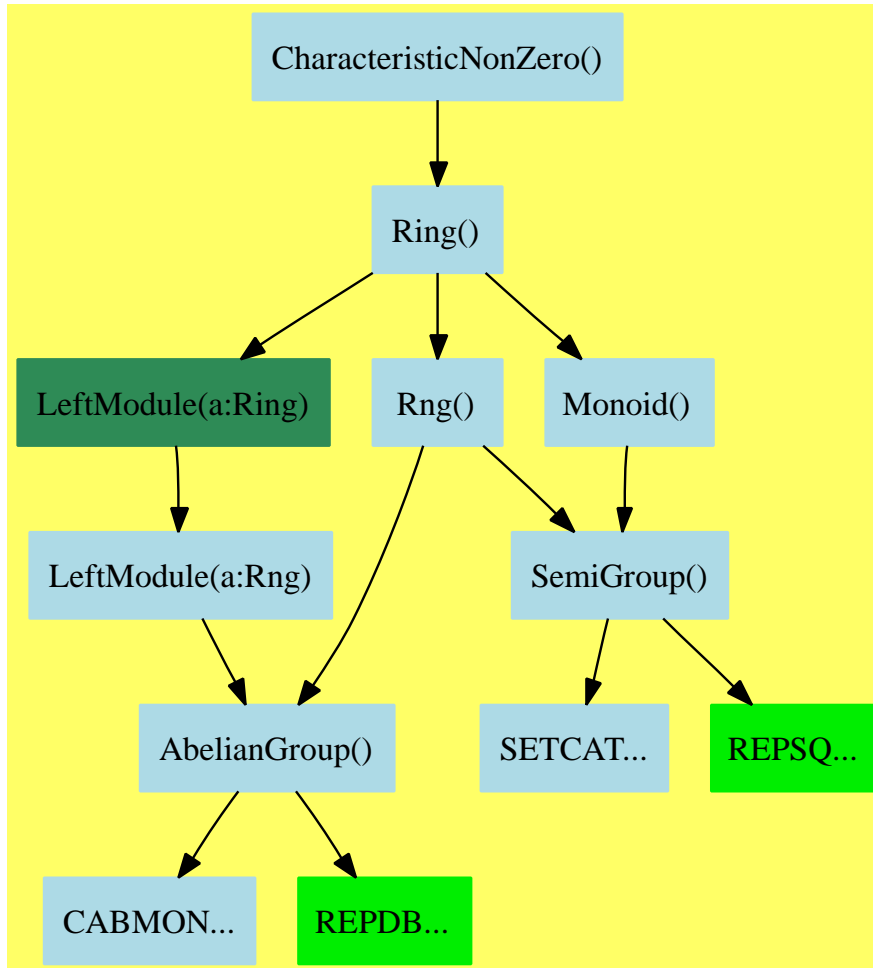
  "FiniteLinearAggregate(a:Type)" [color=lightblue];
  "FiniteLinearAggregate(a:Type)" -> "LSAGG..."

  "ExtensibleLinearAggregate(a:Type)" [color=lightblue];
  "ExtensibleLinearAggregate(a:Type)" -> "LSAGG..."

  "KDAGG..." [color=lightblue];
  "IXAGG..." [color=lightblue];
  "LSAGG..." [color=lightblue];
}

```

CharacteristicNonZero (CHARNZ)



— CharacteristicNonZero.input —

```

)set break resume
)sys rm -f CharacteristicNonZero.output
)spool CharacteristicNonZero.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show CharacteristicNonZero
--R CharacteristicNonZero is a category constructor

```

```

--R Abbreviation for CharacteristicNonZero is CHARNZ
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for CHARNZ
--R
--R----- Operations -----
--R ?? : (%,%) -> %                ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %  ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %                ?-? : (%,%) -> %
--R -? : % -> %                     ?=? : (%,%) -> Boolean
--R 1 : () -> %                     0 : () -> %
--R ?? : (%,PositiveInteger) -> %   coerce : Integer -> %
--R coerce : % -> OutputForm        hash : % -> SingleInteger
--R latex : % -> String             one? : % -> Boolean
--R recip : % -> Union(%, "failed") sample : () -> %
--R zero? : % -> Boolean             ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed")
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— CharacteristicNonZero.help —

```

=====
CharacteristicNonZero examples
=====

```

The category of Rings of Characteristic Non Zero

See Also:

o)show CharacteristicNonZero

See:

- ⇒ “FieldOfPrimeCharacteristic” (FPC) [17](#) on page [1374](#)
- ⇒ “FiniteRankAlgebra” (FINRAlg) [17](#) on page [1380](#)
- ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
- ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)

← “Ring” (RING) 9 on page 826

Exports:

| | | | | |
|------------|---------------|--------|-------|----------------|
| 1 | 0 | coerce | hash | latex |
| one? | recip | sample | zero? | characteristic |
| charthRoot | subtractIfCan | ?~=? | ?^? | ?*? |
| ?**? | ?+? | ?-? | -? | ?=? |

Attributes exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation `recip` can only return “failed” if its argument is not a unit.

These are directly exported but not implemented:

```
charthRoot : % -> Union(%, "failed")
```

These exports come from (p826) `Ring()`:

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%, %) -> Boolean
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
?*? : (%, %) -> %
?*? : (NonNegativeInteger, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
***? : (%, NonNegativeInteger) -> %
***? : (%, PositiveInteger) -> %
?+? : (%, %) -> %
?-? : (%, %) -> %
-? : % -> %
?=? : (%, %) -> Boolean
```

— category **CHARNZ CharacteristicNonZero** —

```
)abbrev category CHARNZ CharacteristicNonZero
```



```

++ Description:
++ Rings of Characteristic Non Zero

```

```

CharacteristicNonZero():Category == Ring with
  charthRoot: % -> Union(%, "failed")
  ++ charthRoot(x) returns the pth root of x
  ++ where p is the characteristic of the ring.

```

— CHARNZ.dotabb —

```

"CHARNZ"
  [color=lightblue, href="bookvol10.2.pdf#nameddest=CHARNZ"];
"CHARNZ" -> "RING"

```

— CHARNZ.dotfull —

```

"CharacteristicNonZero()"
  [color=lightblue, href="bookvol10.2.pdf#nameddest=CHARNZ"];
"CharacteristicNonZero()" -> "Ring()"

```

— CHARNZ.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CharacteristicNonZero()" [color=lightblue];
  "CharacteristicNonZero()" -> "Ring()"

  "Ring()" [color=lightblue];
  "Ring()" -> "Rng()"
  "Ring()" -> "Monoid()"
  "Ring()" -> "LeftModule(a:Ring)"

  "Rng()" [color=lightblue];
  "Rng()" -> "AbelianGroup()"
  "Rng()" -> "SemiGroup()"

```

```

"Monoid()" [color=lightblue];
"Monoid()" -> "SemiGroup()"

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "AbelianGroup()"

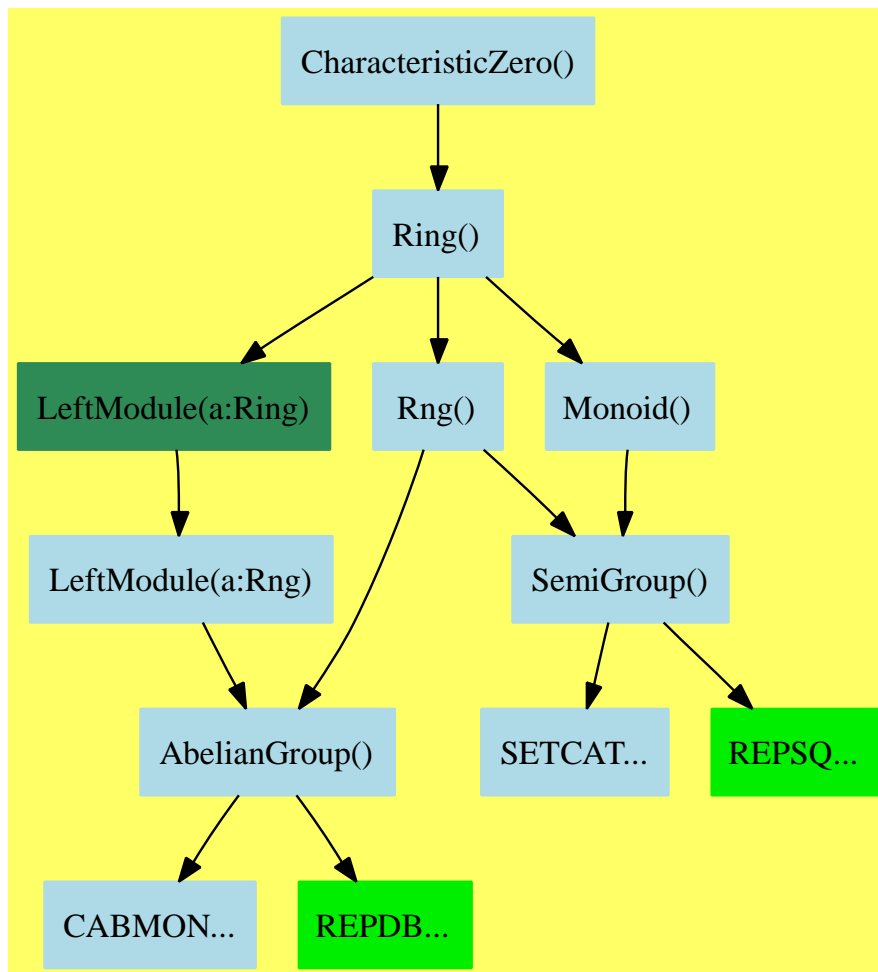
"AbelianGroup()" [color=lightblue];
"AbelianGroup()" -> "CABMON..."
"AbelianGroup()" -> "REPDB..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"CABMON..." [color=lightblue];
}

```

CharacteristicZero (CHARZ)



— CharacteristicZero.input —

```

)set break resume
)sys rm -f CharacteristicZero.output
)spool CharacteristicZero.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show CharacteristicZero
--R CharacteristicZero is a category constructor

```

```

--R Abbreviation for CharacteristicZero is CHARZ
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for CHARZ
--R
--R----- Operations -----
--R ??? : (%,% ) -> %           ??? : (Integer,% ) -> %
--R ??? : (PositiveInteger,% ) -> %   ??? : (% ,PositiveInteger) -> %
--R ??? : (%,% ) -> %           ?-? : (%,% ) -> %
--R -? : % -> %                 ?=? : (%,% ) -> Boolean
--R 1 : () -> %                 0 : () -> %
--R ?? : (% ,PositiveInteger) -> %   coerce : Integer -> %
--R coerce : % -> OutputForm         hash : % -> SingleInteger
--R latex : % -> String             one? : % -> Boolean
--R recip : % -> Union(% , "failed") sample : () -> %
--R zero? : % -> Boolean           ?~=? : (%,% ) -> Boolean
--R ??? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ?? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R subtractIfCan : (%,% ) -> Union(% , "failed")
--R
--E 1

)spool
)lisp (bye)

```

— CharacteristicZero.help —

```

=====
CharacteristicZero examples
=====

```

The category of Rings of Characteristic Zero.

See Also:

o)show CharacteristicZero

See:

- ⇒ “FiniteRankAlgebra” (FINRAlg) [17](#) on page [1380](#)
- ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
- ⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)
- ⇒ “PAdicIntegerCategory” (PADICCT) [16](#) on page [1299](#)
- ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)

⇒ “RealClosedField” (RCFIELD) [17](#) on page [1441](#)

⇒ “RealNumberSystem” (RNS) [17](#) on page [1451](#)

⇐ “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | | |
|---------------|-------|--------|-------|----------------|
| 1 | 0 | coerce | hash | latex |
| one? | recip | sample | zero? | characteristic |
| subtractIfCan | ?~=? | ?^? | ?*? | |
| ?**? | ?+? | ?-? | -? | ?=? |

Attributes exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation `recip` can only return “failed” if its argument is not a unit.

These exports come from (p[826](#)) `Ring()`:

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%, %) -> Boolean
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
?*? : (%, %) -> %
?*? : (NonNegativeInteger, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?*?? : (%, NonNegativeInteger) -> %
?*?? : (%, PositiveInteger) -> %
?+? : (%, %) -> %
?-? : (%, %) -> %
-? : % -> %
?=? : (%, %) -> Boolean

```

— category CHARZ CharacteristicZero —

```

)abbrev category CHARZ CharacteristicZero
++ Description:
++ Rings of Characteristic Zero.

```

```
CharacteristicZero():Category == Ring
```

— CHARZ.dotabb —

```
"CHARZ"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CHARZ"];
"CHARZ" -> "RING"
```

— CHARZ.dotfull —

```
"CharacteristicZero()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CHARZ"];
"CharacteristicZero()" -> "Ring()"
```

— CHARZ.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CharacteristicZero()" [color=lightblue];
  "CharacteristicZero()" -> "Ring()"

  "Ring()" [color=lightblue];
  "Ring()" -> "Rng()"
  "Ring()" -> "Monoid()"
  "Ring()" -> "LeftModule(a:Ring)"

  "Rng()" [color=lightblue];
  "Rng()" -> "AbelianGroup()"
  "Rng()" -> "SemiGroup()"

  "Monoid()" [color=lightblue];
  "Monoid()" -> "SemiGroup()"

  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"
```

```

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "AbelianGroup()"

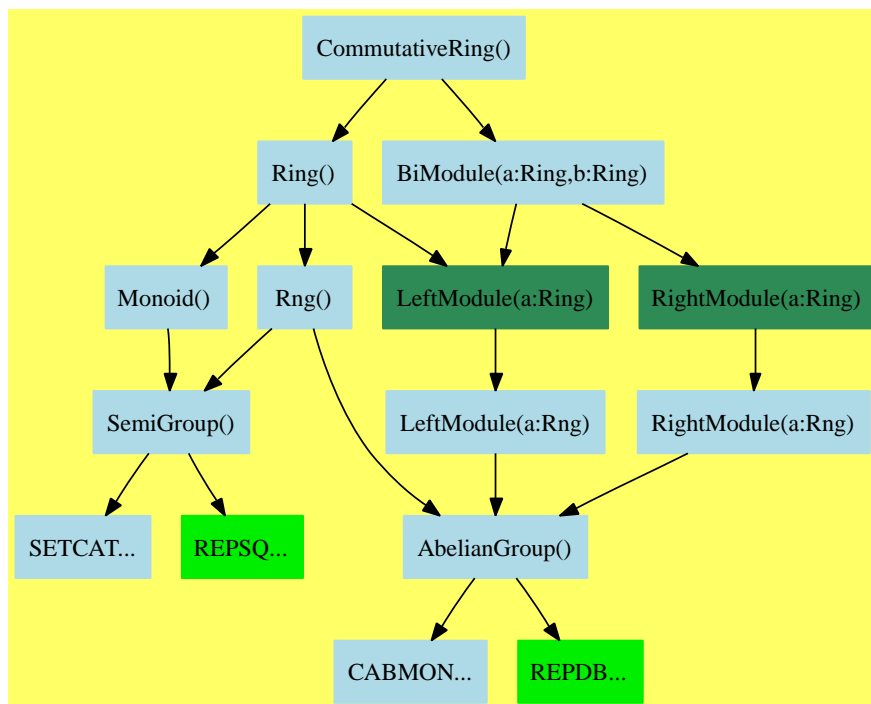
"AbelianGroup()" [color=lightblue];
"AbelianGroup()" -> "CABMON..."
"AbelianGroup()" -> "REPDB..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"CABMON..." [color=lightblue];
}

```

CommutativeRing (COMRING)



— CommutativeRing.input —

```
)set break resume
)sys rm -f CommutativeRing.output
)spool CommutativeRing.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show CommutativeRing
--R CommutativeRing is a category constructor
--R Abbreviation for CommutativeRing is COMRING
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for COMRING
--R
--R----- Operations -----
--R ?? : (% ,%) -> %
--R ?? : (PositiveInteger,% ) -> %
--R ?? : (% ,%) -> %
--R -? : % -> %
--R 1 : () -> %
--R ^? : (% ,PositiveInteger) -> %
--R coerce : % -> OutputForm
--R latex : % -> String
--R recip : % -> Union(% ,"failed")
--R zero? : % -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ^? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R subtractIfCan : (% ,%) -> Union(% ,"failed")
--R
--R
--R ?? : (Integer,% ) -> %
--R ??? : (% ,PositiveInteger) -> %
--R -? : (% ,%) -> %
--R ?? : (% ,%) -> Boolean
--R 0 : () -> %
--R coerce : Integer -> %
--R hash : % -> SingleInteger
--R one? : % -> Boolean
--R sample : () -> %
--R ?? : (% ,%) -> Boolean

--E 1

)spool
)lisp (bye)
```

— CommutativeRing.help —

```
=====
CommutativeRing examples
=====
```

The category of commutative rings with unity, i.e. rings where * is

commutative, and which have a multiplicative identity element.

See Also:

o)show CommutativeRing

Commutative Rings are a subset of IntegralDomains.

⇒ “IntegralDomain” (INTDOM) [12](#) on page [1097](#).

See:

⇒ “ComplexCategory” (COMPCAT) [20](#) on page [1671](#)

⇒ “IntegralDomain” (INTDOM) [12](#) on page [1097](#)

⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)

⇒ “MonogenicAlgebra” (MONOGEN) [19](#) on page [1651](#)

⇒ “RealClosedField” (RCFIELD) [17](#) on page [1441](#)

⇒ “UnivariatePolynomialCategory” (UPOLYC) [17](#) on page [1522](#)

⇐ “BiModule” (BMODULE) [9](#) on page [782](#)

⇐ “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | | |
|---------------|-------|--------|-------|----------------|
| 1 | 0 | coerce | hash | latex |
| one? | recip | sample | zero? | characteristic |
| subtractIfCan | ?~=? | ?^? | ?*? | ?**? |
| ?+? | ?-? | -? | ?=? | |

Attributes exported:

- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These exports come from ([p826](#)) **Ring()**:

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
```

```

one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (%, %) -> %
?*? : (Integer, %) -> %
?*? : (NonNegativeInteger, %) -> %
?*? : (PositiveInteger, %) -> %
?-? : (%, %) -> %
-? : % -> %
?^? : (%, PositiveInteger) -> %
?^? : (%, NonNegativeInteger) -> %
?*** : (%, NonNegativeInteger) -> %
?*** : (%, PositiveInteger) -> %

```

— category COMRING CommutativeRing —

```

)abbrev category COMRING CommutativeRing
++ Description:
++ The category of commutative rings with unity, i.e. rings where
++ \spadop{*} is commutative, and which have a multiplicative identity
++ element.

--CommutativeRing():Category == Join(Ring,BiModule(%:Ring,%:Ring)) with
CommutativeRing():Category == Join(Ring,BiModule(%,%)) with
    commutative(" *") ++ multiplication is commutative.

```

— COMRING.dotabb —

```

"COMRING"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=COMRING"];
"COMRING" -> "RING"
"COMRING" -> "BMODULE"

```

— COMRING.dotfull —

```

"CommutativeRing()"

```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=COMRING"];
"CommutativeRing()" -> "Ring()"
"CommutativeRing()" -> "BiModule(a:Ring,b:Ring)"
```

—————

— COMRING.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "CommutativeRing()" [color=lightblue];
  "CommutativeRing()" -> "Ring()"
  "CommutativeRing()" -> "BiModule(a:Ring,b:Ring)"

  "Ring()" [color=lightblue];
  "Ring()" -> "Rng()"
  "Ring()" -> "Monoid()"
  "Ring()" -> "LeftModule(a:Ring)"

  "BiModule(a:Ring,b:Ring)" [color=lightblue];
  "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
  "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

  "RightModule(a:Ring)" [color=seagreen];
  "RightModule(a:Ring)" -> "RightModule(a:Rng)"

  "RightModule(a:Rng)" [color=lightblue];
  "RightModule(a:Rng)" -> "AbelianGroup()"

  "Rng()" [color=lightblue];
  "Rng()" -> "AbelianGroup()"
  "Rng()" -> "SemiGroup()"

  "Monoid()" [color=lightblue];
  "Monoid()" -> "SemiGroup()"

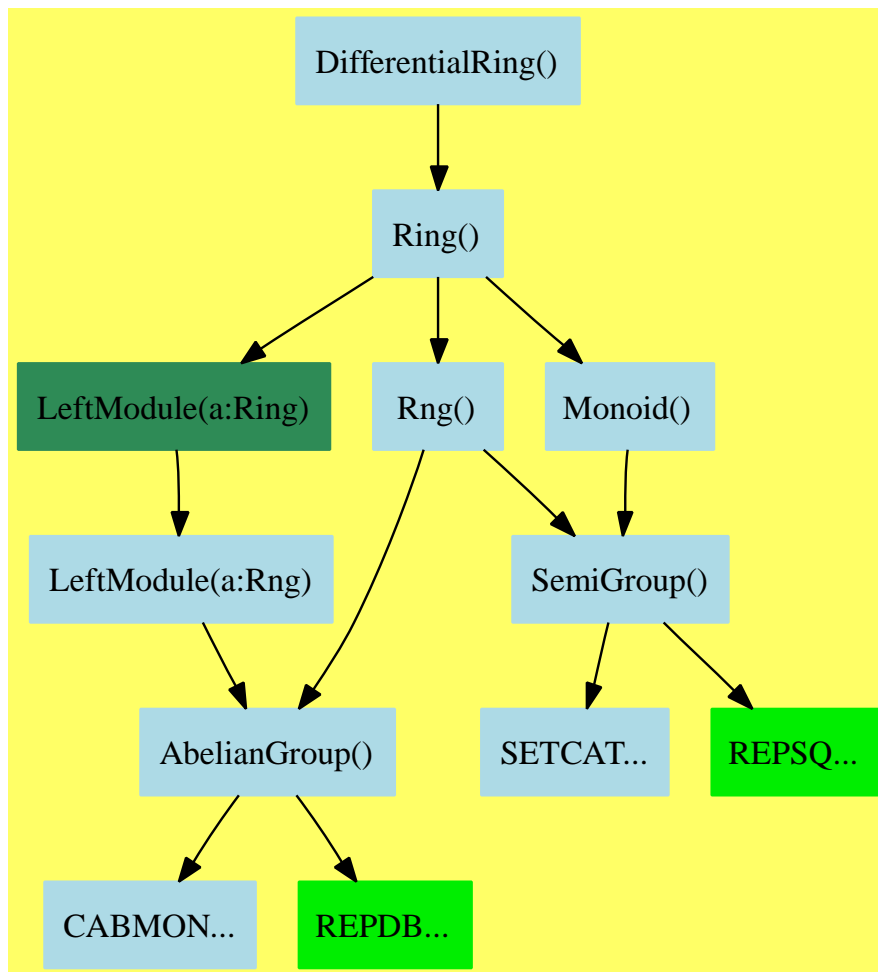
  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

  "LeftModule(a:Rng)" [color=lightblue];
  "LeftModule(a:Rng)" -> "AbelianGroup()"

  "AbelianGroup()" [color=lightblue];
  "AbelianGroup()" -> "CABMON..."
  "AbelianGroup()" -> "REPDB..."
```

```
"SemiGroup()" [color=lightblue];  
"SemiGroup()" -> "SETCAT..."  
"SemiGroup()" -> "REPSQ..."  
  
"REPDB..." [color="#00EE00"];  
"REPSQ..." [color="#00EE00"];  
"SETCAT..." [color=lightblue];  
"CABMON..." [color=lightblue];  
}
```

DifferentialRing (DIFRING)



— DifferentialRing.input —

```

)set break resume
)sys rm -f DifferentialRing.output
)spool DifferentialRing.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show DifferentialRing
--R DifferentialRing is a category constructor

```

```

--R Abbreviation for DifferentialRing is DIFRING
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DIFRING
--R
--R----- Operations -----
--R ??? : (%,% ) -> %           ??? : (Integer,% ) -> %
--R ??? : (PositiveInteger,% ) -> %   ??? : (% ,PositiveInteger) -> %
--R ?+? : (%,% ) -> %           ?-? : (%,% ) -> %
--R -? : % -> %                 ?=? : (%,% ) -> Boolean
--R D : (% ,NonNegativeInteger) -> %   D : % -> %
--R 1 : () -> %                 0 : () -> %
--R ?? : (% ,PositiveInteger) -> %   coerce : Integer -> %
--R coerce : % -> OutputForm         differentiate : % -> %
--R hash : % -> SingleInteger        latex : % -> String
--R one? : % -> Boolean              recip : % -> Union(% ,"failed")
--R sample : () -> %                zero? : % -> Boolean
--R ?~=? : (%,% ) -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ?? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R differentiate : (% ,NonNegativeInteger) -> %
--R subtractIfCan : (%,% ) -> Union(% ,"failed")
--R
--E 1

)spool
)lisp (bye)

```

— DifferentialRing.help —

=====

DifferentialRing examples

=====

An ordinary differential ring, that is, a ring with an operation
differentiate.

Axioms:

```

differentiate(x+y) = differentiate(x)+differentiate(y)
differentiate(x*y) = x*differentiate(y) + differentiate(x)*y

```

See Also:

o)show DifferentialRing

See:

⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)
 ⇒ “FiniteFieldCategory” (FFIELDC) [18](#) on page [1570](#)
 ⇒ “UnivariatePolynomialCategory” (UPOLYC) [17](#) on page [1522](#)
 ⇐ “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | | |
|---------------|---------------|----------------|--------|-------|
| 1 | 0 | characteristic | coerce | D |
| differentiate | hash | latex | one? | recip |
| sample | subtractIfCan | zero? | ?~=? | ?**? |
| ?^? | ?*? | ?+? | ?-? | -? |
| ?=? | | | | |

Attributes exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.

These are directly exported but not implemented:

```
differentiate : % -> %
```

These are implemented by this category:

```
D : % -> %
D : (% , NonNegativeInteger) -> %
differentiate : (% , NonNegativeInteger) -> %
```

These exports come from (p[826](#)) `Ring()`:

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (% , %) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (% , %) -> Boolean
?**? : (% , NonNegativeInteger) -> %
?**? : (% , PositiveInteger) -> %
?^? : (% , NonNegativeInteger) -> %
?^? : (% , PositiveInteger) -> %
```

```

?? : (%,% ) -> %
?? : (NonNegativeInteger,% ) -> %
?? : (Integer,% ) -> %
?? : (PositiveInteger,% ) -> %
?? : (%,% ) -> %
?-? : (%,% ) -> %
-? : % -> %
?=? : (%,% ) -> Boolean

```

— category DIFRING DifferentialRing —

```

)abbrev category DIFRING DifferentialRing
++ Description:
++ An ordinary differential ring, that is, a ring with an operation
++ \spadfun{differentiate}.
++
++ Axioms\br
++ \tab{5}\spad{differentiate(x+y) = differentiate(x)+differentiate(y)}\br
++ \tab{5}\spad{differentiate(x*y) = x*differentiate(y) + differentiate(x)*y}

DifferentialRing(): Category == Ring with
  differentiate: % -> %
    ++ differentiate(x) returns the derivative of x.
    ++ This function is a simple differential operator
    ++ where no variable needs to be specified.
  D: % -> %
    ++ D(x) returns the derivative of x.
    ++ This function is a simple differential operator
    ++ where no variable needs to be specified.
  differentiate: (% , NonNegativeInteger) -> %
    ++ differentiate(x, n) returns the n-th derivative of x.
  D: (% , NonNegativeInteger) -> %
    ++ D(x, n) returns the n-th derivative of x.

add
  D r == differentiate r
  differentiate(r, n) ==
    for i in 1..n repeat r := differentiate r
    r
  D(r,n) == differentiate(r,n)

```

—————

— DIFRING.dotabb —

```

"DIFRING"
[color=lightblue,href="bookvol10.2.pdf#nameddest=DIFRING"];
"DIFRING" -> "RING"

```

— DIFRING.dotfull —

```
"DifferentialRing()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=DIFRING"];
"DifferentialRing()" -> "Ring()"
```

— DIFRING.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

"DifferentialRing()" [color=lightblue];
"DifferentialRing()" -> "Ring()"

"Ring()" [color=lightblue];
"Ring()" -> "Rng()"
"Ring()" -> "Monoid()"
"Ring()" -> "LeftModule(a:Ring)"

"Rng()" [color=lightblue];
"Rng()" -> "AbelianGroup()"
"Rng()" -> "SemiGroup()"

"Monoid()" [color=lightblue];
"Monoid()" -> "SemiGroup()"

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "AbelianGroup()"

"AbelianGroup()" [color=lightblue];
"AbelianGroup()" -> "CABMON..."
"AbelianGroup()" -> "REPDB..."

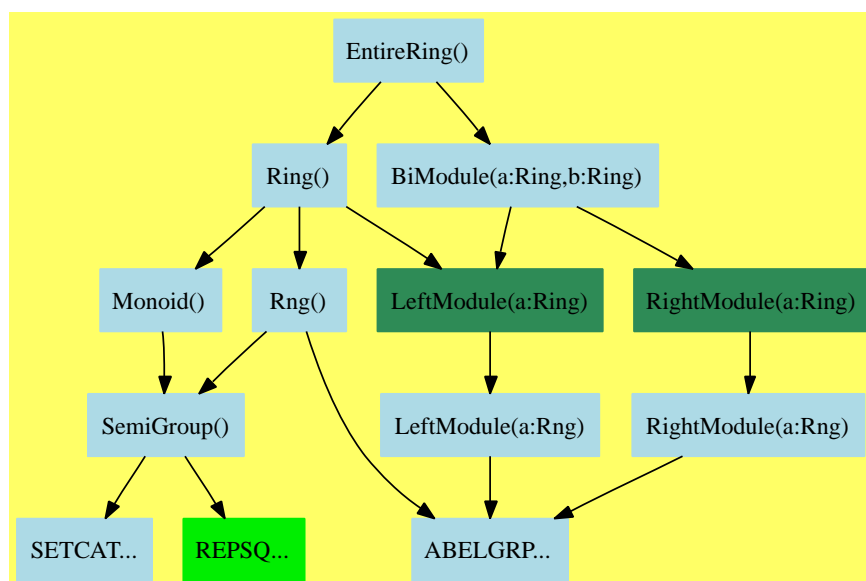
"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."
```

```

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"CABMON..." [color=lightblue];
}

```

EntireRing (ENTIRER)



— EntireRing.input —

```

)set break resume
)sys rm -f EntireRing.output
)spool EntireRing.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show EntireRing
--R EntireRing is a category constructor
--R Abbreviation for EntireRing is ENTIRER

```

```

--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ENTIRER
--R
--R----- Operations -----
--R ??? : (%,%) -> %                ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %    ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %                ?-? : (%,%) -> %
--R -? : % -> %                    ?=? : (%,%) -> Boolean
--R 1 : () -> %                    0 : () -> %
--R ?? : (%,PositiveInteger) -> %    coerce : Integer -> %
--R coerce : % -> OutputForm          hash : % -> SingleInteger
--R latex : % -> String              one? : % -> Boolean
--R recip : % -> Union(%, "failed")   sample : () -> %
--R zero? : % -> Boolean              ?~=? : (%,%) -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

```

```

)spool
)lisp (bye)

```

— EntireRing.help —

=====

EntireRing examples

=====

Entire Rings (non-commutative Integral Domains), i.e. a ring
not necessarily commutative which has no zero divisors.

Axioms:

```

    ab=0 => a=0 or b=0  -- known as noZeroDivisors
    not(1=0)

```

See Also:

```

o )show EntireRing

```

See:

⇒ “DivisionRing” (DIVRING) [12](#) on page [1063](#)

⇒ “IntegralDomain” (INTDOM) [12](#) on page [1097](#)

⇐ “BiModule” (BMODULE) [9](#) on page [782](#)

⇐ “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | | |
|-------|------|----------------|--------|---------------|
| 1 | 0 | characteristic | coerce | hash |
| latex | one? | recip | sample | subtractIfCan |
| zero? | ?^? | ?~=? | ?*? | ?**? |
| ?+? | ?-? | -? | ?=? | |

Attributes Exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These exports come from (p[826](#)) `Ring()`:

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (%, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (NonNegativeInteger, %) -> %
?-? : (%, %) -> %
-? : % -> %
?^? : (%, PositiveInteger) -> %
?^? : (%, NonNegativeInteger) -> %
?**? : (%, NonNegativeInteger) -> %
?**? : (%, PositiveInteger) -> %

```

— category ENTIRER EntireRing —

```
)abbrev category ENTIRER EntireRing
++ Description:
++ Entire Rings (non-commutative Integral Domains), i.e. a ring
++ not necessarily commutative which has no zero divisors.
++
++ Axioms\br
++ \tab{5}\spad{ab=0 => a=0 or b=0} -- known as noZeroDivisors\br
++ \tab{5}\spad{not(1=0)}

--EntireRing():Category == Join(Ring,BiModule(%:Ring,%:Ring)) with
EntireRing():Category == Join(Ring,BiModule(%,%)) with
    noZeroDivisors ++ if a product is zero then one of the factors
                    ++ must be zero.
```

—————

— ENTIRER.dotabb —

```
"ENTIRER"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ENTIRER"];
"ENTIRER" -> "RING"
"ENTIRER" -> "BMODULE"
```

—————

— ENTIRER.dotfull —

```
"EntireRing()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ENTIRER"];
"EntireRing()" -> "Ring()"
"EntireRing()" -> "BiModule(a:Ring,b:Ring)"
```

—————

— ENTIRER.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];
```

```

"EntireRing()" [color=lightblue];
"EntireRing()" -> "Ring()"
"EntireRing()" -> "BiModule(a:Ring,b:Ring)"

"Ring()" [color=lightblue];
"Ring()" -> "Rng()"
"Ring()" -> "Monoid()"
"Ring()" -> "LeftModule(a:Ring)"

"Rng()" [color=lightblue];
"Rng()" -> "ABELGRP..."
"Rng()" -> "SemiGroup()"

"Monoid()" [color=lightblue];
"Monoid()" -> "SemiGroup()"

"BiModule(a:Ring,b:Ring)" [color=lightblue];
"BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
"BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

"RightModule(a:Ring)" [color=seagreen];
"RightModule(a:Ring)" -> "RightModule(a:Rng)"

"RightModule(a:Rng)" [color=lightblue];
"RightModule(a:Rng)" -> "ABELGRP..."

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

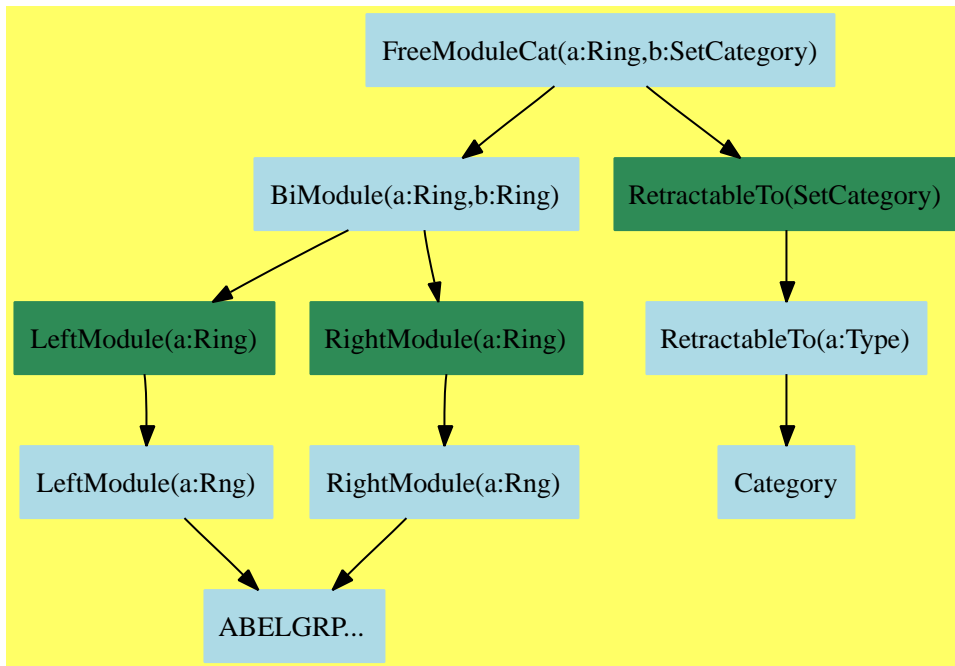
"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "ABELGRP..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"ABELGRP..." [color=lightblue];
}

```

FreeModuleCat (FMCAT)



— FreeModuleCat.input —

```

)set break resume
)sys rm -f FreeModuleCat.output
)spool FreeModuleCat.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FreeModuleCat
--R
--R FreeModuleCat(R: Ring,Basis: SetCategory) is a category constructor
--R Abbreviation for FreeModuleCat is FMCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FMCAT
--R
--R----- Operations -----
--R ?? : (R,Basis) -> %          ?? : (% ,R) -> %
--R ?? : (R,% ) -> %            ?? : (Integer,% ) -> %
--R ?? : (PositiveInteger,% ) -> %    ?+? : (% ,% ) -> %
--R ?-? : (% ,% ) -> %          -? : % -> %

```

```

--R ?=? : (%,%) -> Boolean
--R coefficient : (%,Basis) -> R
--R coerce : Basis -> %
--R hash : % -> SingleInteger
--R leadingCoefficient : % -> R
--R map : ((R -> R),%) -> %
--R monomial? : % -> Boolean
--R reductum : % -> %
--R sample : () -> %
--R ?~=? : (%,%) -> Boolean
--R ?*? : (NonNegativeInteger,%) -> %
--R leadingTerm : % -> Record(k: Basis,c: R)
--R listOfTerms : % -> List(Record(k: Basis,c: R))
--R numberOfMonomials : % -> NonNegativeInteger
--R retractIfCan : % -> Union(Basis,"failed")
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— FreeModuleCat.help —

=====

FreeModuleCat examples

=====

A domain of this category implements formal linear combinations of elements from a domain Basis with coefficients in a domain R. The domain Basis needs only to belong to the category SetCategory and R to the category Ring. Thus the coefficient ring may be non-commutative. See the XDistributedPolynomial constructor for examples of domains built with the FreeModuleCat category constructor.

See Also:

- o)show FreeModuleCat
- o)show XDistributedPolynomial

See:

⇐ “BiModule” (BMODULE) [9](#) on page 782

⇐ “RetractableTo” (RETRACT) [2](#) on page 95

Exports:

| | | | |
|-------------|--------------|--------------------|-----------------|
| 0 | coefficient | coefficients | coerce |
| hash | latex | leadingCoefficient | leadingMonomial |
| leadingTerm | listOfTerms | map | monom |
| monomial? | monomials | numberOfMonomials | reductum |
| retract | retractIfCan | sample | subtractIfCan |
| zero? | ?~=? | ?*? | ?+? |
| ?-? | -? | ?=? | |

Attributes Exported:

- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```

coefficient : (% ,Basis) -> R
coefficients : % -> List R
leadingCoefficient : % -> R
leadingMonomial : % -> Basis
leadingTerm : % -> Record(k: Basis,c: R)
listOfTerms : % -> List Record(k: Basis,c: R)
map : ((R -> R),%) -> %
monom : (Basis,R) -> %
monomial? : % -> Boolean
monomials : % -> List %
numberOfMonomials : % -> NonNegativeInteger
reductum : % -> %
?*? : (R,Basis) -> %

```

These exports come from (p782) `BiModule(R:Ring,R:Ring)`:

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (% ,%) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (% ,%) -> Boolean
?*? : (R,%) -> %
?=? : (% ,%) -> Boolean
?+? : (% ,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?*? : (Integer,%) -> %
?-? : (% ,%) -> %
-? : % -> %
?*? : (% ,R) -> %

```

These exports come from (p95) `RetractableTo(Basis:SetCategory)`:

```
coerce : Basis -> %
retract : % -> Basis
retractIfCan : % -> Union(Basis,"failed")
```

— category FMCAT FreeModuleCat —

```
)abbrev category FMCAT FreeModuleCat
++ Author: Michel Petitot petitot@lifl.fr
++ Date Created: 91
++ Date Last Updated: 7 Juillet 92
++ Fix History: compilation v 2.1 le 13 dec 98
++ Description:
++ A domain of this category
++ implements formal linear combinations
++ of elements from a domain \spad{Basis} with coefficients
++ in a domain \spad{R}. The domain \spad{Basis} needs only
++ to belong to the category \spadtype{SetCategory} and \spad{R}
++ to the category \spadtype{Ring}. Thus the coefficient ring
++ may be non-commutative.
++ See the \spadtype{XDistributedPolynomial} constructor
++ for examples of domains built with the \spadtype{FreeModuleCat}
++ category constructor.

FreeModuleCat(R, Basis):Category == Exports where
  R: Ring
  Basis: SetCategory
  TERM ==> Record(k: Basis, c: R)

Exports == Join(BiModule(R,R), RetractableTo Basis) with
  "*" : (R, Basis) -> %
  ++ \spad{r*b} returns the product of \spad{r} by \spad{b}.
  coefficient : (% , Basis) -> R
  ++ \spad{coefficient(x,b)} returns the coefficient
  ++ of \spad{b} in \spad{x}.
  map : (R -> R, %) -> %
  ++ \spad{map(fn,u)} maps function \spad{fn} onto the coefficients
  ++ of the non-zero monomials of \spad{u}.
  monom : (Basis, R) -> %
  ++ \spad{monom(b,r)} returns the element with the single monomial
  ++ \spad{b} and coefficient \spad{r}.
  monomial? : % -> Boolean
  ++ \spad{monomial?(x)} returns true if \spad{x} contains a single
  ++ monomial.
  listOfTerms : % -> List TERM
  ++ \spad{listOfTerms(x)} returns a list \spad{lt} of terms with type
  ++ \spad{Record(k: Basis, c: R)} such that \spad{x} equals
  ++ \spad{reduce(+, map(x +-> monom(x.k, x.c), lt))}.
```

```

coefficients      : % -> List R
++ \spad{coefficients(x)} returns the list of coefficients of \spad{x}
monomials         : % -> List %
++ \spad{monomials(x)} returns the list of \spad{r_i*b_i}
++ whose sum is \spad{x}.
numberOfMonomials : % -> NonNegativeInteger
++ \spad{numberOfMonomials(x)} returns the number of monomials
++ of \spad{x}.
leadingMonomial    : % -> Basis
++ \spad{leadingMonomial(x)} returns the first element from
++ \spad{Basis} which appears in \spad{listOfTerms(x)}.
leadingCoefficient : % -> R
++ \spad{leadingCoefficient(x)} returns the first coefficient
++ which appears in \spad{listOfTerms(x)}.
leadingTerm        : % -> TERM
++ \spad{leadingTerm(x)} returns the first term which
++ appears in \spad{listOfTerms(x)}.
reductum           : % -> %
++ \spad{reductum(x)} returns \spad{x} minus its leading term.

-- attributs
if R has CommutativeRing then Module(R)

```

— FMCAT.dotabb —

```

"FMCAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=FMCAT" ];
"FMCAT" -> "BMODULE"
"FMCAT" -> "RETRACT"

```

— FMCAT.dotfull —

```

"FreeModuleCat(a:Ring,b:SetCategory)"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=FMCAT" ];
"FreeModuleCat(a:Ring,b:SetCategory)" -> "BiModule(a:Ring,b:Ring)"
"FreeModuleCat(a:Ring,b:SetCategory)" -> "RetractableTo(SetCategory)"

```

— FMCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FreeModuleCat(a:Ring,b:SetCategory)" [color=lightblue];
  "FreeModuleCat(a:Ring,b:SetCategory)" -> "BiModule(a:Ring,b:Ring)"
  "FreeModuleCat(a:Ring,b:SetCategory)" -> "RetractableTo(SetCategory)"

  "RetractableTo(SetCategory)" [color=seagreen];
  "RetractableTo(SetCategory)" -> "RetractableTo(a:Type)"

  "RetractableTo(a:Type)" [color=lightblue];
  "RetractableTo(a:Type)" -> "Category"

  "Category" [color=lightblue];

  "BiModule(a:Ring,b:Ring)" [color=lightblue];
  "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
  "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

  "RightModule(a:Ring)" [color=seagreen];
  "RightModule(a:Ring)" -> "RightModule(a:Rng)"

  "RightModule(a:Rng)" [color=lightblue];
  "RightModule(a:Rng)" -> "ABELGRP..."

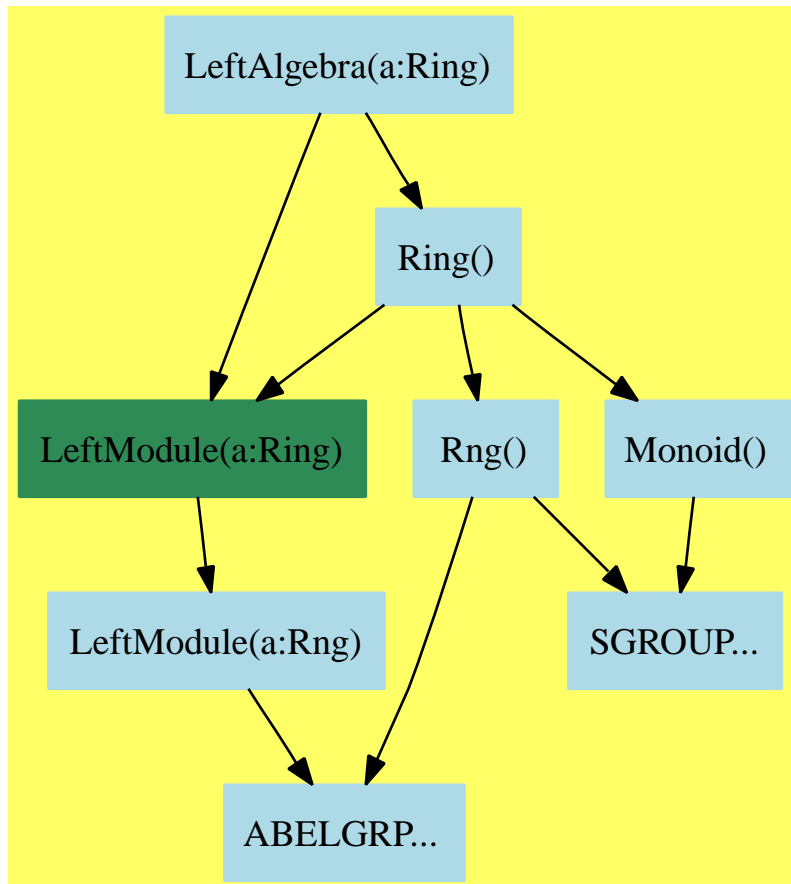
  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

  "LeftModule(a:Rng)" [color=lightblue];
  "LeftModule(a:Rng)" -> "ABELGRP..."

  "ABELGRP..." [color=lightblue];
}

```

LeftAlgebra (LALG)



— LeftAlgebra.input —

```

)set break resume
)sys rm -f LeftAlgebra.output
)spool LeftAlgebra.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show LeftAlgebra
--R
--R LeftAlgebra(R: Ring) is a category constructor
--R Abbreviation for LeftAlgebra is LALG
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LALG
--R
--R----- Operations -----
--R ??? : (R,%) -> %          ??? : (%,%) -> %
--R ??? : (Integer,%) -> %    ??? : (PositiveInteger,%) -> %
--R ??? : (%,PositiveInteger) -> %    ?+? : (%,%) -> %
--R ?-? : (%,%) -> %          -? : % -> %
--R ?=? : (%,%) -> Boolean     1 : () -> %
--R 0 : () -> %               ?^? : (%,PositiveInteger) -> %
--R coerce : R -> %           coerce : Integer -> %
--R coerce : % -> OutputForm   hash : % -> SingleInteger
--R latex : % -> String        one? : % -> Boolean
--R recip : % -> Union(%, "failed") sample : () -> %
--R zero? : % -> Boolean       ?^=? : (%,%) -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?^? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

```

```

)spool
)lisp (bye)

```

— LeftAlgebra.help —

```

=====
LeftAlgebra examples
=====

```

The category of all left algebras over an arbitrary ring.

See Also:

o)show LeftAlgebra

See:

⇐ “LeftModule” (LMODULE) 8 on page 710

⇐ “Ring” (RING) 9 on page 826

Exports:

| | | | | |
|---------------|-------|--------|-------|----------------|
| 0 | 1 | coerce | hash | latex |
| one? | recip | sample | zero? | characteristic |
| subtractIfCan | ?*? | ?+? | ?-? | -? |
| ?=? | ?~=? | ?**? | ?^? | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.

These are implemented by this category:

```
coerce : R -> %
```

These exports come from (p826) `Ring()`:

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : % -> OutputForm
coerce : Integer -> %
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (NonNegativeInteger, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (Integer, %) -> %
?*? : (%, %) -> %
?-? : (%, %) -> %
-? : % -> %
?*?? : (%, PositiveInteger) -> %
?*?? : (%, NonNegativeInteger) -> %
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
```

These exports come from (p710) `LeftModule(R:Type)`:

```
?*? : (R, %) -> %
```

```

)abbrev category LALG LeftAlgebra
++ Author: Larry A. Lambe
++ Date   : 03/01/89; revised 03/17/89; revised 12/02/90.
++ Description:
++ The category of all left algebras over an arbitrary ring.

LeftAlgebra(R:Ring): Category == Join(Ring, LeftModule R) with
  coerce: R -> %
  ++ coerce(r) returns r * 1 where 1 is the identity of the
  ++ left algebra.
add
  coerce(x:R):% == x * 1$%

```

— LALG.dotabb —

```

"LALG"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=LALG"];
"LALG" -> "LMODULE"
"LALG" -> "RING"

```

— LALG.dotfull —

```

"LeftAlgebra(a:Ring)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=LALG"];
"LeftAlgebra(a:Ring)" -> "LeftModule(a:Ring)"
"LeftAlgebra(a:Ring)" -> "Ring()"

```

— LALG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "LeftAlgebra(a:Ring)" [color=lightblue];
  "LeftAlgebra(a:Ring)" -> "LeftModule(a:Ring)"
  "LeftAlgebra(a:Ring)" -> "Ring()"

  "Ring()" [color=lightblue];

```



```

"Ring()" -> "Rng()"
"Ring()" -> "Monoid()"
"Ring()" -> "LeftModule(a:Ring)"

"Rng()" [color=lightblue];
"Rng()" -> "ABELGRP..."
"Rng()" -> "SGROUP..."

"Monoid()" [color=lightblue];
"Monoid()" -> "SGROUP..."

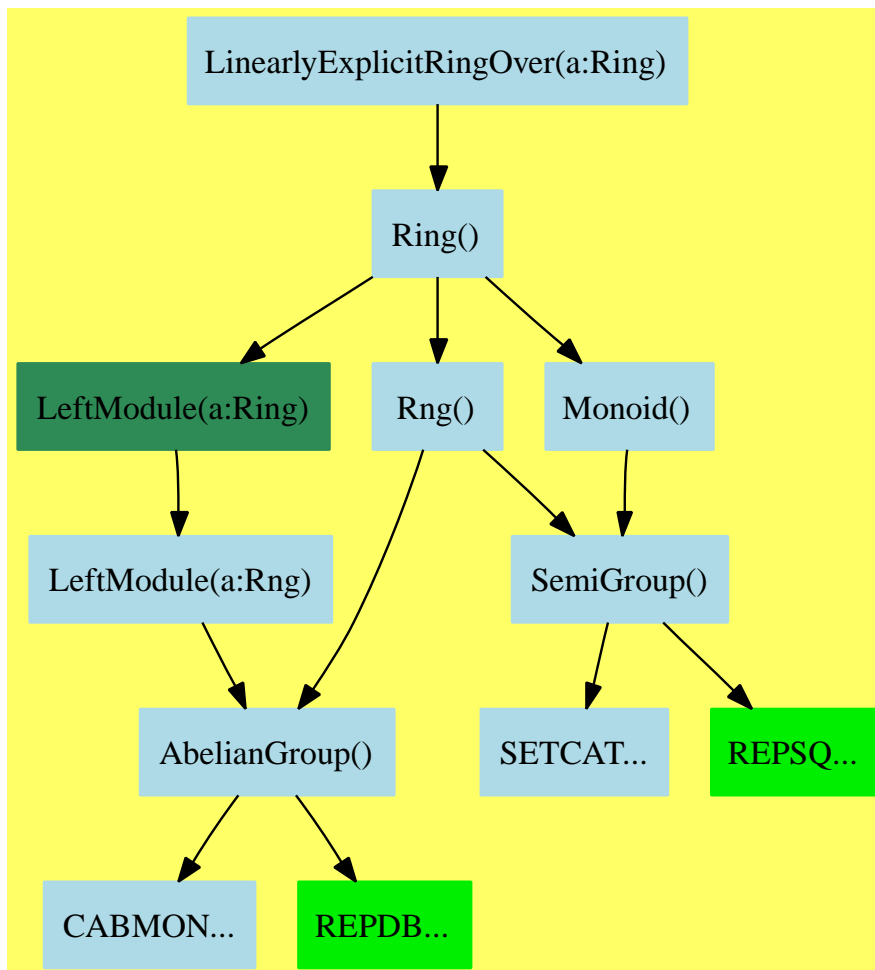
"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "ABELGRP..."

"SGROUP..." [color=lightblue];
"ABELGRP..." [color=lightblue];
}

```

LinearlyExplicitRingOver (LINEXP)



— LinearlyExplicitRingOver.input —

```

)set break resume
)sys rm -f LinearlyExplicitRingOver.output
)spool LinearlyExplicitRingOver.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show LinearlyExplicitRingOver
--R

```

```

--R LinearlyExplicitRingOver(R: Ring) is a category constructor
--R Abbreviation for LinearlyExplicitRingOver is LINEXP
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LINEXP
--R
--R----- Operations -----
--R ?? : (%,% ) -> %                ?? : (Integer,% ) -> %
--R ?? : (PositiveInteger,% ) -> %   ??? : (% ,PositiveInteger) -> %
--R ?+? : (%,% ) -> %                ?-? : (%,% ) -> %
--R -? : % -> %                      ?=? : (%,% ) -> Boolean
--R 1 : () -> %                      0 : () -> %
--R ?^? : (% ,PositiveInteger) -> %   coerce : Integer -> %
--R coerce : % -> OutputForm          hash : % -> SingleInteger
--R latex : % -> String               one? : % -> Boolean
--R recip : % -> Union(% ,"failed")   sample : () -> %
--R zero? : % -> Boolean              ?~=? : (%,% ) -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ?^? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R reducedSystem : (Matrix(% ),Vector(% )) -> Record(mat: Matrix(R),vec: Vector(R))
--R reducedSystem : Matrix(% ) -> Matrix(R)
--R subtractIfCan : (%,% ) -> Union(% ,"failed")
--R
--E 1

)spool
)lisp (bye)

```

— LinearlyExplicitRingOver.help —

```

=====
LinearlyExplicitRingOver examples
=====

```

An extension ring with an explicit linear dependence test.

See Also:

o)show LinearlyExplicitRingOver

See:

⇒ “FullyLinearlyExplicitRingOver” (FLINEXP) [11](#) on page [1012](#)

⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)

⇒ “MonogenicAlgebra” (MONOGEN) [19](#) on page [1651](#)

⇐ “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | | |
|--------|-------|----------------|---------------|---------------|
| 0 | 1 | characteristic | coerce | hash |
| latex | one? | recip | reducedSystem | subtractIfCan |
| sample | zero? | ?*? | ***? | ?+? |
| ?-? | -? | ?=? | ?^? | ?~=? |

Attributes exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return

These are directly exported but not implemented:

```
reducedSystem : (Matrix %,Vector %) ->
  Record(mat: Matrix R,vec: Vector R)
reducedSystem : Matrix % -> Matrix R
```

These exports come from (p[826](#)) Ring():

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (Integer,%) -> %
?*? : (%,%) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%,PositiveInteger) -> %
***? : (%,NonNegativeInteger) -> %
^? : (%,PositiveInteger) -> %
^? : (%,NonNegativeInteger) -> %
```

```

)abbrev category LINEXP LinearlyExplicitRingOver
++ Description:
++ An extension ring with an explicit linear dependence test.

LinearlyExplicitRingOver(R:Ring): Category == Ring with
  reducedSystem: Matrix % -> Matrix R
  ++ reducedSystem(A) returns a matrix B such that \spad{A x = 0}
  ++ and \spad{B x = 0} have the same solutions in R.
  reducedSystem: (Matrix %,Vector %) -> Record(mat:Matrix R,vec:Vector R)
  ++ reducedSystem(A, v) returns a matrix B and a vector w such that
  ++ \spad{A x = v} and \spad{B x = w} have the same solutions in R.

```

— LINEXP.dotabb —

```

"LINEXP"
[color=lightblue,href="bookvol10.2.pdf#nameddest=LINEXP"];
"LINEXP" -> "RING"

```

— LINEXP.dotfull —

```

"LinearlyExplicitRingOver(a:Ring)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=LINEXP"];
"LinearlyExplicitRingOver(a:Ring)" -> "Ring()"

"LinearlyExplicitRingOver(Integer)"
[color=seagreen,href="bookvol10.2.pdf#nameddest=LINEXP"];
"LinearlyExplicitRingOver(Integer)" -> "LinearlyExplicitRingOver(a:Ring)"

"LinearlyExplicitRingOver(Fraction(Integer))"
[color=seagreen,href="bookvol10.2.pdf#nameddest=LINEXP"];
"LinearlyExplicitRingOver(Fraction(Integer))" ->
  "LinearlyExplicitRingOver(a:Ring)"

```

— LINEXP.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

```

```

"LinearlyExplicitRingOver(a:Ring)" [color=lightblue];
"LinearlyExplicitRingOver(a:Ring)" -> "Ring()"

"Ring()" [color=lightblue];
"Ring()" -> "Rng()"
"Ring()" -> "Monoid()"
"Ring()" -> "LeftModule(a:Ring)"

"Rng()" [color=lightblue];
"Rng()" -> "AbelianGroup()"
"Rng()" -> "SemiGroup()"

"Monoid()" [color=lightblue];
"Monoid()" -> "SemiGroup()"

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "AbelianGroup()"

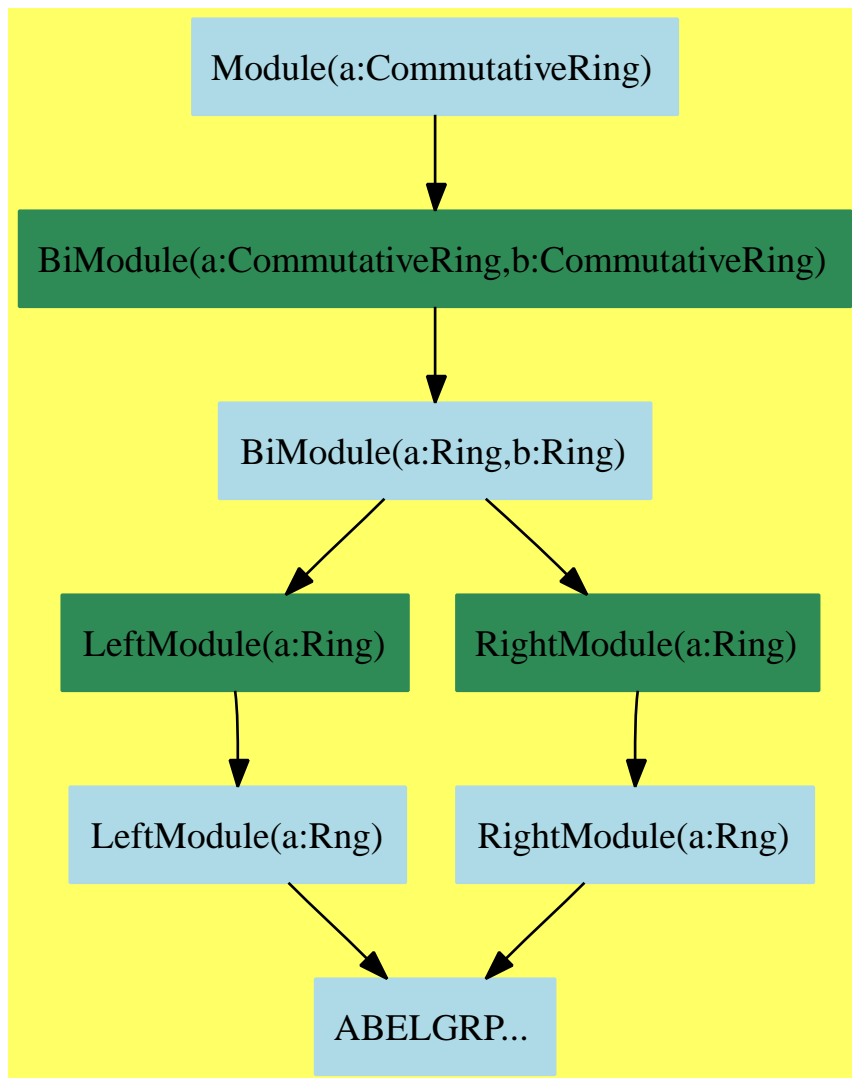
"AbelianGroup()" [color=lightblue];
"AbelianGroup()" -> "CABMON..."
"AbelianGroup()" -> "REPDB..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"CABMON..." [color=lightblue];
}

```

Module (MODULE)



— Module.input —

```

)set break resume
)sys rm -f Module.output
)spool Module.output
)set message test on
)set message auto off
)clear all
  
```

```

--S 1 of 1
)show Module
--R
--R Module(R: CommutativeRing) is a category constructor
--R Abbreviation for Module is MODULE
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MODULE
--R
--R----- Operations -----
--R ?? : (R,%) -> %           ?? : (R,%) -> %
--R ?? : (Integer,%) -> %     ?? : (PositiveInteger,%) -> %
--R ?? : (%,%) -> %          ?-? : (%,%) -> %
--R -? : % -> %              ?=? : (%,%) -> Boolean
--R 0 : () -> %              coerce : % -> OutputForm
--R hash : % -> SingleInteger latex : % -> String
--R sample : () -> %          zero? : % -> Boolean
--R ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— Module.help —

=====

Module examples

=====

The category of modules over a commutative ring.

Axioms:

```

1*x = x
(a*b)*x = a*(b*x)
(a+b)*x = (a*x)+(b*x)
a*(x+y) = (a*x)+(a*y)

```

See Also:

o)show Module

See:

\Rightarrow “Algebra” (ALGEBRA) [11](#) on page [999](#)
 \Rightarrow “LieAlgebra” (LIECAT) [11](#) on page [1018](#)
 \Rightarrow “NonAssociativeAlgebra” (NAALG) [11](#) on page [1032](#)
 \Rightarrow “RectangularMatrixCategory” (RMATCAT) [10](#) on page [954](#)
 \Rightarrow “VectorSpace” (VSPACE) [11](#) on page [1038](#)
 \Leftarrow “BiModule” (BMODULE) [9](#) on page [782](#)

Exports:

| | | | | |
|---------------|--------|------|-------|--------|
| 0 | coerce | hash | latex | sample |
| subtractIfCan | zero? | ?~=? | ?*? | ?+? |
| ?-? | -? | ?=? | | |

Attributes exported:

- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are implemented by this category:

```
?*? : (% , R) -> %
```

These exports come from ([p782](#)) BiModule(a:Ring,b:Ring):

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (% , %) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (% , %) -> Boolean
?*? : (NonNegativeInteger, %) -> %
?*? : (R, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?+? : (% , %) -> %
?-? : (% , %) -> %
-? : % -> %
?=? : (% , %) -> Boolean

```

— category MODULE Module —

```

)abbrev category MODULE Module
++ Description:
++ The category of modules over a commutative ring.

```

```

++
++ Axioms\br
++ \tab{5}\spad{1*x = x}\br
++ \tab{5}\spad{(a*b)*x = a*(b*x)}\br
++ \tab{5}\spad{(a+b)*x = (a*x)+(b*x)}\br
++ \tab{5}\spad{a*(x+y) = (a*x)+(a*y)}

Module(R:CommutativeRing): Category == BiModule(R,R)
add
  if not(R is %) then x:%*r:R == r*x

-----

— MODULE.dotabb —

"MODULE"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MODULE"];
"MODULE" -> "BMODULE"

-----

— MODULE.dotfull —

"Module(a:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MODULE"];
"Module(a:CommutativeRing)" ->
  "BiModule(a:CommutativeRing,b:CommutativeRing)"

"Module(Field)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=MODULE"];
"Module(Field)" -> "Module(a:CommutativeRing)"

-----

— MODULE.dotpic —

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" ->
  "BiModule(a:CommutativeRing,b:CommutativeRing)"

```

```

"BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BiModule(a:Ring,b:Ring)"

"BiModule(a:Ring,b:Ring)" [color=lightblue];
"BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
"BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

"RightModule(a:Ring)" [color=seagreen];
"RightModule(a:Ring)" -> "RightModule(a:Rng)"

"RightModule(a:Rng)" [color=lightblue];
"RightModule(a:Rng)" -> "ABELGRP..."

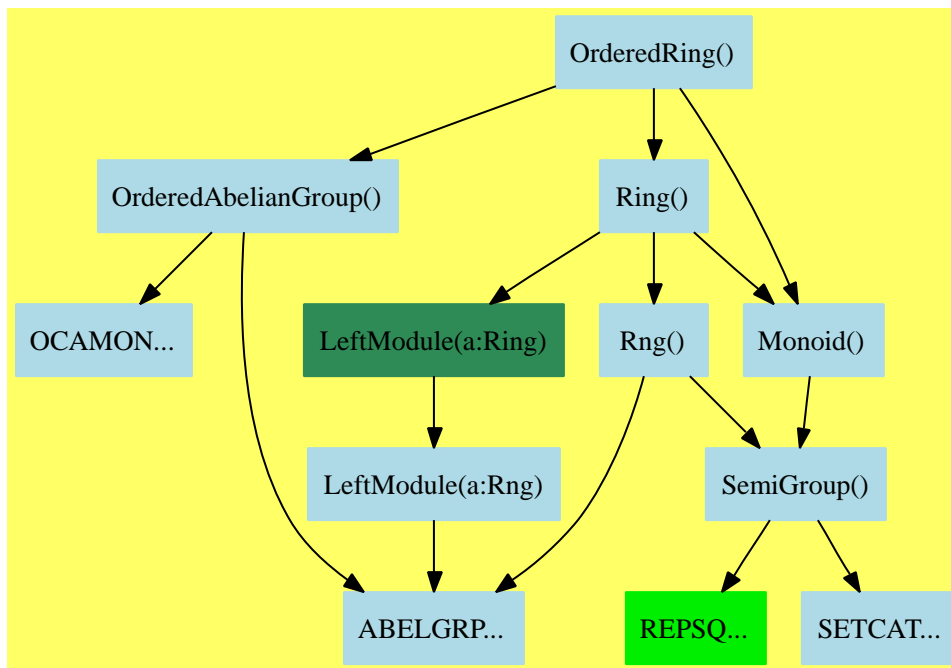
"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "ABELGRP..."

"ABELGRP..." [color=lightblue];
}

```

OrderedRing (ORDRING)



— OrderedRing.input —

```

)set break resume
)sys rm -f OrderedRing.output
)spool OrderedRing.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrderedRing
--R OrderedRing is a category constructor
--R Abbreviation for OrderedRing is ORDRING
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ORDRING
--R
--R----- Operations -----
--R ?? : (% ,%) -> %
--R ?? : (PositiveInteger ,%) -> %
--R ?? : (% ,%) -> %
--R ?? : (% ,%) -> %
--R ?<=? : (% ,%) -> Boolean
--R ?? : (Integer ,%) -> %
--R ??? : (% ,PositiveInteger) -> %
--R -? : % -> %
--R ?<? : (% ,%) -> Boolean
--R ?=? : (% ,%) -> Boolean

```

```

--R ?>? : (%,% ) -> Boolean
--R 1 : () -> %
--R ?^? : (% ,PositiveInteger) -> %
--R coerce : Integer -> %
--R hash : % -> SingleInteger
--R max : (% ,%) -> %
--R negative? : % -> Boolean
--R positive? : % -> Boolean
--R sample : () -> %
--R zero? : % -> Boolean
--R ?? : (NonNegativeInteger ,%) -> %
--R ***? : (% ,NonNegativeInteger) -> %
--R ?^? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R subtractIfCan : (% ,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— OrderedRing.help —

=====
OrderedRing examples
=====

Ordered sets which are also rings, that is, domains where the ring operations are compatible with the ordering.

Axiom:

$$0 < a \text{ and } b < c \Rightarrow ab < ac$$

See Also:

o)show OrderedRing

See:

- ⇒ “DirectProductCategory” (DIRPCAT) [12](#) on page [1051](#)
- ⇒ “OrderedIntegralDomain” (OINTDOM) [13](#) on page [1185](#)
- ⇒ “RealClosedField” (RCFIELD) [17](#) on page [1441](#)
- ⇒ “RealNumberSystem” (RNS) [17](#) on page [1451](#)
- ⇐ “Monoid” (MONOID) [5](#) on page [386](#)

← “OrderedAbelianGroup” (OAGROUP) [9](#) on page [811](#)

← “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | | |
|---------------|-----------|-------|----------------|-----------|
| 1 | 0 | abs | characteristic | coerce |
| hash | latex | max | min | negative? |
| one? | positive? | recip | sample | sign |
| subtractIfCan | zero? | ?^? | ?^=? | ?*? |
| ?**? | ?+? | -? | ?-? | ?<? |
| ?<=? | ?=? | ?>? | ?>=? | |

Attributes exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.

These are implemented by this category:

```
abs : % -> %
negative? : % -> Boolean
positive? : % -> Boolean
sign : % -> Integer
```

These exports come from (p[811](#)) OrderedAbelianGroup():

```
0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
max : (%,%) -> %
min : (%,%) -> %
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?<? : (%,%) -> Boolean
?<=? : (%,%) -> Boolean
?=? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean
?^=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (Integer,%) -> %
?+? : (%,%) -> %
-? : % -> %
?-? : (%,%) -> %
```

These exports come from (p[826](#)) Ring():

```

1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
one? : % -> Boolean
recip : % -> Union(%, "failed")
***? : (%, NonNegativeInteger) -> %
***? : (%, PositiveInteger) -> %
**? : (%, %) -> %
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %

```

— category ORDRING OrderedRing —

```

)abbrev category ORDRING OrderedRing
++ Description:
++ Ordered sets which are also rings, that is, domains where the ring
++ operations are compatible with the ordering.
++
++ Axiom\br
++ \tab{5}\spad{0<a and b<c => ab< ac}

OrderedRing(): Category == Join(OrderedAbelianGroup, Ring, Monoid) with
  positive?: % -> Boolean
    ++ positive?(x) tests whether x is strictly greater than 0.
  negative?: % -> Boolean
    ++ negative?(x) tests whether x is strictly less than 0.
  sign : % -> Integer
    ++ sign(x) is 1 if x is positive, -1 if x is negative,
    ++ 0 if x equals 0.
  abs : % -> %
    ++ abs(x) returns the absolute value of x.
add
  positive? x == x>0
  negative? x == x<0
  sign x ==
    positive? x => 1
    negative? x => -1
    zero? x => 0
    error "x satisfies neither positive?, negative? or zero?"
  abs x ==
    positive? x => x
    negative? x => -x
    zero? x => 0
    error "x satisfies neither positive?, negative? or zero?"

```

— ORDRING.dotabb —

```
"ORDRING"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ORDRING"];
"ORDRING" -> "OAGROUP"
"ORDRING" -> "RING"
"ORDRING" -> "MONOID"
```

— ORDRING.dotfull —

```
"OrderedRing()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ORDRING"];
"OrderedRing()" -> "OrderedAbelianGroup()"
"OrderedRing()" -> "Ring()"
"OrderedRing()" -> "Monoid()"
```

— ORDRING.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrderedRing()" [color=lightblue];
  "OrderedRing()" -> "OrderedAbelianGroup()"
  "OrderedRing()" -> "Ring()"
  "OrderedRing()" -> "Monoid()"

  "Ring()" [color=lightblue];
  "Ring()" -> "Rng()"
  "Ring()" -> "Monoid()"
  "Ring()" -> "LeftModule(a:Ring)"

  "Rng()" [color=lightblue];
  "Rng()" -> "ABELGRP..."
  "Rng()" -> "SemiGroup()"

  "Monoid()" [color=lightblue];
  "Monoid()" -> "SemiGroup()"

  "OrderedAbelianGroup()" [color=lightblue];
  "OrderedAbelianGroup()" -> "OCAMON..."
```



```
"OrderedAbelianGroup()" -> "ABELGRP..."

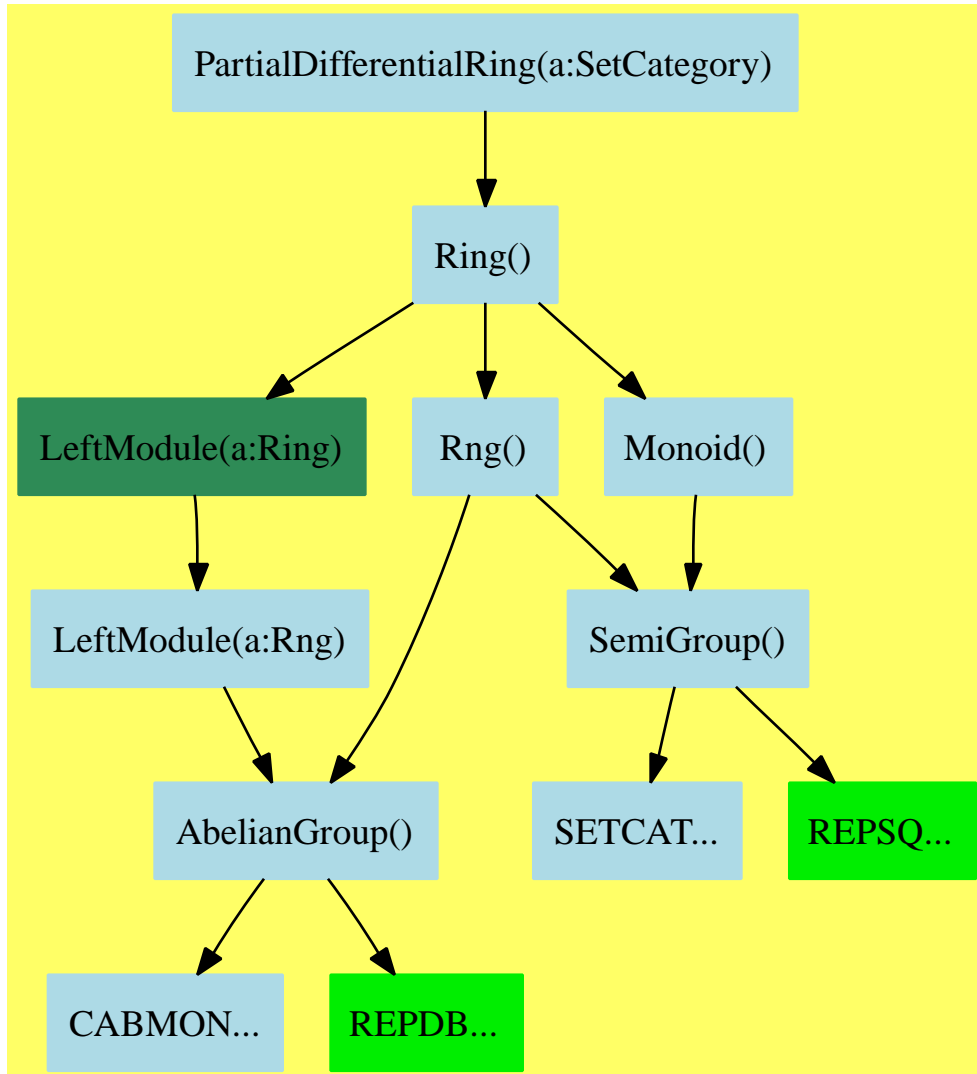
"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "ABELGRP..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"REPSQ..." [color="#00EE00"];
"OCAMON..." [color=lightblue];
"SETCAT..." [color=lightblue];
"ABELGRP..." [color=lightblue];
}
```

PartialDifferentialRing (PDRING)



— PartialDifferentialRing.input —

```

)set break resume
)sys rm -f PartialDifferentialRing.output
)spool PartialDifferentialRing.output
)set message test on
)set message auto off
)clear all
  
```

```

--S 1 of 1
)show PartialDifferentialRing
--R
--R PartialDifferentialRing(S: SetCategory) is a category constructor
--R Abbreviation for PartialDifferentialRing is PDRING
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PDRING
--R
--R----- Operations -----
--R ?? : (% ,%) -> %                ?? : (Integer,% ) -> %
--R ?? : (PositiveInteger,% ) -> %  ??? : (% ,PositiveInteger) -> %
--R ?+? : (% ,%) -> %                ?-? : (% ,%) -> %
--R -? : % -> %                      ?=? : (% ,%) -> Boolean
--R D : (% ,List(S)) -> %            D : (% ,S) -> %
--R 1 : () -> %                      0 : () -> %
--R ?? : (% ,PositiveInteger) -> %    coerce : Integer -> %
--R coerce : % -> OutputForm          differentiate : (% ,List(S)) -> %
--R differentiate : (% ,S) -> %        hash : % -> SingleInteger
--R latex : % -> String               one? : % -> Boolean
--R recip : % -> Union(% ,"failed")    sample : () -> %
--R zero? : % -> Boolean               ?~=? : (% ,%) -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R D : (% ,List(S),List(NonNegativeInteger)) -> %
--R D : (% ,S,NonNegativeInteger) -> %
--R ?? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R differentiate : (% ,List(S),List(NonNegativeInteger)) -> %
--R differentiate : (% ,S,NonNegativeInteger) -> %
--R subtractIfCan : (% ,%) -> Union(% ,"failed")
--R
--E 1

)spool
)lisp (bye)

```

— PartialDifferentialRing.help —

PartialDifferentialRing examples

A partial differential ring with differentiations indexed by a parameter type S.

Axioms:

```

differentiate(x+y,e)=differentiate(x,e)+differentiate(y,e)
differentiate(x*y,e)=x*differentiate(y,e)+differentiate(x,e)*y

```

See Also:

o)show PartialDifferentialRing

See:

⇒ “DifferentialExtension” (DIFEXT) [11](#) on page [1005](#)

⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)

⇒ “MultivariateTaylorSeriesCategory” (MTSCAT) [15](#) on page [1243](#)

⇒ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)

⇐ “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | | |
|---------------|---------------|----------------|--------|-------|
| 1 | 0 | characteristic | coerce | D |
| differentiate | hash | latex | one? | recip |
| sample | subtractIfCan | zero? | ?^? | ?*? |
| ?~=? | ?**? | ?+? | ?-? | -? |
| ?=? | | | | |

Attributes exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.

These are directly exported but not implemented:

```
differentiate : (% , S) -> %
```

These are implemented by this category:

```

D : (% , S) -> %
D : (% , List S) -> %
D : (% , S , NonNegativeInteger) -> %
D : (% , List S , List NonNegativeInteger) -> %
differentiate : (% , List S) -> %
differentiate : (% , S , NonNegativeInteger) -> %
differentiate : (% , List S , List NonNegativeInteger) -> %

```

These exports come from (p[826](#)) Ring():

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger

```

```

coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (%, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (NonNegativeInteger, %) -> %
?-? : (%, %) -> %
-? : % -> %
?^? : (%, PositiveInteger) -> %
?^? : (%, NonNegativeInteger) -> %
***? : (%, NonNegativeInteger) -> %
***? : (%, PositiveInteger) -> %

```

— category PDRING PartialDifferentialRing —

```

)abbrev category PDRING PartialDifferentialRing
++ Description:
++ A partial differential ring with differentiations indexed by a
++ parameter type S.
++
++ Axioms\br
++ \tab{5}\spad{differentiate(x+y,e)=differentiate(x,e)+differentiate(y,e)}\br
++ \tab{5}\spad{differentiate(x*y,e)=x*differentiate(y,e)+differentiate(x,e)*y}

```

```

PartialDifferentialRing(S:SetCategory): Category == Ring with

```

```

differentiate: (%, S) -> %
++ differentiate(x,v) computes the partial derivative of x
++ with respect to v.

differentiate: (%, List S) -> %
++ differentiate(x,[s1,...sn]) computes successive partial
++ derivatives,
++ that is, \spad{differentiate(...differentiate(x, s1)..., sn)}.

differentiate: (%, S, NonNegativeInteger) -> %
++ differentiate(x, s, n) computes multiple partial derivatives,
++ that is, n-th derivative of x with respect to s.

```

```

differentiate: (% , List S, List NonNegativeInteger) -> %
  ++ differentiate(x, [s1,...,sn], [n1,...,nn]) computes
  ++ multiple partial derivatives, that is, \spad{D(...D(x, s1)..., sn)}.

D: (% , S) -> %
  ++ D(x,v) computes the partial derivative of x
  ++ with respect to v.

D: (% , List S) -> %
  ++ D(x,[s1,...,sn]) computes successive partial derivatives,
  ++ that is, \spad{D(...D(x, s1)..., sn)}.

D: (% , S, NonNegativeInteger) -> %
  ++ D(x, s, n) computes multiple partial derivatives, that is,
  ++ n-th derivative of x with respect to s.

D: (% , List S, List NonNegativeInteger) -> %
  ++ D(x, [s1,...,sn], [n1,...,nn]) computes
  ++ multiple partial derivatives, that is,
  ++ \spad{D(...D(x, s1, n1)..., sn, nn)}.
add
differentiate(r:%, l:List S) ==
  for s in l repeat r := differentiate(r, s)
  r

differentiate(r:%, s:S, n:NonNegativeInteger) ==
  for i in 1..n repeat r := differentiate(r, s)
  r

differentiate(r:%, ls:List S, ln:List NonNegativeInteger) ==
  for s in ls for n in ln repeat r := differentiate(r, s, n)
  r

D(r:%, v:S) == differentiate(r,v)
D(r:%, lv:List S) == differentiate(r,lv)
D(r:%, v:S, n:NonNegativeInteger) == differentiate(r,v,n)
D(r:%, lv:List S, ln:List NonNegativeInteger) == differentiate(r, lv, ln)

```

— PDRING.dotabb —

```

"PDRING"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=PDRING" ];
"PDRING" -> "RING"

```

— PDRING.dotfull —

```

"PartialDifferentialRing(a:SetCategory)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PDRING"];
"PartialDifferentialRing(a:SetCategory)" -> "Ring()"

"PartialDifferentialRing(a:OrderedSet)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=PDRING"];
"PartialDifferentialRing(a:OrderedSet)" ->
  "PartialDifferentialRing(a:SetCategory)"

"PartialDifferentialRing(Symbol)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=PDRING"];
"PartialDifferentialRing(Symbol)" ->
  "PartialDifferentialRing(a:SetCategory)"

```

—————→

— PDRING.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PartialDifferentialRing(a:SetCategory)" [color=lightblue];
  "PartialDifferentialRing(a:SetCategory)" -> "Ring()"

  "Ring()" [color=lightblue];
  "Ring()" -> "Rng()"
  "Ring()" -> "Monoid()"
  "Ring()" -> "LeftModule(a:Ring)"

  "Rng()" [color=lightblue];
  "Rng()" -> "AbelianGroup()"
  "Rng()" -> "SemiGroup()"

  "Monoid()" [color=lightblue];
  "Monoid()" -> "SemiGroup()"

  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

  "LeftModule(a:Rng)" [color=lightblue];
  "LeftModule(a:Rng)" -> "AbelianGroup()"

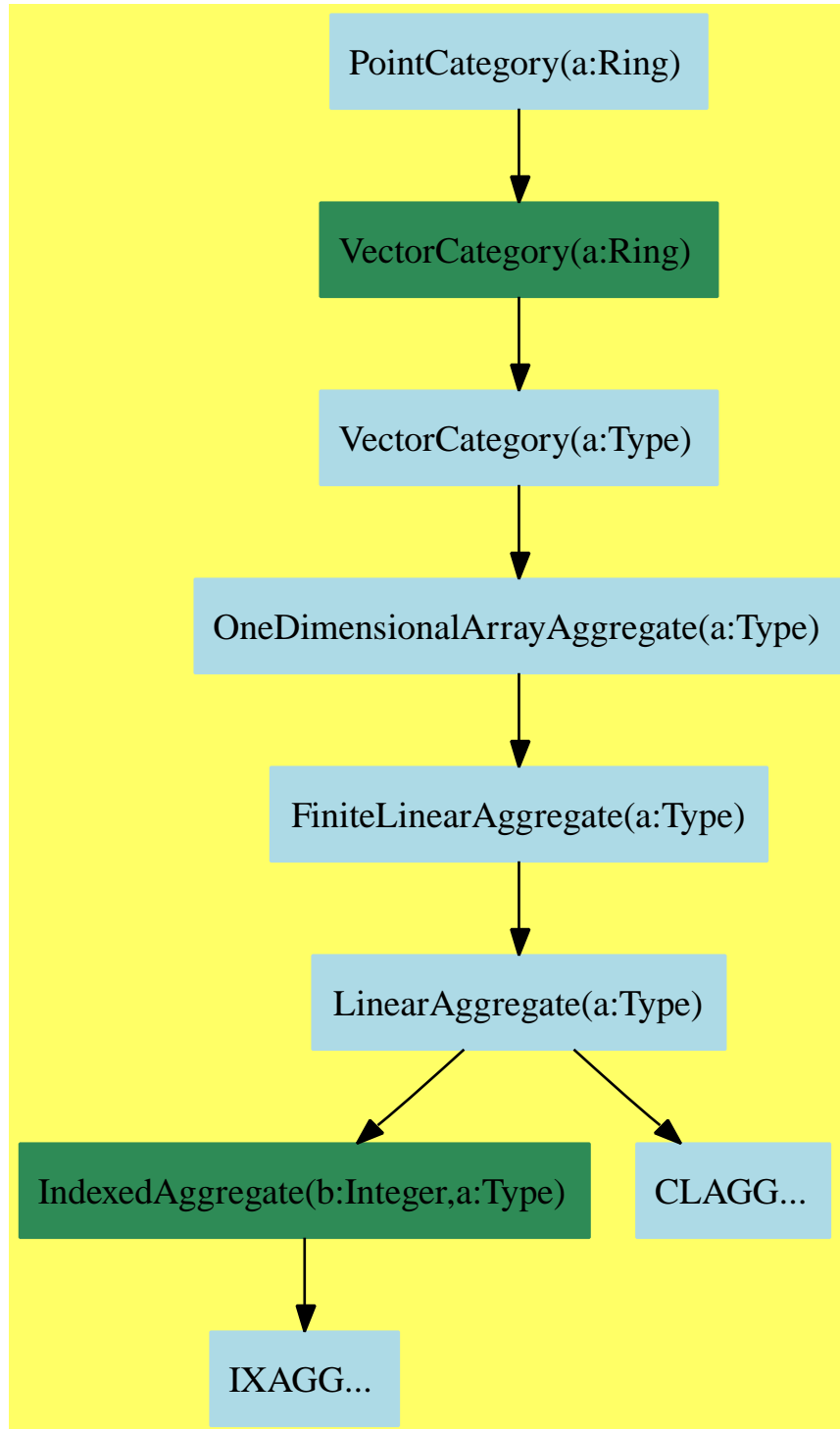
  "AbelianGroup()" [color=lightblue];

```

```
"AbelianGroup()" -> "CABMON..."
"AbelianGroup()" -> "REPDB..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"CABMON..." [color=lightblue];
}
```

PointCategory (PTCAT)

— PointCategory.input —

```

)set break resume
)sys rm -f PointCategory.output
)spool PointCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PointCategory
--R
--R PointCategory(R: Ring) is a category constructor
--R Abbreviation for PointCategory is PTCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PTCAT
--R
--R----- Operations -----
--R -? : % -> % if R has ABELGRP          concat : List(%) -> %
--R concat : (%,%) -> %                  concat : (R,%) -> %
--R concat : (%,R) -> %                  construct : List(R) -> %
--R convert : List(R) -> %              copy : % -> %
--R cross : (%,%) -> %                  delete : (%,Integer) -> %
--R dimension : % -> PositiveInteger    ?.? : (%,Integer) -> R
--R elt : (%,Integer,R) -> R            empty : () -> %
--R empty? : % -> Boolean               entries : % -> List(R)
--R eq? : (%,%) -> Boolean              extend : (%,List(R)) -> %
--R index? : (Integer,%) -> Boolean     indices : % -> List(Integer)
--R insert : (%,%,Integer) -> %         insert : (R,%,Integer) -> %
--R map : (((R,R) -> R),%,%) -> %       map : ((R -> R),%) -> %
--R new : (NonNegativeInteger,R) -> %   point : List(R) -> %
--R qelt : (%,Integer) -> R            reverse : % -> %
--R sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?? : (%,R) -> % if R has MONOID
--R ?? : (R,%) -> % if R has MONOID
--R ?? : (Integer,%) -> % if R has ABELGRP
--R ?? : (%,%) -> % if R has ABELSG
--R ?-? : (%,%) -> % if R has ABELGRP
--R ?<? : (%,%) -> Boolean if R has ORDSET
--R ?<=? : (%,%) -> Boolean if R has ORDSET
--R ?=? : (%,%) -> Boolean if R has SETCAT
--R ?>? : (%,%) -> Boolean if R has ORDSET
--R ?>=? : (%,%) -> Boolean if R has ORDSET
--R any? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
--R coerce : % -> OutputForm if R has SETCAT
--R convert : % -> InputForm if R has KONVERT(INFORM)

```

```

--R copyInto! : (%,%,Integer) -> % if $ has shallowlyMutable
--R count : (R,%) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
--R count : ((R -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R delete : (%,UniversalSegment(Integer)) -> %
--R dot : (%,%) -> R if R has RING
--R ?? : (%,UniversalSegment(Integer)) -> %
--R entry? : (R,%) -> Boolean if $ has finiteAggregate and R has SETCAT
--R eval : (%,List(R),List(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,R,R) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,Equation(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,List(Equation(R))) -> % if R has EVALAB(R) and R has SETCAT
--R every? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (%,R) -> % if $ has shallowlyMutable
--R find : ((R -> Boolean),%) -> Union(R,"failed")
--R first : % -> R if Integer has ORDSET
--R hash : % -> SingleInteger if R has SETCAT
--R latex : % -> String if R has SETCAT
--R length : % -> R if R has RING and R has RADCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R magnitude : % -> R if R has RING and R has RADCAT
--R map! : ((R -> R),%) -> % if $ has shallowlyMutable
--R max : (%,%) -> % if R has ORDSET
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (R,%) -> Boolean if R has SETCAT and $ has finiteAggregate
--R members : % -> List(R) if $ has finiteAggregate
--R merge : (%,%) -> % if R has ORDSET
--R merge : ((R,R) -> Boolean),%,%) -> %
--R min : (%,%) -> % if R has ORDSET
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (%,NonNegativeInteger) -> Boolean
--R outerProduct : (%,%) -> Matrix(R) if R has RING
--R parts : % -> List(R) if $ has finiteAggregate
--R position : (R,%,Integer) -> Integer if R has SETCAT
--R position : (R,%) -> Integer if R has SETCAT
--R position : ((R -> Boolean),%) -> Integer
--R qsetelt! : (%,Integer,R) -> R if $ has shallowlyMutable
--R reduce : ((R,R) -> R),%) -> R if $ has finiteAggregate
--R reduce : ((R,R) -> R),%,R) -> R if $ has finiteAggregate
--R reduce : ((R,R) -> R),%,R,R) -> R if R has SETCAT and $ has finiteAggregate
--R remove : ((R -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (R,%) -> % if R has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if R has SETCAT and $ has finiteAggregate
--R reverse! : % -> % if $ has shallowlyMutable
--R select : ((R -> Boolean),%) -> % if $ has finiteAggregate
--R setelt : (%,UniversalSegment(Integer),R) -> R if $ has shallowlyMutable
--R setelt : (%,Integer,R) -> R if $ has shallowlyMutable
--R size? : (%,NonNegativeInteger) -> Boolean
--R sort : % -> % if R has ORDSET
--R sort : ((R,R) -> Boolean),%) -> %
--R sort! : % -> % if R has ORDSET and $ has shallowlyMutable

```

```

--R sort! : ((R,R) -> Boolean),%) -> % if $ has shallowlyMutable
--R sorted? : % -> Boolean if R has ORDSET
--R sorted? : ((R,R) -> Boolean),%) -> Boolean
--R swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable
--R zero : NonNegativeInteger -> % if R has ABELMON
--R ?~=? : (%,% ) -> Boolean if R has SETCAT
--R
--E 1

```

```

)spool
)lisp (bye)

```

— **PointCategory.help** —

```

=====
PointCategory examples
=====

```

PointCategory is the category of points in space which may be plotted via the graphics facilities. Functions are provided for defining points and handling elements of points.

See Also:

o)show PointCategory

See:

⇐ “VectorCategory” (VECTCAT) [9](#) on page [863](#)

Exports:

| | | | | |
|-----------|------------------|---------|--------------|---------|
| any? | coerce | concat | construct | convert |
| copy | copyInto! | cross | count | delete |
| dimension | dot | elt | empty | empty? |
| entry? | entries | eq? | eval | every? |
| extend | fill! | find | first | hash |
| index? | indices | insert | latex | length |
| less? | magnitude | map | map! | max |
| maxIndex | member? | members | merge | min |
| minIndex | more? | new | outerProduct | parts |
| point | position | qelt | qsetelt! | reduce |
| remove | removeDuplicates | reverse | reverse! | sample |
| select | setelt | size? | sort | sort! |
| sorted? | swap! | zero | #? | ?? |
| ?~=? | -? | ?*? | ?+? | ?-? |
| ?<? | ?<=? | ?=? | ?>? | ?>=? |

Attributes Exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

These are directly exported but not implemented:

```
convert : List R -> %
cross : (%,% ) -> %
dimension : % -> PositiveInteger
extend : (% ,List R) -> %
point : List R -> %
```

These exports come from (p863) VectorCategory(R:Ring):

```
any? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
coerce : % -> OutputForm if R has SETCAT
concat : List % -> %
concat : (% ,%) -> %
concat : (R ,%) -> %
concat : (% ,R) -> %
construct : List R -> %
convert : % -> InputForm if R has KONVERT INFORM
copy : % -> %
copyInto! : (% ,%,Integer) -> % if $ has shallowlyMutable
count : (R ,%) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
count : ((R -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
delete : (% ,Integer) -> %
```

```

delete : (% , UniversalSegment Integer) -> %
dot : (% , %) -> R if R has RING
elt : (% , Integer, R) -> R
empty : () -> %
empty? : % -> Boolean
entry? : (R, %) -> Boolean if $ has finiteAggregate and R has SETCAT
entries : % -> List R
eq? : (% , %) -> Boolean
eval : (% , List R, List R) -> % if R has EVALAB R and R has SETCAT
eval : (% , R, R) -> % if R has EVALAB R and R has SETCAT
eval : (% , Equation R) -> % if R has EVALAB R and R has SETCAT
eval : (% , List Equation R) -> % if R has EVALAB R and R has SETCAT
every? : ((R -> Boolean), %) -> Boolean if $ has finiteAggregate
fill! : (% , R) -> % if $ has shallowlyMutable
find : ((R -> Boolean), %) -> Union(R, "failed")
first : % -> R if Integer has ORDSET
hash : % -> SingleInteger if R has SETCAT
index? : (Integer, %) -> Boolean
indices : % -> List Integer
insert : (% , %, Integer) -> %
insert : (R, %, Integer) -> %
latex : % -> String if R has SETCAT
length : % -> R if R has RING and R has RADCAT
less? : (% , NonNegativeInteger) -> Boolean
magnitude : % -> R if R has RING and R has RADCAT
map : (((R, R) -> R), %, %) -> %
map : ((R -> R), %) -> %
map! : ((R -> R), %) -> % if $ has shallowlyMutable
max : (% , %) -> % if R has ORDSET
maxIndex : % -> Integer if Integer has ORDSET
member? : (R, %) -> Boolean if R has SETCAT and $ has finiteAggregate
members : % -> List R if $ has finiteAggregate
merge : (% , %) -> % if R has ORDSET
merge : (((R, R) -> Boolean), %, %) -> %
min : (% , %) -> % if R has ORDSET
minIndex : % -> Integer if Integer has ORDSET
more? : (% , NonNegativeInteger) -> Boolean
new : (NonNegativeInteger, R) -> %
outerProduct : (% , %) -> Matrix R if R has RING
parts : % -> List R if $ has finiteAggregate
position : (R, %, Integer) -> Integer if R has SETCAT
position : (R, %) -> Integer if R has SETCAT
position : ((R -> Boolean), %) -> Integer
qelt : (% , Integer) -> R
qsetelt! : (% , Integer, R) -> R if $ has shallowlyMutable
reduce : (((R, R) -> R), %, %) -> R if $ has finiteAggregate
reduce : (((R, R) -> R), %, R) -> R if $ has finiteAggregate
reduce : (((R, R) -> R), %, R, R) -> R if R has SETCAT and $ has finiteAggregate
remove : ((R -> Boolean), %) -> % if $ has finiteAggregate
remove : (R, %) -> % if R has SETCAT and $ has finiteAggregate

```

```

removeDuplicates : % -> % if R has SETCAT and $ has finiteAggregate
reverse : % -> %
reverse! : % -> % if $ has shallowlyMutable
sample : () -> %
select : ((R -> Boolean),%) -> % if $ has finiteAggregate
setelt : (% , UniversalSegment Integer, R) -> R if $ has shallowlyMutable
setelt : (% , Integer, R) -> R if $ has shallowlyMutable
size? : (% , NonNegativeInteger) -> Boolean
sort : % -> % if R has ORDSET
sort : ((R, R) -> Boolean),% -> %
sort! : % -> % if R has ORDSET and $ has shallowlyMutable
sort! : ((R, R) -> Boolean),% -> % if $ has shallowlyMutable
sorted? : % -> Boolean if R has ORDSET
sorted? : ((R, R) -> Boolean),% -> Boolean
swap! : (% , Integer, Integer) -> Void if $ has shallowlyMutable
zero : NonNegativeInteger -> % if R has ABELMON
#? : % -> NonNegativeInteger if $ has finiteAggregate
?.? : (% , Integer) -> R
?.? : (% , UniversalSegment Integer) -> %
?~=? : (% , %) -> Boolean if R has SETCAT
?<? : (% , %) -> Boolean if R has ORDSET
?<=? : (% , %) -> Boolean if R has ORDSET
?=? : (% , %) -> Boolean if R has SETCAT
?>? : (% , %) -> Boolean if R has ORDSET
?>=? : (% , %) -> Boolean if R has ORDSET
?*? : (Integer, %) -> % if R has ABELGRP
?*? : (% , R) -> % if R has MONOID
?*? : (R, %) -> % if R has MONOID
?-? : (% , %) -> % if R has ABELGRP
-? : % -> % if R has ABELGRP
?+? : (% , %) -> % if R has ABELSG

```

— category PTCAT PointCategory —

```

)abbrev category PTCAT PointCategory
++ Description:
++ PointCategory is the category of points in space which
++ may be plotted via the graphics facilities. Functions are provided for
++ defining points and handling elements of points.

PointCategory(R:Ring) : Category == VectorCategory(R) with
  point: List R -> %
    ++ point(l) returns a point category defined by a list l of elements from
    ++ the domain R.
  dimension: % -> PositiveInteger
    ++ dimension(s) returns the dimension of the point category s.
  convert: List R -> %
    ++ convert(l) takes a list of elements, l, from the domain Ring and
    ++ returns the form of point category.

```

```

cross: (%,% ) -> %
  ++ cross(p,q) computes the cross product of the two points \spad{p}
  ++ and \spad{q}. Error if the p and q are not 3 dimensional
extend : (% ,List R) -> %
  ++ extend(x,l,r) \undocumented

```

— PTCAT.dotabb —

```

"PTCAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=PTCAT" ];
"PTCAT" -> "VECTCAT"

```

— PTCAT.dotfull —

```

"PointCategory(a:Ring)"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=PTCAT" ];
"PointCategory(a:Ring)" -> "VectorCategory(a:Ring)"

```

— PTCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PointCategory(a:Ring)" [color=lightblue];
  "PointCategory(a:Ring)" -> "VectorCategory(a:Ring)"

  "VectorCategory(a:Ring)" [color=seagreen];
  "VectorCategory(a:Ring)" -> "VectorCategory(a:Type)"

  "VectorCategory(a:Type)" [color=lightblue];
  "VectorCategory(a:Type)" -> "OneDimensionalArrayAggregate(a:Type)"

  "OneDimensionalArrayAggregate(a:Type)" [color=lightblue];
  "OneDimensionalArrayAggregate(a:Type)" ->
    "FiniteLinearAggregate(a:Type)"

  "FiniteLinearAggregate(a:Type)" [color=lightblue];

```



```

"FiniteLinearAggregate(a:Type)" -> "LinearAggregate(a:Type)"

"LinearAggregate(a:Type)" [color=lightblue];
"LinearAggregate(a:Type)" -> "IndexedAggregate(b:Integer,a:Type)"
"LinearAggregate(a:Type)" -> "CLAGG..."

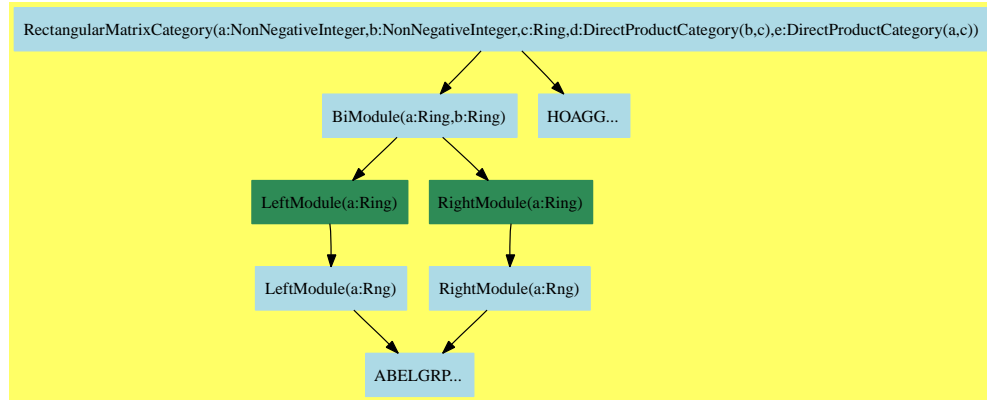
"IndexedAggregate(b:Integer,a:Type)" [color=seagreen];
"IndexedAggregate(b:Integer,a:Type)" -> "IXAGG..."

"CLAGG..." [color=lightblue];
"IXAGG..." [color=lightblue];
}

```

—————→

RectangularMatrixCategory (RMATCAT)



We define three categories for matrices

- MatrixCategory is the category of all matrices
- RectangularMatrixCategory is the category of all matrices of a given dimension
- SquareMatrixCategory inherits from RectangularMatrixCategory

RectangularMatrixCategory does not automatically inherit MatrixCategory. Note that domains in DirectProductCategory(n,R), which are expected as parameters of RectangularMatrixCategory do not satisfy FiniteLinearAggregate(R) as required in MatrixCategory.

The RectangularMatrix domain is matrices of fixed dimension.

— RectangularMatrixCategory.input —

```

)set break resume
)sys rm -f RectangularMatrixCategory.output
)spool RectangularMatrixCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RectangularMatrixCategory
--R
--R RectangularMatrixCategory(m: NonNegativeInteger,n: NonNegativeInteger,R: Ring,Row: DirectProductCategory,
--R Abbreviation for RectangularMatrixCategory is RMACAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RMACAT
--R
--R----- Operations -----
--R ??? : (%,R) -> %           ??? : (R,%) -> %
--R ??? : (Integer,%) -> %     ??? : (PositiveInteger,%) -> %
--R ?+? : (%,%) -> %          ?-? : (%,%) -> %
--R -? : % -> %               ?=? : (%,%) -> Boolean
--R 0 : () -> %               antisymmetric? : % -> Boolean
--R coerce : % -> OutputForm  column : (%,Integer) -> Col
--R copy : % -> %              diagonal? : % -> Boolean
--R elt : (%,Integer,Integer,R) -> R  elt : (%,Integer,Integer) -> R
--R empty : () -> %            empty? : % -> Boolean
--R eq? : (%,%) -> Boolean      hash : % -> SingleInteger
--R latex : % -> String         listOfLists : % -> List(List(R))
--R map : (((R,R) -> R),%,%) -> %    map : ((R -> R),%) -> %
--R matrix : List(List(R)) -> %      maxColIndex : % -> Integer
--R maxRowIndex : % -> Integer        minColIndex : % -> Integer
--R minRowIndex : % -> Integer        ncols : % -> NonNegativeInteger
--R nrows : % -> NonNegativeInteger   qelt : (%,Integer,Integer) -> R
--R row : (%,Integer) -> Row          sample : () -> %
--R square? : % -> Boolean            symmetric? : % -> Boolean
--R zero? : % -> Boolean             ?~=? : (%,%) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ??? : (NonNegativeInteger,%) -> %
--R ?/? : (%,R) -> % if R has FIELD
--R any? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
--R count : ((R -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R count : (R,%) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
--R eval : (%,List(Equation(R))) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,Equation(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,R,R) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,List(R),List(R)) -> % if R has EVALAB(R) and R has SETCAT
--R every? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
--R exquo : (%,R) -> Union(%, "failed") if R has INTDOM
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((R -> R),%) -> % if $ has shallowlyMutable
--R member? : (R,%) -> Boolean if R has SETCAT and $ has finiteAggregate

```

```

--R members : % -> List(R) if $ has finiteAggregate
--R more? : (% , NonNegativeInteger) -> Boolean
--R nullSpace : % -> List(Col) if R has INTDOM
--R nullity : % -> NonNegativeInteger if R has INTDOM
--R parts : % -> List(R) if $ has finiteAggregate
--R rank : % -> NonNegativeInteger if R has INTDOM
--R rowEchelon : % -> % if R has EUCDOM
--R size? : (% , NonNegativeInteger) -> Boolean
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— RectangularMatrixCategory.help —

```

=====
RectangularMatrixCategory examples
=====

```

RectangularMatrixCategory is a category of matrices of fixed dimensions.
 The dimensions of the matrix will be parameters of the domain.
 Domains in this category will be R-modules and will be non-mutable.

See Also:
 o)show RectangularMatrixCategory

See:

⇒ “SquareMatrixCategory” (SMATCAT) [12](#) on page [1131](#)
 ⇐ “BiModule” (BMODULE) [9](#) on page [782](#)
 ⇐ “HomogeneousAggregate” (HOAGG) [4](#) on page [233](#)
 ⇐ “MatrixCategory” (MATCAT) [6](#) on page [466](#)

Exports:

| | | | | |
|---------|----------------|-------------|-------------|---------|
| 0 | antisymmetric? | any? | coerce | column |
| copy | count | diagonal? | elt | empty |
| empty? | eq? | eval | every? | exquo |
| hash | latex | less? | listOfLists | map |
| map! | matrix | maxColIndex | maxRowIndex | member? |
| members | minColIndex | minRowIndex | more? | ncols |
| nrows | nullSpace | nullity | parts | qelt |
| rank | row | rowEchelon | sample | size? |
| square? | subtractIfCan | symmetric? | zero? | #? |
| ?* | ?/? | ?+? | ?-? | -? |
| ?=? | ?~=? | | | |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- **nil**

These are directly exported but not implemented:

```

column : (%,Integer) -> Col
elt : (%,Integer,Integer) -> R
elt : (%,Integer,Integer,R) -> R
exquo : (% ,R) -> Union(%,"failed") if R has INTDOM
listOfLists : % -> List List R
map : (((R,R) -> R),%,%) -> %
map : ((R -> R),%) -> %
maxColIndex : % -> Integer
maxRowIndex : % -> Integer
matrix : List List R -> %
minColIndex : % -> Integer
minRowIndex : % -> Integer
nullity : % -> NonNegativeInteger if R has INTDOM
nullSpace : % -> List Col if R has INTDOM
qelt : (%,Integer,Integer) -> R
rank : % -> NonNegativeInteger if R has INTDOM
row : (%,Integer) -> Row
rowEchelon : % -> % if R has EUCDOM
?/? : (% ,R) -> % if R has FIELD

```

These are implemented by this category:

```

antisymmetric? : % -> Boolean
diagonal? : % -> Boolean
ncols : % -> NonNegativeInteger
nrows : % -> NonNegativeInteger

```

```

square? : % -> Boolean
symmetric? : % -> Boolean

```

These exports come from (p782) BiModule(a:Ring,b:Ring)

```

0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%,%) -> Boolean
?*? : (R,%) -> %
?*? : (%,R) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?*? : (Integer,%) -> %
?=?: (%,%) -> Boolean
?+?: (%,%) -> %
?-?: (%,%) -> %
-?: % -> %

```

These exports come from (p233) HomogeneousAggregate(Ring)”

```

any? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
copy : % -> %
count : ((R -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
count : (R,%) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List Equation R) -> % if R has EVALAB R and R has SETCAT
eval : (%,Equation R) -> % if R has EVALAB R and R has SETCAT
eval : (%,R,R) -> % if R has EVALAB R and R has SETCAT
eval : (%,List R,List R) -> % if R has EVALAB R and R has SETCAT
every? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
less? : (%,NonNegativeInteger) -> Boolean
map! : ((R -> R),%) -> % if $ has shallowlyMutable
members : % -> List R if $ has finiteAggregate
member? : (R,%) -> Boolean if R has SETCAT and $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List R if $ has finiteAggregate
size? : (%,NonNegativeInteger) -> Boolean
#?: % -> NonNegativeInteger if $ has finiteAggregate

```

— category RMatCAT RectangularMatrixCategory —

```

)abbrev category RMatCAT RectangularMatrixCategory

```

```

++ Authors: Grabmeier, Gschnitzer, Williamson
++ Date Created: 1987
++ Date Last Updated: July 1990
++ Description:
++ \spadtype{RectangularMatrixCategory} is a category of matrices of fixed
++ dimensions. The dimensions of the matrix will be parameters of the
++ domain. Domains in this category will be R-modules and will be non-mutable.

RectangularMatrixCategory(m,n,R,Row,Col): Category == Definition where
  m,n : NonNegativeInteger
  R    : Ring
  Row  : DirectProductCategory(n,R)
  Col  : DirectProductCategory(m,R)

Definition ==> Join(BiModule(R,R),HomogeneousAggregate(R)) with

  finiteAggregate
    ++ matrices are finite

  if R has CommutativeRing then Module(R)

--% Matrix creation

matrix: List List R -> %
  ++ \spad{matrix(l)} converts the list of lists l to a matrix, where the
  ++ list of lists is viewed as a list of the rows of the matrix.

--% Predicates

square? : % -> Boolean
  ++ \spad{square?(m)} returns true if m is a square matrix (that is, if m
  ++ has the same number of rows as columns) and false otherwise.

diagonal?: % -> Boolean
  ++ \spad{diagonal?(m)} returns true if the matrix m is square and
  ++ diagonal (that is, all entries of m not on the diagonal are zero) and
  ++ false otherwise.

symmetric?: % -> Boolean
  ++ \spad{symmetric?(m)} returns true if the matrix m is square and
  ++ symmetric (that is, \spad{m[i,j] = m[j,i]} for all \spad{i} and j) and
  ++ false otherwise.

antisymmetric?: % -> Boolean
  ++ \spad{antisymmetric?(m)} returns true if the matrix m is square and
  ++ antisymmetric. That is,
  ++ \spad{m[i,j] = -m[j,i]} for all \spad{i} and j
  ++ and false otherwise.

--% Size inquiries

```

```

minRowIndex : % -> Integer
  ++ \spad{minRowIndex(m)} returns the index of the 'first' row of the
  ++ matrix m.

maxRowIndex : % -> Integer
  ++ \spad{maxRowIndex(m)} returns the index of the 'last' row of the
  ++ matrix m.

minColIndex : % -> Integer
  ++ \spad{minColIndex(m)} returns the index of the 'first' column of the
  ++ matrix m.

maxColIndex : % -> Integer
  ++ \spad{maxColIndex(m)} returns the index of the 'last' column of the
  ++ matrix m.

nrows : % -> NonNegativeInteger
  ++ \spad{nrows(m)} returns the number of rows in the matrix m.

ncols : % -> NonNegativeInteger
  ++ \spad{ncols(m)} returns the number of columns in the matrix m.

--% Part extractions

listOfLists: % -> List List R
  ++ \spad{listOfLists(m)} returns the rows of the matrix m as a list
  ++ of lists.

elt: (%,Integer,Integer) -> R
  ++ \spad{elt(m,i,j)} returns the element in the \spad{i}th row and
  ++ \spad{j}th column of the matrix m.
  ++ Error: if indices are outside the proper
  ++ ranges.

qelt: (%,Integer,Integer) -> R
  ++ \spad{qelt(m,i,j)} returns the element in the \spad{i}th row and
  ++ \spad{j}th column of
  ++ the matrix m. Note that there is NO error check to determine
  ++ if indices are in the proper ranges.

elt: (%,Integer,Integer,R) -> R
  ++ \spad{elt(m,i,j,r)} returns the element in the \spad{i}th row and
  ++ \spad{j}th column of the matrix m, if m has an \spad{i}th row and a
  ++ \spad{j}th column, and returns r otherwise.

row: (%,Integer) -> Row
  ++ \spad{row(m,i)} returns the \spad{i}th row of the matrix m.
  ++ Error: if the index is outside the proper range.

```

```

column: (%,Integer) -> Col
++ \spad{column(m,j)} returns the \spad{j}th column of the matrix m.
++ Error: if the index outside the proper range.

--% Map and Zip

map: (R -> R,%) -> %
++ \spad{map(f,a)} returns b, where \spad{b(i,j) = a(i,j)} for all i, j.

map: ((R,R) -> R,%,%) -> %
++ \spad{map(f,a,b)} returns c, where c is such that
++ \spad{c(i,j) = f(a(i,j),b(i,j))} for all \spad{i}, j.

--% Arithmetic

if R has IntegralDomain then

    "exquo": (%,R) -> Union(%, "failed")
    ++ \spad{exquo(m,r)} computes the exact quotient of the elements
    ++ of m by r, returning \axiom{"failed"} if this is not possible.

if R has Field then

    "/": (%,R) -> %
    ++ \spad{m/r} divides the elements of m by r. Error: if \spad{r = 0}.

--% Linear algebra

if R has EuclideanDomain then

    rowEchelon: % -> %
    ++ \spad{rowEchelon(m)} returns the row echelon form of the matrix m.

if R has IntegralDomain then

    rank: % -> NonNegativeInteger
    ++ \spad{rank(m)} returns the rank of the matrix m.

    nullity: % -> NonNegativeInteger
    ++ \spad{nullity(m)} returns the nullity of the matrix m. This is
    ++ the dimension of the null space of the matrix m.

    nullSpace: % -> List Col
    ++ \spad{nullSpace(m)}+ returns a basis for the null space of
    ++ the matrix m.

add
nrows x == m

ncols x == n

```



```

square? x == m = n

diagonal? x ==
  not square? x => false
  for i in minRowIndex x .. maxRowIndex x repeat
    for j in minColIndex x .. maxColIndex x
      | (j - minColIndex x) ^= (i - minRowIndex x) repeat
        not zero? qelt(x, i, j) => return false
  true

symmetric? x ==
  m ^= n => false
  mr := minRowIndex x; mc := minColIndex x
  for i in 0..(n - 1) repeat
    for j in (i + 1)..(n - 1) repeat
      qelt(x, mr + i, mc + j) ^= qelt(x, mr + j, mc + i) => return false
  true

antisymmetric? x ==
  m ^= n => false
  mr := minRowIndex x; mc := minColIndex x
  for i in 0..(n - 1) repeat
    for j in i..(n - 1) repeat
      qelt(x, mr + i, mc + j) ^= -qelt(x, mr + j, mc + i) =>
        return false
  true

```

— RMATCAT.dotabb —

```

"RMATCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RMATCAT"];
"RMATCAT" -> "BMODULE"
"RMATCAT" -> "HOAGG"

```

— RMATCAT.dotfull —

```

"RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductCateg
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RMATCAT"];
"RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductCateg
-> "BiModule(a:Ring,b:Ring)"
"RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductCateg
-> "HomogeneousAggregate(Ring)"

```

— RMatCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductCategory(b,c),e:Ring)"
    [color=lightblue];
  "RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductCategory(b,c),e:Ring)"
    -> "BiModule(a:Ring,b:Ring)"
  "RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductCategory(b,c),e:Ring)"
    -> "HOAGG..."

  "HOAGG..." [color=lightblue];
  "ABELGRP..." [color=lightblue];

  "BiModule(a:Ring,b:Ring)" [color=lightblue];
  "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
  "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

  "RightModule(a:Ring)" [color=seagreen];
  "RightModule(a:Ring)" -> "RightModule(a:Rng)"

  "RightModule(a:Rng)" [color=lightblue];
  "RightModule(a:Rng)" -> "ABELGRP..."

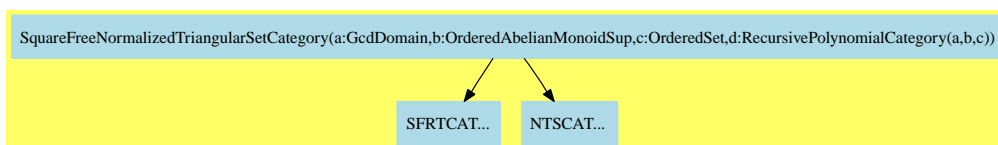
  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

  "LeftModule(a:Rng)" [color=lightblue];
  "LeftModule(a:Rng)" -> "ABELGRP..."

}

```

SquareFreeNormalizedTriangularSetCategory (SNTSCAT)



— SquareFreeNormalizedTriangularSetCategory.input —

```

)set break resume
)sys rm -f SquareFreeNormalizedTriangularSetCategory.output
)spool SquareFreeNormalizedTriangularSetCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show SquareFreeNormalizedTriangularSetCategory
--R
--R SquareFreeNormalizedTriangularSetCategory(R: GcdDomain,E: OrderedAbelianMonoidSup,V: Ordered
--R Abbreviation for SquareFreeNormalizedTriangularSetCategory is SNTSCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SNTSCAT
--R
--R----- Operations -----
--R ?=? : (% ,%) -> Boolean
--R algebraicVariables : % -> List(V)
--R augment : (P,List(%)) -> List(%)
--R coerce : % -> List(P)
--R collect : (% ,V) -> %
--R collectUnder : (% ,V) -> %
--R construct : List(P) -> %
--R degree : % -> NonNegativeInteger
--R empty? : % -> Boolean
--R extend : (List(P),%) -> List(%)
--R extend : (P,%) -> List(%)
--R first : % -> Union(P,"failed")
--R headReduce : (P,%) -> P
--R headReduced? : (P,%) -> Boolean
--R initiallyReduce : (P,%) -> P
--R initials : % -> List(P)
--R intersect : (P,%) -> List(%)
--R invertibleSet : (P,%) -> List(%)
--R latex : % -> String
--R mainVariables : % -> List(V)
--R mvar : % -> V
--R normalized? : (P,%) -> Boolean
--R reduceByQuasiMonic : (P,%) -> P
--R rest : % -> Union(%,"failed")
--R sample : () -> %
--R stronglyReduced? : % -> Boolean
--R variables : % -> List(V)
--R ?~=? : (% ,%) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate

algebraic? : (V,%) -> Boolean
augment : (List(P),%) -> List(%)
augment : (P,%) -> List(%)
coerce : % -> OutputForm
collectQuasiMonic : % -> %
collectUpper : (% ,V) -> %
copy : % -> %
empty : () -> %
eq? : (% ,%) -> Boolean
extend : (P,List(%)) -> List(%)
extend : (% ,P) -> %
hash : % -> SingleInteger
headReduced? : % -> Boolean
infRittWu? : (% ,%) -> Boolean
initiallyReduced? : % -> Boolean
internalAugment : (P,%) -> %
invertible? : (P,%) -> Boolean
last : % -> Union(P,"failed")
mainVariable? : (V,%) -> Boolean
map : ((P -> P),%) -> %
normalized? : % -> Boolean
purelyAlgebraic? : % -> Boolean
removeZero : (P,%) -> P
retract : List(P) -> %
stronglyReduce : (P,%) -> P
trivialIdeal? : % -> Boolean
zeroSetSplit : List(P) -> List(%)

```

```

--R algebraicCoefficients? : (P,%) -> Boolean
--R any? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
--R augment : (List(P),List(%)) -> List(%)
--R autoReduced? : (%,((P,List(P)) -> Boolean)) -> Boolean
--R basicSet : (List(P),(P -> Boolean),((P,P) -> Boolean)) -> Union(Record(bas: %,top: List(P)),"failed")
--R basicSet : (List(P),((P,P) -> Boolean)) -> Union(Record(bas: %,top: List(P)),"failed")
--R coHeight : % -> NonNegativeInteger if V has FINITE
--R convert : % -> InputForm if P has KONVERT(INFORM)
--R count : ((P -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R count : (P,%) -> NonNegativeInteger if P has SETCAT and $ has finiteAggregate
--R eval : (%,List(Equation(P))) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (%,Equation(P)) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (%,P,P) -> % if P has EVALAB(P) and P has SETCAT
--R eval : (%,List(P),List(P)) -> % if P has EVALAB(P) and P has SETCAT
--R every? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
--R extend : (List(P),List(%)) -> List(%)
--R extendIfCan : (%,P) -> Union(%, "failed")
--R find : ((P -> Boolean),%) -> Union(P, "failed")
--R headRemainder : (P,%) -> Record(num: P,den: R) if R has INTDOM
--R initiallyReduced? : (P,%) -> Boolean
--R internalAugment : (List(P),%) -> %
--R intersect : (P,List(%)) -> List(%)
--R intersect : (List(P),List(%)) -> List(%)
--R intersect : (List(P),%) -> List(%)
--R invertible? : (P,%) -> List(Record(val: Boolean,tower: %))
--R invertibleElseSplit? : (P,%) -> Union(Boolean,List(%))
--R lastSubResultant : (P,P,%) -> List(Record(val: P,tower: %))
--R lastSubResultantElseSplit : (P,P,%) -> Union(P,List(%))
--R less? : (%,NonNegativeInteger) -> Boolean
--R map! : ((P -> P),%) -> % if $ has shallowlyMutable
--R member? : (P,%) -> Boolean if P has SETCAT and $ has finiteAggregate
--R members : % -> List(P) if $ has finiteAggregate
--R more? : (%,NonNegativeInteger) -> Boolean
--R parts : % -> List(P) if $ has finiteAggregate
--R purelyAlgebraic? : (P,%) -> Boolean
--R purelyAlgebraicLeadingMonomial? : (P,%) -> Boolean
--R purelyTranscendental? : (P,%) -> Boolean
--R quasiComponent : % -> Record(close: List(P),open: List(P))
--R reduce : (P,%,((P,P) -> P),((P,P) -> Boolean)) -> P
--R reduce : (((P,P) -> P),%) -> P if $ has finiteAggregate
--R reduce : (((P,P) -> P),%,P) -> P if $ has finiteAggregate
--R reduce : (((P,P) -> P),%,P,P) -> P if P has SETCAT and $ has finiteAggregate
--R reduced? : (P,%,((P,P) -> Boolean)) -> Boolean
--R remainder : (P,%) -> Record(rnum: R,polnum: P,den: R) if R has INTDOM
--R remove : ((P -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (P,%) -> % if P has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
--R retractIfCan : List(P) -> Union(%, "failed")
--R rewriteIdealWithHeadRemainder : (List(P),%) -> List(P) if R has INTDOM
--R rewriteIdealWithRemainder : (List(P),%) -> List(P) if R has INTDOM

```

```

--R rewriteSetWithReduction : (List(P),%,((P,P) -> P),((P,P) -> Boolean)) -> List(P)
--R roughBase? : % -> Boolean if R has INTDOM
--R roughEqualIdeals? : (%,%) -> Boolean if R has INTDOM
--R roughSubIdeal? : (%,%) -> Boolean if R has INTDOM
--R roughUnitIdeal? : % -> Boolean if R has INTDOM
--R select : (%,V) -> Union(P,"failed")
--R select : ((P -> Boolean),%) -> % if $ has finiteAggregate
--R size? : (%,NonNegativeInteger) -> Boolean
--R sort : (%,V) -> Record(under: %,floor: %,upper: %)
--R squareFreePart : (P,%) -> List(Record(val: P,tower: %))
--R stronglyReduced? : (P,%) -> Boolean
--R triangular? : % -> Boolean if R has INTDOM
--R zeroSetSplit : (List(P),Boolean) -> List(%)
--R zeroSetSplitIntoTriangularSystems : List(P) -> List(Record(close: %,open: List(P)))
--R
--E 1

)spool
)lisp (bye)

```

— SquareFreeNormalizedTriangularSetCategory.help —

=====

SquareFreeNormalizedTriangularSetCategory examples

=====

The category of square-free and normalized triangular sets.
 Thus, up to the primitivity axiom of D. LAZARD
 "A new method for solving algebraic systems of positive dimension",
 these sets are Lazard triangular sets.

See Also:

o)show SquareFreeNormalizedTriangularSetCategory

See:

⇐ "NormalizedTriangularSetCategory" (NTSCAT) [9](#) on page [801](#)
 ⇐ "SquareFreeRegularTriangularSetCategory" (SFRTCAT) [9](#) on page [831](#)

Exports:

| | |
|---------------------------------|-----------------------------------|
| algebraic? | algebraicCoefficients? |
| algebraicVariables | any? |
| augment | autoReduced? |
| basicSet | coerce |
| coHeight | collect |
| collectQuasiMonic | collectUnder |
| collectUpper | construct |
| convert | copy |
| count | degree |
| empty | empty? |
| eq? | eval |
| every? | extend |
| extendIfCan | find |
| first | hash |
| headReduce | headReduced? |
| headRemainder | inFRittWu? |
| initiallyReduce | initiallyReduced? |
| initials | internalAugment |
| intersect | invertible? |
| invertibleElseSplit? | invertibleSet |
| last | lastSubResultant |
| lastSubResultantElseSplit | latex |
| less? | mainVariable? |
| mainVariables | map |
| map! | member? |
| members | more? |
| mvar | normalized? |
| parts | purelyAlgebraic? |
| purelyAlgebraicLeadingMonomial? | purelyTranscendental? |
| quasiComponent | reduce |
| reduced? | reduceByQuasiMonic |
| remainder | remove |
| removeDuplicates | removeZero |
| rest | retract |
| retractIfCan | rewriteIdealWithHeadRemainder |
| rewriteIdealWithRemainder | rewriteSetWithReduction |
| roughBase? | roughEqualIdeals? |
| roughSubIdeal? | roughUnitIdeal? |
| sample | select |
| size? | sort |
| squareFreePart | stronglyReduce |
| stronglyReduced? | triangular? |
| trivialIdeal? | variables |
| zeroSetSplit | zeroSetSplitIntoTriangularSystems |
| #? | ?=? |
| ?~=? | |

Attributes Exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

These exports come from

(p831) SquareFreeRegularTriangularSetCategory(R,E,V,P)
 where R:GcdDomain, E:OrderedAbelianMonoidSup, V:OrderedSet,
 P:RecursivePolynomialCategory(R,E,V):

```

algebraic? : (V,%) -> Boolean
algebraicCoefficients? : (P,%) -> Boolean
algebraicVariables : % -> List V
any? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
augment : (List P,List %) -> List %
augment : (List P,%) -> List %
augment : (P,List %) -> List %
augment : (P,%) -> List %
autoReduced? : (%,((P,List P) -> Boolean)) -> Boolean
basicSet :
  (List P,(P -> Boolean),((P,P) -> Boolean)) ->
    Union(Record(bas: %,top: List P),"failed")
basicSet :
  (List P,((P,P) -> Boolean)) ->
    Union(Record(bas: %,top: List P),"failed")
coerce : % -> List P
coerce : % -> OutputForm
coHeight : % -> NonNegativeInteger if V has FINITE
collect : (%,V) -> %
collectQuasiMonic : % -> %
collectUnder : (%,V) -> %
collectUpper : (%,V) -> %
construct : List P -> %
convert : % -> InputForm if P has KONVERT INFORM
copy : % -> %
count : ((P -> Boolean),%) -> NonNegativeInteger
  if $ has finiteAggregate
count : (P,%) -> NonNegativeInteger
  if P has SETCAT
  and $ has finiteAggregate
degree : % -> NonNegativeInteger
empty : () -> %
empty? : % -> Boolean
eq? : (%,%) -> Boolean
eval : (%,List Equation P) -> % if P has EVALAB P and P has SETCAT

```

```

eval : (%,Equation P) -> % if P has EVALAB P and P has SETCAT
eval : (%,P,P) -> % if P has EVALAB P and P has SETCAT
eval : (%,List P,List P) -> % if P has EVALAB P and P has SETCAT
every? : ((P -> Boolean),%) -> Boolean if $ has finiteAggregate
extend : (List P,List %) -> List %
extend : (List P,%) -> List %
extend : (P,List %) -> List %
extend : (P,%) -> List %
extend : (%,P) -> %
extendIfCan : (%,P) -> Union(%, "failed")
find : ((P -> Boolean),%) -> Union(P, "failed")
first : % -> Union(P, "failed")
hash : % -> SingleInteger
headReduce : (P,%) -> P
headReduced? : % -> Boolean
headReduced? : (P,%) -> Boolean
headRemainder : (P,%) -> Record(num: P,den: R) if R has INTDOM
infRittWu? : (%,%) -> Boolean
initiallyReduce : (P,%) -> P
initiallyReduced? : % -> Boolean
initiallyReduced? : (P,%) -> Boolean
initials : % -> List P
internalAugment : (P,%) -> %
internalAugment : (List P,%) -> %
intersect : (List P,List %) -> List %
intersect : (P,List %) -> List %
intersect : (List P,%) -> List %
intersect : (P,%) -> List %
invertible? : (P,%) -> Boolean
invertible? : (P,%) -> List Record(val: Boolean,tower: %)
invertibleElseSplit? : (P,%) -> Union(Boolean,List %)
invertibleSet : (P,%) -> List %
last : % -> Union(P, "failed")
lastSubResultant : (P,P,%) -> List Record(val: P,tower: %)
lastSubResultantElseSplit : (P,P,%) -> Union(P,List %)
latex : % -> String
less? : (%,NonNegativeInteger) -> Boolean
mainVariable? : (V,%) -> Boolean
mainVariables : % -> List V
map : ((P -> P),%) -> %
map! : ((P -> P),%) -> % if $ has shallowlyMutable
member? : (P,%) -> Boolean if P has SETCAT and $ has finiteAggregate
members : % -> List P if $ has finiteAggregate
more? : (%,NonNegativeInteger) -> Boolean
mvar : % -> V
normalized? : % -> Boolean
normalized? : (P,%) -> Boolean
parts : % -> List P if $ has finiteAggregate
purelyAlgebraic? : % -> Boolean
purelyAlgebraic? : (P,%) -> Boolean

```



```

purelyAlgebraicLeadingMonomial? : (P,%) -> Boolean
purelyTranscendental? : (P,%) -> Boolean
quasiComponent : % -> Record(close: List P,open: List P)
reduce : (P,%,((P,P) -> P),((P,P) -> Boolean)) -> P
reduce : (((P,P) -> P),%) -> P if $ has finiteAggregate
reduce : (((P,P) -> P),%,P) -> P if $ has finiteAggregate
reduce : (((P,P) -> P),%,P,P) -> P
  if P has SETCAT
  and $ has finiteAggregate
reduced? : (P,%,((P,P) -> Boolean)) -> Boolean
reduceByQuasiMonic : (P,%) -> P
remainder : (P,%) -> Record(rnum: R,polnum: P,den: R) if R has INTDOM
remove : ((P -> Boolean),%) -> % if $ has finiteAggregate
remove : (P,%) -> % if P has SETCAT and $ has finiteAggregate
removeDuplicates : % -> % if P has SETCAT and $ has finiteAggregate
removeZero : (P,%) -> P
rest : % -> Union(%, "failed")
retract : List P -> %
retractIfCan : List P -> Union(%, "failed")
rewriteIdealWithHeadRemainder : (List P,%) -> List P if R has INTDOM
rewriteIdealWithRemainder : (List P,%) -> List P if R has INTDOM
rewriteSetWithReduction :
  (List P,%,((P,P) -> P),((P,P) -> Boolean)) -> List P
roughBase? : % -> Boolean if R has INTDOM
roughEqualIdeals? : (%,%) -> Boolean if R has INTDOM
roughSubIdeal? : (%,%) -> Boolean if R has INTDOM
roughUnitIdeal? : % -> Boolean if R has INTDOM
sample : () -> %
select : (%,V) -> Union(P, "failed")
select : ((P -> Boolean),%) -> % if $ has finiteAggregate
size? : (%,NonNegativeInteger) -> Boolean
sort : (%,V) -> Record(under: %,floor: %,upper: %)
squareFreePart : (P,%) -> List Record(val: P,tower: %)
stronglyReduce : (P,%) -> P
stronglyReduced? : (P,%) -> Boolean
stronglyReduced? : % -> Boolean
triangular? : % -> Boolean if R has INTDOM
trivialIdeal? : % -> Boolean
variables : % -> List V
zeroSetSplit : List P -> List %
zeroSetSplit : (List P,Boolean) -> List %
zeroSetSplitIntoTriangularSystems :
  List P -> List Record(close: %,open: List P)
#? : % -> NonNegativeInteger if $ has finiteAggregate
?? : (%,%) -> Boolean
?~? : (%,%) -> Boolean

```

— category SNTSCAT SquareFreeNormalizedTriangularSetCategory

```

)abbrev category SNTSCAT SquareFreeNormalizedTriangularSetCategory
++ Author: Marc Moreno Maza
++ Date Created: 10/07/1998
++ Date Last Updated: 12/16/1998
++ References :
++ [1] D. LAZARD "A new method for solving algebraic systems of
++ positive dimension" Discr. App. Math. 33:147-160,1991
++ Description:
++ The category of square-free and normalized triangular sets.
++ Thus, up to the primitivity axiom of [1], these sets are Lazard
++ triangular sets.

```

```

SquareFreeNormalizedTriangularSetCategory(R:GcdDomain, _
                                         E:OrderedAbelianMonoidSup, _
                                         V:OrderedSet, _
                                         P:RecursivePolynomialCategory(R,E,V)):
    Category ==
    Join(SquareFreeRegularTriangularSetCategory(R,E,V,P), _
        NormalizedTriangularSetCategory(R,E,V,P))

```

— SNTSCAT.dotabb —

```

"SNTSCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SNTSCAT"];
"SNTSCAT" -> "NTSCAT"
"SNTSCAT" -> "SFRTCAT"

```

— SNTSCAT.dotfull —

```

"SquareFreeNormalizedTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P)):
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SNTSCAT"];
"SquareFreeNormalizedTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P)):
->
"SquareFreeRegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P)):
"SquareFreeNormalizedTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P)):
->
"NormalizedRegularTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:RecursivePolynomialCategory(R,E,V,P)):

```

— SNTSCAT.dotpic —

```

digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "SquareFreeNormalizedTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:
    [color=lightblue];
    "SquareFreeNormalizedTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:
    -> "SFRTCAT..."

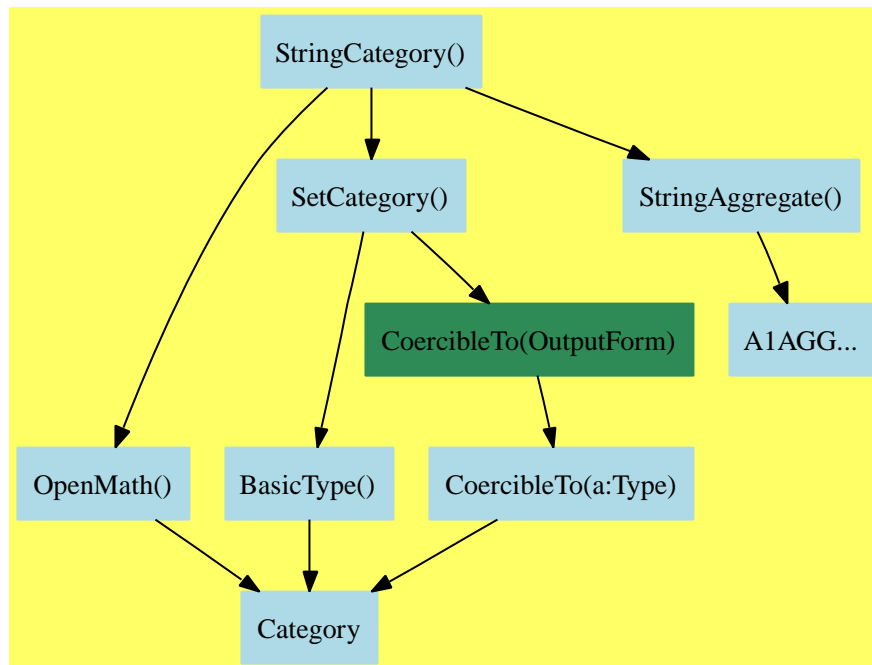
    "SquareFreeNormalizedTriangularSetCategory(a:GcdDomain,b:OrderedAbelianMonoidSup,c:OrderedSet,d:
    -> "NTSCAT..."

    "SFRTCAT..." [color=lightblue];
    "NTSCAT..." [color=lightblue];

}

```

StringCategory (STRICAT)



— StringCategory.input —

```

)set break resume
)sys rm -f StringCategory.output
)spool StringCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show StringCategory
--R
--R StringCategory is a category constructor
--R Abbreviation for StringCategory is STRICAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for STRICAT
--R
--R----- Operations -----
--R ?? : (%,%) -> Boolean          OMwrite : (%,Boolean) -> String
--R OMwrite : % -> String          coerce : % -> OutputForm
--R coerce : Character -> %        concat : List(%) -> %
--R concat : (%,%) -> %           concat : (Character,%) -> %
--R concat : (%,Character) -> %   construct : List(Character) -> %
--R copy : % -> %                 delete : (%,Integer) -> %
--R ?? : (%,%) -> %               ?? : (%,Integer) -> Character
--R empty : () -> %               empty? : % -> Boolean
--R entries : % -> List(Character) eq? : (%,%) -> Boolean
--R hash : % -> SingleInteger      index? : (Integer,%) -> Boolean
--R indices : % -> List(Integer)   insert : (%,%,Integer) -> %
--R latex : % -> String            leftTrim : (%,Character) -> %
--R lowerCase : % -> %             lowerCase! : % -> %
--R prefix? : (%,%) -> Boolean     qelt : (%,Integer) -> Character
--R reverse : % -> %               rightTrim : (%,Character) -> %
--R sample : () -> %              split : (%,Character) -> List(%)
--R string : Integer -> %          suffix? : (%,%) -> Boolean
--R trim : (%,CharacterClass) -> % trim : (%,Character) -> %
--R upperCase : % -> %             upperCase! : % -> %
--R ~=? : (%,%) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R <? : (%,%) -> Boolean if Character has ORDSET
--R <=? : (%,%) -> Boolean if Character has ORDSET
--R >? : (%,%) -> Boolean if Character has ORDSET
--R >=? : (%,%) -> Boolean if Character has ORDSET
--R OMwrite : (OpenMathDevice,%,Boolean) -> Void
--R OMwrite : (OpenMathDevice,%) -> Void
--R any? : ((Character -> Boolean),%) -> Boolean if $ has finiteAggregate
--R convert : % -> InputForm if Character has KONVERT(INFORM)
--R copyInto! : (%,%,Integer) -> % if $ has shallowlyMutable
--R count : (Character,%) -> NonNegativeInteger if Character has SETCAT and $ has finiteAggregate

```

```

--R count : ((Character -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R delete : (%,UniversalSegment(Integer)) -> %
--R ?.? : (%,UniversalSegment(Integer)) -> %
--R elt : (%,Integer,Character) -> Character
--R entry? : (Character,%) -> Boolean if $ has finiteAggregate and Character has SETCAT
--R eval : (%,List(Character),List(Character)) -> % if Character has EVALAB(Char) and Character
--R eval : (%,Character,Character) -> % if Character has EVALAB(Char) and Character has SETCAT
--R eval : (%,Equation(Character)) -> % if Character has EVALAB(Char) and Character has SETCAT
--R eval : (%,List(Equation(Character))) -> % if Character has EVALAB(Char) and Character has SE
--R every? : ((Character -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (%,Character) -> % if $ has shallowlyMutable
--R find : ((Character -> Boolean),%) -> Union(Character,"failed")
--R first : % -> Character if Integer has ORDSET
--R insert : (Character,%,Integer) -> %
--R leftTrim : (%,CharacterClass) -> %
--R less? : (%,NonNegativeInteger) -> Boolean
--R map : (((Character,Character) -> Character),%,%) -> %
--R map : ((Character -> Character),%) -> %
--R map! : ((Character -> Character),%) -> % if $ has shallowlyMutable
--R match : (%,%,Character) -> NonNegativeInteger
--R match? : (%,%,Character) -> Boolean
--R max : (%,%) -> % if Character has ORDSET
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (Character,%) -> Boolean if Character has SETCAT and $ has finiteAggregate
--R members : % -> List(Character) if $ has finiteAggregate
--R merge : (%,%) -> % if Character has ORDSET
--R merge : (((Character,Character) -> Boolean),%,%) -> %
--R min : (%,%) -> % if Character has ORDSET
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (%,NonNegativeInteger) -> Boolean
--R new : (NonNegativeInteger,Character) -> %
--R parts : % -> List(Character) if $ has finiteAggregate
--R position : (CharacterClass,%,Integer) -> Integer
--R position : (%,%,Integer) -> Integer
--R position : (Character,%,Integer) -> Integer if Character has SETCAT
--R position : (Character,%) -> Integer if Character has SETCAT
--R position : ((Character -> Boolean),%) -> Integer
--R qsetelt! : (%,Integer,Character) -> Character if $ has shallowlyMutable
--R reduce : (((Character,Character) -> Character),%) -> Character if $ has finiteAggregate
--R reduce : (((Character,Character) -> Character),%,Character) -> Character if $ has finiteAggr
--R reduce : (((Character,Character) -> Character),%,Character,Character) -> Character if Charac
--R remove : ((Character -> Boolean),%) -> % if $ has finiteAggregate
--R remove : (Character,%) -> % if Character has SETCAT and $ has finiteAggregate
--R removeDuplicates : % -> % if Character has SETCAT and $ has finiteAggregate
--R replace : (%,UniversalSegment(Integer),%) -> %
--R reverse! : % -> % if $ has shallowlyMutable
--R rightTrim : (%,CharacterClass) -> %
--R select : ((Character -> Boolean),%) -> % if $ has finiteAggregate
--R setelt : (%,UniversalSegment(Integer),Character) -> Character if $ has shallowlyMutable
--R setelt : (%,Integer,Character) -> Character if $ has shallowlyMutable

```

```

--R size? : (% , NonNegativeInteger) -> Boolean
--R sort : % -> % if Character has ORDSET
--R sort : (((Character,Character) -> Boolean),%) -> %
--R sort! : % -> % if Character has ORDSET and $ has shallowlyMutable
--R sort! : (((Character,Character) -> Boolean),%) -> % if $ has shallowlyMutable
--R sorted? : % -> Boolean if Character has ORDSET
--R sorted? : (((Character,Character) -> Boolean),%) -> Boolean
--R split : (% , CharacterClass) -> List(%)
--R substring? : (% , %, Integer) -> Boolean
--R swap! : (% , Integer, Integer) -> Void if $ has shallowlyMutable
--R
--E 1

)spool
)lisp (bye)

```

— StringCategory.help —

```

=====
StringCategory examples
=====

```

A category for string-like objects

See Also:

o)show StringCategory

See:

⇐ “OpenMath” (OM) [2](#) on page [76](#)

⇐ “SetCategory” (SETCAT) [3](#) on page [162](#)

⇐ “StringAggregate” (SRAGG) [9](#) on page [841](#)

Exports:

| | | | | |
|------------------|-----------|-----------|------------|------------|
| any? | coerce | concat | construct | convert |
| copy | copyInto! | count | delete | elt |
| empty | empty? | entry? | entries | eq? |
| eval | every? | fill! | find | first |
| hash | index? | indices | insert | latex |
| leftTrim | less? | lowerCase | lowerCase! | map |
| map! | match | match? | max | maxIndex |
| member? | members | merge | min | minIndex |
| more? | new | OMwrite | parts | position |
| prefix? | qelt | qsetelt! | reduce | remove |
| removeDuplicates | replace | reverse | reverse! | rightTrim |
| sample | select | setelt | size? | sort |
| sort! | sorted? | split | string | substring? |
| suffix? | swap! | trim | upperCase | upperCase! |
| #? | ?<? | ?<=? | ?>? | ?>=? |
| ?=? | ?..? | ?~=? | | |

Attributes exported:

- **shallowlyMutable** is true if its values have immediate components that are updateable (mutable). Note that the properties of any component domain are irrelevant to the shallowlyMutable proper.
- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **nil**

These are directly exported but not implemented:

```
string : Integer -> %
```

These exports come from (p841) StringAggregate():

```
any? : ((Character -> Boolean),%) -> Boolean
  if $ has finiteAggregate
coerce : % -> OutputForm
coerce : Character -> %
concat : List % -> %
concat : (%,% ) -> %
concat : (Character,% ) -> %
concat : (% ,Character) -> %
construct : List Character -> %
convert : % -> InputForm
  if Character has KONVERT INFORM
copy : % -> %
copyInto! : (% ,%,Integer) -> %
  if $ has shallowlyMutable
count : (Character,% ) -> NonNegativeInteger
  if Character has SETCAT
```

```

    and $ has finiteAggregate
count : ((Character -> Boolean),%) -> NonNegativeInteger
    if $ has finiteAggregate
delete : (%,UniversalSegment Integer) -> %
delete : (%,Integer) -> %
elt : (%,Integer,Character) -> Character
empty : () -> %
empty? : % -> Boolean
entry? : (Character,%) -> Boolean
    if $ has finiteAggregate
    and Character has SETCAT
entries : % -> List Character
eq? : (%,%) -> Boolean
eval : (%,List Character,List Character) -> %
    if Character has EVALAB CHAR
    and Character has SETCAT
eval : (%,Character,Character) -> %
    if Character has EVALAB CHAR
    and Character has SETCAT
eval : (%,Equation Character) -> %
    if Character has EVALAB CHAR
    and Character has SETCAT
eval : (%,List Equation Character) -> %
    if Character has EVALAB CHAR
    and Character has SETCAT
every? : ((Character -> Boolean),%) -> Boolean
    if $ has finiteAggregate
fill! : (%,Character) -> %
    if $ has shallowlyMutable
find : ((Character -> Boolean),%) -> Union(Character,"failed")
first : % -> Character
    if Integer has ORDSET
hash : % -> SingleInteger
index? : (Integer,%) -> Boolean
indices : % -> List Integer
insert : (%,%,Integer) -> %
insert : (Character,%,Integer) -> %
latex : % -> String
leftTrim : (%,Character) -> %
leftTrim : (%,CharacterClass) -> %
less? : (%,NonNegativeInteger) -> Boolean
lowerCase : % -> %
lowerCase! : % -> %
map : (((Character,Character) -> Character),%,%) -> %
map : ((Character -> Character),%) -> %
map! : ((Character -> Character),%) -> %
    if $ has shallowlyMutable
match : (%,%,Character) -> NonNegativeInteger
match? : (%,%,Character) -> Boolean
max : (%,%) -> % if Character has ORDSET

```



```

maxIndex : % -> Integer if Integer has ORDSET
member? : (Character,%) -> Boolean
    if Character has SETCAT
    and $ has finiteAggregate
members : % -> List Character
    if $ has finiteAggregate
merge : (%,%) -> % if Character has ORDSET
merge : (((Character,Character) -> Boolean),%,%) -> %
min : (%,%) -> % if Character has ORDSET
minIndex : % -> Integer if Integer has ORDSET
more? : (%,NonNegativeInteger) -> Boolean
new : (NonNegativeInteger,Character) -> %
parts : % -> List Character if $ has finiteAggregate
position : (Character,%) -> Integer
    if Character has SETCAT
position : ((Character -> Boolean),%) -> Integer
position : (Character,%,Integer) -> Integer
    if Character has SETCAT
position : (CharacterClass,%,Integer) -> Integer
position : (%,%,Integer) -> Integer
prefix? : (%,%) -> Boolean
qelt : (%,Integer) -> Character
qsetelt! : (%,Integer,Character) -> Character
    if $ has shallowlyMutable
reduce : (((Character,Character) -> Character),%,%)
    -> Character
    if $ has finiteAggregate
reduce : (((Character,Character) -> Character),%,Character)
    -> Character
    if $ has finiteAggregate
reduce :
    (((Character,Character) -> Character),%,Character,Character)
    -> Character
    if Character has SETCAT
    and $ has finiteAggregate
remove : ((Character -> Boolean),%) -> %
    if $ has finiteAggregate
remove : (Character,%) -> %
    if Character has SETCAT
    and $ has finiteAggregate
removeDuplicates : % -> %
    if Character has SETCAT
    and $ has finiteAggregate
replace : (%,UniversalSegment Integer,%) -> %
reverse : % -> %
reverse! : % -> % if $ has shallowlyMutable
rightTrim : (%,CharacterClass) -> %
rightTrim : (%,Character) -> %
sample : () -> %
select : ((Character -> Boolean),%) -> %

```

```

    if $ has finiteAggregate
setelt :
  (%,UniversalSegment Integer,Character) -> Character
    if $ has shallowlyMutable
setelt : (%,Integer,Character) -> Character
    if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
sort : % -> % if Character has ORDSET
sort : (((Character,Character) -> Boolean),%) -> %
sort! : % -> %
    if Character has ORDSET
    and $ has shallowlyMutable
sort! : (((Character,Character) -> Boolean),%) -> %
    if $ has shallowlyMutable
sorted? : (((Character,Character) -> Boolean),%) -> Boolean
sorted? : % -> Boolean if Character has ORDSET
split : (%,CharacterClass) -> List %
split : (%,Character) -> List %
substring? : (%,%,Integer) -> Boolean
suffix? : (%,%) -> Boolean
swap! : (%,Integer,Integer) -> Void
    if $ has shallowlyMutable
trim : (%,CharacterClass) -> %
trim : (%,Character) -> %
upperCase : % -> %
upperCase! : % -> %
#? : % -> NonNegativeInteger if $ has finiteAggregate
?<? : (%,%) -> Boolean if Character has ORDSET
?<=? : (%,%) -> Boolean if Character has ORDSET
?>? : (%,%) -> Boolean if Character has ORDSET
?>=? : (%,%) -> Boolean if Character has ORDSET
?=?: (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?.? : (%,UniversalSegment Integer) -> %
?.? : (%,Integer) -> Character
?.? : (%,%) -> %

```

These exports come from (p162) SetCategory():

These exports come from (p76) OpenMath():

```

OMwrite : (%,Boolean) -> String
OMwrite : % -> String
OMwrite : (OpenMathDevice,%,Boolean) -> Void
OMwrite : (OpenMathDevice,%) -> Void

```

— category STRICAT StringCategory —

```

)abbrev category STRICAT StringCategory
++ Description:
++ A category for string-like objects

StringCategory():Category == _
    Join(StringAggregate(), SetCategory, OpenMath) with
    string: Integer -> %
    ++ string(i) returns the decimal representation of i in a string

```

— STRICAT.dotabb —

```

"STRICAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=STRICAT"];
"STRICAT" -> "OM"
"STRICAT" -> "SETCAT"
"STRICAT" -> "SRAGG"

```

— STRICAT.dotfull —

```

"StringCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=STRICAT"];
"StringCategory()" -> "OpenMath()"
"StringCategory()" -> "SetCategory()"
"StringCategory()" -> "StringAggregate()"

```

— STRICAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "StringCategory()" [color=lightblue];
  "StringCategory()" -> "OpenMath()"
  "StringCategory()" -> "SetCategory()"
  "StringCategory()" -> "StringAggregate()"

  "OpenMath()" [color=lightblue];
  "OpenMath()" -> "Category"

```

```

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

"StringAggregate()" [color=lightblue];
"StringAggregate()" -> "A1AGG..."

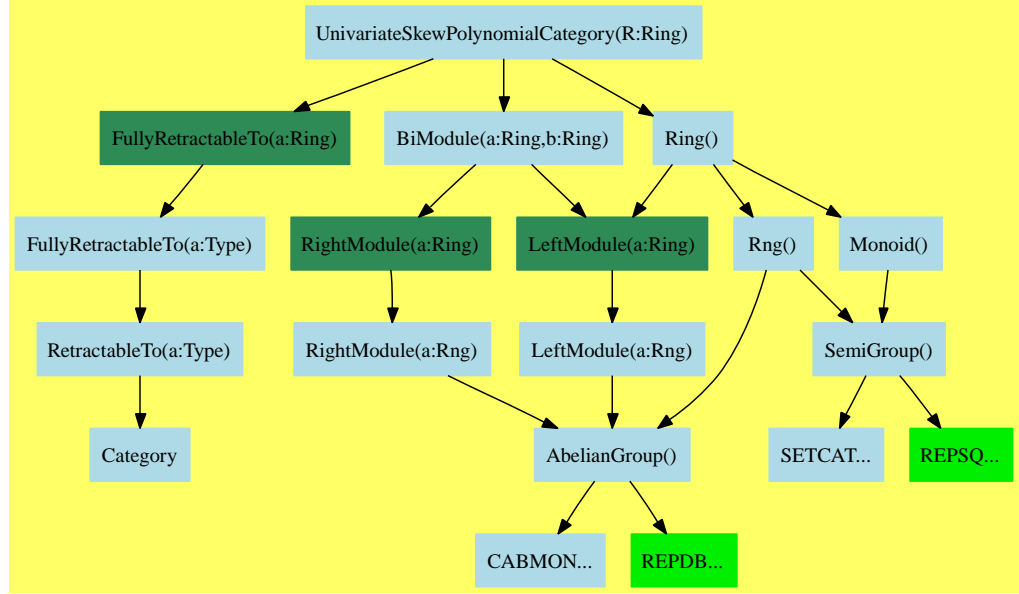
"A1AGG..." [color=lightblue];

"Category" [color=lightblue];

}

```

UnivariateSkewPolynomialCategory (OREPCAT)



— UnivariateSkewPolynomialCategory.input —

```

)set break resume
)sys rm -f UnivariateSkewPolynomialCategory.output
)spool UnivariateSkewPolynomialCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show UnivariateSkewPolynomialCategory
--R
--R UnivariateSkewPolynomialCategory(R: Ring) is a category constructor
--R Abbreviation for UnivariateSkewPolynomialCategory is OREPCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OREPCAT
--R
--R----- Operations -----
--R ?? : (R,%) -> %
--R ?? : (%,%) -> %
--R ?? : (PositiveInteger,%) -> %
--R ?? : (%,%) -> %
--R -? : % -> %
--R 1 : () -> %
--R ?? : (%,PositiveInteger) -> %
--R ?? : (%,R) -> %
--R ?? : (Integer,%) -> %
--R *** : (%,PositiveInteger) -> %
--R -? : (%,%) -> %
--R ?? : (%,%) -> Boolean
--R 0 : () -> %
--R apply : (%,R,R) -> R

```

```

--R coefficients : % -> List(R)          coerce : R -> %
--R coerce : Integer -> %                coerce : % -> OutputForm
--R degree : % -> NonNegativeInteger     hash : % -> SingleInteger
--R latex : % -> String                  leadingCoefficient : % -> R
--R one? : % -> Boolean                  recip : % -> Union(%, "failed")
--R reductum : % -> %                    retract : % -> R
--R sample : () -> %                     zero? : % -> Boolean
--R ?=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R coefficient : (%,NonNegativeInteger) -> R
--R coerce : Fraction(Integer) -> % if R has RETRACT(FRAC(INT))
--R content : % -> R if R has GCDDOM
--R exquo : (%,R) -> Union(%, "failed") if R has INTDOM
--R leftDivide : (%,%) -> Record(quotient: %,remainder: %) if R has FIELD
--R leftExactQuotient : (%,%) -> Union(%, "failed") if R has FIELD
--R leftExtendedGcd : (%,%) -> Record(coef1: %,coef2: %,generator: %) if R has FIELD
--R leftGcd : (%,%) -> % if R has FIELD
--R leftLcm : (%,%) -> % if R has FIELD
--R leftQuotient : (%,%) -> % if R has FIELD
--R leftRemainder : (%,%) -> % if R has FIELD
--R minimumDegree : % -> NonNegativeInteger
--R monicLeftDivide : (%,%) -> Record(quotient: %,remainder: %) if R has INTDOM
--R monicRightDivide : (%,%) -> Record(quotient: %,remainder: %) if R has INTDOM
--R monomial : (R,NonNegativeInteger) -> %
--R primitivePart : % -> % if R has GCDDOM
--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retract : % -> Integer if R has RETRACT(INT)
--R retractIfCan : % -> Union(R, "failed")
--R retractIfCan : % -> Union(Fraction(Integer), "failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer, "failed") if R has RETRACT(INT)
--R rightDivide : (%,%) -> Record(quotient: %,remainder: %) if R has FIELD
--R rightExactQuotient : (%,%) -> Union(%, "failed") if R has FIELD
--R rightExtendedGcd : (%,%) -> Record(coef1: %,coef2: %,generator: %) if R has FIELD
--R rightGcd : (%,%) -> % if R has FIELD
--R rightLcm : (%,%) -> % if R has FIELD
--R rightQuotient : (%,%) -> % if R has FIELD
--R rightRemainder : (%,%) -> % if R has FIELD
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— `UnivariateSkewPolynomialCategory.help` —

===== UnivariateSkewPolynomialCategory examples =====

This is the category of univariate skew polynomials over an Ore coefficient ring. The multiplication is given by

$$x a = \sigma(a) x + \delta a$$

This category is an evolution of the types `MonogenicLinearOperator`, `OppositeMonogenicLinearOperator`, and `NonCommutativeOperatorDivision`

See Also:

`o)show UnivariateSkewPolynomialCategory`

See:

⇒ “`LinearOrdinaryDifferentialOperatorCategory`” (LODOCAT) [11](#) on page [1023](#)

⇐ “`BiModule`” (BMODULE) [9](#) on page [782](#)

⇐ “`FullyRetractableTo`” (FRETRCT) [3](#) on page [136](#)

⇐ “`Ring`” (RING) [9](#) on page [826](#)

Exports:

| | | | |
|---------------------------------|------------------------------|--------------------------------|---------------------------------|
| <code>0</code> | <code>1</code> | <code>apply</code> | <code>characteristic</code> |
| <code>coefficient</code> | <code>coefficients</code> | <code>coerce</code> | <code>content</code> |
| <code>degree</code> | <code>exquo</code> | <code>hash</code> | <code>latex</code> |
| <code>leadingCoefficient</code> | <code>leftDivide</code> | <code>leftExactQuotient</code> | <code>leftExtendedGcd</code> |
| <code>leftGcd</code> | <code>leftLcm</code> | <code>leftQuotient</code> | <code>leftRemainder</code> |
| <code>minimumDegree</code> | <code>monicLeftDivide</code> | <code>monicRightDivide</code> | <code>monomial</code> |
| <code>one?</code> | <code>primitivePart</code> | <code>recip</code> | <code>reductum</code> |
| <code>retract</code> | <code>retractIfCan</code> | <code>rightDivide</code> | <code>rightExactQuotient</code> |
| <code>rightExtendedGcd</code> | <code>rightGcd</code> | <code>rightLcm</code> | <code>rightQuotient</code> |
| <code>rightRemainder</code> | <code>sample</code> | <code>subtractIfCan</code> | <code>zero?</code> |
| <code>?*?</code> | <code>?**?</code> | <code>?+?</code> | <code>?-?</code> |
| <code>-?</code> | <code>?=?</code> | <code>?^?</code> | <code>?~=?</code> |

Attributes Exported:

- **`unitsKnown`** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **`leftUnitary`** is true if $1 * x = x$ for all x .
- **`rightUnitary`** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```

apply : (% , R , R) -> R
coefficient : (% , NonNegativeInteger) -> R
degree : % -> NonNegativeInteger
leadingCoefficient : % -> R
leftDivide : (% , %) -> Record(quotient: % , remainder: %) if R has FIELD
minimumDegree : % -> NonNegativeInteger
monicLeftDivide : (% , %) -> Record(quotient: % , remainder: %) if R has INTDOM
monicRightDivide : (% , %) -> Record(quotient: % , remainder: %) if R has INTDOM
monomial : (R , NonNegativeInteger) -> %
reductum : % -> %
rightDivide : (% , %) -> Record(quotient: % , remainder: %) if R has FIELD

```

These are implemented by this category:

```

coefficients : % -> List R
coerce : R -> %
content : % -> R if R has GCDDOM
exquo : (% , R) -> Union(% , "failed") if R has INTDOM
leftExactQuotient : (% , %) -> Union(% , "failed") if R has FIELD
leftExtendedGcd : (% , %) -> Record(coef1: % , coef2: % , generator: %) if R has FIELD
leftGcd : (% , %) -> % if R has FIELD
leftLcm : (% , %) -> % if R has FIELD
leftQuotient : (% , %) -> % if R has FIELD
leftRemainder : (% , %) -> % if R has FIELD
primitivePart : % -> % if R has GCDDOM
retractIfCan : % -> Union(R , "failed")
rightExactQuotient : (% , %) -> Union(% , "failed") if R has FIELD
rightExtendedGcd : (% , %) -> Record(coef1: % , coef2: % , generator: %) if R has FIELD
rightGcd : (% , %) -> % if R has FIELD
rightLcm : (% , %) -> % if R has FIELD
rightQuotient : (% , %) -> % if R has FIELD
rightRemainder : (% , %) -> % if R has FIELD
?? : (R , %) -> %

```

These exports come from (p826) Ring():

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : % -> OutputForm
coerce : Integer -> %
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(% , "failed")
sample : () -> %
subtractIfCan : (% , %) -> Union(% , "failed")
zero? : % -> Boolean
?? : (% , NonNegativeInteger) -> %
?? : (% , NonNegativeInteger) -> %

```



```

?+? : (%,% ) -> %
?= ? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (NonNegativeInteger,% ) -> %
?*? : (PositiveInteger,% ) -> %
?*? : (Integer,% ) -> %
?*? : (%,% ) -> %
?-? : (%,% ) -> %
-? : % -> %
?*?? : (% ,PositiveInteger) -> %
?^? : (% ,PositiveInteger) -> %

```

These exports come from (p782) BiModule(R:Ring,R:Ring):

```

?*? : (% ,R) -> %

```

These exports come from (p136) FullyRetractableTo(R:Ring):

```

coerce : Fraction Integer -> % if R has RETRACT FRAC INT
retract : % -> R
retract : % -> Fraction Integer if R has RETRACT FRAC INT
retract : % -> Integer if R has RETRACT INT
retractIfCan : % -> Union(Fraction Integer,"failed") if R has RETRACT FRAC INT
retractIfCan : % -> Union(Integer,"failed") if R has RETRACT INT

```

— category OREPCAT UnivariateSkewPolynomialCategory —

```

)abbrev category OREPCAT UnivariateSkewPolynomialCategory
++ Author: Manuel Bronstein, Jean Della Dora, Stephen M. Watt
++ Date Created: 19 October 1993
++ Date Last Updated: 1 February 1994
++ Description:
++ This is the category of univariate skew polynomials over an Ore
++ coefficient ring.
++ The multiplication is given by \spad{x a = \sigma(a) x + \delta a}.
++ This category is an evolution of the types
++ MonogenicLinearOperator, OppositeMonogenicLinearOperator, and
++ NonCommutativeOperatorDivision

```

```

UnivariateSkewPolynomialCategory(R:Ring):
  Category == Join(Ring, BiModule(R, R), FullyRetractableTo R) with
    degree: $ -> NonNegativeInteger
      ++ degree(l) is \spad{n} if
      ++ \spad{l = sum(monomial(a(i),i), i = 0..n)}.
    minimumDegree: $ -> NonNegativeInteger
      ++ minimumDegree(l) is the smallest \spad{k} such that
      ++ \spad{a(k) ^= 0} if
      ++ \spad{l = sum(monomial(a(i),i), i = 0..n)}.

```

```

leadingCoefficient: $ -> R
  ++ leadingCoefficient(l) is \spad{a(n)} if
  ++ \spad{l = sum(monomial(a(i),i), i = 0..n)}.
reductum: $ -> $
  ++ reductum(l) is \spad{l - monomial(a(n),n)} if
  ++ \spad{l = sum(monomial(a(i),i), i = 0..n)}.
coefficient: ($, NonNegativeInteger) -> R
  ++ coefficient(l,k) is \spad{a(k)} if
  ++ \spad{l = sum(monomial(a(i),i), i = 0..n)}.
monomial: (R, NonNegativeInteger) -> $
  ++ monomial(c,k) produces c times the k-th power of
  ++ the generating operator, \spad{monomial(1,1)}.
coefficients: % -> List R
  ++ coefficients(l) returns the list of all the nonzero
  ++ coefficients of l.
apply: (% , R, R) -> R
  ++ apply(p, c, m) returns \spad{p(m)} where the action is
  ++ given by \spad{x m = c sigma(m) + delta(m)}.
if R has CommutativeRing then Algebra R
if R has IntegralDomain then
  "exquo": (% , R) -> Union(% , "failed")
  ++ exquo(l, a) returns the exact quotient of l by a,
  ++ returning \axiom{"failed"} if this is not possible.
monicLeftDivide: (% , %) -> Record(quotient: % , remainder: %)
  ++ monicLeftDivide(a,b) returns the pair \spad{[q,r]} such that
  ++ \spad{a = b*q + r} and the degree of \spad{r} is
  ++ less than the degree of \spad{b}.
  ++ \spad{b} must be monic.
  ++ This process is called 'left division'.
monicRightDivide: (% , %) -> Record(quotient: % , remainder: %)
  ++ monicRightDivide(a,b) returns the pair \spad{[q,r]} such that
  ++ \spad{a = q*b + r} and the degree of \spad{r} is
  ++ less than the degree of \spad{b}.
  ++ \spad{b} must be monic.
  ++ This process is called 'right division'.
if R has GcdDomain then
  content: % -> R
  ++ content(l) returns the gcd of all the coefficients of l.
  primitivePart: % -> %
  ++ primitivePart(l) returns l0 such that \spad{l = a * l0}
  ++ for some a in R, and \spad{content(l0) = 1}.
if R has Field then
  leftDivide: (% , %) -> Record(quotient: % , remainder: %)
  ++ leftDivide(a,b) returns the pair \spad{[q,r]} such that
  ++ \spad{a = b*q + r} and the degree of \spad{r} is
  ++ less than the degree of \spad{b}.
  ++ This process is called 'left division'.
  leftQuotient: (% , %) -> %
  ++ leftQuotient(a,b) computes the pair \spad{[q,r]} such that
  ++ \spad{a = b*q + r} and the degree of \spad{r} is

```

```

++ less than the degree of \spad{b}.
++ The value \spad{q} is returned.
leftRemainder:  (% , %) -> %
++ leftRemainder(a,b) computes the pair \spad{[q,r]} such that
++ \spad{a = b*q + r} and the degree of \spad{r} is
++ less than the degree of \spad{b}.
++ The value \spad{r} is returned.
leftExactQuotient:(% , %) -> Union(% , "failed")
++ leftExactQuotient(a,b) computes the value \spad{q}, if it exists,
++ such that \spad{a = b*q}.
leftGcd:  (% , %) -> %
++ leftGcd(a,b) computes the value \spad{g} of highest degree
++ such that
++ \spad{a = g*aa}
++ \spad{b = g*bb}
++ for some values \spad{aa} and \spad{bb}.
++ The value \spad{g} is computed using left-division.
leftExtendedGcd:  (% , %) -> Record(coef1:% , coef2:% , generator:%)
++ leftExtendedGcd(a,b) returns \spad{[c,d]} such that
++ \spad{g = a * c + b * d = leftGcd(a, b)}.
rightLcm:  (% , %) -> %
++ rightLcm(a,b) computes the value \spad{m} of lowest degree
++ such that \spad{m = a*aa = b*bb} for some values
++ \spad{aa} and \spad{bb}. The value \spad{m} is
++ computed using left-division.
rightDivide:  (% , %) -> Record(quotient: % , remainder: %)
++ rightDivide(a,b) returns the pair \spad{[q,r]} such that
++ \spad{a = q*b + r} and the degree of \spad{r} is
++ less than the degree of \spad{b}.
++ This process is called 'right division'.
rightQuotient:  (% , %) -> %
++ rightQuotient(a,b) computes the pair \spad{[q,r]} such that
++ \spad{a = q*b + r} and the degree of \spad{r} is
++ less than the degree of \spad{b}.
++ The value \spad{q} is returned.
rightRemainder:  (% , %) -> %
++ rightRemainder(a,b) computes the pair \spad{[q,r]} such that
++ \spad{a = q*b + r} and the degree of \spad{r} is
++ less than the degree of \spad{b}.
++ The value \spad{r} is returned.
rightExactQuotient:(% , %) -> Union(% , "failed")
++ rightExactQuotient(a,b) computes the value \spad{q}, if it exists
++ such that \spad{a = q*b}.
rightGcd:  (% , %) -> %
++ rightGcd(a,b) computes the value \spad{g} of highest degree
++ such that
++ \spad{a = aa*g}
++ \spad{b = bb*g}
++ for some values \spad{aa} and \spad{bb}.
++ The value \spad{g} is computed using right-division.

```

```

rightExtendedGcd:  (% , %) -> Record(coef1:%, coef2:%, generator:%)
  ++ rightExtendedGcd(a,b) returns \spad{[c,d]} such that
  ++ \spad{g = c * a + d * b = rightGcd(a, b)}.
leftLcm:  (% , %) -> %
  ++ leftLcm(a,b) computes the value \spad{m} of lowest degree
  ++ such that \spad{m = aa*a = bb*b} for some values
  ++ \spad{aa} and \spad{bb}. The value \spad{m} is
  ++ computed using right-division.

add
coerce(x:R):% == monomial(x, 0)

coefficients l ==
ans:List(R) := empty()
while l ^= 0 repeat
  ans := concat(leadingCoefficient l, ans)
  l := reductum l
ans

a:R * y:% ==
z:% := 0
while y ^= 0 repeat
  z := z + monomial(a * leadingCoefficient y, degree y)
  y := reductum y
z

retractIfCan(x:%):Union(R, "failed") ==
  zero? x or zero? degree x => leadingCoefficient x
  "failed"

if R has IntegralDomain then
  l exquo a ==
  ans:% := 0
  while l ^= 0 repeat
    (u := (leadingCoefficient(l) exquo a)) case "failed" =>
      return "failed"
    ans := ans + monomial(u::R, degree l)
    l := reductum l
  ans

if R has GcdDomain then
  content l == gcd coefficients l

  primitivePart l == (l exquo content l)::%

if R has Field then
  leftEEA:  (% , %) -> Record(gcd:%, coef1:%, coef2:%, lcm:%)
  rightEEA: (% , %) -> Record(gcd:%, coef1:%, coef2:%, lcm:%)
  ncgcd:    (% , %, (% , %) -> %) -> %
  nclcm:    (% , %, (% , %) -> Record(gcd:%, coef1:%, coef2:%, lcm:%)) -> %

```

```

exactQuotient: Record(quotient:%, remainder:%) -> Union(%, "failed")
extended: (% , %, (% , %) -> Record(gcd:%, coef1:%, coef2:%, lcm:%)) ->
    Record(coef1:%, coef2:%, generator:%)

leftQuotient(a, b)      == leftDivide(a,b).quotient
leftRemainder(a, b)     == leftDivide(a,b).remainder
leftExtendedGcd(a, b)   == extended(a, b, leftEEA)
rightLcm(a, b)          == nclcm(a, b, leftEEA)
rightQuotient(a, b)     == rightDivide(a,b).quotient
rightRemainder(a, b)    == rightDivide(a,b).remainder
rightExtendedGcd(a, b)  == extended(a, b, rightEEA)
leftLcm(a, b)           == nclcm(a, b, rightEEA)
leftExactQuotient(a, b) == exactQuotient leftDivide(a, b)
rightExactQuotient(a, b) == exactQuotient rightDivide(a, b)
rightGcd(a, b)          == ncgcd(a, b, rightRemainder)
leftGcd(a, b)           == ncgcd(a, b, leftRemainder)

exactQuotient qr == (zero?(qr.remainder) => qr.quotient; "failed")

-- returns [g = leftGcd(a, b), c, d, l = rightLcm(a, b)]
-- such that g := a c + b d
leftEEA(a, b) ==
  a0 := a
  u0:% := v:% := 1
  v0:% := u:% := 0
  while b ^= 0 repeat
    qr := leftDivide(a, b)
    (a, b) := (b, qr.remainder)
    (u0, u) := (u, u0 - u * qr.quotient)
    (v0, v) := (v, v0 - v * qr.quotient)
  [a, u0, v0, a0 * u]

ncgcd(a, b, ncrem) ==
  zero? a => b
  zero? b => a
  degree a < degree b => ncgcd(b, a, ncrem)
  while b ^= 0 repeat (a, b) := (b, ncrem(a, b))
  a

```

```

extended(a, b, eea) ==
  zero? a => [0, 1, b]
  zero? b => [1, 0, a]
  degree a < degree b =>
    rec := eea(b, a)
    [rec.coef2, rec.coef1, rec.gcd]
  rec := eea(a, b)
  [rec.coef1, rec.coef2, rec.gcd]

nclcm(a, b, eea) ==
  zero? a or zero? b => 0
  degree a < degree b => nclcm(b, a, eea)
  rec := eea(a, b)
  rec.lcm

-- returns [g = rightGcd(a, b), c, d, l = leftLcm(a, b)]
-- such that g := a c + b d
rightEEA(a, b) ==
  a0 := a
  u0:% := v:% := 1
  v0:% := u:% := 0
  while b ^= 0 repeat
    qr := rightDivide(a, b)
    (a, b) := (b, qr.remainder)
    (u0, u) := (u, u0 - qr.quotient * u)
    (v0, v) := (v, v0 - qr.quotient * v)
  [a, u0, v0, u * a0]

```

— OREPCAT.dotabb —

```

"OREPCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OREPCAT"];
"OREPCAT" -> "BMODULE"
"OREPCAT" -> "FRETRCT"
"OREPCAT" -> "RING"

```

— OREPCAT.dotfull —

```

"UnivariateSkewPolynomialCategory(R:Ring)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OREPCAT"];
"UnivariateSkewPolynomialCategory(R:Ring)"
  -> "BiModule(a:Ring,b:Ring)"

```

```

"UnivariateSkewPolynomialCategory(R:Ring)"
-> "FullyRetractableTo(a:Ring)"
"UnivariateSkewPolynomialCategory(R:Ring)"
-> "Ring()"

```

— OREPCAT.dotpic —

```

digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "UnivariateSkewPolynomialCategory(R:Ring)" [color=lightblue];
    "UnivariateSkewPolynomialCategory(R:Ring)"
    -> "BiModule(a:Ring,b:Ring)"
    "UnivariateSkewPolynomialCategory(R:Ring)"
    -> "FullyRetractableTo(a:Ring)"
    "UnivariateSkewPolynomialCategory(R:Ring)"
    -> "Ring()"

    "FullyRetractableTo(a:Ring)" [color=seagreen];
    "FullyRetractableTo(a:Ring)" -> "FullyRetractableTo(a:Type)"

    "FullyRetractableTo(a:Type)" [color=lightblue];
    "FullyRetractableTo(a:Type)" -> "RetractableTo(a:Type)"

    "RetractableTo(a:Type)" [color=lightblue];
    "RetractableTo(a:Type)" -> "Category"

    "Category" [color=lightblue];

    "Ring()" [color=lightblue];
    "Ring()" -> "Rng()"
    "Ring()" -> "Monoid()"
    "Ring()" -> "LeftModule(a:Ring)"

    "Rng()" [color=lightblue];
    "Rng()" -> "AbelianGroup()"
    "Rng()" -> "SemiGroup()"

    "Monoid()" [color=lightblue];
    "Monoid()" -> "SemiGroup()"

    "BiModule(a:Ring,b:Ring)" [color=lightblue];
    "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
    "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

```

```

"RightModule(a:Ring)" [color=seagreen];
"RightModule(a:Ring)" -> "RightModule(a:Rng)"

"RightModule(a:Rng)" [color=lightblue];
"RightModule(a:Rng)" -> "AbelianGroup()"

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "AbelianGroup()"

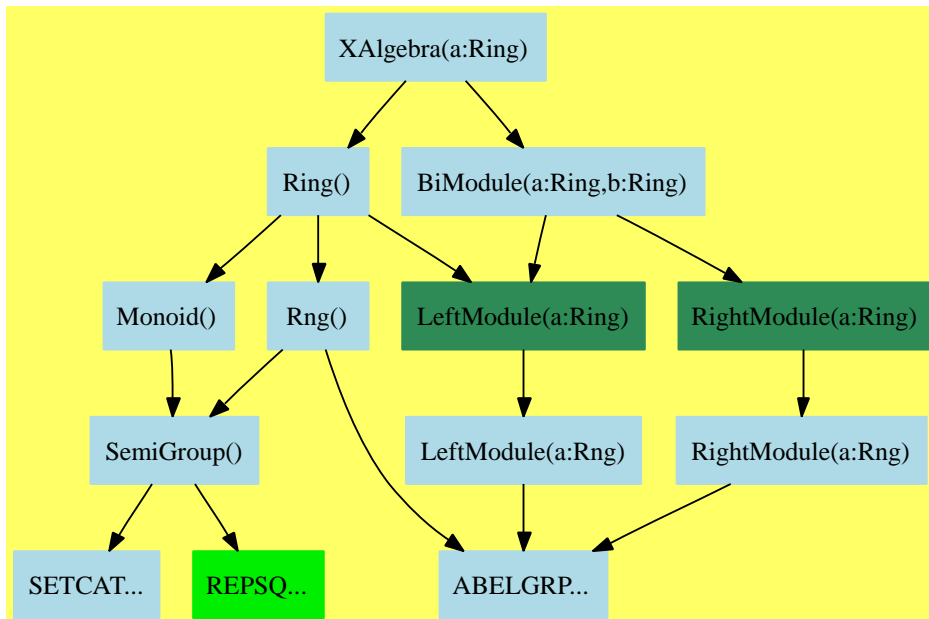
"AbelianGroup()" [color=lightblue];
"AbelianGroup()" -> "CABMON..."
"AbelianGroup()" -> "REPDB..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"CABMON..." [color=lightblue];
}

```

XAlgebra (XALG)



— XAlgebra.input —

```

)set break resume
)sys rm -f XAlgebra.output
)spool XAlgebra.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show XAlgebra
--R
--R XAlgebra(R: Ring) is a category constructor
--R Abbreviation for XAlgebra is XALG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for XALG
--R
--R----- Operations -----
--R ??? : (R,%) -> %           ??? : (%,R) -> %
--R ??? : (%,%) -> %           ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %                 ?=? : (%,%) -> Boolean
--R 1 : () -> %                 0 : () -> %

```

```

--R ?? : (%,PositiveInteger) -> %      coerce : R -> %
--R coerce : Integer -> %              coerce : % -> OutputForm
--R hash : % -> SingleInteger           latex : % -> String
--R one? : % -> Boolean                 recip : % -> Union(%, "failed")
--R sample : () -> %                   zero? : % -> Boolean
--R ~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R **? : (%,NonNegativeInteger) -> %
--R ^? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

```

```

)spool
)lisp (bye)

```

— XAlgebra.help —

=====

XAlgebra examples

=====

This is the category of algebras over non-commutative rings.
It is used by constructors of non-commutative algebras such as
XPolynomialRing and XFreeAlgebra

See Also:
o)show XAlgebra

See:

⇒ “XFreeAlgebra” (XFALG) [11](#) on page [1042](#)
⇐ “BiModule” (BMODULE) [9](#) on page [782](#)
⇐ “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | | |
|-------|------|----------------|--------|---------------|
| 0 | 1 | characteristic | coerce | hash |
| latex | one? | recip | sample | subtractIfCan |
| zero? | ?^? | ?~=? | ?*? | ?**? |
| ?+? | ?-? | -? | ?=? | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
coerce : R -> %
```

These exports come from (p826) `Ring()`:

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : % -> OutputForm
coerce : Integer -> %
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (NonNegativeInteger, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (Integer, %) -> %
?*? : (%, %) -> %
?-? : (%, %) -> %
-? : % -> %
?*?* : (%, NonNegativeInteger) -> %
?*?* : (%, PositiveInteger) -> %
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
```

These exports come from (p782) `BiModule(R:Ring,R:Ring)`:

```
?*? : (R, %) -> %
?*? : (%, R) -> %
```

— category XALG XAlgebra —

```
)abbrev category XALG XAlgebra
++ Author: Michel Petitot petitot@lifl.fr
```

```

++ Date Created: 91
++ Date Last Updated: 7 Juillet 92
++ Fix History: compilation v 2.1 le 13 dec 98
++ Description:
++ This is the category of algebras over non-commutative rings.
++ It is used by constructors of non-commutative algebras such as
++ XPolynomialRing and XFreeAlgebra

```

```

XAlgebra(R: Ring): Category ==
  Join(Ring, BiModule(R,R)) with
    coerce: R -> %
    ++ \spad{coerce(r)} equals \spad{r*1}.
    if R has CommutativeRing then Algebra(R)

```

— XALG.dotabb —

```

"XALG"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=XALG"];
"XALG" -> "BMODULE"
"XALG" -> "RING"

```

— XALG.dotfull —

```

"XAlgebra(a:Ring)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=XALG"];
"XAlgebra(a:Ring)" -> "Ring()"
"XAlgebra(a:Ring)" -> "BiModule(a:Ring,b:Ring)"

```

— XALG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "XAlgebra(a:Ring)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=XALG"];
  "XAlgebra(a:Ring)" -> "Ring()"
  "XAlgebra(a:Ring)" -> "BiModule(a:Ring,b:Ring)"

```

```

"Ring()" [color=lightblue];
"Ring()" -> "Rng()"
"Ring()" -> "Monoid()"
"Ring()" -> "LeftModule(a:Ring)"

"BiModule(a:Ring,b:Ring)" [color=lightblue];
"BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
"BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

"RightModule(a:Ring)" [color=seagreen];
"RightModule(a:Ring)" -> "RightModule(a:Rng)"

"RightModule(a:Rng)" [color=lightblue];
"RightModule(a:Rng)" -> "ABELGRP..."

"Rng()" [color=lightblue];
"Rng()" -> "ABELGRP..."
"Rng()" -> "SemiGroup()"

"Monoid()" [color=lightblue];
"Monoid()" -> "SemiGroup()"

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "ABELGRP..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

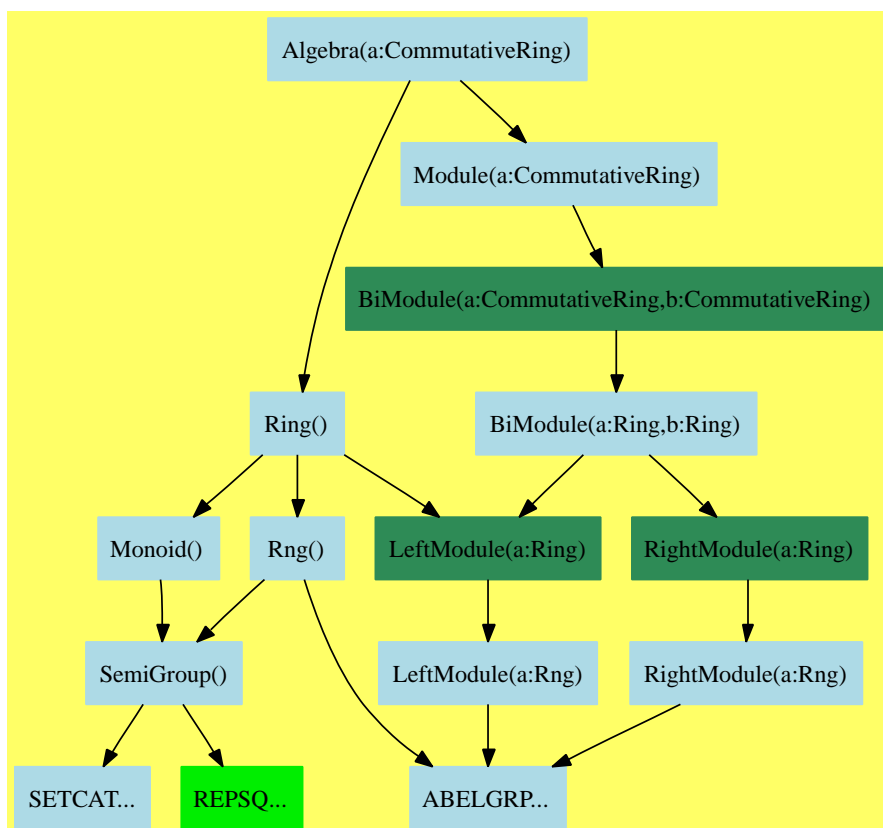
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"ABELGRP..." [color=lightblue];
}

```

Chapter 11

Category Layer 10

Algebra (ALGEBRA)



— Algebra.input —

```

)set break resume
)sys rm -f Algebra.output
)spool Algebra.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show Algebra
--R
--R Algebra(R: CommutativeRing) is a category constructor
--R Abbreviation for Algebra is ALGEBRA
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ALGEBRA
--R
--R----- Operations -----
--R ?? : (R,%) -> %           ?? : (%,R) -> %
--R ?? : (%,%) -> %           ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %               ?=? : (%,%) -> Boolean
--R 1 : () -> %               0 : () -> %
--R ^? : (%,PositiveInteger) -> %   coerce : R -> %
--R coerce : Integer -> %           coerce : % -> OutputForm
--R hash : % -> SingleInteger       latex : % -> String
--R one? : % -> Boolean             recip : % -> Union(%, "failed")
--R sample : () -> %               zero? : % -> Boolean
--R ~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?^? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— Algebra.help —

```

=====
Algebra examples
=====

```

The category of associative algebras (modules which are themselves rings).

Axioms:

```
(b+c)::% = (b::%) + (c::%)
(b*c)::% = (b::%) * (c::%)
(1::R)::% = 1::%
b*x = (b::%)*x
r*(a*b) = (r*a)*b = a*(r*b)
```

See Also:

o)show Algebra

See:

⇒ “DivisionRing” (DIVRING) [12](#) on page [1063](#)
 ⇒ “FiniteRankAlgebra” (FINRANG) [17](#) on page [1380](#)
 ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
 ⇒ “IntegralDomain” (INTDOM) [12](#) on page [1097](#)
 ⇒ “MonogenicLinearOperator” (MLO) [12](#) on page [1103](#)
 ⇒ “OctonionCategory” (OC) [12](#) on page [1109](#)
 ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
 ⇒ “QuaternionCategory” (QUATCAT) [12](#) on page [1120](#)
 ⇒ “RealClosedField” (RCFIELD) [17](#) on page [1441](#)
 ⇐ “Module” (MODULE) [10](#) on page [928](#)
 ⇐ “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | | |
|-------|------|----------------|--------|---------------|
| 1 | 0 | characteristic | coerce | hash |
| latex | one? | recip | sample | subtractIfCan |
| zero? | ?*? | ?+? | ?-? | -? |
| ?=? | ?~=? | ?**? | ?^? | |

Attributes exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are implemented by this category:

```
coerce : R -> %
```


These exports come from (p826) `Ring()`:

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (NonNegativeInteger, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (Integer, %) -> %
?*? : (%, %) -> %
?-? : (%, %) -> %
-? : % -> %
***? : (%, PositiveInteger) -> %
***? : (%, NonNegativeInteger) -> %
??^ : (%, NonNegativeInteger) -> %
??^ : (%, PositiveInteger) -> %

```

These exports come from (p928) `Module(R:CommutativeRing)`:

```

?*? : (R, %) -> %
?*? : (%, R) -> %

```

— category ALGEBRA Algebra —

```

)abbrev category ALGEBRA Algebra
++ Description:
++ The category of associative algebras (modules which are themselves rings).
++
++ Axioms\br
++ \tab{5}\spad{(b+c)::% = (b::%) + (c::%)}\br
++ \tab{5}\spad{(b*c)::% = (b::%) * (c::%)}\br
++ \tab{5}\spad{(1::R)::% = 1::%}\br
++ \tab{5}\spad{b*x = (b::%)*x}\br
++ \tab{5}\spad{r*(a*b) = (r*a)*b = a*(r*b)}

Algebra(R:CommutativeRing): Category ==
  Join(Ring, Module R) with

```

```

coerce: R -> %
  ++ coerce(r) maps the ring element r to a member of the algebra.
add
coerce(x:R):% == x * 1$%

```

— ALGEBRA.dotabb —

```

"ALGEBRA"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"ALGEBRA" -> "RING"
"ALGEBRA" -> "MODULE"

```

— ALGEBRA.dotfull —

```

"Algebra(a:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(a:CommutativeRing)" -> "Ring()"
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

"Algebra(a:Field)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(a:Field)" -> "Algebra(a:CommutativeRing)"

"Algebra(a:CommutativeRing)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

"Algebra(Fraction(Integer))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(Fraction(Integer))" -> "Algebra(a:CommutativeRing)"

"Algebra(Integer)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(Integer)" -> "Algebra(a:CommutativeRing)"

"Algebra(IntegralDomain)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(IntegralDomain)" -> "Algebra(a:CommutativeRing)"

```

— ALGEBRA.dotpic —

```

digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "Algebra(a:CommutativeRing)" [color=lightblue];
    "Algebra(a:CommutativeRing)" -> "Ring()"
    "Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

    "Ring()" [color=lightblue];
    "Ring()" -> "Rng()"
    "Ring()" -> "Monoid()"
    "Ring()" -> "LeftModule(a:Ring)"

    "Rng()" [color=lightblue];
    "Rng()" -> "ABELGRP..."
    "Rng()" -> "SemiGroup()"

    "SemiGroup()" [color=lightblue];
    "SemiGroup()" -> "SETCAT..."
    "SemiGroup()" -> "REPSQ..."

    "Monoid()" [color=lightblue];
    "Monoid()" -> "SemiGroup()"

    "Module(a:CommutativeRing)" [color=lightblue];
    "Module(a:CommutativeRing)" ->
        "BiModule(a:CommutativeRing,b:CommutativeRing)"

    "BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
    "BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BiModule(a:Ring,b:Ring)"

    "BiModule(a:Ring,b:Ring)" [color=lightblue];
    "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
    "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

    "RightModule(a:Ring)" [color=seagreen];
    "RightModule(a:Ring)" -> "RightModule(a:Rng)"

    "RightModule(a:Rng)" [color=lightblue];
    "RightModule(a:Rng)" -> "ABELGRP..."

    "LeftModule(a:Ring)" [color=seagreen];
    "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

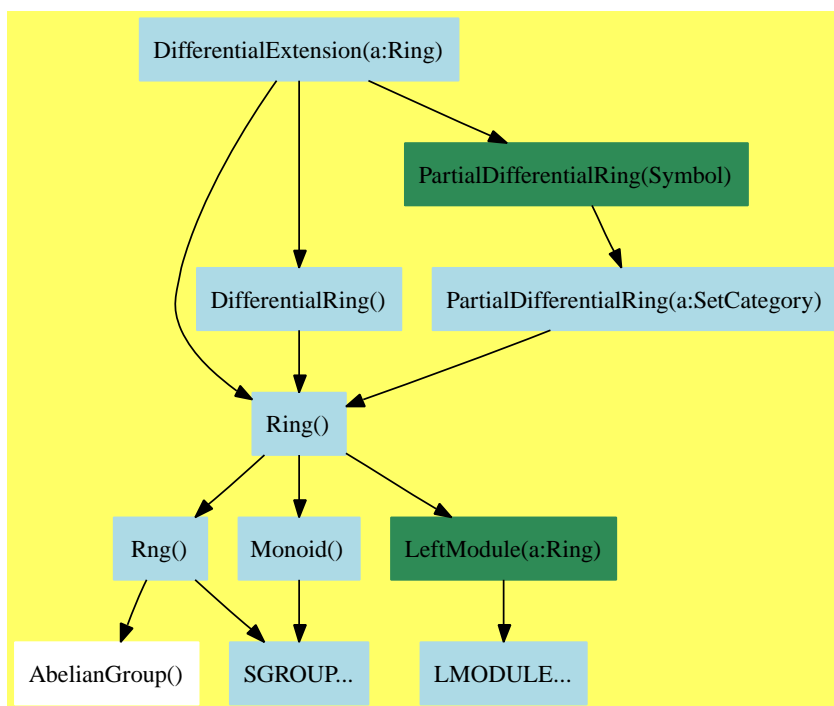
    "LeftModule(a:Rng)" [color=lightblue];
    "LeftModule(a:Rng)" -> "ABELGRP..."

    "ABELGRP..." [color=lightblue];
    "REPSQ..." [color="#00EE00"];

```

```
"SETCAT..." [color=lightblue];
}
```

DifferentialExtension (DIFEXT)



— DifferentialExtension.input —

```
)set break resume
)sys rm -f DifferentialExtension.output
)spool DifferentialExtension.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show DifferentialExtension
--R
```

```

--R DifferentialExtension(R: Ring) is a category constructor
--R Abbreviation for DifferentialExtension is DIFEXT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DIFEXT
--R
--R----- Operations -----
--R ?? : (%,%) -> %                ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %                ?-? : (%,%) -> %
--R -? : % -> %                     ?? : (%,%) -> Boolean
--R D : % -> % if R has DIFRING      D : (%,(R -> R)) -> %
--R 1 : () -> %                     0 : () -> %
--R ?? : (%,PositiveInteger) -> %   coerce : Integer -> %
--R coerce : % -> OutputForm        hash : % -> SingleInteger
--R latex : % -> String             one? : % -> Boolean
--R recip : % -> Union(%, "failed") sample : () -> %
--R zero? : % -> Boolean            ?~? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R D : (%,NonNegativeInteger) -> % if R has DIFRING
--R D : (%,Symbol) -> % if R has PDRING(SYMBOL)
--R D : (%,List(Symbol)) -> % if R has PDRING(SYMBOL)
--R D : (%,Symbol,NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R D : (%,List(Symbol),List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R D : (%,(R -> R),NonNegativeInteger) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R differentiate : % -> % if R has DIFRING
--R differentiate : (%,NonNegativeInteger) -> % if R has DIFRING
--R differentiate : (%,Symbol) -> % if R has PDRING(SYMBOL)
--R differentiate : (%,List(Symbol)) -> % if R has PDRING(SYMBOL)
--R differentiate : (%,Symbol,NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R differentiate : (%,List(Symbol),List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R differentiate : (%,(R -> R),NonNegativeInteger) -> %
--R differentiate : (%,(R -> R)) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— DifferentialExtension.help —

```

=====
DifferentialExtension examples
=====

```

Differential extensions of a ring R. Given a differentiation on R,
extend it to a differentiation on %.

See Also:

o)show DifferentialExtension

See:

⇒ “ComplexCategory” (COMPCAT) [20](#) on page [1671](#)
 ⇒ “DifferentialPolynomialCategory” (DPOLCAT) [17](#) on page [1356](#)
 ⇒ “DirectProductCategory” (DIRPCAT) [12](#) on page [1051](#)
 ⇒ “QuaternionCategory” (QUATCAT) [12](#) on page [1120](#)
 ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
 ⇒ “SquareMatrixCategory” (SMATCAT) [12](#) on page [1131](#)
 ⇒ “UnivariatePolynomialCategory” (UPOLYC) [17](#) on page [1522](#)
 ⇐ “PartialDifferentialRing” (PDRING) [10](#) on page [939](#)
 ⇐ “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | | |
|---------------|---------------|----------------|--------|-------|
| 1 | 0 | characteristic | coerce | D |
| differentiate | hash | latex | one? | recip |
| sample | subtractIfCan | zero? | ?*? | ?~=? |
| ?**? | ?+? | ?-? | -? | ?=? |
| ?^? | | | | |

Attributes exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.

These are directly exported but not implemented:

```
differentiate : (%,(R -> R)) -> %
```

These are implemented by this category:

```
D : (%,(R -> R)) -> %
D : (%,(R -> R),NonNegativeInteger) -> %
differentiate : % -> % if R has DIFRING
differentiate : (%,(R -> R),NonNegativeInteger) -> %
differentiate : (%,Symbol) -> % if R has PDRING SYMBOL
```

These exports come from (p[826](#)) Ring():

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (%, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (NonNegativeInteger, %) -> %
?-? : (%, %) -> %
-? : % -> %
?*?? : (%, NonNegativeInteger) -> %
?*?? : (%, PositiveInteger) -> %
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %

```

These exports come from (p902) `DifferentialRing()`:

```

D : % -> % if R has DIFRING
D : (%, NonNegativeInteger) -> % if R has DIFRING
differentiate : (%, NonNegativeInteger) -> %
    if R has DIFRING

```

These exports come from (p939) `PartialDifferentialRing(Symbol)`:

```

D : (%, Symbol) -> % if R has PDRING SYMBOL
D : (%, List Symbol) -> % if R has PDRING SYMBOL
D : (%, Symbol, NonNegativeInteger) -> %
    if R has PDRING SYMBOL
D : (%, List Symbol, List NonNegativeInteger) -> %
    if R has PDRING SYMBOL
differentiate : (%, List Symbol) -> %
    if R has PDRING SYMBOL
differentiate : (%, Symbol, NonNegativeInteger) -> %
    if R has PDRING SYMBOL
differentiate : (%, List Symbol, List NonNegativeInteger) -> %
    if R has PDRING SYMBOL

```

```

)abbrev category DIFEXT DifferentialExtension
++ Description:
++ Differential extensions of a ring R.
++ Given a differentiation on R, extend it to a differentiation on %.

DifferentialExtension(R:Ring): Category == Ring with
  differentiate: (% , R -> R) -> %
    ++ differentiate(x, deriv) differentiates x extending
    ++ the derivation deriv on R.
  differentiate: (% , R -> R, NonNegativeInteger) -> %
    ++ differentiate(x, deriv, n) differentiate x n times
    ++ using a derivation which extends deriv on R.
  D: (% , R -> R) -> %
    ++ D(x, deriv) differentiates x extending
    ++ the derivation deriv on R.
  D: (% , R -> R, NonNegativeInteger) -> %
    ++ D(x, deriv, n) differentiate x n times
    ++ using a derivation which extends deriv on R.
  if R has DifferentialRing then DifferentialRing
  if R has PartialDifferentialRing(Symbol) then
    PartialDifferentialRing(Symbol)
add
  differentiate(x:%, derivation: R -> R, n:NonNegativeInteger):% ==
    for i in 1..n repeat x := differentiate(x, derivation)
    x
  D(x:%, derivation: R -> R) == differentiate(x, derivation)
  D(x:%, derivation: R -> R, n:NonNegativeInteger) ==
    differentiate(x, derivation, n)

  if R has DifferentialRing then
    differentiate x == differentiate(x, differentiate$R)

  if R has PartialDifferentialRing Symbol then
    differentiate(x:%, v:Symbol):% ==
      differentiate(x, s +-> differentiate(s, v)$R)



---


— DIFEXT.dotabb —

"DIFEXT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=DIFEXT" ];
"DIFEXT" -> "RING"
"DIFEXT" -> "DIFRING"
"DIFEXT" -> "PDRING"

```

— DIFEXT.dotfull —

```

"DifferentialExtension(a:Ring)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=DIFEXT"];
"DifferentialExtension(a:Ring)" -> "Ring()"
"DifferentialExtension(a:Ring)" -> "DifferentialRing()"
"DifferentialExtension(a:Ring)" -> "PartialDifferentialRing(Symbol)"

"DifferentialExtension(IntegralDomain)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=DIFEXT"];
"DifferentialExtension(IntegralDomain)" ->
  "DifferentialExtension(a:Ring)"

"DifferentialExtension(CommutativeRing)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=DIFEXT"];
"DifferentialExtension(CommutativeRing)" ->
  "DifferentialExtension(a:Ring)"

```

— DIFEXT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "DifferentialExtension(a:Ring)" [color=lightblue];
  "DifferentialExtension(a:Ring)" -> "Ring()"
  "DifferentialExtension(a:Ring)" -> "DifferentialRing()"
  "DifferentialExtension(a:Ring)" -> "PartialDifferentialRing(Symbol)"

  "PartialDifferentialRing(Symbol)"
    [color=seagreen,href="bookvol10.2.pdf#nameddest=PDRING"];
  "PartialDifferentialRing(Symbol)" ->
    "PartialDifferentialRing(a:SetCategory)"

  "PartialDifferentialRing(a:SetCategory)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=PDRING"];
  "PartialDifferentialRing(a:SetCategory)" -> "Ring()"

  "DifferentialRing()" [color=lightblue];
  "DifferentialRing()" -> "Ring()"

  "Ring()" [color=lightblue];
  "Ring()" -> "Rng()"
  "Ring()" -> "Monoid()"

```

```

"Ring()" -> "LeftModule(a:Ring)"

"Rng()" [color=lightblue];
"Rng()" -> "AbelianGroup()"
"Rng()" -> "SGROUP..."

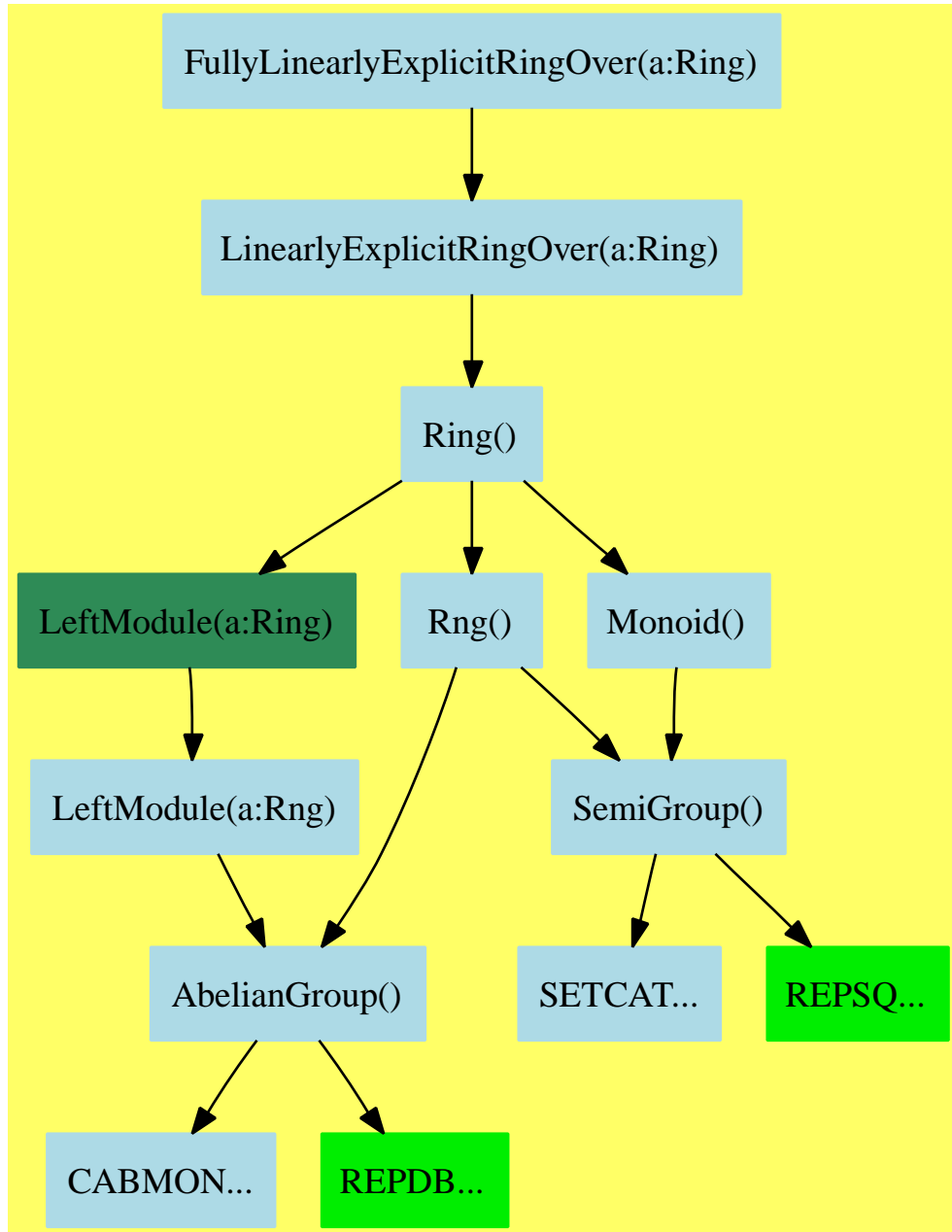
"Monoid()" [color=lightblue];
"Monoid()" -> "SGROUP..."

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LMODULE..."

"SGROUP..." [color=lightblue];
"LMODULE..." [color=lightblue];
}

```

FullyLinearlyExplicitRingOver (FLINEXP)



— FullyLinearlyExplicitRingOver.input —

```

)set break resume
)sys rm -f FullyLinearlyExplicitRingOver.output
)spool FullyLinearlyExplicitRingOver.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FullyLinearlyExplicitRingOver
--R
--R FullyLinearlyExplicitRingOver(R: Ring) is a category constructor
--R Abbreviation for FullyLinearlyExplicitRingOver is FLINEXP
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FLINEXP
--R
--R----- Operations -----
--R ??? : (%,%) -> %                ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %    ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %                ?-? : (%,%) -> %
--R -? : % -> %                     ?=? : (%,%) -> Boolean
--R 1 : () -> %                     0 : () -> %
--R ??? : (%,PositiveInteger) -> %    coerce : Integer -> %
--R coerce : % -> OutputForm          hash : % -> SingleInteger
--R latex : % -> String              one? : % -> Boolean
--R recip : % -> Union(%, "failed")    sample : () -> %
--R zero? : % -> Boolean              ?~=? : (%,%) -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R reducedSystem : Matrix(%) -> Matrix(Integer) if R has LINEXP(INT)
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Integer),vec: Vector(Integer)) if R has LINEXP(INT)
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(R),vec: Vector(R))
--R reducedSystem : Matrix(%) -> Matrix(R)
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— FullyLinearlyExplicitRingOver.help —

```

=====
FullyLinearlyExplicitRingOver examples
=====

```

`S` is `FullyLinearlyExplicitRingOver R` means that `S` is a `LinearlyExplicitRingOver R` and, in addition, if `R` is a `LinearlyExplicitRingOver Integer`, then so is `S`

See Also:

o `)show FullyLinearlyExplicitRingOver`

See:

⇒ “ComplexCategory” (COMPCAT) [20](#) on page [1671](#)
 ⇒ “DirectProductCategory” (DIRPCAT) [12](#) on page [1051](#)
 ⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
 ⇒ “MonogenicAlgebra” (MONOGEN) [19](#) on page [1651](#)
 ⇒ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)
 ⇒ “QuaternionCategory” (QUATCAT) [12](#) on page [1120](#)
 ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
 ⇒ “SquareMatrixCategory” (SMATCAT) [12](#) on page [1131](#)
 ⇐ “LinearlyExplicitRingOver” (LINEXP) [10](#) on page [923](#)

Exports:

| | | | | |
|----------------------------|--------------------|-----------------------------|----------------------------|---------------------|
| <code>1</code> | <code>0</code> | <code>characteristic</code> | <code>coerce</code> | <code>hash</code> |
| <code>latex</code> | <code>one?</code> | <code>recip</code> | <code>reducedSystem</code> | <code>sample</code> |
| <code>subtractIfCan</code> | <code>zero?</code> | <code>?*?</code> | <code>?**?</code> | <code>?+?</code> |
| <code>?-?</code> | <code>-?</code> | <code>?=?</code> | <code>?^?</code> | <code>?~=?</code> |

Attributes exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.

These are implemented by this category:

```
reducedSystem : Matrix % ->
  Matrix Integer if R has LINEXP INT
reducedSystem : (Matrix %,Vector %) ->
  Record(mat: Matrix Integer,vec: Vector Integer)
  if R has LINEXP INT
```

These exports come from ([p923](#)) `LinearlyExplicitRingOver(a:Ring)`:

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
```

```

hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
reducedSystem : (Matrix %, Vector %) ->
  Record(mat: Matrix R, vec: Vector R)
reducedSystem : Matrix % -> Matrix R
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (%, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (NonNegativeInteger, %) -> %
?-? : (%, %) -> %
-? : % -> %
?*** : (%, PositiveInteger) -> %
?*** : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
?^? : (%, NonNegativeInteger) -> %

```

— category FLINEXP FullyLinearlyExplicitRingOver —

```

)abbrev category FLINEXP FullyLinearlyExplicitRingOver
++ Description:
++ S is \spadtype{FullyLinearlyExplicitRingOver R} means that S is a
++ \spadtype{LinearlyExplicitRingOver R} and, in addition, if R is a
++ \spadtype{LinearlyExplicitRingOver Integer}, then so is S

FullyLinearlyExplicitRingOver(R:Ring):Category ==
  LinearlyExplicitRingOver R with
    if (R has LinearlyExplicitRingOver Integer) then
      LinearlyExplicitRingOver Integer
add
  if not(R is Integer) then
    if (R has LinearlyExplicitRingOver Integer) then
      reducedSystem(m:Matrix %):Matrix(Integer) ==
        reducedSystem(reducedSystem(m)@Matrix(R))

  reducedSystem(m:Matrix %, v:Vector %):
    Record(mat:Matrix(Integer), vec:Vector(Integer)) ==
      rec := reducedSystem(m, v)@Record(mat:Matrix R, vec:Vector R)
      reducedSystem(rec.mat, rec.vec)

```

— FLINEXP.dotabb —

```
"FLINEXP"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FLINEXP"];
"FLINEXP" -> "LINEXP"
```

— FLINEXP.dotfull —

```
"FullyLinearlyExplicitRingOver(a:Ring)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FLINEXP"];
"FullyLinearlyExplicitRingOver(a:Ring)" ->
  "LinearlyExplicitRingOver(a:Ring)"

"FullyLinearlyExplicitRingOver(a:CommutativeRing)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FLINEXP"];
"FullyLinearlyExplicitRingOver(a:CommutativeRing)" ->
  "FullyLinearlyExplicitRingOver(a:Ring)"

"FullyLinearlyExplicitRingOver(IntegralDomain)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FLINEXP"];
"FullyLinearlyExplicitRingOver(IntegralDomain)" ->
  "FullyLinearlyExplicitRingOver(a:Ring)"
```

— FLINEXP.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FullyLinearlyExplicitRingOver(a:Ring)" [color=lightblue];
  "FullyLinearlyExplicitRingOver(a:Ring)" ->
    "LinearlyExplicitRingOver(a:Ring)"

  "LinearlyExplicitRingOver(a:Ring)" [color=lightblue];
  "LinearlyExplicitRingOver(a:Ring)" -> "Ring()"

  "Ring()" [color=lightblue];
  "Ring()" -> "Rng()"
  "Ring()" -> "Monoid()"
  "Ring()" -> "LeftModule(a:Ring)"
```

```

"Rng()" [color=lightblue];
"Rng()" -> "AbelianGroup()"
"Rng()" -> "SemiGroup()"

"Monoid()" [color=lightblue];
"Monoid()" -> "SemiGroup()"

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

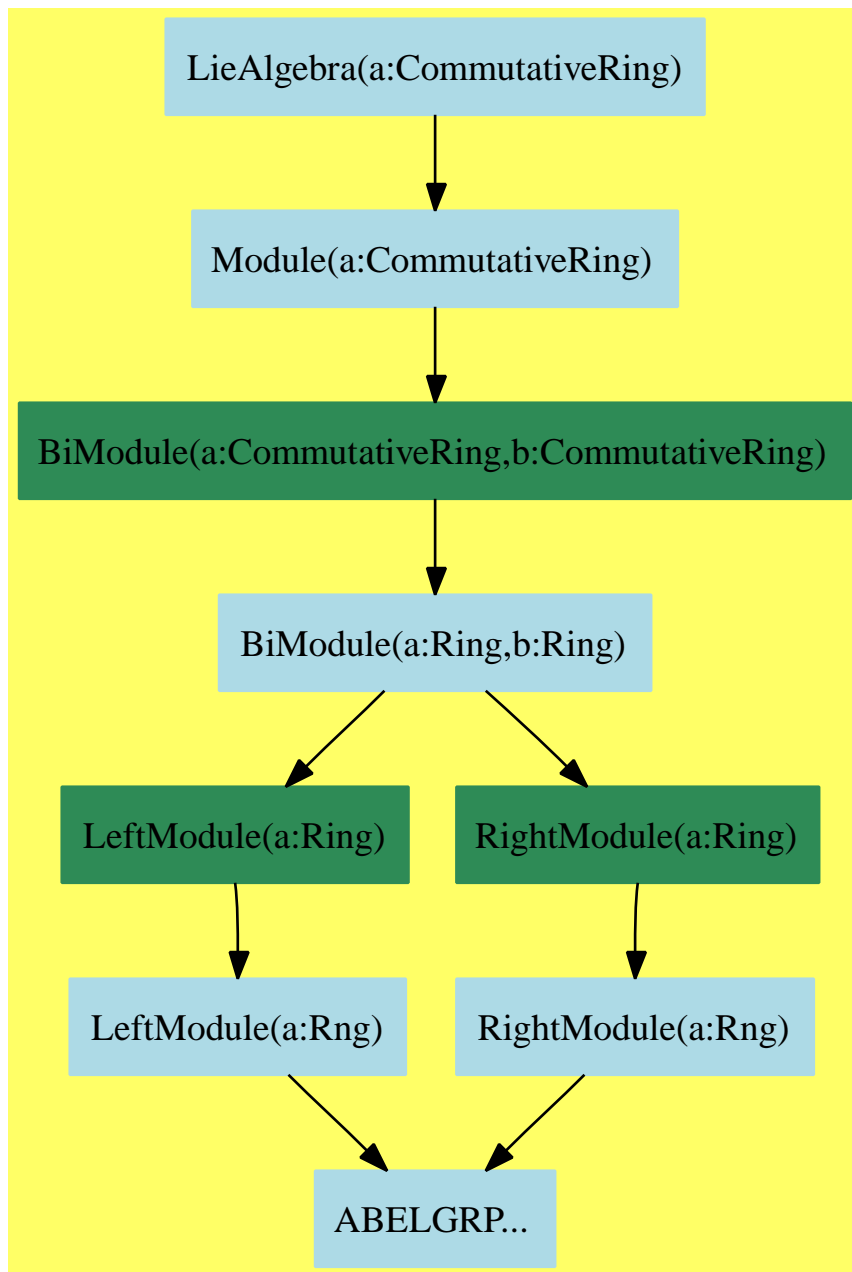
"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "AbelianGroup()"

"AbelianGroup()" [color=lightblue];
"AbelianGroup()" -> "CABMON..."
"AbelianGroup()" -> "REPDB..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"CABMON..." [color=lightblue];
}

```

LieAlgebra (LIECAT)

— LieAlgebra.input —

```

)set break resume
)sys rm -f LieAlgebra.output
)spool LieAlgebra.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show LieAlgebra
--R
--R LieAlgebra(R: CommutativeRing) is a category constructor
--R Abbreviation for LieAlgebra is LIECAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LIECAT
--R
--R----- Operations -----
--R ??? : (%,R) -> %           ??? : (R,%) -> %
--R ??? : (Integer,%) -> %     ??? : (PositiveInteger,%) -> %
--R ?+? : (%,%) -> %          ?-? : (%,%) -> %
--R -? : % -> %               ?=? : (%,%) -> Boolean
--R 0 : () -> %               coerce : % -> OutputForm
--R construct : (%,%) -> %     hash : % -> SingleInteger
--R latex : % -> String        sample : () -> %
--R zero? : % -> Boolean       ?~=? : (%,%) -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R ?/? : (%,R) -> % if R has FIELD
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— LieAlgebra.help —

=====

LieAlgebra examples

=====

The category of Lie Algebras. It is used by the domains of non-commutative algebra, LiePolynomial and XPBWPolynomial.

See Also:

o)show LieAlgebra

See:

\Rightarrow “FreeLieAlgebra” (FLALG) [12](#) on page [1091](#)

\Leftarrow “Module” (MODULE) [10](#) on page [928](#)

Exports:

| | | | | |
|--------|---------------|-----------|------|-------|
| 0 | coerce | construct | hash | latex |
| sample | subtractIfCan | zero? | ?~=? | ?/? |
| ?*? | ?+? | ?-? | -? | ?=? |

Attributes Exported:

- **NullSquare** means that $[x, x] = 0$ holds. See **LieAlgebra**.
- **JacobiIdentity** means that $[x, [y, z]] + [y, [z, x]] + [z, [x, y]] = 0$ holds. See **LieAlgebra**.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
construct : (%,% ) -> %
```

These are implemented by this category:

```
?/? : (% , R) -> % if R has FIELD
```

These exports come from ([p928](#)) `Module(R:Ring)`:

```
0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,% ) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%,% ) -> Boolean
?? : (NonNegativeInteger,% ) -> %
?? : (% , R) -> %
?? : (R,% ) -> %
?? : (Integer,% ) -> %
?? : (PositiveInteger,% ) -> %
?+? : (%,% ) -> %
?-? : (%,% ) -> %
-? : % -> %
?=? : (%,% ) -> Boolean
```

— category LIECAT LieAlgebra —

```

)abbrev category LIECAT LieAlgebra
++ Author: Michel Petitot (petitot@lifl.fr).
++ Date Created: 91
++ Date Last Updated: 7 Juillet 92
++ Description:
++ The category of Lie Algebras.
++ It is used by the domains of non-commutative algebra,
++ LiePolynomial and XPBWPolynomial.

LieAlgebra(R: CommutativeRing): Category == Module(R) with
  construct: ($,$) -> $
    ++ \axiom{construct(x,y)} returns the Lie bracket of \axiom{x}
    ++ and \axiom{y}.
  NullSquare
    ++ \axiom{NullSquare} means that \axiom{[x,x] = 0} holds.
  JacobiIdentity
    ++ \axiom{JacobiIdentity} means that
    ++ \axiom{[x,[y,z]]+[y,[z,x]]+[z,[x,y]] = 0} holds.
  if R has Field then
    "/" : ($,R) -> $
      ++ \axiom{x/r} returns the division of \axiom{x} by \axiom{r}.
  add
    if R has Field then x / r == inv(r)$R * x

```

— LIECAT.dotabb —

```

"LIECAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=LIECAT" ];
"LIECAT" -> "MODULE"

```

— LIECAT.dotfull —

```

"LieAlgebra(a:CommutativeRing)"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=LIECAT" ];
"LieAlgebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

```

— LIECAT.dotpic —

```

digraph pic {

```

```

fontsize=10;
bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"LieAlgebra(a:CommutativeRing)" [color=lightblue];
"LieAlgebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" ->
  "BiModule(a:CommutativeRing,b:CommutativeRing)"

"BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BiModule(a:Ring,b:Ring)"

"BiModule(a:Ring,b:Ring)" [color=lightblue];
"BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
"BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

"RightModule(a:Ring)" [color=seagreen];
"RightModule(a:Ring)" -> "RightModule(a:Rng)"

"RightModule(a:Rng)" [color=lightblue];
"RightModule(a:Rng)" -> "ABELGRP..."

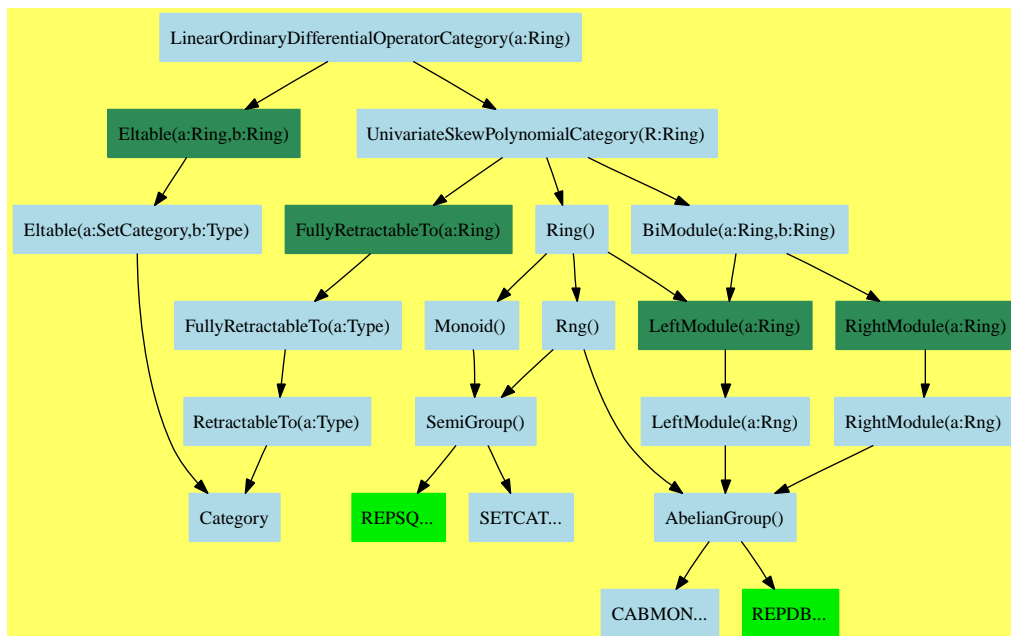
"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "ABELGRP..."

"ABELGRP..." [color=lightblue];
}

```

LinearOrdinaryDifferentialOperatorCategory (LODOCAT)



— LinearOrdinaryDifferentialOperatorCategory.input —

```

)set break resume
)sys rm -f LinearOrdinaryDifferentialOperatorCategory.output
)spool LinearOrdinaryDifferentialOperatorCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show LinearOrdinaryDifferentialOperatorCategory
--R
--R LinearOrdinaryDifferentialOperatorCategory(A: Ring) is a category constructor
--R Abbreviation for LinearOrdinaryDifferentialOperatorCategory is LODOCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LODOCAT
--R
--R----- Operations -----
--R ?? : (A,%) -> %
--R ?? : (%,%) -> %
--R ?? : (PositiveInteger,%) -> %
--R ?+? : (%,%) -> %
--R -? : % -> %
--R ?? : (%,A) -> %
--R ?? : (Integer,%) -> %
--R ??? : (%,PositiveInteger) -> %
--R ?-? : (%,%) -> %
--R ?=? : (%,%) -> Boolean

```

```

--R D : () -> %
--R 0 : () -> %
--R adjoint : % -> %
--R coefficients : % -> List(A)
--R coerce : Integer -> %
--R degree : % -> NonNegativeInteger
--R hash : % -> SingleInteger
--R leadingCoefficient : % -> A
--R recip : % -> Union(%, "failed")
--R retract : % -> A
--R zero? : % -> Boolean
--R ?? : (NonNegativeInteger, %) -> %
--R ***? : (%, NonNegativeInteger) -> %
--R ?? : (%, NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R coefficient : (%, NonNegativeInteger) -> A
--R coerce : Fraction(Integer) -> % if A has RETRACT(FRAC(INT))
--R content : % -> A if A has GCDDOM
--R directSum : (%, %) -> % if A has FIELD
--R exquo : (%, A) -> Union(%, "failed") if A has INTDOM
--R leftDivide : (%, %) -> Record(quotient: %, remainder: %) if A has FIELD
--R leftExactQuotient : (%, %) -> Union(%, "failed") if A has FIELD
--R leftExtendedGcd : (%, %) -> Record(coef1: %, coef2: %, generator: %) if A has FIELD
--R leftGcd : (%, %) -> % if A has FIELD
--R leftLcm : (%, %) -> % if A has FIELD
--R leftQuotient : (%, %) -> % if A has FIELD
--R leftRemainder : (%, %) -> % if A has FIELD
--R minimumDegree : % -> NonNegativeInteger
--R monicLeftDivide : (%, %) -> Record(quotient: %, remainder: %) if A has INTDOM
--R monicRightDivide : (%, %) -> Record(quotient: %, remainder: %) if A has INTDOM
--R monomial : (A, NonNegativeInteger) -> %
--R primitivePart : % -> % if A has GCDDOM
--R retract : % -> Fraction(Integer) if A has RETRACT(FRAC(INT))
--R retract : % -> Integer if A has RETRACT(INT)
--R retractIfCan : % -> Union(A, "failed")
--R retractIfCan : % -> Union(Fraction(Integer), "failed") if A has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer, "failed") if A has RETRACT(INT)
--R rightDivide : (%, %) -> Record(quotient: %, remainder: %) if A has FIELD
--R rightExactQuotient : (%, %) -> Union(%, "failed") if A has FIELD
--R rightExtendedGcd : (%, %) -> Record(coef1: %, coef2: %, generator: %) if A has FIELD
--R rightGcd : (%, %) -> % if A has FIELD
--R rightLcm : (%, %) -> % if A has FIELD
--R rightQuotient : (%, %) -> % if A has FIELD
--R rightRemainder : (%, %) -> % if A has FIELD
--R subtractIfCan : (%, %) -> Union(%, "failed")
--R symmetricPower : (%, NonNegativeInteger) -> % if A has FIELD
--R symmetricProduct : (%, %) -> % if A has FIELD
--R symmetricSquare : % -> % if A has FIELD
--R
--E 1

```

```
)spool
)lisp (bye)
```

— **LinearOrdinaryDifferentialOperatorCategory.help** —

```
=====
LinearOrdinaryDifferentialOperatorCategory examples
=====
```

LinearOrdinaryDifferentialOperatorCategory is the category
of differential operators with coefficients in a ring A with a given
derivation.

Multiplication of operators corresponds to functional composition:
 $(L1 * L2).(f) = L1 L2 f$

See Also:

o)show LinearOrdinaryDifferentialOperatorCategory

See:

⇐ “Eltable” (ELTAB) [2](#) on page [48](#)

⇐ “UnivariateSkewPolynomialCategory” (OREPCAT) [10](#) on page [982](#)

Exports:

| | | |
|--------------------|--------------------|-------------------|
| 0 | 1 | adjoint |
| apply | characteristic | coefficient |
| coefficients | coerce | content |
| D | degree | directSum |
| exquo | hash | latex |
| leadingCoefficient | leftDivide | leftExactQuotient |
| leftExtendedGcd | leftGcd | leftLcm |
| leftQuotient | leftRemainder | minimumDegree |
| monicLeftDivide | monicRightDivide | monomial |
| one? | primitivePart | recip |
| reductum | retract | retractIfCan |
| rightDivide | rightExactQuotient | rightExtendedGcd |
| rightGcd | rightLcm | rightQuotient |
| rightRemainder | sample | subtractIfCan |
| symmetricPower | symmetricProduct | symmetricSquare |
| zero? | ?^? | ?..? |
| ?~=? | ?*? | ?**? |
| ?+? | ?-? | -? |
| ?=? | | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
directSum : (%,% ) -> % if A has FIELD
symmetricPower : (% ,NonNegativeInteger) -> % if A has FIELD
symmetricProduct : (%,% ) -> % if A has FIELD
```

These are implemented by this category:

```
adjoint : % -> %
D : () -> %
symmetricSquare : % -> % if A has FIELD
```

These exports come from (p982) `UnivariateSkewPolynomialCategory(A:Ring)`:

```
0 : () -> %
1 : () -> %
apply : (% ,A,A) -> A
characteristic : () -> NonNegativeInteger
coefficient : (% ,NonNegativeInteger) -> A
```

```

coefficients : % -> List A
coerce : % -> OutputForm
coerce : Integer -> %
coerce : A -> %
coerce : Fraction Integer -> % if A has RETRACT FRAC INT
content : % -> A if A has GCDDOM
degree : % -> NonNegativeInteger
exquo : (%,A) -> Union(%, "failed") if A has INTDOM
hash : % -> SingleInteger
latex : % -> String
leadingCoefficient : % -> A
leftDivide : (%,%) -> Record(quotient: %,remainder: %)
    if A has FIELD
leftExactQuotient : (%,%) -> Union(%, "failed") if A has FIELD
leftExtendedGcd : (%,%) -> Record(coef1: %,coef2: %,generator: %)
    if A has FIELD
leftGcd : (%,%) -> % if A has FIELD
leftLcm : (%,%) -> % if A has FIELD
leftQuotient : (%,%) -> % if A has FIELD
leftRemainder : (%,%) -> % if A has FIELD
minimumDegree : % -> NonNegativeInteger
monicLeftDivide : (%,%) -> Record(quotient: %,remainder: %)
    if A has INTDOM
monicRightDivide : (%,%) -> Record(quotient: %,remainder: %)
    if A has INTDOM
monomial : (A,NonNegativeInteger) -> %
one? : % -> Boolean
primitivePart : % -> % if A has GCDDOM
recip : % -> Union(%, "failed")
reductum : % -> %
retract : % -> A
retract : % -> Fraction Integer if A has RETRACT FRAC INT
retract : % -> Integer if A has RETRACT INT
retractIfCan : % -> Union(Fraction Integer, "failed")
    if A has RETRACT FRAC INT
retractIfCan : % -> Union(Integer, "failed")
    if A has RETRACT INT
retractIfCan : % -> Union(A, "failed")
rightDivide : (%,%) -> Record(quotient: %,remainder: %)
    if A has FIELD
rightExactQuotient : (%,%) -> Union(%, "failed") if A has FIELD
rightExtendedGcd :
    (%,%) -> Record(coef1: %,coef2: %,generator: %) if A has FIELD
rightGcd : (%,%) -> % if A has FIELD
rightLcm : (%,%) -> % if A has FIELD
rightQuotient : (%,%) -> % if A has FIELD
rightRemainder : (%,%) -> % if A has FIELD
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean

```

```

***? : (% , NonNegativeInteger) -> %
?^? : (% , NonNegativeInteger) -> %
?+? : (% , %) -> %
?*? : (% , A) -> %
?*? : (A , %) -> %
?~=? : (% , %) -> Boolean
?= ? : (% , %) -> Boolean
?*? : (NonNegativeInteger , %) -> %
?*? : (PositiveInteger , %) -> %
?*? : (Integer , %) -> %
?*? : (% , %) -> %
?-? : (% , %) -> %
-? : % -> %
***? : (% , PositiveInteger) -> %
?^? : (% , PositiveInteger) -> %

```

These exports come from (p48) Eltable(A:Ring,A:Ring):

```

?.? : (% , A) -> A

```

— category LODOCAT LinearOrdinaryDifferentialOperatorCategory

```

)abbrev category LODOCAT LinearOrdinaryDifferentialOperatorCategory
++ Author: Manuel Bronstein
++ Date Created: 9 December 1993
++ Date Last Updated: 15 April 1994
++ Description:
++ LinearOrdinaryDifferentialOperatorCategory is the category
++ of differential operators with coefficients in a ring A with a given
++ derivation.
++
++ Multiplication of operators corresponds to functional composition:\br
++ (L1 * L2).(f) = L1 L2 f

LinearOrdinaryDifferentialOperatorCategory(A:Ring): Category ==
  Join(UnivariateSkewPolynomialCategory A, Eltable(A, A)) with
    D: () -> %
      ++ D() provides the operator corresponding to a derivation
      ++ in the ring \spad{A}.
    adjoint: % -> %
      ++ adjoint(a) returns the adjoint operator of a.
    if A has Field then
      symmetricProduct: (% , %) -> %
        ++ symmetricProduct(a,b) computes an operator \spad{c} of
        ++ minimal order such that the nullspace of \spad{c} is
        ++ generated by all the products of a solution of \spad{a} by
        ++ a solution of \spad{b}.

```

```

symmetricPower : (%, NonNegativeInteger) -> %
  ++ symmetricPower(a,n) computes an operator \spad{c} of
  ++ minimal order such that the nullspace of \spad{c} is
  ++ generated by all the products of \spad{n} solutions
  ++ of \spad{a}.
symmetricSquare : % -> %
  ++ symmetricSquare(a) computes \spad{symmetricProduct(a,a)}
  ++ using a more efficient method.
directSum: (%, %) -> %
  ++ directSum(a,b) computes an operator \spad{c} of
  ++ minimal order such that the nullspace of \spad{c} is
  ++ generated by all the sums of a solution of \spad{a} by
  ++ a solution of \spad{b}.
add
m1monom: NonNegativeInteger -> %

D() == monomial(1, 1)

m1monom n ==
  a:A := (odd? n => -1; 1)
  monomial(a, n)

adjoint a ==
  ans:% := 0
  while a ^= 0 repeat
    ans := ans + m1monom(degree a) * leadingCoefficient(a)::%
    a := reductum a
  ans

if A has Field then symmetricSquare 1 == symmetricPower(1, 2)



---


— LODOCAT.dotabb —

"LODOCAT"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=LODOCAT" ];
"LODOCAT" -> "ELTAB"
"LODOCAT" -> "OREPCAT"



---


— LODOCAT.dotfull —

"LinearOrdinaryDifferentialOperatorCategory(a:Ring)"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=LODOCAT" ];

```

```

"LinearOrdinaryDifferentialOperatorCategory(a:Ring)"
-> "Eltable(a:Ring,b:Ring)"
"LinearOrdinaryDifferentialOperatorCategory(a:Ring)"
-> "UnivariateSkewPolynomialCategory(R:Ring)"

```

— LODOCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "LinearOrdinaryDifferentialOperatorCategory(a:Ring)" [color=lightblue];
  "LinearOrdinaryDifferentialOperatorCategory(a:Ring)"
    -> "Eltable(a:Ring,b:Ring)"
  "LinearOrdinaryDifferentialOperatorCategory(a:Ring)"
    -> "UnivariateSkewPolynomialCategory(R:Ring)"

  "Eltable(a:Ring,b:Ring)"
    [color=seagreen,href="bookvol10.2.pdf#nameddest=ELTAB"];
  "Eltable(a:Ring,b:Ring)" ->
    "Eltable(a:SetCategory,b:Type)"

  "Eltable(a:SetCategory,b:Type)" [color=lightblue];
  "Eltable(a:SetCategory,b:Type)" -> "Category"

  "UnivariateSkewPolynomialCategory(R:Ring)" [color=lightblue];
  "UnivariateSkewPolynomialCategory(R:Ring)"
    -> "BiModule(a:Ring,b:Ring)"
  "UnivariateSkewPolynomialCategory(R:Ring)"
    -> "FullyRetractableTo(a:Ring)"
  "UnivariateSkewPolynomialCategory(R:Ring)"
    -> "Ring()"

  "FullyRetractableTo(a:Ring)" [color=seagreen];
  "FullyRetractableTo(a:Ring)" -> "FullyRetractableTo(a:Type)"

  "FullyRetractableTo(a:Type)" [color=lightblue];
  "FullyRetractableTo(a:Type)" -> "RetractableTo(a:Type)"

  "RetractableTo(a:Type)" [color=lightblue];
  "RetractableTo(a:Type)" -> "Category"

  "Category" [color=lightblue];

  "Ring()" [color=lightblue];

```

```

"Ring()" -> "Rng()"
"Ring()" -> "Monoid()"
"Ring()" -> "LeftModule(a:Ring)"

"Rng()" [color=lightblue];
"Rng()" -> "AbelianGroup()"
"Rng()" -> "SemiGroup()"

"Monoid()" [color=lightblue];
"Monoid()" -> "SemiGroup()"

"BiModule(a:Ring,b:Ring)" [color=lightblue];
"BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
"BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

"RightModule(a:Ring)" [color=seagreen];
"RightModule(a:Ring)" -> "RightModule(a:Rng)"

"RightModule(a:Rng)" [color=lightblue];
"RightModule(a:Rng)" -> "AbelianGroup()"

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "AbelianGroup()"

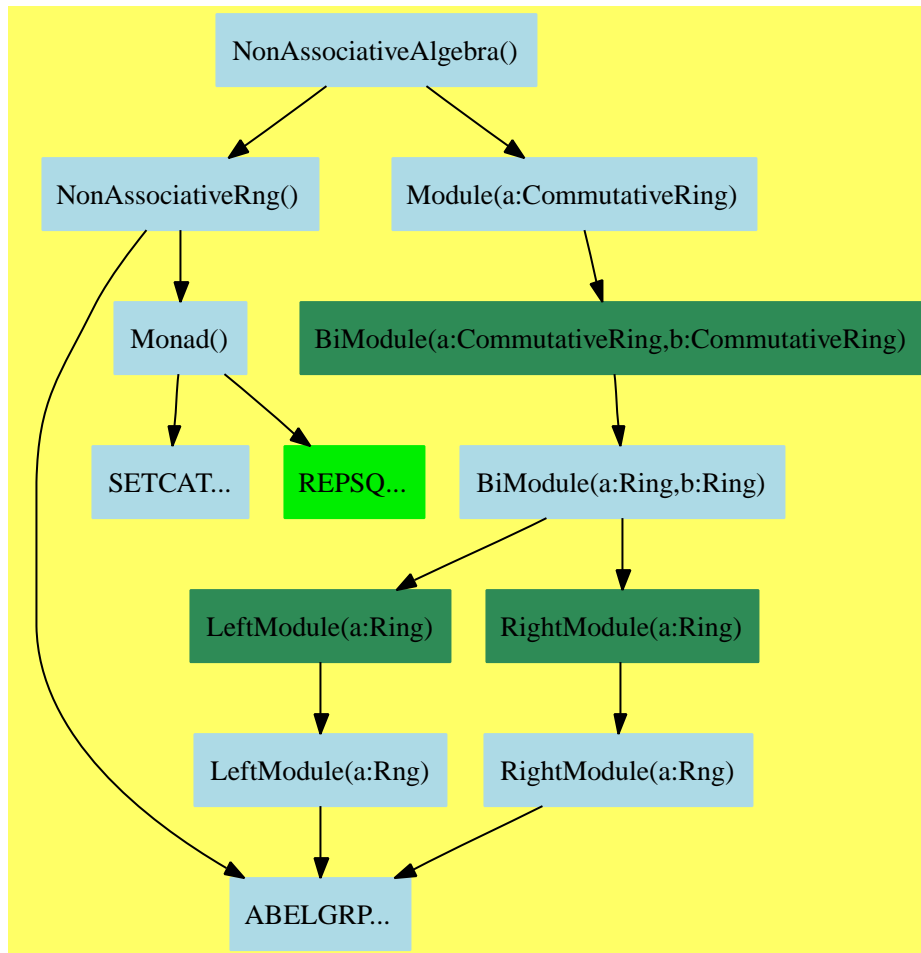
"AbelianGroup()" [color=lightblue];
"AbelianGroup()" -> "CABMON..."
"AbelianGroup()" -> "REPDB..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"CABMON..." [color=lightblue];
}

```

NonAssociativeAlgebra (NAALG)



— NonAssociativeAlgebra.input —

```

)set break resume
)sys rm -f NonAssociativeAlgebra.output
)spool NonAssociativeAlgebra.output
)set message test on
)set message auto off
)clear all

```

```

--S 1 of 1
)show NonAssociativeAlgebra
--R

```

```

--R NonAssociativeAlgebra(R: CommutativeRing) is a category constructor
--R Abbreviation for NonAssociativeAlgebra is NAALG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for NAALG
--R
--R----- Operations -----
--R ??? : (R,%) -> %           ??? : (%,R) -> %
--R ??? : (%,%) -> %           ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %                 ?? : (%,%) -> Boolean
--R 0 : () -> %                 antiCommutator : (%,%) -> %
--R associator : (%,%,%) -> %     coerce : % -> OutputForm
--R commutator : (%,%) -> %        hash : % -> SingleInteger
--R latex : % -> String           sample : () -> %
--R zero? : % -> Boolean          ?~=? : (%,%) -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R leftPower : (%,PositiveInteger) -> %
--R plenaryPower : (%,PositiveInteger) -> %
--R rightPower : (%,PositiveInteger) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— NonAssociativeAlgebra.help —

```

=====
NonAssociativeAlgebra examples
=====

```

NonAssociativeAlgebra is the category of non associative algebras
(modules which are themselves non associative rngs).\br

Axiom:

$$r*(a*b) = (r*a)*b = a*(r*b)$$

See Also:

o)show NonAssociativeAlgebra

See:

⇒ “FiniteRankNonAssociativeAlgebra” (FINAALG) [12](#) on page [1069](#)

← “Module” (MODULE) [10](#) on page [928](#)

← “NonAssociativeRng” (NARNG) [8](#) on page [734](#)

Exports:

| | | | | |
|--------|----------------|------------|--------------|------------|
| 0 | antiCommutator | associator | coerce | commutator |
| hash | latex | leftPower | plenaryPower | rightPower |
| sample | subtractIfCan | zero? | ?~=? | ?*? |
| ?**? | ?+? | ?-? | -? | ?=? |

Attributes exported:

- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are implemented by this category:

```
plenaryPower : (%,PositiveInteger) -> %
```

These exports come from ([p734](#)) NonAssociativeRng():

```
0 : () -> %
antiCommutator : (%,%) -> %
associator : (%,%,%) -> %
coerce : % -> OutputForm
commutator : (%,%) -> %
hash : % -> SingleInteger
latex : % -> String
leftPower : (%,PositiveInteger) -> %
rightPower : (%,PositiveInteger) -> %
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%,%) -> Boolean
?*? : (PositiveInteger,%) -> %
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?*? : (Integer,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
?*? : (%,%) -> %
?*? : (%,PositiveInteger) -> %
```

These exports come from ([p928](#)) Module(R:CommutativeRing):

```
?*? : (R,%) -> %
?*? : (%,R) -> %
```

— category NAALG NonAssociativeAlgebra —

```

)abbrev category NAALG NonAssociativeAlgebra
++ Author: J. Grabmeier, R. Wisbauer
++ Date Created: 01 March 1991
++ Date Last Updated: 11 June 1991
++ Reference:
++ R.D. Schafer: An Introduction to Nonassociative Algebras
++ Academic Press, New York, 1966
++ Description:
++ NonAssociativeAlgebra is the category of non associative algebras
++ (modules which are themselves non associative rngs).\br
++
++ Axioms\br
++ \tab{5}r*(a*b) = (r*a)*b = a*(r*b)

NonAssociativeAlgebra(R:CommutativeRing): Category == _
  Join(NonAssociativeRng, Module R) with
    plenaryPower : (%,PositiveInteger) -> %
      ++ plenaryPower(a,n) is recursively defined to be
      ++ \spad{plenaryPower(a,n-1)*plenaryPower(a,n-1)} for \spad{n>1}
      ++ and \spad{a} for \spad{n=1}.
  add
    plenaryPower(a,n) ==
--      one? n => a
      ( n = 1 ) => a
      n1 : PositiveInteger := (n-1)::NonNegativeInteger::PositiveInteger
      plenaryPower(a,n1) * plenaryPower(a,n1)

```

— NAALG.dotabb —

```

"NAALG"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=NAALG"];
"NAALG" -> "NARNG"
"NAALG" -> "MODULE"

```

— NAALG.dotfull —

```

"NonAssociativeAlgebra(a:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=NAALG"];
"NonAssociativeAlgebra(a:CommutativeRing)" -> "NonAssociativeRng()"

```

```
"NonAssociativeAlgebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"
```

— NAALG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "NonAssociativeAlgebra(a:CommutativeRing)" [color=lightblue];
  "NonAssociativeAlgebra(a:CommutativeRing)" -> "NonAssociativeRng()"
  "NonAssociativeAlgebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

  "NonAssociativeRng()" [color=lightblue];
  "NonAssociativeRng()" -> "ABELGRP..."
  "NonAssociativeRng()" -> "Monad()"

  "Monad()" [color=lightblue];
  "Monad()" -> "SETCAT..."
  "Monad()" -> "REPSQ..."

  "Module(a:CommutativeRing)" [color=lightblue];
  "Module(a:CommutativeRing)" ->
    "BiModule(a:CommutativeRing,b:CommutativeRing)"

  "BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
  "BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BiModule(a:Ring,b:Ring)"

  "BiModule(a:Ring,b:Ring)" [color=lightblue];
  "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
  "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

  "RightModule(a:Ring)" [color=seagreen];
  "RightModule(a:Ring)" -> "RightModule(a:Rng)"

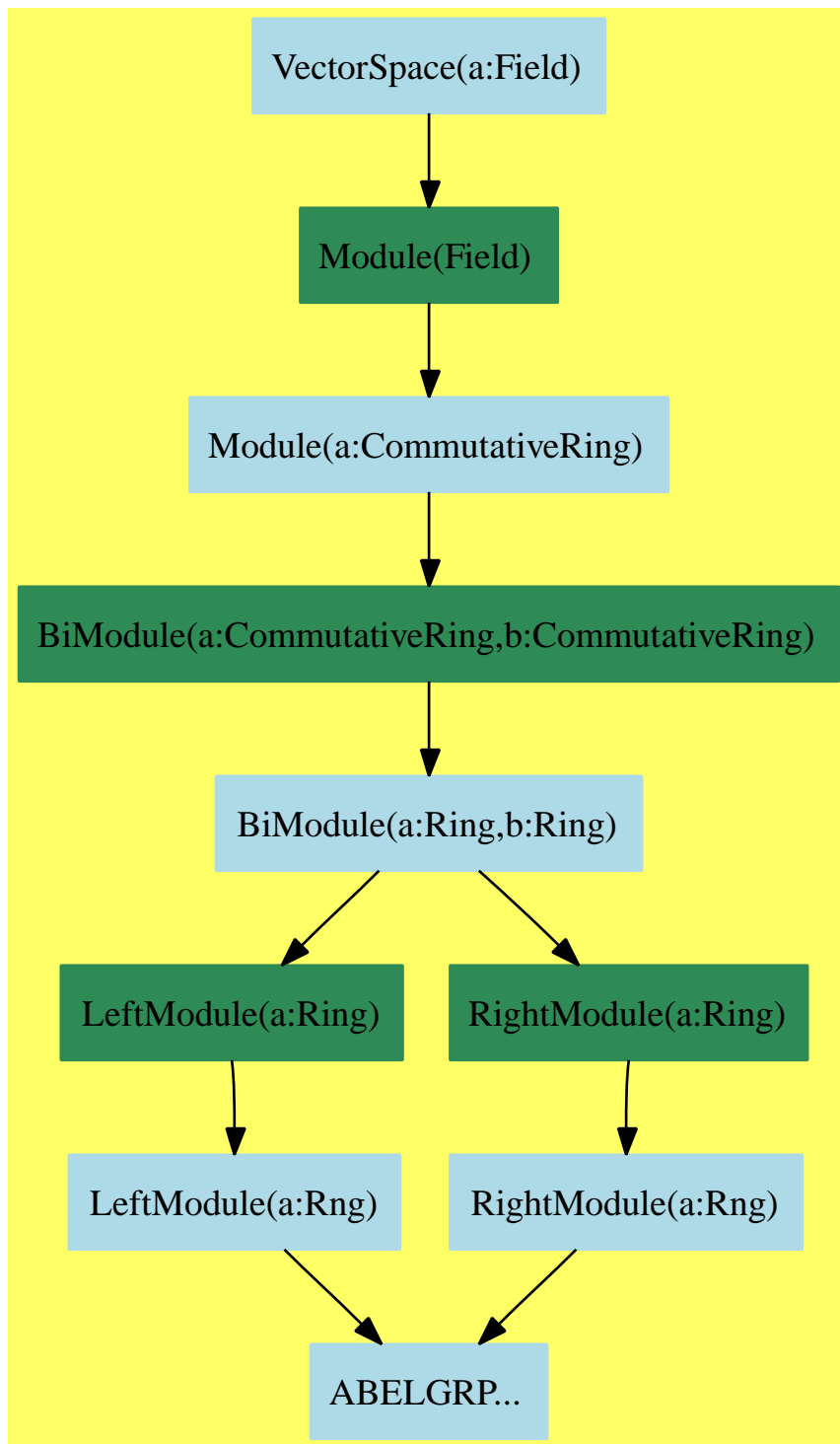
  "RightModule(a:Rng)" [color=lightblue];
  "RightModule(a:Rng)" -> "ABELGRP..."

  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

  "LeftModule(a:Rng)" [color=lightblue];
  "LeftModule(a:Rng)" -> "ABELGRP..."

  "REPSQ..." [color="#00EE00"];
  "SETCAT..." [color=lightblue];
```

```
"ABELGRP..." [color=lightblue];  
}
```

VectorSpace (VSPACE)

— VectorSpace.input —

```
)set break resume
)sys rm -f VectorSpace.output
)spool VectorSpace.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show VectorSpace
--R
--R VectorSpace(S: Field) is a category constructor
--R Abbreviation for VectorSpace is VSPACE
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for VSPACE
--R
--R----- Operations -----
--R ?? : (%,S) -> %           ?? : (S,%) -> %
--R ?? : (Integer,%) -> %     ?? : (PositiveInteger,%) -> %
--R ?? : (%,%) -> %          ?-? : (%,%) -> %
--R -? : % -> %              ?/? : (%,S) -> %
--R ?? : (%,%) -> Boolean    0 : () -> %
--R coerce : % -> OutputForm dimension : () -> CardinalNumber
--R hash : % -> SingleInteger latex : % -> String
--R sample : () -> %         zero? : % -> Boolean
--R ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)
```

— VectorSpace.help —

```
=====
VectorSpace examples
=====
```

Vector Spaces (not necessarily finite dimensional) over a field.

See Also:

o)show VectorSpace

See:

\Rightarrow “ExtensionField” (XF) [18](#) on page [1562](#)

\Leftarrow “Module” (MODULE) [10](#) on page [928](#)

Exports:

| | | | | |
|--------|---------------|-----------|------|-------|
| 0 | coerce | dimension | hash | latex |
| sample | subtractIfCan | zero? | ?~=? | ?*? |
| ?+? | ?-? | -? | ?/? | ?=? |

Attributes exported:

- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
dimension : () -> CardinalNumber
```

These are implemented by this category:

```
?/? : (%,S) -> %
```

These exports come from (p[928](#)) Module():

```
?*? : (%,S) -> %
0 : () -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (S,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?+? : (%,%) -> %
?-? : (%,%) -> %
-? : % -> %
?=? : (%,%) -> Boolean
```

— category VSPACE VectorSpace —

```

)abbrev category VSPACE VectorSpace
++ Description:
++ Vector Spaces (not necessarily finite dimensional) over a field.

VectorSpace(S:Field): Category == Module(S) with
  "/"      : (% , S) -> %
  ++ x/y divides the vector x by the scalar y.
  dimension: () -> CardinalNumber
  ++ dimension() returns the dimensionality of the vector space.
add
  (v:% / s:S):% == inv(s) * v

```

— VSPACE.dotabb —

```

"VSPACE"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=VSPACE"];
"VSPACE" -> "MODULE"

```

— VSPACE.dotfull —

```

"VectorSpace(a:Field)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=VSPACE"];
"VectorSpace(a:Field)" -> "Module(Field)"

```

— VSPACE.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "VectorSpace(a:Field)" [color=lightblue];
  "VectorSpace(a:Field)" -> "Module(Field)"

  "Module(Field)" [color=seagreen];
  "Module(Field)" -> "Module(a:CommutativeRing)"

  "Module(a:CommutativeRing)" [color=lightblue];
  "Module(a:CommutativeRing)" ->

```



```

"BiModule(a:CommutativeRing,b:CommutativeRing)"

"BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BiModule(a:Ring,b:Ring)"

"BiModule(a:Ring,b:Ring)" [color=lightblue];
"BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
"BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

"RightModule(a:Ring)" [color=seagreen];
"RightModule(a:Ring)" -> "RightModule(a:Rng)"

"RightModule(a:Rng)" [color=lightblue];
"RightModule(a:Rng)" -> "ABELGRP..."

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

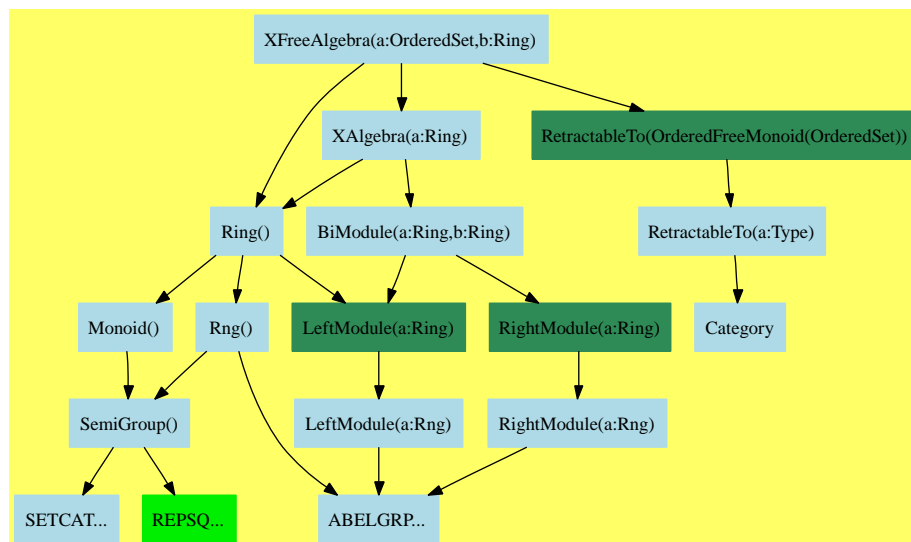
"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "ABELGRP..."

"ABELGRP..." [color=lightblue];
}

```

→

XFreeAlgebra (XFALG)



— XFreeAlgebra.input —

```

)set break resume
)sys rm -f XFreeAlgebra.output
)spool XFreeAlgebra.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show XFreeAlgebra
--R
--R XFreeAlgebra(vl: OrderedSet,R: Ring) is a category constructor
--R Abbreviation for XFreeAlgebra is XFALG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for XFALG
--R
--R----- Operations -----
--R ??? : (vl,%) -> %           ??? : (%,R) -> %
--R ??? : (R,%) -> %           ??? : (%,%) -> %
--R ??? : (Integer,%) -> %     ??? : (PositiveInteger,%) -> %
--R ??? : (%,PositiveInteger) -> %  ?+? : (%,%) -> %
--R ?-? : (%,%) -> %           -? : % -> %
--R ?? : (%,%) -> Boolean      1 : () -> %
--R 0 : () -> %               ?? : (%,PositiveInteger) -> %
--R coef : (%,%) -> R         coerce : vl -> %
--R coerce : R -> %           coerce : Integer -> %
--R coerce : % -> OutputForm  constant : % -> R
--R constant? : % -> Boolean  hash : % -> SingleInteger
--R latex : % -> String      lquo : (%,%) -> %
--R lquo : (%,vl) -> %       map : ((R -> R),%) -> %
--R mirror : % -> %          monomial? : % -> Boolean
--R one? : % -> Boolean       quasiRegular : % -> %
--R quasiRegular? : % -> Boolean recip : % -> Union(%, "failed")
--R rquo : (%,%) -> %         rquo : (%,vl) -> %
--R sample : () -> %         varList : % -> List(vl)
--R zero? : % -> Boolean     ?~=? : (%,%) -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R coef : (%,OrderedFreeMonoid(vl)) -> R
--R coerce : OrderedFreeMonoid(vl) -> %
--R lquo : (%,OrderedFreeMonoid(vl)) -> %
--R mindeg : % -> OrderedFreeMonoid(vl)
--R mindegTerm : % -> Record(k: OrderedFreeMonoid(vl),c: R)
--R monom : (OrderedFreeMonoid(vl),R) -> %

```

```

--R retract : % -> OrderedFreeMonoid(v1)
--R retractIfCan : % -> Union(OrderedFreeMonoid(v1),"failed")
--R rquo : (% , OrderedFreeMonoid(v1)) -> %
--R sh : (% , NonNegativeInteger) -> % if R has COMRING
--R sh : (% , %) -> % if R has COMRING
--R subtractIfCan : (% , %) -> Union(% , "failed")
--R
--E 1

```

```

)spool
)lisp (bye)

```

— XFreeAlgebra.help —

=====

XFreeAlgebra examples

=====

This category specifies operations for polynomials and formal series with non-commutative variables.

See Also:

o)show XFreeAlgebra

See:

⇒ “XPolynomialsCat” (XPOLYC) [12](#) on page [1144](#)

⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

⇐ “Ring” (RING) [9](#) on page [826](#)

⇐ “XAlgebra” (XALG) [10](#) on page [994](#)

Exports:

| | | | | |
|---------------|--------------|----------------|---------------|--------|
| 0 | 1 | characteristic | coef | coerce |
| constant | constant? | hash | latex | lquo |
| map | mindeg | mindegTerm | mirror | monom |
| monomial? | one? | quasiRegular | quasiRegular? | recip |
| retract | retractIfCan | rquo | sample | sh |
| subtractIfCan | varList | zero? | ??? | ??? |
| ?+? | ?-? | -? | ?=? | ?^? |
| ?~=? | | | | |

Attributes Exported:

- if Ring has noZeroDivisors then noZeroDivisors where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- **commutative**("*") is true if it has an operation " * " : $(D,D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return "failed" if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```

coef : (%,OrderedFreeMonoid v1) -> R
coef : (%,%) -> R
coerce : v1 -> %
constant : % -> R
constant? : % -> Boolean
lquo : (%,v1) -> %
lquo : (%,%) -> %
lquo : (%,OrderedFreeMonoid v1) -> %
map : ((R -> R),%) -> %
mindeg : % -> OrderedFreeMonoid v1
mindegTerm : % -> Record(k: OrderedFreeMonoid v1,c: R)
mirror : % -> %
monom : (OrderedFreeMonoid v1,R) -> %
monomial? : % -> Boolean
quasiRegular : % -> %
quasiRegular? : % -> Boolean
rquo : (%,OrderedFreeMonoid v1) -> %
rquo : (%,%) -> %
rquo : (%,v1) -> %
sh : (%,NonNegativeInteger) -> % if R has COMRING
sh : (%,%) -> % if R has COMRING
varList : % -> List v1
?? : (v1,%) -> %
?? : (%,R) -> %

```

These exports come from (p826) Ring():

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : % -> OutputForm
coerce : Integer -> %
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean

```

```

recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (NonNegativeInteger, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (Integer, %) -> %
?*? : (%, %) -> %
?-? : (%, %) -> %
-? : % -> %
***? : (%, PositiveInteger) -> %
***? : (%, NonNegativeInteger) -> %
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %

```

These exports come from (p994) XAlgebra(a:Ring):

```

coerce : R -> %
?*? : (R, %) -> %

```

These exports come from (p95) RetractableTo(WORD)
where WORD:OrderedFreeMonoid(OrderedSet))

```

coerce : OrderedFreeMonoid vl -> %
retract : % -> OrderedFreeMonoid vl
retractIfCan : % -> Union(OrderedFreeMonoid vl, "failed")

```

— category XFALG XFreeAlgebra —

```

)abbrev category XFALG XFreeAlgebra
++ Author: Michel Petitot petitot@lifl.fr
++ Date Created: 91
++ Date Last Updated: 7 Juillet 92
++ Fix History: compilation v 2.1 le 13 dec 98
++ Description:
++ This category specifies operations for polynomials
++ and formal series with non-commutative variables.

XFreeAlgebra(vl:OrderedSet,R:Ring):Category == Catdef where
  WORD ==> OrderedFreeMonoid(vl)      -- monoïde libre
  NNI   ==> NonNegativeInteger
  I     ==> Integer
  TERM  ==> Record(k: WORD, c: R)

Catdef == Join(Ring, XAlgebra(R), RetractableTo WORD)

```

```

with
  "(": (v1,%) -> %
    ++ \spad{v * x} returns the product of a variable \spad{x}
    ++ by \spad{x}.
  "(": (%, R) -> %
    ++ \spad{x * r} returns the product of \spad{x} by \spad{r}.
    ++ Usefull if \spad{R} is a non-commutative Ring.
mindeg: % -> WORD
  ++ \spad{mindeg(x)} returns the little word which appears
  ++ in \spad{x}. Error if \spad{x}=0.
mindegTerm: % -> TERM
  ++ \spad{mindegTerm(x)} returns the term whose word is
  ++ \spad{mindeg(x)}.
coef : (%,WORD) -> R
  ++ \spad{coef(x,w)} returns the coefficient of the word \spad{w}
  ++ in \spad{x}.
coef : (%,%) -> R
  ++ \spad{coef(x,y)} returns scalar product of \spad{x} by \spad{y},
  ++ the set of words being regarded as an orthogonal basis.
lquo : (%,v1) -> %
  ++ \spad{lquo(x,v)} returns the left simplification of \spad{x}
  ++ by the variable \spad{v}.
lquo : (%,WORD) -> %
  ++ \spad{lquo(x,w)} returns the left simplification of \spad{x}
  ++ by the word \spad{w}.
lquo : (%,%) -> %
  ++ \spad{lquo(x,y)} returns the left simplification of \spad{x}
  ++ by \spad{y}.
rquo : (%,v1) -> %
  ++ \spad{rquo(x,v)} returns the right simplification of \spad{x}
  ++ by the variable \spad{v}.
rquo : (%,WORD) -> %
  ++ \spad{rquo(x,w)} returns the right simplification of \spad{x}
  ++ by \spad{w}.
rquo : (%,%) -> %
  ++ \spad{rquo(x,y)} returns the right simplification of \spad{x}
  ++ by \spad{y}.
monom : (WORD , R) -> %
  ++ \spad{monom(w,r)} returns the product of the word \spad{w}
  ++ by the coefficient \spad{r}.
monomial? : % -> Boolean
  ++ \spad{monomial?(x)} returns true if \spad{x} is a monomial
mirror: % -> %
  ++ \spad{mirror(x)} returns \spad{Sum(r_i mirror(w_i))} if
  ++ \spad{x} writes \spad{Sum(r_i w_i)}.
coerce : v1 -> %
  ++ \spad{coerce(v)} returns \spad{v}.
constant?:% -> Boolean
  ++ \spad{constant?(x)} returns true if \spad{x} is constant.
constant: % -> R

```

```

    ++ \spad{constant(x)} returns the constant term of \spad{x}.
quasiRegular? : % -> Boolean
    ++ \spad{quasiRegular?(x)} return true if \spad{constant(x)} is zero
quasiRegular : % -> %
    ++ \spad{quasiRegular(x)} return \spad{x} minus its constant term.
if R has CommutativeRing then
    sh :(%,% ) -> %
        ++ \spad{sh(x,y)} returns the shuffle-product of \spad{x}
        ++ by \spad{y}.
        ++ This multiplication is associative and commutative.
    sh :(% ,NNI) -> %
        ++ \spad{sh(x,n)} returns the shuffle power of \spad{x} to
        ++ the \spad{n}.
    map : (R -> R, %) -> %
        ++ \spad{map(fn,x)} returns \spad{Sum(fn(r_i) w_i)} if \spad{x}
        ++ writes \spad{Sum(r_i w_i)}.
    varList: % -> List vl
        ++ \spad{varList(x)} returns the list of variables which
        ++ appear in \spad{x}.

-- Attributs
if R has noZeroDivisors then noZeroDivisors

```

— XFALG.dotabb —

```

"XFALG"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=XFALG"];
"XFALG" -> "RETRACT"
"XFALG" -> "RING"
"XFALG" -> "XALG"

```

— XFALG.dotfull —

```

"XFreeAlgebra(a:OrderedSet,b:Ring)"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=XFALG"];
"XFreeAlgebra(a:OrderedSet,b:Ring)" -> "Ring()"
"XFreeAlgebra(a:OrderedSet,b:Ring)" -> "XAlgebra(a:Ring)"
"XFreeAlgebra(a:OrderedSet,b:Ring)" ->
    "RetractableTo(OrderedFreeMonoid(OrderedSet))"

```

— XFALG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "XFreeAlgebra(a:OrderedSet,b:Ring)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=XFALG"];
  "XFreeAlgebra(a:OrderedSet,b:Ring)" -> "Ring()"
  "XFreeAlgebra(a:OrderedSet,b:Ring)" -> "XAlgebra(a:Ring)"
  "XFreeAlgebra(a:OrderedSet,b:Ring)" ->
    "RetractableTo(OrderedFreeMonoid(OrderedSet))"

  "RetractableTo(OrderedFreeMonoid(OrderedSet))"
    [color=seagreen,href="bookvol10.2.pdf#nameddest=RETRACT"];
  "RetractableTo(OrderedFreeMonoid(OrderedSet))" -> "RetractableTo(a:Type)"

  "XAlgebra(a:Ring)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=XALG"];
  "XAlgebra(a:Ring)" -> "Ring()"
  "XAlgebra(a:Ring)" -> "BiModule(a:Ring,b:Ring)"

  "Ring()" [color=lightblue];
  "Ring()" -> "Rng()"
  "Ring()" -> "Monoid()"
  "Ring()" -> "LeftModule(a:Ring)"

  "BiModule(a:Ring,b:Ring)" [color=lightblue];
  "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
  "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

  "RightModule(a:Ring)" [color=seagreen];
  "RightModule(a:Ring)" -> "RightModule(a:Rng)"

  "RightModule(a:Rng)" [color=lightblue];
  "RightModule(a:Rng)" -> "ABELGRP..."

  "Rng()" [color=lightblue];
  "Rng()" -> "ABELGRP..."
  "Rng()" -> "SemiGroup()"

  "Monoid()" [color=lightblue];
  "Monoid()" -> "SemiGroup()"

  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

  "LeftModule(a:Rng)" [color=lightblue];

```



```

"LeftModule(a:Rng)" -> "ABELGRP..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"RetractableTo(a:Type)" [color=lightblue];
"RetractableTo(a:Type)" -> "Category"

"Category" [color=lightblue];

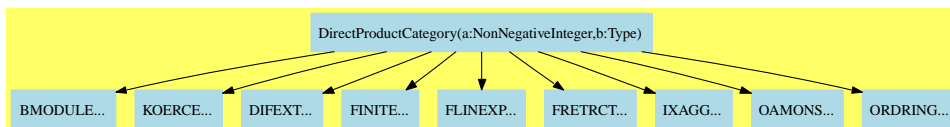
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"ABELGRP..." [color=lightblue];
}

```

Chapter 12

Category Layer 11

DirectProductCategory (DIRPCAT)



— DirectProductCategory.input —

```

)set break resume
)sys rm -f DirectProductCategory.output
)spool DirectProductCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show DirectProductCategory
--R
--R DirectProductCategory(dim: NonNegativeInteger,R: Type) is a category constructor
--R Abbreviation for DirectProductCategory is DIRPCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DIRPCAT
--R
--R----- Operations -----
--R -? : % -> % if R has RING
--R 0 : () -> % if R has CABMON
--R copy : % -> %
--R ?.? : (%,Integer) -> R
--R empty : () -> %
--R 1 : () -> % if R has MONOID
--R coerce : % -> Vector(R)
--R directProduct : Vector(R) -> %
--R elt : (%,Integer,R) -> R
--R empty? : % -> Boolean

```

```

--R entries : % -> List(R)                      eq? : (%,% ) -> Boolean
--R index? : (Integer,% ) -> Boolean              indices : % -> List(Integer)
--R map : ((R -> R),%) -> %                      qelt : (% ,Integer) -> R
--R sample : () -> %
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?? : (PositiveInteger,% ) -> % if R has ABELSG
--R ?? : (NonNegativeInteger,% ) -> % if R has CABMON
--R ?? : (R,% ) -> % if R has MONOID
--R ?? : (% ,R) -> % if R has MONOID
--R ?? : (% ,%) -> % if R has MONOID
--R ?? : (Integer,% ) -> % if R has RING
--R ??? : (% ,PositiveInteger) -> % if R has MONOID
--R ??? : (% ,NonNegativeInteger) -> % if R has MONOID
--R ?+? : (% ,%) -> % if R has ABELSG
--R ?-? : (% ,%) -> % if R has RING
--R ?/? : (% ,R) -> % if R has FIELD
--R ?<? : (% ,%) -> Boolean if R has ORDRING or R has OAMONS
--R ?<=? : (% ,%) -> Boolean if R has ORDRING or R has OAMONS
--R ?=? : (% ,%) -> Boolean if R has SETCAT
--R ?>? : (% ,%) -> Boolean if R has ORDRING or R has OAMONS
--R ?>=? : (% ,%) -> Boolean if R has ORDRING or R has OAMONS
--R D : (% ,(R -> R)) -> % if R has RING
--R D : (% ,(R -> R),NonNegativeInteger) -> % if R has RING
--R D : (% ,List(Symbol),List(NonNegativeInteger)) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Ring))
--R D : (% ,Symbol,NonNegativeInteger) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Ring))
--R D : (% ,List(Symbol)) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Ring))
--R D : (% ,Symbol) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Ring))
--R D : (% ,NonNegativeInteger) -> % if and(has(R,DifferentialRing),has(R,Ring))
--R D : % -> % if and(has(R,DifferentialRing),has(R,Ring))
--R ^? : (% ,PositiveInteger) -> % if R has MONOID
--R ^? : (% ,NonNegativeInteger) -> % if R has MONOID
--R abs : % -> % if R has ORDRING
--R any? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
--R characteristic : () -> NonNegativeInteger if R has RING
--R coerce : R -> % if R has SETCAT
--R coerce : Fraction(Integer) -> % if and(has(R,RetractableTo(Fraction(Integer))),has(R,SetCategory))
--R coerce : Integer -> % if and(has(R,RetractableTo(Integer)),has(R,SetCategory)) or R has RING
--R coerce : % -> OutputForm if R has SETCAT
--R count : (R,% ) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
--R count : ((R -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
--R differentiate : (% ,(R -> R)) -> % if R has RING
--R differentiate : (% ,(R -> R),NonNegativeInteger) -> % if R has RING
--R differentiate : (% ,List(Symbol),List(NonNegativeInteger)) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Ring))
--R differentiate : (% ,Symbol,NonNegativeInteger) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Ring))
--R differentiate : (% ,List(Symbol)) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Ring))
--R differentiate : (% ,Symbol) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Ring))
--R differentiate : (% ,NonNegativeInteger) -> % if and(has(R,DifferentialRing),has(R,Ring))
--R differentiate : % -> % if and(has(R,DifferentialRing),has(R,Ring))
--R dimension : () -> CardinalNumber if R has FIELD
--R dot : (% ,%) -> R if R has RING

```

```

--R entry? : (R,%) -> Boolean if $ has finiteAggregate and R has SETCAT
--R enumerate : () -> List(%) if R has FINITE
--R eval : (%,List(R),List(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,R,R) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,Equation(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (%,List(Equation(R))) -> % if R has EVALAB(R) and R has SETCAT
--R every? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
--R fill! : (%,R) -> % if $ has shallowlyMutable
--R first : % -> R if Integer has ORDSET
--R hash : % -> SingleInteger if R has SETCAT
--R index : PositiveInteger -> % if R has FINITE
--R latex : % -> String if R has SETCAT
--R less? : (%,NonNegativeInteger) -> Boolean
--R lookup : % -> PositiveInteger if R has FINITE
--R map! : ((R -> R),%) -> % if $ has shallowlyMutable
--R max : (%,%) -> % if R has ORDRING or R has OAMONS
--R maxIndex : % -> Integer if Integer has ORDSET
--R member? : (R,%) -> Boolean if R has SETCAT and $ has finiteAggregate
--R members : % -> List(R) if $ has finiteAggregate
--R min : (%,%) -> % if R has ORDRING or R has OAMONS
--R minIndex : % -> Integer if Integer has ORDSET
--R more? : (%,NonNegativeInteger) -> Boolean
--R negative? : % -> Boolean if R has ORDRING
--R one? : % -> Boolean if R has MONOID
--R parts : % -> List(R) if $ has finiteAggregate
--R positive? : % -> Boolean if R has ORDRING
--R qsetelt! : (%,Integer,R) -> R if $ has shallowlyMutable
--R random : () -> % if R has FINITE
--R recip : % -> Union(%, "failed") if R has MONOID
--R reducedSystem : Matrix(%) -> Matrix(R) if R has RING
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(R),vec: Vector(R)) if R has RING
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Integer),vec: Vector(Integer)) if and(has(R
--R reducedSystem : Matrix(%) -> Matrix(Integer) if and(has(R,LinearlyExplicitRingOver(Integer)),has(R,Ring
--R retract : % -> R if R has SETCAT
--R retract : % -> Fraction(Integer) if and(has(R,RetractableTo(Fraction(Integer))),has(R,SetCategory))
--R retract : % -> Integer if and(has(R,RetractableTo(Integer)),has(R,SetCategory))
--R retractIfCan : % -> Union(R, "failed") if R has SETCAT
--R retractIfCan : % -> Union(Fraction(Integer), "failed") if and(has(R,RetractableTo(Fraction(Integer))),has
--R retractIfCan : % -> Union(Integer, "failed") if and(has(R,RetractableTo(Integer)),has(R,SetCategory))
--R setelt : (%,Integer,R) -> R if $ has shallowlyMutable
--R sign : % -> Integer if R has ORDRING
--R size : () -> NonNegativeInteger if R has FINITE
--R size? : (%,NonNegativeInteger) -> Boolean
--R subtractIfCan : (%,%) -> Union(%, "failed") if R has CABMON
--R sup : (%,%) -> % if R has OAMONS
--R swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable
--R unitVector : PositiveInteger -> % if R has RING
--R zero? : % -> Boolean if R has CABMON
--R ~=? : (%,%) -> Boolean if R has SETCAT
--R

```

```
--E 1
```

```
)spool
)lisp (bye)
```

— DirectProductCategory.help —

```
=====
DirectProductCategory examples
=====
```

This category represents a finite cartesian product of a given type.
Many categorical properties are preserved under this construction.

See Also:

o)show DirectProductCategory

See:

- ⇐ “BiModule” (BMODULE) [9](#) on page [782](#)
- ⇐ “CoercibleTo” (KOERCE) [2](#) on page [33](#)
- ⇐ “DifferentialExtension” (DIFEXT) [11](#) on page [1005](#)
- ⇐ “IndexedAggregate” (IXAGG) [5](#) on page [372](#)
- ⇐ “Finite” (FINITE) [4](#) on page [218](#)
- ⇐ “FullyLinearlyExplicitRingOver” (FLINEXP) [11](#) on page [1012](#)
- ⇐ “FullyRetractableTo” (FRETRCT) [3](#) on page [136](#)
- ⇐ “OrderedRing” (ORDRING) [10](#) on page [933](#)
- ⇐ “OrderedAbelianMonoidSup” (OAMONS) [9](#) on page [815](#)

Exports:

| | | | | |
|---------------|---------------|---------------|------------|----------------|
| 0 | 1 | abs | any? | characteristic |
| coerce | copy | count | D | differentiate |
| dimension | directProduct | dot | elt | empty |
| empty? | entry? | entries | eq? | eval |
| every? | fill! | first | hash | index |
| index? | indices | latex | less? | lookup |
| map | map! | max | maxIndex | member? |
| members | min | minIndex | more? | negative? |
| one? | parts | positive? | qelt | qsetelt! |
| random | recip | reducedSystem | retract | retractIfCan |
| sample | setelt | sign | size | size? |
| subtractIfCan | sup | swap! | unitVector | zero? |
| ?~=? | -? | ?.? | #? | ?*? |
| ?**? | ?+? | ?-? | ?/? ?<? | |
| ?<=? | ?=? | ?>? | ?>=? | ?^? |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- if #2 has commutativeRing then commutative(“*”) where **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- if #2 has unitsKnown then unitsKnown where **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- if #2 has Ring then rightUnitary where **leftUnitary** is true if $1 * x = x$ for all x.
- if #2 has Ring then rightUnitary where **rightUnitary** is true if $x * 1 = x$ for all x.
- **nil**

These are directly exported but not implemented:

```
directProduct : Vector R -> %
dot : (%,%)-> R if R has RING
unitVector : PositiveInteger -> % if R has RING
?*: (R,%) -> % if R has MONOID
?*: (% ,R) -> % if R has MONOID
```

These are implemented by this category:

```
characteristic : () -> NonNegativeInteger if R has RING
coerce : Integer -> %
  if and(has(R,RetractableTo Integer),
        has(R,SetCategory))
  or R has RING
differentiate : (%,(R -> R)) -> % if R has RING
```

```

dimension : () -> CardinalNumber if R has FIELD
reducedSystem : Matrix % -> Matrix R if R has RING
reducedSystem :
  (Matrix %,Vector %) ->
    Record(mat: Matrix R,vec: Vector R)
      if R has RING
size : () -> NonNegativeInteger if R has FINITE
?/? : (% ,R) -> % if R has FIELD

```

These exports come from (p372) `IndexedAggregate(a:SetCategory,R:Type):`

```

any? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
coerce : % -> OutputForm if R has SETCAT
copy : % -> %
count : (R,%) -> NonNegativeInteger
  if R has SETCAT
    and $ has finiteAggregate
count : ((R -> Boolean),%) -> NonNegativeInteger
  if $ has finiteAggregate
elt : (% ,Integer,R) -> R
empty : () -> %
empty? : % -> Boolean
entries : % -> List R
entry? : (R,%) -> Boolean
  if $ has finiteAggregate
    and R has SETCAT
eq? : (% ,%) -> Boolean
eval : (% ,List R,List R) -> %
  if R has EVALAB R
    and R has SETCAT
eval : (% ,R,R) -> %
  if R has EVALAB R
    and R has SETCAT
eval : (% ,Equation R) -> %
  if R has EVALAB R
    and R has SETCAT
eval : (% ,List Equation R) -> %
  if R has EVALAB R
    and R has SETCAT
every? : ((R -> Boolean),%) -> Boolean
  if $ has finiteAggregate
fill! : (% ,R) -> % if $ has shallowlyMutable
first : % -> R if Integer has ORDSET
hash : % -> SingleInteger if R has SETCAT
index? : (Integer,%) -> Boolean
indices : % -> List Integer
less? : (% ,NonNegativeInteger) -> Boolean
latex : % -> String if R has SETCAT
map : ((R -> R),%) -> %
map! : ((R -> R),%) -> % if $ has shallowlyMutable

```

```

maxIndex : % -> Integer if Integer has ORDSET
member? : (R,%) -> Boolean
  if R has SETCAT
    and $ has finiteAggregate
members : % -> List R if $ has finiteAggregate
minIndex : % -> Integer if Integer has ORDSET
more? : (%,NonNegativeInteger) -> Boolean
parts : % -> List R if $ has finiteAggregate
qelt : (%,Integer) -> R
qsetelt! : (%,Integer,R) -> R if $ has shallowlyMutable
sample : () -> %
setelt : (%,Integer,R) -> R if $ has shallowlyMutable
size? : (%,NonNegativeInteger) -> Boolean
swap! : (%,Integer,Integer) -> Void if $ has shallowlyMutable
#? : % -> NonNegativeInteger if $ has finiteAggregate
?.? : (%,Integer) -> R
?? : (%,%) -> Boolean if R has SETCAT
?~? : (%,%) -> Boolean if R has SETCAT

```

These exports come from (p33) CoercibleTo(Vector(R:Type)):

```
coerce : % -> Vector R
```

These exports come from (p136) FullyRetractableTo(R:SetCategory):

```

coerce : R -> % if R has SETCAT
coerce : Fraction Integer -> %
  if and(has(R,RetractableTo Fraction Integer),
    has(R,SetCategory))
retract : % -> Integer
  if and(has(R,RetractableTo Integer),
    has(R,SetCategory))
retract : % -> R if R has SETCAT
retract : % -> Fraction Integer
  if and(has(R,RetractableTo Fraction Integer),
    has(R,SetCategory))
retractIfCan : % -> Union(Integer,"failed")
  if and(has(R,RetractableTo Integer),
    has(R,SetCategory))
retractIfCan : % -> Union(R,"failed") if R has SETCAT
retractIfCan : % -> Union(Fraction Integer,"failed")
  if and(has(R,RetractableTo Fraction Integer),
    has(R,SetCategory))

```

These exports come from (p782) BiModule(R:Ring,R:Ring):

```

0 : () -> % if R has CABMON
subtractIfCan : (%,%) -> Union(%, "failed") if R has CABMON
zero? : % -> Boolean if R has CABMON

```



```

?+? : (%,% ) -> % if R has ABELSG
?*? : (PositiveInteger,% ) -> % if R has ABELSG
?*? : (NonNegativeInteger,% ) -> % if R has CABMON
?*? : (Integer,% ) -> % if R has RING
?-? : (%,% ) -> % if R has RING
-? : % -> % if R has RING

```

These exports come from (p1005) DifferentialExtension(R:Ring):

```

1 : () -> % if R has RING
D : (%,(R -> R)) -> % if R has RING
D : (%,(R -> R),NonNegativeInteger) -> % if R has RING
D : % -> % if and(has(R,DifferentialRing),has(R,Ring))
D : (%,(NonNegativeInteger) -> %
    if and(has(R,DifferentialRing),has(R,Ring))
differentiate : (%,(NonNegativeInteger) -> %
    if and(has(R,DifferentialRing),has(R,Ring))
D : (%,(List Symbol,List NonNegativeInteger) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Ring))
D : (%,(Symbol,NonNegativeInteger) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Ring))
D : (%,(List Symbol) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Ring))
D : (%,(Symbol) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Ring))
differentiate : (%,(List Symbol,List NonNegativeInteger) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Ring))
differentiate : (%,(Symbol,NonNegativeInteger) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Ring))
differentiate : (%,(List Symbol) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Ring))
differentiate : % -> %
    if and(has(R,DifferentialRing),has(R,Ring))
differentiate : (%,(R -> R),NonNegativeInteger) -> %
    if R has RING
differentiate : (%,(Symbol) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Ring))
one? : % -> Boolean if R has RING
recip : % -> Union(%,"failed") if R has RING
?*? : (%,% ) -> % if R has RING
?*?: (%,(PositiveInteger) -> % if R has RING
?*?: (%,(NonNegativeInteger) -> % if R has RING
??: (%,(PositiveInteger) -> % if R has RING
??: (%,(NonNegativeInteger) -> % if R has RING

```

These exports come from (p1012) FullyLinearlyExplicitRingOver(R:Ring):

```

reducedSystem :
  (Matrix %,Vector %) ->
    Record(mat: Matrix Integer,vec: Vector Integer)

```

```

    if and(has(R,LinearlyExplicitRingOver Integer),has(R,Ring))
  reducedSystem : Matrix % -> Matrix Integer
    if and(has(R,LinearlyExplicitRingOver Integer),has(R,Ring))

```

These exports come from (p218) Finite():

```

index : PositiveInteger -> % if R has FINITE
lookup : % -> PositiveInteger if R has FINITE
random : () -> % if R has FINITE

```

These exports come from (p933) OrderedRing():

```

abs : % -> % if R has ORDRING
max : (%,%) -> % if R has ORDRING or R has OAMONS
min : (%,%) -> % if R has ORDRING or R has OAMONS
negative? : % -> Boolean if R has ORDRING
positive? : % -> Boolean if R has ORDRING
sign : % -> Integer if R has ORDRING
?<? : (%,%) -> Boolean if R has ORDRING or R has OAMONS
?<=? : (%,%) -> Boolean if R has ORDRING or R has OAMONS
?>? : (%,%) -> Boolean if R has ORDRING or R has OAMONS
?>=? : (%,%) -> Boolean if R has ORDRING or R has OAMONS

```

These exports come from (p815) OrderedAbelianMonoidSup():

```

sup : (%,%) -> % if R has OAMONS

```

— category DIRPCAT DirectProductCategory —

```

)abbrev category DIRPCAT DirectProductCategory
++ Description:
++ This category represents a finite cartesian product of a given type.
++ Many categorical properties are preserved under this construction.
-- all direct product category domains must be compiled
-- without subsumption, set SourceLevelSubset to EQUAL
-->bo $noSubsumption := true

```

```

DirectProductCategory(dim:NonNegativeInteger, R:Type): Category ==
  Join(IndexedAggregate(Integer, R), CoercibleTo Vector R) with

```

```

  finiteAggregate
    ++ attribute to indicate an aggregate of finite size

  directProduct: Vector R -> %
    ++ directProduct(v) converts the vector v to become
    ++ a direct product. Error: if the length of v is
    ++ different from dim.

```

```

if R has SetCategory then FullyRetractableTo R

if R has Ring then

  BiModule(R, R)

  DifferentialExtension R

  FullyLinearlyExplicitRingOver R

  unitVector: PositiveInteger -> %
    ++ unitVector(n) produces a vector with 1 in position n and
    ++ zero elsewhere.

  dot: (% , %) -> R
    ++ dot(x,y) computes the inner product of the vectors x and y.

if R has AbelianSemiGroup then AbelianSemiGroup

if R has CancellationAbelianMonoid then CancellationAbelianMonoid

if R has Monoid then

  Monoid

  _* : (R, %) -> %
    ++ r * y multiplies the element r times each component of the
    ++ vector y.

  _* : (% , R) -> %
    ++ y * r multiplies each component of the vector y
    ++ by the element r.

if R has Finite then Finite

if R has CommutativeRing then

  Algebra R

  CommutativeRing

if R has unitsKnown then unitsKnown

if R has OrderedRing then OrderedRing

if R has OrderedAbelianMonoidSup then OrderedAbelianMonoidSup

if R has Field then VectorSpace R
add
if R has Ring then

```

```

equation2R: Vector % -> Matrix R

coerce(n:Integer):%          == n::R::%

characteristic()              == characteristic()$R

differentiate(z:%, d:R -> R) == map(d, z)

equation2R v ==
  ans:Matrix(R) := new(dim, #v, 0)
  for i in minRowIndex ans .. maxRowIndex ans repeat
    for j in minColIndex ans .. maxColIndex ans repeat
      qsetelt_!(ans, i, j, qelt(qelt(v, j), i))
  ans

reducedSystem(m:Matrix %):Matrix(R) ==
  empty? m => new(0, 0, 0)
  reduce(vertConcat, [equation2R row(m, i)
    for i in minRowIndex m .. maxRowIndex m])$List(Matrix R)

reducedSystem(m:Matrix %, v:Vector %):
  Record(mat:Matrix R, vec:Vector R) ==
    vh:Vector(R) :=
      empty? v => empty()
      rh := reducedSystem(v::Matrix %)%Matrix(R)
      column(rh, minColIndex rh)
    [reducedSystem(m)%Matrix(R), vh]

if R has Finite then size == size$R ** dim

if R has Field then
  x / b          == x * inv b

dimension() == dim::CardinalNumber

```

— DIRPCAT.dotabb —

```

"DIRPCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=DIRPCAT"];
"DIRPCAT" -> "IXAGG"
"DIRPCAT" -> "KOERCE"
"DIRPCAT" -> "FRETRCT"
"DIRPCAT" -> "BMODULE"
"DIRPCAT" -> "DIFEXT"
"DIRPCAT" -> "FLINEXP"
"DIRPCAT" -> "FINITE"

```

```
"DIRPCAT" -> "ORDRING"
"DIRPCAT" -> "OAMONS"
```

— DIRPCAT.dotfull —

```
"DirectProductCategory(a:NonNegativeInteger,b:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=DIRPCAT"];
"DirectProductCategory(a:NonNegativeInteger,b:Type)"
  -> "IndexedAggregate(a:SetCategory,b:Type)"
"DirectProductCategory(a:NonNegativeInteger,b:Type)"
  -> "CoercibleTo(a:Type)"
"DirectProductCategory(a:NonNegativeInteger,b:Type)"
  -> "FullyRetractableTo(a:Type)"
"DirectProductCategory(a:NonNegativeInteger,b:Type)"
  -> "BiModule(a:Ring,b:Ring)"
"DirectProductCategory(a:NonNegativeInteger,b:Type)"
  -> "DifferentialExtension(a:Ring)"
"DirectProductCategory(a:NonNegativeInteger,b:Type)"
  -> "FullyLinearlyExplicitRingOver(a:Ring)"
"DirectProductCategory(a:NonNegativeInteger,b:Type)"
  -> "Finite()"
"DirectProductCategory(a:NonNegativeInteger,b:Type)"
  -> "OrderedRing()"
"DirectProductCategory(a:NonNegativeInteger,b:Type)"
  -> "OrderedAbelianMonoidSup()"
```

— DIRPCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "DirectProductCategory(a:NonNegativeInteger,b:Type)" [color=lightblue];
  "DirectProductCategory(a:NonNegativeInteger,b:Type)" -> "BMODULE..."
  "DirectProductCategory(a:NonNegativeInteger,b:Type)" -> "KOERCE..."
  "DirectProductCategory(a:NonNegativeInteger,b:Type)" -> "DIFEXT..."
  "DirectProductCategory(a:NonNegativeInteger,b:Type)" -> "FINITE..."
  "DirectProductCategory(a:NonNegativeInteger,b:Type)" -> "FLINEXP..."
  "DirectProductCategory(a:NonNegativeInteger,b:Type)" -> "FRETRCT..."
  "DirectProductCategory(a:NonNegativeInteger,b:Type)" -> "IXAGG..."
  "DirectProductCategory(a:NonNegativeInteger,b:Type)" -> "OAMONS..."
```

```

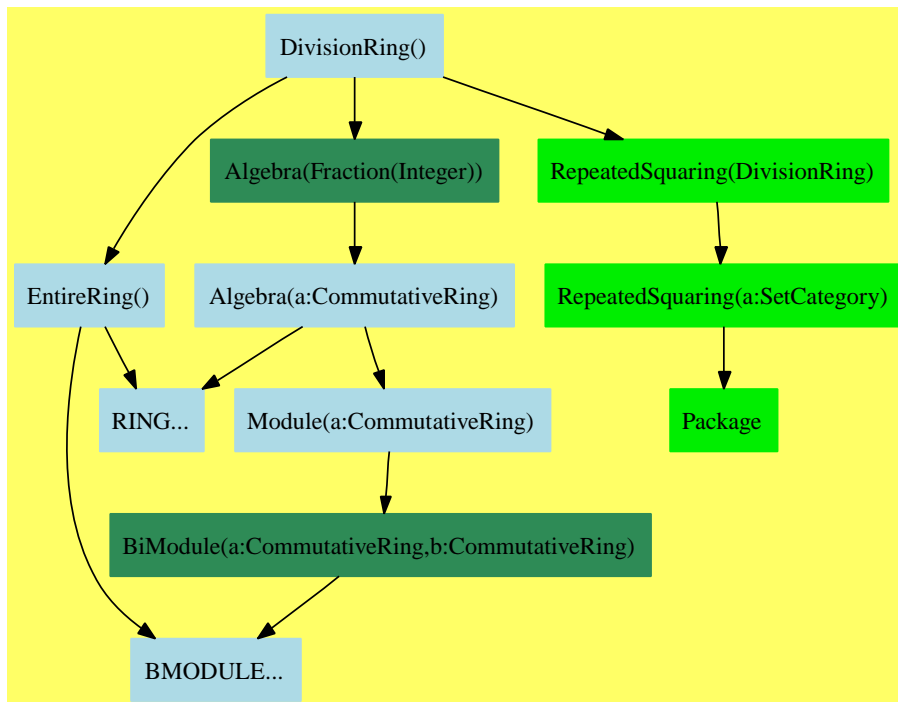
"DirectProductCategory(a:NonNegativeInteger,b:Type)" -> "ORDRING..."

"BMODULE..." [color=lightblue];
"KOERCE..." [color=lightblue];
"DIFEXT..." [color=lightblue];
"FINITE..." [color=lightblue];
"FLINEXP..." [color=lightblue];
"FRETRACT..." [color=lightblue];
"IXAGG..." [color=lightblue];
"OAMONS..." [color=lightblue];
"ORDRING..." [color=lightblue];

}

```

DivisionRing (DIVRING)



— DivisionRing.input —

```

)set break resume
)sys rm -f DivisionRing.output
)spool DivisionRing.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show DivisionRing
--R
--R DivisionRing is a category constructor
--R Abbreviation for DivisionRing is DIVRING
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DIVRING
--R
--R----- Operations -----
--R ???: (% , Fraction(Integer)) -> %      ??? : (Fraction(Integer), %) -> %
--R ??? : (% , %) -> %                      ??? : (Integer, %) -> %
--R ??? : (PositiveInteger, %) -> %         ??? : (% , Integer) -> %
--R ??? : (% , PositiveInteger) -> %       ?+? : (% , %) -> %
--R ?-? : (% , %) -> %                     -? : % -> %
--R ?=? : (% , %) -> Boolean                1 : () -> %
--R 0 : () -> %                             ?^? : (% , Integer) -> %
--R ?^? : (% , PositiveInteger) -> %        coerce : Fraction(Integer) -> %
--R coerce : Integer -> %                  coerce : % -> OutputForm
--R hash : % -> SingleInteger              inv : % -> %
--R latex : % -> String                    one? : % -> Boolean
--R recip : % -> Union(%, "failed")        sample : () -> %
--R zero? : % -> Boolean                   ?~=? : (% , %) -> Boolean
--R ??? : (NonNegativeInteger, %) -> %
--R ??? : (% , NonNegativeInteger) -> %
--R ?^? : (% , NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— DivisionRing.help —

=====

DivisionRing examples

=====

A division ring (sometimes called a skew field), i.e. a not necessarily

commutative ring where all non-zero elements have multiplicative inverses.

See Also:

o)show DivisionRing

See:

⇒ “Field” (FIELD) [16](#) on page [1271](#)

⇐ “Algebra” (ALGEBRA) [11](#) on page [999](#)

⇐ “EntireRing” (ENTIRER) [10](#) on page [907](#)

Exports:

| | | | | |
|---------------|-------|----------------|--------|--------|
| 1 | 0 | characteristic | coerce | hash |
| inv | latex | one? | recip | sample |
| subtractIfCan | zero? | ?^? | ?~=? | ?**? |
| ?*? | ?+? | ?-? | -? | ?=? |

Attributes exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.
- **nil**

These are directly exported but not implemented:

inv : % -> %

These are implemented by this category:

?^? : (% , Integer) -> %
 ?**? : (% , Integer) -> %

These exports come from (p[907](#)) EntireRing():

0 : () -> %
 1 : () -> %
 characteristic : () -> NonNegativeInteger
 coerce : Integer -> %
 coerce : % -> OutputForm


```

hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (%, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (NonNegativeInteger, %) -> %
?-? : (%, %) -> %
-? : % -> %
?^? : (%, PositiveInteger) -> %
?^? : (%, NonNegativeInteger) -> %
***? : (%, NonNegativeInteger) -> %
***? : (%, PositiveInteger) -> %

```

These exports come from (p999) `Algebra(Fraction(Integer))`:

```

coerce : Fraction Integer -> %
?*? : (%, Fraction Integer) -> %
?*? : (Fraction Integer, %) -> %

```

— category DIVRING DivisionRing —

```

)abbrev category DIVRING DivisionRing
++ Description:
++ A division ring (sometimes called a skew field),
++ i.e. a not necessarily commutative ring where
++ all non-zero elements have multiplicative inverses.

DivisionRing(): Category ==
Join(EntireRing, Algebra Fraction Integer) with
  "***": (%, Integer) -> %
    ++ x**n returns x raised to the integer power n.
  "^" : (%, Integer) -> %
    ++ x^n returns x raised to the integer power n.
  inv : % -> %
    ++ inv x returns the multiplicative inverse of x.
    ++ Error: if x is 0.
-- Q-algebra is a lie, should be conditional on characteristic 0,
-- but knownInfo cannot handle the following commented
-- if % has CharacteristicZero then Algebra Fraction Integer
add
  n: Integer

```

```

x: %
_^(x:%, n:Integer):% == x ** n
import RepeatedSquaring(%)
x ** n: Integer ==
  zero? n => 1
  zero? x =>
    n<0 => error "division by zero"
    x
  n<0 =>
    expt(inv x, (-n) pretend PositiveInteger)
    expt(x, n pretend PositiveInteger)
-- if % has CharacteristicZero() then
q:Fraction(Integer) * x:% == numer(q) * inv(denom(q)::%) * x

```

— DIVRING.dotabb —

```

"DIVRING"
[color=lightblue, href="bookvol10.2.pdf#nameddest=DIVRING"];
"DIVRING" -> "ENTIRER"
"DIVRING" -> "ALGEBRA"

```

— DIVRING.dotfull —

```

"DivisionRing()"
[color=lightblue, href="bookvol10.2.pdf#nameddest=DIVRING"];
"DivisionRing()" -> "EntireRing()"
"DivisionRing()" -> "Algebra(Fraction(Integer))"
"DivisionRing()" -> "RepeatedSquaring(DivisionRing)"

```

— DIVRING.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "DivisionRing()" [color=lightblue];
  "DivisionRing()" -> "EntireRing()"
  "DivisionRing()" -> "Algebra(Fraction(Integer))"

```

```

"DivisionRing()" -> "RepeatedSquaring(DivisionRing)"

"RepeatedSquaring(DivisionRing)" [color="#00EE00"];
"RepeatedSquaring(DivisionRing)" -> "RepeatedSquaring(a:SetCategory)"

"RepeatedSquaring(a:SetCategory)" [color="#00EE00"];
"RepeatedSquaring(a:SetCategory)" -> "Package"

"Package" [color="#00EE00"];

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BMODULE..."

"Algebra(Fraction(Integer))" [color=seagreen];
"Algebra(Fraction(Integer))" -> "Algebra(a:CommutativeRing)"

"Algebra(a:CommutativeRing)" [color=lightblue];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

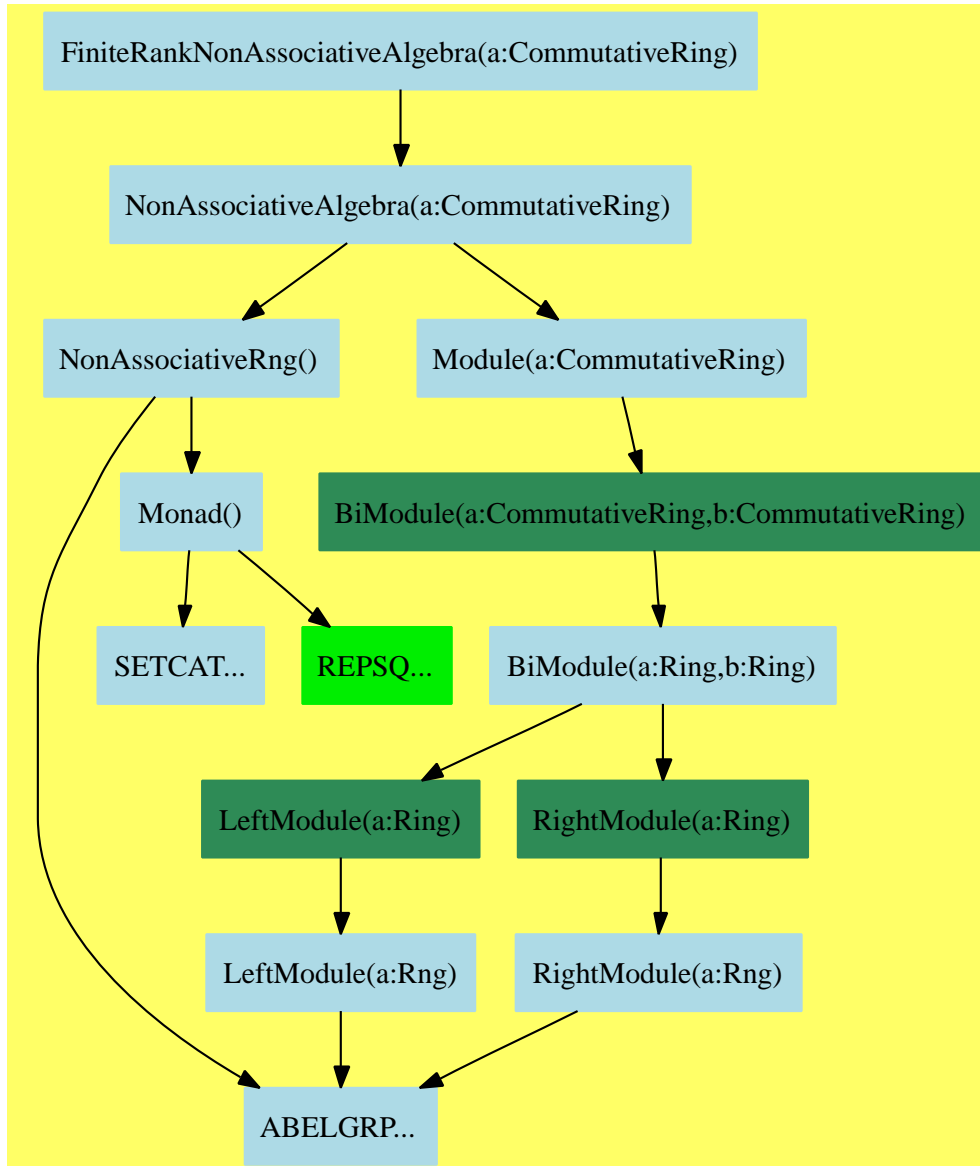
"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" ->
  "BiModule(a:CommutativeRing,b:CommutativeRing)"

"BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BMODULE..."

"RING..." [color=lightblue];
"BMODULE..." [color=lightblue];
}

```

FiniteRankNonAssociativeAlgebra (FINAALG)



— FiniteRankNonAssociativeAlgebra.input —

```

)set break resume
)sys rm -f FiniteRankNonAssociativeAlgebra.output
)spool FiniteRankNonAssociativeAlgebra.output

```

```

)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FiniteRankNonAssociativeAlgebra
--R
--R FiniteRankNonAssociativeAlgebra(R: CommutativeRing) is a category constructor
--R Abbreviation for FiniteRankNonAssociativeAlgebra is FINAALG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FINAALG
--R
--R----- Operations -----
--R ?? : (R,%) -> %           ?? : (%,R) -> %
--R ?? : (%,%) -> %           ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %               ?=? : (%,%) -> Boolean
--R 0 : () -> %               alternative? : () -> Boolean
--R antiAssociative? : () -> Boolean   antiCommutative? : () -> Boolean
--R antiCommutator : (%,%) -> %       associative? : () -> Boolean
--R associator : (%,%,%) -> %         coerce : % -> OutputForm
--R commutative? : () -> Boolean       commutator : (%,%) -> %
--R flexible? : () -> Boolean         hash : % -> SingleInteger
--R jacobIdentity? : () -> Boolean     jordanAdmissible? : () -> Boolean
--R jordanAlgebra? : () -> Boolean     latex : % -> String
--R leftAlternative? : () -> Boolean    leftDiscriminant : Vector(%) -> R
--R leftNorm : % -> R                 leftTrace : % -> R
--R lieAdmissible? : () -> Boolean      lieAlgebra? : () -> Boolean
--R powerAssociative? : () -> Boolean   rank : () -> PositiveInteger
--R rightAlternative? : () -> Boolean   rightNorm : % -> R
--R rightTrace : % -> R                sample : () -> %
--R someBasis : () -> Vector(%)        zero? : % -> Boolean
--R ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R associatorDependence : () -> List(Vector(R)) if R has INTDOM
--R conditionsForIdempotents : Vector(%) -> List(Polynomial(R))
--R coordinates : (Vector(%),Vector(%%)) -> Matrix(R)
--R coordinates : (%,Vector(%%)) -> Vector(R)
--R leftCharacteristicPolynomial : % -> SparseUnivariatePolynomial(R)
--R leftMinimalPolynomial : % -> SparseUnivariatePolynomial(R) if R has INTDOM
--R leftPower : (%,PositiveInteger) -> %
--R leftRecip : % -> Union(%, "failed") if R has INTDOM
--R leftRegularRepresentation : (%,Vector(%%)) -> Matrix(R)
--R leftTraceMatrix : Vector(%) -> Matrix(R)
--R leftUnit : () -> Union(%, "failed") if R has INTDOM
--R leftUnits : () -> Union(Record(particular: %, basis: List(%)), "failed") if R has INTDOM
--R noncommutativeJordanAlgebra? : () -> Boolean
--R plenaryPower : (%,PositiveInteger) -> %
--R recip : % -> Union(%, "failed") if R has INTDOM

```

```

--R represents : (Vector(R),Vector(%)) -> %
--R rightCharacteristicPolynomial : % -> SparseUnivariatePolynomial(R)
--R rightDiscriminant : Vector(%) -> R
--R rightMinimalPolynomial : % -> SparseUnivariatePolynomial(R) if R has INTDOM
--R rightPower : (%,PositiveInteger) -> %
--R rightRecip : % -> Union(%, "failed") if R has INTDOM
--R rightRegularRepresentation : (%,Vector(%)) -> Matrix(R)
--R rightTraceMatrix : Vector(%) -> Matrix(R)
--R rightUnit : () -> Union(%, "failed") if R has INTDOM
--R rightUnits : () -> Union(Record(particular: %,basis: List(%)), "failed") if R has INTDOM
--R structuralConstants : Vector(%) -> Vector(Matrix(R))
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unit : () -> Union(%, "failed") if R has INTDOM
--R
--E 1

)spool
)lisp (bye)

```

— FiniteRankNonAssociativeAlgebra.help —

=====

FiniteRankNonAssociativeAlgebra examples

=====

A FiniteRankNonAssociativeAlgebra is a non associative algebra over a commutative ring R which is a free R-module of finite rank.

See Also:

o)show FiniteRankNonAssociativeAlgebra

See:

⇒ “FramedNonAssociativeAlgebra” (FRNAALG) [13](#) on page [1165](#)

⇐ “NonAssociativeAlgebra” (NAALG) [11](#) on page [1032](#)

Exports:

| | |
|-------------------------------|------------------------------|
| 0 | alternative? |
| antiAssociative? | antiCommutative? |
| antiCommutator | associative? |
| associator | associatorDependence |
| coerce | commutative? |
| commutator | conditionsForIdempotents |
| coordinates | flexible? |
| hash | jacobiIdentity? |
| jordanAdmissible? | jordanAlgebra? |
| latex | leftAlternative? |
| leftCharacteristicPolynomial | leftDiscriminant |
| leftMinimalPolynomial | leftNorm |
| leftPower | leftRecip |
| leftRegularRepresentation | leftTrace |
| leftTraceMatrix | leftUnit |
| leftUnits | lieAdmissible? |
| lieAlgebra? | noncommutativeJordanAlgebra? |
| plenaryPower | powerAssociative? |
| rank | recip |
| represents | rightAlternative? |
| rightCharacteristicPolynomial | rightDiscriminant |
| rightMinimalPolynomial | rightNorm |
| rightPower | rightRecip |
| rightRegularRepresentation | rightTrace |
| rightTraceMatrix | rightUnit |
| rightUnits | sample |
| someBasis | structuralConstants |
| subtractIfCan | unit |
| zero? | ?*? |
| ?**? | ?+? |
| ?-? | -? |
| ?=? | ?~=? |

Attributes Exported:

- if R has IntegralDomain then unitsKnown where **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```
conditionsForIdempotents : Vector % -> List Polynomial R
coordinates : (% , Vector %) -> Vector R
leftUnit : () -> Union(%, "failed") if R has INTDOM
```

```

leftUnits : () -> Union(Record(particular: %,basis: List %),"failed")
  if R has INTDOM
powerAssociative? : () -> Boolean
rank : () -> PositiveInteger
rightUnit : () -> Union(%,"failed") if R has INTDOM
rightUnits : () -> Union(Record(particular: %,basis: List %),"failed")
  if R has INTDOM
someBasis : () -> Vector %
unit : () -> Union(%,"failed") if R has INTDOM

```

These are implemented by this category:

```

alternative? : () -> Boolean
antiAssociative? : () -> Boolean
antiCommutative? : () -> Boolean
associative? : () -> Boolean
associatorDependence : () -> List Vector R if R has INTDOM
commutative? : () -> Boolean
coordinates : (Vector %,Vector %) -> Matrix R
flexible? : () -> Boolean
jacobiIdentity? : () -> Boolean
jordanAdmissible? : () -> Boolean
jordanAlgebra? : () -> Boolean
leftAlternative? : () -> Boolean
leftCharacteristicPolynomial : % -> SparseUnivariatePolynomial R
leftDiscriminant : Vector % -> R
leftMinimalPolynomial : % -> SparseUnivariatePolynomial R if R has INTDOM
leftNorm : % -> R
leftRecip : % -> Union(%,"failed") if R has INTDOM
leftRegularRepresentation : (% ,Vector %) -> Matrix R
leftTrace : % -> R
leftTraceMatrix : Vector % -> Matrix R
lieAdmissible? : () -> Boolean
lieAlgebra? : () -> Boolean
noncommutativeJordanAlgebra? : () -> Boolean
recip : % -> Union(%,"failed") if R has INTDOM
represents : (Vector R,Vector %) -> %
rightAlternative? : () -> Boolean
rightCharacteristicPolynomial : % -> SparseUnivariatePolynomial R
rightDiscriminant : Vector % -> R
rightMinimalPolynomial : % -> SparseUnivariatePolynomial R if R has INTDOM
rightNorm : % -> R
rightRecip : % -> Union(%,"failed") if R has INTDOM
rightRegularRepresentation : (% ,Vector %) -> Matrix R
rightTrace : % -> R
rightTraceMatrix : Vector % -> Matrix R
structuralConstants : Vector % -> Vector Matrix R

```

These exports come from (p1032) NonAssociativeAlgebra(R:CommutativeRing):


```

0 : () -> %
antiCommutator : (%,% ) -> %
associator : (%,%,% ) -> %
coerce : % -> OutputForm
commutator : (%,% ) -> %
hash : % -> SingleInteger
latex : % -> String
leftPower : (% ,PositiveInteger) -> %
plenaryPower : (% ,PositiveInteger) -> %
rightPower : (% ,PositiveInteger) -> %
sample : () -> %
subtractIfCan : (%,% ) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%,% ) -> Boolean
?? : (PositiveInteger,% ) -> %
?? : (%,% ) -> %
?? : (Integer,% ) -> %
?? : (NonNegativeInteger,% ) -> %
?? : (R,% ) -> %
?? : (% ,R) -> %
?? : (%,% ) -> %
?? : (%,% ) -> Boolean
?-? : (%,% ) -> %
-? : % -> %
???: (% ,PositiveInteger) -> %

```

— category FINAALG FiniteRankNonAssociativeAlgebra —

```

)abbrev category FINAALG FiniteRankNonAssociativeAlgebra
++ Author: J. Grabmeier, R. Wisbauer
++ Date Created: 01 March 1991
++ Date Last Updated: 12 June 1991
++ References:
++   R.D. Schafer: An Introduction to Nonassociative Algebras
++   Academic Press, New York, 1966
++
++   R. Wisbauer: Bimodule Structure of Algebra
++   Lecture Notes Univ. Duesseldorf 1991
++ Description:
++ A FiniteRankNonAssociativeAlgebra is a non associative algebra over
++ a commutative ring R which is a free \spad{R}-module of finite rank.

FiniteRankNonAssociativeAlgebra(R:CommutativeRing):
  Category == NonAssociativeAlgebra R with

  someBasis : () -> Vector %
    ++ someBasis() returns some \spad{R}-module basis.

  rank : () -> PositiveInteger

```

```

++ rank() returns the rank of the algebra as \spad{R}-module.

conditionsForIdempotents: Vector % -> List Polynomial R
++ conditionsForIdempotents([v1,...,vn]) determines a complete list
++ of polynomial equations for the coefficients of idempotents
++ with respect to the \spad{R}-module basis \spad{v1},...,\spad{vn}.

structuralConstants: Vector % -> Vector Matrix R
++ structuralConstants([v1,v2,...,vm]) calculates the structural
++ constants \spad{[(gammaijk) for k in 1..m]} defined by
++ \spad{vi * vj = gammaij1 * v1 + ... + gammaijm * vm},
++ where \spad{[v1,...,vm]} is an \spad{R}-module basis
++ of a subalgebra.

leftRegularRepresentation: (% , Vector %) -> Matrix R
++ leftRegularRepresentation(a,[v1,...,vn]) returns the matrix of
++ the linear map defined by left multiplication by \spad{a}
++ with respect to the \spad{R}-module basis \spad{[v1,...,vn]}.

rightRegularRepresentation: (% , Vector %) -> Matrix R
++ rightRegularRepresentation(a,[v1,...,vn]) returns the matrix of
++ the linear map defined by right multiplication by \spad{a}
++ with respect to the \spad{R}-module basis \spad{[v1,...,vn]}.

leftTrace: % -> R
++ leftTrace(a) returns the trace of the left regular representation
++ of \spad{a}.

rightTrace: % -> R
++ rightTrace(a) returns the trace of the right regular representation
++ of \spad{a}.

leftNorm: % -> R
++ leftNorm(a) returns the determinant of the left regular
++ representation of \spad{a}.

rightNorm: % -> R
++ rightNorm(a) returns the determinant of the right regular
++ representation of \spad{a}.

coordinates: (% , Vector %) -> Vector R
++ coordinates(a,[v1,...,vn]) returns the coordinates of \spad{a}
++ with respect to the \spad{R}-module basis \spad{v1},...,\spad{vn}.

coordinates: (Vector %, Vector %) -> Matrix R
++ coordinates([a1,...,am],[v1,...,vn]) returns a matrix whose
++ i-th row is formed by the coordinates of \spad{ai}
++ with respect to the \spad{R}-module basis \spad{v1},...,\spad{vn}.

represents: (Vector R, Vector %) -> %

```

```

++ represents([a1,...,am],[v1,...,vm]) returns the linear
++ combination \spad{a1*vm + ... + an*vm}.

leftDiscriminant: Vector % -> R
++ leftDiscriminant([v1,...,vn]) returns the determinant of the
++ \spad{n}-by-\spad{n} matrix whose element at the \spad{i}-th row
++ and \spad{j}-th column is given by the left trace of the product
++ \spad{vi*vj}. Note that this is the same as
++ \spad{determinant(leftTraceMatrix([v1,...,vn]))}.

rightDiscriminant: Vector % -> R
++ rightDiscriminant([v1,...,vn]) returns the determinant of the
++ \spad{n}-by-\spad{n} matrix whose element at the \spad{i}-th row
++ and \spad{j}-th column is given by the right trace of the product
++ \spad{vi*vj}. Note that this is the same as
++ \spad{determinant(rightTraceMatrix([v1,...,vn]))}.

leftTraceMatrix: Vector % -> Matrix R
++ leftTraceMatrix([v1,...,vn]) is the \spad{n}-by-\spad{n} matrix
++ whose element at the \spad{i}-th row and \spad{j}-th column is given
++ by the left trace of the product \spad{vi*vj}.

rightTraceMatrix: Vector % -> Matrix R
++ rightTraceMatrix([v1,...,vn]) is the \spad{n}-by-\spad{n} matrix
++ whose element at the \spad{i}-th row and \spad{j}-th column is given
++ by the right trace of the product \spad{vi*vj}.

leftCharacteristicPolynomial: % -> SparseUnivariatePolynomial R
++ leftCharacteristicPolynomial(a) returns the characteristic
++ polynomial of the left regular representation of \spad{a}
++ with respect to any basis.

rightCharacteristicPolynomial: % -> SparseUnivariatePolynomial R
++ rightCharacteristicPolynomial(a) returns the characteristic
++ polynomial of the right regular representation of \spad{a}
++ with respect to any basis.

--we not necessarily have a unit
--if R has CharacteristicZero then CharacteristicZero
--if R has CharacteristicNonZero then CharacteristicNonZero

commutative?()-> Boolean
++ commutative?() tests if multiplication in the algebra
++ is commutative.

antiCommutative?()-> Boolean
++ antiCommutative?() tests if \spad{a*a} = 0
++ for all \spad{a} in the algebra.
++ Note that this implies \spad{a*b} + b*a = 0 for all
++ \spad{a} and \spad{b}.

```

```

associative?:(-)-> Boolean
++ associative?() tests if multiplication in algebra
++ is associative.

antiAssociative?:(-)-> Boolean
++ antiAssociative?() tests if multiplication in algebra
++ is anti-associative, that is, \spad{(a*b)*c + a*(b*c) = 0}
++ for all \spad{a},b,c in the algebra.

leftAlternative?: (-)-> Boolean
++ leftAlternative?() tests if \spad{2*associator(a,a,b) = 0}
++ for all \spad{a}, b in the algebra.
++ Note that we only can test this; in general we don't know
++ whether \spad{2*a=0} implies \spad{a=0}.

rightAlternative?: (-)-> Boolean
++ rightAlternative?() tests if \spad{2*associator(a,b,b) = 0}
++ for all \spad{a}, b in the algebra.
++ Note that we only can test this; in general we don't know
++ whether \spad{2*a=0} implies \spad{a=0}.

flexible?: (-)-> Boolean
++ flexible?() tests if \spad{2*associator(a,b,a) = 0}
++ for all \spad{a}, b in the algebra.
++ Note that we only can test this; in general we don't know
++ whether \spad{2*a=0} implies \spad{a=0}.

alternative?: (-)-> Boolean
++ alternative?() tests if
++ \spad{2*associator(a,a,b) = 0 = 2*associator(a,b,b)}
++ for all \spad{a}, b in the algebra.
++ Note that we only can test this; in general we don't know
++ whether \spad{2*a=0} implies \spad{a=0}.

powerAssociative?:(-)-> Boolean
++ powerAssociative?() tests if all subalgebras
++ generated by a single element are associative.

jacobiIdentity?:() -> Boolean
++ jacobiIdentity?() tests if \spad{(a*b)*c + (b*c)*a + (c*a)*b = 0}
++ for all \spad{a},b,c in the algebra. For example, this holds
++ for crossed products of 3-dimensional vectors.

lieAdmissible?: () -> Boolean
++ lieAdmissible?() tests if the algebra defined by the commutators
++ is a Lie algebra, that is, satisfies the Jacobi identity.
++ The property of anticommutativity follows from definition.

jordanAdmissible?: () -> Boolean

```

```

++ jordanAdmissible?() tests if 2 is invertible in the
++ coefficient domain and the multiplication defined by
++ \spad{(1/2)(a*b+b*a)} determines a
++ Jordan algebra, that is, satisfies the Jordan identity.
++ The property of \spadatt{commutative("*")}
++ follows from by definition.

noncommutativeJordanAlgebra?: () -> Boolean
++ noncommutativeJordanAlgebra?() tests if the algebra
++ is flexible and Jordan admissible.

jordanAlgebra?:() -> Boolean
++ jordanAlgebra?() tests if the algebra is commutative,
++ characteristic is not 2, and \spad{(a*b)*a**2 - a*(b*a**2) = 0}
++ for all \spad{a},b,c in the algebra (Jordan identity).
++ Example:
++ for every associative algebra \spad{(A,+,@)} we can construct a
++ Jordan algebra \spad{(A,+,*)}, where \spad{a*b := (a@b+b@a)/2}.

lieAlgebra?:() -> Boolean
++ lieAlgebra?() tests if the algebra is anticommutative
++ and \spad{(a*b)*c + (b*c)*a + (c*a)*b = 0}
++ for all \spad{a},b,c in the algebra (Jacobi identity).
++ Example:
++ for every associative algebra \spad{(A,+,@)} we can construct a
++ Lie algebra \spad{(A,+,*)}, where \spad{a*b := a@b-b@a}.

if R has IntegralDomain then

-- we not neccessarily have a unit, hence we don't inherit
-- the next 3 functions anc hence copy them from MonadWithUnit:

recip: % -> Union(%, "failed")
++ recip(a) returns an element, which is both a left and a right
++ inverse of \spad{a},
++ or \spad{"failed"} if there is no unit element, if such an
++ element doesn't exist or cannot be determined (see unitsKnown).

leftRecip: % -> Union(%, "failed")
++ leftRecip(a) returns an element, which is a left inverse of
++ \spad{a}, or \spad{"failed"} if there is no unit element, if such
++ an element doesn't exist or cannot be determined (see unitsKnown).

rightRecip: % -> Union(%, "failed")
++ rightRecip(a) returns an element, which is a right inverse of
++ \spad{a},
++ or \spad{"failed"} if there is no unit element, if such an
++ element doesn't exist or cannot be determined (see unitsKnown).

associatorDependence:() -> List Vector R

```

```

++ associatorDependence() looks for the associator identities, that
++ is, finds a basis of the solutions of the linear combinations of the
++ six permutations of \spad{associator(a,b,c)} which yield 0,
++ for all \spad{a},b,c in the algebra.
++ The order of the permutations is \spad{123 231 312 132 321 213}.

leftMinimalPolynomial : % -> SparseUnivariatePolynomial R
++ leftMinimalPolynomial(a) returns the polynomial determined by the
++ smallest non-trivial linear combination of left powers of
++ \spad{a}. Note that the polynomial never has a constant term as in
++ general the algebra has no unit.

rightMinimalPolynomial : % -> SparseUnivariatePolynomial R
++ rightMinimalPolynomial(a) returns the polynomial determined by the
++ smallest non-trivial linear
++ combination of right powers of \spad{a}.
++ Note that the polynomial never has a constant term as in general
++ the algebra has no unit.

leftUnits() -> Union(Record(particular: %, basis: List %), "failed")
++ leftUnits() returns the affine space of all left units of the
++ algebra, or \spad{"failed"} if there is none.

rightUnits() -> Union(Record(particular: %, basis: List %), "failed")
++ rightUnits() returns the affine space of all right units of the
++ algebra, or \spad{"failed"} if there is none.

leftUnit() -> Union(%, "failed")
++ leftUnit() returns a left unit of the algebra
++ (not necessarily unique), or \spad{"failed"} if there is none.

rightUnit() -> Union(%, "failed")
++ rightUnit() returns a right unit of the algebra
++ (not necessarily unique), or \spad{"failed"} if there is none.

unit() -> Union(%, "failed")
++ unit() returns a unit of the algebra (necessarily unique),
++ or \spad{"failed"} if there is none.

-- we not necessarily have a unit, hence we can't say anything
-- about characteristic
-- if R has CharacteristicZero then CharacteristicZero
-- if R has CharacteristicNonZero then CharacteristicNonZero

unitsKnown
++ unitsKnown means that \spadfun{recip} truly yields reciprocal
++ or \spad{"failed"} if not a unit,
++ similarly for \spadfun{leftRecip} and
++ \spadfun{rightRecip}. The reason is that we use left, respectively
++ right, minimal polynomials to decide this question.

```

```

add
--n := rank()
--b := someBasis()
--gamma : Vector Matrix R := structuralConstants b
-- here is a problem: there seems to be a problem having local
-- variables in the capsule of a category, furthermore
-- see the commented code of conditionsForIdempotents, where
-- we call structuralConstants, which also doesn't work
-- at runtime, i.e. is not properly inherited, hence for
-- the moment we put the code for
-- conditionsForIdempotents, structuralConstants, unit, leftUnit,
-- rightUnit into the domain constructor ALGSC
V ==> Vector
M ==> Matrix
REC ==> Record(particular: Union(V R,"failed"),basis: List V R)
LSMP ==> LinearSystemMatrixPackage(R,V R,V R, M R)

SUP ==> SparseUnivariatePolynomial
NNI ==> NonNegativeInteger
-- next 2 functions: use a general characteristicPolynomial
leftCharacteristicPolynomial a ==
  n := rank()$%
  ma : Matrix R := leftRegularRepresentation(a,someBasis()$%)
  mb : Matrix SUP R := zero(n,n)
  for i in 1..n repeat
    for j in 1..n repeat
      mb(i,j):=
        i=j => monomial(ma(i,j),0)$SUP(R) - monomial(1,1)$SUP(R)
        monomial(ma(i,j),1)$SUP(R)
  determinant mb

rightCharacteristicPolynomial a ==
  n := rank()$%
  ma : Matrix R := rightRegularRepresentation(a,someBasis()$%)
  mb : Matrix SUP R := zero(n,n)
  for i in 1..n repeat
    for j in 1..n repeat
      mb(i,j):=
        i=j => monomial(ma(i,j),0)$SUP(R) - monomial(1,1)$SUP(R)
        monomial(ma(i,j),1)$SUP(R)
  determinant mb

leftTrace a ==
  t : R := 0
  ma : Matrix R := leftRegularRepresentation(a,someBasis()$%)
  for i in 1..rank()$% repeat
    t := t + elt(ma,i,i)
  t

```

```

rightTrace a ==
  t : R := 0
  ma : Matrix R := rightRegularRepresentation(a,someBasis()$%)
  for i in 1..rank()$% repeat
    t := t + elt(ma,i,i)
  t

leftNorm a == determinant leftRegularRepresentation(a,someBasis()$%)

rightNorm a == determinant rightRegularRepresentation(a,someBasis()$%)

antiAssociative?() ==
  b := someBasis()
  n := rank()
  for i in 1..n repeat
    for j in 1..n repeat
      for k in 1..n repeat
        not zero? ( (b.i*b.j)*b.k + b.i*(b.j*b.k) ) =>
          messagePrint("algebra is not anti-associative")$OutputForm
          return false
  messagePrint("algebra is anti-associative")$OutputForm
  true

jordanAdmissible?() ==
  b := someBasis()
  n := rank()
  recip(2 * 1$R) case "failed" =>
    messagePrint("this algebra is not Jordan admissible, " _
      "as 2 is not invertible in the ground ring")$OutputForm
    false
  for i in 1..n repeat
    for j in 1..n repeat
      for k in 1..n repeat
        for l in 1..n repeat
          not zero? ( _
            antiCommutator(antiCommutator(b.i,b.j),_
              antiCommutator(b.l,b.k)) + _
            antiCommutator(antiCommutator(b.l,b.j),_
              antiCommutator(b.k,b.i)) + _
            antiCommutator(antiCommutator(b.k,b.j),_
              antiCommutator(b.i,b.l)) _
          ) =>
            messagePrint(_
              "this algebra is not Jordan admissible")$OutputForm
            return false
  messagePrint("this algebra is Jordan admissible")$OutputForm
  true

lieAdmissible?() ==
  n := rank()

```



```

b := someBasis()
for i in 1..n repeat
  for j in 1..n repeat
    for k in 1..n repeat
      not zero? (commutator(commutator(b.i,b.j),b.k) _
        + commutator(commutator(b.j,b.k),b.i) _
        + commutator(commutator(b.k,b.i),b.j)) =>
        messagePrint("this algebra is not Lie admissible")$OutputForm
      return false
    messagePrint("this algebra is Lie admissible")$OutputForm
  true

-- conditionsForIdempotents b ==
-- n := rank()
-- gamma : Vector Matrix R := structuralConstants b
-- listOfNumbers : List String := [STRINGIMAGE(q)$Lisp for q in 1..n]
-- symbolsForCoef : Vector Symbol :=
--   [concat("%", concat("x", i))::Symbol for i in listOfNumbers]
-- conditions : List Polynomial R := []
-- for k in 1..n repeat
--   xk := symbolsForCoef.k
--   p : Polynomial R := monomial( - 1$Polynomial(R), [xk], [1] )
--   for i in 1..n repeat
--     for j in 1..n repeat
--       xi := symbolsForCoef.i
--       xj := symbolsForCoef.j
--       p := p + monomial(_
--         elt((gamma.k),i,j) :: Polynomial(R), [xi,xj], [1,1])
--       conditions := cons(p,conditions)
--   conditions

structuralConstants b ==
--n := rank()
-- be careful with the possibility that b is not a basis
m : NonNegativeInteger := (maxIndex b) :: NonNegativeInteger
sC : Vector Matrix R := [new(m,m,0$R) for k in 1..m]
for i in 1..m repeat
  for j in 1..m repeat
    covec : Vector R := coordinates(b.i * b.j, b)
    for k in 1..m repeat
      setelt( sC.k, i, j, covec.k )
sC

if R has IntegralDomain then

leftRecip x ==
  zero? x => "failed"
  lu := leftUnit()
  lu case "failed" => "failed"
  b := someBasis()

```

```

xx : % := (lu :: %)
k : PositiveInteger := 1
cond : Matrix R := coordinates(xx,b) :: Matrix(R)
listOfPowers : List % := [xx]
while rank(cond) = k repeat
  k := k+1
  xx := xx*x
  listOfPowers := cons(xx,listOfPowers)
  cond := horizConcat(cond, coordinates(xx,b) :: Matrix(R) )
vectorOfCoef : Vector R := (nullSpace(cond)$Matrix(R)).first
invC := recip vectorOfCoef.1
invC case "failed" => "failed"
invCR : R := - (invC :: R)
reduce(_+, [(invCR*vectorOfCoef.i)*power for i in _
  2..maxIndex vectorOfCoef for power in reverse listOfPowers])

rightRecip x ==
  zero? x => "failed"
  ru := rightUnit()
  ru case "failed" => "failed"
  b := someBasis()
  xx : % := (ru :: %)
  k : PositiveInteger := 1
  cond : Matrix R := coordinates(xx,b) :: Matrix(R)
  listOfPowers : List % := [xx]
  while rank(cond) = k repeat
    k := k+1
    xx := x*xx
    listOfPowers := cons(xx,listOfPowers)
    cond := horizConcat(cond, coordinates(xx,b) :: Matrix(R) )
  vectorOfCoef : Vector R := (nullSpace(cond)$Matrix(R)).first
  invC := recip vectorOfCoef.1
  invC case "failed" => "failed"
  invCR : R := - (invC :: R)
  reduce(_+, [(invCR*vectorOfCoef.i)*power for i in _
    2..maxIndex vectorOfCoef for power in reverse listOfPowers])

recip x ==
  lrx := leftRecip x
  lrx case "failed" => "failed"
  rrx := rightRecip x
  rrx case "failed" => "failed"
  (lrx :: %) ^= (rrx :: %) => "failed"
  lrx :: %

leftMinimalPolynomial x ==
  zero? x => monomial(1$R,1)$(SparseUnivariatePolynomial R)
  b := someBasis()
  xx : % := x
  k : PositiveInteger := 1

```

```

cond : Matrix R := coordinates(xx,b) :: Matrix(R)
while rank(cond) = k repeat
  k := k+1
  xx := x*xx
  cond := horizConcat(cond, coordinates(xx,b) :: Matrix(R) )
vectorOfCoef : Vector R := (nullSpace(cond)$Matrix(R)).first
res : SparseUnivariatePolynomial R := 0
for i in 1..k repeat
  res:=res+monomial(vectorOfCoef.i,i)$(SparseUnivariatePolynomial R)
res

rightMinimalPolynomial x ==
zero? x => monomial(1$R,1)$(SparseUnivariatePolynomial R)
b := someBasis()
xx : % := x
k : PositiveInteger := 1
cond : Matrix R := coordinates(xx,b) :: Matrix(R)
while rank(cond) = k repeat
  k := k+1
  xx := xx*x
  cond := horizConcat(cond, coordinates(xx,b) :: Matrix(R) )
vectorOfCoef : Vector R := (nullSpace(cond)$Matrix(R)).first
res : SparseUnivariatePolynomial R := 0
for i in 1..k repeat
  res:=res+monomial(vectorOfCoef.i,i)$(SparseUnivariatePolynomial R)
res

associatorDependence() ==
n := rank()
b := someBasis()
cond : Matrix(R) := new(n**4,6,0$R)$Matrix(R)
z : Integer := 0
for i in 1..n repeat
  for j in 1..n repeat
    for k in 1..n repeat
      a123 : Vector R := coordinates(associator(b.i,b.j,b.k),b)
      a231 : Vector R := coordinates(associator(b.j,b.k,b.i),b)
      a312 : Vector R := coordinates(associator(b.k,b.i,b.j),b)
      a132 : Vector R := coordinates(associator(b.i,b.k,b.j),b)
      a321 : Vector R := coordinates(associator(b.k,b.j,b.i),b)
      a213 : Vector R := coordinates(associator(b.j,b.i,b.k),b)
    for r in 1..n repeat
      z:= z+1
      setelt(cond,z,1,elt(a123,r))
      setelt(cond,z,2,elt(a231,r))
      setelt(cond,z,3,elt(a312,r))
      setelt(cond,z,4,elt(a132,r))
      setelt(cond,z,5,elt(a321,r))
      setelt(cond,z,6,elt(a213,r))
nullSpace(cond)

```

```

jacobiIdentity?() ==
  n := rank()
  b := someBasis()
  for i in 1..n repeat
    for j in 1..n repeat
      for k in 1..n repeat
        not zero? ((b.i*b.j)*b.k + (b.j*b.k)*b.i + (b.k*b.i)*b.j) =>
          messagePrint("Jacobi identity does not hold")$OutputForm
          return false
      messagePrint("Jacobi identity holds")$OutputForm
  true

lieAlgebra?() ==
  not antiCommutative?() =>
    messagePrint("this is not a Lie algebra")$OutputForm
    false
  not jacobiIdentity?() =>
    messagePrint("this is not a Lie algebra")$OutputForm
    false
  messagePrint("this is a Lie algebra")$OutputForm
  true

jordanAlgebra?() ==
  b := someBasis()
  n := rank()
  recip(2 * 1$R) case "failed" =>
    messagePrint("this is not a Jordan algebra, as 2 is not " _
      "invertible in the ground ring")$OutputForm
    false
  not commutative?() =>
    messagePrint("this is not a Jordan algebra")$OutputForm
    false
  for i in 1..n repeat
    for j in 1..n repeat
      for k in 1..n repeat
        for l in 1..n repeat
          not zero? (associator(b.i,b.j,b.l*b.k)+_
            associator(b.l,b.j,b.k*b.i)+associator(b.k,b.j,b.i*b.l)) =>
            messagePrint("not a Jordan algebra")$OutputForm
            return false
        messagePrint("this is a Jordan algebra")$OutputForm
  true

noncommutativeJordanAlgebra?() ==
  b := someBasis()
  n := rank()
  recip(2 * 1$R) case "failed" =>
    messagePrint("this is not a noncommutative Jordan algebra,_
  as 2 is not invertible in the ground ring")$OutputForm

```

```

    false
    not flexible?()$% =>
      messagePrint("this is not a noncommutative Jordan algebra,_"
as it is not flexible")$OutputForm
    false
    not jordanAdmissible?()$% =>
      messagePrint("this is not a noncommutative Jordan algebra,_"
as it is not Jordan admissible")$OutputForm
    false
    messagePrint("this is a noncommutative Jordan algebra")$OutputForm
    true

antiCommutative?() ==
  b := someBasis()
  n := rank()
  for i in 1..n repeat
    for j in i..n repeat
      not zero? (i=j => b.i*b.i; b.i*b.j + b.j*b.i) =>
        messagePrint("algebra is not anti-commutative")$OutputForm
        return false
    messagePrint("algebra is anti-commutative")$OutputForm
    true

commutative?() ==
  b := someBasis()
  n := rank()
  for i in 1..n repeat
    for j in i+1..n repeat
      not zero? commutator(b.i,b.j) =>
        messagePrint("algebra is not commutative")$OutputForm
        return false
    messagePrint("algebra is commutative")$OutputForm
    true

associative?() ==
  b := someBasis()
  n := rank()
  for i in 1..n repeat
    for j in 1..n repeat
      for k in 1..n repeat
        not zero? associator(b.i,b.j,b.k) =>
          messagePrint("algebra is not associative")$OutputForm
          return false
    messagePrint("algebra is associative")$OutputForm
    true

leftAlternative?() ==
  b := someBasis()
  n := rank()
  for i in 1..n repeat

```

```

    for j in 1..n repeat
      for k in 1..n repeat
        not zero? (associator(b.i,b.j,b.k) + associator(b.j,b.i,b.k)) =>
          messagePrint("algebra is not left alternative")$OutputForm
          return false
      messagePrint("algebra satisfies 2*associator(a,a,b) = 0")$OutputForm
    true

rightAlternative?() ==
  b := someBasis()
  n := rank()
  for i in 1..n repeat
    for j in 1..n repeat
      for k in 1..n repeat
        not zero? (associator(b.i,b.j,b.k) + associator(b.i,b.k,b.j)) =>
          messagePrint("algebra is not right alternative")$OutputForm
          return false
      messagePrint("algebra satisfies 2*associator(a,b,b) = 0")$OutputForm
    true

flexible?() ==
  b := someBasis()
  n := rank()
  for i in 1..n repeat
    for j in 1..n repeat
      for k in 1..n repeat
        not zero? (associator(b.i,b.j,b.k) + associator(b.k,b.j,b.i)) =>
          messagePrint("algebra is not flexible")$OutputForm
          return false
      messagePrint("algebra satisfies 2*associator(a,b,a) = 0")$OutputForm
    true

alternative?() ==
  b := someBasis()
  n := rank()
  for i in 1..n repeat
    for j in 1..n repeat
      for k in 1..n repeat
        not zero? (associator(b.i,b.j,b.k) + associator(b.j,b.i,b.k)) =>
          messagePrint("algebra is not alternative")$OutputForm
          return false
        not zero? (associator(b.i,b.j,b.k) + associator(b.i,b.k,b.j)) =>
          messagePrint("algebra is not alternative")$OutputForm
          return false
      messagePrint("algebra satisfies 2*associator(a,b,b) = 0 " _
        " = 2*associator(a,a,b) = 0")$OutputForm
    true

leftDiscriminant v == determinant leftTraceMatrix v
rightDiscriminant v == determinant rightTraceMatrix v

```

```

coordinates(v:Vector %, b:Vector %) ==
  m := new(#v, #b, 0)$Matrix(R)
  for i in minIndex v .. maxIndex v for j in minRowIndex m .. repeat
    setRow_!(m, j, coordinates(qelt(v, i), b))
  m

represents(v, b) ==
  m := minIndex v - 1
  reduce(_+, [v(i+m) * b(i+m) for i in 1..maxIndex b])

leftTraceMatrix v ==
  matrix [[leftTrace(v.i*v.j) for j in minIndex v..maxIndex v]$List(R)
    for i in minIndex v .. maxIndex v]$List(List R)

rightTraceMatrix v ==
  matrix [[rightTrace(v.i*v.j) for j in minIndex v..maxIndex v]$List(R)
    for i in minIndex v .. maxIndex v]$List(List R)

leftRegularRepresentation(x, b) ==
  m := minIndex b - 1
  matrix
    [parts coordinates(x*b(i+m),b) for i in 1..rank()]$List(List R)

rightRegularRepresentation(x, b) ==
  m := minIndex b - 1
  matrix
    [parts coordinates(b(i+m)*x,b) for i in 1..rank()]$List(List R)

```

— FINAALG.dotabb —

```

"FINAALG"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FINAALG"];
"FINAALG" -> "NAALG"

```

— FINAALG.dotfull —

```

"FiniteRankNonAssociativeAlgebra(a:CommutativeRing)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FINAALG"];
"FiniteRankNonAssociativeAlgebra(a:CommutativeRing)" ->
  "NonAssociativeAlgebra(a:CommutativeRing)"

```

— FINAALG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FiniteRankNonAssociativeAlgebra(a:CommutativeRing)" [color=lightblue];
  "FiniteRankNonAssociativeAlgebra(a:CommutativeRing)" ->
    "NonAssociativeAlgebra(a:CommutativeRing)"

  "NonAssociativeAlgebra(a:CommutativeRing)" [color=lightblue];
  "NonAssociativeAlgebra(a:CommutativeRing)" -> "NonAssociativeRng()"
  "NonAssociativeAlgebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

  "NonAssociativeRng()" [color=lightblue];
  "NonAssociativeRng()" -> "ABELGRP..."
  "NonAssociativeRng()" -> "Monad()"

  "Monad()" [color=lightblue];
  "Monad()" -> "SETCAT..."
  "Monad()" -> "REPSQ..."

  "Module(a:CommutativeRing)" [color=lightblue];
  "Module(a:CommutativeRing)" ->
    "BiModule(a:CommutativeRing,b:CommutativeRing)"

  "BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
  "BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BiModule(a:Ring,b:Ring)"

  "BiModule(a:Ring,b:Ring)" [color=lightblue];
  "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
  "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

  "RightModule(a:Ring)" [color=seagreen];
  "RightModule(a:Ring)" -> "RightModule(a:Rng)"

  "RightModule(a:Rng)" [color=lightblue];
  "RightModule(a:Rng)" -> "ABELGRP..."

  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

  "LeftModule(a:Rng)" [color=lightblue];
  "LeftModule(a:Rng)" -> "ABELGRP..."

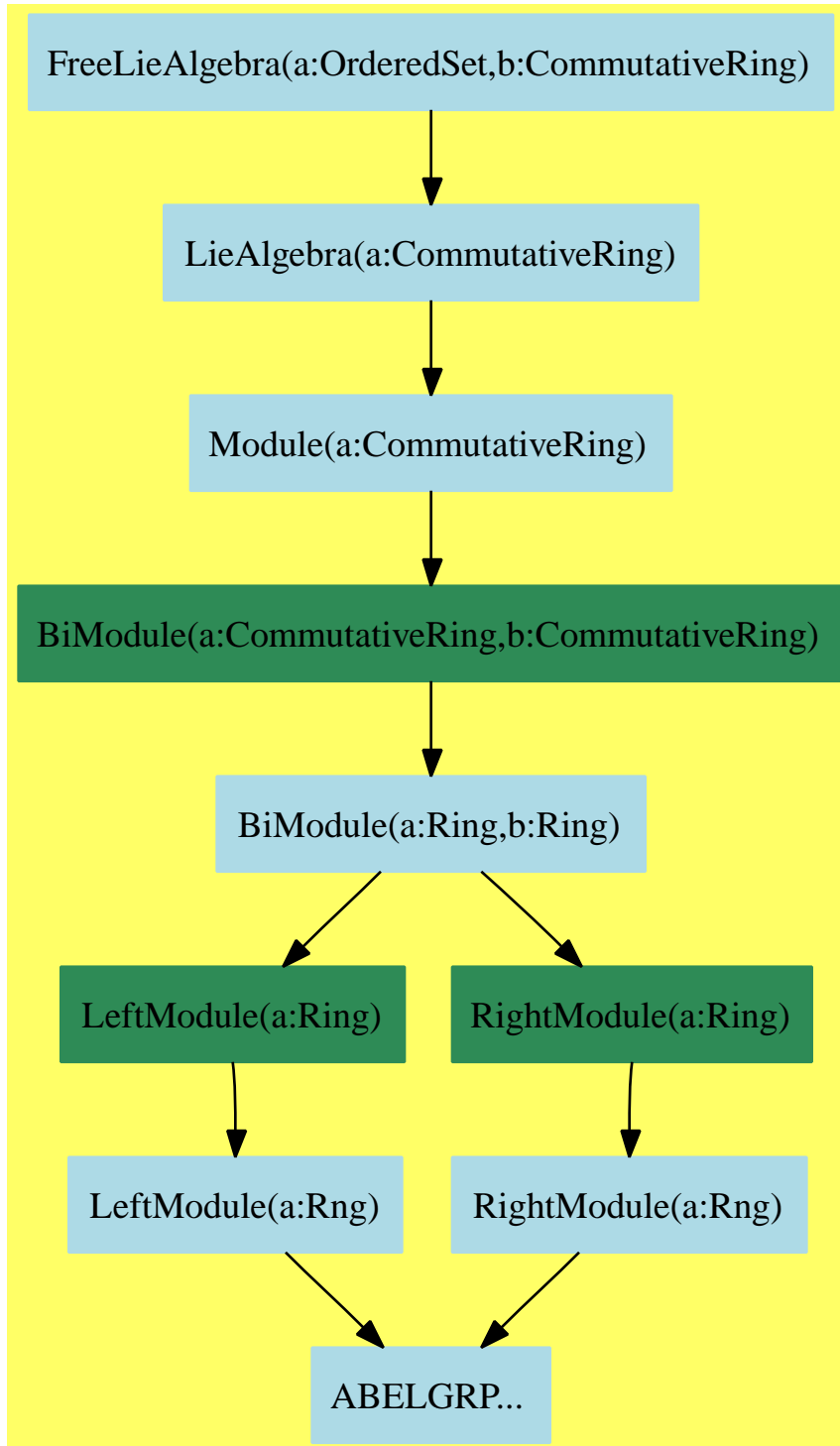
  "REPSQ..." [color="#00EE00"];

```



```
"SETCAT..." [color=lightblue];  
"ABELGRP..." [color=lightblue];  
}
```

FreeLieAlgebra (FLALG)



— FreeLieAlgebra.input —

```

)set break resume
)sys rm -f FreeLieAlgebra.output
)spool FreeLieAlgebra.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FreeLieAlgebra
--R
--R FreeLieAlgebra(VarSet: OrderedSet,R: CommutativeRing) is a category constructor
--R Abbreviation for FreeLieAlgebra is FLALG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FLALG
--R
--R----- Operations -----
--R ?? : (%,R) -> %           ?? : (R,%) -> %
--R ?? : (Integer,%) -> %     ?? : (PositiveInteger,%) -> %
--R ?? : (%,%) -> %          ?-? : (%,%) -> %
--R -? : % -> %              ?=? : (%,%) -> Boolean
--R LiePoly : LyndonWord(VarSet) -> %   0 : () -> %
--R coerce : VarSet -> %              coerce : % -> OutputForm
--R construct : (%,%) -> %            degree : % -> NonNegativeInteger
--R eval : (%,VarSet,%) -> %          hash : % -> SingleInteger
--R latex : % -> String              mirror : % -> %
--R sample : () -> %                 varList : % -> List(VarSet)
--R zero? : % -> Boolean             ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ?/? : (%,R) -> % if R has FIELD
--R coef : (XRecursivePolynomial(VarSet,R),%) -> R
--R coerce : % -> XRecursivePolynomial(VarSet,R)
--R coerce : % -> XDistributedPolynomial(VarSet,R)
--R eval : (%,List(VarSet),List(%)) -> %
--R lquo : (XRecursivePolynomial(VarSet,R),%) -> XRecursivePolynomial(VarSet,R)
--R rquo : (XRecursivePolynomial(VarSet,R),%) -> XRecursivePolynomial(VarSet,R)
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R trunc : (%,NonNegativeInteger) -> %
--R
--E 1

)spool
)lisp (bye)

```

— FreeLieAlgebra.help —

=====

FreeLieAlgebra examples

=====

The category of free Lie algebras. It is used by domains of non-commutative algebra such as LiePolynomial and XPBWPolynomial.

See Also:

o)show FreeLieAlgebra

See:

← “LieAlgebra” (LIECAT) [11](#) on page [1018](#)

Exports:

| | | | | |
|---------|-------|--------|---------------|--------|
| 0 | coef | coerce | construct | degree |
| eval | hash | latex | LiePoly | lquo |
| mirror | rquo | sample | subtractIfCan | trunc |
| varList | zero? | ?~=? | ?*? | ?/? |
| ?+? | ?-? | -? | ?=? | |

Attributes Exported:

- **NullSquare** means that $[x, x] = 0$ holds. See LieAlgebra.
- **JacobiIdentity** means that $[x, [y, z]] + [y, [z, x]] + [z, [x, y]] = 0$ holds. See LieAlgebra.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```
coef : (XRecursivePolynomial(VarSet,R),%) -> R
coerce : VarSet -> %
coerce : % -> XRecursivePolynomial(VarSet,R)
coerce : % -> XDistributedPolynomial(VarSet,R)
degree : % -> NonNegativeInteger
eval : (%,List VarSet,List %) -> %
eval : (%,VarSet,%) -> %
LiePoly : LyndonWord VarSet -> %
lquo : (XRecursivePolynomial(VarSet,R),%) -> XRecursivePolynomial(VarSet,R)
mirror : % -> %
rqquo : (XRecursivePolynomial(VarSet,R),%) -> XRecursivePolynomial(VarSet,R)
```

```
trunc : (% , NonNegativeInteger) -> %
varList : % -> List VarSet
```

These exports come from (p1018) LieAlgebra(CommutativeRing):

```
0 : () -> %
coerce : % -> OutputForm
construct : (% , %) -> %
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (% , %) -> Union(%, "failed")
zero? : % -> Boolean
?/? : (% , R) -> % if R has FIELD
?~=? : (% , %) -> Boolean
?*? : (NonNegativeInteger , %) -> %
?*? : (% , R) -> %
?*? : (R , %) -> %
?*? : (Integer , %) -> %
?*? : (PositiveInteger , %) -> %
?+? : (% , %) -> %
?-? : (% , %) -> %
-? : % -> %
?=? : (% , %) -> Boolean
```

— category FLALG FreeLieAlgebra —

```
)abbrev category FLALG FreeLieAlgebra
++ Author: Michel Petitot (petitot@lifl.fr)
++ Date Created: 91
++ Date Last Updated: 7 Juillet 92
++ Fix History: compilation v 2.1 le 13 dec 98
++ Description:
++ The category of free Lie algebras.
++ It is used by domains of non-commutative algebra:
++ \spadtype{LiePolynomial} and
++ \spadtype{XPBWPolynomial}.

FreeLieAlgebra(VarSet:OrderedSet, R:CommutativeRing) :Category == _
CatDef where
  XRPOLY ==> XRecursivePolynomial(VarSet,R)
  XDPOLY ==> XDistributedPolynomial(VarSet,R)
  RN      ==> Fraction Integer
  LWORD   ==> LyndonWord(VarSet)

CatDef == Join(LieAlgebra(R)) with
  coef      : (XRPOLY , $) -> R
  ++ \axiom{coef(x,y)} returns the scalar product of \axiom{x} by
  ++ \axiom{y}, the set of words being regarded as an orthogonal basis.
```

```

coerce      : VarSet -> $
  ++ \axiom{coerce(x)} returns \axiom{x} as a Lie polynomial.
coerce      : $ -> XDPOLY
  ++ \axiom{coerce(x)} returns \axiom{x} as distributed polynomial.
coerce      : $ -> XRPOLY
  ++ \axiom{coerce(x)} returns \axiom{x} as a recursive polynomial.
degree      : $ -> NonNegativeInteger
  ++ \axiom{degree(x)} returns the greatest length of a word in the
  ++ support of \axiom{x}.
--if R has Module(RN) then
-- Hausdorff : ($,$,PositiveInteger) -> $
lquo        : (XRPOLY , $) -> XRPOLY
  ++ \axiom{lquo(x,y)} returns the left simplification of \axiom{x}
  ++ by \axiom{y}.
rquo        : (XRPOLY , $) -> XRPOLY
  ++ \axiom{rquo(x,y)} returns the right simplification of \axiom{x}
  ++ by \axiom{y}.
LiePoly     : LWORD -> $
  ++ \axiom{LiePoly(l)} returns the bracketed form of \axiom{l} as
  ++ a Lie polynomial.
mirror      : $ -> $
  ++ \axiom{mirror(x)} returns \axiom{Sum(r_i mirror(w_i))}
  ++ if \axiom{x} is \axiom{Sum(r_i w_i)}.
trunc       : ($, NonNegativeInteger) -> $
  ++ \axiom{trunc(p,n)} returns the polynomial \axiom{p}
  ++ truncated at order \axiom{n}.
varList     : $ -> List VarSet
  ++ \axiom{varList(x)} returns the list of distinct entries
  ++ of \axiom{x}.
eval        : ($, VarSet, $) -> $
  ++ \axiom{eval(p, x, v)} replaces \axiom{x} by \axiom{v}
  ++ in \axiom{p}.
eval        : ($, List VarSet, List $) -> $
  ++ \axiom{eval(p, [x1,...,xn], [v1,...,vn])} replaces \axiom{xi}
  ++ by \axiom{vi} in \axiom{p}.

```

— FLALG.dotabb —

"FLALG"

[color=lightblue,href="bookvol10.2.pdf#nameddest=FLALG"];

"FLALG" -> "LIECAT"

— FLALG.dotfull —

```

"FreeLieAlgebra(a:OrderedSet,b:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FLALG"];
"FreeLieAlgebra(a:OrderedSet,b:CommutativeRing)" ->
  "LieAlgebra(a:CommutativeRing)"

```

— FLALG.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FreeLieAlgebra(a:OrderedSet,b:CommutativeRing)" [color=lightblue];
  "FreeLieAlgebra(a:OrderedSet,b:CommutativeRing)" ->
    "LieAlgebra(a:CommutativeRing)"

  "LieAlgebra(a:CommutativeRing)" [color=lightblue];
  "LieAlgebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

  "Module(a:CommutativeRing)" [color=lightblue];
  "Module(a:CommutativeRing)" ->
    "BiModule(a:CommutativeRing,b:CommutativeRing)"

  "BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
  "BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BiModule(a:Ring,b:Ring)"

  "BiModule(a:Ring,b:Ring)" [color=lightblue];
  "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
  "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

  "RightModule(a:Ring)" [color=seagreen];
  "RightModule(a:Ring)" -> "RightModule(a:Rng)"

  "RightModule(a:Rng)" [color=lightblue];
  "RightModule(a:Rng)" -> "ABELGRP..."

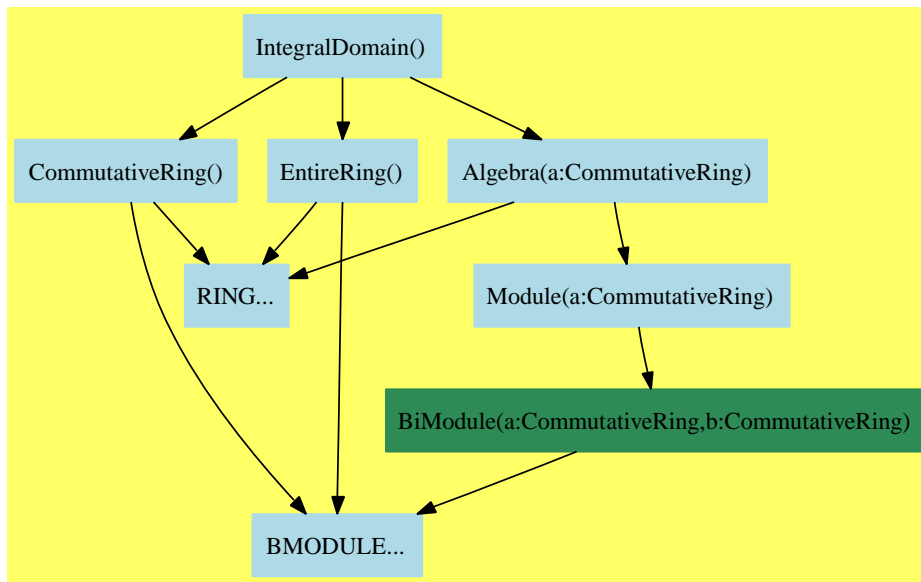
  "LeftModule(a:Ring)" [color=seagreen];
  "LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

  "LeftModule(a:Rng)" [color=lightblue];
  "LeftModule(a:Rng)" -> "ABELGRP..."

  "ABELGRP..." [color=lightblue];
}

```

IntegralDomain (INTDOM)



— IntegralDomain.input —

```

)set break resume
)sys rm -f IntegralDomain.output
)spool IntegralDomain.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show IntegralDomain
--R IntegralDomain is a category constructor
--R Abbreviation for IntegralDomain is INTDOM
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for INTDOM
--R
--R----- Operations -----
--R ?? : (% , %) -> %
--R ?? : (PositiveInteger , %) -> %
--R ?+? : (% , %) -> %
--R -? : % -> %
--R 1 : () -> %
--R ?? : (Integer , %) -> %
--R ***? : (% , PositiveInteger) -> %
--R ?-? : (% , %) -> %
--R ?=? : (% , %) -> Boolean
--R 0 : () -> %

```



```

--R ?? : (% , PositiveInteger) -> %      associates? : (% , %) -> Boolean
--R coerce : % -> %                      coerce : Integer -> %
--R coerce : % -> OutputForm              hash : % -> SingleInteger
--R latex : % -> String                   one? : % -> Boolean
--R recip : % -> Union(%, "failed")       sample : () -> %
--R unit? : % -> Boolean                  unitCanonical : % -> %
--R zero? : % -> Boolean                  ~=? : (% , %) -> Boolean
--R ??? : (NonNegativeInteger, %) -> %
--R ***? : (% , NonNegativeInteger) -> %
--R ?? : (% , NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R exquo : (% , %) -> Union(%, "failed")
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— IntegralDomain.help —

=====

IntegralDomain examples

=====

The category of commutative integral domains, i.e. commutative rings with no zero divisors.

Conditional attributes:

canonicalUnitNormal - the canonical field is the same for all associates
 canonicalsClosed - the product of two canonicals is itself canonical

See Also:

o)show IntegralDomain

All Commutative Rings are Integral Domains.

⇐ “CommutativeRing” (COMRING) [10](#) on page [896](#) Integral Domains are a subset of Unique Factorization domains.

⇒ “UniqueFactorizationDomain” (UFD) [14](#) on page [1222](#).

See:

⇒ “FortranMachineTypeCategory” (FMTC) [13](#) on page [1158](#)

⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)
 ⇒ “GcdDomain” (GCDDOM) [13](#) on page [1179](#)
 ⇒ “OrderedIntegralDomain” (OINTDOM) [13](#) on page [1185](#)
 ⇒ “UnivariatePolynomialCategory” (UPOLYC) [17](#) on page [1522](#)
 ⇐ “Algebra” (ALGEBRA) [11](#) on page [999](#)
 ⇐ “CommutativeRing” (COMRING) [10](#) on page [896](#)
 ⇐ “EntireRing” (ENTIRER) [10](#) on page [907](#)

Exports:

| | | | | |
|--------|---------------|-------------|----------------|------------|
| 0 | 1 | associates? | characteristic | coerce |
| exquo | hash | latex | one? | recip |
| sample | subtractIfCan | unit? | unitCanonical | unitNormal |
| zero? | ?^=? | ?*? | ?**? | ?^? |
| ?+? | ?-? | -? | ?=? | |

Attributes exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

Attributes Used:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?**(a, b) returns true if and only if **unitCanonical**(a) = **unitCanonical**(b).

These are directly exported but not implemented:

```
exquo : (% , %) -> Union(%, "failed")
```

These are implemented by this category:

```

associates? : (% , %) -> Boolean
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %, canonical: %, associate: %)

```

These exports come from (p[896](#)) **CommutativeRing**():

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (%, %) -> %
?*? : (Integer, %) -> %
?*? : (NonNegativeInteger, %) -> %
?*? : (PositiveInteger, %) -> %
?-? : (%, %) -> %
-? : % -> %
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
?*?* : (%, NonNegativeInteger) -> %
?*?* : (%, PositiveInteger) -> %

```

TPDHERE: Should we construct this coercion?

These exports come from (p999) Algebra(a:IntegralDomain):

```

coerce : % -> %

```

— category INTDOM IntegralDomain —

```

)abbrev category INTDOM IntegralDomain
++ Description:
++ The category of commutative integral domains, i.e. commutative
++ rings with no zero divisors.
++
++ Conditional attributes\br
++ canonicalUnitNormal\tab{5}the canonical field is the same for
++ all associates\br
++ canonicalsClosed\tab{5}the product of two canonicals is itself canonical

```

```

IntegralDomain(): Category ==
  Join(CommutativeRing, Algebra(%), EntireRing) with
    "exquo": (%, %) -> Union(%, "failed")
    ++ exquo(a,b) either returns an element c such that
    ++ \spad{c*b=a} or "failed" if no such element can be found.

```

```

unitNormal: % -> Record(unit:%,canonical:%,associate:%)
  ++ unitNormal(x) tries to choose a canonical element
  ++ from the associate class of x.
  ++ The attribute canonicalUnitNormal, if asserted, means that
  ++ the "canonical" element is the same across all associates of x
  ++ if \spad{unitNormal(x) = [u,c,a]} then
  ++ \spad{u*c = x}, \spad{a*u = 1}.
unitCanonical: % -> %
  ++ \spad{unitCanonical(x)} returns \spad{unitNormal(x).canonical}.
associates?: (%,% ) -> Boolean
  ++ associates?(x,y) tests whether x and y are associates, i.e.
  ++ differ by a unit factor.
unit?: % -> Boolean
  ++ unit?(x) tests whether x is a unit, i.e. is invertible.
add
  x,y: %

UCA ==> Record(unit:%,canonical:%,associate:%)
if not (% has Field) then
  unitNormal(x) == [1$,x,1$]$UCA -- the non-canonical definition
  unitCanonical(x) == unitNormal(x).canonical -- always true
  recip(x) == if zero? x then "failed" else _exquo(1$,x)
  unit?(x) == (recip x case "failed" => false; true)
  if % has canonicalUnitNormal then
    associates?(x,y) ==
      (unitNormal x).canonical = (unitNormal y).canonical
  else
    associates?(x,y) ==
      zero? x => zero? y
      zero? y => false
      x exquo y case "failed" => false
      y exquo x case "failed" => false
      true



---



— INTDOM.dotabb —

"INTDOM"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=INTDOM" ];
"INTDOM" -> "COMRING"
"INTDOM" -> "ALGEBRA"
"INTDOM" -> "ENTIRER"



---



— INTDOM.dotfull —

```

```

"IntegralDomain()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=INTDOM" ];
"IntegralDomain()" -> "CommutativeRing()"
"IntegralDomain()" -> "Algebra(a:CommutativeRing)"
"IntegralDomain()" -> "EntireRing()"

```

— INTDOM.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "IntegralDomain()" [color=lightblue];
  "IntegralDomain()" -> "CommutativeRing()"
  "IntegralDomain()" -> "Algebra(a:CommutativeRing)"
  "IntegralDomain()" -> "EntireRing()"

  "CommutativeRing()" [color=lightblue];
  "CommutativeRing()" -> "RING..."
  "CommutativeRing()" -> "BMODULE..."

  "EntireRing()" [color=lightblue];
  "EntireRing()" -> "RING..."
  "EntireRing()" -> "BMODULE..."

  "Algebra(a:CommutativeRing)" [color=lightblue];
  "Algebra(a:CommutativeRing)" -> "RING..."
  "Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

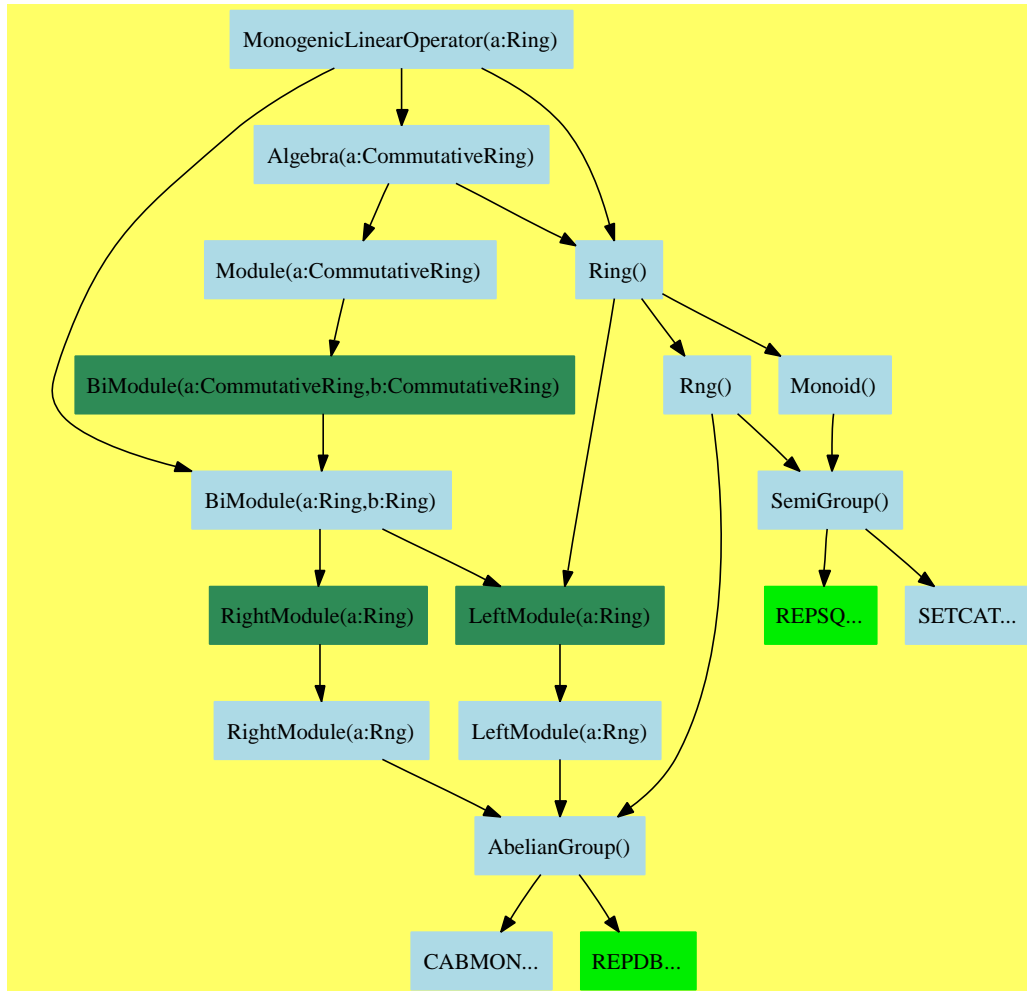
  "Module(a:CommutativeRing)" [color=lightblue];
  "Module(a:CommutativeRing)" ->
    "BiModule(a:CommutativeRing,b:CommutativeRing)"

  "BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
  "BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BMODULE..."

  "BMODULE..." [color=lightblue];
  "RING..." [color=lightblue];
}

```

MonogenicLinearOperator (MLO)



— MonogenicLinearOperator.input —

```

)set break resume
)sys rm -f MonogenicLinearOperator.output
)spool MonogenicLinearOperator.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show MonogenicLinearOperator

```

```

--R
--R MonogenicLinearOperator(R: Ring) is a category constructor
--R Abbreviation for MonogenicLinearOperator is MLO
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MLO
--R
--R----- Operations -----
--R ?? : (R,%) -> %           ?? : (%,R) -> %
--R ?? : (%,%) -> %           ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?? : (%,%) -> %           ?-? : (%,%) -> %
--R ?-? : % -> %               ?=? : (%,%) -> Boolean
--R 1 : () -> %               0 : () -> %
--R ?^? : (%,PositiveInteger) -> %   coerce : Integer -> %
--R coerce : % -> OutputForm         degree : % -> NonNegativeInteger
--R hash : % -> SingleInteger         latex : % -> String
--R leadingCoefficient : % -> R       one? : % -> Boolean
--R recip : % -> Union(%, "failed")   reductum : % -> %
--R sample : () -> %                 zero? : % -> Boolean
--R ~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?^? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R coefficient : (%,NonNegativeInteger) -> R
--R coerce : R -> % if R has COMRING
--R minimumDegree : % -> NonNegativeInteger
--R monomial : (R,NonNegativeInteger) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— MonogenicLinearOperator.help —

=====

MonogenicLinearOperator examples

=====

This is the category of linear operator rings with one generator.
The generator is not named by the category but can always be
constructed as `monomial(1,1)`.

For convenience, call the generator `G`.
Then each value is equal to

```
sum(a(i)*G**i, i = 0..n)
for some unique n and a(i) in R.
```

Note that multiplication is not necessarily commutative.
In fact, if a is in R , it is quite normal to have $a \cdot G \neq G \cdot a$.

See Also:

```
o )show MonogenicLinearOperator
```

See:

← “Algebra” (ALGEBRA) [11](#) on page [999](#)

← “BiModule” (BMODULE) [9](#) on page [782](#)

← “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | |
|--------------------|---------------|----------------|---------------|
| 0 | 1 | characteristic | coefficient |
| coerce | degree | hash | latex |
| leadingCoefficient | minimumDegree | monomial | one? |
| recip | reductum | sample | subtractIfCan |
| zero? | ?*? | ?**? | ?+? |
| ?-? | -? | ?=? | ?^? |
| ?~=? | | | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
coefficient : (% , NonNegativeInteger) -> R
degree : % -> NonNegativeInteger
leadingCoefficient : % -> R
minimumDegree : % -> NonNegativeInteger
monomial : (R, NonNegativeInteger) -> %
reductum : % -> %
```

These exports come from (p[826](#)) `Ring()`:

```
0 : () -> %
```



```

1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : % -> OutputForm
coerce : Integer -> %
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (NonNegativeInteger, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (Integer, %) -> %
?*? : (%, %) -> %
?-? : (%, %) -> %
-? : % -> %
?*?? : (%, PositiveInteger) -> %
?^? : (%, PositiveInteger) -> %
?*?? : (%, NonNegativeInteger) -> %
?^? : (%, NonNegativeInteger) -> %

```

These exports come from (p782) `BiModule(R:Ring,R:Ring)`:

```

?*? : (R, %) -> %
?*? : (%, R) -> %

```

These exports come from (p999) `Algebra(R:CommutativeRing)`:

```

coerce : R -> % if R has COMRING

```

— category MLO MonogenicLinearOperator —

```

)abbrev category MLO MonogenicLinearOperator
++ Author: Stephen M. Watt
++ Date Created: 1986
++ Date Last Updated: May 30, 1991
++ Description:
++ This is the category of linear operator rings with one generator.
++ The generator is not named by the category but can always be
++ constructed as \spad{monomial(1,1)}.
++
++ For convenience, call the generator \spad{G}.
++ Then each value is equal to
++ \spad{sum(a(i)*G**i, i = 0..n)}

```

```

++ for some unique \spad{n} and \spad{a(i)} in \spad{R}.
++
++ Note that multiplication is not necessarily commutative.
++ In fact, if \spad{a} is in \spad{R}, it is quite normal
++ to have \spad{a*G} \^= G*a}.

MonogenicLinearOperator(R): Category == Defn where
  E ==> NonNegativeInteger
  R: Ring
  Defn == Join(Ring, BiModule(R,R)) with
    if R has CommutativeRing then Algebra(R)
    degree: $ -> E
      ++ degree(l) is \spad{n} if
      ++ \spad{l} = sum(monomial(a(i),i), i = 0..n)}.
    minimumDegree: $ -> E
      ++ minimumDegree(l) is the smallest \spad{k} such that
      ++ \spad{a(k)} \^= 0} if
      ++ \spad{l} = sum(monomial(a(i),i), i = 0..n)}.
    leadingCoefficient: $ -> R
      ++ leadingCoefficient(l) is \spad{a(n)} if
      ++ \spad{l} = sum(monomial(a(i),i), i = 0..n)}.
    reductum: $ -> $
      ++ reductum(l) is \spad{l - monomial(a(n),n)} if
      ++ \spad{l} = sum(monomial(a(i),i), i = 0..n)}.
    coefficient: ($, E) -> R
      ++ coefficient(l,k) is \spad{a(k)} if
      ++ \spad{l} = sum(monomial(a(i),i), i = 0..n)}.
    monomial: (R, E) -> $
      ++ monomial(c,k) produces c times the k-th power of
      ++ the generating operator, \spad{monomial(1,1)}.

```

— MLO.dotabb —

```

"MLO"
[color=lightblue,href="bookvol10.2.pdf#nameddest=MLO"];
"MLO" -> "BMODULE"
"MLO" -> "RING"
"MLO" -> "ALGEBRA"

```

— MLO.dotfull —

```

"MonogenicLinearOperator(a:Ring)"

```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=MLO"];
"MonogenicLinearOperator(a:Ring)" -> "Ring()"
"MonogenicLinearOperator(a:Ring)" -> "BiModule(a:Ring,b:Ring)"
"MonogenicLinearOperator(a:Ring)" -> "Algebra(a:CommutativeRing)"
```

— MLO.dotpic —

```
digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "MonogenicLinearOperator(a:Ring)" [color=lightblue];
    "MonogenicLinearOperator(a:Ring)" -> "Ring()"
    "MonogenicLinearOperator(a:Ring)" -> "BiModule(a:Ring,b:Ring)"
    "MonogenicLinearOperator(a:Ring)" -> "Algebra(a:CommutativeRing)"

    "Algebra(a:CommutativeRing)" [color=lightblue];
    "Algebra(a:CommutativeRing)" -> "Ring()"
    "Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

    "Ring()" [color=lightblue];
    "Ring()" -> "Rng()"
    "Ring()" -> "Monoid()"
    "Ring()" -> "LeftModule(a:Ring)"

    "Module(a:CommutativeRing)" [color=lightblue];
    "Module(a:CommutativeRing)" ->
        "BiModule(a:CommutativeRing,b:CommutativeRing)"

    "BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
    "BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BiModule(a:Ring,b:Ring)"

    "BiModule(a:Ring,b:Ring)" [color=lightblue];
    "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
    "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

    "Rng()" [color=lightblue];
    "Rng()" -> "AbelianGroup()"
    "Rng()" -> "SemiGroup()"

    "Monoid()" [color=lightblue];
    "Monoid()" -> "SemiGroup()"

    "RightModule(a:Ring)" [color=seagreen];
    "RightModule(a:Ring)" -> "RightModule(a:Rng)"
```

```

"RightModule(a:Rng)" [color=lightblue];
"RightModule(a:Rng)" -> "AbelianGroup()"

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "AbelianGroup()"

"AbelianGroup()" [color=lightblue];
"AbelianGroup()" -> "CABMON..."
"AbelianGroup()" -> "REPDB..."

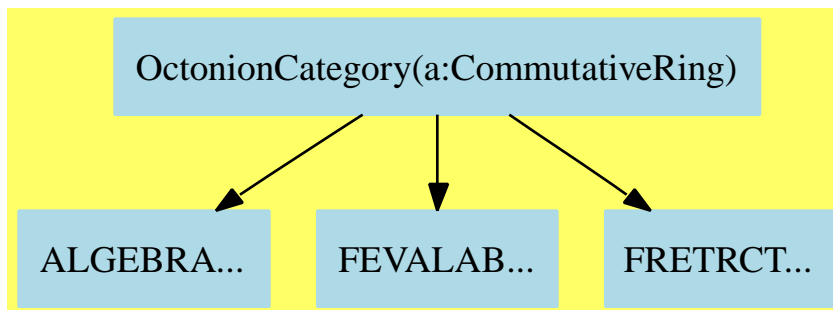
"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"REPDB..." [color="#00EE00"];
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"CABMON..." [color=lightblue];
}

```

—————

OctonionCategory (OC)



— OctonionCategory.input —

```

)set break resume
)sys rm -f OctonionCategory.output
)spool OctonionCategory.output

```

```

)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OctonionCategory
--R OctonionCategory(R: CommutativeRing) is a category constructor
--R Abbreviation for OctonionCategory is OC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OC
--R
--R----- Operations -----
--R ?? : (R,%) -> %          ?? : (% ,R) -> %
--R ?? : (% ,%) -> %          ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %    ??? : (% ,PositiveInteger) -> %
--R ?? : (% ,%) -> %          ?-? : (% ,%) -> %
--R -? : % -> %              ?=? : (% ,%) -> Boolean
--R 1 : () -> %              0 : () -> %
--R ?? : (% ,PositiveInteger) -> %    abs : % -> R if R has RNS
--R coerce : R -> %              coerce : Integer -> %
--R coerce : % -> OutputForm        conjugate : % -> %
--R hash : % -> SingleInteger        image : % -> R
--R imagI : % -> R                  imagJ : % -> R
--R imagK : % -> R                  imagi : % -> R
--R imagj : % -> R                  imagk : % -> R
--R inv : % -> % if R has FIELD      latex : % -> String
--R map : ((R -> R),%) -> %          norm : % -> R
--R octon : (R,R,R,R,R,R,R) -> %    one? : % -> Boolean
--R real : % -> R                  recip : % -> Union(%,"failed")
--R retract : % -> R               sample : () -> %
--R zero? : % -> Boolean           ?~=? : (% ,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ?<? : (% ,%) -> Boolean if R has ORDSET
--R ?<=? : (% ,%) -> Boolean if R has ORDSET
--R ?>? : (% ,%) -> Boolean if R has ORDSET
--R ?>=? : (% ,%) -> Boolean if R has ORDSET
--R ?^? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%,"failed") if R has CHARNZ
--R coerce : Fraction(Integer) -> % if R has RETRACT(FRAC(INT))
--R convert : % -> InputForm if R has KONVERT(INFORM)
--R ?.? : (% ,R) -> % if R has ELTAB(R,R)
--R enumerate : () -> List(%) if R has FINITE
--R eval : (% ,Symbol,R) -> % if R has IEVALAB(SYMBOL,R)
--R eval : (% ,List(Symbol),List(R)) -> % if R has IEVALAB(SYMBOL,R)
--R eval : (% ,List(Equation(R))) -> % if R has EVALAB(R)
--R eval : (% ,Equation(R)) -> % if R has EVALAB(R)
--R eval : (% ,R,R) -> % if R has EVALAB(R)
--R eval : (% ,List(R),List(R)) -> % if R has EVALAB(R)

```

```

--R index : PositiveInteger -> % if R has FINITE
--R lookup : % -> PositiveInteger if R has FINITE
--R max : (% , %) -> % if R has ORDSET
--R min : (% , %) -> % if R has ORDSET
--R random : () -> % if R has FINITE
--R rational : % -> Fraction(Integer) if R has INS
--R rational? : % -> Boolean if R has INS
--R rationalIfCan : % -> Union(Fraction(Integer), "failed") if R has INS
--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retract : % -> Integer if R has RETRACT(INT)
--R retractIfCan : % -> Union(R, "failed")
--R retractIfCan : % -> Union(Fraction(Integer), "failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer, "failed") if R has RETRACT(INT)
--R size : () -> NonNegativeInteger if R has FINITE
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R
--E 1

)spool
)lisp (bye)

```

— OctonionCategory.help —

OctonionCategory examples

OctonionCategory gives the categorial frame for the octonions, and eight-dimensional non-associative algebra, doubling the the quaternions in the same way as doubling the Complex numbers to get the quaternions.

See Also:

o)show OctonionCategory

See:

⇐ “Algebra” (ALGEBRA) [11](#) on page [999](#)
 ⇐ “FullyEvalableOver” (FEVALAB) [4](#) on page [209](#)
 ⇐ “FullyRetractableTo” (FRETRCT) [3](#) on page [136](#)

Exports:

| | | | | |
|---------------|-----------|---------------|----------------|--------------|
| 0 | 1 | abs | characteristic | charthRoot |
| coerce | conjugate | convert | eval | hash |
| imagE | imagI | imagJ | imagK | imagi |
| imagj | imagk | index | inv | latex |
| lookup | map | max | min | norm |
| octon | one? | random | rational | rational? |
| rationalIfCan | real | recip | retract | retractIfCan |
| sample | size | subtractIfCan | zero? | ?*? |
| ?**? | ?+? | ?-? | -? | ?=? |
| ?^? | ?~=? | ?<? | ?<=? | ?>? |
| ?>=? | ?..? | | | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```

imagi : % -> R
imagj : % -> R
imagk : % -> R
image : % -> R
imagI : % -> R
imagJ : % -> R
imagK : % -> R
octon : (R,R,R,R,R,R,R,R) -> %
real : % -> R

```

These are implemented by this category:

```

abs : % -> R if R has RNS
characteristic : () -> NonNegativeInteger
coerce : R -> %
coerce : Integer -> %
coerce : % -> OutputForm
conjugate : % -> %
convert : % -> InputForm if R has KONVERT INFORM
inv : % -> % if R has FIELD
map : ((R -> R),%) -> %
norm : % -> R
rational : % -> Fraction Integer if R has INS
rational? : % -> Boolean if R has INS
rationalIfCan : % -> Union(Fraction Integer,"failed") if R has INS
retract : % -> R

```

```

retractIfCan : % -> Union(R,"failed")
zero? : % -> Boolean
?<? : (%,% ) -> Boolean if R has ORDSET
?=? : (%,% ) -> Boolean
?+? : (%,% ) -> %
-? : % -> %
?*? : (R,% ) -> %
?*? : (Integer,% ) -> %

```

These exports come from (p999) Algebra(R:CommutativeRing):

```

0 : () -> %
1 : () -> %
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%,"failed")
sample : () -> %
subtractIfCan : (%,% ) -> Union(%,"failed")
?~=? : (%,% ) -> Boolean
?*? : (NonNegativeInteger,% ) -> %
?*? : (PositiveInteger,% ) -> %
?*? : (%,% ) -> %
?~? : (%,% ) -> %
?*?? : (% ,NonNegativeInteger) -> %
?*?? : (% ,PositiveInteger) -> %
?^? : (% ,PositiveInteger) -> %
?^? : (% ,NonNegativeInteger) -> %
?*? : (% ,R) -> %

```

These exports come from (p136) FullyRetractableTo(R:CommutativeRing):

```

coerce : Fraction Integer -> % if R has RETRACT FRAC INT
retract : % -> Fraction Integer if R has RETRACT FRAC INT
retract : % -> Integer if R has RETRACT INT
retractIfCan : % -> Union(Fraction Integer,"failed") if R has RETRACT FRAC INT
retractIfCan : % -> Union(Integer,"failed") if R has RETRACT INT

```

These exports come from (p209) FullyEvalableOver(R:CommutativeRing):

```

eval : (% ,Equation R) -> % if R has EVALAB R
eval : (% ,List Symbol,List R) -> % if R has IEVALAB(SYMBOL,R)
eval : (% ,List Equation R) -> % if R has EVALAB R
eval : (% ,R,R) -> % if R has EVALAB R
eval : (% ,List R,List R) -> % if R has EVALAB R
eval : (% ,Symbol,R) -> % if R has IEVALAB(SYMBOL,R)
?.? : (% ,R) -> % if R has ELTAB(R,R)

```

These exports come from (p218) Finite():


```

index : PositiveInteger -> % if R has FINITE
lookup : % -> PositiveInteger if R has FINITE
random : () -> % if R has FINITE
size : () -> NonNegativeInteger if R has FINITE

```

These exports come from (p269) `OrderedSet()`:

```

max : (%,%) -> % if R has ORDSET
min : (%,%) -> % if R has ORDSET
?<=? : (%,%) -> Boolean if R has ORDSET
?>? : (%,%) -> Boolean if R has ORDSET
?>=? : (%,%) -> Boolean if R has ORDSET

```

These exports come from (p887) `CharacteristicNonZero()`:

```

charthRoot : % -> Union(%, "failed") if R has CHARNZ

```

— category OC OctonionCategory —

```

)abbrev category OC OctonionCategory
++ Author: R. Wisbauer, J. Grabmeier
++ Date Created: 05 September 1990
++ Date Last Updated: 19 September 1990
++ References: e.g. I.L Kantor, A.S. Solodovnikov:
++ Hypercomplex Numbers, Springer Verlag Heidelberg, 1989,
++ ISBN 0-387-96980-2
++ Description:
++ OctonionCategory gives the categorial frame for the
++ octonions, and eight-dimensional non-associative algebra,
++ doubling the the quaternions in the same way as doubling
++ the Complex numbers to get the quaternions.

OctonionCategory(R: CommutativeRing): Category ==
  -- we are cheating a little bit, algebras in \Language{}
  -- are mainly considered to be associative, but that's not
  -- an attribute and we can't guarantee that there is no piece
  -- of code which implicitly
  -- uses this. In a later version we shall properly combine
  -- all this code in the context of general, non-associative
  -- algebras, which are meanwhile implemented in \Language{}
  Join(Algebra R, FullyRetractableTo R, FullyEvalableOver R) with
    conjugate: % -> %
      ++ conjugate(o) negates the imaginary parts i,j,k,E,I,J,K of octonian o.
    real: % -> R
      ++ real(o) extracts real part of octonion o.
    imagi: % -> R
      ++ imagi(o) extracts the i part of octonion o.
    imagj: % -> R

```

```

    ++ imagj(o) extracts the j part of octonion o.
imagk:  % -> R
    ++ imagk(o) extracts the k part of octonion o.
imagE:  % -> R
    ++ imagE(o) extracts the imaginary E part of octonion o.
imagI:  % -> R
    ++ imagI(o) extracts the imaginary I part of octonion o.
imagJ:  % -> R
    ++ imagJ(o) extracts the imaginary J part of octonion o.
imagK:  % -> R
    ++ imagK(o) extracts the imaginary K part of octonion o.
norm:   % -> R
    ++ norm(o) returns the norm of an octonion, equal to
    ++ the sum of the squares
    ++ of its coefficients.
octon: (R,R,R,R,R,R,R,R) -> %
    ++ octon(re,ri,rj,rk,rE,rI,rJ,rK) constructs an octonion
    ++ from scalars.
if R has Finite then Finite
if R has OrderedSet then OrderedSet
if R has ConvertibleTo InputForm then ConvertibleTo InputForm
if R has CharacteristicZero then CharacteristicZero
if R has CharacteristicNonZero then CharacteristicNonZero
if R has RealNumberSystem then
    abs:  % -> R
        ++ abs(o) computes the absolute value of an octonion, equal to
        ++ the square root of the \spadfunFrom{norm}{Octonion}.
if R has IntegerNumberSystem then
    rational? : % -> Boolean
        ++ rational?(o) tests if o is rational, i.e. that all seven
        ++ imaginary parts are 0.
    rational : % -> Fraction Integer
        ++ rational(o) returns the real part if all seven
        ++ imaginary parts are 0.
        ++ Error: if o is not rational.
    rationalIfCan: % -> Union(Fraction Integer, "failed")
        ++ rationalIfCan(o) returns the real part if
        ++ all seven imaginary parts are 0, and "failed" otherwise.
if R has Field then
    inv : % -> %
        ++ inv(o) returns the inverse of o if it exists.
add
characteristic() ==
    characteristic()$R

conjugate x ==
    octon(real x, - imagi x, - imagj x, - imagk x, - imagE x, _
    - imagI x, - imagJ x, - imagK x)

map(fn, x) ==

```

```

octon(fn real x,fn imagi x,fn imagj x,fn imagk x, fn imagE x,_
      fn imagI x, fn imagJ x,fn imagK x)

norm x ==
  real x * real x + imagi x * imagi x + _
  imagj x * imagj x + imagk x * imagk x + _
  imagE x * imagE x + imagI x * imagI x + _
  imagJ x * imagJ x + imagK x * imagK x

x = y      ==
  (real x = real y) and (imagi x = imagi y) and _
  (imagj x = imagj y) and (imagk x = imagk y) and _
  (imagE x = imagE y) and (imagI x = imagI y) and _
  (imagJ x = imagJ y) and (imagK x = imagK y)

x + y      ==
  octon(real x + real y, imagi x + imagi y,_
        imagj x + imagj y, imagk x + imagk y,_
        imagE x + imagE y, imagI x + imagI y,_
        imagJ x + imagJ y, imagK x + imagK y)

- x        ==
  octon(- real x, - imagi x, - imagj x, - imagk x,_
        - imagE x, - imagI x, - imagJ x, - imagK x)

r:R * x:%  ==
  octon(r * real x, r * imagi x, r * imagj x, r * imagk x,_
        r * imagE x, r * imagI x, r * imagJ x, r * imagK x)

n:Integer * x:% ==
  octon(n * real x, n * imagi x, n * imagj x, n * imagk x,_
        n * imagE x, n * imagI x, n * imagJ x, n * imagK x)

coerce(r:R) ==
  octon(r,0$R,0$R,0$R,0$R,0$R,0$R,0$R)

coerce(n:Integer) ==
  octon(n :: R,0$R,0$R,0$R,0$R,0$R,0$R,0$R)

zero? x ==
  zero? real x and zero? imagi x and _
  zero? imagj x and zero? imagk x and _
  zero? imagE x and zero? imagI x and _
  zero? imagJ x and zero? imagK x

retract(x):R ==
  not (zero? imagi x and zero? imagj x and zero? imagk x and _
  zero? imagE x and zero? imagI x and zero? imagJ x and zero? imagK x)=>
    error "Cannot retract octonion."
  real x

```

```

retractIfCan(x):Union(R,"failed") ==
  not (zero? imagi x and zero? imagj x and zero? imagk x and _
    zero? imagE x and zero? imagI x and zero? imagJ x and zero? imagK x)=>
    "failed"
  real x

coerce(x:%):OutputForm ==
  part,z : OutputForm
  y : %
  zero? x => (0$R) :: OutputForm
  not zero?(real x) =>
    y := octon(0$R,imagi(x),imagj(x),imagk(x),imagE(x),
      imagI(x),imagJ(x),imagK(x))
    zero? y => real(x) :: OutputForm
    (real(x) :: OutputForm) + (y :: OutputForm)
  -- we know that the real part is 0
  not zero?(imagi(x)) =>
    y := octon(0$R,0$R,imagj(x),imagk(x),imagE(x),
      imagI(x),imagJ(x),imagK(x))
    z :=
      part := "i"::Symbol::OutputForm
      one? imagi(x) => part
      (imagi(x) = 1) => part
      (imagi(x) :: OutputForm) * part
      zero? y => z
      z + (y :: OutputForm)
  -- we know that the real part and i part are 0
  not zero?(imagj(x)) =>
    y := octon(0$R,0$R,0$R,imagk(x),imagE(x),
      imagI(x),imagJ(x),imagK(x))
    z :=
      part := "j"::Symbol::OutputForm
      one? imagj(x) => part
      (imagj(x) = 1) => part
      (imagj(x) :: OutputForm) * part
      zero? y => z
      z + (y :: OutputForm)
  -- we know that the real part and i and j parts are 0
  not zero?(imagk(x)) =>
    y := octon(0$R,0$R,0$R,0$R,imagE(x),
      imagI(x),imagJ(x),imagK(x))
    z :=
      part := "k"::Symbol::OutputForm
      one? imagk(x) => part
      (imagk(x) = 1) => part
      (imagk(x) :: OutputForm) * part
      zero? y => z
      z + (y :: OutputForm)
  -- we know that the real part,i,j,k parts are 0

```

```

not zero?(imagE(x)) =>
  y := octon(0$R,0$R,0$R,0$R,0$R,
    imagI(x),imagJ(x),imagK(x))
  z :=
    part := "E"::Symbol::OutputForm
--    one? imagE(x) => part
    (imagE(x) = 1) => part
    (imagE(x) :: OutputForm) * part
  zero? y => z
  z + (y :: OutputForm)
-- we know that the real part,i,j,k,E parts are 0
not zero?(imagI(x)) =>
  y := octon(0$R,0$R,0$R,0$R,0$R,0$R,imagJ(x),imagK(x))
  z :=
    part := "I"::Symbol::OutputForm
--    one? imagI(x) => part
    (imagI(x) = 1) => part
    (imagI(x) :: OutputForm) * part
  zero? y => z
  z + (y :: OutputForm)
-- we know that the real part,i,j,k,E,I parts are 0
not zero?(imagJ(x)) =>
  y := octon(0$R,0$R,0$R,0$R,0$R,0$R,0$R,imagK(x))
  z :=
    part := "J"::Symbol::OutputForm
--    one? imagJ(x) => part
    (imagJ(x) = 1) => part
    (imagJ(x) :: OutputForm) * part
  zero? y => z
  z + (y :: OutputForm)
-- we know that the real part,i,j,k,E,I,J parts are 0
part := "K"::Symbol::OutputForm
--    one? imagK(x) => part
    (imagK(x) = 1) => part
    (imagK(x) :: OutputForm) * part

if R has Field then
  inv x ==
    (norm x) = 0 => error "This octonion is not invertible."
    (inv norm x) * conjugate x

if R has ConvertibleTo InputForm then
  convert(x:%):InputForm ==
    l : List InputForm := [convert("octon" :: Symbol),
      convert(real x)$R, convert(imagi x)$R, convert(imagj x)$R,_
      convert(imagk x)$R, convert(imagE x)$R,_
      convert(imagI x)$R, convert(imagJ x)$R,_
      convert(imagK x)$R]
  convert(l)$InputForm

```

```

if R has OrderedSet then
  x < y ==
    real x = real y =>
      imagi x = imagi y =>
        imagj x = imagj y =>
          imagk x = imagk y =>
            imagE x = imagE y =>
              imagI x = imagI y =>
                imagJ x = imagJ y =>
                  imagK x < imagK y
                imagJ x < imagJ y
              imagI x < imagI y
            imagE x < imagE y
          imagk x < imagk y
        imagj x < imagj y
      imagi x < imagi y
    real x < real y

if R has RealNumberSystem then
  abs x == sqrt norm x

if R has IntegerNumberSystem then
  rational? x ==
    (zero? imagi x) and (zero? imagj x) and (zero? imagk x) and _
    (zero? imagE x) and (zero? imagI x) and (zero? imagJ x) and _
    (zero? imagK x)

  rational x ==
    rational? x => rational real x
    error "Not a rational number"

  rationalIfCan x ==
    rational? x => rational real x
    "failed"

```

— OC.dotabb —

```

"OC"
[color=lightblue,href="bookvol10.2.pdf#nameddest=OC"];
"OC" -> "ALGEBRA"
"OC" -> "FEVALAB"
"OC" -> "FRETRCT"

```

— OC.dotfull —

```
"OctonionCategory(a:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OC"];
"OctonionCategory(a:CommutativeRing)" -> "Algebra(a:CommutativeRing)"
"OctonionCategory(a:CommutativeRing)" -> "FullyEvaluableOver(CommutativeRing)"
"OctonionCategory(a:CommutativeRing)" ->
  "FullyRetractableTo(a:CommutativeRing)"
```

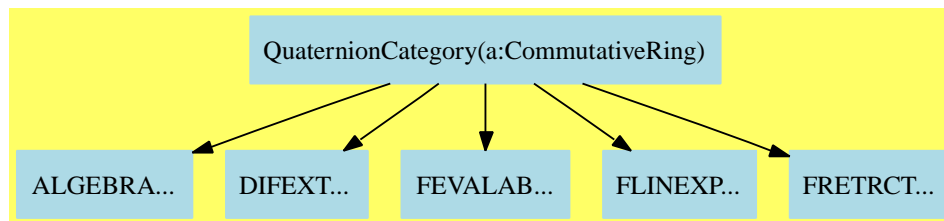
— OC.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OctonionCategory(a:CommutativeRing)" [color=lightblue];
  "OctonionCategory(a:CommutativeRing)" -> "ALGEBRA..."
  "OctonionCategory(a:CommutativeRing)" -> "FEVALAB..."
  "OctonionCategory(a:CommutativeRing)" -> "FRETRCT..."

  "ALGEBRA..." [color=lightblue];
  "FEVALAB..." [color=lightblue];
  "FRETRCT..." [color=lightblue];
}
```

QuaternionCategory (QUATCAT)



— QuaternionCategory.input —

```

)set break resume
)sys rm -f QuaternionCategory.output
)spool QuaternionCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show QuaternionCategory
--R
--R QuaternionCategory(R: CommutativeRing) is a category constructor
--R Abbreviation for QuaternionCategory is QUATCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for QUATCAT
--R
--R----- Operations -----
--R ??? : (R,%) -> %          ??? : (%,R) -> %
--R ??? : (%,%) -> %          ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %    ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %          ?-? : (%,%) -> %
--R -? : % -> %              ?=? : (%,%) -> Boolean
--R D : (%,(R -> R)) -> %      D : % -> % if R has DIFRING
--R 1 : () -> %              0 : () -> %
--R ?? : (%,PositiveInteger) -> %    abs : % -> R if R has RNS
--R coerce : R -> %            coerce : Integer -> %
--R coerce : % -> OutputForm      conjugate : % -> %
--R hash : % -> SingleInteger      imagI : % -> R
--R imagJ : % -> R                imagK : % -> R
--R inv : % -> % if R has FIELD      latex : % -> String
--R map : ((R -> R),%) -> %          norm : % -> R
--R one? : % -> Boolean            quatern : (R,R,R,R) -> %
--R real : % -> R                  recip : % -> Union(%, "failed")
--R retract : % -> R              sample : () -> %
--R zero? : % -> Boolean           ?~=? : (%,%) -> Boolean
--R ??? : (Fraction(Integer),%) -> % if R has FIELD
--R ??? : (%,Fraction(Integer)) -> % if R has FIELD
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,Integer) -> % if R has FIELD
--R ??? : (%,NonNegativeInteger) -> %
--R ?<? : (%,%) -> Boolean if R has ORDSET
--R ?<=? : (%,%) -> Boolean if R has ORDSET
--R ?>? : (%,%) -> Boolean if R has ORDSET
--R ?>=? : (%,%) -> Boolean if R has ORDSET
--R D : (%,(R -> R),NonNegativeInteger) -> %
--R D : (%,List(Symbol),List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R D : (%,Symbol,NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R D : (%,List(Symbol)) -> % if R has PDRING(SYMBOL)
--R D : (%,Symbol) -> % if R has PDRING(SYMBOL)
--R D : (%,NonNegativeInteger) -> % if R has DIFRING
--R ??? : (%,Integer) -> % if R has FIELD

```



```

--R ?? : (% , NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(% , "failed") if R has CHARNZ
--R coerce : Fraction(Integer) -> % if R has FIELD or R has RETRACT(FRAC(INT))
--R convert : % -> InputForm if R has KONVERT(INFORM)
--R differentiate : (% , (R -> R)) -> %
--R differentiate : (% , (R -> R) , NonNegativeInteger) -> %
--R differentiate : (% , List(Symbol) , List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , Symbol , NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , List(Symbol)) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , Symbol) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , NonNegativeInteger) -> % if R has DIFRING
--R differentiate : % -> % if R has DIFRING
--R ?.? : (% , R) -> % if R has ELTAB(R , R)
--R eval : (% , Symbol , R) -> % if R has IEVALAB(SYMBOL , R)
--R eval : (% , List(Symbol) , List(R)) -> % if R has IEVALAB(SYMBOL , R)
--R eval : (% , List(Equation(R))) -> % if R has EVALAB(R)
--R eval : (% , Equation(R)) -> % if R has EVALAB(R)
--R eval : (% , R , R) -> % if R has EVALAB(R)
--R eval : (% , List(R) , List(R)) -> % if R has EVALAB(R)
--R max : (% , %) -> % if R has ORDSET
--R min : (% , %) -> % if R has ORDSET
--R rational : % -> Fraction(Integer) if R has INS
--R rational? : % -> Boolean if R has INS
--R rationalIfCan : % -> Union(Fraction(Integer) , "failed") if R has INS
--R reducedSystem : Matrix(%) -> Matrix(R)
--R reducedSystem : (Matrix(%) , Vector(%)) -> Record(mat: Matrix(R) , vec: Vector(R))
--R reducedSystem : (Matrix(%) , Vector(%)) -> Record(mat: Matrix(Integer) , vec: Vector(Integer)) if R has LINEXP(INT)
--R reducedSystem : Matrix(%) -> Matrix(Integer) if R has LINEXP(INT)
--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retract : % -> Integer if R has RETRACT(INT)
--R retractIfCan : % -> Union(R , "failed")
--R retractIfCan : % -> Union(Fraction(Integer) , "failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer , "failed") if R has RETRACT(INT)
--R subtractIfCan : (% , %) -> Union(% , "failed")
--R
--E 1

)spool
)lisp (bye)

```

— QuaternionCategory.help —

```

=====
QuaternionCategory examples
=====

```

QuaternionCategory describes the category of quaternions and implements functions that are not representation specific.

See Also:

o)show QuaternionCategory

See:

⇐ “Algebra” (ALGEBRA) [11](#) on page [999](#)
 ⇐ “DifferentialExtension” (DIFEXT) [11](#) on page [1005](#)
 ⇐ “FullyEvaluableOver” (FEVALAB) [4](#) on page [209](#)
 ⇐ “FullyLinearlyExplicitRingOver” (FLINEXP) [11](#) on page [1012](#)
 ⇐ “FullyRetractableTo” (FRETRCT) [3](#) on page [136](#)

Exports:

| | | | |
|---------------|---------------|--------------|----------------|
| 0 | 1 | abs | characteristic |
| charthRoot | coerce | conjugate | convert |
| D | differentiate | eval | hash |
| imagI | imagJ | imagK | inv |
| latex | map | max | min |
| norm | one? | quatern | rational |
| rational? | rationalIfCan | real | recip |
| reducedSystem | retract | retractIfCan | sample |
| subtractIfCan | zero? | ?*? | ?**? |
| ?+? | ?-? | ?-? | ?=? |
| ?^? | ?~=? | ?<? | ?<=? |
| ?>? | ?>=? | ?..? | |

Attributes Exported:

- if #1 has EntireRing then noZeroDivisors where **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```
imagI : % -> R
imagJ : % -> R
imagK : % -> R
```

```
quatern : (R,R,R,R) -> %
real : % -> R
```

These are implemented by this category:

```
abs : % -> R if R has RNS
characteristic : () -> NonNegativeInteger
coerce : R -> %
coerce : Integer -> %
coerce : % -> OutputForm
conjugate : % -> %
convert : % -> InputForm if R has KONVERT INFORM
differentiate : (%,(R -> R)) -> %
inv : % -> % if R has FIELD
map : ((R -> R),%) -> %
norm : % -> R
one? : % -> Boolean
rational : % -> Fraction Integer if R has INS
rational? : % -> Boolean if R has INS
rationalIfCan : % -> Union(Fraction Integer,"failed") if R has INS
retract : % -> R
retractIfCan : % -> Union(R,"failed")
zero? : % -> Boolean
?=? : (%,%) -> Boolean
?+? : (%,%) -> %
?-? : (%,%) -> %
-? : % -> %
?*? : (R,%) -> %
?*? : (Integer,%) -> %
?<? : (%,%) -> Boolean if R has ORDSET
```

These exports come from (p999) Algebra(R:CommutativeRing):

```
0 : () -> %
1 : () -> %
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,%) -> Union(%,"failed")
?~=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?*?* : (% ,PositiveInteger) -> %
?*?* : (% ,NonNegativeInteger) -> %
?^? : (% ,PositiveInteger) -> %
?^? : (% ,NonNegativeInteger) -> %
?*? : (% ,R) -> %
```

These exports come from (p136) FullyRetractableTo(R:CommutativeRing):

```

coerce : Fraction Integer -> % if R has FIELD or R has RETRACT FRAC INT
retract : % -> Fraction Integer if R has RETRACT FRAC INT
retract : % -> Integer if R has RETRACT INT
retractIfCan : % -> Union(Fraction Integer,"failed")
  if R has RETRACT FRAC INT
retractIfCan : % -> Union(Integer,"failed") if R has RETRACT INT

```

These exports come from (p1005) DifferentialExtension(R:CommutativeRing):

```

D : % -> % if R has DIFRING
D : (% , NonNegativeInteger) -> % if R has DIFRING
D : (% , (R -> R)) -> %
D : (% , (R -> R) , NonNegativeInteger) -> %
D : (% , Symbol) -> % if R has PDRING SYMBOL
D : (% , List Symbol) -> % if R has PDRING SYMBOL
D : (% , Symbol , NonNegativeInteger) -> % if R has PDRING SYMBOL
D : (% , List Symbol , List NonNegativeInteger) -> % if R has PDRING SYMBOL
differentiate : (% , List Symbol , List NonNegativeInteger) -> %
  if R has PDRING SYMBOL
differentiate : (% , Symbol , NonNegativeInteger) -> % if R has PDRING SYMBOL
differentiate : (% , List Symbol) -> % if R has PDRING SYMBOL
differentiate : (% , NonNegativeInteger) -> % if R has DIFRING
differentiate : % -> % if R has DIFRING
differentiate : (% , (R -> R) , NonNegativeInteger) -> %
differentiate : (% , Symbol) -> % if R has PDRING SYMBOL
? * ? : (% , %) -> %

```

These exports come from (p209) FullyEvaluableOver(R:CommutativeRing):

```

eval : (% , Equation R) -> % if R has EVALAB R
eval : (% , List Symbol , List R) -> % if R has IEVALAB(SYMBOL,R)
eval : (% , List Equation R) -> % if R has EVALAB R
eval : (% , R , R) -> % if R has EVALAB R
eval : (% , List R , List R) -> % if R has EVALAB R
eval : (% , Symbol , R) -> % if R has IEVALAB(SYMBOL,R)
? . ? : (% , R) -> % if R has ELTAB(R,R)

```

These exports come from (p1012) FullyLinearlyExplicitRingOver(R)
where R:CommutativeRing:

```

recip : % -> Union(%,"failed")
reducedSystem : Matrix % -> Matrix Integer if R has LINEXP INT
reducedSystem :
  (Matrix % , Vector %) ->
    Record(mat: Matrix Integer , vec: Vector Integer)
  if R has LINEXP INT
reducedSystem : Matrix % -> Matrix R
reducedSystem : (Matrix % , Vector %) -> Record(mat: Matrix R , vec: Vector R)

```

These exports come from (p269) OrderedSet():

```

max : (%,% ) -> % if R has ORDSET
min : (%,% ) -> % if R has ORDSET
?<=? : (%,% ) -> Boolean if R has ORDSET
?>? : (%,% ) -> Boolean if R has ORDSET
?>=? : (%,% ) -> Boolean if R has ORDSET

```

These exports come from (p1063) DivisionRing():

```

***? : (%,Integer) -> % if R has FIELD
?^? : (%,Integer) -> % if R has FIELD
?*? : (Fraction Integer,% ) -> % if R has FIELD
?*? : (% ,Fraction Integer) -> % if R has FIELD

```

These exports come from (p887) CharacteristicNonZero():

```

charthRoot : % -> Union(%,"failed") if R has CHARNZ

```

— category QUATCAT QuaternionCategory —

```

)abbrev category QUATCAT QuaternionCategory
++ Author: Robert S. Sutor
++ Date Created: 23 May 1990
++ Change History: 10 September 1990
++ Description:
++ \spadtype{QuaternionCategory} describes the category of quaternions
++ and implements functions that are not representation specific.

QuaternionCategory(R: CommutativeRing): Category ==
  Join(Algebra R, FullyRetractableTo R, DifferentialExtension R,
    FullyEvaluableOver R, FullyLinearlyExplicitRingOver R) with

    conjugate: $ -> $
      ++ conjugate(q) negates the imaginary parts of quaternion \spad{q}.
    imagI: $ -> R
      ++ imagI(q) extracts the imaginary i part of quaternion \spad{q}.
    imagJ: $ -> R
      ++ imagJ(q) extracts the imaginary j part of quaternion \spad{q}.
    imagK: $ -> R
      ++ imagK(q) extracts the imaginary k part of quaternion \spad{q}.
    norm: $ -> R
      ++ norm(q) computes the norm of \spad{q} (the sum of the
      ++ squares of the components).
    quatern: (R,R,R,R) -> $
      ++ quatern(r,i,j,k) constructs a quaternion from scalars.
    real: $ -> R
      ++ real(q) extracts the real part of quaternion \spad{q}.

    if R has EntireRing then EntireRing

```

```

if R has OrderedSet then OrderedSet
if R has Field then DivisionRing
if R has ConvertibleTo InputForm then ConvertibleTo InputForm
if R has CharacteristicZero then CharacteristicZero
if R has CharacteristicNonZero then CharacteristicNonZero
if R has RealNumberSystem then
  abs      : $ -> R
  ++ abs(q) computes the absolute value of quaternion \spad{q}
  ++ (sqrt of norm).
if R has IntegerNumberSystem then
  rational? : $ -> Boolean
  ++ rational?(q) returns {\it true} if all the imaginary
  ++ parts of \spad{q} are zero and the real part can be
  ++ converted into a rational number, and {\it false}
  ++ otherwise.
  rational  : $ -> Fraction Integer
  ++ rational(q) tries to convert \spad{q} into a
  ++ rational number. Error: if this is not
  ++ possible. If \spad{rational?(q)} is true, the
  ++ conversion will be done and the rational number returned.
  rationalIfCan : $ -> Union(Fraction Integer, "failed")
  ++ rationalIfCan(q) returns \spad{q} as a rational number,
  ++ or "failed" if this is not possible.
  ++ Note that if \spad{rational?(q)} is true, the conversion
  ++ can be done and the rational number will be returned.

add

characteristic() ==
  characteristic($R)

conjugate x      ==
  quatern(real x, - imagI x, - imagJ x, - imagK x)

map(fn, x)       ==
  quatern(fn real x, fn imagI x, fn imagJ x, fn imagK x)

norm x ==
  real x * real x + imagI x * imagI x +
  imagJ x * imagJ x + imagK x * imagK x

x = y            ==
  (real x = real y) and (imagI x = imagI y) and
  (imagJ x = imagJ y) and (imagK x = imagK y)

x + y            ==
  quatern(real x + real y, imagI x + imagI y,
  imagJ x + imagJ y, imagK x + imagK y)

x - y            ==

```

```

    quatern(real x - real y, imagI x - imagI y,
            imagJ x - imagJ y, imagK x - imagK y)

- x ==
    quatern(- real x, - imagI x, - imagJ x, - imagK x)

r:R * x:$ ==
    quatern(r * real x, r * imagI x, r * imagJ x, r * imagK x)

n:Integer * x:$ ==
    quatern(n * real x, n * imagI x, n * imagJ x, n * imagK x)

differentiate(x:$, d:R -> R) ==
    quatern(d real x, d imagI x, d imagJ x, d imagK x)

coerce(r:R) ==
    quatern(r, 0$R, 0$R, 0$R)

coerce(n:Integer) ==
    quatern(n :: R, 0$R, 0$R, 0$R)

one? x ==
--   one? real x and zero? imagI x and
    (real x) = 1 and zero? imagI x and
    zero? imagJ x and zero? imagK x

zero? x ==
    zero? real x and zero? imagI x and
    zero? imagJ x and zero? imagK x

retract(x):R ==
    not (zero? imagI x and zero? imagJ x and zero? imagK x) =>
        error "Cannot retract quaternion."
    real x

retractIfCan(x):Union(R, "failed") ==
    not (zero? imagI x and zero? imagJ x and zero? imagK x) =>
        "failed"
    real x

coerce(x:$):OutputForm ==
    part, z : OutputForm
    y : $
    zero? x => (0$R) :: OutputForm
    not zero?(real x) =>
        y := quatern(0$R, imagI(x), imagJ(x), imagK(x))
        zero? y => real(x) :: OutputForm
        (real(x) :: OutputForm) + (y :: OutputForm)
-- we know that the real part is 0
    not zero?(imagI(x)) =>

```

```

y := quatern(0$R,0$R,imagJ(x),imagK(x))
z :=
  part := "i"::Symbol::OutputForm
--   one? imagI(x) => part
   (imagI(x) = 1) => part
   (imagI(x) :: OutputForm) * part
zero? y => z
z + (y :: OutputForm)
-- we know that the real part and i part are 0
not zero?(imagJ(x)) =>
y := quatern(0$R,0$R,0$R,imagK(x))
z :=
  part := "j"::Symbol::OutputForm
--   one? imagJ(x) => part
   (imagJ(x) = 1) => part
   (imagJ(x) :: OutputForm) * part
zero? y => z
z + (y :: OutputForm)
-- we know that the real part and i and j parts are 0
part := "k"::Symbol::OutputForm
--   one? imagK(x) => part
   (imagK(x) = 1) => part
   (imagK(x) :: OutputForm) * part

if R has Field then
  inv x ==
    norm x = 0 => error "This quaternion is not invertible."
    (inv norm x) * conjugate x

if R has ConvertibleTo InputForm then
  convert(x:$):InputForm ==
    l : List InputForm := [convert("quatern" :: Symbol),
      convert(real x)$R, convert(imagI x)$R, convert(imagJ x)$R,
      convert(imagK x)$R]
  convert(l)$InputForm

if R has OrderedSet then
  x < y ==
    real x = real y =>
      imagI x = imagI y =>
        imagJ x = imagJ y =>
          imagK x < imagK y
          imagJ x < imagJ y
          imagI x < imagI y
      real x < real y

if R has RealNumberSystem then
  abs x == sqrt norm x

if R has IntegerNumberSystem then

```



```

rational? x ==
  (zero? imagI x) and (zero? imagJ x) and (zero? imagK x)

rational x ==
  rational? x => rational real x
  error "Not a rational number"

rationalIfCan x ==
  rational? x => rational real x
  "failed"

```

— QUATCAT.dotabb —

```

"QUATCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=QUATCAT"];
"QUATCAT" -> "ALGEBRA"
"QUATCAT" -> "DIFEXT"
"QUATCAT" -> "FEVALAB"
"QUATCAT" -> "FLINEXP"
"QUATCAT" -> "FRETRCT"

```

— QUATCAT.dotfull —

```

"QuaternionCategory(a:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=QUATCAT"];
"QuaternionCategory(a:CommutativeRing)" ->
  "Algebra(a:CommutativeRing)"
"QuaternionCategory(a:CommutativeRing)" ->
  "DifferentialExtension(CommutativeRing)"
"QuaternionCategory(a:CommutativeRing)" ->
  "FullyEvaluableOver(CommutativeRing)"
"QuaternionCategory(a:CommutativeRing)" ->
  "FullyLinearlyExplicitRingOver(a:CommutativeRing)"
"QuaternionCategory(a:CommutativeRing)" ->
  "FullyRetractableTo(a:CommutativeRing)"

```

— QUATCAT.dotpic —

```

digraph pic {

```

```

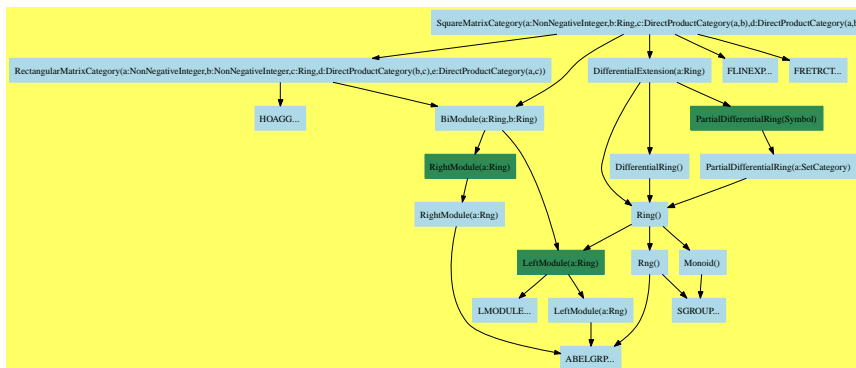
fontsize=10;
bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"QuaternionCategory(a:CommutativeRing)" [color=lightblue];
"QuaternionCategory(a:CommutativeRing)" -> "ALGEBRA..."
"QuaternionCategory(a:CommutativeRing)" -> "DIFEXT..."
"QuaternionCategory(a:CommutativeRing)" -> "FEVALAB..."
"QuaternionCategory(a:CommutativeRing)" -> "FLINEXP..."
"QuaternionCategory(a:CommutativeRing)" -> "FRETRCT..."

"ALGEBRA..." [color=lightblue];
"DIFEXT..." [color=lightblue];
"FEVALAB..." [color=lightblue];
"FLINEXP..." [color=lightblue];
"FRETRCT..." [color=lightblue];
}

```

SquareMatrixCategory (SMATCAT)



We define three categories for matrices

- MatrixCategory is the category of all matrices
- RectangularMatrixCategory is the category of all matrices of a given dimension
- SquareMatrixCategory inherits from RectangularMatrixCategory

The SquareMatrix domain is for square matrices of fixed dimension.

— SquareMatrixCategory.input —

```

)set break resume
)sys rm -f SquareMatrixCategory.output
)spool SquareMatrixCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show SquareMatrixCategory
--R
--R SquareMatrixCategory(ndim: NonNegativeInteger,R: Ring,Row: DirectProductCategory(t#1,t#2),Co
--R Abbreviation for SquareMatrixCategory is SMATCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for SMATCAT
--R
--R----- Operations -----
--R ?? : (Row,%) -> Row          ?? : (%,Col) -> Col
--R ?? : (R,%) -> %             ?? : (%,R) -> %
--R ?? : (%,%) -> %             ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R +? : (%,%) -> %             ?-? : (%,%) -> %
--R -? : % -> %                 ?? : (%,%) -> Boolean
--R D : % -> % if R has DIFRING   D : (%,(R -> R)) -> %
--R 1 : () -> %                 0 : () -> %
--R ^? : (%,PositiveInteger) -> %   antisymmetric? : % -> Boolean
--R coerce : R -> %               coerce : Integer -> %
--R coerce : % -> OutputForm       column : (%,Integer) -> Col
--R copy : % -> %                 diagonal : % -> Row
--R diagonal? : % -> Boolean       diagonalMatrix : List(R) -> %
--R diagonalProduct : % -> R       elt : (%,Integer,Integer) -> R
--R elt : (%,Integer,Integer,R) -> R   empty : () -> %
--R empty? : % -> Boolean          eq? : (%,%) -> Boolean
--R hash : % -> SingleInteger       latex : % -> String
--R listOfLists : % -> List(List(R))   map : ((R -> R),%) -> %
--R map : ((R,R) -> R,%,%) -> %       matrix : List(List(R)) -> %
--R maxColIndex : % -> Integer       maxRowIndex : % -> Integer
--R minColIndex : % -> Integer       minRowIndex : % -> Integer
--R ncols : % -> NonNegativeInteger   nrows : % -> NonNegativeInteger
--R one? : % -> Boolean              qelt : (%,Integer,Integer) -> R
--R recip : % -> Union(%, "failed")   retract : % -> R
--R row : (%,Integer) -> Row         sample : () -> %
--R scalarMatrix : R -> %           square? : % -> Boolean
--R symmetric? : % -> Boolean        trace : % -> R
--R zero? : % -> Boolean             ~=? : (%,%) -> Boolean
--R #? : % -> NonNegativeInteger if $ has finiteAggregate
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,Integer) -> % if R has FIELD

```

```

--R ***? : (% , NonNegativeInteger) -> %
--R ?/? : (% , R) -> % if R has FIELD
--R D : (% , NonNegativeInteger) -> % if R has DIFRING
--R D : (% , Symbol) -> % if R has PDRING(SYMBOL)
--R D : (% , List(Symbol)) -> % if R has PDRING(SYMBOL)
--R D : (% , Symbol, NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R D : (% , List(Symbol), List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R D : (% , (R -> R), NonNegativeInteger) -> %
--R ?? : (% , NonNegativeInteger) -> %
--R any? : ((R -> Boolean), %) -> Boolean if $ has finiteAggregate
--R characteristic : () -> NonNegativeInteger
--R coerce : Fraction(Integer) -> % if R has RETRACT(FRAC(INT))
--R count : (R, %) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
--R count : ((R -> Boolean), %) -> NonNegativeInteger if $ has finiteAggregate
--R determinant : % -> R if R has commutative(*)
--R differentiate : % -> % if R has DIFRING
--R differentiate : (% , NonNegativeInteger) -> % if R has DIFRING
--R differentiate : (% , Symbol) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , List(Symbol)) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , Symbol, NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , List(Symbol), List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , (R -> R), NonNegativeInteger) -> %
--R differentiate : (% , (R -> R)) -> %
--R eval : (% , List(R), List(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (% , R, R) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (% , Equation(R)) -> % if R has EVALAB(R) and R has SETCAT
--R eval : (% , List(Equation(R))) -> % if R has EVALAB(R) and R has SETCAT
--R every? : ((R -> Boolean), %) -> Boolean if $ has finiteAggregate
--R exquo : (% , R) -> Union(%, "failed") if R has INTDOM
--R inverse : % -> Union(%, "failed") if R has FIELD
--R less? : (% , NonNegativeInteger) -> Boolean
--R map! : ((R -> R), %) -> % if $ has shallowlyMutable
--R member? : (R, %) -> Boolean if R has SETCAT and $ has finiteAggregate
--R members : % -> List(R) if $ has finiteAggregate
--R minordet : % -> R if R has commutative(*)
--R more? : (% , NonNegativeInteger) -> Boolean
--R nullSpace : % -> List(Col) if R has INTDOM
--R nullity : % -> NonNegativeInteger if R has INTDOM
--R parts : % -> List(R) if $ has finiteAggregate
--R rank : % -> NonNegativeInteger if R has INTDOM
--R reducedSystem : Matrix(%) -> Matrix(R)
--R reducedSystem : (Matrix(%), Vector(%)) -> Record(mat: Matrix(R), vec: Vector(R))
--R reducedSystem : (Matrix(%), Vector(%)) -> Record(mat: Matrix(Integer), vec: Vector(Integer)) if R has LINEAR
--R reducedSystem : Matrix(%) -> Matrix(Integer) if R has LINEAR(INT)
--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retract : % -> Integer if R has RETRACT(INT)
--R retractIfCan : % -> Union(R, "failed")
--R retractIfCan : % -> Union(Fraction(Integer), "failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer, "failed") if R has RETRACT(INT)
--R rowEchelon : % -> % if R has EUCLID

```

```

--R size? : (% , NonNegativeInteger) -> Boolean
--R subtractIfCan : (% , %) -> Union(% , "failed")
--R
--E 1

)spool
)lisp (bye)

```

— SquareMatrixCategory.help —

=====

SquareMatrixCategory examples

=====

SquareMatrixCategory is a general square matrix category which allows different representations and indexing schemes. Rows and columns may be extracted with rows returned as objects of type Row and columns returned as objects of type Col.

See Also:

o)show SquareMatrixCategory

See:

- ⇐ “BiModule” (BMODULE) [9](#) on page [782](#)
- ⇐ “DifferentialExtension” (DIFEXT) [11](#) on page [1005](#)
- ⇐ “FullyLinearlyExplicitRingOver” (FLINEXP) [11](#) on page [1012](#)
- ⇐ “FullyRetractableTo” (FRETRCT) [3](#) on page [136](#)
- ⇐ “MatrixCategory” (MATCAT) [6](#) on page [466](#)
- ⇐ “RectangularMatrixCategory” (RMATCAT) [10](#) on page [954](#)

Exports:

| | | |
|-----------------|----------------|----------------|
| 0 | 1 | antisymmetric? |
| any? | characteristic | coerce |
| column | copy | count |
| D | determinant | differentiate |
| diagonal | diagonal? | diagonalMatrix |
| diagonalProduct | elt | empty |
| empty? | eq? | eval |
| every? | exquo | hash |
| inverse | latex | less? |
| listOfLists | map | map! |
| matrix | maxColIndex | maxRowIndex |
| member? | members | minColIndex |
| minordet | minRowIndex | more? |
| ncols | nrows | nullSpace |
| nullity | one? | parts |
| qelt | rank | recip |
| reducedSystem | retract | retractIfCan |
| row | rowEchelon | sample |
| scalarMatrix | size? | square? |
| subtractIfCan | symmetric? | trace |
| zero? | #? | ?^? |
| ?*? | ?**? | ?+? |
| ?-? | -? | ?=? |
| ?~=? | ?/? | |

Attributes Exported:

- **finiteAggregate** is true if it is an aggregate with a finite number of elements.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **nil**

TPDHERE: How did MATCAT get in the type tower?

```
determinant : % -> R if R has commutative *
inverse : % -> Union(%, "failed") if R has FIELD
```

These are directly exported but not implemented:

```
diagonalMatrix : List R -> %
minordet : % -> R if R has commutative *
scalarMatrix : R -> %
?*? : (Row, %) -> Row
?*? : (% , Col) -> Col
```

These are implemented by this category:

```

coerce : R -> %
diagonal : % -> Row
diagonalProduct : % -> R
differentiate : (%, (R -> R)) -> %
reducedSystem : Matrix % -> Matrix R
reducedSystem : (Matrix %, Vector %) -> Record(mat: Matrix R, vec: Vector R)
retract : % -> R
retractIfCan : % -> Union(R, "failed")
trace : % -> R
***? : (%, Integer) -> % if R has FIELD
***? : (%, NonNegativeInteger) -> %

```

These exports come from (p1005) DifferentialExtension(R:Ring):

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
D : % -> % if R has DIFRING
D : (%, NonNegativeInteger) -> % if R has DIFRING
D : (%, (R -> R)) -> %
D : (%, (R -> R), NonNegativeInteger) -> %
D : (%, Symbol) -> % if R has PDRING SYMBOL
D : (%, List Symbol) -> % if R has PDRING SYMBOL
D : (%, Symbol, NonNegativeInteger) -> % if R has PDRING SYMBOL
D : (%, List Symbol, List NonNegativeInteger) -> % if R has PDRING SYMBOL
differentiate : (%, List Symbol) -> % if R has PDRING SYMBOL
differentiate : (%, Symbol, NonNegativeInteger) -> % if R has PDRING SYMBOL
differentiate : (%, List Symbol, List NonNegativeInteger) -> % if R has PDRING SYMBOL
differentiate : (%, NonNegativeInteger) -> % if R has DIFRING
differentiate : % -> % if R has DIFRING
differentiate : (%, (R -> R), NonNegativeInteger) -> %
differentiate : (%, Symbol) -> % if R has PDRING SYMBOL
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (%, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (NonNegativeInteger, %) -> %

```

```

?-? : (%,% ) -> %
-? : % -> %
***? : (% ,PositiveInteger) -> %
?? : (% ,NonNegativeInteger) -> %
?^? : (% ,PositiveInteger) -> %

```

These exports come from (p782) BiModule(R:Ring,R:Ring):

```

?*? : (R,% ) -> %
?*? : (% ,R) -> %

```

These exports come from

(p954) RectangularMatrixCategory(ndim,ndim,R,Row,Col)
 where ndim:NonNegativeInteger,R:Ring,Row:DirectProductCategory(ndim,R)
 Col:DirectProductCategory(ndim,R):

```

antisymmetric? : % -> Boolean
any? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
column : (% ,Integer) -> Col
copy : % -> %
count : (R,% ) -> NonNegativeInteger if R has SETCAT and $ has finiteAggregate
count : ((R -> Boolean),%) -> NonNegativeInteger if $ has finiteAggregate
diagonal? : % -> Boolean
elt : (% ,Integer,Integer) -> R
elt : (% ,Integer,Integer,R) -> R
empty : () -> %
empty? : % -> Boolean
eq? : (% ,%) -> Boolean
eval : (% ,List R,List R) -> % if R has EVALAB R and R has SETCAT
eval : (% ,R,R) -> % if R has EVALAB R and R has SETCAT
eval : (% ,Equation R) -> % if R has EVALAB R and R has SETCAT
eval : (% ,List Equation R) -> % if R has EVALAB R and R has SETCAT
every? : ((R -> Boolean),%) -> Boolean if $ has finiteAggregate
exquo : (% ,R) -> Union(% ,"failed") if R has INTDOM
less? : (% ,NonNegativeInteger) -> Boolean
listOfLists : % -> List List R
map : ((R -> R),%) -> %
map : (((R,R) -> R),% ,%) -> %
map! : ((R -> R),%) -> % if $ has shallowlyMutable
matrix : List List R -> %
maxColIndex : % -> Integer
maxRowIndex : % -> Integer
minColIndex : % -> Integer
minRowIndex : % -> Integer
members : % -> List R if $ has finiteAggregate
member? : (R,% ) -> Boolean if R has SETCAT and $ has finiteAggregate
more? : (% ,NonNegativeInteger) -> Boolean
ncols : % -> NonNegativeInteger
nrows : % -> NonNegativeInteger

```



```

nullity : % -> NonNegativeInteger if R has INTDOM
nullSpace : % -> List Col if R has INTDOM
parts : % -> List R if $ has finiteAggregate
qelt : (%,Integer,Integer) -> R
rank : % -> NonNegativeInteger if R has INTDOM
row : (%,Integer) -> Row
rowEchelon : % -> % if R has EUCDOM
size? : (%NonNegativeInteger) -> Boolean
square? : % -> Boolean
symmetric? : % -> Boolean
#? : % -> NonNegativeInteger if $ has finiteAggregate
?/? : (%R) -> % if R has FIELD

```

These exports come from (p136) FullyRetractableTo(R:Ring):

```

coerce : Fraction Integer -> % if R has RETRACT FRAC INT
retract : % -> Fraction Integer if R has RETRACT FRAC INT
retract : % -> Integer if R has RETRACT INT
retractIfCan : % -> Union(Fraction Integer,"failed") if R has RETRACT FRAC INT
retractIfCan : % -> Union(Integer,"failed") if R has RETRACT INT

```

These exports come from (p1012) FullyLinearlyExplicitRingOver(R:Ring):

```

reducedSystem : (Matrix %,Vector %) -> Record(mat: Matrix Integer,vec: Vector Integer) if R has
reducedSystem : Matrix % -> Matrix Integer if R has LINEXP INT

```

— category SMATCAT SquareMatrixCategory —

```

)abbrev category SMATCAT SquareMatrixCategory
++ Authors: Grabmeier, Gschnitzer, Williamson
++ Date Created: 1987
++ Date Last Updated: July 1990
++ Description:
++ \spadtype{SquareMatrixCategory} is a general square matrix category which
++ allows different representations and indexing schemes. Rows and
++ columns may be extracted with rows returned as objects of
++ type Row and columns returned as objects of type Col.

```

```

SquareMatrixCategory(ndim,R,Row,Col): Category == Definition where
  ndim : NonNegativeInteger
  R : Ring
  Row : DirectProductCategory(ndim,R)
  Col : DirectProductCategory(ndim,R)
  I ==> Integer

```

```

Definition ==> Join(DifferentialExtension R, BiModule(R, R),_
  RectangularMatrixCategory(ndim,ndim,R,Row,Col),_
  FullyRetractableTo R,_

```

```

        FullyLinearlyExplicitRingOver R) with
if R has CommutativeRing then Module(R)
scalarMatrix: R -> %
    ++ \spad{scalarMatrix(r)} returns an n-by-n matrix with r's on the
    ++ diagonal and zeroes elsewhere.
diagonalMatrix: List R -> %
    ++ \spad{diagonalMatrix(l)} returns a diagonal matrix with the elements
    ++ of l on the diagonal.
diagonal: % -> Row
    ++ \spad{diagonal(m)} returns a row consisting of the elements on the
    ++ diagonal of the matrix m.
trace: % -> R
    ++ \spad{trace(m)} returns the trace of the matrix m. this is the sum
    ++ of the elements on the diagonal of the matrix m.
diagonalProduct: % -> R
    ++ \spad{diagonalProduct(m)} returns the product of the elements on the
    ++ diagonal of the matrix m.
"*": (% ,Col) -> Col
    ++ \spad{x * c} is the product of the matrix x and the column vector c.
    ++ Error: if the dimensions are incompatible.
"*": (Row,% ) -> Row
    ++ \spad{r * x} is the product of the row vector r and the matrix x.
    ++ Error: if the dimensions are incompatible.

--% Linear algebra

if R has commutative("*") then
    Algebra R
    determinant: % -> R
        ++ \spad{determinant(m)} returns the determinant of the matrix m.
    minordet: % -> R
        ++ \spad{minordet(m)} computes the determinant of the matrix m
        ++ using minors.
if R has Field then
    inverse: % -> Union(%, "failed")
        ++ \spad{inverse(m)} returns the inverse of the matrix m, if that
        ++ matrix is invertible and returns "failed" otherwise.
    "**": (% ,Integer) -> %
        ++ \spad{m**n} computes an integral power of the matrix m.
        ++ Error: if the matrix is not invertible.

add
minr ==> minRowIndex
maxr ==> maxRowIndex
minc ==> minColIndex
maxc ==> maxColIndex
mini ==> minIndex
maxi ==> maxIndex

positivePower:(% ,Integer) -> %

```

```

positivePower(x,n) ==
--   one? n => x
   (n = 1) => x
   odd? n => x * positivePower(x,n - 1)
   y := positivePower(x,n quo 2)
   y * y

x:% ** n:NonNegativeInteger ==
   zero? n => scalarMatrix 1
   positivePower(x,n)

coerce(r:R) == scalarMatrix r

equation2R: Vector % -> Matrix R

differentiate(x:%,d:R -> R) == map(d,x)

diagonal x ==
   v:Vector(R) := new(ndim,0)
   for i in minr x .. maxr x
     for j in minc x .. maxc x
       for k in minIndex v .. maxIndex v repeat
         qsetelt_!(v, k, qelt(x, i, j))
   directProduct v

retract(x:%):R ==
   diagonal? x => retract diagonal x
   error "Not retractable"

retractIfCan(x:%):Union(R, "failed") ==
   diagonal? x => retractIfCan diagonal x
   "failed"

equation2R v ==
   ans:Matrix(Col) := new(ndim,#v,0)
   for i in minr ans .. maxr ans repeat
     for j in minc ans .. maxc ans repeat
       qsetelt_!(ans, i, j, column(qelt(v, j), i))
   reducedSystem ans

reducedSystem(x:Matrix %):Matrix(R) ==
   empty? x => new(0,0,0)
   reduce(vertConcat, [equation2R row(x, i)
                        for i in minr x .. maxr x])$List(Matrix R)

reducedSystem(m:Matrix %, v:Vector %):
Record(mat:Matrix R, vec:Vector R) ==
   vh:Vector(R) :=
     empty? v => new(0,0)
   rh := reducedSystem(v::Matrix %) @ Matrix(R)

```

```

        column(rh, minColIndex rh)
    [reducedSystem(m)@Matrix(R), vh]

trace x ==
  tr : R := 0
  for i in minr(x)..maxr(x) for j in minc(x)..maxc(x) repeat
    tr := tr + x(i,j)
  tr

diagonalProduct x ==
  pr : R := 1
  for i in minr(x)..maxr(x) for j in minc(x)..maxc(x) repeat
    pr := pr * x(i,j)
  pr

if R has Field then

  x:% ** n:Integer ==
    zero? n => scalarMatrix 1
    positive? n => positivePower(x,n)
    (xInv := inverse x) case "failed" =>
      error "**: matrix must be invertible"
    positivePower(xInv :: %, -n)



---



— SMATCAT.dotabb —

"SMATCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SMATCAT"];
"SMATCAT" -> "BMODULE"
"SMATCAT" -> "DIFEXT"
"SMATCAT" -> "FLINEXP"
"SMATCAT" -> "FRETRCT"
"SMATCAT" -> "RMATCAT"



---



— SMATCAT.dotfull —

"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCategory(a,b),
  [color=lightblue,href="bookvol10.2.pdf#nameddest=SMATCAT"]);
"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCategory(a,b),
-> "BiModule(a:Ring,b:Ring)"
"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCategory(a,b),
-> "DifferentialExtension(a:Ring)"

```

```

"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCa
-> "FullyLinearlyExplicitRingOver(a:Ring)"
"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCa
-> "FullyRetractableTo(a:Ring)"
"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCa
-> "RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductC

```

— SMATCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCa
  [color=lightblue];
"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCa
-> "BiModule(a:Ring,b:Ring)"
"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCa
-> "DifferentialExtension(a:Ring)"
"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCa
-> "FLINEP..."
"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCa
-> "FRETRCT..."
"SquareMatrixCategory(a:NonNegativeInteger,b:Ring,c:DirectProductCategory(a,b),d:DirectProductCa
-> "RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductC

"DifferentialExtension(a:Ring)" [color=lightblue];
"DifferentialExtension(a:Ring)" -> "Ring()"
"DifferentialExtension(a:Ring)" -> "DifferentialRing()"
"DifferentialExtension(a:Ring)" -> "PartialDifferentialRing(Symbol)"

"PartialDifferentialRing(Symbol)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=PDRING"];
"PartialDifferentialRing(Symbol)" ->
  "PartialDifferentialRing(a:SetCategory)"

"PartialDifferentialRing(a:SetCategory)" [color=lightblue];
"PartialDifferentialRing(a:SetCategory)" -> "Ring()"

"DifferentialRing()" [color=lightblue];
"DifferentialRing()" -> "Ring()"

"Ring()" [color=lightblue];
"Ring()" -> "Rng()"
"Ring()" -> "Monoid()"

```

```

"Ring()" -> "LeftModule(a:Ring)"

"Rng()" [color=lightblue];
"Rng()" -> "ABELGRP..."
"Rng()" -> "SGROUP..."

"Monoid()" [color=lightblue];
"Monoid()" -> "SGROUP..."

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LMODULE..."

"RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductCategory(b,c),e:1)"
  [color=lightblue];
"RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductCategory(b,c),e:1)"
  -> "BiModule(a:Ring,b:Ring)"
"RectangularMatrixCategory(a:NonNegativeInteger,b:NonNegativeInteger,c:Ring,d:DirectProductCategory(b,c),e:1)"
  -> "HOAGG..."

"BiModule(a:Ring,b:Ring)" [color=lightblue];
"BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
"BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

"RightModule(a:Ring)" [color=seagreen];
"RightModule(a:Ring)" -> "RightModule(a:Rng)"

"RightModule(a:Rng)" [color=lightblue];
"RightModule(a:Rng)" -> "ABELGRP..."

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

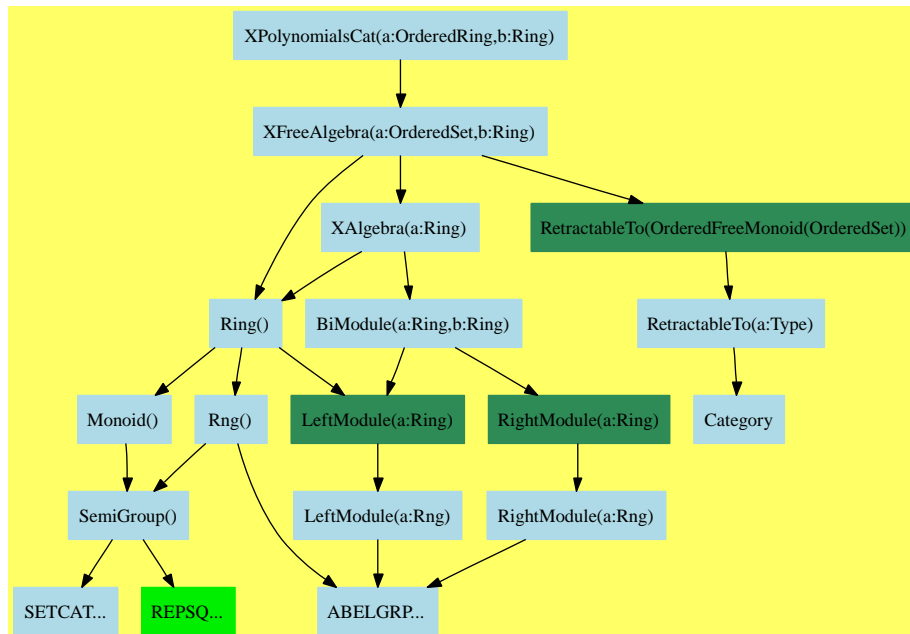
"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "ABELGRP..."

"FRETRCT..." [color=lightblue];
"FLINEXP..." [color=lightblue];
"SGROUP..." [color=lightblue];
"LMODULE..." [color=lightblue];
"HOAGG..." [color=lightblue];
"ABELGRP..." [color=lightblue];

}

```

XPolynomialsCat (XPOLYC)



— XPolynomialsCat.input —

```

)set break resume
)sys rm -f XPolynomialsCat.output
)spool XPolynomialsCat.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show XPolynomialsCat
--R
--R XPolynomialsCat(v1: OrderedSet,R: Ring) is a category constructor
--R Abbreviation for XPolynomialsCat is XPOLYC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for XPOLYC
--R
--R----- Operations -----
--R ?? : (v1,%) -> %           ?? : (%,R) -> %
--R ?? : (R,%) -> %           ?? : (%,%) -> %
--R ?? : (Integer,%) -> %     ?? : (PositiveInteger,%) -> %
--R ??? : (%,PositiveInteger) -> %  ?+? : (%,%) -> %
--R ?-? : (%,%) -> %          -? : % -> %

```

```

--R ?=? : (%,% ) -> Boolean
--R 0 : () -> %
--R coef : (%,% ) -> R
--R coerce : R -> %
--R coerce : % -> OutputForm
--R constant? : % -> Boolean
--R hash : % -> SingleInteger
--R lquo : (%,% ) -> %
--R map : ((R -> R),%) -> %
--R monomial? : % -> Boolean
--R quasiRegular : % -> %
--R recip : % -> Union(%, "failed")
--R rquo : (% , vl) -> %
--R varList : % -> List(vl)
--R ?~=? : (%,% ) -> Boolean
--R ?*? : (NonNegativeInteger,% ) -> %
--R ??? : (% , NonNegativeInteger) -> %
--R ?^? : (% , NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R coef : (% , OrderedFreeMonoid(vl)) -> R
--R coerce : OrderedFreeMonoid(vl) -> %
--R lquo : (% , OrderedFreeMonoid(vl)) -> %
--R maxdeg : % -> OrderedFreeMonoid(vl)
--R mindeg : % -> OrderedFreeMonoid(vl)
--R mindegTerm : % -> Record(k: OrderedFreeMonoid(vl), c: R)
--R monom : (OrderedFreeMonoid(vl), R) -> %
--R retract : % -> OrderedFreeMonoid(vl)
--R retractIfCan : % -> Union(OrderedFreeMonoid(vl), "failed")
--R rquo : (% , OrderedFreeMonoid(vl)) -> %
--R sh : (% , NonNegativeInteger) -> % if R has COMRING
--R sh : (% , %) -> % if R has COMRING
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R trunc : (% , NonNegativeInteger) -> %
--R
--E 1

)spool
)lisp (bye)

```

— XPolynomialsCat.help —

=====

XPolynomialsCat examples

=====

The Category of polynomial rings with non-commutative variables.
The coefficient ring may be non-commutative too.

However coefficients commute with variables.

See Also:

o)show XPolynomialsCat

See:

← “XFreeAlgebra” (XFALG) [11](#) on page [1042](#)

Exports:

| | | | | |
|---------------|-----------|----------------|--------------|--------------|
| 0 | 1 | characteristic | coef | coerce |
| constant | constant? | degree | hash | latex |
| lquo | map | maxdeg | mindeg | mindegTerm |
| mirror | monom | monomial? | one? | quasiRegular |
| quasiRegular? | recip | retract | retractIfCan | rquo |
| sample | sh | subtractIfCan | trunc | varList |
| zero? | ?*? | ?**? | ?+? | ?-? |
| -? | ?=? | ?^? | ?~=? | |

Attributes Exported:

- if Ring has noZeroDivisors then noZeroDivisors where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```
degree : % -> NonNegativeInteger
maxdeg : % -> OrderedFreeMonoid v1
trunc : (% , NonNegativeInteger) -> %
```

These exports come from (p115) Aggregate():

These exports come from (p1042) XFreeAlgebra(vl:OrderedSet,R:Ring):

```
0 : () -> %
1 : () -> %
```

```

characteristic : () -> NonNegativeInteger
coef : (%,OrderedFreeMonoid vl) -> R
coef : (%,%) -> R
coerce : % -> OutputForm
coerce : R -> %
coerce : OrderedFreeMonoid vl -> %
coerce : Integer -> %
coerce : vl -> %
constant : % -> R
constant? : % -> Boolean
hash : % -> SingleInteger
latex : % -> String
lquo : (%,OrderedFreeMonoid vl) -> %
lquo : (%,%) -> %
lquo : (%,vl) -> %
map : ((R -> R),%) -> %
mindeg : % -> OrderedFreeMonoid vl
mindegTerm : % -> Record(k: OrderedFreeMonoid vl,c: R)
mirror : % -> %
monom : (OrderedFreeMonoid vl,R) -> %
monomial? : % -> Boolean
one? : % -> Boolean
quasiRegular : % -> %
quasiRegular? : % -> Boolean
recip : % -> Union(%, "failed")
retract : % -> OrderedFreeMonoid vl
retractIfCan : % -> Union(OrderedFreeMonoid vl, "failed")
rquo : (%,OrderedFreeMonoid vl) -> %
rquo : (%,%) -> %
rquo : (%,vl) -> %
sample : () -> %
sh : (%,NonNegativeInteger) -> % if R has COMRING
sh : (%,%) -> % if R has COMRING
subtractIfCan : (%,%) -> Union(%, "failed")
varList : % -> List vl
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (Integer,%) -> %
?*? : (%,%) -> %
?*? : (R,%) -> %
?*? : (%,R) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%,PositiveInteger) -> %
***? : (%,NonNegativeInteger) -> %
??~ : (%,NonNegativeInteger) -> %

```

```

?? : (% , PositiveInteger) -> %
*? : (v1, %) -> %

```

These exports come from (p162) SetCategory():

— category XPOLYC XPolynomialsCat —

```

)abbrev category XPOLYC XPolynomialsCat
++ Author: Michel Petitot petitot@lifl.fr
++ Date Created: 91
++ Date Last Updated: 7 Juillet 92
++ Fix History: compilation v 2.1 le 13 dec 98
++ Description:
++ The Category of polynomial rings with non-commutative variables.
++ The coefficient ring may be non-commutative too.
++ However coefficients commute with variables.

XPolynomialsCat(v1:OrderedSet,R:Ring):Category == Export where
  WORD ==> OrderedFreeMonoid(v1)

Export == XFreeAlgebra(v1,R) with
  maxdeg: % -> WORD
    ++ \spad{maxdeg(p)} returns the greatest leading word in the
    ++ support of \spad{p}.
  degree: % -> NonNegativeInteger
    ++ \spad{degree(p)} returns the degree of \spad{p}.
    ++ Note that the degree of a word is its length.
  trunc : (% , NonNegativeInteger) -> %
    ++ \spad{trunc(p,n)} returns the polynomial \spad{p} truncated
    ++ at order \spad{n}.

```

— XPOLYC.dotabb —

```

"XPOLYC"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=XPOLYC" ];
"XPOLYC" -> "XFALG"

```

— XPOLYC.dotfull —

```

"XPolynomialsCat(a:OrderedRing,b:Ring)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=XPOLYC"];
"XPolynomialsCat(a:OrderedRing,b:Ring)" ->
  "XFreeAlgebra(a:OrderedSet,b:Ring)"

```

— XPOLYC.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "XPolynomialsCat(a:OrderedRing,b:Ring)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=XPOLYC"];
  "XPolynomialsCat(a:OrderedRing,b:Ring)" ->
    "XFreeAlgebra(a:OrderedSet,b:Ring)"

  "XFreeAlgebra(a:OrderedSet,b:Ring)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=XFALG"];
  "XFreeAlgebra(a:OrderedSet,b:Ring)" -> "Ring()"
  "XFreeAlgebra(a:OrderedSet,b:Ring)" -> "XAlgebra(a:Ring)"
  "XFreeAlgebra(a:OrderedSet,b:Ring)" ->
    "RetractableTo(OrderedFreeMonoid(OrderedSet))"

  "RetractableTo(OrderedFreeMonoid(OrderedSet))"
    [color=seagreen,href="bookvol10.2.pdf#nameddest=RETRACT"];
  "RetractableTo(OrderedFreeMonoid(OrderedSet))" -> "RetractableTo(a:Type)"

  "XAlgebra(a:Ring)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=XALG"];
  "XAlgebra(a:Ring)" -> "Ring()"
  "XAlgebra(a:Ring)" -> "BiModule(a:Ring,b:Ring)"

  "Ring()" [color=lightblue];
  "Ring()" -> "Rng()"
  "Ring()" -> "Monoid()"
  "Ring()" -> "LeftModule(a:Ring)"

  "BiModule(a:Ring,b:Ring)" [color=lightblue];
  "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
  "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

  "RightModule(a:Ring)" [color=seagreen];
  "RightModule(a:Ring)" -> "RightModule(a:Rng)"

  "RightModule(a:Rng)" [color=lightblue];

```

```

"RightModule(a:Rng)" -> "ABELGRP..."

"Rng()" [color=lightblue];
"Rng()" -> "ABELGRP..."
"Rng()" -> "SemiGroup()"

"Monoid()" [color=lightblue];
"Monoid()" -> "SemiGroup()"

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "ABELGRP..."

"SemiGroup()" [color=lightblue];
"SemiGroup()" -> "SETCAT..."
"SemiGroup()" -> "REPSQ..."

"RetractableTo(a:Type)" [color=lightblue];
"RetractableTo(a:Type)" -> "Category"

"Category" [color=lightblue];

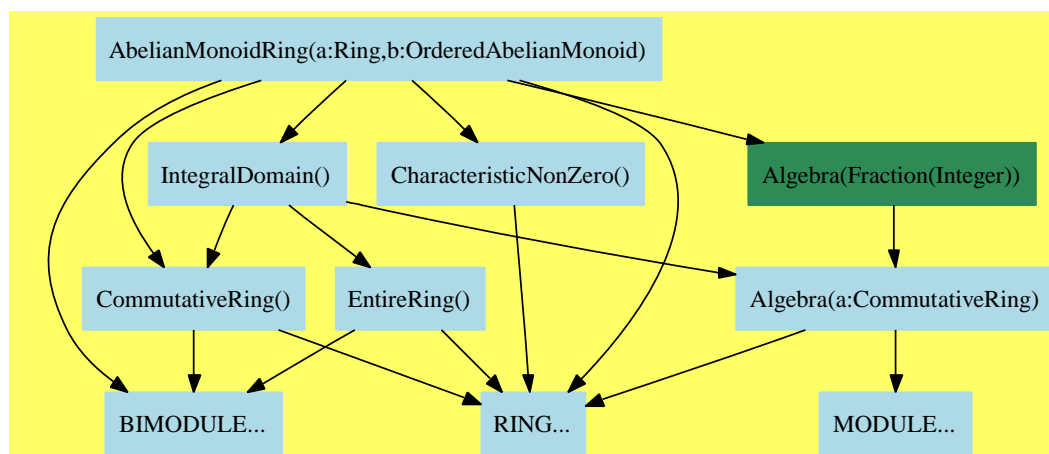
"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"ABELGRP..." [color=lightblue];
}

```

Chapter 13

Category Layer 12

AbelianMonoidRing (AMR)



— AbelianMonoidRing.input —

```
)set break resume
)sys rm -f AbelianMonoidRing.output
)spool AbelianMonoidRing.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show AbelianMonoidRing
--R
```

```

--R AbelianMonoidRing(R: Ring,E: OrderedAbelianMonoid) is a category constructor
--R Abbreviation for AbelianMonoidRing is AMR
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for AMR
--R
--R----- Operations -----
--R ?? : (R,%) -> %           ?? : (%,R) -> %
--R ?? : (%,%) -> %           ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R +? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %               ?? : (%,%) -> Boolean
--R 1 : () -> %               0 : () -> %
--R ?? : (%,PositiveInteger) -> %   coefficient : (%,E) -> R
--R coerce : Integer -> %           coerce : % -> OutputForm
--R degree : % -> E               hash : % -> SingleInteger
--R latex : % -> String           leadingCoefficient : % -> R
--R leadingMonomial : % -> %       map : ((R -> R),%) -> %
--R monomial : (R,E) -> %         monomial? : % -> Boolean
--R one? : % -> Boolean           recip : % -> Union(%, "failed")
--R reductum : % -> %            sample : () -> %
--R zero? : % -> Boolean          ~=? : (%,%) -> Boolean
--R ?? : (%,Fraction(Integer)) -> % if R has ALGEBRA(FRAC(INT))
--R ?? : (Fraction(Integer),%) -> % if R has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?? : (%,R) -> % if R has FIELD
--R ?? : (%,NonNegativeInteger) -> %
--R associates? : (%,%) -> Boolean if R has INTDOM
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if R has CHARNZ
--R coerce : R -> % if R has COMRING
--R coerce : % -> % if R has INTDOM
--R coerce : Fraction(Integer) -> % if R has ALGEBRA(FRAC(INT))
--R exquo : (%,%) -> Union(%, "failed") if R has INTDOM
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unit? : % -> Boolean if R has INTDOM
--R unitCanonical : % -> % if R has INTDOM
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if R has INTDOM
--R
--E 1

)spool
)lisp (bye)

```

— AbelianMonoidRing.help —

=====

AbelianMonoidRing examples

=====

Abelian monoid ring elements (not necessarily of finite support) of this ring are of the form formal SUM ($r_i * e_i$) where the r_i are coefficients and the e_i , elements of the ordered abelian monoid, are thought of as exponents or monomials. The monomials commute with each other, and with the coefficients (which themselves may or may not be commutative).

See `FiniteAbelianMonoidRing` for the case of finite support a useful common model for polynomials and power series. Conceptually at least, only the non-zero terms are ever operated on.

See Also:

`o)show AbelianMonoidRing`

See:

⇒ “FiniteAbelianMonoidRing” (FAMR) [14](#) on page [1191](#)

⇒ “PowerSeriesCategory” (PSCAT) [14](#) on page [1208](#)

⇐ “BiModule” (BMODULE) [9](#) on page [782](#)

⇐ “Ring” (RING) [9](#) on page [826](#)

Exports:

| | | | |
|-----------------|-------------|---------------|--------------------|
| 0 | 1 | associates? | characteristic |
| charthRoot | coefficient | coerce | degree |
| exquo | hash | latex | leadingCoefficient |
| leadingMonomial | map | monomial | monomial? |
| one? | recip | reductum | sample |
| subtractIfCan | unit? | unitCanonical | unitNormal |
| zero? | ?*? | ?**? | ?+? |
| ?-? | -? | ?=? | ?^? |
| ?~=? | ?/? | | |

Attributes exported:

- if \$ has `CommutativeRing` then `commutative(“”)` where **commutative(“”)** is true if it has an operation “ $*$ ” : $(D, D) \rightarrow D$ which is commutative.
- if \$ has `IntegralDomain` then `noZeroDivisors` where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.

- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
coefficient : (% , E) -> R
degree : % -> E
leadingCoefficient : % -> R
leadingMonomial : % -> %
monomial : (R, E) -> %
reductum : % -> %
?/? : (% , R) -> % if R has FIELD
```

These are implemented by this category:

```
map : ((R -> R), %) -> %
monomial? : % -> Boolean
?*? : (Fraction Integer, %) -> % if R has ALGEBRA FRAC INT
```

These exports come from (p826) `Ring()`:

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : % -> OutputForm
coerce : Integer -> %
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (% , %) -> Union(%, "failed")
zero? : % -> Boolean
***? : (% , NonNegativeInteger) -> %
?^? : (% , NonNegativeInteger) -> %
?+? : (% , %) -> %
?=? : (% , %) -> Boolean
?~=? : (% , %) -> Boolean
?*? : (NonNegativeInteger, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (Integer, %) -> %
?*? : (% , %) -> %
?-? : (% , %) -> %
-? : % -> %
***? : (% , PositiveInteger) -> %
?^? : (% , PositiveInteger) -> %
```

These exports come from (p782) `BiModule(R:Ring, R:Ring)`:

```

?? : (R,%) -> %
?? : (% ,R) -> %

```

These exports come from (p1097) IntegralDomain():

```

associates? : (% ,%) -> Boolean if R has INTDOM
coerce : % -> % if R has INTDOM
exquo : (% ,%) -> Union(% , "failed") if R has INTDOM
unit? : % -> Boolean if R has INTDOM
unitCanonical : % -> % if R has INTDOM
unitNormal : % -> Record(unit: % , canonical: % , associate: % ) if R has INTDOM

```

These exports come from (p887) CharacteristicNonZero():

```

charthRoot : % -> Union(% , "failed") if R has CHARNZ

```

These exports come from (p896) CommutativeRing():

```

coerce : R -> % if R has COMRING

```

These exports come from (p999) Algebra(Fraction(Integer)):

```

coerce : Fraction Integer -> % if R has ALGEBRA FRAC INT
?? : (% , Fraction Integer) -> % if R has ALGEBRA FRAC INT

```

— category AMR AbelianMonoidRing —

```

)abbrev category AMR AbelianMonoidRing
++ Description:
++ Abelian monoid ring elements (not necessarily of finite support)
++ of this ring are of the form formal SUM (r_i * e_i)
++ where the r_i are coefficients and the e_i, elements of the
++ ordered abelian monoid, are thought of as exponents or monomials.
++ The monomials commute with each other, and with
++ the coefficients (which themselves may or may not be commutative).
++ See \spadtype{FiniteAbelianMonoidRing} for the case of finite support
++ a useful common model for polynomials and power series.
++ Conceptually at least, only the non-zero terms are ever operated on.

AbelianMonoidRing(R:Ring, E:OrderedAbelianMonoid): Category ==
  Join(Ring, BiModule(R, R)) with
  leadingCoefficient: % -> R
    ++ leadingCoefficient(p) returns the coefficient highest
    ++ degree term of p.
  leadingMonomial: % -> %
    ++ leadingMonomial(p) returns the monomial of p with the highest degree.
  degree: % -> E
    ++ degree(p) returns the maximum of the exponents of the terms of p.

```

```

map: (R -> R, %) -> %
  ++ map(fn,u) maps function fn onto the coefficients
  ++ of the non-zero monomials of u.
monomial?: % -> Boolean
  ++ monomial?(p) tests if p is a single monomial.
monomial: (R,E) -> %
  ++ monomial(r,e) makes a term from a coefficient r and an exponent e.
reductum: % -> %
  ++ reductum(u) returns u minus its leading monomial
  ++ returns zero if handed the zero element.
coefficient: (% ,E) -> R
  ++ coefficient(p,e) extracts the coefficient of the monomial with
  ++ exponent e from polynomial p, or returns zero if exponent
  ++ is not present.
if R has Field then "/": (% ,R) -> %
  ++ p/c divides p by the coefficient c.
if R has CommutativeRing then
  CommutativeRing
  Algebra R
if R has CharacteristicZero then CharacteristicZero
if R has CharacteristicNonZero then CharacteristicNonZero
if R has IntegralDomain then IntegralDomain
if R has Algebra Fraction Integer then Algebra Fraction Integer
add
monomial? x == zero? reductum x

map(fn:R -> R, x: %) ==
  -- this default definition assumes that reductum is cheap
  zero? x => 0
  r:=fn leadingCoefficient x
  zero? r => map(fn,reductum x)
  monomial(r, degree x) + map(fn,reductum x)

if R has Algebra Fraction Integer then
  q:Fraction(Integer) * p:% == map(x1 +-> q * x1, p)

```

— AMR.dotabb —

```

"AMR"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=AMR" ];
"AMR" -> "RING"
"AMR" -> "BMODULE"
"AMR" -> "INTDOM"
"AMR" -> "CHARNZ"
"AMR" -> "COMRING"
"AMR" -> "ALGEBRA"

```

— AMR.dotfull —

```
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=AMR"];
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" -> "Ring()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "BiModule(a:Ring,b:OrderedAbelianMonoid)"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "IntegralDomain()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "CharacteristicNonZero()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "CommutativeRing()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "Algebra(Fraction(Integer))"
```

— AMR.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" [color=lightblue];
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" -> "RING..."
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "BIMODULE..."
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "IntegralDomain()"
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "CharacteristicNonZero()"
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "CommutativeRing()"
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "Algebra(Fraction(Integer))"

  "IntegralDomain()" [color=lightblue];
  "IntegralDomain()" -> "CommutativeRing()"
  "IntegralDomain()" -> "Algebra(a:CommutativeRing)"
  "IntegralDomain()" -> "EntireRing()"
```

```

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BIMODULE..."

"CharacteristicNonZero()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CHARNZ"];
"CharacteristicNonZero()" -> "RING..."

"Algebra(Fraction(Integer))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(Fraction(Integer))" -> "Algebra(a:CommutativeRing)"

"Algebra(a:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "MODULE..."

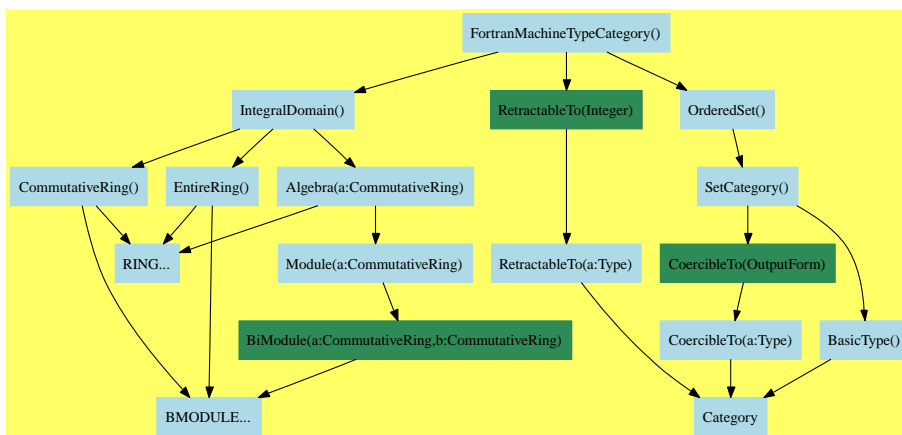
"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BIMODULE..."

"BIMODULE..." [color=lightblue];
"RING..." [color=lightblue];
"MODULE..." [color=lightblue];
}

```

→

FortranMachineTypeCategory (FMTC)



— FortranMachineTypeCategory.input —

```

)set break resume
)sys rm -f FortranMachineTypeCategory.output
)spool FortranMachineTypeCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FortranMachineTypeCategory
--R FortranMachineTypeCategory is a category constructor
--R Abbreviation for FortranMachineTypeCategory is FMTC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FMTC
--R
--R----- Operations -----
--R ??? : (%,%) -> %                ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %  ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %                ?-? : (%,%) -> %
--R -? : % -> %                      ?<? : (%,%) -> Boolean
--R ?<=? : (%,%) -> Boolean          ?=? : (%,%) -> Boolean
--R ?>? : (%,%) -> Boolean          ?>=? : (%,%) -> Boolean
--R 1 : () -> %                     0 : () -> %
--R ??? : (%,PositiveInteger) -> %  associates? : (%,%) -> Boolean
--R coerce : Integer -> %           coerce : % -> %
--R coerce : Integer -> %           coerce : % -> OutputForm
--R hash : % -> SingleInteger       latex : % -> String
--R max : (%,%) -> %                min : (%,%) -> %
--R one? : % -> Boolean              recip : % -> Union(%, "failed")
--R retract : % -> Integer           sample : () -> %
--R unit? : % -> Boolean              unitCanonical : % -> %
--R zero? : % -> Boolean              ?~=? : (%,%) -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R exquo : (%,%) -> Union(%, "failed")
--R retractIfCan : % -> Union(Integer, "failed")
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— FortranMachineTypeCategory.help —

```
=====
FortranMachineTypeCategory examples
=====
```

A category of domains which model machine arithmetic used by machines in the AXIOM-NAG link.

See Also:

o)show FortranMachineTypeCategory

See:

⇐ “IntegralDomain” (INTDOM) [12](#) on page [1097](#)

⇐ “OrderedSet” (ORDSET) [4](#) on page [269](#)

⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

Exports:

| | | | | |
|---------------|-------|---------------|----------------|--------|
| 0 | 1 | associates? | characteristic | coerce |
| exquo | hash | latex | max | min |
| one? | recip | retract | retractIfCan | sample |
| subtractIfCan | unit? | unitCanonical | unitNormal | zero? |
| ?~=? | ?^? | ?*? | ?**? | ?+? |
| ?-? | ?-? | ?<? | ?<=? | ?=? |
| ?>? | ?>=? | | | |

Attributes Exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative(“*”)** is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These exports come from (p[1097](#)) IntegralDomain():

```
0 : () -> %
1 : () -> %
```

```

associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
coerce : % -> %
exquo : (%,%) -> Union(%, "failed")
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
?*** : (%, NonNegativeInteger) -> %
?*** : (%, PositiveInteger) -> %

```

These exports come from (p269) `OrderedSet()`:

```

max : (%,%) -> %
min : (%,%) -> %
?<? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?<=? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean

```

These exports come from (p95) `RetractableTo(Integer)`:

```

coerce : Integer -> %
retract : % -> Integer
retractIfCan : % -> Union(Integer, "failed")

```

— category FMTC FortranMachineTypeCategory —

)abbrev category FMTC FortranMachineTypeCategory


```

++ Author: Mike Dewar
++ Date Created: December 1993
++ Description:
++ A category of domains which model machine arithmetic
++ used by machines in the AXIOM-NAG link.

```

```

FortranMachineTypeCategory():Category == Join(IntegralDomain,OrderedSet,
                                               RetractableTo(Integer) )

```

— FMTC.dotabb —

```

"FMTC"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FMTC"];
"FMTC" -> "INTDOM"
"FMTC" -> "ORDSET"
"FMTC" -> "RETRACT"

```

— FMTC.dotfull —

```

"FortranMachineTypeCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FMTC"];
"FortranMachineTypeCategory()" -> "IntegralDomain()"
"FortranMachineTypeCategory()" -> "OrderedSet()"
"FortranMachineTypeCategory()" -> "RetractableTo(Integer)"

```

— FMTC.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FortranMachineTypeCategory()"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=FMTC"];
  "FortranMachineTypeCategory()" -> "IntegralDomain()"
  "FortranMachineTypeCategory()" -> "OrderedSet()"
  "FortranMachineTypeCategory()" -> "RetractableTo(Integer)"

  "RetractableTo(Integer)"

```

```

[color=seagreen,href="bookvol10.2.pdf#nameddest=RETRACT"];
"RetractableTo(Integer)" -> "RetractableTo(a:Type)"

"RetractableTo(a:Type)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=RETRACT"];
"RetractableTo(a:Type)" -> "Category"

"OrderedSet()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ORDSET"];
"OrderedSet()" -> "SetCategory()"

"IntegralDomain()" [color=lightblue];
"IntegralDomain()" -> "CommutativeRing()"
"IntegralDomain()" -> "Algebra(a:CommutativeRing)"
"IntegralDomain()" -> "EntireRing()"

"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BMODULE..."

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BMODULE..."

"Algebra(a:CommutativeRing)" [color=lightblue];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" ->
  "BiModule(a:CommutativeRing,b:CommutativeRing)"

"BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BMODULE..."

"BMODULE..." [color=lightblue];
"RING..." [color=lightblue];

"SetCategory()" [color=lightblue];
"SetCategory()" -> "BasicType()"
"SetCategory()" -> "CoercibleTo(OutputForm)"

"BasicType()" [color=lightblue];
"BasicType()" -> "Category"

"CoercibleTo(OutputForm)" [color=seagreen];
"CoercibleTo(OutputForm)" -> "CoercibleTo(a:Type)"

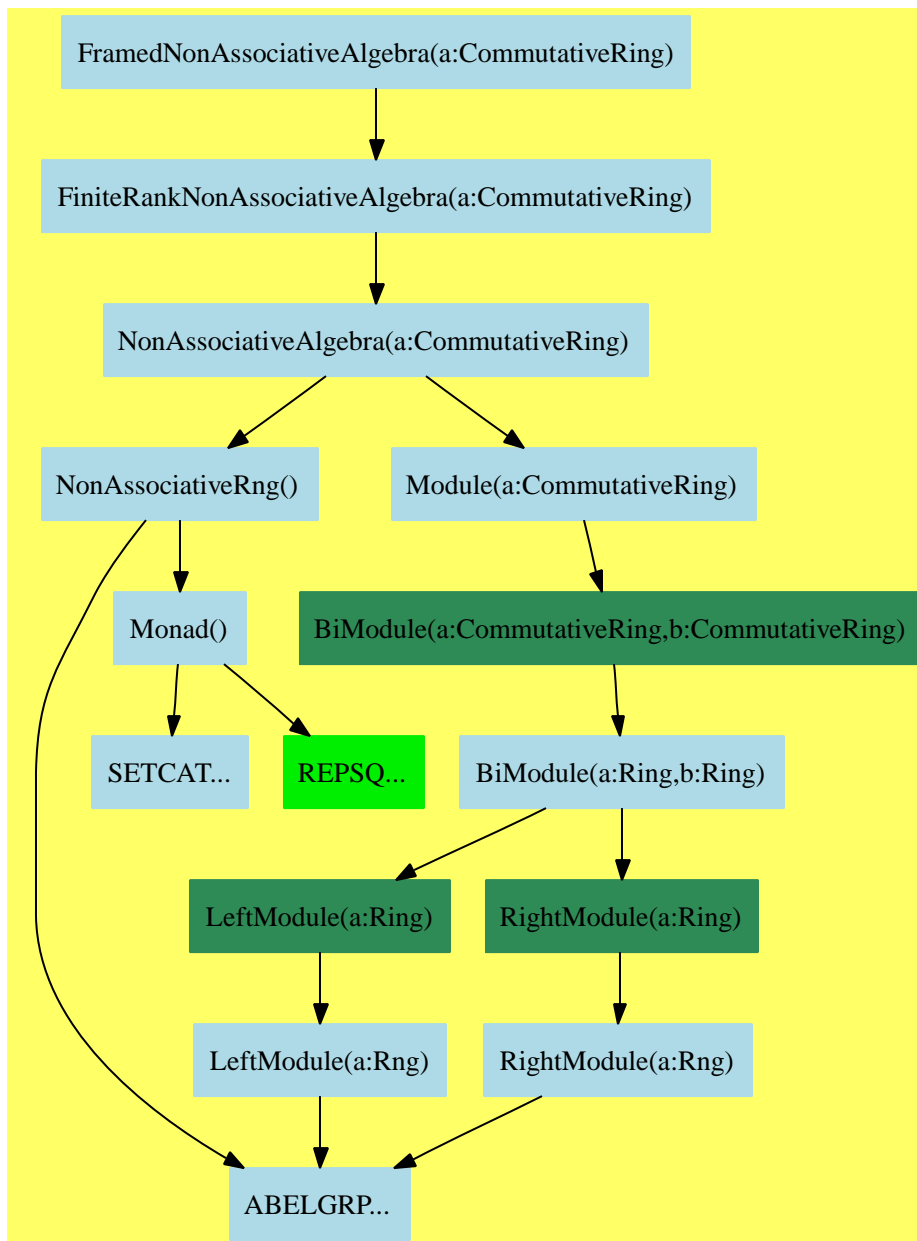
"CoercibleTo(a:Type)" [color=lightblue];
"CoercibleTo(a:Type)" -> "Category"

```

```
"Category" [color=lightblue];  
}
```

—————▶

FramedNonAssociativeAlgebra (FRNAALG)



— FramedNonAssociativeAlgebra.input —

```

)set break resume
)sys rm -f FramedNonAssociativeAlgebra.output
)spool FramedNonAssociativeAlgebra.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FramedNonAssociativeAlgebra
--R
--R FramedNonAssociativeAlgebra(R: CommutativeRing) is a category constructor
--R Abbreviation for FramedNonAssociativeAlgebra is FRNAALG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FRNAALG
--R
--R----- Operations -----
--R ?? : (R,%) -> %                ?? : (%,R) -> %
--R ?? : (%,%) -> %                ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %  ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %                ?-? : (%,%) -> %
--R -? : % -> %                    ?=? : (%,%) -> Boolean
--R 0 : () -> %                    alternative? : () -> Boolean
--R antiAssociative? : () -> Boolean  antiCommutative? : () -> Boolean
--R antiCommutator : (%,%) -> %      apply : (Matrix(R),%) -> %
--R associative? : () -> Boolean      associator : (%,%,%) -> %
--R basis : () -> Vector(%)          coerce : % -> OutputForm
--R commutative? : () -> Boolean      commutator : (%,%) -> %
--R convert : Vector(R) -> %          convert : % -> Vector(R)
--R coordinates : % -> Vector(R)      ?.? : (%,Integer) -> R
--R flexible? : () -> Boolean         hash : % -> SingleInteger
--R jacobiIdentity? : () -> Boolean   jordanAdmissible? : () -> Boolean
--R jordanAlgebra? : () -> Boolean    latex : % -> String
--R leftAlternative? : () -> Boolean   leftDiscriminant : () -> R
--R leftDiscriminant : Vector(%) -> R  leftNorm : % -> R
--R leftTrace : % -> R                leftTraceMatrix : () -> Matrix(R)
--R lieAdmissible? : () -> Boolean     lieAlgebra? : () -> Boolean
--R powerAssociative? : () -> Boolean  rank : () -> PositiveInteger
--R represents : Vector(R) -> %        rightAlternative? : () -> Boolean
--R rightDiscriminant : () -> R        rightNorm : % -> R
--R rightTrace : % -> R                rightTraceMatrix : () -> Matrix(R)
--R sample : () -> %                  someBasis : () -> Vector(%)
--R zero? : % -> Boolean               ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R associatorDependence : () -> List(Vector(R)) if R has INTDOM
--R conditionsForIdempotents : () -> List(Polynomial(R))
--R conditionsForIdempotents : Vector(%) -> List(Polynomial(R))
--R coordinates : Vector(%) -> Matrix(R)
--R coordinates : (Vector(%),Vector(%)) -> Matrix(R)
--R coordinates : (%,Vector(%)) -> Vector(R)
--R leftCharacteristicPolynomial : % -> SparseUnivariatePolynomial(R)

```

```

--R leftMinimalPolynomial : % -> SparseUnivariatePolynomial(R) if R has INTDOM
--R leftPower : (% ,PositiveInteger) -> %
--R leftRankPolynomial : () -> SparseUnivariatePolynomial(Polynomial(R)) if R has FIELD
--R leftRecip : % -> Union(%,"failed") if R has INTDOM
--R leftRegularRepresentation : % -> Matrix(R)
--R leftRegularRepresentation : (% ,Vector(%)) -> Matrix(R)
--R leftTraceMatrix : Vector(% ) -> Matrix(R)
--R leftUnit : () -> Union(%,"failed") if R has INTDOM
--R leftUnits : () -> Union(Record(particular: % ,basis: List(%)), "failed") if R has INTDOM
--R noncommutativeJordanAlgebra? : () -> Boolean
--R plenaryPower : (% ,PositiveInteger) -> %
--R recip : % -> Union(%,"failed") if R has INTDOM
--R represents : (Vector(R),Vector(%)) -> %
--R rightCharacteristicPolynomial : % -> SparseUnivariatePolynomial(R)
--R rightDiscriminant : Vector(% ) -> R
--R rightMinimalPolynomial : % -> SparseUnivariatePolynomial(R) if R has INTDOM
--R rightPower : (% ,PositiveInteger) -> %
--R rightRankPolynomial : () -> SparseUnivariatePolynomial(Polynomial(R)) if R has FIELD
--R rightRecip : % -> Union(%,"failed") if R has INTDOM
--R rightRegularRepresentation : % -> Matrix(R)
--R rightRegularRepresentation : (% ,Vector(%)) -> Matrix(R)
--R rightTraceMatrix : Vector(% ) -> Matrix(R)
--R rightUnit : () -> Union(%,"failed") if R has INTDOM
--R rightUnits : () -> Union(Record(particular: % ,basis: List(%)), "failed") if R has INTDOM
--R structuralConstants : () -> Vector(Matrix(R))
--R structuralConstants : Vector(% ) -> Vector(Matrix(R))
--R subtractIfCan : (% ,%) -> Union(%,"failed")
--R unit : () -> Union(%,"failed") if R has INTDOM
--R
--E 1

)spool
)lisp (bye)

```

— FramedNonAssociativeAlgebra.help —

```

=====
FramedNonAssociativeAlgebra examples
=====

```

FramedNonAssociativeAlgebra(R) is a FiniteRankNonAssociativeAlgebra (i.e. a non associative algebra over R which is a free R-module of finite rank) over a commutative ring R together with a fixed R-module basis.

See Also:

o)show FramedNonAssociativeAlgebra

See:

\Leftarrow “FiniteRankNonAssociativeAlgebra” (FINAALG) [12](#) on page [1069](#)

Exports:

| | |
|-------------------------------|------------------------------|
| 0 | alternative? |
| antiAssociative? | antiCommutative? |
| antiCommutator | apply |
| associative? | associator |
| associatorDependence | basis |
| coerce | commutative? |
| commutator | conditionsForIdempotents |
| convert | coordinates |
| flexible? | hash |
| jacobiIdentity? | jordanAdmissible? |
| jordanAlgebra? | latex |
| leftAlternative? | leftCharacteristicPolynomial |
| leftDiscriminant | leftMinimalPolynomial |
| leftNorm | leftPower |
| leftRankPolynomial | leftRecip |
| leftRegularRepresentation | leftTrace |
| leftTraceMatrix | leftUnit |
| leftUnits | lieAdmissible? |
| lieAlgebra? | noncommutativeJordanAlgebra? |
| plenaryPower | powerAssociative? |
| rank | recip |
| represents | rightAlternative? |
| rightCharacteristicPolynomial | rightDiscriminant |
| rightMinimalPolynomial | rightNorm |
| rightPower | rightRankPolynomial |
| rightRecip | rightRegularRepresentation |
| rightTrace | rightTraceMatrix |
| rightUnit | rightUnits |
| sample | someBasis |
| structuralConstants | subtractIfCan |
| unit | zero? |
| ?*? | ?**? |
| ?+? | ?-? |
| -? | ?=? |
| ?..? | ?~=? |

Attributes exported:

- if \$ has IntegralDomain then unitsKnown where **unitsKnown** is true if a monoid (a

multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.

- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
apply : (Matrix R,% ) -> %
basis : () -> Vector %
convert : Vector R -> %
?.? : (% ,Integer) -> R
```

These are implemented by this category:

```
conditionsForIdempotents : () -> List Polynomial R
convert : % -> Vector R
coordinates : % -> Vector R
coordinates : Vector % -> Matrix R
leftDiscriminant : () -> R
leftRankPolynomial : () ->
  SparseUnivariatePolynomial Polynomial R
  if R has FIELD
leftRegularRepresentation : % -> Matrix R
leftTraceMatrix : () -> Matrix R
leftUnit : () -> Union(%,"failed") if R has INTDOM
leftUnits : () ->
  Union(Record(particular: %,basis: List %),"failed")
  if R has INTDOM
represents : Vector R -> %
rightDiscriminant : () -> R
rightRankPolynomial : () ->
  SparseUnivariatePolynomial Polynomial R
  if R has FIELD
rightRegularRepresentation : % -> Matrix R
rightTraceMatrix : () -> Matrix R
rightUnit : () -> Union(%,"failed") if R has INTDOM
rightUnits : () ->
  Union(Record(particular: %,basis: List %),"failed")
  if R has INTDOM
structuralConstants : () -> Vector Matrix R
unit : () -> Union(%,"failed") if R has INTDOM
```

These exports come from (p1069) `FiniteRankNonAssociativeAlgebra(R)` where `R:CommutativeRing`:

```
0 : () -> %
alternative? : () -> Boolean
```



```

antiAssociative? : () -> Boolean
antiCommutative? : () -> Boolean
antiCommutator : (%,% ) -> %
associative? : () -> Boolean
associator : (%,%,% ) -> %
associatorDependence : () -> List Vector R
    if R has INTDOM
coerce : % -> OutputForm
commutative? : () -> Boolean
commutator : (%,% ) -> %
conditionsForIdempotents : Vector % -> List Polynomial R
coordinates : (Vector %,Vector %) -> Matrix R
coordinates : (% ,Vector %) -> Vector R
flexible? : () -> Boolean
hash : % -> SingleInteger
jacobiIdentity? : () -> Boolean
jordanAdmissible? : () -> Boolean
jordanAlgebra? : () -> Boolean
latex : % -> String
leftAlternative? : () -> Boolean
leftCharacteristicPolynomial : % ->
    SparseUnivariatePolynomial R
leftDiscriminant : Vector % -> R
leftMinimalPolynomial : % ->
    SparseUnivariatePolynomial R
    if R has INTDOM
leftNorm : % -> R
leftPower : (% ,PositiveInteger) -> %
leftRecip : % -> Union(% ,"failed") if R has INTDOM
leftRegularRepresentation : (% ,Vector %) -> Matrix R
leftTrace : % -> R
leftTraceMatrix : Vector % -> Matrix R
lieAdmissible? : () -> Boolean
lieAlgebra? : () -> Boolean
noncommutativeJordanAlgebra? : () -> Boolean
plenaryPower : (% ,PositiveInteger) -> %
powerAssociative? : () -> Boolean
rank : () -> PositiveInteger
recip : % -> Union(% ,"failed") if R has INTDOM
represents : (Vector R ,Vector %) -> %
rightAlternative? : () -> Boolean
rightCharacteristicPolynomial : % ->
    SparseUnivariatePolynomial R
rightDiscriminant : Vector % -> R
rightMinimalPolynomial : % ->
    SparseUnivariatePolynomial R
    if R has INTDOM
rightNorm : % -> R
rightPower : (% ,PositiveInteger) -> %
rightRecip : % -> Union(% ,"failed") if R has INTDOM

```

```

rightRegularRepresentation : (% , Vector %) -> Matrix R
rightTrace : % -> R
rightTraceMatrix : Vector % -> Matrix R
sample : () -> %
someBasis : () -> Vector %
structuralConstants : Vector % -> Vector Matrix R
subtractIfCan : (% , %) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (% , %) -> Boolean
?*? : (PositiveInteger, %) -> %
?*? : (% , %) -> %
?*? : (Integer, %) -> %
?*? : (NonNegativeInteger, %) -> %
?*? : (R, %) -> %
?*? : (% , R) -> %
?+? : (% , %) -> %
?=? : (% , %) -> Boolean
?-? : (% , %) -> %
-? : % -> %
?*?* : (% , PositiveInteger) -> %

```

— category FRNAALG FramedNonAssociativeAlgebra —

```

)abbrev category FRNAALG FramedNonAssociativeAlgebra
++ Author: J. Grabmeier, R. Wisbauer
++ Date Created: 01 March 1991
++ Date Last Updated: 11 June 1991
++ Reference:
++ R.D. Schafer: An Introduction to Nonassociative Algebras
++ Academic Press, New York, 1966
++ Description:
++ FramedNonAssociativeAlgebra(R) is a
++ \spadtype{FiniteRankNonAssociativeAlgebra} (i.e. a non associative
++ algebra over R which is a free \spad{R}-module of finite rank)
++ over a commutative ring R together with a fixed \spad{R}-module basis.

FramedNonAssociativeAlgebra(R:CommutativeRing):
  Category == FiniteRankNonAssociativeAlgebra(R) with
  basis: () -> Vector %
    ++ basis() returns the fixed \spad{R}-module basis.
  coordinates: % -> Vector R
    ++ coordinates(a) returns the coordinates of \spad{a}
    ++ with respect to the
    ++ fixed \spad{R}-module basis.
  coordinates: Vector % -> Matrix R
    ++ coordinates([a1,...,am]) returns a matrix whose i-th row
    ++ is formed by the coordinates of \spad{ai} with respect to the
    ++ fixed \spad{R}-module basis.
  elt : (% , Integer) -> R

```

```

++ elt(a,i) returns the i-th coefficient of \spad{a} with respect
++ to the fixed \spad{R}-module basis.
structuralConstants:() -> Vector Matrix R
++ structuralConstants() calculates the structural constants
++ \spad{[(gamma_ijk) for k in 1..rank()] } defined by
++ \spad{v_i * v_j = gamma_{ij1} * v_1 + ... + gamma_{ijn} * v_n},
++ where \spad{v_1},...,\spad{v_n} is the fixed \spad{R}-module basis.
conditionsForIdempotents: () -> List Polynomial R
++ conditionsForIdempotents() determines a complete list
++ of polynomial equations for the coefficients of idempotents
++ with respect to the fixed \spad{R}-module basis.
represents: Vector R -> %
++ represents([a1,...,an]) returns \spad{a1*v1 + ... + an*v_n},
++ where \spad{v_1}, ... , \spad{v_n} are the elements of the
++ fixed \spad{R}-module basis.
convert: % -> Vector R
++ convert(a) returns the coordinates of \spad{a} with respect to the
++ fixed \spad{R}-module basis.
convert: Vector R -> %
++ convert([a1,...,an]) returns \spad{a1*v1 + ... + an*v_n},
++ where \spad{v_1}, ... , \spad{v_n} are the elements of the
++ fixed \spad{R}-module basis.
leftDiscriminant : () -> R
++ leftDiscriminant() returns the
++ determinant of the \spad{n}-by-\spad{n}
++ matrix whose element at the \spad{i}-th row and \spad{j}-th column
++ is given by the left trace of the product \spad{v_i*v_j}, where
++ \spad{v_1},...,\spad{v_n} are the
++ elements of the fixed \spad{R}-module basis.
++ Note that the same as \spad{determinant(leftTraceMatrix())}.
rightDiscriminant : () -> R
++ rightDiscriminant() returns the determinant of the
++ \spad{n}-by-\spad{n} matrix whose element at the \spad{i}-th row
++ and \spad{j}-th column is
++ given by the right trace of the product \spad{v_i*v_j}, where
++ \spad{v_1},...,\spad{v_n} are the elements of
++ the fixed \spad{R}-module basis.
++ Note that the same as \spad{determinant(rightTraceMatrix())}.
leftTraceMatrix : () -> Matrix R
++ leftTraceMatrix() is the \spad{n}-by-\spad{n}
++ matrix whose element at the \spad{i}-th row and \spad{j}-th column
++ is given by left trace of the product \spad{v_i*v_j},
++ where \spad{v_1},...,\spad{v_n} are the
++ elements of the fixed \spad{R}-module basis.
rightTraceMatrix : () -> Matrix R
++ rightTraceMatrix() is the \spad{n}-by-\spad{n}
++ matrix whose element at the \spad{i}-th row and \spad{j}-th column
++ is given by the right trace of the product \spad{v_i*v_j}, where
++ \spad{v_1},...,\spad{v_n} are the elements
++ of the fixed \spad{R}-module basis.

```

```

leftRegularRepresentation : % -> Matrix R
++ leftRegularRepresentation(a) returns the matrix of the linear
++ map defined by left multiplication by \spad{a} with respect
++ to the fixed \spad{R}-module basis.
rightRegularRepresentation : % -> Matrix R
++ rightRegularRepresentation(a) returns the matrix of the linear
++ map defined by right multiplication by \spad{a} with respect
++ to the fixed \spad{R}-module basis.
if R has Field then
  leftRankPolynomial : () -> SparseUnivariatePolynomial Polynomial R
  ++ leftRankPolynomial() calculates the left minimal polynomial
  ++ of the generic element in the algebra,
  ++ defined by the same structural
  ++ constants over the polynomial ring in symbolic coefficients with
  ++ respect to the fixed basis.
  rightRankPolynomial : () -> SparseUnivariatePolynomial Polynomial R
  ++ rightRankPolynomial() calculates the right minimal polynomial
  ++ of the generic element in the algebra,
  ++ defined by the same structural
  ++ constants over the polynomial ring in symbolic coefficients with
  ++ respect to the fixed basis.
apply: (Matrix R, %) -> %
++ apply(m,a) defines a left operation of n by n matrices
++ where n is the rank of the algebra in terms of matrix-vector
++ multiplication, this is a substitute for a left module structure.
++ Error: if shape of matrix doesn't fit.
--attributes
--separable <=> discriminant() ^= 0
add

V ==> Vector
M ==> Matrix
P ==> Polynomial
F ==> Fraction
REC ==> Record(particular: Union(V R,"failed"),basis: List V R)
LSMP ==> LinearSystemMatrixPackage(R,V R,V R, M R)
CVMP ==> CoerceVectorMatrixPackage(R)

--GA ==> GenericNonAssociativeAlgebra(R,rank())$%,_
-- [random()$Character :: String :: Symbol for i in 1..rank()$%], _
-- structuralConstants()$%)
--y : GA := generic()
if R has Field then
  leftRankPolynomial() ==
    n := rank()
    b := basis()
    gamma : Vector Matrix R := structuralConstants b
    listOfNumbers : List String := [STRINGIMAGE(q)$Lisp for q in 1..n]
    symbolsForCoef : Vector Symbol :=
      [concat("%", concat("x", i))::Symbol for i in listOfNumbers]

```

```

xx : M P R
mo : P R
x : M P R := new(1,n,0)
for i in 1..n repeat
  mo := monomial(1, [symbolsForCoef.i], [1])$(P R)
  qsetelt_!(x,1,i,mo)
y : M P R := copy x
k : PositiveInteger := 1
cond : M P R := copy x
-- multiplication in the generic algebra means using
-- the structural matrices as bilinear forms.
-- left multiplication by x, we prepare for that:
genGamma : V M P R := coerceP$CVMP gamma
x := reduce(horizConcat,[x*genGamma(i) for i in 1..#genGamma])
while rank(cond) = k repeat
  k := k+1
  for i in 1..n repeat
    setelt(xx,[1],[i],x*transpose y)
  y := copy xx
  cond := horizConcat(cond, xx)
vectorOfCoef : Vector P R := (nullSpace(cond)$Matrix(P R)).first
res : SparseUnivariatePolynomial P R := 0
for i in 1..k repeat
  res:=res+monomial(vectorOfCoef.i,i)$(SparseUnivariatePolynomial P R)
res

rightRankPolynomial() ==
n := rank()
b := basis()
gamma : Vector Matrix R := structuralConstants b
listOfNumbers : List String := [STRINGIMAGE(q)$Lisp for q in 1..n]
symbolsForCoef : Vector Symbol :=
  [concat("%", concat("x", i))::Symbol for i in listOfNumbers]
xx : M P R
mo : P R
x : M P R := new(1,n,0)
for i in 1..n repeat
  mo := monomial(1, [symbolsForCoef.i], [1])$(P R)
  qsetelt_!(x,1,i,mo)
y : M P R := copy x
k : PositiveInteger := 1
cond : M P R := copy x
-- multiplication in the generic algebra means using
-- the structural matrices as bilinear forms.
-- left multiplication by x, we prepare for that:
genGamma : V M P R := coerceP$CVMP gamma
x := _
  reduce(horizConcat,[genGamma(i)*transpose x for i in 1..#genGamma])
while rank(cond) = k repeat
  k := k+1

```

```

    for i in 1..n repeat
        setelt(xx,[1],[i],y * transpose x)
    y := copy xx
    cond := horizConcat(cond, xx)
vectorOfCoef : Vector P R := (nullSpace(cond)$Matrix(P R)).first
res : SparseUnivariatePolynomial P R := 0
for i in 1..k repeat
    res := _
    res+monomial(vectorOfCoef.i,i)$(SparseUnivariatePolynomial P R)
res

leftUnitsInternal : () -> REC
leftUnitsInternal() ==
    n := rank()
    b := basis()
    gamma : Vector Matrix R := structuralConstants b
    cond : Matrix(R) := new(n**2,n,0$R)$Matrix(R)
    rhs : Vector(R) := new(n**2,0$R)$Vector(R)
    z : Integer := 0
    addOn : R := 0
    for k in 1..n repeat
        for i in 1..n repeat
            z := z+1 -- index for the rows
            addOn :=
                k=i => 1
                0
            setelt(rhs,z,addOn)$Vector(R)
            for j in 1..n repeat -- index for the columns
                setelt(cond,z,j,elt(gamma.k,j,i))$Matrix(R)
    solve(cond,rhs)$LSMP

leftUnit() ==
    res : REC := leftUnitsInternal()
    res.particular case "failed" =>
        messagePrint("this algebra has no left unit")$OutputForm
        "failed"
    represents (res.particular :: V R)

leftUnits() ==
    res : REC := leftUnitsInternal()
    res.particular case "failed" =>
        messagePrint("this algebra has no left unit")$OutputForm
        "failed"
    [represents(res.particular :: V R)$%, _
    map(represents, res.basis)$ListFunctions2(Vector R, %) ]

rightUnitsInternal : () -> REC
rightUnitsInternal() ==
    n := rank()

```

```

b := basis()
gamma : Vector Matrix R := structuralConstants b
condo : Matrix(R) := new(n**2,n,0$R)$Matrix(R)
rhs : Vector(R) := new(n**2,0$R)$Vector(R)
z : Integer := 0
addOn : R := 0
for k in 1..n repeat
  for i in 1..n repeat
    z := z+1 -- index for the rows
    addOn :=
      k=i => 1
      0
    setelt(rhs,z,addOn)$Vector(R)
    for j in 1..n repeat -- index for the columns
      setelt(condo,z,j,elt(gamma.k,i,j))$Matrix(R)
  solve(condo,rhs)$LSMP

rightUnit() ==
res : REC := rightUnitsInternal()
res.particular case "failed" =>
  messagePrint("this algebra has no right unit")$OutputForm
  "failed"
represents (res.particular :: V R)

rightUnits() ==
res : REC := rightUnitsInternal()
res.particular case "failed" =>
  messagePrint("this algebra has no right unit")$OutputForm
  "failed"
[represents(res.particular :: V R)$%, _
 map(represents, res.basis)$ListFunctions2(Vector R, %) ]

unit() ==
n := rank()
b := basis()
gamma : Vector Matrix R := structuralConstants b
cond : Matrix(R) := new(2*n**2,n,0$R)$Matrix(R)
rhs : Vector(R) := new(2*n**2,0$R)$Vector(R)
z : Integer := 0
u : Integer := n*n
addOn : R := 0
for k in 1..n repeat
  for i in 1..n repeat
    z := z+1 -- index for the rows
    addOn :=
      k=i => 1
      0
    setelt(rhs,z,addOn)$Vector(R)
    setelt(rhs,u,addOn)$Vector(R)
  for j in 1..n repeat -- index for the columns

```

```

        setelt(cond,z,j,elt(gamma.k,j,i))$Matrix(R)
        setelt(cond,u,j,elt(gamma.k,i,j))$Matrix(R)
    res : REC := solve(cond,rhs)$LSMP
    res.particular case "failed" =>
        messagePrint("this algebra has no unit")$OutputForm
        "failed"
    represents (res.particular :: V R)
apply(m:Matrix(R),a:%) ==
    v : Vector R := coordinates(a)
    v := m *$Matrix(R) v
    convert v

structuralConstants() == structuralConstants basis()
conditionsForIdempotents() == conditionsForIdempotents basis()
convert(x:%) : Vector(R) == coordinates(x, basis())
convert(v:Vector R) : % == represents(v, basis())
leftTraceMatrix() == leftTraceMatrix basis()
rightTraceMatrix() == rightTraceMatrix basis()
leftDiscriminant() == leftDiscriminant basis()
rightDiscriminant() == rightDiscriminant basis()
leftRegularRepresentation x == leftRegularRepresentation(x, basis())
rightRegularRepresentation x == rightRegularRepresentation(x, basis())
coordinates x == coordinates(x, basis())
represents(v:Vector R) : % == represents(v, basis())

coordinates(v:Vector %) ==
    m := new(#v, rank(), 0)$Matrix(R)
    for i in minIndex v .. maxIndex v for j in minRowIndex m .. repeat
        setRow_!(m, j, coordinates qelt(v, i))
    m



---


— FRNAALG.dotabb —

"FRNAALG"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FRNAALG"];
"FRNAALG" -> "FRNAALG"



---


— FRNAALG.dotfull —

"FramedNonAssociativeAlgebra(a:CommutativeRing)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FRNAALG"];

```



```
"FramedNonAssociativeAlgebra(a:CommutativeRing)" ->
  "FiniteRankNonAssociativeAlgebra(a:CommutativeRing)"
```

— FRNAALG.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FramedNonAssociativeAlgebra(a:CommutativeRing)" [color=lightblue];
  "FramedNonAssociativeAlgebra(a:CommutativeRing)" ->
    "FiniteRankNonAssociativeAlgebra(a:CommutativeRing)"

  "FiniteRankNonAssociativeAlgebra(a:CommutativeRing)" [color=lightblue];
  "FiniteRankNonAssociativeAlgebra(a:CommutativeRing)" ->
    "NonAssociativeAlgebra(a:CommutativeRing)"

  "NonAssociativeAlgebra(a:CommutativeRing)" [color=lightblue];
  "NonAssociativeAlgebra(a:CommutativeRing)" -> "NonAssociativeRng()"
  "NonAssociativeAlgebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

  "NonAssociativeRng()" [color=lightblue];
  "NonAssociativeRng()" -> "ABELGRP..."
  "NonAssociativeRng()" -> "Monad()"

  "Monad()" [color=lightblue];
  "Monad()" -> "SETCAT..."
  "Monad()" -> "REPSQ..."

  "Module(a:CommutativeRing)" [color=lightblue];
  "Module(a:CommutativeRing)" ->
    "BiModule(a:CommutativeRing,b:CommutativeRing)"

  "BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
  "BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BiModule(a:Ring,b:Ring)"

  "BiModule(a:Ring,b:Ring)" [color=lightblue];
  "BiModule(a:Ring,b:Ring)" -> "LeftModule(a:Ring)"
  "BiModule(a:Ring,b:Ring)" -> "RightModule(a:Ring)"

  "RightModule(a:Ring)" [color=seagreen];
  "RightModule(a:Ring)" -> "RightModule(a:Rng)"

  "RightModule(a:Rng)" [color=lightblue];
  "RightModule(a:Rng)" -> "ABELGRP..."
```

```

"LeftModule(a:Ring)" [color=seagreen];
"LeftModule(a:Ring)" -> "LeftModule(a:Rng)"

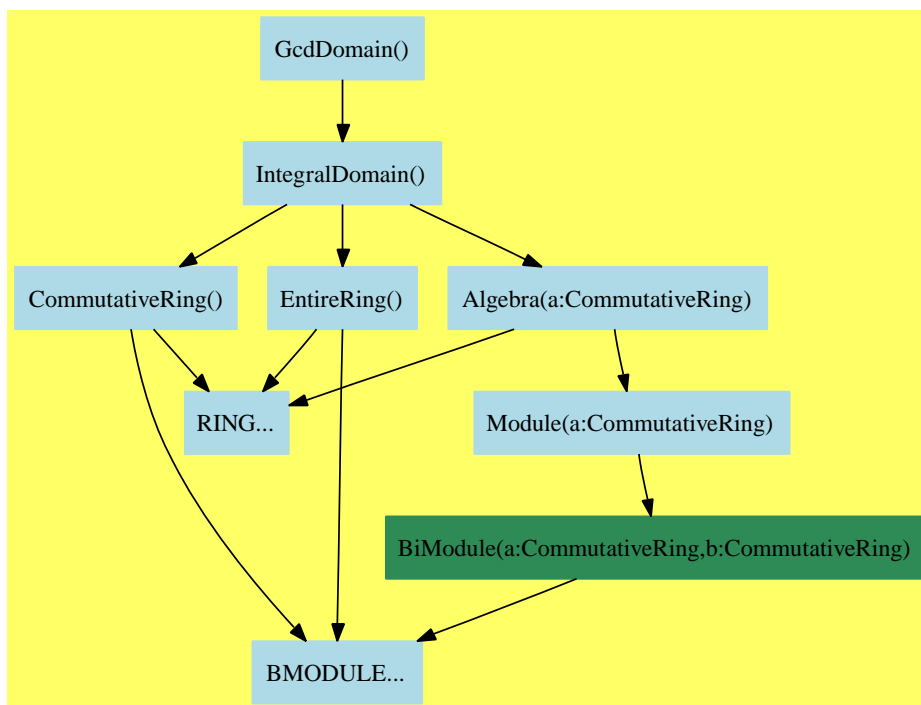
"LeftModule(a:Rng)" [color=lightblue];
"LeftModule(a:Rng)" -> "ABELGRP..."

"REPSQ..." [color="#00EE00"];
"SETCAT..." [color=lightblue];
"ABELGRP..." [color=lightblue];
}

```

—————→

GcdDomain (GCDDOM)



— GcdDomain.input —

```
)set break resume
```

```

)sys rm -f GcdDomain.output
)spool GcdDomain.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show GcdDomain
--R
--R GcdDomain is a category constructor
--R Abbreviation for GcdDomain is GCDDOM
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for GCDDOM
--R
--R----- Operations -----
--R ?? : (% , %) -> %
--R ?? : (PositiveInteger , %) -> %
--R +? : (% , %) -> %
--R -? : % -> %
--R 1 : () -> %
--R ?? : (% , PositiveInteger) -> %
--R coerce : % -> %
--R coerce : % -> OutputForm
--R gcd : (% , %) -> %
--R latex : % -> String
--R lcm : (% , %) -> %
--R recip : % -> Union(%, "failed")
--R unit? : % -> Boolean
--R zero? : % -> Boolean
--R ?? : (NonNegativeInteger , %) -> %
--R ?? : (% , NonNegativeInteger) -> %
--R ?? : (% , NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R exquo : (% , %) -> Union(%, "failed")
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— GcdDomain.help —

=====

GcdDomain examples

=====

This category describes domains where gcd can be computed but where there is no guarantee of the existence of factor operation for factorisation into irreducibles. However, if such a factor operation exist, factorization will be unique up to order and units.

See Also:

o)show GcdDomain

See:

⇒ “IntervalCategory” (INTCAT) [14](#) on page [1200](#)
 ⇒ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)
 ⇒ “PrincipalIdealDomain” (PID) [14](#) on page [1216](#)
 ⇒ “UniqueFactorizationDomain” (UFD) [14](#) on page [1222](#)
 ⇒ “UnivariatePolynomialCategory” (UPOLYC) [17](#) on page [1522](#)
 ⇐ “IntegralDomain” (INTDOM) [12](#) on page [1097](#)

Exports:

| | | | | |
|-------|---------------|---------------|----------------|---------------|
| 0 | 1 | associates? | characteristic | coerce |
| exquo | gcd | gcdPolynomial | hash | latex |
| lcm | one? | recip | sample | subtractIfCan |
| unit? | unitCanonical | unitNormal | zero? | ?*? |
| ?**? | ?+? | ?-? | -? | ?=? |
| ?^? | ?~=? | | | |

Attributes exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

gcd : (%,%) -> %

These are implemented by this category:

```

gcd : List % -> %
gcdPolynomial : (SparseUnivariatePolynomial %,
                  SparseUnivariatePolynomial %) ->
                  SparseUnivariatePolynomial %
lcm : (%,% ) -> %
lcm : List % -> %

```

These exports come from (p1097) `IntegralDomain()`:

```

0 : () -> %
1 : () -> %
associates? : (%,% ) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
exquo : (%,% ) -> Union(%, "failed")
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%,% ) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
zero? : % -> Boolean
?+? : (%,% ) -> %
?=?: (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
?*?: (%,% ) -> %
?*?: (Integer,% ) -> %
?*?: (PositiveInteger,% ) -> %
?*?: (NonNegativeInteger,% ) -> %
?-?: (%,% ) -> %
-?: % -> %
?*?: (% , PositiveInteger) -> %
?*?: (% , NonNegativeInteger) -> %
?^?: (% , PositiveInteger) -> %
?^?: (% , NonNegativeInteger) -> %

```

— category GCDDOM GcdDomain —

```

)abbrev category GCDDOM GcdDomain
++ Description:
++ This category describes domains where
++ \spadfun{gcd} can be computed but where there is no guarantee
++ of the existence of \spadfun{factor} operation for factorisation
++ into irreducibles. However, if such a \spadfun{factor} operation exist,

```

```

++ factorization will be unique up to order and units.

GcdDomain(): Category == Join(IntegralDomain, LeftOreRing) with
  gcd: (%,%)->%
    ++ gcd(x,y) returns the greatest common divisor of x and y.
    -- gcd(x,y) = gcd(y,x) in the presence of canonicalUnitNormal,
    -- but not necessarily elsewhere
  gcd: List(%)->%
    ++ gcd(l) returns the common gcd of the elements in the list l.
  lcm: (%,%)->%
    ++ lcm(x,y) returns the least common multiple of x and y.
    -- lcm(x,y) = lcm(y,x) in the presence of canonicalUnitNormal,
    -- but not necessarily elsewhere
  lcm: List(%)->%
    ++ lcm(l) returns the least common multiple of the elements of
    ++ the list l.
  gcdPolynomial: (SparseUnivariatePolynomial %, _
                  SparseUnivariatePolynomial %) -> _
                  SparseUnivariatePolynomial %
    ++ gcdPolynomial(p,q) returns the greatest common divisor (gcd) of
    ++ univariate polynomials over the domain
add

lcm(x: %,y: %) ==
  y = 0 => 0
  x = 0 => 0
  LCM : Union(%, "failed") := y exquo gcd(x,y)
  LCM case % => x * LCM
  error "bad gcd in lcm computation"

lcm(l:List %) == reduce(lcm, l, 1, 0)

gcd(l:List %) == reduce(gcd, l, 0, 1)

SUP ==> SparseUnivariatePolynomial

gcdPolynomial(p1,p2) ==
  zero? p1 => unitCanonical p2
  zero? p2 => unitCanonical p1
  c1:= content(p1); c2:= content(p2)
  p1:= (p1 exquo c1)::SUP %
  p2:= (p2 exquo c2)::SUP %
  if (e1:=minimumDegree p1) > 0 then p1:=(p1 exquo monomial(1,e1))::SUP %
  if (e2:=minimumDegree p2) > 0 then p2:=(p2 exquo monomial(1,e2))::SUP %
  e1:=min(e1,e2); c1:=gcd(c1,c2)
  p1:=
    degree p1 = 0 or degree p2 = 0 => monomial(c1,0)
    p:= subResultantGcd(p1,p2)
    degree p = 0 => monomial(c1,0)
    c2:= gcd(leadingCoefficient p1,leadingCoefficient p2)

```

```

    unitCanonical(_
      c1 * primitivePart(((c2*p) exquo leadingCoefficient p)::SUP %))
    zero? e1 => p1
    monomial(1,e1)*p1

-- See [Delenclos 06], [Bronstein 96a]
lcmCoef(c1, c2) ==
  g := gcd(c1, c2)
  cc1 := (c2 exquo g)::%
  cc2 := (c1 exquo g)::%
  [cc1*c1, cc1, cc2]

```

— GCDDOM.dotabb —

```

"GCDDOM"
[color=lightblue,href="bookvol10.2.pdf#nameddest=GCDDOM"];
"GCDDOM" -> "INTDOM"

```

— GCDDOM.dotfull —

```

"GcdDomain()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=GCDDOM"];
"GcdDomain()" -> "IntegralDomain()"

```

— GCDDOM.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "GcdDomain()" [color=lightblue];
  "GcdDomain()" -> "IntegralDomain()"

  "IntegralDomain()" [color=lightblue];
  "IntegralDomain()" -> "CommutativeRing()"
  "IntegralDomain()" -> "Algebra(a:CommutativeRing)"
  "IntegralDomain()" -> "EntireRing()"
}

```

```

"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BMODULE..."

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BMODULE..."

"Algebra(a:CommutativeRing)" [color=lightblue];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

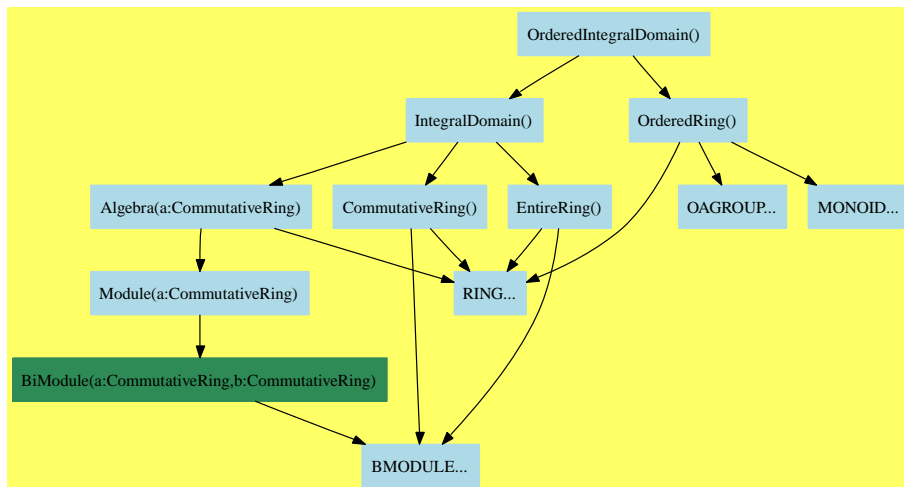
"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" ->
  "BiModule(a:CommutativeRing,b:CommutativeRing)"

"BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BMODULE..."

"BMODULE..." [color=lightblue];
"RING..." [color=lightblue];
}

```

OrderedIntegralDomain (OINTDOM)



— OrderedIntegralDomain.input —

```

)set break resume
)sys rm -f OrderedIntegralDomain.output
)spool OrderedIntegralDomain.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show OrderedIntegralDomain
--R OrderedIntegralDomain is a category constructor
--R Abbreviation for OrderedIntegralDomain is OINTDOM
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for OINTDOM
--R
--R----- Operations -----
--R ?? : (%,% ) -> %                ?? : (Integer,% ) -> %
--R ?? : (PositiveInteger,% ) -> %   ??? : (% ,PositiveInteger) -> %
--R +? : (%,% ) -> %                ?-? : (%,% ) -> %
--R -? : % -> %                     ?<? : (%,% ) -> Boolean
--R ?<=? : (%,% ) -> Boolean         ?=? : (%,% ) -> Boolean
--R ?>? : (%,% ) -> Boolean         ?>=? : (%,% ) -> Boolean
--R 1 : () -> %                     0 : () -> %
--R ^? : (% ,PositiveInteger) -> %   abs : % -> %
--R associates? : (%,% ) -> Boolean   coerce : % -> %
--R coerce : Integer -> %             coerce : % -> OutputForm
--R hash : % -> SingleInteger         latex : % -> String
--R max : (%,% ) -> %                 min : (%,% ) -> %
--R negative? : % -> Boolean           one? : % -> Boolean
--R positive? : % -> Boolean           recip : % -> Union(%,"failed")
--R sample : () -> %                  sign : % -> Integer
--R unit? : % -> Boolean               unitCanonical : % -> %
--R zero? : % -> Boolean              ?~=? : (%,% ) -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ^? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R exquo : (%,% ) -> Union(%,"failed")
--R subtractIfCan : (%,% ) -> Union(%,"failed")
--R unitNormal : % -> Record(unit: % ,canonical: % ,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— OrderedIntegralDomain.help —

```
=====
OrderedIntegralDomain examples
=====
```

The category of ordered commutative integral domains, where ordering and the arithmetic operations are compatible

See Also:

o)show OrderedIntegralDomain

See:

⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)
 ⇐ “IntegralDomain” (INTDOM) [12](#) on page [1097](#)
 ⇐ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
 ⇐ “OrderedRing” (ORDRING) [10](#) on page [933](#)

Exports:

| | | | | |
|------------|-----------|---------------|-------------|----------------|
| 1 | 0 | abs | associates? | characteristic |
| coerce | exquo | hash | latex | max |
| min | negative? | one? | positive? | recip |
| sample | sign | subtractIfCan | unit? | unitCanonical |
| unitNormal | zero? | ?*? | ?**? | ?+? |
| ?-? | -? | ?<? | ?<=? | ?=? |
| ?>? | ?>=? | ?^? | ?~=? | |

Attributes exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These exports come from (p[1097](#)) IntegralDomain():

```
0 : () -> %
1 : () -> %
```

```

associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
exquo : (%,%) -> Union(%, "failed")
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%, NonNegativeInteger) -> %
***? : (%, PositiveInteger) -> %
?<? : (%,%) -> Boolean
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %

```

These exports come from (p933) `OrderedRing()`:

```

abs : % -> %
max : (%,%) -> %
min : (%,%) -> %
negative? : % -> Boolean
positive? : % -> Boolean
sign : % -> Integer
?<=? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean

```

— category OINTDOM OrderedIntegralDomain —

```

)abbrev category OINTDOM OrderedIntegralDomain
++ Author: JH Davenport (after L Gonzalez-Vega)
++ Date Created: 30.1.96
++ Description:

```

```

++ The category of ordered commutative integral domains, where ordering
++ and the arithmetic operations are compatible

```

```

OrderedIntegralDomain(): Category ==
  Join(IntegralDomain, OrderedRing)

```

— OINTDOM.dotabb —

```

"OINTDOM"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OINTDOM"];
"OINTDOM" -> "INTDOM"
"OINTDOM" -> "ORDRING"

```

— OINTDOM.dotfull —

```

"OrderedIntegralDomain()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=OINTDOM"];
"OrderedIntegralDomain()" -> "IntegralDomain()"
"OrderedIntegralDomain()" -> "OrderedRing()"

```

— OINTDOM.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "OrderedIntegralDomain()"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=OINTDOM"];
  "OrderedIntegralDomain()" -> "IntegralDomain()"
  "OrderedIntegralDomain()" -> "OrderedRing()"

  "IntegralDomain()" [color=lightblue];
  "IntegralDomain()" -> "CommutativeRing()"
  "IntegralDomain()" -> "Algebra(a:CommutativeRing)"
  "IntegralDomain()" -> "EntireRing()"

  "OrderedRing()" [color=lightblue];
  "OrderedRing()" -> "OAGROUP..."

```

```

"OrderedRing()" -> "RING..."
"OrderedRing()" -> "MONOID..."

"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BMODULE..."

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BMODULE..."

"Algebra(a:CommutativeRing)" [color=lightblue];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" ->
  "BiModule(a:CommutativeRing,b:CommutativeRing)"

"BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BMODULE..."

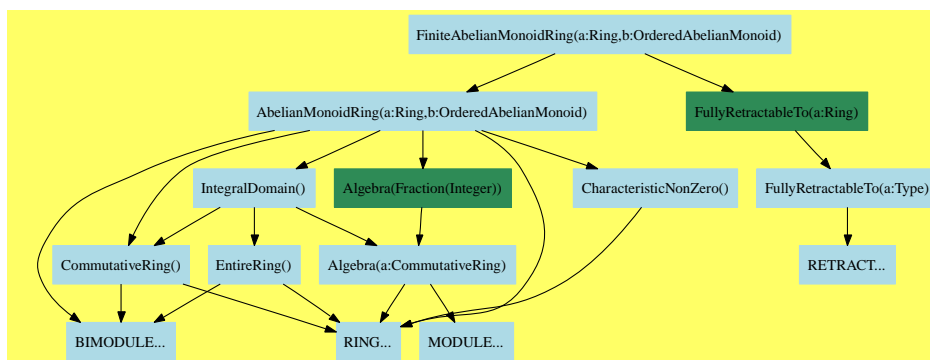
"OAGROUP..." [color=lightblue];
"BMODULE..." [color=lightblue];
"RING..." [color=lightblue];
"MONOID..." [color=lightblue];
}

```

Chapter 14

Category Layer 13

FiniteAbelianMonoidRing (FAMR)



— FiniteAbelianMonoidRing.input —

```

)set break resume
)sys rm -f FiniteAbelianMonoidRing.output
)spool FiniteAbelianMonoidRing.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FiniteAbelianMonoidRing
--R
--R FiniteAbelianMonoidRing(R: Ring,E: OrderedAbelianMonoid) is a category constructor
--R Abbreviation for FiniteAbelianMonoidRing is FAMR
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FAMR
--R
--R----- Operations -----
--R ?? : (R,%) -> %           ?? : (%,R) -> %
--R ?? : (%,%) -> %           ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R +? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %               ?=? : (%,%) -> Boolean
--R 1 : () -> %               0 : () -> %
--R ?? : (%,PositiveInteger) -> %   coefficient : (%,E) -> R
--R coefficients : % -> List(R)     coerce : R -> %
--R coerce : Integer -> %           coerce : % -> OutputForm
--R degree : % -> E               ground : % -> R
--R ground? : % -> Boolean         hash : % -> SingleInteger
--R latex : % -> String           leadingCoefficient : % -> R
--R leadingMonomial : % -> %       map : ((R -> R),%) -> %
--R mapExponents : ((E -> E),%) -> %   minimumDegree : % -> E
--R monomial : (R,E) -> %         monomial? : % -> Boolean
--R one? : % -> Boolean           pomopo! : (%,R,E,%) -> %
--R recip : % -> Union(%, "failed")   reductum : % -> %
--R retract : % -> R             sample : () -> %
--R zero? : % -> Boolean         ?~=? : (%,%) -> Boolean
--R ?? : (%,Fraction(Integer)) -> % if R has ALGEBRA(FRAC(INT))
--R ?? : (Fraction(Integer),%) -> % if R has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,R) -> % if R has FIELD
--R ?? : (%,NonNegativeInteger) -> %
--R associates? : (%,%) -> Boolean if R has INTDOM
--R binomThmExpt : (%,%,NonNegativeInteger) -> % if R has COMRING
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if R has CHARNZ
--R coerce : Fraction(Integer) -> % if R has RETRACT(FRAC(INT)) or R has ALGEBRA(FRAC(INT))
--R coerce : % -> % if R has INTDOM
--R content : % -> R if R has GCDDOM
--R exquo : (%,R) -> Union(%, "failed") if R has INTDOM
--R exquo : (%,%) -> Union(%, "failed") if R has INTDOM
--R numberOfMonomials : % -> NonNegativeInteger
--R primitivePart : % -> % if R has GCDDOM
--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retract : % -> Integer if R has RETRACT(INT)
--R retractIfCan : % -> Union(R, "failed")
--R retractIfCan : % -> Union(Fraction(Integer), "failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer, "failed") if R has RETRACT(INT)
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unit? : % -> Boolean if R has INTDOM
--R unitCanonical : % -> % if R has INTDOM
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if R has INTDOM
--R
--E 1

```

```
)spool
)lisp (bye)
```

— **FiniteAbelianMonoidRing.help** —

=====

FiniteAbelianMonoidRing examples

=====

This category is similar to `AbelianMonoidRing`, except that the sum is assumed to be finite. It is a useful model for polynomials, but is somewhat more general.

See Also:

o `)show FiniteAbelianMonoidRing`

See:

⇒ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)

⇐ “AbelianMonoidRing” (AMR) [13](#) on page [1151](#)

⇐ “FullyRetractableTo” (FRETRCT) [3](#) on page [136](#)

Exports:

| | | | |
|--------------------|-----------------|---------------|-------------------|
| 0 | 1 | associates? | binomThmExpt |
| characteristic | charthRoot | coefficient | coefficients |
| coerce | content | degree | exquo |
| ground | ground? | hash | latex |
| leadingCoefficient | leadingMonomial | map | mapExponents |
| minimumDegree | monomial | monomial? | numberOfMonomials |
| one? | pomopo! | primitivePart | recip |
| reductum | retract | retractIfCan | sample |
| subtractIfCan | unit? | unitCanonical | unitNormal |
| zero? | ?*? | ?**? | ?+? |
| ?-? | -? | ?=? | ?^? |
| ?~=? | ?/? | | |

Attributes exported:

- if \$ has `CommutativeRing` then `commutative(“*”)` where **commutative(“*”)** is true if it has an operation “ $*$ ” : $(D, D) \rightarrow D$ which is commutative.
- if \$ has `IntegralDomain` then `noZeroDivisors` where **noZeroDivisors** is true if $x*y \neq 0$

implies both x and y are non-zero.

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
minimumDegree : % -> E
numberOfMonomials : % -> NonNegativeInteger
```

These are implemented by this category:

```
binomThmExpt : (%,%,NonNegativeInteger) -> %
  if R has COMRING
coefficients : % -> List R
content : % -> R if R has GCDDOM
exquo : (%,R) -> Union(%, "failed") if R has INTDOM
ground : % -> R
ground? : % -> Boolean
mapExponents : ((E -> E),%) -> %
pomopo! : (%,R,E,%) -> %
primitivePart : % -> % if R has GCDDOM
?/? : (%,R) -> % if R has FIELD
```

These exports come from (p1151) `AbelianMonoidRing(R,E)`
 where R :Ring and E :OrderedAbelianMonoid:

```
0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean if R has INTDOM
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(%, "failed") if R has CHARNZ
coefficient : (%,E) -> R
coerce : R -> %
coerce : Fraction Integer -> %
  if R has RETRACT FRAC INT
  or R has ALGEBRA FRAC INT
coerce : % -> % if R has INTDOM
coerce : % -> OutputForm
coerce : Integer -> %
degree : % -> E
exquo : (%,%) -> Union(%, "failed") if R has INTDOM
hash : % -> SingleInteger
latex : % -> String
leadingCoefficient : % -> R
leadingMonomial : % -> %
```

```

map : ((R -> R),%) -> %
monomial : (R,E) -> %
monomial? : % -> Boolean
one? : % -> Boolean
recip : % -> Union(%, "failed")
reductum : % -> %
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean if R has INTDOM
unitCanonical : % -> % if R has INTDOM
unitNormal :
  % -> Record(unit: %, canonical: %, associate: %)
  if R has INTDOM
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (R,%) -> %
?*? : (%,R) -> %
?*? : (Fraction Integer,%) -> % if R has ALGEBRA FRAC INT
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (Integer,%) -> %
?*? : (%,%) -> %
?*? : (%,Fraction Integer) -> % if R has ALGEBRA FRAC INT
***? : (%,NonNegativeInteger) -> %
?~? : (%,NonNegativeInteger) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%,PositiveInteger) -> %
?^? : (%,PositiveInteger) -> %

```

These exports come from (p136) FullyRetractableTo(R:Ring):

```

retract : % -> Fraction Integer
  if R has RETRACT FRAC INT
retract : % -> Integer if R has RETRACT INT
retract : % -> R
retractIfCan : % -> Union(R, "failed")
retractIfCan : % -> Union(Integer, "failed")
  if R has RETRACT INT
retractIfCan : % -> Union(Fraction Integer, "failed")
  if R has RETRACT FRAC INT

```

— category FAMR FiniteAbelianMonoidRing —

```

)abbrev category FAMR FiniteAbelianMonoidRing
++ Date Last Updated: 14.08.2000 Exported pomopo! and binomThmExpt [MMM]
++ Description:

```

```

++ This category is similar to AbelianMonoidRing, except that the sum is
++ assumed to be finite. It is a useful model for polynomials,
++ but is somewhat more general.

FiniteAbelianMonoidRing(R:Ring, E:OrderedAbelianMonoid): Category ==
  Join(AbelianMonoidRing(R,E),FullyRetractableTo R) with
    ground?: % -> Boolean
      ++ ground?(p) tests if polynomial p is a member of the
      ++ coefficient ring.
      -- can't be defined earlier, since a power series
      -- might not know if there were other terms or not
    ground: % -> R
      ++ ground(p) retracts polynomial p to the coefficient ring.
    coefficients: % -> List R
      ++ coefficients(p) gives the list of non-zero coefficients
      ++ of polynomial p.
    numberOfMonomials: % -> NonNegativeInteger
      ++ numberOfMonomials(p) gives the number of non-zero monomials
      ++ in polynomial p.
    minimumDegree: % -> E
      ++ minimumDegree(p) gives the least exponent of a non-zero term
      ++ of polynomial p. Error: if applied to 0.
    mapExponents: (E -> E, %) -> %
      ++ mapExponents(fn,u) maps function fn onto the exponents
      ++ of the non-zero monomials of polynomial u.
    pomopo!: (% ,R,E,%) -> %
      ++ \spad{pomopo!(p1,r,e,p2)} returns \spad{p1 + monomial(e,r) * p2}
      ++ and may use \spad{p1} as workspace. The constant \spad{r} is
      ++ assumed to be nonzero.
    if R has CommutativeRing then
      binomThmExpt: (% ,%,NonNegativeInteger) -> %
        ++ \spad{binomThmExpt(p,q,n)} returns \spad{(x+y)^n}
        ++ by means of the binomial theorem trick.
    if R has IntegralDomain then
      "exquo": (% ,R) -> Union(%, "failed")
      ++ exquo(p,r) returns the exact quotient of polynomial p by r,
      ++ or "failed" if none exists.
    if R has GcdDomain then
      content: % -> R
        ++ content(p) gives the gcd of the coefficients of polynomial p.
      primitivePart: % -> %
        ++ primitivePart(p) returns the unit normalized form of polynomial p
        ++ divided by the content of p.
  add
    pomopo!(p1,r,e,p2) == p1 + r * mapExponents(x1+>x1+e,p2)

    if R has CommutativeRing then
      binomThmExpt(x,y,nn) ==
        nn = 0 => 1$%
        ans,xn,yn: %

```

```

        bincoef: Integer
        powl: List(%):= [x]
        for i in 2..nn repeat powl:=[x * powl.first, :powl]
        yn:=y; ans:=powl.first; i:=1; bincoef:=nn
        for xn in powl.rest repeat
            ans:= bincoef * xn * yn + ans
            bincoef:= (nn-i) * bincoef quo (i+1); i:= i+1
            -- last I and BINCOEF unused
            yn:= y * yn
            ans + yn
ground? x ==
    retractIfCan(x)@Union(R,"failed") case "failed" => false
    true

ground x == retract(x)@R

mapExponents (fn:E -> E, x: %) ==
    -- this default definition assumes that reductum is cheap
    zero? x => 0
    monomial(leadingCoefficient x,fn degree x)+mapExponents(fn,reductum x)

coefficients x ==
    zero? x => empty()
    concat(leadingCoefficient x, coefficients reductum x)

if R has Field then
    x/r == map(x1+>x1/r,x)

if R has IntegralDomain then
    x exquo r ==
        -- probably not a very good definition in most special cases
        zero? x => 0
        ans:% :=0
        t:=leadingCoefficient x exquo r
        while not (t case "failed") and not zero? x repeat
            ans:=ans+monomial(t::R,degree x)
            x:=reductum x
            if not zero? x then t:=leadingCoefficient x exquo r
        t case "failed" => "failed"
        ans

if R has GcdDomain then
    content x == -- this assumes reductum is cheap
        zero? x => 0
        r:=leadingCoefficient x
        x:=reductum x
--        while not zero? x and not one? r repeat
        while not zero? x and not (r = 1) repeat
            r:=gcd(r,leadingCoefficient x)
            x:=reductum x

```

r

```
primitivePart x ==
  zero? x => x
  c := content x
  unitCanonical((x exquo c)::%)
```

— FAMR.dotabb —

```
"FAMR"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FAMR"];
"FAMR" -> "AMR"
"FAMR" -> "FRETRCT"
```

— FAMR.dotfull —

```
"FiniteAbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FAMR"];
"FiniteAbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)"
"FiniteAbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "FullyRetractableTo(a:Ring)"

"FiniteAbelianMonoidRing(a:Ring,b:OrderedAbelianMonoidSup)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FAMR"];
"FiniteAbelianMonoidRing(a:Ring,b:OrderedAbelianMonoidSup)" ->
  "FiniteAbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)"
```

— FAMR.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FiniteAbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" [color=lightblue];
  "FiniteAbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)"
  "FiniteAbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
```

```

"FullyRetractableTo(a:Ring)"

"FullyRetractableTo(a:Ring)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=FRETRACT"];
"FullyRetractableTo(a:Ring)" -> "FullyRetractableTo(a:Type)"

"FullyRetractableTo(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FRETRACT"];
"FullyRetractableTo(a:Type)" -> "RETRACT..."

"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" [color=lightblue];
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" -> "RING..."
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "BIMODULE..."
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "IntegralDomain()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "CharacteristicNonZero()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "CommutativeRing()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "Algebra(Fraction(Integer))"

"IntegralDomain()" [color=lightblue];
"IntegralDomain()" -> "CommutativeRing()"
"IntegralDomain()" -> "Algebra(a:CommutativeRing)"
"IntegralDomain()" -> "EntireRing()"

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BIMODULE..."

"CharacteristicNonZero()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CHARNZ"];
"CharacteristicNonZero()" -> "RING..."

"Algebra(Fraction(Integer))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(Fraction(Integer))" -> "Algebra(a:CommutativeRing)"

"Algebra(a:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "MODULE..."

"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BIMODULE..."

"RETRACT..." [color=lightblue];

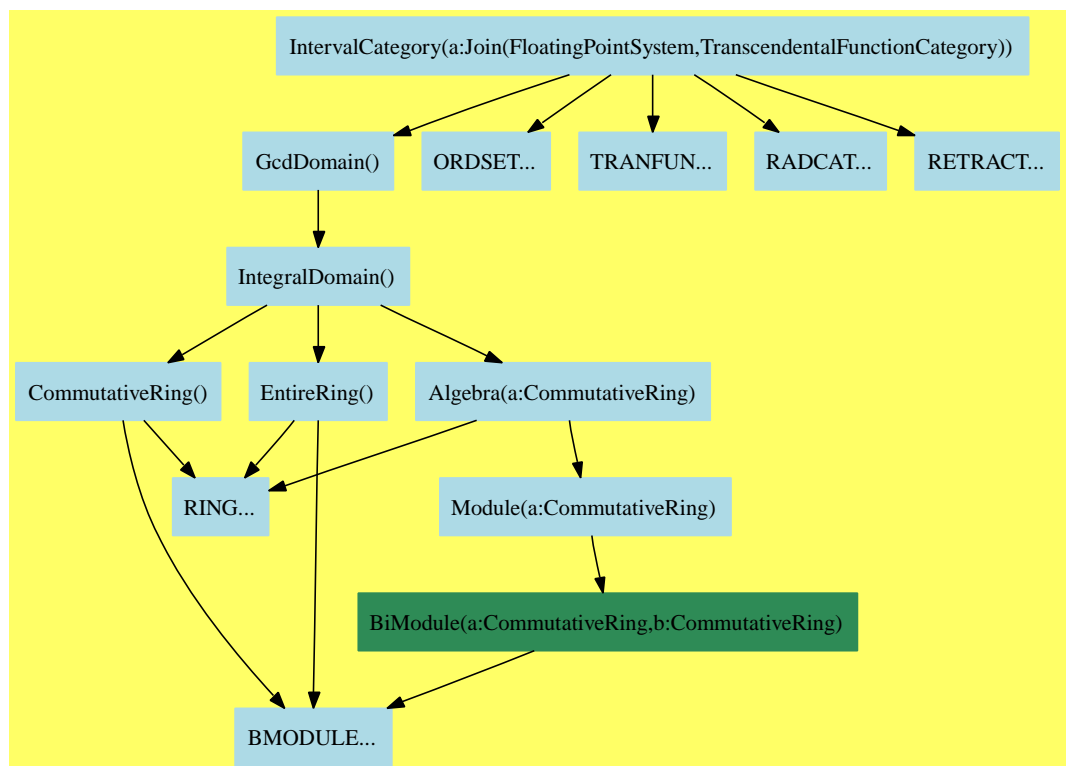
```

```

"BIMODULE..." [color=lightblue];
"RING..." [color=lightblue];
"MODULE..." [color=lightblue];
}

```

IntervalCategory (INTCAT)



— IntervalCategory.input —

```

)set break resume
)sys rm -f IntervalCategory.output
)spool IntervalCategory.output
)set message test on
)set message auto off
)clear all

```

```

--S 1 of 1
)show IntervalCategory
--R
--R IntervalCategory(R: Join(FloatingPointSystem,TranscendentalFunctionCategory)) is a category constructor
--R Abbreviation for IntervalCategory is INTCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for INTCAT
--R
--R----- Operations -----
--R ?? : (%,% ) -> %
--R ?? : (PositiveInteger,% ) -> %
--R ??? : (% ,PositiveInteger) -> %
--R ?-? : (%,% ) -> %
--R ?<? : (%,% ) -> Boolean
--R ?=? : (%,% ) -> Boolean
--R ?>=? : (%,% ) -> Boolean
--R 0 : () -> %
--R acos : % -> %
--R acot : % -> %
--R acsc : % -> %
--R asec : % -> %
--R asin : % -> %
--R associates? : (%,% ) -> Boolean
--R atanh : % -> %
--R coerce : % -> %
--R coerce : % -> OutputForm
--R cos : % -> %
--R cot : % -> %
--R csc : % -> %
--R exp : % -> %
--R gcd : (%,% ) -> %
--R inf : % -> R
--R interval : R -> %
--R latex : % -> String
--R lcm : (%,% ) -> %
--R max : (%,% ) -> %
--R negative? : % -> Boolean
--R one? : % -> Boolean
--R positive? : % -> Boolean
--R recip : % -> Union(%,"failed")
--R sample : () -> %
--R sech : % -> %
--R sinh : % -> %
--R sup : % -> R
--R tanh : % -> %
--R unitCanonical : % -> %
--R zero? : % -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,Fraction(Integer)) -> %
?? : (Integer,% ) -> %
??? : (%,% ) -> %
?+? : (%,% ) -> %
-? : % -> %
?<=? : (%,% ) -> Boolean
?>? : (%,% ) -> Boolean
1 : () -> %
?^? : (% ,PositiveInteger) -> %
acosh : % -> %
acoth : % -> %
acsch : % -> %
asech : % -> %
asinh : % -> %
atan : % -> %
coerce : Integer -> %
coerce : Integer -> %
contains? : (% ,R) -> Boolean
cosh : % -> %
coth : % -> %
csch : % -> %
gcd : List(% ) -> %
hash : % -> SingleInteger
interval : Fraction(Integer) -> %
interval : (R,R) -> %
lcm : List(% ) -> %
log : % -> %
min : (%,% ) -> %
nthRoot : (% ,Integer) -> %
pi : () -> %
qinterval : (R,R) -> %
retract : % -> Integer
sec : % -> %
sin : % -> %
sqrt : % -> %
tan : % -> %
unit? : % -> Boolean
width : % -> R
?~=? : (%,% ) -> Boolean

```



```

--R ??? : (% , NonNegativeInteger) -> %
--R ?^? : (% , NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R exquo : (% , %) -> Union(%, "failed")
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R retractIfCan : % -> Union(Integer, "failed")
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— IntervalCategory.help —

IntervalCategory examples

This category implements of interval arithmetic and transcendental functions over intervals.

See Also:

o)show IntervalCategory

See:

- ⇐ “GcdDomain” (GCDDOM) [13](#) on page [1179](#)
- ⇐ “OrderedSet” (ORDSET) [4](#) on page [269](#)
- ⇐ “RadicalCategory” (RADCAT) [2](#) on page [92](#)
- ⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)
- ⇐ “TranscendentalFunctionCategory” (TRANFUN) [3](#) on page [166](#)

Exports:

| | | | | |
|----------------|---------------|---------------|---------|--------------|
| 0 | 1 | acos | acosh | acot |
| acoth | acsc | acsch | asec | asech |
| asin | asinh | associates? | atan | atanh |
| characteristic | coerce | contains? | cos | cosh |
| cot | coth | csc | csch | exp |
| exquo | gcd | gcdPolynomial | hash | inf |
| interval | latex | lcm | log | max |
| min | negative? | nthRoot | one? | pi |
| positive? | qinterval | recip | retract | retractIfCan |
| sample | sec | sech | sin | sinh |
| sqrt | subtractIfCan | sup | tan | tanh |
| unit? | unitCanonical | unitNormal | width | zero? |
| ?*? | ?*? | ?+? | ?-? | -? |
| ?<? | ?<=? | ?=? | ?>? | ?>=? |
| ?^? | ?~=? | | | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **approximate** means “is an approximation to the real numbers”.

TPDHERE: Note that the signature **coerce** : **Integer** -> % shows up twice.

These are directly exported but not implemented:

```
contains? : (% , R) -> Boolean
inf : % -> R
interval : (R, R) -> %
interval : R -> %
interval : Fraction Integer -> %
negative? : % -> Boolean
positive? : % -> Boolean
qinterval : (R, R) -> %
sup : % -> R
width : % -> R
```

These exports come from (p1179) GcdDomain():

```

0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
exquo : (%,%) -> Union(%, "failed")
gcd : (%,%) -> %
gcd : List % -> %
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
hash : % -> SingleInteger
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
?*?* : (%, PositiveInteger) -> %
?*?* : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
?^? : (%, NonNegativeInteger) -> %

```

These exports come from (p269) `OrderedSet()`:

```

max : (%,%) -> %
min : (%,%) -> %
?<=? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean
?<? : (%,%) -> Boolean

```

These exports come from (p166) `TranscendentalFunctionCategory()`:

```

acos : % -> %
acosh : % -> %
acot : % -> %
acoth : % -> %
acsc : % -> %
acsch : % -> %
asec : % -> %
asech : % -> %
asin : % -> %
asinh : % -> %
atan : % -> %
atanh : % -> %
cos : % -> %
cosh : % -> %
cot : % -> %
coth : % -> %
csc : % -> %
csch : % -> %
exp : % -> %
log : % -> %
pi : () -> %
sec : % -> %
sech : % -> %
sin : % -> %
sinh : % -> %
tan : % -> %
tanh : % -> %
***? : (%,% ) -> %

```

These exports come from (p92) RadicalCategory():

```

nthRoot : (%,Integer) -> %
sqrt : % -> %
***? : (% ,Fraction Integer) -> %

```

These exports come from (p95) RetractableTo(Integer):

```

coerce : Integer -> %
retract : % -> Integer
retractIfCan : % -> Union(Integer,"failed")

```

— category INTCAT IntervalCategory —

```

)abbrev category INTCAT IntervalCategory
++ Author: Mike Dewar
++ Date Created: November 1996
++ Description:
++ This category implements of interval arithmetic and transcendental

```

++ functions over intervals.

```
IntervalCategory(R: Join(FloatingPointSystem,TranscendentalFunctionCategory)):
Category == _
  Join(GcdDomain, OrderedSet, TranscendentalFunctionCategory, _
    RadicalCategory, RetractableTo(Integer)) with
approximate
interval : (R,R) -> %
  ++ interval(inf,sup) creates a new interval, either \axiom{[inf,sup]} if
  ++ \axiom{inf <= sup} or \axiom{[sup,in]} otherwise.
qinterval : (R,R) -> %
  ++ qinterval(inf,sup) creates a new interval \axiom{[inf,sup]}, without
  ++ checking the ordering on the elements.
interval : R -> %
  ++ interval(f) creates a new interval around f.
interval : Fraction Integer -> %
  ++ interval(f) creates a new interval around f.
inf : % -> R
  ++ inf(u) returns the infimum of \axiom{u}.
sup : % -> R
  ++ sup(u) returns the supremum of \axiom{u}.
width : % -> R
  ++ width(u) returns \axiom{sup(u) - inf(u)}.
positive? : % -> Boolean
  ++ positive?(u) returns \axiom{true} if every element of u is positive,
  ++ \axiom{false} otherwise.
negative? : % -> Boolean
  ++ negative?(u) returns \axiom{true} if every element of u is negative,
  ++ \axiom{false} otherwise.
contains? : (% ,R) -> Boolean
  ++ contains?(i,f) returns true if \axiom{f} is contained within the
  ++ interval \axiom{i}, false otherwise.
```

— INTCAT.dotabb —

```
"INTCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=INTCAT"];
"INTCAT" -> "GCDDOM"
"INTCAT" -> "ORDSET"
"INTCAT" -> "RADCAT"
"INTCAT" -> "RETRACT"
"INTCAT" -> "TRANFUN"
```

— INTCAT.dotfull —

```

"IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
  [color=lightblue, href="bookvol10.2.pdf#nameddest=INTCAT"];
"IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
  -> "GcdDomain()"
"IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
  -> "OrderedSet()"
"IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
  -> "TranscendentalFunctionCategory()"
"IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
  -> "RadicalCategory()"
"IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
  -> "RetractableTo(Integer)"

```

— INTCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
    [color=lightblue];
  "IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
    -> "GcdDomain()"
  "IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
    -> "ORDSET..."
  "IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
    -> "TRANFUN..."
  "IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
    -> "RADCAT..."
  "IntervalCategory(a: Join(FloatingPointSystem, TranscendentalFunctionCategory))"
    -> "RETRACT..."

  "GcdDomain()" [color=lightblue];
  "GcdDomain()" -> "IntegralDomain()"

  "IntegralDomain()" [color=lightblue];
  "IntegralDomain()" -> "CommutativeRing()"
  "IntegralDomain()" -> "Algebra(a: CommutativeRing)"
  "IntegralDomain()" -> "EntireRing()"

  "CommutativeRing()" [color=lightblue];
  "CommutativeRing()" -> "RING..."
  "CommutativeRing()" -> "BMODULE..."

```

```

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BMODULE..."

"Algebra(a:CommutativeRing)" [color=lightblue];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

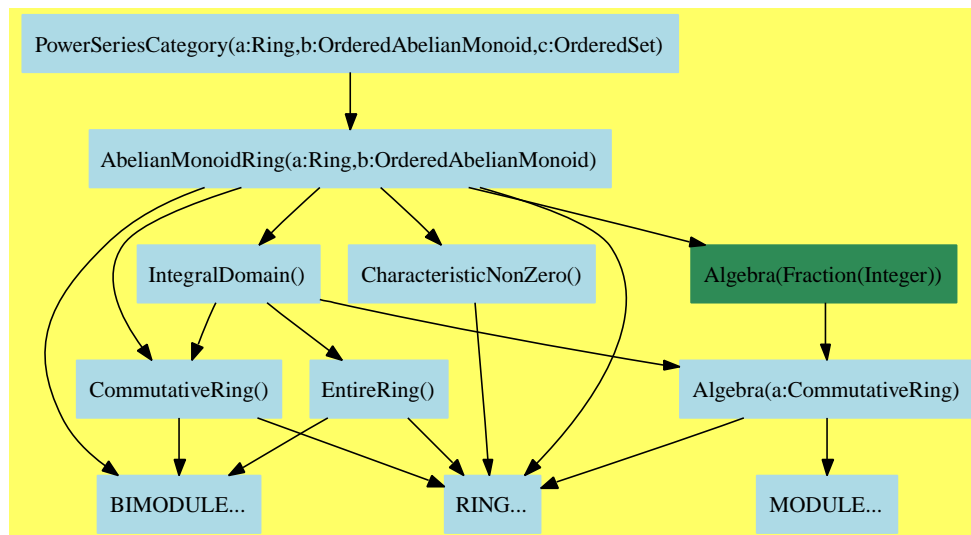
"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" ->
  "BiModule(a:CommutativeRing,b:CommutativeRing)"

"BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BMODULE..."

"RETRACT..." [color=lightblue];
"RADCAT..." [color=lightblue];
"TRANFUN..." [color=lightblue];
"ORDSET..." [color=lightblue];
"BMODULE..." [color=lightblue];
"RING..." [color=lightblue];
}

```

PowerSeriesCategory (PSCAT)



— PowerSeriesCategory.input —

```

)set break resume
)sys rm -f PowerSeriesCategory.output
)spool PowerSeriesCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PowerSeriesCategory
--R
--R PowerSeriesCategory(Coef: Ring, Expon: OrderedAbelianMonoid, Var: OrderedSet) is a category constructor
--R Abbreviation for PowerSeriesCategory is PSCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PSCAT
--R
--R----- Operations -----
--R ?? : (Coef, %) -> %          ?? : (% , Coef) -> %
--R ?? : (% , %) -> %          ?? : (Integer, %) -> %
--R ?? : (PositiveInteger, %) -> %   ??? : (% , PositiveInteger) -> %
--R ?+? : (% , %) -> %          ?-? : (% , %) -> %
--R -? : % -> %                ?=? : (% , %) -> Boolean
--R 1 : () -> %                0 : () -> %
--R ?? : (% , PositiveInteger) -> %   coefficient : (% , Expon) -> Coef
--R coerce : Integer -> %            coerce : % -> OutputForm
--R complete : % -> %              degree : % -> Expon
--R hash : % -> SingleInteger       latex : % -> String
--R leadingCoefficient : % -> Coef   leadingMonomial : % -> %
--R map : ((Coef -> Coef), %) -> %   monomial : (% , Var, Expon) -> %
--R monomial : (Coef, Expon) -> %    monomial? : % -> Boolean
--R one? : % -> Boolean              pole? : % -> Boolean
--R recip : % -> Union(%, "failed")   reductum : % -> %
--R sample : () -> %                 variables : % -> List(Var)
--R zero? : % -> Boolean              ?~=? : (% , %) -> Boolean
--R ?? : (% , Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (Fraction(Integer), %) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger, %) -> %
--R ??? : (% , NonNegativeInteger) -> %
--R ?/? : (% , Coef) -> % if Coef has FIELD
--R ?^? : (% , NonNegativeInteger) -> %
--R associates? : (% , %) -> Boolean if Coef has INTDOM
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
--R coerce : Coef -> % if Coef has COMRING
--R coerce : % -> % if Coef has INTDOM
--R coerce : Fraction(Integer) -> % if Coef has ALGEBRA(FRAC(INT))

```



```

--R exquo : (%,%) -> Union(%, "failed") if Coef has INTDOM
--R monomial : (%, List(Var), List(Expon)) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unit? : % -> Boolean if Coef has INTDOM
--R unitCanonical : % -> % if Coef has INTDOM
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %) if Coef has INTDOM
--R
--E 1

```

```

)spool
)lisp (bye)

```

— **PowerSeriesCategory.help** —

=====

PowerSeriesCategory examples

=====

PowerSeriesCategory is the most general power series category with exponents in an ordered abelian monoid.

See Also:

o)show PowerSeriesCategory

See:

⇒ “MultivariateTaylorSeriesCategory” (MTSCAT) [15](#) on page [1243](#)

⇒ “UnivariatePowerSeriesCategory” (UPSCAT) [15](#) on page [1260](#)

⇐ “AbelianMonoidRing” (AMR) [13](#) on page [1151](#)

Exports:

| | | | | |
|---------------|------------|--------------------|-----------------|------------|
| 0 | 1 | associates? | characteristic | charthRoot |
| coefficient | coerce | complete | degree | exquo |
| hash | latex | leadingCoefficient | leadingMonomial | map |
| monomial | monomial? | one? | pole? | recip |
| reductum | sample | subtractIfCan | variables | unit? |
| unitCanonical | unitNormal | zero? | ?*? | ?**? |
| ?+? | ?-? | -? | ?=? | ?~=? |
| ?/? | ?^? | | | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.

- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- if #1 has IntegralDomain then noZeroDivisors where **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- if #1 has CommutativeRing then commutative(“*”) where **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.

These are directly exported but not implemented:

```
complete : % -> %
degree : % -> Expon
leadingCoefficient : % -> Coef
leadingMonomial : % -> %
monomial : (% , List Var , List Expon) -> %
monomial : (% , Var , Expon) -> %
pole? : % -> Boolean
variables : % -> List Var
```

These are implemented by this category:

```
?*? : (Integer, %) -> %
?*? : (Coef, %) -> %
?*? : (% , Coef) -> %
?*? : (% , Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
?*? : (Fraction Integer, %) -> % if Coef has ALGEBRA FRAC INT
?/? : (% , Coef) -> % if Coef has FIELD
-? : % -> %
```

These exports come from (p1151) AbelianMonoidRing(Coef,Expon)
where Coef:Ring and Expon:OrderedAbelianMonoid:

```
0 : () -> %
1 : () -> %
associates? : (% , %) -> Boolean if Coef has INTDOM
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(% , "failed") if Coef has CHARNZ
coefficient : (% , Expon) -> Coef
coerce : Coef -> % if Coef has COMRING
coerce : Fraction Integer -> % if Coef has ALGEBRA FRAC INT
coerce : % -> % if Coef has INTDOM
coerce : % -> OutputForm
coerce : Integer -> %
exquo : (% , %) -> Union(% , "failed") if Coef has INTDOM
hash : % -> SingleInteger
latex : % -> String
map : ((Coef -> Coef), %) -> %
monomial : (Coef, Expon) -> %
```

```

monomial? : % -> Boolean
one? : % -> Boolean
recip : % -> Union(%, "failed")
reductum : % -> %
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
unit? : % -> Boolean if Coef has INTDOM
unitCanonical : % -> % if Coef has INTDOM
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
    if Coef has INTDOM
zero? : % -> Boolean
***? : (%, NonNegativeInteger) -> %
?^? : (%, NonNegativeInteger) -> %
+? : (%, %) -> %
=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
*? : (NonNegativeInteger, %) -> %
*? : (PositiveInteger, %) -> %
*? : (%, %) -> %
?-? : (%, %) -> %
***? : (%, PositiveInteger) -> %
?^? : (%, PositiveInteger) -> %

```

— category PSCAT PowerSeriesCategory —

```

)abbrev category PSCAT PowerSeriesCategory
++ Author: Clifton J. Williamson
++ Date Created: 21 December 1989
++ Date Last Updated: 25 February 1990
++ Description:
++ \spadtype{PowerSeriesCategory} is the most general power series
++ category with exponents in an ordered abelian monoid.

PowerSeriesCategory(Coef, Expon, Var): Category == Definition where
  Coef : Ring
  Expon : OrderedAbelianMonoid
  Var : OrderedSet
  I ==> Integer
  RN ==> Fraction Integer

Definition ==> AbelianMonoidRing(Coef, Expon) with
  monomial: (%, Var, Expon) -> %
    ++ \spad{monomial(a, x, n)} computes \spad{a*x**n}.
  monomial: (%, List Var, List Expon) -> %
    ++ \spad{monomial(a, [x1, ..., xk], [n1, ..., nk])} computes
    ++ \spad{a * x1**n1 * ... * xk**nk}.
  leadingMonomial: % -> %
    ++ leadingMonomial(f) returns the monomial of \spad{f} of lowest order.
  leadingCoefficient: % -> Coef

```

```

    ++ leadingCoefficient(f) returns the coefficient of the lowest order
    ++ term of \spad{f}
degree : % -> Expon
    ++ degree(f) returns the exponent of the lowest order term of \spad{f}.
variables: % -> List Var
    ++ \spad{variables(f)} returns a list of the variables occuring in the
    ++ power series f.
pole?: % -> Boolean
    ++ \spad{pole?(f)} determines if the power series f has a pole.
complete: % -> %
    ++ \spad{complete(f)} causes all terms of f to be computed.
    ++ Note that this results in an infinite loop
    ++ if f has infinitely many terms.

add
n:I    * ps:% == (zero? n => 0; map((r1:Coef):Coef +-> n * r1,ps))

r:Coef * ps:% == (zero? r => 0; map((r1:Coef):Coef +-> r * r1,ps))

ps:% * r:Coef == (zero? r => 0; map((r1:Coef):Coef +-> r1 * r,ps))

- ps          == map((r1:Coef):Coef +-> -r1,ps)

if Coef has Algebra Fraction Integer then
    r:RN * ps:% == (zero? r => 0; map((r1:Coef):Coef +-> r * r1,ps))

    ps:% * r:RN == (zero? r => 0; map((r1:Coef):Coef +-> r1 * r,ps))

if Coef has Field then
    ps:% / r:Coef == map((r1:Coef):Coef +-> r1 / r,ps)



---



— PSCAT.dotabb —

"PSCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PSCAT"];
"PSCAT" -> "AMR"



---



— PSCAT.dotfull —

"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PSCAT"];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)" ->

```

```

"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)"

"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=PSCAT"];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
  -> "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"

"PowerSeriesCategory(a:Ring,IndexedExponents(b:OrderedSet),c:OrderedSet)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=PSCAT"];
"PowerSeriesCategory(a:Ring,IndexedExponents(b:OrderedSet),c:OrderedSet)"
  -> "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"

```

— PSCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"
  [color=lightblue];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)" ->
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)"

"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" [color=lightblue];
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" -> "RING..."
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "BIMODULE..."
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "IntegralDomain()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "CharacteristicNonZero()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "CommutativeRing()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "Algebra(Fraction(Integer))"

"IntegralDomain()" [color=lightblue];
"IntegralDomain()" -> "CommutativeRing()"
"IntegralDomain()" -> "Algebra(a:CommutativeRing)"
"IntegralDomain()" -> "EntireRing()"

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BIMODULE..."

```

```

"CharacteristicNonZero()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CHARNZ"];
"CharacteristicNonZero()" -> "RING..."

"Algebra(Fraction(Integer))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(Fraction(Integer))" -> "Algebra(a:CommutativeRing)"

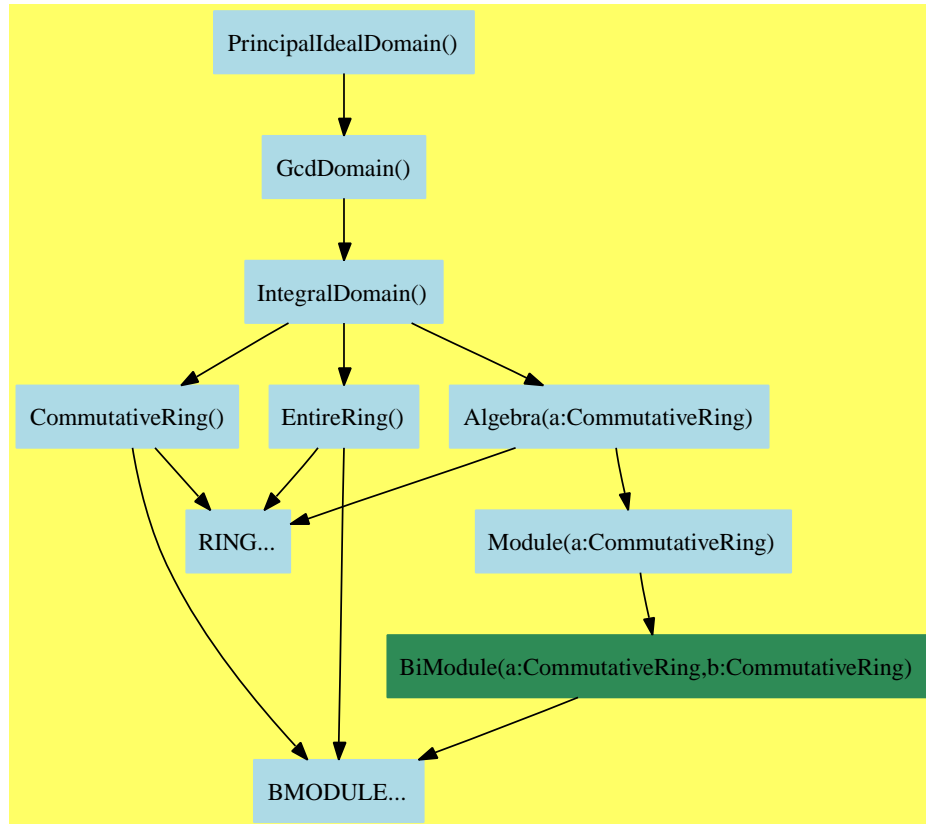
"Algebra(a:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "MODULE..."

"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BIMODULE..."

"BIMODULE..." [color=lightblue];
"RING..." [color=lightblue];
"MODULE..." [color=lightblue];
}

```

PrincipalIdealDomain (PID)



— PrincipalIdealDomain.input —

```

)set break resume
)sys rm -f PrincipalIdealDomain.output
)spool PrincipalIdealDomain.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PrincipalIdealDomain
--R
--R PrincipalIdealDomain is a category constructor
--R Abbreviation for PrincipalIdealDomain is PID
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PID
--R

```

```

--R----- Operations -----
--R ?? : (%,% ) -> %          ?? : (Integer,% ) -> %
--R ?? : (PositiveInteger,% ) -> %    ??? : (% ,PositiveInteger) -> %
--R ?? : (%,% ) -> %          ?-? : (%,% ) -> %
--R -? : % -> %              ?=? : (%,% ) -> Boolean
--R 1 : () -> %              0 : () -> %
--R ?? : (% ,PositiveInteger) -> %    associates? : (%,% ) -> Boolean
--R coerce : % -> %            coerce : Integer -> %
--R coerce : % -> OutputForm      gcd : List(% ) -> %
--R gcd : (%,% ) -> %            hash : % -> SingleInteger
--R latex : % -> String          lcm : List(% ) -> %
--R lcm : (%,% ) -> %            one? : % -> Boolean
--R recip : % -> Union(% ,"failed")    sample : () -> %
--R unit? : % -> Boolean          unitCanonical : % -> %
--R zero? : % -> Boolean          ?~=? : (%,% ) -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ?? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R expressIdealMember : (List(% ),% ) -> Union(List(% ),"failed")
--R exquo : (%,% ) -> Union(% ,"failed")
--R gcdPolynomial : (SparseUnivariatePolynomial(% ),SparseUnivariatePolynomial(% )) -> SparseUnivariatePolynomial(% )
--R principalIdeal : List(% ) -> Record(coef: List(% ),generator: % )
--R subtractIfCan : (%,% ) -> Union(% ,"failed")
--R unitNormal : % -> Record(unit: % ,canonical: % ,associate: % )
--R
--E 1

)spool
)lisp (bye)

```

— PrincipalIdealDomain.help —

PrincipalIdealDomain examples

The category of constructive principal ideal domains, i.e. where a single generator can be constructively found for any ideal given by a finite set of generators. Note that this constructive definition only implies that finitely generated ideals are principal. It is not clear what we would mean by an infinitely generated ideal.

See Also:

o)show PrincipalIdealDomain

See:

Unique Factorization Domains are a subset of Principal Ideal Domains.

⇐ “UniqueFactorizationDomain” (UFD) [14](#) on page [1222](#) Principal Ideal Domains are a subset of Euclidean Domains.

⇒ “EuclideanDomain” (EUCDOM) [15](#) on page [1235](#)

⇐ “GcdDomain” (GCDDOM) [13](#) on page [1179](#)

Exports:

| | | | | |
|--------------------|---------------|-------------|----------------|------------|
| 0 | 1 | associates? | characteristic | coerce |
| expressIdealMember | exquo | gcd | gcdPolynomial | hash |
| latex | lcm | one? | principalIdeal | recip |
| sample | subtractIfCan | unit? | unitCanonical | unitNormal |
| zero? | ?+? | ?-? | -? | ?=? |
| ?~=? | ?*? | ?**? | ?^? | |

Attributes exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**(“”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```
expressIdealMember : (List %, %) -> Union(List %, "failed")
principalIdeal : List % -> Record(coef: List %, generator: %)
```

These exports come from (p[1179](#)) GcdDomain():

```
associates? : (%, %) -> Boolean
exquo : (%, %) -> Union(%, "failed")
gcd : (%, %) -> %
gcd : List % -> %
gcdPolynomial : (SparseUnivariatePolynomial %,
                  SparseUnivariatePolynomial %) ->
                  SparseUnivariatePolynomial %
lcm : List % -> %
lcm : (%, %) -> %
unit? : % -> Boolean
unitCanonical : % -> %
```

```

unitNormal : % -> Record(unit: %,canonical: %,associate: %)
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
?*?* : (%,PositiveInteger) -> %
?*?* : (%,NonNegativeInteger) -> %
?^? : (%,PositiveInteger) -> %
?^? : (%,NonNegativeInteger) -> %

```

— category PID PrincipalIdealDomain —

```

)abbrev category PID PrincipalIdealDomain
++ Description:
++ The category of constructive principal ideal domains, i.e.
++ where a single generator can be constructively found for
++ any ideal given by a finite set of generators.
++ Note that this constructive definition only implies that
++ finitely generated ideals are principal. It is not clear
++ what we would mean by an infinitely generated ideal.

PrincipalIdealDomain(): Category == GcdDomain with
  principalIdeal: List % -> Record(coef:List %,generator:%)
    ++ principalIdeal([f1,...,fn]) returns a record whose
    ++ generator component is a generator of the ideal
    ++ generated by \spad{[f1,...,fn]} whose coef component satisfies
    ++ \spad{generator = sum (input.i * coef.i)}
  expressIdealMember: (List %,%) -> Union(List %, "failed")
    ++ expressIdealMember([f1,...,fn],h) returns a representation
    ++ of h as a linear combination of the fi or "failed" if h
    ++ is not in the ideal generated by the fi.

```

— PID.dotabb —

```
"PID"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PID"];
"PID" -> "GCDDOM"
```

— PID.dotfull —

```
"PrincipalIdealDomain()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PID"];
"PrincipalIdealDomain()" -> "GcdDomain()"
```

— PID.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PrincipalIdealDomain()" [color=lightblue];
  "PrincipalIdealDomain()" -> "GcdDomain()"

  "GcdDomain()" [color=lightblue];
  "GcdDomain()" -> "IntegralDomain()"

  "IntegralDomain()" [color=lightblue];
  "IntegralDomain()" -> "CommutativeRing()"
  "IntegralDomain()" -> "Algebra(a:CommutativeRing)"
  "IntegralDomain()" -> "EntireRing()"

  "CommutativeRing()" [color=lightblue];
  "CommutativeRing()" -> "RING..."
  "CommutativeRing()" -> "BMODULE..."

  "EntireRing()" [color=lightblue];
  "EntireRing()" -> "RING..."
  "EntireRing()" -> "BMODULE..."
```

```

"Algebra(a:CommutativeRing)" [color=lightblue];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

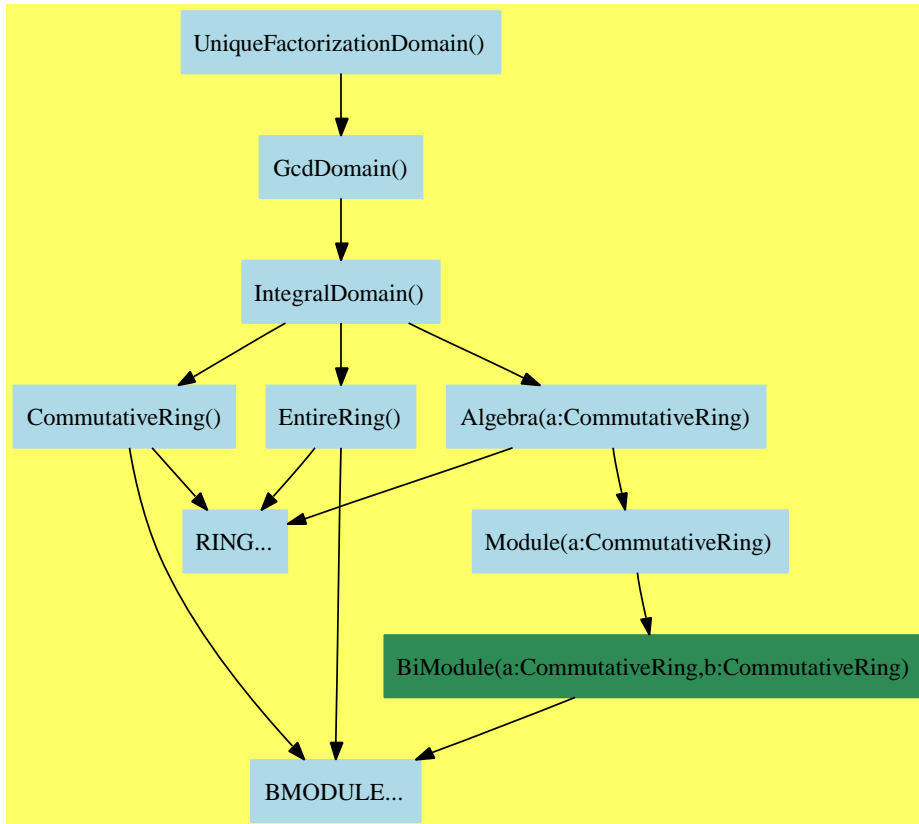
"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" ->
  "BiModule(a:CommutativeRing,b:CommutativeRing)"

"BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BMODULE..."

"BMODULE..." [color=lightblue];
"RING..." [color=lightblue];
}

```

UniqueFactorizationDomain (UFD)



— UniqueFactorizationDomain.input —

```

)set break resume
)sys rm -f UniqueFactorizationDomain.output
)spool UniqueFactorizationDomain.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show UniqueFactorizationDomain
--R
--R UniqueFactorizationDomain is a category constructor
--R Abbreviation for UniqueFactorizationDomain is UFD
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for UFD
--R

```

```

--R----- Operations -----
--R ?? : (% , %) -> %
--R ?? : (PositiveInteger, %) -> %
--R ?? : (% , %) -> %
--R -? : % -> %
--R 1 : () -> %
--R ?? : (% , PositiveInteger) -> %
--R coerce : % -> %
--R coerce : % -> OutputForm
--R gcd : List(%) -> %
--R hash : % -> SingleInteger
--R lcm : List(%) -> %
--R one? : % -> Boolean
--R recip : % -> Union(%, "failed")
--R squareFree : % -> Factored(%)
--R unit? : % -> Boolean
--R zero? : % -> Boolean
--R ?? : (NonNegativeInteger, %) -> %
--R ??? : (% , NonNegativeInteger) -> %
--R ?? : (% , NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R exquo : (% , %) -> Union(%, "failed")
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— UniqueFactorizationDomain.help —

```

=====
UniqueFactorizationDomain examples
=====

```

A constructive unique factorization domain, i.e. where we can constructively factor members into a product of a finite number of irreducible elements.

See Also:

```
o )show UniqueFactorizationDomain
```

All Integral Domains are UniqueFactorizationDomains.

⇐ “IntegralDomain” (INTDOM) [12](#) on page [1097](#). Unique Factorization Domains are a subset of Principal Ideal Domains.

⇒ “PrincipalIdealDomain” (PID) [14](#) on page [1216](#)

See:

⇒ “Field” (FIELD) [16](#) on page [1271](#)

⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)

⇒ “PolynomialFactorizationExplicit” (PFECAT) [15](#) on page [1253](#)

⇐ “GcdDomain” (GCDDOM) [13](#) on page [1179](#)

Exports:

| | | | | |
|---------------|------------|----------------|----------------|--------|
| 0 | 1 | associates? | characteristic | coerce |
| exquo | factor | gcd | gcdPolynomial | hash |
| latex | lcm | one? | prime? | recip |
| sample | squareFree | squareFreePart | subtractIfCan | unit? |
| unitCanonical | unitNormal | zero? | ?*? | ?**? |
| ?+? | ?-? | -? | ?=? | ?~=? |
| ?^? | | | | |

Attributes exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**(“*****”) is true if it has an operation “*****” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
factor : % -> Factored %
squareFree : % -> Factored %
```

These are implemented by this category:

```
prime? : % -> Boolean
squareFreePart : % -> %
```

These exports come from (p[1179](#)) GcdDomain():

```
0 : () -> %
1 : () -> %
```

```

associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
exquo : (%,%) -> Union(%, "failed")
gcd : (%,%) -> %
gcd : List % -> %
gcdPolynomial : (SparseUnivariatePolynomial %,
                  SparseUnivariatePolynomial %) ->
                  SparseUnivariatePolynomial %
hash : % -> SingleInteger
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (NonNegativeInteger, %) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%, PositiveInteger) -> %
***? : (%, NonNegativeInteger) -> %
?? : (%, PositiveInteger) -> %
?? : (%, NonNegativeInteger) -> %

```

— category UFD UniqueFactorizationDomain —

```

)abbrev category UFD UniqueFactorizationDomain
++ Description:
++ A constructive unique factorization domain, i.e. where
++ we can constructively factor members into a product of
++ a finite number of irreducible elements.

UniqueFactorizationDomain(): Category == GcdDomain with
  prime?: % -> Boolean
  ++ prime?(x) tests if x can never be written as the product of two
  ++ non-units of the ring,

```



```

    ++ i.e., x is an irreducible element.
squareFree    : % -> Factored(%)
    ++ squareFree(x) returns the square-free factorization of x
    ++ i.e. such that the factors are pairwise relatively prime
    ++ and each has multiple prime factors.
squareFreePart: % -> %
    ++ squareFreePart(x) returns a product of prime factors of
    ++ x each taken with multiplicity one.
factor: % -> Factored(%)
    ++ factor(x) returns the factorization of x into irreducibles.
add
squareFreePart x ==
    unit(s := squareFree x) * _*/[f.factor for f in factors s]

prime? x == # factorList factor x = 1

```

— UFD.dotabb —

```

"UFD"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=UFD" ];
"UFD" -> "GCDDOM"

```

— UFD.dotfull —

```

"UniqueFactorizationDomain()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=UFD" ];
"UniqueFactorizationDomain()" -> "GcdDomain()"

```

— UFD.dotpic —

```

digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "UniqueFactorizationDomain()" [color=lightblue];
    "UniqueFactorizationDomain()" -> "GcdDomain()"

    "GcdDomain()" [color=lightblue];
}

```

```

"GcdDomain()" -> "IntegralDomain()"

"IntegralDomain()" [color=lightblue];
"IntegralDomain()" -> "CommutativeRing()"
"IntegralDomain()" -> "Algebra(a:CommutativeRing)"
"IntegralDomain()" -> "EntireRing()"

"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BMODULE..."

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BMODULE..."

"Algebra(a:CommutativeRing)" [color=lightblue];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" ->
    "BiModule(a:CommutativeRing,b:CommutativeRing)"

"BiModule(a:CommutativeRing,b:CommutativeRing)" [color=seagreen];
"BiModule(a:CommutativeRing,b:CommutativeRing)" -> "BMODULE..."

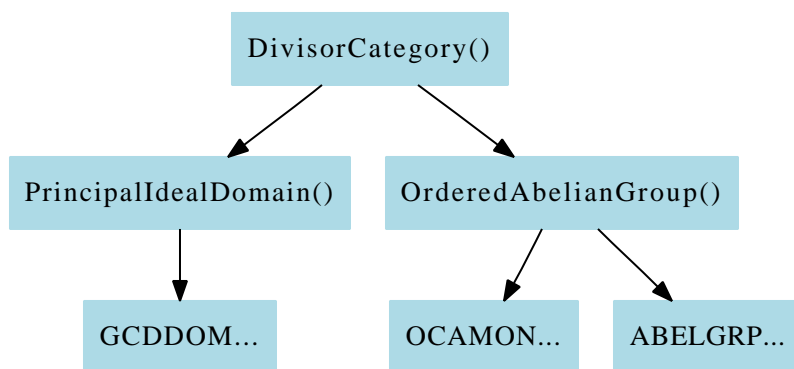
"BMODULE..." [color=lightblue];
"RING..." [color=lightblue];
}

```

Chapter 15

Category Layer 14

DivisorCategory (DIVCAT)



— DivisorCategory.input —

```
)set break resume
)sys rm -f DivisorCategory.output
)spool DivisorCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show DivisorCategory
--R
--R DivisorCategory(S: SetCategory) is a category constructor
--R Abbreviation for DivisorCategory is DIVCAT
--R This constructor is exposed in this frame.
```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DIVCAT
--R
--R----- Operations -----
--R ?? : (Integer,S) -> %           ?? : (Integer,%) -> %
--R ?? : (%,Integer) -> %           ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ?+? : (S,%) -> %
--R ?+? : (%,%) -> %               ?-? : (%,%) -> %
--R -? : % -> %                   ?<=? : (%,%) -> Boolean
--R ?=? : (%,%) -> Boolean         0 : () -> %
--R coefficient : (S,%) -> Integer  coerce : S -> %
--R coerce : % -> OutputForm       collect : % -> %
--R concat : (%,%) -> %           degree : % -> Integer
--R divOfPole : % -> %            divOfZero : % -> %
--R effective? : % -> Boolean     hash : % -> SingleInteger
--R incr : % -> %                 latex : % -> String
--R mapGen : ((S -> S),%) -> %    nthCoef : (%,Integer) -> Integer
--R nthFactor : (%,Integer) -> S  retract : % -> S
--R sample : () -> %              size : % -> NonNegativeInteger
--R split : % -> List(%)          supp : % -> List(S)
--R suppOfPole : % -> List(S)     suppOfZero : % -> List(S)
--R zero? : % -> Boolean          ?^=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R highCommonTerms : (%,%) -> % if Integer has OAMON
--R mapCoef : ((Integer -> Integer),%) -> %
--R retractIfCan : % -> Union(S,"failed")
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R terms : % -> List(Record(gen: S,exp: Integer))
--R
--E 1

```

```

)spool
)lisp (bye)

```

— DivisorCategory.help —

DivisorCategory examples

This category exports the function for domains.

See Also:
o)show DivisorCategory

See:

← “OrderedAbelianGroup” (OAGROUP) [9](#) on page [811](#)

← “PrincipalIdealDomain” (PID) [14](#) on page [1216](#)

Exports:

| | | | |
|-------------|-----------------|-----------|------------|
| 0 | -? | ?*? | ?+? |
| ?-? | ?<=? | ?=? | ?~=? |
| coefficient | coerce | collect | concat |
| degree | divOfPole | divOfZero | effective? |
| hash | highCommonTerms | incr | latex |
| mapCoef | mapGen | nthCoef | nthFactor |
| retract | retractIfCan | sample | size |
| split | subtractIfCan | supp | suppOfPole |
| suppOfZero | terms | zero? | |

These operations are exported but not implemented:

```
?<=? : (%,% ) -> Boolean
collect : % -> %
concat : (%,% ) -> %
degree : % -> Integer
divOfPole : % -> %
divOfZero : % -> %
effective? : % -> Boolean
incr : % -> %
split : % -> List %
supp : % -> List S
suppOfPole : % -> List S
suppOfZero : % -> List S
```

These operations come from (p[574](#)) AbelianGroup:

```
0 : () -> %
-? : % -> %
?*? : (Integer,% ) -> %
?*? : (NonNegativeInteger,% ) -> %
?*? : (PositiveInteger,% ) -> %
?+? : (%,% ) -> %
?-? : (%,% ) -> %
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
sample : () -> %
subtractIfCan : (%,% ) -> Union(%, "failed")
zero? : % -> Boolean
```

These operations come from (p[928](#)) Module(Integer):

```

?? : (Integer,%) -> %
?? : (%,Integer) -> %

```

These operations come from (p617) `FreeAbelianMonoidCategory(S: SetCategory,E: CancellationAbelianMonoid)`

```

?? : (E,S) -> %
?+? : (S,%) -> %
coefficient : (S,%) -> E
coerce : S -> %
highCommonTerms : (%,% ) -> % if E has OAMON
mapCoef : ((E -> E),%) -> %
mapGen : ((S -> S),%) -> %
nthCoef : (%,Integer) -> E
nthFactor : (%,Integer) -> S
retract : % -> S
retractIfCan : % -> Union(S,"failed")
size : % -> NonNegativeInteger
terms : % -> List Record(gen: S,exp: E)

```

— category DIVCAT DivisorCategory —

```

)abbrev category DIVCAT DivisorCategory
++ Authors: Gaetan Hache
++ Date Created: may 1997
++ Date Last Updated: April 2010, by Tim Daly
++ Description: This category exports the function for domains
DivisorCategory(S:SetCategory):Category == Exports where

INT      ==> Integer
BOOLEAN ==> Boolean
LIST     ==> List

Exports ==> _
  Join(AbelianGroup,Module Integer,FreeAbelianMonoidCategory(S,Integer)) with

  degree: % -> INT
    ++ degree(d) returns the degree of the divisor d

  split: % -> List %
    ++ split(d) splits the divisor d. For example,
    ++ split( 2 p1 + 3p2 ) returns the list [ 2 p1, 3 p2 ].

  "<=" : (%,% ) -> BOOLEAN

  collect: % -> %
    ++ collect collects the duplicative points in the divisor.

```

```

concat: (%,% ) -> %
  ++ concat(a,b) concats the divisor a and b
  ++ without collecting the duplicative points.

effective?: % -> BOOLEAN
  ++ effective?(d) returns true if d >= 0.

supp: % -> LIST(S)
  ++ supp(d) returns the support of the divisor d.

suppOfZero: % -> LIST(S)
  ++ suppOfZero(d) returns the elements of the support of d that
  ++ have a positive coefficient.

suppOfPole: % -> LIST(S)
  ++ suppOfZero(d) returns the elements of the support of d that
  ++ have a negative coefficient.

divOfZero: % -> %
  ++ divOfZero(d) returns the positive part of d.

divOfPole: % -> %
  ++ divOfPole(d) returns the negative part of d.

incr: % -> %

```

— DIVCAT.dotabb —

```

"DIVCAT" [color=lightblue,href="bookvol10.2.pdf#nameddest=DIVCAT"];
"OAGROUP" [color=lightblue,href="bookvol10.2.pdf#nameddest=OAGROUP"];
"PID" [color=lightblue,href="bookvol10.2.pdf#nameddest=PID"];
"DIVCAT" -> "OAGROUP"
"DIVCAT" -> "PID"

```

— DIVCAT.dotfull —

```

"DivisorCategory()" [color=lightblue,href="bookvol10.2.pdf#nameddest=DIVCAT"];
"DivisorCategory()" -> "PrincipalIdealDomain()"

```

— DIVCAT.dotpic —


```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "DivisorCategory()" [color=lightblue];
  "DivisorCategory()" -> "PrincipalIdealDomain()"
  "DivisorCategory()" -> "OrderedAbelianGroup()"

  "PrincipalIdealDomain()" [color=lightblue];
  "PrincipalIdealDomain()" -> "GCDDOM..."

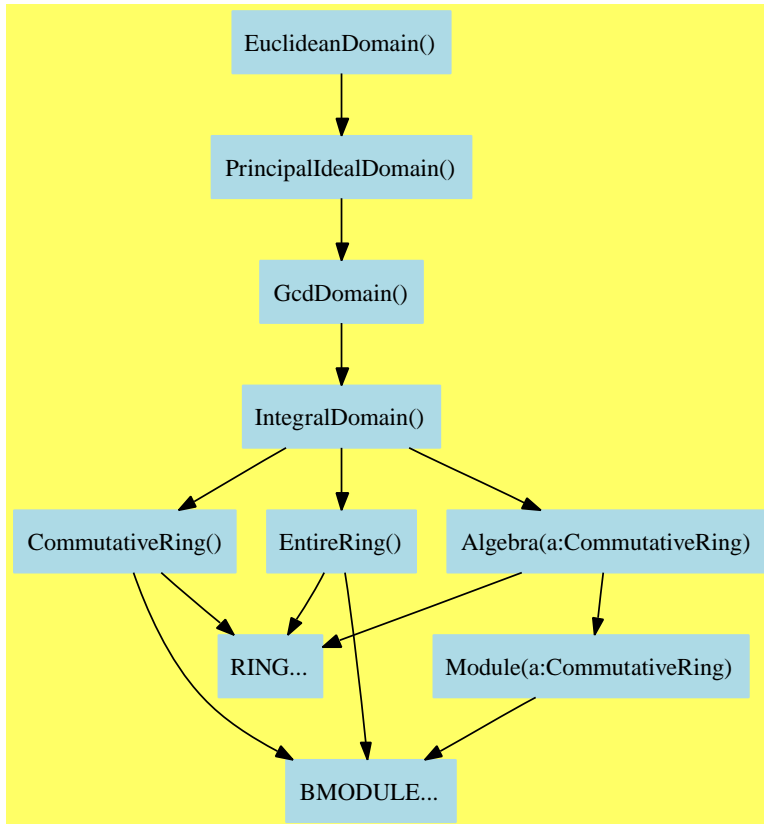
  "OrderedAbelianGroup()" [color=lightblue];
  "OrderedAbelianGroup()" -> "OCAMON..."
  "OrderedAbelianGroup()" -> "ABELGRP..."

  "GCDDOM..." [color=lightblue];
  "OCAMON..." [color=lightblue];
  "ABELGRP..." [color=lightblue];

}

```

EuclideanDomain (EUCDOM)



— EuclideanDomain.input —

```

)set break resume
)sys rm -f EuclideanDomain.output
)spool EuclideanDomain.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show EuclideanDomain
--R
--R EuclideanDomain is a category constructor
--R Abbreviation for EuclideanDomain is EUCDOM
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for EUCDOM
--R

```

```

--R----- Operations -----
--R ?? : (%,% ) -> %           ?? : (Integer,% ) -> %
--R ?? : (PositiveInteger,% ) -> %   ??? : (% ,PositiveInteger) -> %
--R +? : (%,% ) -> %           ?-? : (%,% ) -> %
--R -? : % -> %               ?=? : (%,% ) -> Boolean
--R 1 : () -> %               0 : () -> %
--R ^? : (% ,PositiveInteger) -> %   associates? : (%,% ) -> Boolean
--R coerce : % -> %           coerce : Integer -> %
--R coerce : % -> OutputForm       gcd : List(% ) -> %
--R gcd : (%,% ) -> %           hash : % -> SingleInteger
--R latex : % -> String         lcm : List(% ) -> %
--R lcm : (%,% ) -> %           one? : % -> Boolean
--R ?quo? : (%,% ) -> %         recip : % -> Union(% ,"failed")
--R ?rem? : (%,% ) -> %         sample : () -> %
--R sizeLess? : (%,% ) -> Boolean   unit? : % -> Boolean
--R unitCanonical : % -> %         zero? : % -> Boolean
--R ~=? : (%,% ) -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ^? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R divide : (%,% ) -> Record(quotient: % ,remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(% ),%) -> Union(List(% ),"failed")
--R exquo : (%,% ) -> Union(% ,"failed")
--R extendedEuclidean : (% ,% ,%) -> Union(Record(coef1: % ,coef2: % ),"failed")
--R extendedEuclidean : (%,% ) -> Record(coef1: % ,coef2: % ,generator: %)
--R gcdPolynomial : (SparseUnivariatePolynomial(% ),SparseUnivariatePolynomial(% )) -> SparseUniva
--R multiEuclidean : (List(% ),%) -> Union(List(% ),"failed")
--R principalIdeal : List(% ) -> Record(coef: List(% ),generator: %)
--R subtractIfCan : (%,% ) -> Union(% ,"failed")
--R unitNormal : % -> Record(unit: % ,canonical: % ,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— EuclideanDomain.help —

=====

EuclideanDomain examples

=====

A constructive euclidean domain, i.e. one can divide producing a quotient and a remainder where the remainder is either zero or is smaller (euclideanSize) than the divisor.

Conditional attributes:

```

multiplicativeValuation - Size(a*b)=Size(a)*Size(b)
additiveValuation      - Size(a*b)=Size(a)+Size(b)

```

Principal Ideal Domains are a subset of Euclidean Domains.
Euclidean Domains are a subset of Fields.

See Also:

o)show EuclideanDomain

⇐ “PrincipalIdealDomain” (PID) [14](#) on page [1216](#).

⇒ “Field” (FIELD) [16](#) on page [1271](#)

See:

⇒ “Field” (FIELD) [16](#) on page [1271](#)

⇒ “IntegerNumberSystem” (INS) [16](#) on page [1278](#)

⇒ “PAdicIntegerCategory” (PADICCT) [16](#) on page [1299](#)

⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)

⇐ “PrincipalIdealDomain” (PID) [14](#) on page [1216](#)

Exports:

| | | | | |
|----------------|---------------|--------------------|----------------|-------------------|
| 1 | 0 | associates? | characteristic | coerce |
| divide | euclideanSize | expressIdealMember | exquo | extendedEuclidean |
| gcd | gcdPolynomial | hash | latex | lcm |
| multiEuclidean | one? | principalIdeal | recip | sample |
| sizeLess? | subtractIfCan | unit? | unitCanonical | unitNormal |
| zero? | ?+? | ?-? | -? | ?=? |
| ?quo? | ?rem? | ?~=? | ?*? | ?**? |
| ?^? | | | | |

Attributes exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
```

These are implemented by this category:

```
expressIdealMember : (List %,%) -> Union(List %, "failed")
exquo : (%,%) -> Union(%, "failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
gcd : (%,%) -> %
multiEuclidean : (List %,%) -> Union(List %, "failed")
principalIdeal : List % -> Record(coef: List %,generator: %)
sizeLess? : (%,%) -> Boolean
?quo? : (%,%) -> %
?rem? : (%,%) -> %
```

These exports come from (p1216) `PrincipalIdealDomain()`:

```
0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
gcd : List % -> %
gcdPolynomial : (SparseUnivariatePolynomial %,
                  SparseUnivariatePolynomial %) ->
                  SparseUnivariatePolynomial %
hash : % -> SingleInteger
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
```

```

?? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%,PositiveInteger) -> %
***? : (%,NonNegativeInteger) -> %
?? : (%,PositiveInteger) -> %
?? : (%,NonNegativeInteger) -> %

```

— category EUCDOM EuclideanDomain —

```

)abbrev category EUCDOM EuclideanDomain
++ Description:
++ A constructive euclidean domain, i.e. one can divide producing
++ a quotient and a remainder where the remainder is either zero
++ or is smaller (\spadfun{euclideanSize}) than the divisor.
++
++ Conditional attributes\br
++ \tab{5}multiplicativeValuation\tab{5}Size(a*b)=Size(a)*Size(b)\br
++ \tab{5}additiveValuation\tab{11}Size(a*b)=Size(a)+Size(b)

EuclideanDomain(): Category == PrincipalIdealDomain with
sizeLess?: (%,%) -> Boolean
++ sizeLess?(x,y) tests whether x is strictly
++ smaller than y with respect to the
++ \spadfunFrom{euclideanSize}{EuclideanDomain}.
euclideanSize: % -> NonNegativeInteger
++ euclideanSize(x) returns the euclidean size of the element x.
++ Error: if x is zero.
divide: (%,%) -> Record(quotient:%,remainder:%)
++ divide(x,y) divides x by y producing a record containing a
++ \spad{quotient} and \spad{remainder},
++ where the remainder is smaller (see
++ \spadfunFrom{sizeLess?}{EuclideanDomain}) than the divisor y.
"quo" : (%,%) -> %
++ x quo y is the same as \spad{divide(x,y).quotient}.
++ See \spadfunFrom{divide}{EuclideanDomain}.
"rem": (%,%) -> %
++ x rem y is the same as \spad{divide(x,y).remainder}.
++ See \spadfunFrom{divide}{EuclideanDomain}.
extendedEuclidean: (%,%) -> Record(coef1:%,coef2:%,generator:%)
-- formerly called princIdeal
++ extendedEuclidean(x,y) returns a record rec where
++ \spad{rec.coef1*x+rec.coef2*y = rec.generator} and
++ rec.generator is a gcd of x and y.
++ The gcd is unique only
++ up to associates if \spadatt{canonicalUnitNormal} is not asserted.
++ \spadfun{principalIdeal} provides a version of this operation
++ which accepts an arbitrary length list of arguments.
extendedEuclidean: (%,%,%) -> Union(Record(coef1:%,coef2:%),"failed")

```

```

-- formerly called expressIdealElt
++ extendedEuclidean(x,y,z) either returns a record rec
++ where \spad{rec.coef1*x+rec.coef2*y=z} or returns "failed"
++ if z cannot be expressed as a linear combination of x and y.
multiEuclidean: (List %,%) -> Union(List %,"failed")
++ multiEuclidean([f1,...,fn],z) returns a list of coefficients
++ \spad{[a1, ..., an]} such that
++ \spad{ z / prod fi = sum aj/fj}.
++ If no such list of coefficients exists, "failed" is returned.
add
  x,y,z: %
  l: List %

  sizeLess?(x,y) ==
    zero? y => false
    zero? x => true
    euclideanSize(x)<euclideanSize(y)

  x quo y == divide(x,y).quotient --divide must be user-supplied

  x rem y == divide(x,y).remainder

  x exquo y ==
    zero? x => 0
    zero? y => "failed"
    qr:=divide(x,y)
    zero?(qr.remainder) => qr.quotient
    "failed"

  gcd(x,y) == --Euclidean Algorithm
    x:=unitCanonical x
    y:=unitCanonical y
    while not zero? y repeat
      (x,y):= (y,x rem y)
      y:=unitCanonical y -- this doesn't affect the
                        -- correctness of Euclid's algorithm,
                        -- but
                        -- a) may improve performance
                        -- b) ensures gcd(x,y)=gcd(y,x)
                        -- if canonicalUnitNormal

    x

  IdealElt ==> Record(coef1:%,coef2:%,generator:%)

  unitNormalizeIdealElt(s:IdealElt):IdealElt ==
    (u,c,a):=unitNormal(s.generator)
    (a = 1) => s
    [a*s.coef1,a*s.coef2,c]$IdealElt

  extendedEuclidean(x,y) == --Extended Euclidean Algorithm

```

```

s1:=unitNormalizeIdealElt([1$,0$,x]$IdealElt)
s2:=unitNormalizeIdealElt([0$,1$,y]$IdealElt)
zero? y => s1
zero? x => s2
while not zero?(s2.generator) repeat
  qr:= divide(s1.generator, s2.generator)
  s3:=[s1.coef1 - qr.quotient * s2.coef1,
      s1.coef2 - qr.quotient * s2.coef2, qr.remainder]$IdealElt
  s1:=s2
  s2:=unitNormalizeIdealElt s3
if not(zero?(s1.coef1)) and not sizeLess?(s1.coef1,y)
then
  qr:= divide(s1.coef1,y)
  s1.coef1:= qr.remainder
  s1.coef2:= s1.coef2 + qr.quotient * x
  s1 := unitNormalizeIdealElt s1
s1

TwoCoefs ==> Record(coef1:%,coef2:%)

extendedEuclidean(x,y,z) ==
  zero? z => [0,0]$TwoCoefs
  s:= extendedEuclidean(x,y)
  (w:= z exquo s.generator) case "failed" => "failed"
  zero? y => [s.coef1 * w, s.coef2 * w]$TwoCoefs
  qr:= divide((s.coef1 * w), y)
  [qr.remainder, s.coef2 * w + qr.quotient * x]$TwoCoefs

principalIdeal l ==
  l = [] => error "empty list passed to principalIdeal"
  rest l = [] =>
    uca:=unitNormal(first l)
    [[uca.unit],uca.canonical]
  rest rest l = [] =>
    u:= extendedEuclidean(first l,second l)
    [[u.coef1, u.coef2], u.generator]
  v:=principalIdeal rest l
  u:= extendedEuclidean(first l,v.generator)
  [[u.coef1,[u.coef2*vv for vv in v.coef]],u.generator]

expressIdealMember(l,z) ==
  z = 0 => [0 for v in l]
  pid := principalIdeal l
  (q := z exquo (pid.generator)) case "failed" => "failed"
  [q*v for v in pid.coef]

multiEuclidean(l,z) ==
  n := #l
  zero? n => error "empty list passed to multiEuclidean"
  n = 1 => [z]

```



```

l1 := copy l
l2 := split!(l1, n quo 2)
u:= extendedEuclidean(*l1, *l2, z)
u case "failed" => "failed"
v1 := multiEuclidean(l1,u.coef2)
v1 case "failed" => "failed"
v2 := multiEuclidean(l2,u.coef1)
v2 case "failed" => "failed"
concat(v1,v2)

```

— EUCDOM.dotabb —

```

"EUCDOM"
[color=lightblue,href="bookvol10.2.pdf#nameddest=EUCDOM"];
"EUCDOM" -> "PID"

```

— EUCDOM.dotfull —

```

"EuclideanDomain()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=EUCDOM"];
"EuclideanDomain()" -> "PrincipalIdealDomain()"

```

— EUCDOM.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "EuclideanDomain()" [color=lightblue];
  "EuclideanDomain()" -> "PrincipalIdealDomain()"

  "PrincipalIdealDomain()" [color=lightblue];
  "PrincipalIdealDomain()" -> "GcdDomain()"

  "GcdDomain()" [color=lightblue];
  "GcdDomain()" -> "IntegralDomain()"

  "IntegralDomain()" [color=lightblue];

```

```

"IntegralDomain()" -> "CommutativeRing()"
"IntegralDomain()" -> "Algebra(a:CommutativeRing)"
"IntegralDomain()" -> "EntireRing()"

"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BMODULE..."

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BMODULE..."

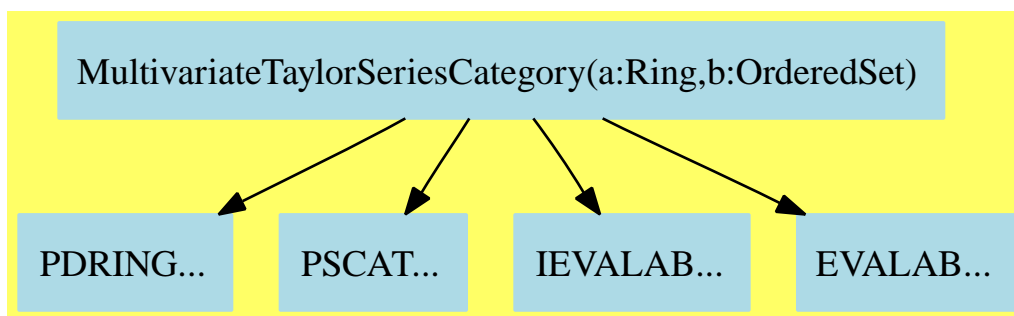
"Algebra(a:CommutativeRing)" [color=lightblue];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" -> "BMODULE..."

"BMODULE..." [color=lightblue];
"RING..." [color=lightblue];
}

```

MultivariateTaylorSeriesCategory (MTSCAT)



— MultivariateTaylorSeriesCategory.input —

```

)set break resume
)sys rm -f MultivariateTaylorSeriesCategory.output
)spool MultivariateTaylorSeriesCategory.output
)set message test on

```

```

)set message auto off
)clear all

--S 1 of 1
)show MultivariateTaylorSeriesCategory
--R
--R MultivariateTaylorSeriesCategory(Coef: Ring,Var: OrderedSet) is a category constructor
--R Abbreviation for MultivariateTaylorSeriesCategory is MTSCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MTSCAT
--R
--R----- Operations -----
--R ?? : (%,Coef) -> %           ?? : (Coef,%) -> %
--R ?? : (%,%) -> %             ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %             ?-? : (%,%) -> %
--R -? : % -> %                  ?=? : (%,%) -> Boolean
--R D : (%,List(Var)) -> %        D : (%,Var) -> %
--R 1 : () -> %                  0 : () -> %
--R ?^? : (%,PositiveInteger) -> %  coerce : Integer -> %
--R coerce : % -> OutputForm      complete : % -> %
--R differentiate : (%,Var) -> %   eval : (%,%,%) -> %
--R eval : (%,Equation(%)) -> %    eval : (%,Var,%) -> %
--R hash : % -> SingleInteger      latex : % -> String
--R leadingCoefficient : % -> Coef  leadingMonomial : % -> %
--R map : ((Coef -> Coef),%) -> %  monomial? : % -> Boolean
--R one? : % -> Boolean             pole? : % -> Boolean
--R recip : % -> Union(%, "failed") reductum : % -> %
--R sample : () -> %               variables : % -> List(Var)
--R zero? : % -> Boolean           ?~=? : (%,%) -> Boolean
--R ?? : (Fraction(Integer),%) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (%,Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (%,%) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,Coef) -> % if Coef has FIELD
--R D : (%,List(Var),List(NonNegativeInteger)) -> %
--R D : (%,Var,NonNegativeInteger) -> %
--R ?^? : (%,NonNegativeInteger) -> %
--R acos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acoth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asinh : % -> % if Coef has ALGEBRA(FRAC(INT))

```

```

--R associates? : (% , %) -> Boolean if Coef has INTDOM
--R atan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R atanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
--R coefficient : (% , List(Var) , List(NonNegativeInteger)) -> %
--R coefficient : (% , Var , NonNegativeInteger) -> %
--R coefficient : (% , IndexedExponents(Var)) -> Coef
--R coerce : Fraction(Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R coerce : % -> % if Coef has INTDOM
--R coerce : Coef -> % if Coef has COMRING
--R cos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R coth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R degree : % -> IndexedExponents(Var)
--R differentiate : (% , List(Var) , List(NonNegativeInteger)) -> %
--R differentiate : (% , Var , NonNegativeInteger) -> %
--R differentiate : (% , List(Var)) -> %
--R eval : (% , List(% ) , List(% )) -> %
--R eval : (% , List(Equation(% ))) -> %
--R eval : (% , List(Var) , List(% )) -> %
--R exp : % -> % if Coef has ALGEBRA(FRAC(INT))
--R exquo : (% , %) -> Union(%, "failed") if Coef has INTDOM
--R extend : (% , NonNegativeInteger) -> %
--R integrate : (% , Var) -> % if Coef has ALGEBRA(FRAC(INT))
--R log : % -> % if Coef has ALGEBRA(FRAC(INT))
--R monomial : (% , List(Var) , List(NonNegativeInteger)) -> %
--R monomial : (% , Var , NonNegativeInteger) -> %
--R monomial : (Coef , IndexedExponents(Var)) -> %
--R monomial : (% , Var , IndexedExponents(Var)) -> %
--R monomial : (% , List(Var) , List(IndexedExponents(Var))) -> %
--R nthRoot : (% , Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R order : (% , Var , NonNegativeInteger) -> NonNegativeInteger
--R order : (% , Var) -> NonNegativeInteger
--R pi : () -> % if Coef has ALGEBRA(FRAC(INT))
--R polynomial : (% , NonNegativeInteger , NonNegativeInteger) -> Polynomial(Coef)
--R polynomial : (% , NonNegativeInteger) -> Polynomial(Coef)
--R sec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sinh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sqrt : % -> % if Coef has ALGEBRA(FRAC(INT))
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R tan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R tanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R unit? : % -> Boolean if Coef has INTDOM
--R unitCanonical : % -> % if Coef has INTDOM

```

```
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if Coef has INTDOM
--R
--E 1

)spool
)lisp (bye)
```

— MultivariateTaylorSeriesCategory.help —

```
=====
MultivariateTaylorSeriesCategory examples
=====
```

MultivariateTaylorSeriesCategory is the most general multivariate Taylor series category.

See Also:

o)show MultivariateTaylorSeriesCategory

See:

⇐ “Evalable” (EVALAB) [3](#) on page [129](#)
 ⇐ “InnerEvalable” (IEVALAB) [2](#) on page [56](#)
 ⇐ “PartialDifferentialRing” (PDRING) [10](#) on page [939](#)
 ⇐ “PowerSeriesCategory” (PSCAT) [14](#) on page [1208](#)

Exports:

| | | | | |
|----------------|--------------------|-----------------|---------------|-----------|
| 0 | 1 | acos | acosh | acot |
| acoth | acsc | acsch | asec | asech |
| asin | asinh | associates? | atan | atanh |
| characteristic | charthRoot | coefficient | coerce | complete |
| cos | cosh | cot | coth | csc |
| csch | D | degree | differentiate | eval |
| exp | exquo | extend | hash | integrate |
| latex | leadingCoefficient | leadingMonomial | log | map |
| monomial | monomial? | nthRoot | order | one? |
| pi | pole? | polynomial | recip | reductum |
| sample | sec | sech | sin | sinh |
| sqrt | subtractIfCan | tan | tanh | unit? |
| unitCanonical | unitNormal | variables | zero? | ?*? |
| ?**? | ?+? | ?-? | -? | ?=? |
| ?^? | ?~=? | ?/? | | |

Attributes Exported:

- if \$ has CommutativeRing then commutative(“”) where **commutative**(“”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- if \$ has IntegralDomain then noZeroDivisors where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```
coefficient : (% , Var , NonNegativeInteger) -> %
coefficient : (% , List Var , List NonNegativeInteger) -> %
extend : (% , NonNegativeInteger) -> %
integrate : (% , Var) -> % if Coef has ALGEBRA FRAC INT
monomial : (% , Var , NonNegativeInteger) -> %
monomial : (% , List Var , List NonNegativeInteger) -> %
order : (% , Var , NonNegativeInteger) -> NonNegativeInteger
order : (% , Var) -> NonNegativeInteger
polynomial : (% , NonNegativeInteger , NonNegativeInteger) -> Polynomial Coef
polynomial : (% , NonNegativeInteger) -> Polynomial Coef
```

These exports come from (p939) PartialDifferentialRing(OrderedSet):

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
D : (% , Var) -> %
D : (% , List Var) -> %
D : (% , List Var , List NonNegativeInteger) -> %
D : (% , Var , NonNegativeInteger) -> %
differentiate : (% , Var) -> %
differentiate : (% , List Var , List NonNegativeInteger) -> %
differentiate : (% , Var , NonNegativeInteger) -> %
differentiate : (% , List Var) -> %
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(% , "failed")
sample : () -> %
subtractIfCan : (% , %) -> Union(% , "failed")
zero? : % -> Boolean
```

```

?+? : (%,% ) -> %
?= ? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (%,% ) -> %
?*? : (Integer,% ) -> %
?*? : (PositiveInteger,% ) -> %
?*? : (NonNegativeInteger,% ) -> %
?-? : (%,% ) -> %
-? : % -> %
?^? : (% ,PositiveInteger) -> %
?^? : (% ,NonNegativeInteger) -> %
?***? : (% ,NonNegativeInteger) -> %
?***? : (% ,PositiveInteger) -> %

```

These exports come from (p1208) `PowerSeriesCategory(A,B,C)` where A:Ring, B:IndexedExponents(OrderedSet) and C:OrderedSet:

```

associates? : (%,% ) -> Boolean if Coef has INTDOM
charthRoot : % -> Union(%,"failed") if Coef has CHARNZ
coefficient : (% ,IndexedExponents Var) -> Coef
coerce : Coef -> % if Coef has COMRING
coerce : Fraction Integer -> % if Coef has ALGEBRA FRAC INT
coerce : % -> % if Coef has INTDOM
complete : % -> %
degree : % -> IndexedExponents Var
exquo : (%,% ) -> Union(%,"failed") if Coef has INTDOM
leadingCoefficient : % -> Coef
leadingMonomial : % -> %
map : ((Coef -> Coef),%) -> %
monomial : (Coef,IndexedExponents Var) -> %
monomial? : % -> Boolean
monomial : (% ,List Var,List IndexedExponents Var) -> %
monomial : (% ,Var,IndexedExponents Var) -> %
pole? : % -> Boolean
reductum : % -> %
unit? : % -> Boolean if Coef has INTDOM
unitCanonical : % -> % if Coef has INTDOM
unitNormal : % -> Record(unit: % ,canonical: % ,associate: %)
    if Coef has INTDOM
variables : % -> List Var
?*? : (% ,Coef) -> %
?*? : (Coef,% ) -> %
?*? : (Fraction Integer,% ) -> % if Coef has ALGEBRA FRAC INT
?*? : (% ,Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
?/? : (% ,Coef) -> % if Coef has FIELD

```

These exports come from (p56) `InnerEvaluable(OrderedSet,`

```

eval : (% ,Var,% ) -> %
eval : (% ,List Var,List %) -> %

```

These exports come from (p129) Evaluable(

```
eval : (%,List Equation %) -> %
eval : (%,Equation %) -> %
eval : (%,List %,List %) -> %
eval : (%,%,%) -> %
```

These exports come from (p92) RadicalCategory():

```
nthRoot : (%,Integer) -> % if Coef has ALGEBRA FRAC INT
sqrt : % -> % if Coef has ALGEBRA FRAC INT
?***? : (%,Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
```

These exports come from (p166) TranscendentalFunctionCategory():

```
acos : % -> % if Coef has ALGEBRA FRAC INT
acosh : % -> % if Coef has ALGEBRA FRAC INT
acot : % -> % if Coef has ALGEBRA FRAC INT
acoth : % -> % if Coef has ALGEBRA FRAC INT
acsc : % -> % if Coef has ALGEBRA FRAC INT
acsch : % -> % if Coef has ALGEBRA FRAC INT
asec : % -> % if Coef has ALGEBRA FRAC INT
asech : % -> % if Coef has ALGEBRA FRAC INT
asin : % -> % if Coef has ALGEBRA FRAC INT
asinh : % -> % if Coef has ALGEBRA FRAC INT
atan : % -> % if Coef has ALGEBRA FRAC INT
atanh : % -> % if Coef has ALGEBRA FRAC INT
cos : % -> % if Coef has ALGEBRA FRAC INT
cosh : % -> % if Coef has ALGEBRA FRAC INT
cot : % -> % if Coef has ALGEBRA FRAC INT
coth : % -> % if Coef has ALGEBRA FRAC INT
csc : % -> % if Coef has ALGEBRA FRAC INT
csch : % -> % if Coef has ALGEBRA FRAC INT
exp : % -> % if Coef has ALGEBRA FRAC INT
log : % -> % if Coef has ALGEBRA FRAC INT
pi : () -> % if Coef has ALGEBRA FRAC INT
sec : % -> % if Coef has ALGEBRA FRAC INT
sech : % -> % if Coef has ALGEBRA FRAC INT
sin : % -> % if Coef has ALGEBRA FRAC INT
sinh : % -> % if Coef has ALGEBRA FRAC INT
tan : % -> % if Coef has ALGEBRA FRAC INT
tanh : % -> % if Coef has ALGEBRA FRAC INT
?***? : (%,%) -> % if Coef has ALGEBRA FRAC INT
```

— category MTSCAT MultivariateTaylorSeriesCategory —

```
)abbrev category MTSCAT MultivariateTaylorSeriesCategory
++ Author: Clifton J. Williamson
```



```

++ Date Created: 6 March 1990
++ Date Last Updated: 6 March 1990
++ Description:
++ \spadtype{MultivariateTaylorSeriesCategory} is the most general
++ multivariate Taylor series category.

MultivariateTaylorSeriesCategory(Coef,Var): Category == Definition where
  Coef : Ring
  Var  : OrderedSet
  L    ==> List
  NNI  ==> NonNegativeInteger

Definition ==> Join(PartialDifferentialRing Var, _
  PowerSeriesCategory(Coef,IndexedExponents Var,Var), _
  InnerEvalable(Var,%),Evalable %) with
coefficient: (% ,Var,NNI) -> %
  ++ \spad{coefficient(f,x,n)} returns the coefficient of \spad{x^n} in f.
coefficient: (% ,L Var,L NNI) -> %
  ++ \spad{coefficient(f,[x1,x2,...,xk],[n1,n2,...,nk])} returns the
  ++ coefficient of \spad{x1^n1 * ... * xk^nk} in f.
extend: (% ,NNI) -> %
  ++ \spad{extend(f,n)} causes all terms of f of degree
  ++ \spad{<= n} to be computed.
monomial: (% ,Var,NNI) -> %
  ++ \spad{monomial(a,x,n)} returns \spad{a*x^n}.
monomial: (% ,L Var,L NNI) -> %
  ++ \spad{monomial(a,[x1,x2,...,xk],[n1,n2,...,nk])} returns
  ++ \spad{a * x1^n1 * ... * xk^nk}.
order: (% ,Var) -> NNI
  ++ \spad{order(f,x)} returns the order of f viewed as a series in x
  ++ may result in an infinite loop if f has no non-zero terms.
order: (% ,Var,NNI) -> NNI
  ++ \spad{order(f,x,n)} returns \spad{min(n,order(f,x))}.
polynomial: (% ,NNI) -> Polynomial Coef
  ++ \spad{polynomial(f,k)} returns a polynomial consisting of the sum
  ++ of all terms of f of degree \spad{<= k}.
polynomial: (% ,NNI,NNI) -> Polynomial Coef
  ++ \spad{polynomial(f,k1,k2)} returns a polynomial consisting of the
  ++ sum of all terms of f of degree d with \spad{k1 <= d <= k2}.
if Coef has Algebra Fraction Integer then
  integrate: (% ,Var) -> %
    ++ \spad{integrate(f,x)} returns the anti-derivative of the power
    ++ series \spad{f(x)} with respect to the variable x with constant
    ++ coefficient 1. We may integrate a series when we can divide
    ++ coefficients by integers.
RadicalCategory
  --++ We provide rational powers when we can divide coefficients
  --++ by integers.
TranscendentalFunctionCategory
  --++ We provide transcendental functions when we can divide

```

--++ coefficients by integers.

— MTSCAT.dotabb —

```
"MTSCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MTSCAT"];
"MTSCAT" -> "PDRING"
"MTSCAT" -> "PSCAT"
"MTSCAT" -> "IEVALAB"
"MTSCAT" -> "EVALAB"
```

— MTSCAT.dotfull —

```
"MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MTSCAT"];
"MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet)" ->
  "PartialDifferentialRing(a:OrderedSet)"
"MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet)" ->
  "PowerSeriesCategory(a:Ring,IndexedExponents(b:OrderedSet),c:OrderedSet))"
"MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet)" ->
  "InnerEvaluable(a:Ring,MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet))"
"MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet)" ->
  "Evaluable(MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet))"
```

— MTSCAT.dotpic —

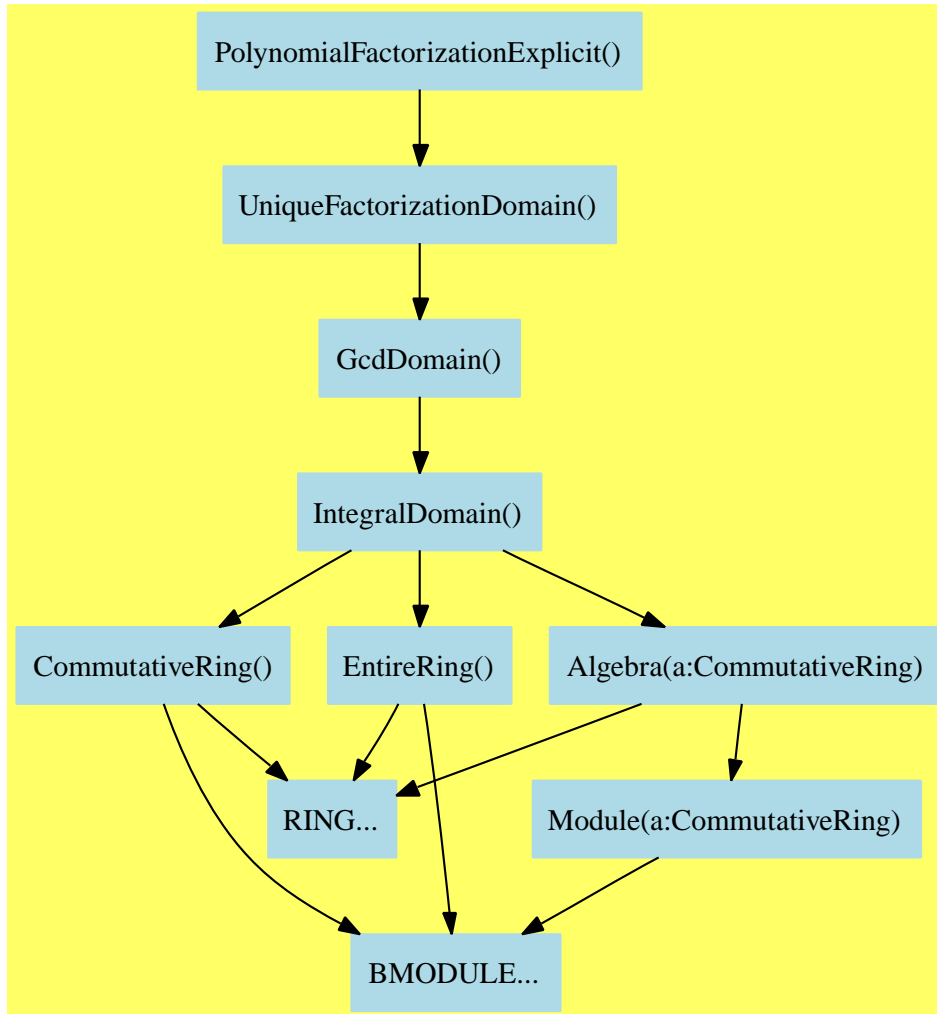
```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet)" [color=lightblue];
  "MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet)" ->
    "PDRING..."
  "MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet)" ->
    "PSCAT..."
  "MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet)" ->
    "IEVALAB..."
  "MultivariateTaylorSeriesCategory(a:Ring,b:OrderedSet)" ->
```

```
"EVALAB..."  
  
"PDRING..." [color=lightblue];  
"PSCAT..." [color=lightblue];  
"IEVALAB..." [color=lightblue];  
"EVALAB..." [color=lightblue];  
  
}
```

—————→

PolynomialFactorizationExplicit (PFECAT)



— PolynomialFactorizationExplicit.input —

```

)set break resume
)sys rm -f PolynomialFactorizationExplicit.output
)spool PolynomialFactorizationExplicit.output
)set message test on
)set message auto off
)clear all

```

--S 1 of 1

```

)show PolynomialFactorizationExplicit
--R
--R PolynomialFactorizationExplicit is a category constructor
--R Abbreviation for PolynomialFactorizationExplicit is PFECAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PFECAT
--R
--R----- Operations -----
--R ?? : (%,%) -> %                ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %  ??? : (%,PositiveInteger) -> %
--R ?? : (%,%) -> %                ?-? : (%,%) -> %
--R -? : % -> %                    ?? : (%,%) -> Boolean
--R 1 : () -> %                    0 : () -> %
--R ?^? : (%,PositiveInteger) -> % associates? : (%,%) -> Boolean
--R coerce : % -> %                coerce : Integer -> %
--R coerce : % -> OutputForm        factor : % -> Factored(%)
--R gcd : List(%) -> %              gcd : (%,%) -> %
--R hash : % -> SingleInteger        latex : % -> String
--R lcm : List(%) -> %              lcm : (%,%) -> %
--R one? : % -> Boolean              prime? : % -> Boolean
--R recip : % -> Union(%, "failed") sample : () -> %
--R squareFree : % -> Factored(%)    squareFreePart : % -> %
--R unit? : % -> Boolean              unitCanonical : % -> %
--R zero? : % -> Boolean              ?~? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?^? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if $ has CHARNZ
--R conditionP : Matrix(%) -> Union(Vector(%), "failed") if $ has CHARNZ
--R exquo : (%,%) -> Union(%, "failed")
--R factorPolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%))
--R factorSquareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%))
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R solveLinearPolynomialEquation : (List(SparseUnivariatePolynomial(%)), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R squareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%))
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— PolynomialFactorizationExplicit.help —

=====

PolynomialFactorizationExplicit examples

=====

This is the category of domains that know "enough" about themselves in order to factor univariate polynomials over themselves. This will be used in future releases for supporting factorization over finitely generated coefficient fields, it is not yet available in the current release of Axiom.

See Also:

o)show PolynomialFactorizationExplicit

See:

⇒ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)
 ⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)
 ⇒ “UnivariatePolynomialCategory” (UPOLYC) [17](#) on page [1522](#)
 ⇐ “UniqueFactorizationDomain” (UFD) [14](#) on page [1222](#)

Exports:

| | | |
|------------------|----------------------------|-------------------------------|
| 0 | 1 | associates? |
| characteristic | charthRoot | coerce |
| conditionP | exquo | factor |
| factorPolynomial | factorSquareFreePolynomial | gcd |
| gcdPolynomial | hash | latex |
| lcm | one? | prime? |
| recip | sample | solveLinearPolynomialEquation |
| squareFree | squareFreePart | squareFreePolynomial |
| subtractIfCan | unit? | unitNormal |
| unitCanonical | zero? | ?*? |
| ?**? | ?+? | ?-? |
| -? | ?=? | ?^? |
| ?~=? | | |

Attributes exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.

- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
conditionP : Matrix % -> Union(Vector %,"failed")
  if $ has CHARNZ
factorPolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
factorSquareFreePolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
squareFreePolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
```

These are implemented by this category:

```
charthRoot : % -> Union(%, "failed") if $ has CHARNZ
gcdPolynomial : (SparseUnivariatePolynomial %,
  SparseUnivariatePolynomial %) ->
  SparseUnivariatePolynomial %
solveLinearPolynomialEquation :
  (List SparseUnivariatePolynomial %,
  SparseUnivariatePolynomial %) ->
  Union(List SparseUnivariatePolynomial %, "failed")
```

These exports come from ([p1222](#)) UniqueFactorizationDomain():

```
factor : % -> Factored %
squareFree : % -> Factored %
0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
exquo : (%,%) -> Union(%, "failed")
gcd : List % -> %
gcd : (%,%) -> %
hash : % -> SingleInteger
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
one? : % -> Boolean
prime? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
```

```

squareFreePart : % -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
unitCanonical : % -> %
zero? : % -> Boolean
?+? : (%,%) -> %
?= ? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%, PositiveInteger) -> %
***? : (%, NonNegativeInteger) -> %
??^ : (%, PositiveInteger) -> %
??^ : (%, NonNegativeInteger) -> %

```

— category PFECAT PolynomialFactorizationExplicit —

```

)abbrev category PFECAT PolynomialFactorizationExplicit
++ Author: James Davenport
++ Description:
++ This is the category of domains that know "enough" about
++ themselves in order to factor univariate polynomials over themselves.
++ This will be used in future releases for supporting factorization
++ over finitely generated coefficient fields, it is not yet available
++ in the current release of axiom.

PolynomialFactorizationExplicit(): Category == Definition where
  P ==> SparseUnivariatePolynomial %
  Definition ==>
    UniqueFactorizationDomain with
      squareFreePolynomial: P -> Factored(P)
        ++ squareFreePolynomial(p) returns the
        ++ square-free factorization of the
        ++ univariate polynomial p.
      factorPolynomial: P -> Factored(P)
        ++ factorPolynomial(p) returns the factorization
        ++ into irreducibles of the univariate polynomial p.
      factorSquareFreePolynomial: P -> Factored(P)
        ++ factorSquareFreePolynomial(p) factors the
        ++ univariate polynomial p into irreducibles
        ++ where p is known to be square free
        ++ and primitive with respect to its main variable.
      gcdPolynomial: (P, P) -> P
        ++ gcdPolynomial(p,q) returns the gcd of the univariate

```



```

++ polynomials p and q.
-- defaults to Euclidean, but should be implemented via
-- modular or p-adic methods.
solveLinearPolynomialEquation: (List P, P) -> Union(List P,"failed")
++ solveLinearPolynomialEquation([f1, ..., fn], g)
++ (where the fi are relatively prime to each other)
++ returns a list of ai such that
++ \spad{g}/prod fi = sum ai/fi}
++ or returns "failed" if no such list of ai's exists.
if % has CharacteristicNonZero then
conditionP: Matrix % -> Union(Vector %,"failed")
++ conditionP(m) returns a vector of elements, not all zero,
++ whose \spad{p}-th powers (p is the characteristic of the domain)
++ are a solution of the homogenous linear system represented
++ by m, or "failed" if there is no such vector.
charthRoot: % -> Union(%,"failed")
++ charthRoot(r) returns the \spad{p}-th root of r, or "failed"
++ if none exists in the domain.
-- this is a special case of conditionP, but often the one we want
add
gcdPolynomial(f,g) ==
  zero? f => g
  zero? g => f
  cf:=content f
  if not one? cf then f:=(f exquo cf)::P
  cg:=content g
  if not one? cg then g:=(g exquo cg)::P
  ans:=subResultantGcd(f,g)$P
  gcd(cf,cg)*(ans exquo content ans)::P
if % has CharacteristicNonZero then
charthRoot f ==
  -- to take p'th root of f, solve the system X-fY=0,
  -- so solution is [x,y]
  -- with x^p=X and y^p=Y, then (x/y)^p = f
  zero? f => 0
  m:Matrix % := matrix [[1,-f]]
  ans:= conditionP m
  ans case "failed" => "failed"
  (ans.1) exquo (ans.2)
if % has Field then
  solveLinearPolynomialEquation(lf,g) ==
    multiEuclidean(lf,g)$P
else solveLinearPolynomialEquation(lf,g) ==
  LPE ==> LinearPolynomialEquationByFractions %
  solveLinearPolynomialEquationByFractions(lf,g)$LPE

```

— PFECAT.dotabb —

```
"PFECAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PFECAT"];
"PFECAT" -> "UFD"
```

— PFECAT.dotfull —

```
"PolynomialFactorizationExplicit()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PFECAT"];
"PolynomialFactorizationExplicit()" -> "UniqueFactorizationDomain()"
```

— PFECAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PolynomialFactorizationExplicit()" [color=lightblue];
  "PolynomialFactorizationExplicit()" -> "UniqueFactorizationDomain()"

  "UniqueFactorizationDomain()" [color=lightblue];
  "UniqueFactorizationDomain()" -> "GcdDomain()"

  "GcdDomain()" [color=lightblue];
  "GcdDomain()" -> "IntegralDomain()"

  "IntegralDomain()" [color=lightblue];
  "IntegralDomain()" -> "CommutativeRing()"
  "IntegralDomain()" -> "Algebra(a:CommutativeRing)"
  "IntegralDomain()" -> "EntireRing()"

  "CommutativeRing()" [color=lightblue];
  "CommutativeRing()" -> "RING..."
  "CommutativeRing()" -> "BMODULE..."

  "EntireRing()" [color=lightblue];
  "EntireRing()" -> "RING..."
  "EntireRing()" -> "BMODULE..."

  "Algebra(a:CommutativeRing)" [color=lightblue];
```

```

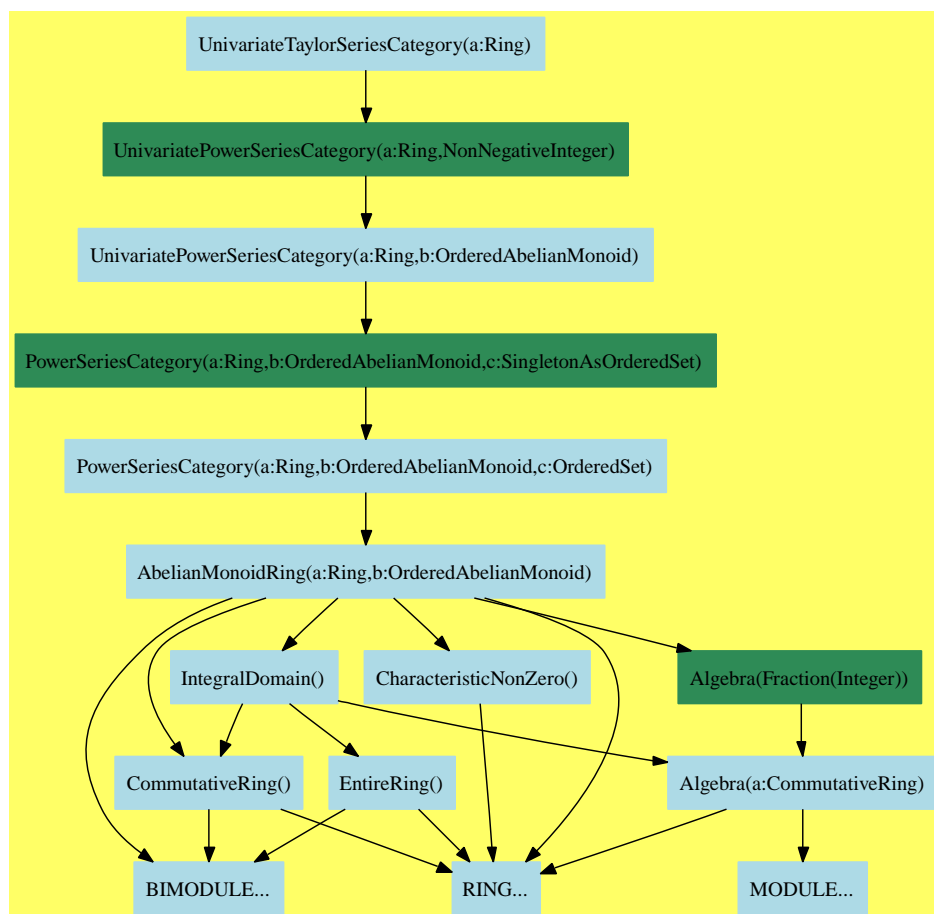
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" -> "BMODULE..."

"BMODULE..." [color=lightblue];
"RING..." [color=lightblue];
}

```

UnivariatePowerSeriesCategory (UPSCAT)



— UnivariatePowerSeriesCategory.input —

```

)set break resume
)sys rm -f UnivariatePowerSeriesCategory.output
)spool UnivariatePowerSeriesCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show UnivariatePowerSeriesCategory
--R
--R UnivariatePowerSeriesCategory(Coef: Ring,Expon: OrderedAbelianMonoid) is a category constructor
--R Abbreviation for UnivariatePowerSeriesCategory is UPSCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for UPSCAT
--R
--R----- Operations -----
--R ?? : (Coef,%) -> %           ?? : (%,Coef) -> %
--R ?? : (%,%) -> %             ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> % ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %                 ?? : (%,%) -> Boolean
--R 1 : () -> %                 0 : () -> %
--R ?? : (%,PositiveInteger) -> % center : % -> Coef
--R coefficient : (%,Expon) -> Coef coerce : Integer -> %
--R coerce : % -> OutputForm      complete : % -> %
--R degree : % -> Expon           ?.? : (%,Expon) -> Coef
--R extend : (%,Expon) -> %       hash : % -> SingleInteger
--R latex : % -> String           leadingCoefficient : % -> Coef
--R leadingMonomial : % -> %      map : ((Coef -> Coef),%) -> %
--R monomial : (Coef,Expon) -> %  monomial? : % -> Boolean
--R one? : % -> Boolean           order : (%,Expon) -> Expon
--R order : % -> Expon           pole? : % -> Boolean
--R recip : % -> Union(%, "failed") reductum : % -> %
--R sample : () -> %             truncate : (%,Expon,Expon) -> %
--R truncate : (%,Expon) -> %     variable : % -> Symbol
--R zero? : % -> Boolean          ?~=? : (%,%) -> Boolean
--R ?? : (%,Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (Fraction(Integer),%) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,Coef) -> % if Coef has FIELD
--R D : % -> % if Coef has *: (Expon,Coef) -> Coef
--R D : (%,NonNegativeInteger) -> % if Coef has *: (Expon,Coef) -> Coef
--R D : (%,Symbol) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Expon,Coef) -> Coef
--R D : (%,List(Symbol)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Expon,Coef) -> Coef
--R D : (%,Symbol,NonNegativeInteger) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Expon,Coef) -> Coef
--R D : (%,List(Symbol),List(NonNegativeInteger)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Expon,Coef) -> Coef

```

```

--R ?? : (%,NonNegativeInteger) -> %
--R approximate : (%,Expon) -> Coef if Coef has **: (Coef,Expon) -> Coef and Coef has coerce: Sy
--R associates? : (%,%) -> Boolean if Coef has INTDOM
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
--R coerce : Coef -> % if Coef has COMRING
--R coerce : % -> % if Coef has INTDOM
--R coerce : Fraction(Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R differentiate : % -> % if Coef has *: (Expon,Coef) -> Coef
--R differentiate : (%,NonNegativeInteger) -> % if Coef has *: (Expon,Coef) -> Coef
--R differentiate : (%,Symbol) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Expon,Coef) -> C
--R differentiate : (%,List(Symbol)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Expon,Coef
--R differentiate : (%,Symbol,NonNegativeInteger) -> % if Coef has PDRING(SYMBOL) and Coef has *
--R differentiate : (%,List(Symbol),List(NonNegativeInteger)) -> % if Coef has PDRING(SYMBOL) an
--R ?.? : (%,%) -> % if Expon has SGROUP
--R eval : (%,Coef) -> Stream(Coef) if Coef has **: (Coef,Expon) -> Coef
--R exquo : (%,%) -> Union(%, "failed") if Coef has INTDOM
--R monomial : (%,List(SingletonAsOrderedSet),List(Expon)) -> %
--R monomial : (%,SingletonAsOrderedSet,Expon) -> %
--R multiplyExponents : (%,PositiveInteger) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R terms : % -> Stream(Record(k: Expon,c: Coef))
--R unit? : % -> Boolean if Coef has INTDOM
--R unitCanonical : % -> % if Coef has INTDOM
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if Coef has INTDOM
--R variables : % -> List(SingletonAsOrderedSet)
--R
--E 1

)spool
)lisp (bye)

```

— UnivariatePowerSeriesCategory.help —

=====

UnivariatePowerSeriesCategory examples

=====

UnivariatePowerSeriesCategory is the most general univariate power series category with exponents in an ordered abelian monoid. Note that this category exports a substitution function if it is possible to multiply exponents. Also note that this category exports a derivative operation if it is possible to multiply coefficients by exponents.

See Also:

o)show UnivariatePowerSeriesCategory

See:

- ⇒ “LocalPowerSeriesCategory” (LOCPOWC) [16](#) on page [1289](#)
- ⇒ “UnivariateLaurentSeriesCategory” (ULSCAT) [17](#) on page [1499](#)
- ⇒ “UnivariatePuisseuxSeriesCategory” (UPXSCAT) [17](#) on page [1511](#)
- ⇒ “UnivariateTaylorSeriesCategory” (UTSCAT) [16](#) on page [1327](#)
- ⇐ “PowerSeriesCategory” (PSCAT) [14](#) on page [1208](#)

Exports:

| | | | | |
|----------------|------------|---------------|--------------------|-----------------|
| 0 | 1 | approximate | associates? | center |
| characteristic | charthRoot | coefficient | coerce | complete |
| D | degree | differentiate | eval | exquo |
| extend | hash | latex | leadingCoefficient | leadingMonomial |
| map | monomial | monomial? | multiplyExponents | one? |
| order | pole? | recip | reductum | sample |
| subtractIfCan | truncate | terms | unit? | unitCanonical |
| unitNormal | variable | variables | zero? | ?*? |
| ?**? | ?+? | ?-? | -? | ?=? |
| ?^? | ?..? | ?~=? | ?/? | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- if #1 has IntegralDomain then noZeroDivisors where **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- if #1 has CommutativeRing then commutative(“*”) where **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.

These are directly exported but not implemented:

```

approximate : (% , Expon) -> Coef
  if Coef has **: (Coef, Expon) -> Coef
  and Coef has coerce: Symbol -> Coef
center : % -> Coef
eval : (% , Coef) -> Stream Coef if Coef has **: (Coef, Expon) -> Coef
extend : (% , Expon) -> %
multiplyExponents : (% , PositiveInteger) -> %
order : % -> Expon
order : (% , Expon) -> Expon
terms : % -> Stream Record(k: Expon, c: Coef)

```

```

truncate : (%,Expon) -> %
truncate : (%,Expon,Expon) -> %
variable : % -> Symbol
?.? : (%,Expon) -> Coef

```

These are implemented by this category:

```

degree : % -> Expon
leadingCoefficient : % -> Coef
leadingMonomial : % -> %
monomial : (%,SingletonAsOrderedSet,Expon) -> %
reductum : % -> %
variables : % -> List SingletonAsOrderedSet

```

These exports come from (p1208) `PowerSeriesCategory(C,E,S)`
 where `C:Ring`, `E:OrderedAbelianMonoid`, `S:SingletonAsOrderedSet`:

```

0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean if Coef has INTDOM
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
coefficient : (%,Expon) -> Coef
coerce : Coef -> % if Coef has COMRING
coerce : % -> % if Coef has INTDOM
coerce : Fraction Integer -> % if Coef has ALGEBRA FRAC INT
coerce : Integer -> %
coerce : % -> OutputForm
complete : % -> %
exquo : (%,%) -> Union(%, "failed") if Coef has INTDOM
hash : % -> SingleInteger
latex : % -> String
map : ((Coef -> Coef),%) -> %
monomial : (%,List Var,List Expon) -> %
monomial : (Coef,Expon) -> %
monomial? : % -> Boolean
one? : % -> Boolean
recip : % -> Union(%, "failed")
pole? : % -> Boolean
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean if Coef has INTDOM
unitCanonical : % -> % if Coef has INTDOM
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
    if Coef has INTDOM
zero? : % -> Boolean
***? : (%,NonNegativeInteger) -> %
?^? : (%,NonNegativeInteger) -> %

```

```

?+? : (%,% ) -> %
?= ? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (NonNegativeInteger,% ) -> %
?*? : (PositiveInteger,% ) -> %
?*? : (%,% ) -> %
?-? : (%,% ) -> %
?*?* : (% ,PositiveInteger) -> %
?^? : (% ,PositiveInteger) -> %
?*? : (Integer,% ) -> %
?*? : (Coef,% ) -> %
?*? : (% ,Coef) -> %
?*? : (% ,Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
?*? : (Fraction Integer,% ) -> % if Coef has ALGEBRA FRAC INT
?/? : (% ,Coef) -> % if Coef has FIELD
-? : % -> %

```

These exports come from (p48) Eltable(%,%):

```

?.? : (%,% ) -> % if Expon has SGROUP

```

These exports come from (p902) DifferentialRing():

```

D : % -> %
  if Coef has *: (Expon,Coef) -> Coef
D : (% ,NonNegativeInteger) -> %
  if Coef has *: (Expon,Coef) -> Coef
differentiate : (% ,NonNegativeInteger) -> %
  if Coef has *: (Expon,Coef) -> Coef
differentiate : % -> %
  if Coef has *: (Expon,Coef) -> Coef

```

These exports come from (p939) PartialDifferentialRing(Symbol):

```

D : (% ,Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Expon,Coef) -> Coef
D : (% ,List Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Expon,Coef) -> Coef
D : (% ,Symbol,NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Expon,Coef) -> Coef
D : (% ,List Symbol,List NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Expon,Coef) -> Coef
differentiate : (% ,List Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Expon,Coef) -> Coef

```



```

differentiate : (% , Symbol, NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
    and Coef has *: (Expon, Coef) -> Coef
differentiate : (% , List Symbol, List NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
    and Coef has *: (Expon, Coef) -> Coef
differentiate : (% , Symbol) -> %
  if Coef has PDRING SYMBOL
    and Coef has *: (Expon, Coef) -> Coef

```

— category UPSCAT UnivariatePowerSeriesCategory —

```

)abbrev category UPSCAT UnivariatePowerSeriesCategory
++ Author: Clifton J. Williamson
++ Date Created: 21 December 1989
++ Date Last Updated: 20 September 1993
++ Description:
++ \spadtype{UnivariatePowerSeriesCategory} is the most general
++ univariate power series category with exponents in an ordered
++ abelian monoid.
++ Note that this category exports a substitution function if it is
++ possible to multiply exponents.
++ Also note that this category exports a derivative operation if it is
++ possible to multiply coefficients by exponents.

UnivariatePowerSeriesCategory(Coef, Expon): Category == Definition where
  Coef    : Ring
  Expon   : OrderedAbelianMonoid
  Term ==> Record(k:Expon, c:Coef)

Definition ==> PowerSeriesCategory(Coef, Expon, SingletonAsOrderedSet) with

  terms: % -> Stream Term
    ++ \spad{terms(f(x))} returns a stream of non-zero terms, where a
    ++ a term is an exponent-coefficient pair. The terms in the stream
    ++ are ordered by increasing order of exponents.
  --series: Stream Term -> %
    ---+ \spad{series(st)} creates a series from a stream of non-zero terms,
    ---+ where a term is an exponent-coefficient pair. The terms in the
    ---+ stream should be ordered by increasing order of exponents.
  elt: (% , Expon) -> Coef
    ++ \spad{elt(f(x), r)} returns the coefficient of the term of degree r in
    ++ \spad{f(x)}. This is the same as the function \spadfun{coefficient}.
  variable: % -> Symbol
    ++ \spad{variable(f)} returns the (unique) power series variable of
    ++ the power series f.
  center: % -> Coef
    ++ \spad{center(f)} returns the point about which the series f is
    ++ expanded.

```

```

multiplyExponents: (%PositiveInteger) -> %
  ++ \spad{multiplyExponents(f,n)} multiplies all exponents of the power
  ++ series f by the positive integer n.
order: % -> Expon
  ++ \spad{order(f)} is the degree of the lowest order non-zero term in f.
  ++ This will result in an infinite loop if f has no non-zero terms.
order: (%Expon) -> Expon
  ++ \spad{order(f,n) = min(m,n)}, where m is the degree of the
  ++ lowest order non-zero term in f.
truncate: (%Expon) -> %
  ++ \spad{truncate(f,k)} returns a (finite) power series consisting of
  ++ the sum of all terms of f of degree \spad{<= k}.
truncate: (%Expon,Expon) -> %
  ++ \spad{truncate(f,k1,k2)} returns a (finite) power
  ++ series consisting of
  ++ the sum of all terms of f of degree d with \spad{k1 <= d <= k2}.
if Coef has coerce: Symbol -> Coef then
  if Coef has "***":(Coef,Expon) -> Coef then
    approximate: (%Expon) -> Coef
      ++ \spad{approximate(f)} returns a truncated power series with the
      ++ series variable viewed as an element of the coefficient domain.
extend: (%Expon) -> %
  ++ \spad{extend(f,n)} causes all terms of f of degree <= n
  ++ to be computed.
if Expon has SemiGroup then Eltable(%,%)
if Coef has "*": (Expon,Coef) -> Coef then
  DifferentialRing
  --!! DifferentialExtension Coef
  if Coef has PartialDifferentialRing Symbol then
    PartialDifferentialRing Symbol
if Coef has "***": (Coef,Expon) -> Coef then
  eval: (%Coef) -> Stream Coef
    ++ \spad{eval(f,a)} evaluates a power series at a value in the
    ++ ground ring by returning a stream of partial sums.

add
degree f == order f

leadingCoefficient f == coefficient(f,order f)

leadingMonomial f ==
  ord := order f
  monomial(coefficient(f,ord),ord)

monomial(f:%,listVar:List SingletonAsOrderedSet,listExpon:List Expon) ==
  empty? listVar or not empty? rest listVar =>
    error "monomial: variable list must have exactly one entry"
  empty? listExpon or not empty? rest listExpon =>
    error "monomial: exponent list must have exactly one entry"
  f * monomial(1,first listExpon)

```

```

monomial(f:%,v:SingletonAsOrderedSet,n:Expon) ==
  f * monomial(1,n)

reductum f == f - leadingMonomial f

variables f == list create()

-----

— UPSCAT.dotabb —

"UPSCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=UPSCAT"];
"UPSCAT" -> "PSCAT"

-----

— UPSCAT.dotfull —

"UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=UPSCAT"];
"UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)" ->
  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"

"UnivariatePowerSeriesCategory(a:Ring,NonNegativeInteger)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=UPSCAT"];
"UnivariatePowerSeriesCategory(a:Ring,NonNegativeInteger)" ->
  "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"

"UnivariatePowerSeriesCategory(a:Ring,Integer)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=UPSCAT"];
"UnivariatePowerSeriesCategory(a:Ring,Integer)" ->
  "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"

"UnivariatePowerSeriesCategory(a:Ring,Fraction(Integer))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=UPSCAT"];
"UnivariatePowerSeriesCategory(a:Ring,Fraction(Integer))" ->
  "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"

-----

— UPSCAT.dotpic —

digraph pic {

```

```

fontsize=10;
bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"
  [color=lightblue];
"UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)" ->
  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"

"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
  [color=seagreen];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
  -> "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"

"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"
  [color=lightblue];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)" ->
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)"

"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" [color=lightblue];
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" -> "RING..."
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "BIMODULE..."
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "IntegralDomain()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "CharacteristicNonZero()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "CommutativeRing()"
"AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
  "Algebra(Fraction(Integer))"

"IntegralDomain()" [color=lightblue];
"IntegralDomain()" -> "CommutativeRing()"
"IntegralDomain()" -> "Algebra(a:CommutativeRing)"
"IntegralDomain()" -> "EntireRing()"

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BIMODULE..."

"CharacteristicNonZero()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CHARNZ"];
"CharacteristicNonZero()" -> "RING..."

"Algebra(Fraction(Integer))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(Fraction(Integer))" -> "Algebra(a:CommutativeRing)"

"Algebra(a:CommutativeRing)"

```

```
[color=lightblue,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "MODULE..."

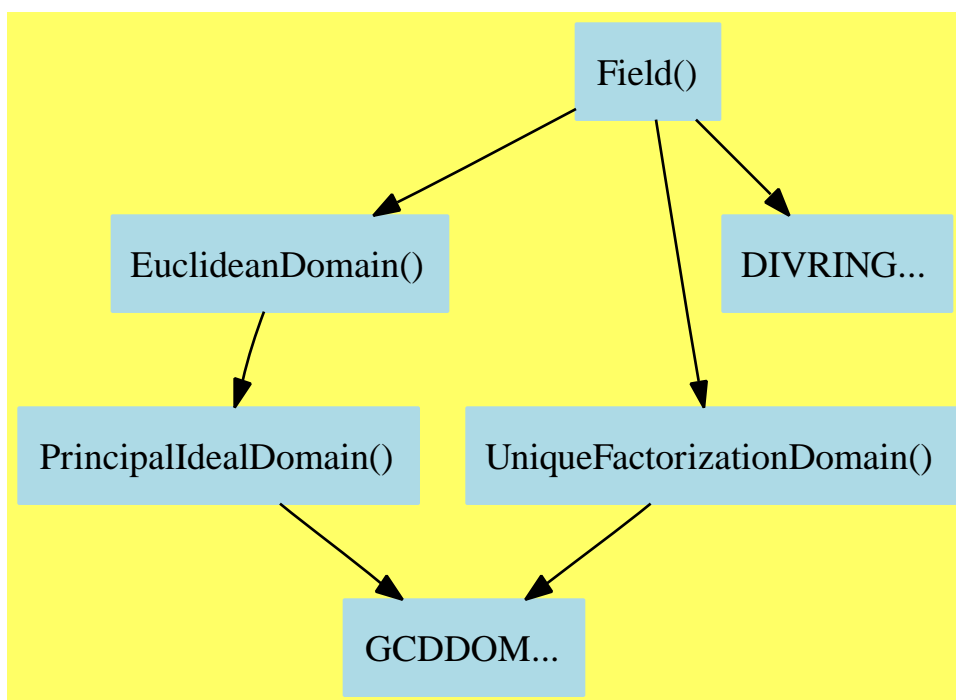
"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BIMODULE..."

"BIMODULE..." [color=lightblue];
"RING..." [color=lightblue];
"MODULE..." [color=lightblue];
}
```

Chapter 16

Category Layer 15

Field (FIELD)



— Field.input —

```
)set break resume  
)sys rm -f Field.output
```

```

)spool Field.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show Field
--R
--R Field is a category constructor
--R Abbreviation for Field is FIELD
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FIELD
--R
--R----- Operations -----
--R ???: (Fraction(Integer),%) -> %      ??? : (%,Fraction(Integer)) -> %
--R ??? : (%,%) -> %                    ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %      ??? : (%,Integer) -> %
--R ??? : (%,PositiveInteger) -> %     ?+?: (%,%) -> %
--R ?-?: (%,%) -> %                    -?: % -> %
--R ?/? : (%,%) -> %                  ?=: (%,%) -> Boolean
--R 1 : () -> %                       0 : () -> %
--R ?? : (%,Integer) -> %              ??? : (%,PositiveInteger) -> %
--R associates? : (%,%) -> Boolean     coerce : Fraction(Integer) -> %
--R coerce : % -> %                   coerce : Integer -> %
--R coerce : % -> OutputForm           factor : % -> Factored(%)
--R gcd : List(%) -> %                 gcd : (%,%) -> %
--R hash : % -> SingleInteger          inv : % -> %
--R latex : % -> String                lcm : List(%) -> %
--R lcm : (%,%) -> %                  one? : % -> Boolean
--R prime? : % -> Boolean              ?quo? : (%,%) -> %
--R recip : % -> Union(%, "failed")    ?rem? : (%,%) -> %
--R sample : () -> %                  sizeLess? : (%,%) -> Boolean
--R squareFree : % -> Factored(%)      squareFreePart : % -> %
--R unit? : % -> Boolean               unitCanonical : % -> %
--R zero? : % -> Boolean              ?~?: (%,%) -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R divide : (%,%) -> Record(quotient: %,remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%), "failed")
--R exquo : (%,%) -> Union(%, "failed")
--R extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
--R extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R multiEuclidean : (List(%),%) -> Union(List(%), "failed")
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)

```

```
--R
--E 1
```

```
)spool
)lisp (bye)
```

— **Field.help** —

=====

Field examples

=====

The category of commutative fields, i.e. commutative rings where all non-zero elements have multiplicative inverses. The factor operation while trivial is useful to have defined.

Axioms:

```
a*(b/a) = b
inv(a) = 1/a
```

See Also:

```
o )show Field
```

Euclidean Domains are a subset of Fields.

← “EuclideanDomain” (EUCDOM) [15](#) on page [1235](#)

⇒ “PseudoAlgebraicClosureOfPerfectFieldCategory” (PACPERC) [17](#) on page [1420](#)

See:

⇒ “AlgebraicallyClosedField” (ACF) [17](#) on page [1343](#)

⇒ “ExtensionField” (XF) [18](#) on page [1562](#)

⇒ “FieldOfPrimeCharacteristic” (FPC) [17](#) on page [1374](#)

⇒ “FiniteRankAlgebra” (FINRAlg) [17](#) on page [1380](#)

⇒ “FunctionSpace” (FS) [17](#) on page [1387](#)

⇒ “QuotientFieldCategory” (QFCAT) [17](#) on page [1427](#)

⇒ “RealClosedField” (RCFIELD) [17](#) on page [1441](#)

⇒ “RealNumberSystem” (RNS) [17](#) on page [1451](#)

⇒ “UnivariateLaurentSeriesCategory” (ULSCAT) [17](#) on page [1499](#)

⇒ “UnivariatePolynomialCategory” (UPOLYC) [17](#) on page [1522](#)

⇒ “UnivariatePuisseuxSeriesCategory” (UPXSCAT) [17](#) on page [1511](#)

← “DivisionRing” (DIVRING) [12](#) on page [1063](#)

← “EuclideanDomain” (EUCDOM) [15](#) on page [1235](#)

← “UniqueFactorizationDomain” (UFD) [14](#) on page [1222](#)

Exports:

| | | | | |
|----------------|---------------|--------------------|----------------|-------------------|
| 0 | 1 | associates? | characteristic | coerce |
| divide | euclideanSize | expressIdealMember | exquo | extendedEuclidean |
| factor | gcd | gcdPolynomial | hash | inv |
| latex | lcm | multiEuclidean | one? | prime? |
| principalIdeal | recip | sample | sizeLess? | squareFree |
| squareFreePart | subtractIfCan | unit? | unitCanonical | unitNormal |
| zero? | ?*? | ?**? | ?+? | ?-? |
| -? | ?/? | ?=? | ?^? | ?quo? |
| ?rem? | ?~=? | | | |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?(a,b)** returns true if and only if **unitCanonical(a) = unitCanonical(b)**.
- **canonicalsClosed** is true if **unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)**.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative(“*”)** is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has **unitsKnown** means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are implemented by this category:

```

associates? : (%,% ) -> Boolean
divide : (%,% ) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
exquo : (%,% ) -> Union(%,"failed")
factor : % -> Factored %
gcd : (%,% ) -> %
inv : % -> %
prime? : % -> Boolean
squareFree : % -> Factored %
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
?/? : (%,% ) -> %

```

These exports come from (p1235) EuclideanDomain():

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
expressIdealMember : (List %,%) -> Union(List %,"failed")
extendedEuclidean : (%,%,% ) -> Union(Record(coef1: %,coef2: %),"failed")
extendedEuclidean : (%,% ) -> Record(coef1: %,coef2: %,generator: %)
gcd : List % -> %
gcdPolynomial : (SparseUnivariatePolynomial %,
                  SparseUnivariatePolynomial %) ->
                  SparseUnivariatePolynomial %
hash : % -> SingleInteger
latex : % -> String
lcm : List % -> %
lcm : (%,% ) -> %
multiEuclidean : (List %,%) -> Union(List %,"failed")
one? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%,"failed")
sample : () -> %
sizeLess? : (%,% ) -> Boolean
subtractIfCan : (%,% ) -> Union(%,"failed")
unit? : % -> Boolean
zero? : % -> Boolean
?+? : (%,% ) -> %
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (%,% ) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-? : (%,% ) -> %
-? : % -> %
?**? : (% ,PositiveInteger) -> %
?**? : (% ,NonNegativeInteger) -> %
?^? : (% ,PositiveInteger) -> %
?^? : (% ,NonNegativeInteger) -> %
?quo? : (%,% ) -> %
?rem? : (%,% ) -> %

```

These exports come from (p1222) UniqueFactorizationDomain():

```
squareFreePart : % -> %
```

These exports come from (p1063) DivisionRing():

```
coerce : Fraction Integer -> %
?*? : (Fraction Integer,%) -> %
```

```

???: (% , Fraction Integer) -> %
***?: (% , Integer) -> %
???: (% , Integer) -> %

```

— category FIELD Field —

```

)abbrev category FIELD Field
++ Description:
++ The category of commutative fields, i.e. commutative rings
++ where all non-zero elements have multiplicative inverses.
++ The \spadfun{factor} operation while trivial is useful to have defined.
++
++ Axioms\br
++ \tab{5}\spad{a*(b/a) = b}\br
++ \tab{5}\spad{inv(a) = 1/a}

Field(): Category == Join(EuclideanDomain, UniqueFactorizationDomain,
  DivisionRing) with
  "/" : (% , %) -> %
    ++ x/y divides the element x by the element y.
    ++ Error: if y is 0.
  canonicalUnitNormal ++ either 0 or 1.
  canonicalsClosed ++ since \spad{0*0=0}, \spad{1*1=1}
add
  x, y: %
  n: Integer

UCA ==> Record(unit:%, canonical:%, associate:%)

unitNormal(x) ==
  if zero? x then [1$, 0$, 1$]$UCA else [x, 1$, inv(x)]$UCA

unitCanonical(x) == if zero? x then x else 1

associates?(x, y) == if zero? x then zero? y else not(zero? y)

inv x == ((u:=recip x) case "failed" => error "not invertible"; u)

x exquo y == (y=0 => "failed"; x / y)

gcd(x, y) == 1

euclideanSize(x) == 0

prime? x == false

squareFree x == x::Factored(%)

factor x == x::Factored(%)

```

```

x / y == (zero? y => error "catdef: division by zero"; x * inv(y))

divide(x,y) == [x / y,0]

```

— FIELD.dotabb —

```

"FIELD"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FIELD"];
"FIELD" -> "EUCDOM"
"FIELD" -> "UFD"
"FIELD" -> "DIVRING"

```

— FIELD.dotfull —

```

"Field()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FIELD"];
"Field()" -> "EuclideanDomain()"
"Field()" -> "UniqueFactorizationDomain()"
"Field()" -> "DivisionRing()"

```

— FIELD.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "Field()" [color=lightblue];
  "Field()" -> "EuclideanDomain()"
  "Field()" -> "UniqueFactorizationDomain()"
  "Field()" -> "DIVRING..."

  "EuclideanDomain()" [color=lightblue];
  "EuclideanDomain()" -> "PrincipalIdealDomain()"

  "UniqueFactorizationDomain()" [color=lightblue];
  "UniqueFactorizationDomain()" -> "GCDDOM..."

```

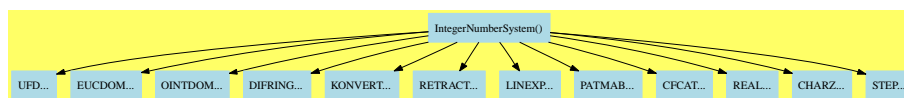
```

"PrincipalIdealDomain()" [color=lightblue];
"PrincipalIdealDomain()" -> "GCDDOM..."

"DIVRING..." [color=lightblue];
"GCDDOM..." [color=lightblue];
}

```

IntegerNumberSystem (INS)



— IntegerNumberSystem.input —

```

)set break resume
)sys rm -f IntegerNumberSystem.output
)spool IntegerNumberSystem.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show IntegerNumberSystem
--R
--R IntegerNumberSystem is a category constructor
--R Abbreviation for IntegerNumberSystem is INS
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for INS
--R
--R----- Operations -----
--R ?? : (% , %) -> %
--R ?? : (PositiveInteger , %) -> %
--R ?+? : (% , %) -> %
--R -? : % -> %
--R ?<=? : (% , %) -> Boolean
--R ?>? : (% , %) -> Boolean
--R D : % -> %
--R 1 : () -> %
--R ?^? : (% , PositiveInteger) -> %
--R addmod : (% , % , %) -> %
--R base : () -> %
--R
--R ?? : (Integer , %) -> %
--R ??? : (% , PositiveInteger) -> %
--R ?-? : (% , %) -> %
--R ?<? : (% , %) -> Boolean
--R ?=? : (% , %) -> Boolean
--R ?>=? : (% , %) -> Boolean
--R D : (% , NonNegativeInteger) -> %
--R 0 : () -> %
--R abs : % -> %
--R associates? : (% , %) -> Boolean
--R binomial : (% , %) -> %

```

```

--R bit? : (% ,%) -> Boolean
--R coerce : % -> %
--R coerce : % -> OutputForm
--R convert : % -> Float
--R convert : % -> InputForm
--R copy : % -> %
--R differentiate : % -> %
--R factor : % -> Factored(%)
--R gcd : List(%) -> %
--R hash : % -> %
--R inc : % -> %
--R invmod : (% ,%) -> %
--R lcm : List(%) -> %
--R length : % -> %
--R max : (% ,%) -> %
--R mulmod : (% ,%,%) -> %
--R odd? : % -> Boolean
--R permutation : (% ,%) -> %
--R positiveRemainder : (% ,%) -> %
--R prime? : % -> Boolean
--R random : % -> %
--R rational : % -> Fraction(Integer)
--R recip : % -> Union(%, "failed")
--R retract : % -> Integer
--R shift : (% ,%) -> %
--R sizeLess? : (% ,%) -> Boolean
--R squareFreePart : % -> %
--R symmetricRemainder : (% ,%) -> %
--R unitCanonical : % -> %
--R ?=? : (% ,%) -> Boolean
--R ?*? : (NonNegativeInteger,%) -> %
--R ?**? : (% ,NonNegativeInteger) -> %
--R ?^? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R differentiate : (% ,NonNegativeInteger) -> %
--R divide : (% ,%) -> Record(quotient: %, remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%), "failed")
--R exquo : (% ,%) -> Union(%, "failed")
--R extendedEuclidean : (% ,%) -> Record(coef1: %, coef2: %, generator: %)
--R extendedEuclidean : (% ,%,%) -> Union(Record(coef1: %, coef2: %), "failed")
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R multiEuclidean : (List(%),%) -> Union(List(%), "failed")
--R nextItem : % -> Union(%, "failed")
--R patternMatch : (% ,Pattern(Integer), PatternMatchResult(Integer,%)) -> PatternMatchResult(Integer,% )
--R principalIdeal : List(%) -> Record(coef: List(%), generator: %)
--R rationalIfCan : % -> Union(Fraction(Integer), "failed")
--R reducedSystem : Matrix(%) -> Matrix(Integer)
--R reducedSystem : (Matrix(%), Vector(%)) -> Record(mat: Matrix(Integer), vec: Vector(Integer))
--R retractIfCan : % -> Union(Integer, "failed")
--R coerce : Integer -> %
--R coerce : Integer -> %
--R convert : % -> DoubleFloat
--R convert : % -> Pattern(Integer)
--R convert : % -> Integer
--R dec : % -> %
--R even? : % -> Boolean
--R factorial : % -> %
--R gcd : (% ,%) -> %
--R hash : % -> SingleInteger
--R init : () -> %
--R latex : % -> String
--R lcm : (% ,%) -> %
--R mask : % -> %
--R min : (% ,%) -> %
--R negative? : % -> Boolean
--R one? : % -> Boolean
--R positive? : % -> Boolean
--R powmod : (% ,%,%) -> %
--R ?quo? : (% ,%) -> %
--R random : () -> %
--R rational? : % -> Boolean
--R ?rem? : (% ,%) -> %
--R sample : () -> %
--R sign : % -> Integer
--R squareFree : % -> Factored(%)
--R submod : (% ,%,%) -> %
--R unit? : % -> Boolean
--R zero? : % -> Boolean

```

```

--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— IntegerNumberSystem.help —

```

=====
IntegerNumberSystem examples
=====

```

An IntegerNumberSystem is a model for the integers.

See Also:

o)show IntegerNumberSystem

See:

⇐ “CharacteristicZero” (CHARZ) [10](#) on page [892](#)
 ⇐ “CombinatorialFunctionCategory” (CFCAT) [2](#) on page [36](#)
 ⇐ “ConvertibleTo” (KONVERT) [2](#) on page [41](#)
 ⇐ “DifferentialRing” (DIFRING) [10](#) on page [902](#)
 ⇐ “EuclideanDomain” (EUCDOM) [15](#) on page [1235](#)
 ⇐ “LinearlyExplicitRingOver” (LINEXP) [10](#) on page [923](#)
 ⇐ “OrderedIntegralDomain” (OINTDOM) [13](#) on page [1185](#)
 ⇐ “Patternable” (PATAB) [2](#) on page [86](#)
 ⇐ “RealConstant” (REAL) [3](#) on page [155](#)
 ⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)
 ⇐ “StepThrough” (STEP) [4](#) on page [305](#)
 ⇐ “UniqueFactorizationDomain” (UFD) [14](#) on page [1222](#)

Exports:

| | | | |
|--------------------|----------------|--------------------|----------------|
| 0 | 1 | abs | addmod |
| associates? | base | binomial | bit? |
| characteristic | coerce | convert | copy |
| D | dec | differentiate | divide |
| euclideanSize | even? | expressIdealMember | exquo |
| extendedEuclidean | factor | factorial | gcd |
| gcdPolynomial | hash | inc | init |
| invmod | latex | lcm | length |
| mask | max | min | mulmod |
| multiEuclidean | negative? | nextItem | odd? |
| one? | patternMatch | permutation | positive? |
| positiveRemainder | powmod | prime? | principalIdeal |
| random | rational | rational? | rationalIfCan |
| recip | reducedSystem | retract | retractIfCan |
| sample | shift | sign | sizeLess? |
| squareFree | squareFreePart | submod | subtractIfCan |
| symmetricRemainder | unit? | unitCanonical | unitNormal |
| zero? | ?*? | ?**? | ?+? |
| ?-? | -? | ?<? | ?<=? |
| ?=? | ?>? | ?>=? | ?^? |
| ?~=? | ?quo? | ?rem? | |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **multiplicativeValuation** implies `euclideanSize(a*b)=euclideanSize(a)*euclideanSize(b)`.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative("*)** is true if it has an operation " $*$ " : $(D,D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return "failed" if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
addmod : (%,%,% ) -> %
base : () -> %
dec : % -> %
hash : % -> %
```



```

inc : % -> %
length : % -> %
mulmod : (%,%,%) -> %
odd? : % -> Boolean
positiveRemainder : (%,%) -> %
random : () -> %
random : % -> %
shift : (%,%) -> %
submod : (%,%,%) -> %

```

These are implemented by this category:

```

binomial : (%,%) -> %
bit? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
convert : % -> Float
convert : % -> DoubleFloat
convert : % -> InputForm
convert : % -> Pattern Integer
copy : % -> %
differentiate : % -> %
euclideanSize : % -> NonNegativeInteger
even? : % -> Boolean
factor : % -> Factored %
factorial : % -> %
init : () -> %
invmod : (%,%) -> %
mask : % -> %
nextItem : % -> Union(%, "failed")
patternMatch :
  (%, Pattern Integer, PatternMatchResult(Integer, %)) ->
    PatternMatchResult(Integer, %)
permutation : (%,%) -> %
positive? : % -> Boolean
powmod : (%,%,%) -> %
prime? : % -> Boolean
rational : % -> Fraction Integer
rational? : % -> Boolean
rationalIfCan : % -> Union(Fraction Integer, "failed")
retract : % -> Integer
retractIfCan : % -> Union(Integer, "failed")
squareFree : % -> Factored %
symmetricRemainder : (%,%) -> %

```

These exports come from (p1222) UniqueFactorizationDomain():

```

0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
coerce : % -> %

```

```

coerce : Integer -> %
coerce : Integer -> %
coerce : % -> OutputForm
exquo : (%,% ) -> Union(%, "failed")
gcd : List % -> %
gcd : (%,% ) -> %
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
hash : % -> SingleInteger
latex : % -> String
lcm : List % -> %
lcm : (%,% ) -> %
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
squareFreePart : % -> %
subtractIfCan : (%,% ) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
zero? : % -> Boolean
?+? : (%,% ) -> %
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (%,% ) -> %
?*? : (Integer,% ) -> %
?*? : (PositiveInteger,% ) -> %
?*? : (NonNegativeInteger,% ) -> %
?-? : (%,% ) -> %
-? : % -> %
***? : (% , PositiveInteger) -> %
***? : (% , NonNegativeInteger) -> %
?? : (% , PositiveInteger) -> %
?? : (% , NonNegativeInteger) -> %

```

These exports come from (p1235) EuclideanDomain():

```

divide : (%,% ) -> Record(quotient: %, remainder: %)
expressIdealMember : (List %,% ) -> Union(List %, "failed")
extendedEuclidean : (%,% ) -> Record(coef1: %, coef2: %, generator: %)
extendedEuclidean : (%,% ,%) -> Union(Record(coef1: %, coef2: %), "failed")
multiEuclidean : (List %,% ) -> Union(List %, "failed")
principalIdeal : List % -> Record(coef: List %, generator: %)
sizeLess? : (%,% ) -> Boolean
?quo? : (%,% ) -> %
?rem? : (%,% ) -> %

```

These exports come from (p1185) OrderedIntegralDomain():

```

abs : % -> %
max : (%,% ) -> %
min : (%,% ) -> %
negative? : % -> Boolean
sign : % -> Integer
?<? : (%,% ) -> Boolean
?<=? : (%,% ) -> Boolean
?>? : (%,% ) -> Boolean
?>=? : (%,% ) -> Boolean

```

These exports come from (p902) `DifferentialRing()`:

```

D : % -> %
D : (% , NonNegativeInteger) -> %
differentiate : (% , NonNegativeInteger) -> %

```

These exports come from (p41) `ConvertibleTo(Integer)`:

```

convert : % -> Integer

```

These exports come from (p923) `LinearlyExplicitRingOver(Integer)`:

```

reducedSystem : Matrix % -> Matrix Integer
reducedSystem : (Matrix % , Vector %) ->
  Record(mat: Matrix Integer , vec: Vector Integer)

```

— category INS IntegerNumberSystem —

```

)abbrev category INS IntegerNumberSystem
++ Author: Stephen M. Watt
++ Date Created: January 1988
++ Description:
++ An \spad{IntegerNumberSystem} is a model for the integers.

IntegerNumberSystem(): Category ==
  Join(UniqueFactorizationDomain, EuclideanDomain, OrderedIntegralDomain,
    DifferentialRing, ConvertibleTo Integer, RetractableTo Integer,
    LinearlyExplicitRingOver Integer, ConvertibleTo InputForm,
    ConvertibleTo Pattern Integer, PatternMatchable Integer,
    CombinatorialFunctionCategory, RealConstant,
    CharacteristicZero, StepThrough) with
  odd?      : % -> Boolean
    ++ odd?(n) returns true if and only if n is odd.
  even?     : % -> Boolean
    ++ even?(n) returns true if and only if n is even.
  multiplicativeValuation
    ++ euclideanSize(a*b) returns \spad{euclideanSize(a)*euclideanSize(b)}.
  base      : () -> %

```

```

    ++ base() returns the base for the operations of
    ++ \spad{IntegerNumberSystem}.
length    : % -> %
    ++ length(a) length of \spad{a} in digits.
shift     : (% , %) -> %
    ++ shift(a,i) shift \spad{a} by i digits.
bit?      : (% , %) -> Boolean
    ++ bit?(n,i) returns true if and only if i-th bit of n is a 1.
positiveRemainder : (% , %) -> %
    ++ positiveRemainder(a,b) (where \spad{b > 1}) yields r
    ++ where \spad{0 <= r < b} and \spad{r == a rem b}.
symmetricRemainder : (% , %) -> %
    ++ symmetricRemainder(a,b) (where \spad{b > 1}) yields r
    ++ where \spad{-b/2 <= r < b/2 }.
rational? : % -> Boolean
    ++ rational?(n) tests if n is a rational number
    ++ (see \spadtype{Fraction Integer}).
rational  : % -> Fraction Integer
    ++ rational(n) creates a rational number
    ++ (see \spadtype{Fraction Integer})..
rationalIfCan : % -> Union(Fraction Integer, "failed")
    ++ rationalIfCan(n) creates a rational number, or returns "failed"
    ++ if this is not possible.
random    : () -> %
    ++ random() creates a random element.
random    : % -> %
    ++ random(a) creates a random element from 0 to \spad{n-1}.
hash      : % -> %
    ++ hash(n) returns the hash code of n.
copy      : % -> %
    ++ copy(n) gives a copy of n.
inc       : % -> %
    ++ inc(x) returns \spad{x + 1}.
dec       : % -> %
    ++ dec(x) returns \spad{x - 1}.
mask      : % -> %
    ++ mask(n) returns \spad{2**n-1} (an n bit mask).
addmod    : (% , % , %) -> %
    ++ addmod(a,b,p), \spad{0<=a,b<p>1}, means \spad{a+b mod p}.
submod    : (% , % , %) -> %
    ++ submod(a,b,p), \spad{0<=a,b<p>1}, means \spad{a-b mod p}.
mulmod    : (% , % , %) -> %
    ++ mulmod(a,b,p), \spad{0<=a,b<p>1}, means \spad{a*b mod p}.
powmod    : (% , % , %) -> %
    ++ powmod(a,b,p), \spad{0<=a,b<p>1}, means \spad{a**b mod p}.
invmod    : (% , %) -> %
    ++ invmod(a,b), \spad{0<=a<b>1}, \spad{(a,b)=1} means \spad{1/a mod b}.
canonicalUnitNormal
-- commutative(*) -- follows from the above

```

```

add
  characteristic()      == 0

  differentiate x        == 0

  even? x                == not odd? x

  positive? x            == x > 0

  copy x                 == x

  bit?(x, i)             == odd? shift(x, -i)

  mask n                 == dec shift(1, n)

  rational? x            == true

  euclideanSize(x)       ==
    x=0 => error "euclideanSize called on zero"
    x<0 => (-convert(x)@Integer)::NonNegativeInteger
    convert(x)@Integer::NonNegativeInteger

  convert(x:%):Float      == (convert(x)@Integer)::Float

  convert(x:%):DoubleFloat == (convert(x)@Integer)::DoubleFloat

  convert(x:%):InputForm  == convert(convert(x)@Integer)

  retract(x:%):Integer    == convert(x)@Integer

  convert(x:%):Pattern(Integer) == convert(x)@Integer :: Pattern(Integer)

  factor x               == factor(x)$IntegerFactorizationPackage(%)

  squareFree x           == squareFree(x)$IntegerFactorizationPackage(%)

  prime? x               == prime?(x)$IntegerPrimesPackage(%)

  factorial x            == factorial(x)$IntegerCombinatoricFunctions(%)

  binomial(n, m)         == binomial(n, m)$IntegerCombinatoricFunctions(%)

  permutation(n, m) == permutation(n,m)$IntegerCombinatoricFunctions(%)

  retractIfCan(x:%):Union(Integer, "failed") == convert(x)@Integer

  init() == 0

  -- iterates in order 0,1,-1,2,-2,3,-3,...
  nextItem(n) ==

```

```

zero? n => 1
n>0 => -n
1-n

patternMatch(x, p, l) ==
  patternMatch(x, p, l)$PatternMatchIntegerNumberSystem(%)

rational(x:%):Fraction(Integer) ==
  (convert(x)@Integer)::Fraction(Integer)

rationalIfCan(x:%):Union(Fraction Integer, "failed") ==
  (convert(x)@Integer)::Fraction(Integer)

symmetricRemainder(x, n) ==
  r := x rem n
  r = 0 => r
  if n < 0 then n:=-n
  r > 0 =>
    2 * r > n => r - n
    r
  2*r + n <= 0 => r + n
  r

invmod(a, b) ==
  if negative? a then a := positiveRemainder(a, b)
  c := a; c1:% := 1
  d := b; d1:% := 0
  while not zero? d repeat
    q := c quo d
    r := c-q*d
    r1 := c1-q*d1
    c := d; c1 := d1
    d := r; d1 := r1
--   not one? c => error "inverse does not exist"
  not (c = 1) => error "inverse does not exist"
  negative? c1 => c1 + b
  c1

powmod(x, n, p) ==
  if negative? x then x := positiveRemainder(x, p)
  zero? x => 0
  zero? n => 1
  y:% := 1
  z := x
  repeat
    if odd? n then y := mulmod(y, z, p)
    zero?(n := shift(n, -1)) => return y
    z := mulmod(z, z, p)

```

— INS.dotabb —

```
"INS"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=INS" ];
"INS" -> "UFD"
"INS" -> "EUCDOM"
"INS" -> "OINTDOM"
"INS" -> "DIFRING"
"INS" -> "KONVERT"
"INS" -> "RETRACT"
"INS" -> "LINEXP"
"INS" -> "PATMAB"
"INS" -> "CFCAT"
"INS" -> "REAL"
"INS" -> "CHARZ"
"INS" -> "STEP"
```

— INS.dotfull —

```
"IntegerNumberSystem()"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=INS" ];
"IntegerNumberSystem()" -> "UniqueFactorizationDomain()"
"IntegerNumberSystem()" -> "EuclideanDomain()"
"IntegerNumberSystem()" -> "OrderedIntegralDomain()"
"IntegerNumberSystem()" -> "DifferentialRing()"
"IntegerNumberSystem()" -> "ConvertibleTo(Integer)"
"IntegerNumberSystem()" -> "ConvertibleTo(InputForm)"
"IntegerNumberSystem()" -> "ConvertibleTo(Pattern(Integer))"
"IntegerNumberSystem()" -> "RetractableTo(Integer)"
"IntegerNumberSystem()" -> "LinearlyExplicitRingOver(Integer)"
"IntegerNumberSystem()" -> "PatternMatchable(Integer)"
"IntegerNumberSystem()" -> "CombinatorialFunctionCategory()"
"IntegerNumberSystem()" -> "RealConstant()"
"IntegerNumberSystem()" -> "CharacteristicZero()"
"IntegerNumberSystem()" -> "StepThrough()"
```

— INS.dotpic —

```
digraph pic {
  fontsize=10;
```

```

bgcolor="#ECEA81";
node [shape=box, color=white, style=filled];

"IntegerNumberSystem()" [color=lightblue];
"IntegerNumberSystem()" -> "UFD..."
"IntegerNumberSystem()" -> "EUCDOM..."
"IntegerNumberSystem()" -> "OINTDOM..."
"IntegerNumberSystem()" -> "DIFRING..."
"IntegerNumberSystem()" -> "KONVERT..."
"IntegerNumberSystem()" -> "RETRACT..."
"IntegerNumberSystem()" -> "LINEXP..."
"IntegerNumberSystem()" -> "PATMAB..."
"IntegerNumberSystem()" -> "CFCAT..."
"IntegerNumberSystem()" -> "REAL..."
"IntegerNumberSystem()" -> "CHARZ..."
"IntegerNumberSystem()" -> "STEP..."

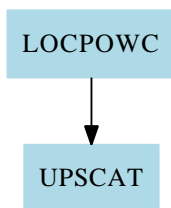
"UFD..." [color=lightblue];
"EUCDOM..." [color=lightblue];
"OINTDOM..." [color=lightblue];
"DIFRING..." [color=lightblue];
"KONVERT..." [color=lightblue];
"RETRACT..." [color=lightblue];
"LINEXP..." [color=lightblue];
"PATMAB..." [color=lightblue];
"CFCAT..." [color=lightblue];
"REAL..." [color=lightblue];
"CHARZ..." [color=lightblue];
"STEP..." [color=lightblue];

}

```

————→

LocalPowerSeriesCategory (LOCPOWC)



— LocalPowerSeriesCategory.input —


```

)set break resume
)sys rm -f LocalPowerSeriesCategory.output
)spool LocalPowerSeriesCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show LocalPowerSeriesCategory
--R
--R LocalPowerSeriesCategory(K: Field) is a category constructor
--R Abbreviation for LocalPowerSeriesCategory is LOCPOWC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for LOCPOWC
--R
--R----- Operations -----
--R ?? : (%,K) -> %
--R ?? : (Fraction(Integer),%) -> %
--R ?? : (%,%) -> %
--R ?? : (PositiveInteger,%) -> %
--R ??? : (%,PositiveInteger) -> %
--R ?? : (%,%) -> %
--R ?? : (%,%) -> %
--R 1 : () -> %
--R ?? : (%,Integer) -> %
--R associates? : (%,%) -> Boolean
--R coefOfFirstNonZeroTerm : % -> K
--R coerce : Fraction(Integer) -> %
--R coerce : Integer -> %
--R complete : % -> %
--R delay : (() -> %) -> %
--R extend : (%,Integer) -> %
--R filterUpTo : (%,Integer) -> %
--R gcd : List(%) -> %
--R hash : % -> SingleInteger
--R latex : % -> String
--R lcm : (%,%) -> %
--R leadingMonomial : % -> %
--R monomial : (K,Integer) -> %
--R one? : % -> Boolean
--R order : % -> Integer
--R pole? : % -> Boolean
--R prime? : % -> Boolean
--R printInfo : Boolean -> Boolean
--R recip : % -> Union(%, "failed")
--R rem? : (%,%) -> %
--R removeZeroes : % -> %
--R sample : () -> %
--R series : (Integer,K,%) -> %
--R sizeLess? : (%,%) -> Boolean
--R ?? : (K,%) -> %
--R ?? : (%,Fraction(Integer)) -> %
--R ?? : (Integer,%) -> %
--R ??? : (%,Integer) -> %
--R +? : (%,%) -> %
--R -? : % -> %
--R ?? : (%,%) -> Boolean
--R 0 : () -> %
--R ?? : (%,PositiveInteger) -> %
--R center : % -> K
--R coefficient : (%,Integer) -> K
--R coerce : % -> %
--R coerce : % -> OutputForm
--R degree : % -> Integer
--R ?.? : (%,Integer) -> K
--R factor : % -> Factored(%)
--R findCoef : (%,Integer) -> K
--R gcd : (%,%) -> %
--R inv : % -> %
--R lcm : List(%) -> %
--R leadingCoefficient : % -> K
--R map : ((K -> K),%) -> %
--R monomial? : % -> Boolean
--R order : % -> Integer
--R order : (%,Integer) -> Integer
--R posExpnPart : % -> %
--R printInfo : () -> Boolean
--R ?quo? : (%,%) -> %
--R reductum : % -> %
--R removeFirstZeroes : % -> %
--R removeZeroes : (Integer,%) -> %
--R sbt : (%,%) -> %
--R shift : (%,Integer) -> %
--R squareFree : % -> Factored(%)

```

```

--R squareFreePart : % -> %
--R unit? : % -> Boolean
--R variable : % -> Symbol
--R ?~=? : (%,% ) -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R *** : (% ,NonNegativeInteger) -> %
--R ?/? : (% ,K) -> % if K has FIELD
--R D : (% ,List(Symbol),List(NonNegativeInteger)) -> % if K has PDRING(SYMBOL) and K has *: (Integer,K) -> K
--R D : (% ,Symbol,NonNegativeInteger) -> % if K has PDRING(SYMBOL) and K has *: (Integer,K) -> K
--R D : (% ,List(Symbol)) -> % if K has PDRING(SYMBOL) and K has *: (Integer,K) -> K
--R D : (% ,Symbol) -> % if K has PDRING(SYMBOL) and K has *: (Integer,K) -> K
--R D : (% ,NonNegativeInteger) -> % if K has *: (Integer,K) -> K
--R D : % -> % if K has *: (Integer,K) -> K
--R ?^? : (% ,NonNegativeInteger) -> %
--R approximate : (% ,Integer) -> K if K has **: (K,Integer) -> K and K has coerce: Symbol -> K
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(% ,"failed") if K has CHARNZ
--R coerce : % -> Stream(Record(k: Integer,c: K))
--R coerce : Stream(Record(k: Integer,c: K)) -> %
--R coerce : K -> % if K has COMRING
--R differentiate : (% ,List(Symbol),List(NonNegativeInteger)) -> % if K has PDRING(SYMBOL) and K has *: (Integer,K) -> K
--R differentiate : (% ,Symbol,NonNegativeInteger) -> % if K has PDRING(SYMBOL) and K has *: (Integer,K) -> K
--R differentiate : (% ,List(Symbol)) -> % if K has PDRING(SYMBOL) and K has *: (Integer,K) -> K
--R differentiate : (% ,Symbol) -> % if K has PDRING(SYMBOL) and K has *: (Integer,K) -> K
--R differentiate : (% ,NonNegativeInteger) -> % if K has *: (Integer,K) -> K
--R differentiate : % -> % if K has *: (Integer,K) -> K
--R divide : (% ,%) -> Record(quotient: %,remainder: %)
--R ?? : (% ,%) -> % if Integer has SGROUP
--R euclideanSize : % -> NonNegativeInteger
--R eval : (% ,K) -> Stream(K) if K has **: (K,Integer) -> K
--R expressIdealMember : (List(% ),%) -> Union(List(% ),"failed")
--R exquo : (% ,%) -> Union(% ,"failed")
--R extendedEuclidean : (% ,%,%) -> Union(Record(coef1: %,coef2: % ),"failed")
--R extendedEuclidean : (% ,%) -> Record(coef1: %,coef2: %,generator: %)
--R gcdPolynomial : (SparseUnivariatePolynomial(% ),SparseUnivariatePolynomial(% )) -> SparseUnivariatePolynomial(% )
--R monomial : (% ,List(SingletonAsOrderedSet,Integer)) -> %
--R monomial : (% ,List(SingletonAsOrderedSet),List(Integer)) -> %
--R monomial2series : (List(% ),List(NonNegativeInteger,Integer)) -> %
--R multiEuclidean : (List(% ),%) -> Union(List(% ),"failed")
--R multiplyExponents : (% ,PositiveInteger) -> %
--R orderIfNegative : % -> Union(Integer,"failed")
--R principalIdeal : List(% ) -> Record(coef: List(% ),generator: %)
--R subtractIfCan : (% ,%) -> Union(% ,"failed")
--R terms : % -> Stream(Record(k: Integer,c: K))
--R truncate : (% ,Integer,Integer) -> %
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R variables : % -> List(SingletonAsOrderedSet)
--R
--E 1

```

```
)spool  
)lisp (bye)
```

— LocalPowerSeriesCategory.help —

```
=====
LocalPowerSeriesCategory examples
=====
```

See Also:
o)show LocalPowerSeriesCategory

See:

- ⇐ “CharacteristicZero” (CHARZ) [10](#) on page [892](#)
- ⇐ “EuclideanDomain” (EUCDOM) [15](#) on page [1235](#)
- ⇐ “UnivariatePowerSeriesCategory” (UPSCAT) [15](#) on page [1260](#)

Exports:

| | | |
|--------------------|------------------------|--------------------|
| 0 | 1 | -? |
| ?**? | ?+? | ?-? |
| ?/? | ?/? | ?=? |
| ?^? | ?~=? | ?quo? |
| ?rem? | D | approximate |
| associates? | center | characteristic |
| charthRoot | coefOfFirstNonZeroTerm | coefficient |
| coerce | complete | degree |
| delay | differentiate | divide |
| euclideanSize | eval | expressIdealMember |
| exquo | extend | extendedEuclidean |
| factor | filterUpTo | findCoef |
| gcd | gcdPolynomial | hash |
| inv | latex | lcm |
| leadingCoefficient | leadingMonomial | map |
| monomial | monomial2series | monomial? |
| multiEuclidean | multiplyExponents | one? |
| order | orderIfNegative | pole? |
| posExpnPart | prime? | principalIdeal |
| printInfo | recip | reductum |
| removeFirstZeroes | removeZeroes | sample |
| sbt | series | shift |
| sizeLess? | squareFree | squareFreePart |
| subtractIfCan | terms | truncate |
| unit? | unitCanonical | unitNormal |
| variable | variables | zero? |

Attributes Exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**("*") is true if it has an operation " $*$ " : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return "failed" if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?**(a, b) returns true if and only if **unitCanonical**(a) = **unitCanonical**(b).
- **canonicalsClosed** is true if
 $\text{unitCanonical}(a) * \text{unitCanonical}(b) = \text{unitCanonical}(a * b)$.

These are directly exported but not implemented

```

coefOfFirstNonZeroTerm : % -> K
coerce : % -> Stream Record(k: Integer,c: K)
coerce : Stream Record(k: Integer,c: K) -> %
delay : (() -> %) -> %
filterUpTo : (%,Integer) -> %
findCoef : (%,Integer) -> K
monomial2series : (List %,List NonNegativeInteger,Integer) -> %
order : % -> Integer
orderIfNegative : % -> Union(Integer,"failed")
posExpnPart : % -> %
printInfo : () -> Boolean
printInfo : Boolean -> Boolean
removeFirstZeroes : % -> %
removeZeroes : % -> %
removeZeroes : (Integer,%) -> %
sbt : (%,%) -> %
series : (Integer,K,%) -> %
shift : (%,Integer) -> %

```

These exports come from (p1260) `UnivariatePowerSeriesCategory()`:

```

-? : % -> %
0 : () -> %
1 : () -> %
***? : (%,NonNegativeInteger) -> %
***? : (%,PositiveInteger) -> %
**? : (%,%) -> %
**? : (%,Fraction Integer) -> %
**? : (Fraction Integer,%) -> %
**? : (Integer,%) -> %
**? : (NonNegativeInteger,%) -> %
**? : (PositiveInteger,%) -> %
+? : (%,%) -> %
-? : (%,%) -> %
.?. : (%,%) -> % if Integer has SGROUP
.?. : (%,Integer) -> K
?/? : (%,%) -> %
?=? : (%,%) -> Boolean
?? : (%,NonNegativeInteger) -> %
?? : (%,PositiveInteger) -> %
?~=? : (%,%) -> Boolean
D : % -> % if K has *: (Integer,K) -> K
D : (%,List Symbol) -> %
    if K has PDRING SYMBOL and K has *: (Integer,K) -> K
D : (%,List Symbol,List NonNegativeInteger) -> %
    if K has PDRING SYMBOL and K has *: (Integer,K) -> K
D : (%,NonNegativeInteger) -> % if K has *: (Integer,K) -> K
D : (%,Symbol) -> % if K has PDRING SYMBOL and K has *: (Integer,K) -> K
D : (%,Symbol,NonNegativeInteger) -> %
    if K has PDRING SYMBOL and K has *: (Integer,K) -> K

```

```

approximate : (%,Integer) -> K
  if K has **: (K,Integer) -> K and K has coerce: Symbol -> K
associates? : (%,:) -> Boolean
center : % -> K
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(%, "failed") if K has CHARNZ
coefficient : (%,Integer) -> K
coerce : % -> %
coerce : % -> OutputForm
coerce : Fraction Integer -> %
coerce : Integer -> %
coerce : K -> % if K has COMRING
complete : % -> %
degree : % -> Integer
differentiate : % -> % if K has *: (Integer,K) -> K
differentiate : (%,List Symbol) -> %
  if K has PDRING SYMBOL and K has *: (Integer,K) -> K
differentiate : (%,List Symbol,List NonNegativeInteger) -> %
  if K has PDRING SYMBOL and K has *: (Integer,K) -> K
differentiate : (%,NonNegativeInteger) -> %
  if K has *: (Integer,K) -> K
differentiate : (%,Symbol) -> %
  if K has PDRING SYMBOL and K has *: (Integer,K) -> K
differentiate : (%,Symbol,NonNegativeInteger) -> %
  if K has PDRING SYMBOL and K has *: (Integer,K) -> K
eval : (%K) -> Stream K if K has **: (K,Integer) -> K
exquo : (%,:) -> Union(%, "failed")
extend : (%,Integer) -> %
hash : % -> SingleInteger
latex : % -> String
leadingCoefficient : % -> K
leadingMonomial : % -> %
map : ((K -> K),%) -> %
monomial : (%List SingletonAsOrderedSet,List Integer) -> %
monomial : (%SingletonAsOrderedSet,Integer) -> %
monomial : (K,Integer) -> %
monomial? : % -> Boolean
multiplyExponents : (%PositiveInteger) -> %
one? : % -> Boolean
order : % -> Integer
order : (%Integer) -> Integer
pole? : % -> Boolean
recip : % -> Union(%, "failed")
reductum : % -> %
sample : () -> %
subtractIfCan : (%,:) -> Union(%, "failed")
terms : % -> Stream Record(k: Integer,c: K)
truncate : (%Integer) -> %
truncate : (%Integer,Integer) -> %
unit? : % -> Boolean

```

```

unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
variable : % -> Symbol
variables : % -> List SingletonAsOrderedSet
zero? : % -> Boolean

```

These exports come from (p1271) `Field()`:

```

***? : (%,Integer) -> %
**? : (%K) -> %
*? : (K,%) -> %
?/? : (%K) -> % if K has FIELD
^? : (%,Integer) -> %
?quo? : (%,%) -> %
?rem? : (%,%) -> %
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %,"failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed")
factor : % -> Factored %
gcd : (%,%) -> %
gcd : List % -> %
gcdPolynomial :
  (SparseUnivariatePolynomial %,SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
inv : % -> %
lcm : (%,%) -> %
lcm : List % -> %
multiEuclidean : (List %,%) -> Union(List %,"failed")
prime? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
sizeLess? : (%,%) -> Boolean
squareFree : % -> Factored %
squareFreePart : % -> %

```

— category LOCPOWC LocalPowerSeriesCategory —

```

)abbrev category LOCPOWC LocalPowerSeriesCategory
LocalPowerSeriesCategory(K:Field):Category == Implementation where

```

```

INT    ==> Integer
TERM   ==> Record(k:INT,c:K)
SER     ==> Stream(TERM)
NNI     ==> NonNegativeInteger

```

```

Implementation ==>
  Join(Field,UnivariatePowerSeriesCategory(K,INT)) with

```

```

order: % -> Integer
  ++ order(s) returns the order of s.

findCoef: (%,Integer) -> K

coerce: SER -> %

coerce: % -> SER

posExpnPart: % -> %
  ++ posExpnPart(s) returns the series s less the terms with
  ++ negative exponent.

orderIfNegative: % -> Union(Integer,"failed")

removeFirstZeroes: % -> %

sbt: (%,% ) -> %

delay: ( ( ) -> % ) -> %
  ++ delay delayed the computation of the next term of the series given
  ++ by the input function.

monomial2series: (List %, List NNI, INT) -> %
  ++ monomial2series(ls,le,n) returns
  ++ t**n * reduce("",[s ** e for s in ls for e in le])

removeZeroes: (INT,%) -> %
  ++ removeZeroes(n,s) removes the zero terms in the first n terms of s.

removeZeroes: % -> %
  ++ removeZeroes(s) removes the zero terms in s.

series: (INT,K,%) -> %
  ++ series(e,c,s) create the series c*t**e + s.

shift: (% ,INT) -> %
  ++ shift(s,n) returns t**n * s

filterUpTo : (% ,INT) -> %
  ++ filterUpTo(s,n) returns the series consisting of the terms
  ++ of s having degree strictly less than n.

coefOfFirstNonZeroTerm: % -> K
  ++ coefOfFirstNonZeroTerm(s) returns the first non zero coefficient
  ++ of the series.

printInfo: Boolean -> Boolean
  ++ printInfo(b) set a flag such that when true (b <- true) prints
  ++ some information during some critical computation.

```



```

printInfo: () -> Boolean
  ++ returns the value of the \spad{printInfo} flag.

```

— LOCPOWC.dotabb —

```

"LOCPOWC"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=LOCPOWC"];
"LOCPOWC" -> "UPSCAT"

```

— LOCPOWC.dotfull —

```

"LocalPowerSeriesCategory(f:Field)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=LOCPOWC"];
"LocalPowerSeriesCategory(f:Field)" ->
  "UnivariatePowerSeriesCategory(c:Ring,e:OrderedAbelianMonoid)"

```

— LOCPOWC.dotpic —

```

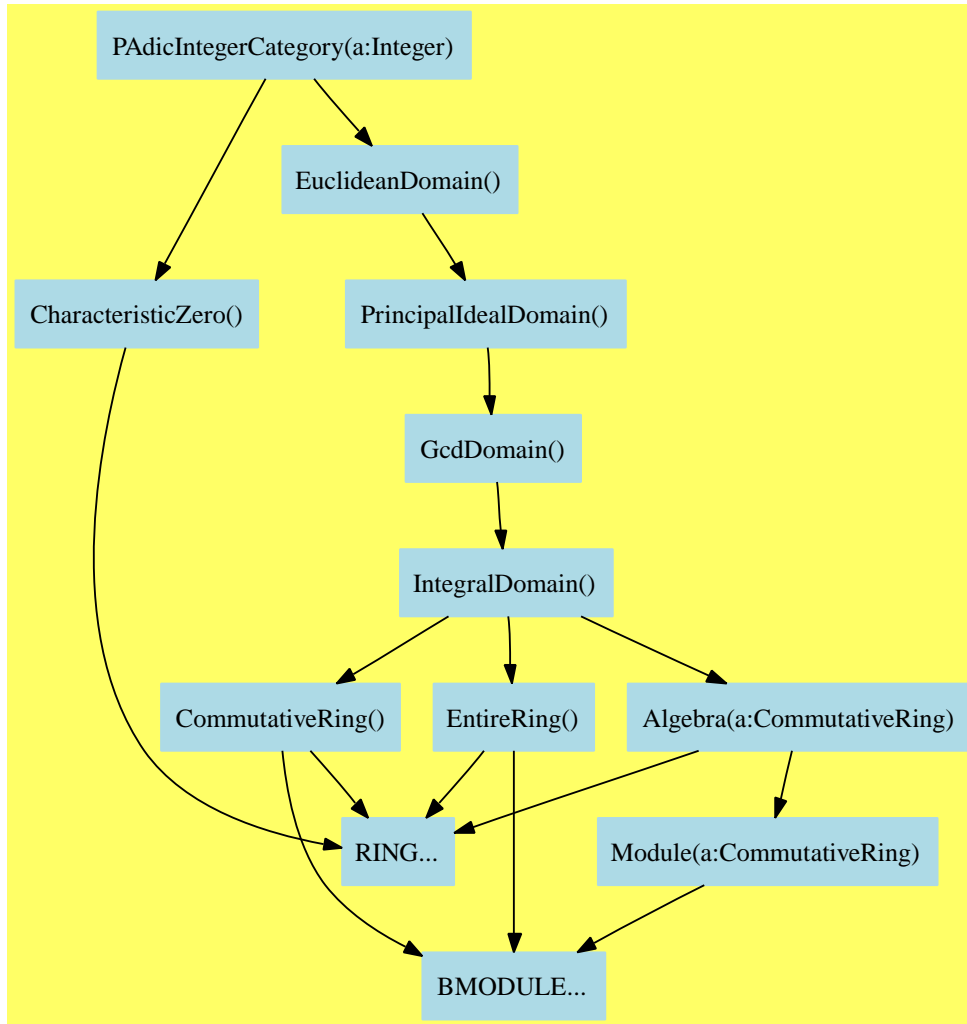
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "LocalPowerSeriesCategory(f:Field)" [color=lightblue];
  "LocalPowerSeriesCategory(f:Field)" ->
    "UnivariatePowerSeriesCategory(c:Ring,e:OrderedAbelianMonoid)"

  "Ring" [color=lightblue];
  "OrderedAbelianMonoid" [color=lightblue];
}

```

PAdicIntegerCategory (PADICCT)



— PAdicIntegerCategory.input —

```

)set break resume
)sys rm -f PAdicIntegerCategory.output
)spool PAdicIntegerCategory.output
)set message test on
)set message auto off
)clear all

```

--S 1 of 1

```

)show PAdicIntegerCategory
--R
--R PAdicIntegerCategory(p: Integer) is a category constructor
--R Abbreviation for PAdicIntegerCategory is PADICCT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PADICCT
--R
--R----- Operations -----
--R ?? : (%,%) -> %                ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %  *** : (%,PositiveInteger) -> %
--R ?? : (%,%) -> %                ?-? : (%,%) -> %
--R -? : % -> %                    ?=? : (%,%) -> Boolean
--R 1 : () -> %                    0 : () -> %
--R ?^? : (%,PositiveInteger) -> % associates? : (%,%) -> Boolean
--R coerce : % -> %                coerce : Integer -> %
--R coerce : % -> OutputForm        complete : % -> %
--R digits : % -> Stream(Integer)   extend : (%,Integer) -> %
--R gcd : List(%) -> %              gcd : (%,%) -> %
--R hash : % -> SingleInteger        latex : % -> String
--R lcm : List(%) -> %              lcm : (%,%) -> %
--R moduloP : % -> Integer          modulus : () -> Integer
--R one? : % -> Boolean             order : % -> NonNegativeInteger
--R ?quo? : (%,%) -> %              quotientByP : % -> %
--R recip : % -> Union(%, "failed") ?rem? : (%,%) -> %
--R sample : () -> %                sizeLess? : (%,%) -> Boolean
--R sqrt : (%,Integer) -> %         unit? : % -> Boolean
--R unitCanonical : % -> %          zero? : % -> Boolean
--R ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R *** : (%,NonNegativeInteger) -> %
--R ?^? : (%,NonNegativeInteger) -> %
--R approximate : (%,Integer) -> Integer
--R characteristic : () -> NonNegativeInteger
--R divide : (%,%) -> Record(quotient: %,remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%), "failed")
--R exquo : (%,%) -> Union(%, "failed")
--R extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
--R extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUniva
--R multiEuclidean : (List(%),%) -> Union(List(%), "failed")
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R root : (SparseUnivariatePolynomial(Integer), Integer) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— PAdicIntegerCategory.help —

=====

PAdicIntegerCategory examples

=====

This is the category of stream-based representations of the p-adic integers.

See Also:

o)show PAdicIntegerCategory

See:

⇐ “CharacteristicZero” (CHARZ) [10](#) on page [892](#)

⇐ “EuclideanDomain” (EUCDOM) [15](#) on page [1235](#)

Exports:

| | | | |
|----------------|-------------------|--------------------|---------------|
| 0 | 1 | approximate | associates? |
| characteristic | coerce | complete | digits |
| divide | euclideanSize | expressIdealMember | exquo |
| extend | extendedEuclidean | gcd | gcdPolynomial |
| hash | latex | lcm | moduloP |
| modulus | multiEuclidean | one? | order |
| principalIdeal | quotientByP | recip | root |
| sample | sizeLess? | sqrt | subtractIfCan |
| unit? | unitCanonical | unitNormal | zero? |
| ?*? | ?**? | ?+? | ?-? |
| -? | ?=? | ?quo? | ?rem? |
| ?~=? | ?^? | | |

Attributes Exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```

approximate : (%,Integer) -> Integer
complete : % -> %
digits : % -> Stream Integer
extend : (%,Integer) -> %
moduloP : % -> Integer
modulus : () -> Integer
order : % -> NonNegativeInteger
quotientByP : % -> %
root : (SparseUnivariatePolynomial Integer,Integer) -> %
sqrt : (%,Integer) -> %

```

These exports come from (p1235) EuclideanDomain():

```

0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %,"failed")
exquo : (%,%) -> Union(%,"failed")
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
gcd : (%,%) -> %
gcd : List % -> %
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
   SparseUnivariatePolynomial %
hash : % -> SingleInteger
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
multiEuclidean : (List %,%) -> Union(List %,"failed")
one? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%,"failed")
sample : () -> %
sizeLess? : (%,%) -> Boolean
subtractIfCan : (%,%) -> Union(%,"failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
zero? : % -> Boolean
?+? : (%,%) -> %

```

```

?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (%,% ) -> %
?*? : (Integer,% ) -> %
?*? : (PositiveInteger,% ) -> %
?*? : (NonNegativeInteger,% ) -> %
?-? : (%,% ) -> %
-? : % -> %
***? : (% ,PositiveInteger) -> %
***? : (% ,NonNegativeInteger) -> %
?^? : (% ,PositiveInteger) -> %
?^? : (% ,NonNegativeInteger) -> %
?quo? : (%,% ) -> %
?rem? : (%,% ) -> %

```

— category PADICCT PAdicIntegerCategory —

```

)abbrev category PADICCT PAdicIntegerCategory
++ Author: Clifton J. Williamson
++ Date Created: 15 May 1990
++ Date Last Updated: 15 May 1990
++ Description:
++ This is the category of stream-based representations of
++ the p-adic integers.

PAdicIntegerCategory(p): Category == Definition where
  p      : Integer
  I      ==> Integer
  NNI    ==> NonNegativeInteger
  ST     ==> Stream
  SUP    ==> SparseUnivariatePolynomial

Definition ==> Join(EuclideanDomain,CharacteristicZero) with
  digits: % -> ST I
    ++ \spad{digits(x)} returns a stream of p-adic digits of x.
  order: % -> NNI
    ++ \spad{order(x)} returns the exponent of the highest power of p
    ++ dividing x.
  extend: (% ,I) -> %
    ++ \spad{extend(x,n)} forces the computation of digits up to order n.
  complete: % -> %
    ++ \spad{complete(x)} forces the computation of all digits.
  modulus: () -> I
    ++ \spad{modulus()} returns the value of p.
  moduloP: % -> I
    ++ \spad{modulo(x)} returns a, where \spad{x = a + b p}.
  quotientByP: % -> %
    ++ \spad{quotientByP(x)} returns b, where \spad{x = a + b p}.
  approximate: (% ,I) -> I

```

```

++ \spad{approximate(x,n)} returns an integer y such that
++ \spad{y = x (mod p^n)}
++ when n is positive, and 0 otherwise.
sqrt: (%,I) -> %
++ \spad{sqrt(b,a)} returns a square root of b.
++ Argument \spad{a} is a square root of b \spad{(mod p)}.
root: (SUP I,I) -> %
++ \spad{root(f,a)} returns a root of the polynomial \spad{f}.
++ Argument \spad{a} must be a root of \spad{f} \spad{(mod p)}.

```

— PADICCT.dotabb —

```

"PADICCT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PADICCT"];
"PADICCT" -> "CHARZ"
"PADICCT" -> "EUCDOM"

```

— PADICCT.dotfull —

```

"PAdicIntegerCategory(a:Integer)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PADICCT"];
"PAdicIntegerCategory(a:Integer)" -> "CharacteristicZero()"
"PAdicIntegerCategory(a:Integer)" -> "EuclideanDomain()"

```

— PADICCT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PAdicIntegerCategory(a:Integer)" [color=lightblue];
  "PAdicIntegerCategory(a:Integer)" -> "CharacteristicZero()"
  "PAdicIntegerCategory(a:Integer)" -> "EuclideanDomain()"

  "CharacteristicZero()" [color=lightblue];
  "CharacteristicZero()" -> "RING..."

  "EuclideanDomain()" [color=lightblue];

```

```

"EuclideanDomain()" -> "PrincipalIdealDomain()"

"PrincipalIdealDomain()" [color=lightblue];
"PrincipalIdealDomain()" -> "GcdDomain()"

"GcdDomain()" [color=lightblue];
"GcdDomain()" -> "IntegralDomain()"

"IntegralDomain()" [color=lightblue];
"IntegralDomain()" -> "CommutativeRing()"
"IntegralDomain()" -> "Algebra(a:CommutativeRing)"
"IntegralDomain()" -> "EntireRing()"

"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BMODULE..."

"EntireRing()" [color=lightblue];
"EntireRing()" -> "RING..."
"EntireRing()" -> "BMODULE..."

"Algebra(a:CommutativeRing)" [color=lightblue];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "Module(a:CommutativeRing)"

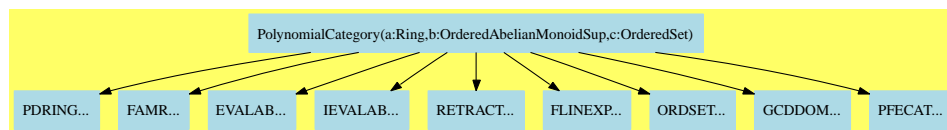
"Module(a:CommutativeRing)" [color=lightblue];
"Module(a:CommutativeRing)" -> "BMODULE..."

"RING..." [color=lightblue];
"BMODULE..." [color=lightblue];
}

```

—————→

PolynomialCategory (POLYCAT)



— PolynomialCategory.input —

```
)set break resume
```



```

)sys rm -f PolynomialCategory.output
)spool PolynomialCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PolynomialCategory
--R
--R PolynomialCategory(R: Ring,E: OrderedAbelianMonoidSup,VarSet: OrderedSet) is a category con
--R Abbreviation for PolynomialCategory is POLYCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for POLYCAT
--R
--R----- Operations -----
--R ???: (%,R) -> %               ??? : (R,%) -> %
--R ??? : (%,%) -> %             ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %             ?-? : (%,%) -> %
--R -? : % -> %                  ?=? : (%,%) -> Boolean
--R D : (%,List(VarSet)) -> %      D : (%,VarSet) -> %
--R 1 : () -> %                  0 : () -> %
--R ???: (%,PositiveInteger) -> %   coefficient : (%,E) -> R
--R coefficients : % -> List(R)     coerce : VarSet -> %
--R coerce : R -> %                 coerce : Integer -> %
--R coerce : % -> OutputForm        degree : % -> E
--R differentiate : (%,VarSet) -> %   eval : (%,VarSet,%) -> %
--R eval : (%,VarSet,R) -> %         eval : (%,%,%) -> %
--R eval : (%,Equation(%)) -> %      ground : % -> R
--R ground? : % -> Boolean           hash : % -> SingleInteger
--R latex : % -> String              leadingCoefficient : % -> R
--R leadingMonomial : % -> %         map : ((R -> R),%) -> %
--R mapExponents : ((E -> E),%) -> %   minimumDegree : % -> E
--R monomial : (R,E) -> %            monomial? : % -> Boolean
--R monomials : % -> List(%)         one? : % -> Boolean
--R pomopo! : (%,R,E,%) -> %         recip : % -> Union(%, "failed")
--R reductum : % -> %                retract : % -> VarSet
--R retract : % -> R                 sample : () -> %
--R variables : % -> List(VarSet)     zero? : % -> Boolean
--R ?~=? : (%,%) -> Boolean
--R ??? : (Fraction(Integer),%) -> % if R has ALGEBRA(FRAC(INT))
--R ??? : (%,Fraction(Integer)) -> % if R has ALGEBRA(FRAC(INT))
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,R) -> % if R has FIELD
--R ?<? : (%,%) -> Boolean if R has ORDSET
--R ?<=? : (%,%) -> Boolean if R has ORDSET
--R ?>? : (%,%) -> Boolean if R has ORDSET
--R ?>=? : (%,%) -> Boolean if R has ORDSET
--R D : (%,List(VarSet),List(NonNegativeInteger)) -> %

```

```

--R D : (% , VarSet, NonNegativeInteger) -> %
--R ?? : (% , NonNegativeInteger) -> %
--R associates? : (% , %) -> Boolean if R has INTDOM
--R binomThmExpt : (% , %, NonNegativeInteger) -> % if R has COMRING
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if and(has($ , CharacteristicNonZero), has(R, PolynomialFactorizationEx
--R coefficient : (% , List(VarSet), List(NonNegativeInteger)) -> %
--R coefficient : (% , VarSet, NonNegativeInteger) -> %
--R coerce : Fraction(Integer) -> % if R has RETRACT(FRAC(INT)) or R has ALGEBRA(FRAC(INT))
--R coerce : % -> % if R has INTDOM
--R conditionP : Matrix(%) -> Union(Vector(%), "failed") if and(has($ , CharacteristicNonZero), has(R, Polynomial
--R content : (% , VarSet) -> % if R has GCDDOM
--R content : % -> R if R has GCDDOM
--R convert : % -> InputForm if VarSet has KONVERT(INFORM) and R has KONVERT(INFORM)
--R convert : % -> Pattern(Integer) if VarSet has KONVERT(PATTERN(INT)) and R has KONVERT(PATTERN(INT))
--R convert : % -> Pattern(Float) if VarSet has KONVERT(PATTERN(FLOAT)) and R has KONVERT(PATTERN(FLOAT))
--R degree : (% , List(VarSet)) -> List(NonNegativeInteger)
--R degree : (% , VarSet) -> NonNegativeInteger
--R differentiate : (% , List(VarSet), List(NonNegativeInteger)) -> %
--R differentiate : (% , VarSet, NonNegativeInteger) -> %
--R differentiate : (% , List(VarSet)) -> %
--R discriminant : (% , VarSet) -> % if R has COMRING
--R eval : (% , List(VarSet), List(%)) -> %
--R eval : (% , List(VarSet), List(R)) -> %
--R eval : (% , List(%), List(%)) -> %
--R eval : (% , List(Equation(%))) -> %
--R exquo : (% , %) -> Union(%, "failed") if R has INTDOM
--R exquo : (% , R) -> Union(%, "failed") if R has INTDOM
--R factor : % -> Factored(%) if R has PFECAT
--R factorPolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%)) if R has PF
--R factorSquareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%)) if
--R gcd : (% , %) -> % if R has GCDDOM
--R gcd : List(%) -> % if R has GCDDOM
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynom
--R isExpt : % -> Union(Record(var: VarSet, exponent: NonNegativeInteger), "failed")
--R isPlus : % -> Union(List(%), "failed")
--R isTimes : % -> Union(List(%), "failed")
--R lcm : (% , %) -> % if R has GCDDOM
--R lcm : List(%) -> % if R has GCDDOM
--R mainVariable : % -> Union(VarSet, "failed")
--R max : (% , %) -> % if R has ORDSET
--R min : (% , %) -> % if R has ORDSET
--R minimumDegree : (% , List(VarSet)) -> List(NonNegativeInteger)
--R minimumDegree : (% , VarSet) -> NonNegativeInteger
--R monicDivide : (% , %, VarSet) -> Record(quotient: %, remainder: %)
--R monomial : (% , List(VarSet), List(NonNegativeInteger)) -> %
--R monomial : (% , VarSet, NonNegativeInteger) -> %
--R multivariate : (SparseUnivariatePolynomial(%), VarSet) -> %
--R multivariate : (SparseUnivariatePolynomial(R), VarSet) -> %
--R numberOfMonomials : % -> NonNegativeInteger

```

```

--R patternMatch : (% , Pattern(Integer), PatternMatchResult(Integer, %)) -> PatternMatchResult(Integer, %)
--R patternMatch : (% , Pattern(Float), PatternMatchResult(Float, %)) -> PatternMatchResult(Float, %)
--R prime? : % -> Boolean if R has PFECAT
--R primitiveMonomials : % -> List(%)
--R primitivePart : (% , VarSet) -> % if R has GCDDOM
--R primitivePart : % -> % if R has GCDDOM
--R reducedSystem : Matrix(%) -> Matrix(R)
--R reducedSystem : (Matrix(%) , Vector(%)) -> Record(mat: Matrix(R), vec: Vector(R))
--R reducedSystem : (Matrix(%) , Vector(%)) -> Record(mat: Matrix(Integer), vec: Vector(Integer)) if R has LINEXP(INT)
--R reducedSystem : Matrix(%) -> Matrix(Integer) if R has LINEXP(INT)
--R resultant : (% , % , VarSet) -> % if R has COMRING
--R retract : % -> Integer if R has RETRACT(INT)
--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(VarSet, "failed")
--R retractIfCan : % -> Union(Integer, "failed") if R has RETRACT(INT)
--R retractIfCan : % -> Union(Fraction(Integer), "failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(R, "failed")
--R solveLinearPolynomialEquation : (List(SparseUnivariatePolynomial(%)) , SparseUnivariatePolynomial(%)) -> List(SparseUnivariatePolynomial(%))
--R squareFree : % -> Factored(%) if R has GCDDOM
--R squareFreePart : % -> % if R has GCDDOM
--R squareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%))
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R totalDegree : (% , List(VarSet)) -> NonNegativeInteger
--R totalDegree : % -> NonNegativeInteger
--R unit? : % -> Boolean if R has INTDOM
--R unitCanonical : % -> % if R has INTDOM
--R unitNormal : % -> Record(unit: % , canonical: % , associate: %) if R has INTDOM
--R univariate : % -> SparseUnivariatePolynomial(R)
--R univariate : (% , VarSet) -> SparseUnivariatePolynomial(%)
--R
--E 1

)spool
)lisp (bye)

```

— PolynomialCategory.help —

```

=====
PolynomialCategory examples
=====

```

The category for general multi-variate polynomials over a ring R,
in variables from VarSet, with exponents from the OrderedAbelianMonoidSup.

See Also:

o)show PolynomialCategory

See:

⇒ “DifferentialPolynomialCategory” (DPOLCAT) [17](#) on page [1356](#)
⇒ “RecursivePolynomialCategory” (RPOLCAT) [17](#) on page [1459](#)
⇒ “UnivariatePolynomialCategory” (UPOLYC) [17](#) on page [1522](#)

⇐ “InnerEvalable” (IEVALAB) [2](#) on page [56](#)
⇐ “Evalable” (EVALAB) [3](#) on page [129](#)
⇐ “FiniteAbelianMonoidRing” (FAMR) [14](#) on page [1191](#)
⇐ “GcdDomain” (GCDDOM) [13](#) on page [1179](#)
⇐ “FullyLinearlyExplicitRingOver” (FLINEXP) [11](#) on page [1012](#)
⇐ “OrderedSet” (ORDSET) [4](#) on page [269](#)
⇐ “PartialDifferentialRing” (PDRING) [10](#) on page [939](#)
⇐ “PolynomialFactorizationExplicit” (PFECAT) [15](#) on page [1253](#)
⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

Exports:

| | | |
|----------------|-------------------------------|----------------------------|
| 0 | 1 | associates? |
| binomThmExpt | characteristic | charthRoot |
| coefficient | coefficients | coerce |
| conditionP | content | convert |
| D | degree | differentiate |
| discriminant | eval | exquo |
| factor | factorPolynomial | factorSquareFreePolynomial |
| gcd | gcdPolynomial | ground |
| ground? | hash | isExpt |
| isPlus | isTimes | latex |
| lcm | leadingCoefficient | leadingMonomial |
| mainVariable | map | mapExponents |
| max | min | minimumDegree |
| monicDivide | monomial | monomial? |
| monomials | multivariate | numberOfMonomials |
| one? | patternMatch | pomopo! |
| prime? | primitiveMonomials | primitivePart |
| recip | reducedSystem | reductum |
| resultant | retract | retractIfCan |
| sample | solveLinearPolynomialEquation | squareFree |
| squareFreePart | squareFreePolynomial | subtractIfCan |
| totalDegree | unit? | unitCanonical |
| unitNormal | univariate | variables |
| zero? | ?*? | ?**? |
| ?+? | ?-? | -? |
| ?=? | ?^? | ?~=? |
| ?/? | ?<? | ?<=? |
| ?>? | ?>=? | |

Attributes Exported:

-
- if R has `canonicalUnitNormal` then `canonicalUnitNormal` where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- if $\$$ has `IntegralDomain` then `noZeroDivisors` where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- if $\$$ has `CommutativeRing` then `commutative(“*”)` where **commutative(“*”)** is true if it has an operation “ $*$ ” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .

- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
degree : (% , VarSet) -> NonNegativeInteger
degree : (% , List VarSet) -> List NonNegativeInteger
mainVariable : % -> Union(VarSet, "failed")
minimumDegree : (% , List VarSet) -> List NonNegativeInteger
minimumDegree : (% , VarSet) -> NonNegativeInteger
monomial : (% , VarSet, NonNegativeInteger) -> %
multivariate : (SparseUnivariatePolynomial % , VarSet) -> %
multivariate : (SparseUnivariatePolynomial R , VarSet) -> %
univariate : (% , VarSet) -> SparseUnivariatePolynomial %
univariate : % -> SparseUnivariatePolynomial R
variables : % -> List VarSet
```

These are implemented by this category:

```
charthRoot : % -> Union(%, "failed")
if
  and(has($, CharacteristicNonZero),
    has(R, PolynomialFactorizationExplicit))
  or R has CHARNZ
coefficient : (% , VarSet, NonNegativeInteger) -> %
coefficient : (% , List VarSet, List NonNegativeInteger) -> %
conditionP : Matrix % -> Union(Vector %, "failed")
if
  and(has($, CharacteristicNonZero),
    has(R, PolynomialFactorizationExplicit))
content : (% , VarSet) -> % if R has GCDDOM
convert : % -> Pattern Integer
  if VarSet has KONVERT PATTERN INT
  and R has KONVERT PATTERN INT
convert : % -> Pattern Float
  if VarSet has KONVERT PATTERN FLOAT
  and R has KONVERT PATTERN FLOAT
convert : % -> InputForm
  if VarSet has KONVERT INFORM
  and R has KONVERT INFORM
discriminant : (% , VarSet) -> % if R has COMRING
eval : (% , List Equation %) -> %
factor : % -> Factored % if R has PFECAT
factorPolynomial :
  SparseUnivariatePolynomial % ->
  Factored SparseUnivariatePolynomial %
  if R has PFECAT
factorSquareFreePolynomial :
  SparseUnivariatePolynomial % ->
  Factored SparseUnivariatePolynomial %
  if R has PFECAT
```

```

gcdPolynomial : (SparseUnivariatePolynomial %,
                  SparseUnivariatePolynomial %) ->
                  SparseUnivariatePolynomial %
    if R has GCDDOM
isExpt : % ->
    Union(Record(var: VarSet,exponent: NonNegativeInteger),"failed")
isPlus : % -> Union(List %,"failed")
isTimes : % -> Union(List %,"failed")
monicDivide : (%,%,VarSet) -> Record(quotient: %,remainder: %)
monomial : (%,List VarSet,List NonNegativeInteger) -> %
monomials : % -> List %
patternMatch :
    (%,Pattern Integer,PatternMatchResult(Integer,%)) ->
        PatternMatchResult(Integer,%)
        if VarSet has PATMAB INT
        and R has PATMAB INT
patternMatch :
    (%,Pattern Float,PatternMatchResult(Float,%)) ->
        PatternMatchResult(Float,%)
        if VarSet has PATMAB FLOAT
        and R has PATMAB FLOAT
primitiveMonomials : % -> List %
primitivePart : % -> % if R has GCDDOM
primitivePart : (%,VarSet) -> % if R has GCDDOM
reducedSystem : Matrix % -> Matrix R
reducedSystem : (Matrix %,Vector %) ->
    Record(mat: Matrix R,vec: Vector R)
resultant : (%,%,VarSet) -> % if R has COMRING
retract : % -> VarSet
retractIfCan : % -> Union(VarSet,"failed")
solveLinearPolynomialEquation :
    (List SparseUnivariatePolynomial %,
     SparseUnivariatePolynomial %) ->
        Union(List SparseUnivariatePolynomial %,"failed")
        if R has PFECAT
squareFree : % -> Factored % if R has GCDDOM
squareFreePart : % -> % if R has GCDDOM
totalDegree : % -> NonNegativeInteger
totalDegree : (%,List VarSet) -> NonNegativeInteger
?<? : (%,%) -> Boolean if R has ORDSET

```

These exports come from (p939) `PartialDifferentialRing(VarSet)`
where `VarSet:OrderedSet`:

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
D : (%,List VarSet) -> %

```

```

D : (% , VarSet) -> %
D : (% , List VarSet , List NonNegativeInteger) -> %
D : (% , VarSet , NonNegativeInteger) -> %
differentiate : (% , VarSet) -> %
differentiate : (% , List VarSet , List NonNegativeInteger) -> %
differentiate : (% , VarSet , NonNegativeInteger) -> %
differentiate : (% , List VarSet) -> %
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (% , %) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (% , %) -> %
?=? : (% , %) -> Boolean
?~=? : (% , %) -> Boolean
?*? : (% , %) -> %
?*? : (Integer , %) -> %
?*? : (PositiveInteger , %) -> %
?*? : (NonNegativeInteger , %) -> %
?-? : (% , %) -> %
-? : % -> %
?^? : (% , PositiveInteger) -> %
?^? : (% , NonNegativeInteger) -> %
***? : (% , NonNegativeInteger) -> %
***? : (% , PositiveInteger) -> %

```

These exports come from (p1191) FiniteAbelianMonoidRing(R,E)
where R:Ring and E:OrderedAbelianMonoidSup:

```

associates? : (% , %) -> Boolean if R has INTDOM
binomThmExpt : (% , %, NonNegativeInteger) -> %
    if R has COMRING
coefficient : (% , E) -> R
coefficients : % -> List R
coerce : R -> %
coerce : Fraction Integer -> %
    if R has RETRACT FRAC INT
    or R has ALGEBRA FRAC INT
coerce : % -> % if R has INTDOM
content : % -> R if R has GCDDOM
degree : % -> E
exquo : (% , R) -> Union(%, "failed") if R has INTDOM
exquo : (% , %) -> Union(%, "failed") if R has INTDOM
ground : % -> R
ground? : % -> Boolean
leadingCoefficient : % -> R
leadingMonomial : % -> %
map : ((R -> R) , %) -> %

```



```

mapExponents : ((E -> E),%) -> %
minimumDegree : % -> E
monomial : (R,E) -> %
monomial? : % -> Boolean
numberOfMonomials : % -> NonNegativeInteger
pomopo! : (% ,R,E,%) -> %
reductum : % -> %
retract : % -> Integer if R has RETRACT INT
retract : % -> Fraction Integer
    if R has RETRACT FRAC INT
retractIfCan : % -> Union(Integer,"failed")
    if R has RETRACT INT
retractIfCan : % -> Union(Fraction Integer,"failed")
    if R has RETRACT FRAC INT
unit? : % -> Boolean if R has INTDOM
unitCanonical : % -> % if R has INTDOM
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
    if R has INTDOM
?? : (% ,R) -> %
?? : (R,%) -> %
?? : (Fraction Integer,%) -> %
    if R has ALGEBRA FRAC INT
?? : (% ,Fraction Integer) -> %
    if R has ALGEBRA FRAC INT
?/? : (% ,R) -> % if R has FIELD

```

These exports come from (p129) Evaluable(PolynomialCategory(...)):

```

eval : (% ,Equation %) -> %
eval : (% ,List % ,List %) -> %
eval : (% ,% ,%) -> %

```

These exports come from (p56) InnerEvaluable(VarSet,R)
where VarSet:OrderedSet and R:Ring

```

eval : (% ,VarSet,R) -> %
eval : (% ,List VarSet,List R) -> %

```

These exports come from (p56) InnerEvaluable(VarSet,R)
where VarSet:OrderedSet and R:PolynomialCategory(...):

```

eval : (% ,VarSet,%) -> %
eval : (% ,List VarSet,List %) -> %

```

These exports come from (p95) RetractableTo(VarSet)
where VarSet:OrderedSet:

```

coerce : VarSet -> %
retract : % -> R
retractIfCan : % -> Union(R,"failed")

```

These exports come from (p1012) FullyLinearlyExplicitRingOver(R)
where R:Ring:

```
reducedSystem : (Matrix %,Vector %) ->
  Record(mat: Matrix Integer,vec: Vector Integer)
  if R has LINEXP INT
reducedSystem : Matrix % -> Matrix Integer
  if R has LINEXP INT
```

These exports come from (p269) OrderedSet():

```
max : (%,%) -> % if R has ORDSET
min : (%,%) -> % if R has ORDSET
?<=? : (%,%) -> Boolean if R has ORDSET
?>? : (%,%) -> Boolean if R has ORDSET
?>=? : (%,%) -> Boolean if R has ORDSET
```

These exports come from (p1179) GcdDomain():

```
gcd : (%,%) -> % if R has GCDDOM
gcd : List % -> % if R has GCDDOM
lcm : (%,%) -> % if R has GCDDOM
lcm : List % -> % if R has GCDDOM
```

These exports come from (p1253) PolynomialFactorizationExplicit():

```
prime? : % -> Boolean if R has PFECAT
squareFreePolynomial : SparseUnivariatePolynomial % ->
  Factored SparseUnivariatePolynomial %
  if R has PFECAT
```

— category POLYCAT PolynomialCategory —

```
)abbrev category POLYCAT PolynomialCategory
++ Description:
++ The category for general multi-variate polynomials over a ring
++ R, in variables from VarSet, with exponents from the
++ \spadtype{OrderedAbelianMonoidSup}.

PolynomialCategory(R:Ring, E:OrderedAbelianMonoidSup, VarSet:OrderedSet):
  Category ==
  Join(PartialDifferentialRing VarSet, FiniteAbelianMonoidRing(R, E),
    Evalable %, InnerEvalable(VarSet, R),
    InnerEvalable(VarSet, %), RetractableTo VarSet,
    FullyLinearlyExplicitRingOver R) with
  degree : (%,VarSet) -> NonNegativeInteger
  ++ degree(p,v) gives the degree of polynomial p with respect
  ++ to the variable v.
```

```

degree : (%,List(VarSet)) -> List(NonNegativeInteger)
++ degree(p,lv) gives the list of degrees of polynomial p
++ with respect to each of the variables in the list lv.
coefficient: (%,VarSet,NonNegativeInteger) -> %
++ coefficient(p,v,n) views the polynomial p as a univariate
++ polynomial in v and returns the coefficient of the \spad{v**n} term.
coefficient: (%,List VarSet,List NonNegativeInteger) -> %
++ coefficient(p, lv, ln) views the polynomial p as a polynomial
++ in the variables of lv and returns the coefficient of the term
++ \spad{lv**ln}, i.e. \spad{prod(lv_i ** ln_i)}.
monomials: % -> List %
++ monomials(p) returns the list of non-zero monomials of
++ polynomial p, i.e.
++ \spad{monomials(sum(a_(i) X^(i))) = [a_(1) X^(1),...,a_(n) X^(n)]}.
univariate : (%,VarSet) -> SparseUnivariatePolynomial(%)
++ univariate(p,v) converts the multivariate polynomial p
++ into a univariate polynomial in v, whose coefficients are still
++ multivariate polynomials (in all the other variables).
univariate : % -> SparseUnivariatePolynomial(R)
++ univariate(p) converts the multivariate polynomial p,
++ which should actually involve only one variable,
++ into a univariate polynomial
++ in that variable, whose coefficients are in the ground ring.
++ Error: if polynomial is genuinely multivariate
mainVariable : % -> Union(VarSet,"failed")
++ mainVariable(p) returns the biggest variable which actually
++ occurs in the polynomial p, or "failed" if no variables are
++ present.
++ fails precisely if polynomial satisfies ground?
minimumDegree : (%,VarSet) -> NonNegativeInteger
++ minimumDegree(p,v) gives the minimum degree of polynomial p
++ with respect to v, i.e. viewed a univariate polynomial in v
minimumDegree : (%,List(VarSet)) -> List(NonNegativeInteger)
++ minimumDegree(p, lv) gives the list of minimum degrees of the
++ polynomial p with respect to each of the variables in the list lv
monicDivide : (%,%,VarSet) -> Record(quotient:%,remainder:%)
++ monicDivide(a,b,v) divides the polynomial a by the polynomial b,
++ with each viewed as a univariate polynomial in v returning
++ both the quotient and remainder.
++ Error: if b is not monic with respect to v.
monomial : (%,VarSet,NonNegativeInteger) -> %
++ monomial(a,x,n) creates the monomial \spad{a*x**n} where \spad{a} is
++ a polynomial, x is a variable and n is a nonnegative integer.
monomial : (%,List VarSet,List NonNegativeInteger) -> %
++ monomial(a,[v1..vn],[e1..en]) returns \spad{a*prod(vi**ei)}.
multivariate : (SparseUnivariatePolynomial(R),VarSet) -> %
++ multivariate(sup,v) converts an anonymous univariable
++ polynomial sup to a polynomial in the variable v.
multivariate : (SparseUnivariatePolynomial(%),VarSet) -> %
++ multivariate(sup,v) converts an anonymous univariable

```

```

    ++ polynomial sup to a polynomial in the variable v.
isPlus: % -> Union(List %, "failed")
    ++ isPlus(p) returns \spad{[m1,...,mn]} if polynomial
    ++ \spad{p = m1 + ... + mn} and
    ++ \spad{n >= 2} and each mi is a nonzero monomial.
isTimes: % -> Union(List %, "failed")
    ++ isTimes(p) returns \spad{[a1,...,an]} if polynomial
    ++ \spad{p = a1 ... an} and \spad{n >= 2}, and, for each i,
    ++ ai is either a nontrivial constant in R or else of the
    ++ form \spad{x**e}, where \spad{e > 0} is an integer
    ++ and x in a member of VarSet.
isExpt: % -> Union(Record(var:VarSet, exponent:NonNegativeInteger),_
    "failed")
    ++ isExpt(p) returns \spad{[x, n]} if polynomial p has the
    ++ form \spad{x**n} and \spad{n > 0}.
totalDegree : % -> NonNegativeInteger
    ++ totalDegree(p) returns the largest sum over all monomials
    ++ of all exponents of a monomial.
totalDegree : (%,List VarSet) -> NonNegativeInteger
    ++ totalDegree(p, lv) returns the maximum sum (over all monomials
    ++ of polynomial p) of the variables in the list lv.
variables : % -> List(VarSet)
    ++ variables(p) returns the list of those variables actually
    ++ appearing in the polynomial p.
primitiveMonomials: % -> List %
    ++ primitiveMonomials(p) gives the list of monomials of the
    ++ polynomial p with their coefficients removed. Note that
    ++ \spad{primitiveMonomials(sum(a_(i) X^(i))) = [X^(1),...,X^(n)]}.
if R has OrderedSet then OrderedSet
-- OrderedRing view removed to allow EXPR to define abs
--if R has OrderedRing then OrderedRing
if (R has ConvertibleTo InputForm) and
    (VarSet has ConvertibleTo InputForm) then
    ConvertibleTo InputForm
if (R has ConvertibleTo Pattern Integer) and
    (VarSet has ConvertibleTo Pattern Integer) then
    ConvertibleTo Pattern Integer
if (R has ConvertibleTo Pattern Float) and
    (VarSet has ConvertibleTo Pattern Float) then
    ConvertibleTo Pattern Float
if (R has PatternMatchable Integer) and
    (VarSet has PatternMatchable Integer) then
    PatternMatchable Integer
if (R has PatternMatchable Float) and
    (VarSet has PatternMatchable Float) then
    PatternMatchable Float
if R has CommutativeRing then
    resultant : (%,% ,VarSet) -> %
        ++ resultant(p,q,v) returns the resultant of the polynomials
        ++ p and q with respect to the variable v.

```

```

discriminant : (%,VarSet) -> %
  ++ discriminant(p,v) returns the discriminant of the polynomial p
  ++ with respect to the variable v.
if R has GcdDomain then
  GcdDomain
  content: (%,VarSet) -> %
    ++ content(p,v) is the gcd of the coefficients of the polynomial p
    ++ when p is viewed as a univariate polynomial with respect to the
    ++ variable v.
    ++ Thus, for polynomial 7*x**2*y + 14*x*y**2, the gcd of the
    ++ coefficients with respect to x is 7*y.
  primitivePart: % -> %
    ++ primitivePart(p) returns the unitCanonical associate of the
    ++ polynomial p with its content divided out.
  primitivePart: (%,VarSet) -> %
    ++ primitivePart(p,v) returns the unitCanonical associate of the
    ++ polynomial p with its content with respect to the variable v
    ++ divided out.
  squareFree: % -> Factored %
    ++ squareFree(p) returns the square free factorization of the
    ++ polynomial p.
  squareFreePart: % -> %
    ++ squareFreePart(p) returns product of all the irreducible factors
    ++ of polynomial p each taken with multiplicity one.

-- assertions
if R has canonicalUnitNormal then canonicalUnitNormal
  ++ we can choose a unique representative for each
  ++ associate class.
  ++ This normalization is chosen to be normalization of
  ++ leading coefficient (by default).
if R has PolynomialFactorizationExplicit then
  PolynomialFactorizationExplicit
add
  p:%
  v:VarSet
  ln:List NonNegativeInteger
  lv:List VarSet
  n:NonNegativeInteger
  pp,qq:SparseUnivariatePolynomial %

  eval(p:%, l:List Equation %) ==
    empty? l => p
    for e in l repeat
      retractIfCan(lhs e)@Union(VarSet,"failed") case "failed" =>
        error "cannot find a variable to evaluate"
    lvar:=[retract(lhs e)@VarSet for e in l]
    eval(p, lvar,[rhs e for e in l]$List(%))

monomials p ==

```

```

--      zero? p => empty()
--      concat(leadingMonomial p, monomials reductum p)
--      replaced by sequential version for efficiency, by WMSIT, 7/30/90
      ml := empty$List(%)
      while p ^= 0 repeat
        ml := concat(leadingMonomial p, ml)
        p := reductum p
      reverse ml

isPlus p ==
  empty? rest(l := monomials p) => "failed"
  1

isTimes p ==
  empty?(lv := variables p) or not monomial? p => "failed"
  l := [monomial(1, v, degree(p, v)) for v in lv]
--      one?(r := leadingCoefficient p) =>
  ((r := leadingCoefficient p) = 1) =>
    empty? rest lv => "failed"
    1
  concat(r::%, l)

isExpt p ==
  (u := mainVariable p) case "failed" => "failed"
  p = monomial(1, u::VarSet, d := degree(p, u::VarSet)) =>
    [u::VarSet, d]
  "failed"

coefficient(p,v,n) == coefficient(univariate(p,v),n)

coefficient(p,lv,ln) ==
  empty? lv =>
    empty? ln => p
    error "mismatched lists in coefficient"
  empty? ln => error "mismatched lists in coefficient"
  coefficient(coefficient(univariate(p,first lv),first ln),
    rest lv,rest ln)

monomial(p,lv,ln) ==
  empty? lv =>
    empty? ln => p
    error "mismatched lists in monomial"
  empty? ln => error "mismatched lists in monomial"
  monomial(monomial(p,first lv, first ln),rest lv, rest ln)

retract(p:%):VarSet ==
  q := mainVariable(p)::VarSet
  q::% = p => q
  error "Polynomial is not a single variable"

```

```

retractIfCan(p:%):Union(VarSet, "failed") ==
  ((q := mainVariable p) case VarSet) and (q::VarSet::% = p) => q
  "failed"

mkPrim(p:%):% == monomial(1,degree p)

primitiveMonomials p == [mkPrim q for q in monomials p]

totalDegree p ==
  ground? p => 0
  u := univariate(p, mainVariable(p)::VarSet)
  d: NonNegativeInteger := 0
  while u ^= 0 repeat
    d := max(d, degree u + totalDegree leadingCoefficient u)
    u := reductum u
  d

totalDegree(p,lv) ==
  ground? p => 0
  u := univariate(p, v:=(mainVariable(p)::VarSet))
  d: NonNegativeInteger := 0
  w: NonNegativeInteger := 0
  if member?(v, lv) then w:=1
  while u ^= 0 repeat
    d := max(d, w*(degree u) + totalDegree(leadingCoefficient u,lv))
    u := reductum u
  d

if R has CommutativeRing then
  resultant(p1,p2,mvar) ==
    resultant(univariate(p1,mvar),univariate(p2,mvar))

  discriminant(p,var) ==
    discriminant(univariate(p,var))

if R has IntegralDomain then
  allMonoms(l>List %):List(%) ==
    removeDuplicates_! concat [primitiveMonomials p for p in l]

P2R(p:%, b>List E, n:NonNegativeInteger):Vector(R) ==
  w := new(n, 0)$Vector(R)
  for i in minIndex w .. maxIndex w for bj in b repeat
    qsetelt_!(w, i, coefficient(p, bj))
  w

eq2R(l>List %, b>List E):Matrix(R) ==
  matrix [[coefficient(p, bj) for p in l] for bj in b]

reducedSystem(m:Matrix %):Matrix(R) ==
  l := listOfLists m

```

```

b := removeDuplicates_!
      concat [allMonoms r for r in l]$List(List(%))
d := [degree bj for bj in b]
mm := eq2R(first l, d)
l := rest l
while not empty? l repeat
  mm := vertConcat(mm, eq2R(first l, d))
  l := rest l
mm

reducedSystem(m:Matrix %, v:Vector %):
Record(mat:Matrix R, vec:Vector R) ==
  l := listOfLists m
  r := entries v
  b : List % := removeDuplicates_! concat(allMonoms r,
      concat [allMonoms s for s in l]$List(List(%)))
  d := [degree bj for bj in b]
  n := #d
  mm := eq2R(first l, d)
  w := P2R(first r, d, n)
  l := rest l
  r := rest r
  while not empty? l repeat
    mm := vertConcat(mm, eq2R(first l, d))
    w := concat(w, P2R(first r, d, n))
    l := rest l
    r := rest r
  [mm, w]

if R has PolynomialFactorizationExplicit then
  -- we might be in trouble if its actually only
  -- a univariate polynomial category - have to remember to
  -- over-ride these in UnivariatePolynomialCategory

  PFBR ==>PolynomialFactorizationByRecursion(R,E,VarSet,%)

  gcdPolynomial(pp,qq) ==
    gcdPolynomial(pp,qq)$GeneralPolynomialGcdPackage(E,VarSet,R,%)

  solveLinearPolynomialEquation(lpp,pp) ==
    solveLinearPolynomialEquationByRecursion(lpp,pp)$PFBR

  factorPolynomial(pp) ==
    factorByRecursion(pp)$PFBR

  factorSquareFreePolynomial(pp) ==
    factorSquareFreeByRecursion(pp)$PFBR

  factor p ==
    v:Union(VarSet,"failed"):=mainVariable p

```



```

v case "failed" =>
  ansR:=factor leadingCoefficient p
  makeFR(unit(ansR)::%,
    [[w.flg,w.fctr::%,w.xpnt] for w in factorList ansR])
up: SparseUnivariatePolynomial %:=univariate(p,v)
ansSUP:=factorByRecursion(up)$PFBR
makeFR(multivariate(unit(ansSUP),v),
  [[ww.flg,multivariate(ww.fctr,v),ww.xpnt]
   for ww in factorList ansSUP])
if R has CharacteristicNonZero then
  mat: Matrix %

conditionP mat ==
  ll:=listOfLists transpose mat --hence each list corresponds to a
                                --column, i.e. to one variable
  llR: List List R := [ empty() for z in first ll]
  monslst: List List % := empty()
  ch:=characteristic()$%
  for l in ll repeat
    mons:= "setUnion"/[primitiveMonomials u for u in l]
    redmons: List % :=[]
    for m in mons repeat
      vars:=variables m
      degs:=degree(m,vars)
      deg1: List NonNegativeInteger
      deg1:= [ ((nd:=d:Integer exquo ch:Integer)
                case "failed" => return "failed" ;
                nd::Integer::NonNegativeInteger)
              for d in degs ]
      redmons:=[monomial(1,vars,deg1),:redmons]
      llR:=[ [ground coefficient(u,vars,degs),:v]_
              for u in l for v in llR]
      monslst:=[redmons,:monslst]
  ans:=conditionP transpose matrix llR
  ans case "failed" => "failed"
  i: NonNegativeInteger:=0
  [ +/[m*(ans.(i:=i+1))::% for m in mons ]
    for mons in monslst]

if R has CharacteristicNonZero then
  charthRootlv:(%,List VarSet,NonNegativeInteger) ->_
                                                    Union(%, "failed")

charthRoot p ==
  vars:= variables p
  empty? vars =>
    ans := charthRoot ground p
    ans case "failed" => "failed"
    ans::R::%
  ch:=characteristic()$%
  charthRootlv(p,vars,ch)

```

```

charthRootlv(p,vars,ch) ==
  empty? vars =>
    ans := charthRoot ground p
    ans case "failed" => "failed"
    ans::R::%
  v:=first vars
  vars:=rest vars
  d:=degree(p,v)
  ans:% := 0
  while (d>0) repeat
    (dd:=(d::Integer exquo ch::Integer)) case "failed" =>
      return "failed"
    cp:=coefficient(p,v,d)
    p:=p-monomial(cp,v,d)
    ansx:=charthRootlv(cp,vars,ch)
    ansx case "failed" => return "failed"
    d:=degree(p,v)
    ans:=ans+monomial(ansx,v,dd::Integer::NonNegativeInteger)
  ansx:=charthRootlv(p,vars,ch)
  ansx case "failed" => return "failed"
  return ans+ansx

monicDivide(p1,p2,mvar) ==
  result:=monicDivide(univariate(p1,mvar),univariate(p2,mvar))
  [multivariate(result.quotient,mvar),
   multivariate(result.remainder,mvar)]

if R has GcdDomain then
  if R has EuclideanDomain and R has CharacteristicZero then
    squareFree p == squareFree(p)$MultivariateSquareFree(E,VarSet,R,%)
  else
    squareFree p == squareFree(p)$PolynomialSquareFree(VarSet,E,R,%)

squareFreePart p ==
  unit(s := squareFree p) * */[f.factor for f in factors s]

content(p,v) == content univariate(p,v)

primitivePart p ==
  zero? p => p
  unitNormal((p exquo content p) ::%).canonical

primitivePart(p,v) ==
  zero? p => p
  unitNormal((p exquo content(p,v)) ::%).canonical

if R has OrderedSet then
  p:% < q:% ==
    (dp:= degree p) < (dq := degree q) => (leadingCoefficient q) > 0

```

```

dq < dp => (leadingCoefficient p) < 0
leadingCoefficient(p - q) < 0

if (R has PatternMatchable Integer) and
  (VarSet has PatternMatchable Integer) then
  patternMatch(p:%, pat:Pattern Integer,
    l:PatternMatchResult(Integer, %)) ==
    patternMatch(p, pat,
      l)$PatternMatchPolynomialCategory(Integer,E,VarSet,R,%)

if (R has PatternMatchable Float) and
  (VarSet has PatternMatchable Float) then
  patternMatch(p:%, pat:Pattern Float,
    l:PatternMatchResult(Float, %)) ==
    patternMatch(p, pat,
      l)$PatternMatchPolynomialCategory(Float,E,VarSet,R,%)

if (R has ConvertibleTo Pattern Integer) and
  (VarSet has ConvertibleTo Pattern Integer) then
  convert(x:%):Pattern(Integer) ==
  map(convert, convert,
    x)$PolynomialCategoryLifting(E,VarSet,R,%,Pattern Integer)

if (R has ConvertibleTo Pattern Float) and
  (VarSet has ConvertibleTo Pattern Float) then
  convert(x:%):Pattern(Float) ==
  map(convert, convert,
    x)$PolynomialCategoryLifting(E, VarSet, R, %, Pattern Float)

if (R has ConvertibleTo InputForm) and
  (VarSet has ConvertibleTo InputForm) then
  convert(p:%):InputForm ==
  map(convert, convert,
    p)$PolynomialCategoryLifting(E,VarSet,R,%,InputForm)

```

— POLYCAT.dotabb —

```

"POLYCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=POLYCAT"];
"POLYCAT" -> "PDRING"
"POLYCAT" -> "FAMR"
"POLYCAT" -> "EVALAB"
"POLYCAT" -> "IEVALAB"
"POLYCAT" -> "RETRACT"
"POLYCAT" -> "FLINEXP"
"POLYCAT" -> "ORDSET"

```

```
"POLYCAT" -> "GCDDOM"
"POLYCAT" -> "PFECAT"
```

— POLYCAT.dotfull —

```
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=POLYCAT"];
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "PartialDifferentialRing(a:OrderedSet)"
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "FiniteAbelianMonoidRing(a:Ring,b:OrderedAbelianMonoidSup)"
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "Evaluable(PolynomialCategory(...))"
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "InnerEvaluable(a:OrderedSet,b:Ring)"
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "InnerEvaluable(a:OrderedSet,b:PolynomialCategory(...))"
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "RetractableTo(a:OrderedSet)"
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "FullyLinearlyExplicitRingOver(a:Ring)"
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "OrderedSet()"
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "GcdDomain()"
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "PolynomialFactorizationExplicit()"

"PolynomialCategory(a:Ring,b:NonNegativeInteger,c:SingletonAsOrderedSet)"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=POLYCAT"];
"PolynomialCategory(a:Ring,b:NonNegativeInteger,c:SingletonAsOrderedSet)"
  -> "PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
```

— POLYCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=POLYCAT"];
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
```

```

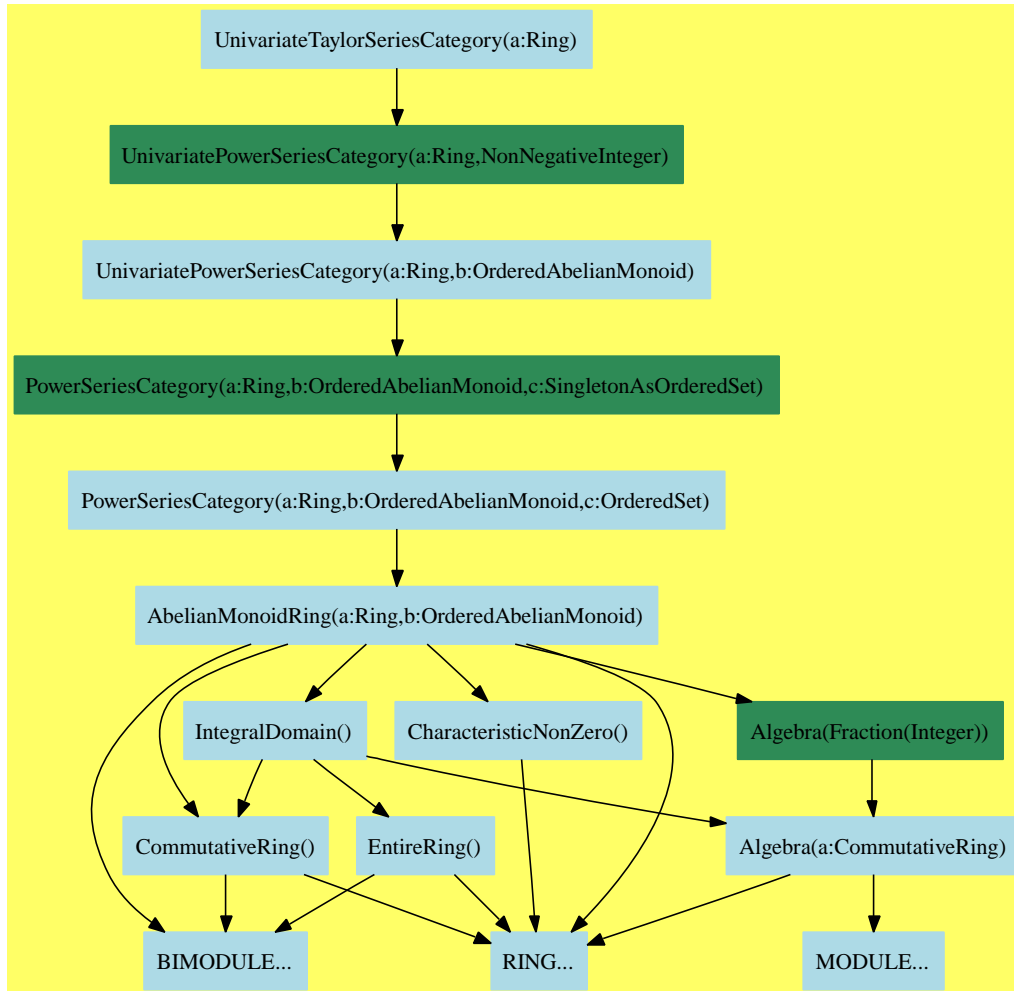
-> "PDRING..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "FAMR..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "EVALAB..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "IEVALAB..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "RETRACT..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "FLINEXP..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "ORDSET..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "GCDDOM..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "PFECAT..."

"PDRING..." [color=lightblue];
"FAMR..." [color=lightblue];
"EVALAB..." [color=lightblue];
"IEVALAB..." [color=lightblue];
"RETRACT..." [color=lightblue];
"FLINEXP..." [color=lightblue];
"ORDSET..." [color=lightblue];
"GCDDOM..." [color=lightblue];
"PFECAT..." [color=lightblue];

}

```

UnivariateTaylorSeriesCategory (UTSCAT)



— UnivariateTaylorSeriesCategory.input —

```

)set break resume
)sys rm -f UnivariateTaylorSeriesCategory.output
)spool UnivariateTaylorSeriesCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show UnivariateTaylorSeriesCategory

```

```

--R
--R UnivariateTaylorSeriesCategory(Coef: Ring) is a category constructor
--R Abbreviation for UnivariateTaylorSeriesCategory is UTSCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for UTSCAT
--R
--R----- Operations -----
--R ?? : (Coef,%) -> %           ?? : (%,Coef) -> %
--R ?? : (%,%) -> %             ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?? : (%,%) -> %             ?-? : (%,%) -> %
--R -? : % -> %                 ?? : (%,%) -> Boolean
--R 1 : () -> %                 0 : () -> %
--R ?? : (%,PositiveInteger) -> %   center : % -> Coef
--R coefficients : % -> Stream(Coef)  coerce : Integer -> %
--R coerce : % -> OutputForm          complete : % -> %
--R degree : % -> NonNegativeInteger  hash : % -> SingleInteger
--R latex : % -> String              leadingCoefficient : % -> Coef
--R leadingMonomial : % -> %         map : ((Coef -> Coef),%) -> %
--R monomial? : % -> Boolean         one? : % -> Boolean
--R order : % -> NonNegativeInteger   pole? : % -> Boolean
--R quoByVar : % -> %               recip : % -> Union(%, "failed")
--R reductum : % -> %               sample : () -> %
--R series : Stream(Coef) -> %       variable : % -> Symbol
--R zero? : % -> Boolean            ?~=? : (%,%) -> Boolean
--R ?? : (%,Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (Fraction(Integer),%) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (%,%) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (%,Coef) -> % if Coef has FIELD
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,Coef) -> % if Coef has FIELD
--R D : % -> % if Coef has *: (NonNegativeInteger,Coef) -> Coef
--R D : (%,NonNegativeInteger) -> % if Coef has *: (NonNegativeInteger,Coef) -> Coef
--R D : (%,Symbol) -> % if Coef has PDRING(SYMBOL) and Coef has *: (NonNegativeInteger,Coef) -> %
--R D : (%,List(Symbol)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (NonNegativeInteger,Coef) -> %
--R D : (%,Symbol,NonNegativeInteger) -> % if Coef has PDRING(SYMBOL) and Coef has *: (NonNegativeInteger,Coef) -> %
--R D : (%,List(Symbol),List(NonNegativeInteger)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (NonNegativeInteger,Coef) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R acos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acoth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R approximate : (%,NonNegativeInteger) -> Coef if Coef has **: (Coef,NonNegativeInteger) -> Coef
--R asec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asin : % -> % if Coef has ALGEBRA(FRAC(INT))

```

```

--R asinh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R associates? : (%,%) -> Boolean if Coef has INTDOM
--R atan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R atanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
--R coefficient : (%, NonNegativeInteger) -> Coef
--R coerce : Coef -> % if Coef has COMRING
--R coerce : % -> % if Coef has INTDOM
--R coerce : Fraction(Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R cos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R coth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R differentiate : % -> % if Coef has *: (NonNegativeInteger, Coef) -> Coef
--R differentiate : (%, NonNegativeInteger) -> % if Coef has *: (NonNegativeInteger, Coef) -> Coef
--R differentiate : (%, Symbol) -> % if Coef has PDRING(SYMBOL) and Coef has *: (NonNegativeInteger, Coef) -> %
--R differentiate : (%, List(Symbol)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (NonNegativeInteger, Coef) -> %
--R differentiate : (%, Symbol, NonNegativeInteger) -> % if Coef has PDRING(SYMBOL) and Coef has *: (NonNegativeInteger, Coef) -> %
--R differentiate : (%, List(Symbol), List(NonNegativeInteger)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (NonNegativeInteger, Coef) -> %
--R ?? : (%,%) -> % if NonNegativeInteger has SGROUP
--R ?? : (%, NonNegativeInteger) -> Coef
--R eval : (%, Coef) -> Stream(Coef) if Coef has **: (Coef, NonNegativeInteger) -> Coef
--R exp : % -> % if Coef has ALGEBRA(FRAC(INT))
--R exquo : (%,%) -> Union(%, "failed") if Coef has INTDOM
--R extend : (%, NonNegativeInteger) -> %
--R integrate : (%, Symbol) -> % if Coef has ACFS(INT) and Coef has PRIMCAT and Coef has TRANFUN and Coef has ALGEBRA(FRAC(INT))
--R integrate : % -> % if Coef has ALGEBRA(FRAC(INT))
--R log : % -> % if Coef has ALGEBRA(FRAC(INT))
--R monomial : (%, List(SingletonAsOrderedSet), List(NonNegativeInteger)) -> %
--R monomial : (%, SingletonAsOrderedSet, NonNegativeInteger) -> %
--R monomial : (Coef, NonNegativeInteger) -> %
--R multiplyCoefficients : ((Integer -> Coef), %) -> %
--R multiplyExponents : (%, PositiveInteger) -> %
--R nthRoot : (%, Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R order : (%, NonNegativeInteger) -> NonNegativeInteger
--R pi : () -> % if Coef has ALGEBRA(FRAC(INT))
--R polynomial : (%, NonNegativeInteger, NonNegativeInteger) -> Polynomial(Coef)
--R polynomial : (%, NonNegativeInteger) -> Polynomial(Coef)
--R sec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R series : Stream(Record(k: NonNegativeInteger, c: Coef)) -> %
--R sin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sinh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sqrt : % -> % if Coef has ALGEBRA(FRAC(INT))
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R tan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R tanh : % -> % if Coef has ALGEBRA(FRAC(INT))

```



```

--R terms : % -> Stream(Record(k: NonNegativeInteger,c: Coef))
--R truncate : (% ,NonNegativeInteger,NonNegativeInteger) -> %
--R truncate : (% ,NonNegativeInteger) -> %
--R unit? : % -> Boolean if Coef has INTDOM
--R unitCanonical : % -> % if Coef has INTDOM
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if Coef has INTDOM
--R variables : % -> List(SingletonAsOrderedSet)
--R
--E 1

)spool
)lisp (bye)

```

— UnivariateTaylorSeriesCategory.help —

=====

UnivariateTaylorSeriesCategory examples

=====

UnivariateTaylorSeriesCategory is the category of Taylor series
in one variable.

See Also:

o)show UnivariateTaylorSeriesCategory

See:

⇐ “RadicalCategory” (RADCAT) [2](#) on page [92](#)
⇐ “TranscendentalFunctionCategory” (TRANFUN) [3](#) on page [166](#)
⇐ “UnivariatePowerSeriesCategory” (UPSCAT) [15](#) on page [1260](#)

Exports:

| | | | |
|-----------------|----------------------|-------------------|--------------------|
| 0 | 1 | acos | acosh |
| acot | acoth | acsc | acsch |
| approximate | asec | asech | asin |
| asinh | associates? | atan | atanh |
| center | characteristic | charthRoot | coefficient |
| coefficients | coerce | complete | cos |
| cosh | cot | coth | csc |
| csch | D | degree | differentiate |
| eval | exp | exquo | extend |
| hash | integrate | latex | leadingCoefficient |
| leadingMonomial | log | map | monomial |
| monomial? | multiplyCoefficients | multiplyExponents | nthRoot |
| one? | order | pi | pole? |
| polynomial | quoByVar | recip | reductum |
| sample | sec | sech | series |
| sin | sinh | sqrt | subtractIfCan |
| tan | tanh | terms | truncate |
| unit? | unitCanonical | unitNormal | variable |
| variables | zero? | ?*? | ?**? |
| ?+? | ?-? | -? | ?=? |
| ?^? | ?~=? | ?/? | ?..? |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- if #1 has IntegralDomain then noZeroDivisors where **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- if #1 has CommutativeRing then commutative(“*”) where **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.

These are directly exported but not implemented:

```

coefficients : % -> Stream Coef
integrate : (% , Symbol) -> %
  if Coef has ACFS INT
  and Coef has PRIMCAT
  and Coef has TRANFUN
  and Coef has ALGEBRA FRAC INT
  or Coef has variables: Coef -> List Symbol
  and Coef has integrate: (Coef, Symbol) -> Coef
  and Coef has ALGEBRA FRAC INT
integrate : % -> % if Coef has ALGEBRA FRAC INT

```

```

multiplyCoefficients : ((Integer -> Coef),%) -> %
polynomial : (%,NonNegativeInteger,NonNegativeInteger) -> Polynomial Coef
polynomial : (%,NonNegativeInteger) -> Polynomial Coef
quoByVar : % -> %
series : Stream Coef -> %
series : Stream Record(k: NonNegativeInteger,c: Coef) -> %

```

These are implemented by this category:

```

acos : % -> % if Coef has ALGEBRA FRAC INT
acosh : % -> % if Coef has ALGEBRA FRAC INT
acot : % -> % if Coef has ALGEBRA FRAC INT
acoth : % -> % if Coef has ALGEBRA FRAC INT
acsc : % -> % if Coef has ALGEBRA FRAC INT
acsch : % -> % if Coef has ALGEBRA FRAC INT
asec : % -> % if Coef has ALGEBRA FRAC INT
asech : % -> % if Coef has ALGEBRA FRAC INT
asin : % -> % if Coef has ALGEBRA FRAC INT
asinh : % -> % if Coef has ALGEBRA FRAC INT
atan : % -> % if Coef has ALGEBRA FRAC INT
atanh : % -> % if Coef has ALGEBRA FRAC INT
coerce : % -> OutputForm
cos : % -> % if Coef has ALGEBRA FRAC INT
cosh : % -> % if Coef has ALGEBRA FRAC INT
cot : % -> % if Coef has ALGEBRA FRAC INT
coth : % -> % if Coef has ALGEBRA FRAC INT
csc : % -> % if Coef has ALGEBRA FRAC INT
csch : % -> % if Coef has ALGEBRA FRAC INT
exp : % -> % if Coef has ALGEBRA FRAC INT
log : % -> % if Coef has ALGEBRA FRAC INT
sinh : % -> % if Coef has ALGEBRA FRAC INT
sec : % -> % if Coef has ALGEBRA FRAC INT
sech : % -> % if Coef has ALGEBRA FRAC INT
sin : % -> % if Coef has ALGEBRA FRAC INT
tan : % -> % if Coef has ALGEBRA FRAC INT
tanh : % -> % if Coef has ALGEBRA FRAC INT
zero? : % -> Boolean
***? : (%,Coef) -> % if Coef has FIELD
***? : (%,%) -> % if Coef has ALGEBRA FRAC INT
***? : (%,Fraction Integer) -> % if Coef has ALGEBRA FRAC INT

```

These exports come from (p1260) `UnivariatePowerSeriesCategory(Coef,NNI)` where `Coef:Ring` and `NNI:NonNegativeInteger`:

```

0 : () -> %
1 : () -> %
approximate : (%,NonNegativeInteger) -> Coef
  if Coef has **: (Coef,NonNegativeInteger) -> Coef
  and Coef has coerce: Symbol -> Coef
associates? : (%,%) -> Boolean if Coef has INTDOM

```

```

center : % -> Coef
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
coefficient : (%, NonNegativeInteger) -> Coef
coerce : Coef -> % if Coef has COMRING
coerce : % -> % if Coef has INTDOM
coerce : Fraction Integer -> % if Coef has ALGEBRA FRAC INT
coerce : Integer -> %
complete : % -> %
D : % -> % if Coef has *: (NonNegativeInteger, Coef) -> Coef
D : (%, NonNegativeInteger) -> %
  if Coef has *: (NonNegativeInteger, Coef) -> Coef
D : (%, Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (NonNegativeInteger, Coef) -> Coef
D : (%, List Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (NonNegativeInteger, Coef) -> Coef
D : (%, Symbol, NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (NonNegativeInteger, Coef) -> Coef
D : (%, List Symbol, List NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (NonNegativeInteger, Coef) -> Coef
differentiate : (%, List Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (NonNegativeInteger, Coef) -> Coef
differentiate : (%, Symbol, NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (NonNegativeInteger, Coef) -> Coef
differentiate : (%, List Symbol, List NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (NonNegativeInteger, Coef) -> Coef
differentiate : (%, Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (NonNegativeInteger, Coef) -> Coef
differentiate : (%, NonNegativeInteger) -> %
  if Coef has *: (NonNegativeInteger, Coef) -> Coef
differentiate : % -> %
  if Coef has *: (NonNegativeInteger, Coef) -> Coef
degree : % -> NonNegativeInteger
extend : (%, NonNegativeInteger) -> %
exquo : (%, %) -> Union(%, "failed") if Coef has INTDOM
eval : (%, Coef) -> Stream Coef
  if Coef has **: (Coef, NonNegativeInteger) -> Coef
hash : % -> SingleInteger
latex : % -> String
leadingCoefficient : % -> Coef
leadingMonomial : % -> %
map : ((Coef -> Coef), %) -> %

```

```

monomial : (Coef, NonNegativeInteger) -> %
monomial : (% , SingletonAsOrderedSet, NonNegativeInteger) -> %
monomial : (% , List SingletonAsOrderedSet, List NonNegativeInteger) -> %
monomial? : % -> Boolean
multiplyExponents : (% , PositiveInteger) -> %
one? : % -> Boolean
order : % -> NonNegativeInteger
order : (% , NonNegativeInteger) -> NonNegativeInteger
pole? : % -> Boolean
recip : % -> Union(%, "failed")
reductum : % -> %
sample : () -> %
subtractIfCan : (% , %) -> Union(%, "failed")
terms : % -> Stream Record(k: NonNegativeInteger, c: Coef)
truncate : (% , NonNegativeInteger, NonNegativeInteger) -> %
truncate : (% , NonNegativeInteger) -> %
unit? : % -> Boolean if Coef has INTDOM
unitCanonical : % -> % if Coef has INTDOM
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
    if Coef has INTDOM
variable : % -> Symbol
variables : % -> List SingletonAsOrderedSet
?^? : (% , NonNegativeInteger) -> %
?+? : (% , %) -> %
?=? : (% , %) -> Boolean
?~=? : (% , %) -> Boolean
?*? : (NonNegativeInteger, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (% , %) -> %
?-? : (% , %) -> %
?*?* : (% , PositiveInteger) -> %
?*?* : (% , NonNegativeInteger) -> %
?^? : (% , PositiveInteger) -> %
?*? : (Integer, %) -> %
?*? : (Coef, %) -> %
?*? : (% , Coef) -> %
?*? : (% , Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
?*? : (Fraction Integer, %) -> % if Coef has ALGEBRA FRAC INT
?/? : (% , Coef) -> % if Coef has FIELD
-? : % -> %
?.? : (% , %) -> % if NonNegativeInteger has SGROUP
?.? : (% , NonNegativeInteger) -> Coef

```

These exports come from (p166) TranscendentalFunctionCategory():

```
pi : () -> % if Coef has ALGEBRA FRAC INT
```

These exports come from (p92) RadicalCategory():

```
nthRoot : (% , Integer) -> % if Coef has ALGEBRA FRAC INT
```

```
sqrt : % -> % if Coef has ALGEBRA FRAC INT
```

— category UTSCAT UnivariateTaylorSeriesCategory —

```
)abbrev category UTSCAT UnivariateTaylorSeriesCategory
++ Author: Clifton J. Williamson
++ Date Created: 21 December 1989
++ Date Last Updated: 26 May 1994
++ Description:
++ \spadtype{UnivariateTaylorSeriesCategory} is the category of Taylor
++ series in one variable.

UnivariateTaylorSeriesCategory(Coef): Category == Definition where
  Coef : Ring
  I    ==> Integer
  L    ==> List
  NNI  ==> NonNegativeInteger
  OUT  ==> OutputForm
  RN   ==> Fraction Integer
  STTA ==> StreamTaylorSeriesOperations Coef
  STTF ==> StreamTranscendentalFunctions Coef
  STNC ==> StreamTranscendentalFunctionsNonCommutative Coef
  Term ==> Record(k:NNI,c:Coef)

Definition ==> UnivariatePowerSeriesCategory(Coef,NNI) with

series: Stream Term -> %
  ++ \spad{series(st)} creates a series from a stream of non-zero terms,
  ++ where a term is an exponent-coefficient pair. The terms in the
  ++ stream should be ordered by increasing order of exponents.
coefficients: % -> Stream Coef
  ++ \spad{coefficients(a0 + a1 x + a2 x**2 + ...)} returns a stream
  ++ of coefficients: \spad{[a0,a1,a2,...]}. The entries of the stream
  ++ may be zero.
series: Stream Coef -> %
  ++ \spad{series([a0,a1,a2,...])} is the Taylor series
  ++ \spad{a0 + a1 x + a2 x**2 + ...}.
quoByVar: % -> %
  ++ \spad{quoByVar(a0 + a1 x + a2 x**2 + ...)}
  ++ returns \spad{a1 + a2 x + a3 x**2 + ...}
  ++ Thus, this function subtracts the constant term and divides by
  ++ the series variable. This function is used when Laurent series
  ++ are represented by a Taylor series and an order.
multiplyCoefficients: (I -> Coef,% ) -> %
  ++ \spad{multiplyCoefficients(f,sum(n = 0..infinity,a[n] * x**n))}
  ++ returns \spad{sum(n = 0..infinity,f(n) * a[n] * x**n)}.
  ++ This function is used when Laurent series are represented by
  ++ a Taylor series and an order.
polynomial: (% ,NNI) -> Polynomial Coef
```

```

++ \spad{polynomial(f,k)} returns a polynomial consisting of the sum
++ of all terms of f of degree \spad{<= k}.
polynomial: (% ,NNI,NNI) -> Polynomial Coef
++ \spad{polynomial(f,k1,k2)} returns a polynomial consisting of the
++ sum of all terms of f of degree d with \spad{k1 <= d <= k2}.

if Coef has Field then
  "**": (% ,Coef) -> %
  ++ \spad{f(x) ** a} computes a power of a power series.
  ++ When the coefficient ring is a field, we may raise a series
  ++ to an exponent from the coefficient ring provided that the
  ++ constant coefficient of the series is 1.

if Coef has Algebra Fraction Integer then
  integrate: % -> %
  ++ \spad{integrate(f(x))} returns an anti-derivative of the power
  ++ series \spad{f(x)} with constant coefficient 0.
  ++ We may integrate a series when we can divide coefficients
  ++ by integers.
  if Coef has integrate: (Coef,Symbol) -> Coef and _
    Coef has variables: Coef -> List Symbol then
      integrate: (% ,Symbol) -> %
      ++ \spad{integrate(f(x),y)} returns an anti-derivative of the
      ++ power series \spad{f(x)} with respect to the variable \spad{y}.
  if Coef has TranscendentalFunctionCategory and _
    Coef has PrimitiveFunctionCategory and _
    Coef has AlgebraicallyClosedFunctionSpace Integer then
      integrate: (% ,Symbol) -> %
      ++ \spad{integrate(f(x),y)} returns an anti-derivative of
      ++ the power series \spad{f(x)} with respect to the variable
      ++ \spad{y}.
  RadicalCategory
  --++ We provide rational powers when we can divide coefficients
  --++ by integers.
  TranscendentalFunctionCategory
  --++ We provide transcendental functions when we can divide
  --++ coefficients by integers.

add

zero? x ==
  empty? (coefs := coefficients x) => true
  (zero? frst coefs) and (empty? rst coefs) => true
  false

--% OutputForms

-- We provide default output functions on UTSCAT using the functions
-- 'coefficients', 'center', and 'variable'.

```

```

factorials?: () -> Boolean
-- check a global Lisp variable
factorials?() == false

termOutput: (I,Coef,OUT) -> OUT
termOutput(k,c,vv) ==
-- creates a term c * vv ** k
  k = 0 => c :: OUT
  mon := (k = 1 => vv; vv ** (k :: OUT))
--   if factorials?() and k > 1 then
--     c := factorial(k)$IntegerCombinatoricFunctions * c
--     mon := mon / hconcat(k :: OUT,"!" :: OUT)
  c = 1 => mon
  c = -1 => -mon
  (c :: OUT) * mon

showAll?: () -> Boolean
-- check a global Lisp variable
showAll?() == true

coerce(p:):OUT ==
  empty? (uu := coefficients p) => (0$Coef) :: OUT
  var := variable p; cen := center p
  vv :=
    zero? cen => var :: OUT
    paren(var :: OUT - cen :: OUT)
  n : NNI ; count : NNI := _$streamCount$Lisp
  l : L OUT := empty()
  for n in 0..count while not empty? uu repeat
    if first(uu) ^= 0 then
      l := concat(termOutput(n :: I,first uu,vv),l)
      uu := rst uu
  if showAll?() then
    for n in (count + 1).. while explicitEntries? uu and _
      not eq?(uu,rst uu) repeat
        if first(uu) ^= 0 then
          l := concat(termOutput(n :: I,first uu,vv),l)
          uu := rst uu
  l :=
    explicitlyEmpty? uu => l
    eq?(uu,rst uu) and first uu = 0 => l
    concat(prefix("0" :: OUT,[vv ** (n :: OUT)]),l)
  empty? l => (0$Coef) :: OUT
  reduce("+",reverse_! l)

if Coef has Field then
  (x:%) ** (r:Coef) == series power(r,coefficients x)$STTA

if Coef has Algebra Fraction Integer then
  if Coef has CommutativeRing then

```



```

(x:%) ** (y:%)    == series(coefficients x **$STTF coefficients y)

(x:%) ** (r:RN)   == series powern(r,coefficients x)$STTA

exp x == series exp(coefficients x)$STTF

log x == series log(coefficients x)$STTF

sin x == series sin(coefficients x)$STTF

cos x == series cos(coefficients x)$STTF

tan x == series tan(coefficients x)$STTF

cot x == series cot(coefficients x)$STTF

sec x == series sec(coefficients x)$STTF

csc x == series csc(coefficients x)$STTF

asin x == series asin(coefficients x)$STTF

acos x == series acos(coefficients x)$STTF

atan x == series atan(coefficients x)$STTF

acot x == series acot(coefficients x)$STTF

asec x == series asec(coefficients x)$STTF

acsc x == series acsc(coefficients x)$STTF

sinh x == series sinh(coefficients x)$STTF

cosh x == series cosh(coefficients x)$STTF

tanh x == series tanh(coefficients x)$STTF

coth x == series coth(coefficients x)$STTF

sech x == series sech(coefficients x)$STTF

csch x == series csch(coefficients x)$STTF

asinh x == series asinh(coefficients x)$STTF

acosh x == series acosh(coefficients x)$STTF

atanh x == series atanh(coefficients x)$STTF

```

```

acoth x == series acoth(coefficients x)$STTF

asech x == series asech(coefficients x)$STTF

acsch x == series acsch(coefficients x)$STTF

else
  (x:%) ** (y:%) == series(coefficients x **$STNC coefficients y)

  (x:%) ** (r:RN) ==
    coefs := coefficients x
    empty? coefs =>
      positive? r => 0
      zero? r => error "0**0 undefined"
      error "0 raised to a negative power"
--    not one? first coefs =>
    not (first coefs = 1) =>
      error "**: constant coefficient should be 1"
    coefs := concat(0,rst coefs)
    onePlusX := monom(1,0)$STTA + $STTA monom(1,1)$STTA
    ratPow := powern(r,onePlusX)$STTA
    series compose(ratPow,coefs)$STTA

exp x == series exp(coefficients x)$STNC

log x == series log(coefficients x)$STNC

sin x == series sin(coefficients x)$STNC

cos x == series cos(coefficients x)$STNC

tan x == series tan(coefficients x)$STNC

cot x == series cot(coefficients x)$STNC

sec x == series sec(coefficients x)$STNC

csc x == series csc(coefficients x)$STNC

asin x == series asin(coefficients x)$STNC

acos x == series acos(coefficients x)$STNC

atan x == series atan(coefficients x)$STNC

acot x == series acot(coefficients x)$STNC

asec x == series asec(coefficients x)$STNC

acsc x == series acsc(coefficients x)$STNC

```

```

sinh x == series sinh(coefficients x)$STNC
cosh x == series cosh(coefficients x)$STNC
tanh x == series tanh(coefficients x)$STNC
coth x == series coth(coefficients x)$STNC
sech x == series sech(coefficients x)$STNC
csch x == series csch(coefficients x)$STNC
asinh x == series asinh(coefficients x)$STNC
acosh x == series acosh(coefficients x)$STNC
atanh x == series atanh(coefficients x)$STNC
acoth x == series acoth(coefficients x)$STNC
asech x == series asech(coefficients x)$STNC
acsch x == series acsch(coefficients x)$STNC

```

— UTSCAT.dotabb —

```

"UTSCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=UTSCAT"];
"UTSCAT" -> "UPSCAT"

```

— UTSCAT.dotfull —

```

"UnivariateTaylorSeriesCategory(a:Ring)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=UTSCAT"];
"UnivariateTaylorSeriesCategory(a:Ring)" ->
  "UnivariatePowerSeriesCategory(a:Ring,NonNegativeInteger)"

```

— UTSCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "UnivariateTaylorSeriesCategory(a:Ring)" [color=lightblue];
  "UnivariateTaylorSeriesCategory(a:Ring)" ->
    "UnivariatePowerSeriesCategory(a:Ring,NonNegativeInteger)"

  "UnivariatePowerSeriesCategory(a:Ring,NonNegativeInteger)"
    [color=seagreen,href="bookvol10.2.pdf#nameddest=UPSCAT"];
  "UnivariatePowerSeriesCategory(a:Ring,NonNegativeInteger)" ->
    "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"

  "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"
    [color=lightblue];
  "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)" ->
    "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"

  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
    [color=seagreen];
  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
    -> "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"

  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"
    [color=lightblue];
  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)" ->
    "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)"

  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" [color=lightblue];
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" -> "RING..."
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "BIMODULE..."
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "IntegralDomain()"
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "CharacteristicNonZero()"
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "CommutativeRing()"
  "AbelianMonoidRing(a:Ring,b:OrderedAbelianMonoid)" ->
    "Algebra(Fraction(Integer))"

  "IntegralDomain()" [color=lightblue];
  "IntegralDomain()" -> "CommutativeRing()"
  "IntegralDomain()" -> "Algebra(a:CommutativeRing)"
  "IntegralDomain()" -> "EntireRing()"

  "EntireRing()" [color=lightblue];
  "EntireRing()" -> "RING..."
  "EntireRing()" -> "BIMODULE..."

```

```

"CharacteristicNonZero()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=CHARNZ"];
"CharacteristicNonZero()" -> "RING..."

"Algebra(Fraction(Integer))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(Fraction(Integer))" -> "Algebra(a:CommutativeRing)"

"Algebra(a:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=ALGEBRA"];
"Algebra(a:CommutativeRing)" -> "RING..."
"Algebra(a:CommutativeRing)" -> "MODULE..."

"CommutativeRing()" [color=lightblue];
"CommutativeRing()" -> "RING..."
"CommutativeRing()" -> "BIMODULE..."

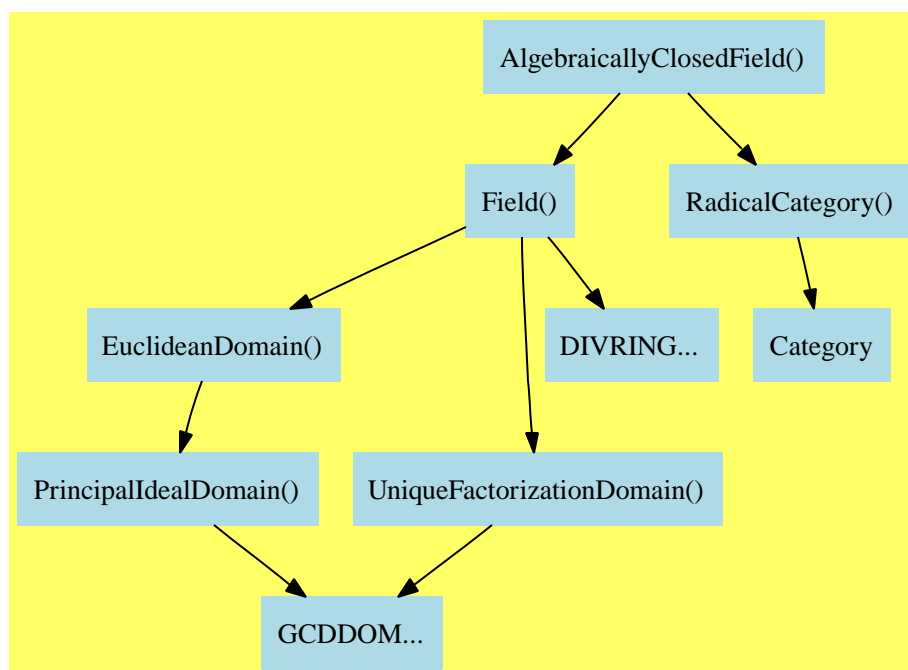
"BIMODULE..." [color=lightblue];
"RING..." [color=lightblue];
"MODULE..." [color=lightblue];
}

```

Chapter 17

Category Layer 16

AlgebraicallyClosedField (ACF)



— AlgebraicallyClosedField.input —

```
)set break resume  
)sys rm -f AlgebraicallyClosedField.output  
)spool AlgebraicallyClosedField.output
```

```

)set message test on
)set message auto off
)clear all

--S 1 of 14
pi:Polynomial(Integer):=-3*x^3+2*x+13
--R
--R
--R      3
--R      (1)  - 3x  + 2x + 13
--R
--R                                          Type: Polynomial(Integer)
--E 1

--S 2 of 14
rootOf(pi)
--R
--R
--R      (2)  x
--R
--R                                          Type: AlgebraicNumber
--E 2

--S 3 of 14
rootsOf(pi)
--R
--R
--R      (3)  [%x0,%x1,- %x1 - %x0]
--R
--R                                          Type: List(AlgebraicNumber)
--E 3

--S 4 of 14
zeroOf(pi)
--R
--R
--R      (4)  x
--R
--R                                          Type: AlgebraicNumber
--E 4

--S 5 of 14
zerosOf(pi)
--R
--R
--R      +-----+
--R      |      2      |      2
--R      - \|- 27%x3  + 24 - 3%x3 \|- 27%x3  + 24 - 3%x3
--R      (5)  [%x3,-----,-----]
--R                  6                  6
--R
--R                                          Type: List(AlgebraicNumber)
--E 5

--S 6 of 14

```

```

sup:SparseUnivariatePolynomial(Integer):=-3*x^3+2*x+13
--R
--R
--R      3
--R  (6)  - 3?  + 2? + 13
--R
--R                                          Type: SparseUnivariatePolynomial(Integer)
--E 6

--S 7 of 14
rootOf(sup)
--R
--R
--R  (7)  %B
--R
--R                                          Type: AlgebraicNumber
--E 7

--S 8 of 14
rootOf(sup,x)
--R
--R
--R  (8)  x
--R
--R                                          Type: AlgebraicNumber
--E 8

--S 9 of 14
rootsOf(sup)
--R
--R
--R  (9)  [%C0,%C1,- %C1 - %C0]
--R
--R                                          Type: List(AlgebraicNumber)
--E 9

--S 10 of 14
rootsOf(sup,x)
--R
--R
--R  (10) [%x6,%x7,- %x7 - %x6]
--R
--R                                          Type: List(AlgebraicNumber)
--E 10

--S 11 of 14
zeroOf(sup)
--R
--R
--R  (11) %D
--R
--R                                          Type: AlgebraicNumber
--E 11

--S 12 of 14
zeroOf(sup,x)

```



```

--R
--R
--R (12) x
--R
--R                                         Type: AlgebraicNumber
--E 12

```

```

--S 13 of 14
zerosOf(sup)
--R
--R
--R
--R          +-----+          +-----+
--R          |      2          |      2
--R      - \|- 27%E0 + 24 - 3%E0 \|- 27%E0 + 24 - 3%E0
--R (13) [%E0,-----,-----]
--R                      6                      6
--R
--R                                         Type: List(AlgebraicNumber)
--E 13

```

```

--S 14 of 14
zerosOf(sup,x)
--R
--R
--R
--R          +-----+          +-----+
--R          |      2          |      2
--R      - \|- 27%x9 + 24 - 3%x9 \|- 27%x9 + 24 - 3%x9
--R (14) [%x9,-----,-----]
--R                      6                      6
--R
--R                                         Type: List(AlgebraicNumber)
--E 14

```

```

)spool
)lisp (bye)

```

— AlgebraicallyClosedField.help —

```

=====
AlgebraicallyClosedField examples
=====

```

This category is a model for algebraically closed fields.

Given the polynomial:

```

pi:Polynomial(Integer):=-3*x^3+2*x+13
      3
    - 3x  + 2x + 13

```

```
rootOf(pi)
      x
```

```
rootsOf(pi)
      [%x0,%x1,- %x1 - %x0]
```

```
zeroOf(pi)
      x
```

```
zerosOf(pi)
      +-----+          +-----+
      |      2          |      2
      - \|- 27%x3  + 24  - 3%x3 \|- 27%x3  + 24  - 3%x3
      [%x3,-----,-----]
              6              6
```

These functions can also be applied to Sparse Univariate Polynomials:

```
sup:SparseUnivariatePolynomial(Integer):=-3*x^3+2*x+13
      3
      - 3?  + 2? + 13
```

```
rootOf(sup)
      %B
```

```
rootOf(sup,x)
      x
```

```
rootsOf(sup)
      [%C0,%C1,- %%C1 - %%C0]
```

```
rootsOf(sup,x)
      [%x6,%x7,- %x7 - %x6]
```

```
zeroOf(sup)
      %D
```

```
zeroOf(sup,x)
      x
```

zerosOf (sup)

$$\left[\frac{-\sqrt{-27} + 24 - 3\sqrt{-27} + 24 - 3\sqrt{-27}}{6}, \frac{-\sqrt{-27} + 24 - 3\sqrt{-27} + 24 - 3\sqrt{-27}}{6} \right]$$

zerosOf (sup, x)

$$\left[\frac{-\sqrt{-27x^9} + 24 - 3\sqrt{-27x^9} + 24 - 3\sqrt{-27x^9}}{6}, \frac{-\sqrt{-27x^9} + 24 - 3\sqrt{-27x^9} + 24 - 3\sqrt{-27x^9}}{6} \right]$$

See Also:

o)show AlgebraicallyClosedField

See:

⇒ “AlgebraicallyClosedFunctionSpace” (ACFS) [18](#) on page [1547](#)

⇐ “Field” (FIELD) [16](#) on page [1271](#)

⇐ “RadicalCategory” (RADCAT) [2](#) on page [92](#)

Exports:

| | | | |
|---------------|-------------------|---------------|--------------------|
| 0 | 1 | associates? | characteristic |
| coerce | divide | euclideanSize | expressIdealMember |
| exquo | extendedEuclidean | factor | gcd |
| gcdPolynomial | hash | inv | latex |
| lcm | multiEuclidean | nthRoot | one? |
| prime? | principalIdeal | recip | rootOf |
| rootsOf | sample | sizeLess? | sqrt |
| squareFree | squareFreePart | subtractIfCan | unit? |
| unitCanonical | unitNormal | zero? | zeroOf |
| zerosOf | ?*? | ?**? | ?+? |
| ?-? | -? | ?/? | ?=? |
| ?quo? | ?rem? | ?~=? | ?^? |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **canonicalsClosed** is true if `unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative("“*”")** is true if it has an operation $" * "$: $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
rootOf : Polynomial % -> %
```

These are implemented by this category:

```
rootOf : SparseUnivariatePolynomial % -> %
rootOf : (SparseUnivariatePolynomial %, Symbol) -> %
rootsOf : Polynomial % -> List %
rootsOf : (SparseUnivariatePolynomial %, Symbol) -> List %
rootsOf : SparseUnivariatePolynomial % -> List %
zeroOf : (SparseUnivariatePolynomial %, Symbol) -> %
zeroOf : Polynomial % -> %
zeroOf : SparseUnivariatePolynomial % -> %
zerosOf : Polynomial % -> List %
zerosOf : (SparseUnivariatePolynomial %, Symbol) -> List %
zerosOf : SparseUnivariatePolynomial % -> List %
```

These exports come from (p1271) `Field()`:

```
0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
coerce : Fraction Integer -> %
divide : (%,%) -> Record(quotient: %, remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %, "failed")
```

```

exquo : (%,%) -> Union(%, "failed")
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
factor : % -> Factored %
gcd : (%,%) -> %
gcd : List % -> %
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
hash : % -> SingleInteger
inv : % -> %
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
multiEuclidean : (List %,%) -> Union(List %, "failed")
one? : % -> Boolean
prime? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%, "failed")
sample : () -> %
sizeLess? : (%,%) -> Boolean
squareFree : % -> Factored %
squareFreePart : % -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
zero? : % -> Boolean
?*? : (Fraction Integer,%) -> %
?*? : (%,Fraction Integer) -> %
***? : (%,Integer) -> %
?^? : (%,Integer) -> %
?+? : (%,%) -> %
?=?: (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-?: (%,%) -> %
-?: % -> %
?*?? : (%,PositiveInteger) -> %
?*?? : (%,NonNegativeInteger) -> %
?^? : (%,PositiveInteger) -> %
?^? : (%,NonNegativeInteger) -> %
?/? : (%,%) -> %
?quo? : (%,%) -> %
?rem? : (%,%) -> %

```

These exports come from (p92) RadicalCategory():

```
nthRoot : (%,Integer) -> %
sqrt : % -> %
?***? : (% , Fraction Integer) -> %
```

— category ACF AlgebraicallyClosedField —

```
)abbrev category ACF AlgebraicallyClosedField
++ Author: Manuel Bronstein
++ Date Created: 22 Mar 1988
++ Date Last Updated: 27 November 1991
++ Description:
++ Model for algebraically closed fields.

AlgebraicallyClosedField(): Category == Join(Field,RadicalCategory) with

rootOf: Polynomial $ -> $
++rootOf(p) returns y such that \spad{p(y) = 0}.
++ Error: if p has more than one variable y.
++
++X a:Polynomial(Integer):=-3*x^3+2*x+13
++X rootOf(a)

rootOf: SparseUnivariatePolynomial $ -> $
++rootOf(p) returns y such that \spad{p(y) = 0}.
++
++X a:SparseUnivariatePolynomial(Integer):=-3*x^3+2*x+13
++X rootOf(a)

rootOf: (SparseUnivariatePolynomial $, Symbol) -> $
++rootOf(p, y) returns y such that \spad{p(y) = 0}.
++ The object returned displays as \spad{'y}.
++
++X a:SparseUnivariatePolynomial(Integer):=-3*x^3+2*x+13
++X rootOf(a,x)

rootsOf: Polynomial $ -> List $
++rootsOf(p) returns \spad{[y1,...,yn]} such that \spad{p(yi) = 0}.
++ Note that the returned symbols y1,...,yn are bound in the
++ interpreter to respective root values.
++ Error: if p has more than one variable y.
++
++X a:Polynomial(Integer):=-3*x^3+2*x+13
++X rootsOf(a)

rootsOf: SparseUnivariatePolynomial $ -> List $
++rootsOf(p) returns \spad{[y1,...,yn]} such that \spad{p(yi) = 0}.
++ Note that the returned symbols y1,...,yn are bound in the interpreter
```

```

++ to respective root values.
++
++X a: SparseUnivariatePolynomial(Integer) := -3*x^3+2*x+13
++X rootsOf(a)

rootsOf: (SparseUnivariatePolynomial $, Symbol) -> List $
++rootsOf(p, y) returns \spad{[y1,...,yn]} such that \spad{p(yi) = 0};
++ The returned roots display as \spad{'y1'},...,\spad{'yn'}.
++ Note that the returned symbols y1,...,yn are bound in the interpreter
++ to respective root values.
++
++X a: SparseUnivariatePolynomial(Integer) := -3*x^3+2*x+13
++X rootsOf(a,x)

zeroOf: Polynomial $ -> $
++zeroOf(p) returns y such that \spad{p(y) = 0}.
++ If possible, y is expressed in terms of radicals.
++ Otherwise it is an implicit algebraic quantity.
++ Error: if p has more than one variable y.
++
++X a: Polynomial(Integer) := -3*x^2+2*x-13
++X zeroOf(a)

zeroOf: SparseUnivariatePolynomial $ -> $
++zeroOf(p) returns y such that \spad{p(y) = 0};
++ if possible, y is expressed in terms of radicals.
++ Otherwise it is an implicit algebraic quantity.
++
++X a: SparseUnivariatePolynomial(Integer) := -3*x^3+2*x+13
++X zeroOf(a)

zeroOf: (SparseUnivariatePolynomial $, Symbol) -> $
++zeroOf(p, y) returns y such that \spad{p(y) = 0};
++ if possible, y is expressed in terms of radicals.
++ Otherwise it is an implicit algebraic quantity which
++ displays as \spad{'y'}.
++
++X a: SparseUnivariatePolynomial(Integer) := -3*x^3+2*x+13
++X zeroOf(a,x)

zerosOf: Polynomial $ -> List $
++zerosOf(p) returns \spad{[y1,...,yn]} such that \spad{p(yi) = 0}.
++ The yi's are expressed in radicals if possible.
++ Otherwise they are implicit algebraic quantities.
++ The returned symbols y1,...,yn are bound in the interpreter
++ to respective root values.
++ Error: if p has more than one variable y.
++
++X a: Polynomial(Integer) := -3*x^2+2*x-13
++X zerosOf(a)

```

```

zerosOf: SparseUnivariatePolynomial $ -> List $
++zerosOf(p) returns \spad{[y1,...,yn]} such that \spad{p(yi) = 0}.
++ The yi's are expressed in radicals if possible, and otherwise
++ as implicit algebraic quantities.
++ The returned symbols y1,...,yn are bound in the interpreter
++ to respective root values.
++
++X a: SparseUnivariatePolynomial(Integer) := -3*x^3+2*x+13
++X zerosOf(a)

zerosOf: (SparseUnivariatePolynomial $, Symbol) -> List $
++zerosOf(p, y) returns \spad{[y1,...,yn]} such that \spad{p(yi) = 0}.
++ The yi's are expressed in radicals if possible, and otherwise
++ as implicit algebraic quantities
++ which display as \spad{'yi}.
++ The returned symbols y1,...,yn are bound in the interpreter
++ to respective root values.
++
++X a: SparseUnivariatePolynomial(Integer) := -3*x^3+2*x+13
++X zerosOf(a,x)

add

SUP ==> SparseUnivariatePolynomial $

assign : (Symbol, $) -> $
allroots: (SUP, Symbol, (SUP, Symbol) -> $) -> List $
binomialRoots: (SUP, Symbol, (SUP, Symbol) -> $) -> List $

zeroOf(p:SUP) == assign(x := new(), zeroOf(p, x))

rootOf(p:SUP) == assign(x := new(), rootOf(p, x))

zerosOf(p:SUP) == zerosOf(p, new())

rootsOf(p:SUP) == rootsOf(p, new())

rootsOf(p:SUP, y:Symbol) == allroots(p, y, rootOf)

zerosOf(p:SUP, y:Symbol) == allroots(p, y, zeroOf)

assign(x, f) == (assignSymbol(x, f, $)$Lisp; f)

zeroOf(p:Polynomial $) ==
  empty?(l := variables p) => error "zeroOf: constant polynomial"
  zeroOf(univariate p, first l)

rootOf(p:Polynomial $) ==
  empty?(l := variables p) => error "rootOf: constant polynomial"

```



```

rootOf(univariate p, first l)

zerosOf(p:Polynomial $) ==
  empty?(l := variables p) => error "zerosOf: constant polynomial"
  zerosOf(univariate p, first l)

rootsOf(p:Polynomial $) ==
  empty?(l := variables p) => error "rootsOf: constant polynomial"
  rootsOf(univariate p, first l)

zeroOf(p:SUP, y:Symbol) ==
  zero?(d := degree p) => error "zeroOf: constant polynomial"
  zero? coefficient(p, 0) => 0
  a := leadingCoefficient p
  d = 2 =>
    b := coefficient(p, 1)
    (sqrt(b**2 - 4 * a * coefficient(p, 0)) - b) / (2 * a)
  (r := retractIfCan(reductum p)@Union($,"failed")) case "failed" =>
    rootOf(p, y)
  nthRoot(- (r::$ / a), d)

binomialRoots(p, y, fn) ==
  -- p = a * x**n + b
  alpha := assign(x := new(y)$Symbol, fn(p, x))
  one?(n := degree p) => [ alpha ]
  ((n := degree p) = 1) => [ alpha ]
  cyclo := cyclotomic(n, monomial(1,1)$SUP)_
    $NumberTheoreticPolynomialFunctions(SUP)
  beta := assign(x := new(y)$Symbol, fn(cyclo, x))
  [alpha*beta**i for i in 0..(n-1)::NonNegativeInteger]

import PolynomialDecomposition(SUP,$)

allroots(p, y, fn) ==
  zero? p => error "allroots: polynomial must be nonzero"
  zero? coefficient(p,0) =>
    concat(0, allroots(p quo monomial(1,1), y, fn))
  zero?(p1:=reductum p) => empty()
  zero? reductum p1 => binomialRoots(p, y, fn)
  decompList := decompose(p)
  # decompList > 1 =>
    h := last decompList
    g := leftFactor(p,h) :: SUP
    roots := allroots(g, y, fn)
    "append"/[allroots(h-r::SUP, y, fn) for r in roots]
  ans := nil()$List($)
  while not ground? p repeat
    alpha := assign(x := new(y)$Symbol, fn(p, x))
    q := monomial(1, 1)$SUP - alpha::SUP
    if not zero?(p alpha) then

```

```

p    := p quo q
ans := concat(alpha, ans)
else while zero?(p alpha) repeat
p    := (p exquo q)::SUP
ans := concat(alpha, ans)
reverse_! ans

```

— ACF.dotabb —

```

"ACF"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ACF"];
"ACF" -> "FIELD"
"ACF" -> "RADCAT"

```

— ACF.dotfull —

```

"AlgebraicallyClosedField()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ACF"];
"AlgebraicallyClosedField()" -> "Field()"
"AlgebraicallyClosedField()" -> "RadicalCategory()"

```

— ACF.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "AlgebraicallyClosedField()" [color=lightblue];
  "AlgebraicallyClosedField()" -> "Field()"
  "AlgebraicallyClosedField()" -> "RadicalCategory()"

  "Field()" [color=lightblue];
  "Field()" -> "EuclideanDomain()"
  "Field()" -> "UniqueFactorizationDomain()"
  "Field()" -> "DIVRING..."

  "EuclideanDomain()" [color=lightblue];
  "EuclideanDomain()" -> "PrincipalIdealDomain()"

```

```

"UniqueFactorizationDomain()" [color=lightblue];
"UniqueFactorizationDomain()" -> "GCDDOM..."

"PrincipalIdealDomain()" [color=lightblue];
"PrincipalIdealDomain()" -> "GCDDOM..."

"DIVRING..." [color=lightblue];
"GCDDOM..." [color=lightblue];

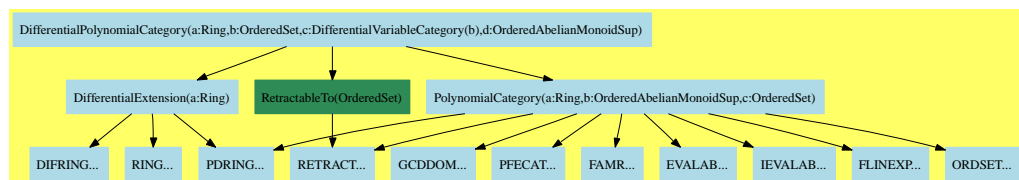
"RadicalCategory()" [color=lightblue];
"RadicalCategory()" -> "Category"

"Category" [color=lightblue];
}

```

—————→

DifferentialPolynomialCategory (DPOLCAT)



— DifferentialPolynomialCategory.input —

```

)set break resume
)sys rm -f DifferentialPolynomialCategory.output
)spool DifferentialPolynomialCategory.output
)set message test on
)set message auto off
)clear all

```

```
--S 1 of 1
```

```
)show DifferentialPolynomialCategory
```

```
--R
```

```
--R DifferentialPolynomialCategory(R: Ring,S: OrderedSet,V: DifferentialVariableCategory(t#2),E:
```

```
--R Abbreviation for DifferentialPolynomialCategory is DPOLCAT
```

```
--R This constructor is exposed in this frame.
```

```
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for DPOLCAT
```

```
--R
```

```

--R----- Operations -----
--R ?? : (%,R) -> %
--R ?? : (%,%) -> %
--R ?? : (PositiveInteger,%) -> %
--R ?? : (%,%) -> %
--R -? : % -> %
--R D : (%,(R -> R)) -> %
--R D : (%,List(V)) -> %
--R 1 : () -> %
--R ?? : (%,PositiveInteger) -> %
--R coefficients : % -> List(R)
--R coerce : V -> %
--R coerce : Integer -> %
--R degree : % -> E
--R differentiate : (%,V) -> %
--R eval : (%,V,%) -> %
--R eval : (%,V,R) -> %
--R eval : (%,Equation(%)) -> %
--R ground? : % -> Boolean
--R initial : % -> %
--R latex : % -> String
--R leadingCoefficient : % -> R
--R map : ((R -> R),%) -> %
--R minimumDegree : % -> E
--R monomial? : % -> Boolean
--R one? : % -> Boolean
--R pomopo! : (%,R,E,%) -> %
--R reductum : % -> %
--R retract : % -> V
--R sample : () -> %
--R variables : % -> List(V)
--R zero? : % -> Boolean
--R ?? : (Fraction(Integer),%) -> % if R has ALGEBRA(FRAC(INT))
--R ?? : (%,Fraction(Integer)) -> % if R has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,R) -> % if R has FIELD
--R ?<? : (%,%) -> Boolean if R has ORDSET
--R ?<=? : (%,%) -> Boolean if R has ORDSET
--R ?>? : (%,%) -> Boolean if R has ORDSET
--R ?>=? : (%,%) -> Boolean if R has ORDSET
--R D : (%,(R -> R),NonNegativeInteger) -> %
--R D : (%,List(Symbol),List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R D : (%,Symbol,NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R D : (%,List(Symbol)) -> % if R has PDRING(SYMBOL)
--R D : (%,Symbol) -> % if R has PDRING(SYMBOL)
--R D : (%,NonNegativeInteger) -> % if R has DIFRING
--R D : (%,List(V),List(NonNegativeInteger)) -> %
--R D : (%,V,NonNegativeInteger) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R ?? : (R,%) -> %
--R ?? : (Integer,%) -> %
--R ??? : (%,PositiveInteger) -> %
--R -? : (%,%) -> %
--R ?=? : (%,%) -> Boolean
--R D : % -> % if R has DIFRING
--R D : (%,V) -> %
--R 0 : () -> %
--R coefficient : (%,E) -> R
--R coerce : S -> %
--R coerce : R -> %
--R coerce : % -> OutputForm
--R differentiate : (%,List(V)) -> %
--R eval : (%,List(V),List(%)) -> %
--R eval : (%,List(V),List(R)) -> %
--R eval : (%,%,%) -> %
--R ground : % -> R
--R hash : % -> SingleInteger
--R isobaric? : % -> Boolean
--R leader : % -> V
--R leadingMonomial : % -> %
--R mapExponents : ((E -> E),%) -> %
--R monomial : (R,E) -> %
--R monomials : % -> List(%)
--R order : % -> NonNegativeInteger
--R recip : % -> Union(%,"failed")
--R retract : % -> S
--R retract : % -> R
--R separant : % -> %
--R weight : % -> NonNegativeInteger
--R ?~=? : (%,%) -> Boolean

```

```

--R associates? : (% , %) -> Boolean if R has INTDOM
--R binomThmExpt : (% , %, NonNegativeInteger) -> % if R has COMRING
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if and(has($, CharacteristicNonZero), has(R, PolynomialFact
--R coefficient : (% , List(V), List(NonNegativeInteger)) -> %
--R coefficient : (% , V, NonNegativeInteger) -> %
--R coerce : % -> % if R has INTDOM
--R coerce : Fraction(Integer) -> % if R has RETRACT(FRAC(INT)) or R has ALGEBRA(FRAC(INT))
--R conditionP : Matrix(%) -> Union(Vector(%), "failed") if and(has($, CharacteristicNonZero), has(
--R content : (% , V) -> % if R has GCDDOM
--R content : % -> R if R has GCDDOM
--R convert : % -> InputForm if V has KONVERT(INFORM) and R has KONVERT(INFORM)
--R convert : % -> Pattern(Integer) if V has KONVERT(PATTERN(INT)) and R has KONVERT(PATTERN(INT
--R convert : % -> Pattern(Float) if V has KONVERT(PATTERN(FLOAT)) and R has KONVERT(PATTERN(FLO
--R degree : (% , S) -> NonNegativeInteger
--R degree : (% , List(V)) -> List(NonNegativeInteger)
--R degree : (% , V) -> NonNegativeInteger
--R differentialVariables : % -> List(S)
--R differentiate : (% , (R -> R)) -> %
--R differentiate : (% , (R -> R), NonNegativeInteger) -> %
--R differentiate : (% , List(Symbol), List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , Symbol, NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , List(Symbol)) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , Symbol) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , NonNegativeInteger) -> % if R has DIFRING
--R differentiate : % -> % if R has DIFRING
--R differentiate : (% , List(V), List(NonNegativeInteger)) -> %
--R differentiate : (% , V, NonNegativeInteger) -> %
--R discriminant : (% , V) -> % if R has COMRING
--R eval : (% , List(S), List(R)) -> % if R has DIFRING
--R eval : (% , S, R) -> % if R has DIFRING
--R eval : (% , List(S), List(%)) -> % if R has DIFRING
--R eval : (% , S, %) -> % if R has DIFRING
--R eval : (% , List(%), List(%)) -> %
--R eval : (% , List(Equation(%))) -> %
--R exquo : (% , %) -> Union(%, "failed") if R has INTDOM
--R exquo : (% , R) -> Union(%, "failed") if R has INTDOM
--R factor : % -> Factored(%) if R has PFECAT
--R factorPolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%))
--R factorSquareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolyn
--R gcd : (% , %) -> % if R has GCDDOM
--R gcd : List(%) -> % if R has GCDDOM
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUniva
--R isExpt : % -> Union(Record(var: V, exponent: NonNegativeInteger), "failed")
--R isPlus : % -> Union(List(%), "failed")
--R isTimes : % -> Union(List(%), "failed")
--R lcm : (% , %) -> % if R has GCDDOM
--R lcm : List(%) -> % if R has GCDDOM
--R mainVariable : % -> Union(V, "failed")
--R makeVariable : % -> (NonNegativeInteger -> %) if R has DIFRING

```

```

--R makeVariable : S -> (NonNegativeInteger -> %)
--R max : (%,%) -> % if R has ORDSET
--R min : (%,%) -> % if R has ORDSET
--R minimumDegree : (%,List(V)) -> List(NonNegativeInteger)
--R minimumDegree : (%,V) -> NonNegativeInteger
--R monicDivide : (%,%,V) -> Record(quotient: %,remainder: %)
--R monomial : (%,List(V),List(NonNegativeInteger)) -> %
--R monomial : (%,V,NonNegativeInteger) -> %
--R multivariate : (SparseUnivariatePolynomial(%),V) -> %
--R multivariate : (SparseUnivariatePolynomial(R),V) -> %
--R numberOfMonomials : % -> NonNegativeInteger
--R order : (%,S) -> NonNegativeInteger
--R patternMatch : (%,Pattern(Integer),PatternMatchResult(Integer,%)) -> PatternMatchResult(Integer,%) if V
--R patternMatch : (%,Pattern(Float),PatternMatchResult(Float,%)) -> PatternMatchResult(Float,%) if V has P
--R prime? : % -> Boolean if R has PFECAT
--R primitiveMonomials : % -> List(%)
--R primitivePart : (%,V) -> % if R has GCDDOM
--R primitivePart : % -> % if R has GCDDOM
--R reducedSystem : Matrix(%) -> Matrix(R)
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(R),vec: Vector(R))
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Integer),vec: Vector(Integer)) if R has LIN
--R reducedSystem : Matrix(%) -> Matrix(Integer) if R has LINEXP(INT)
--R resultant : (%,%,V) -> % if R has COMRING
--R retract : % -> Integer if R has RETRACT(INT)
--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(S,"failed")
--R retractIfCan : % -> Union(V,"failed")
--R retractIfCan : % -> Union(Integer,"failed") if R has RETRACT(INT)
--R retractIfCan : % -> Union(Fraction(Integer),"failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(R,"failed")
--R solveLinearPolynomialEquation : (List(SparseUnivariatePolynomial(%)),SparseUnivariatePolynomial(%)) -> U
--R squareFree : % -> Factored(%) if R has GCDDOM
--R squareFreePart : % -> % if R has GCDDOM
--R squareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%)) if R has
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R totalDegree : (%,List(V)) -> NonNegativeInteger
--R totalDegree : % -> NonNegativeInteger
--R unit? : % -> Boolean if R has INTDOM
--R unitCanonical : % -> % if R has INTDOM
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if R has INTDOM
--R univariate : % -> SparseUnivariatePolynomial(R)
--R univariate : (%,V) -> SparseUnivariatePolynomial(%)
--R weight : (%,S) -> NonNegativeInteger
--R weights : (%,S) -> List(NonNegativeInteger)
--R weights : % -> List(NonNegativeInteger)
--R
--E 1

```

```

)spool
)lisp (bye)

```

— DifferentialPolynomialCategory.help —

=====

DifferentialPolynomialCategory examples

=====

DifferentialPolynomialCategory is a category constructor specifying basic functions in an ordinary differential polynomial ring with a given ordered set of differential indeterminates. In addition, it implements defaults for the basic functions.

The functions `order` and `weight` are extended from the set of derivatives of differential indeterminates to the set of differential polynomials. Other operations provided on differential polynomials are `leader`, `initial`, `separant`, `differentialVariables`, and `isobaric?`. Furthermore, if the ground ring is a differential ring, then evaluation (substitution of differential indeterminates by elements of the ground ring or by differential polynomials) is provided by `eval`.

A convenient way of referencing derivatives is provided by the functions `makeVariable`.

To construct a domain using this constructor, one needs to provide a ground ring `R`, an ordered set `S` of differential indeterminates, a ranking `V` on the set of derivatives of the differential indeterminates, and a set `E` of exponents in bijection with the set of differential monomials in the given differential indeterminates.

See Also:

o `)show DifferentialPolynomialCategory`

See:

- ⇐ “DifferentialExtension” (DIFEXT) [11](#) on page [1005](#)
- ⇐ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)
- ⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

Exports:

| | | |
|----------------------------|-------------------------------|-----------------------|
| 0 | 1 | associates? |
| binomThmExpt | characteristic | charthRoot |
| coefficient | coefficients | coerce |
| conditionP | content | convert |
| D | degree | differentialVariables |
| differentiate | discriminant | eval |
| exquo | factor | factorPolynomial |
| factorSquareFreePolynomial | gcd | gcdPolynomial |
| ground | ground? | hash |
| initial | isExpt | isobaric? |
| isPlus | isTimes | latex |
| lcm | leader | leadingCoefficient |
| leadingMonomial | makeVariable | map |
| mapExponents | max | min |
| minimumDegree | monicDivide | monomial |
| monomial? | monomials | multivariate |
| numberOfMonomials | one? | order |
| patternMatch | pomopo! | prime? |
| primitiveMonomials | primitivePart | recip |
| reducedSystem | reductum | resultant |
| retract | retractIfCan | sample |
| separant | solveLinearPolynomialEquation | squareFree |
| squareFreePart | squareFreePolynomial | subtractIfCan |
| totalDegree | unit? | unitCanonical |
| unitNormal | univariate | variables |
| weight | weights | zero? |
| ?*? | ?**? | ?+? |
| ?-? | ~? | ?=? |
| ?^? | ?~=? | ?/? |
| ?<? | ?<=? | ?>? |
| ?>=? | | |

Attributes Exported:

-
- if R has `canonicalUnitNormal` then `canonicalUnitNormal` where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- if R has `IntegralDomain` then `noZeroDivisors` where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- if R has `CommutativeRing` then `commutative(“*”)` where **commutative(“*”)** is true if it has an operation “ $*$ ” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.

- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are implemented by this category:

```

coerce : S -> %
degree : (%,S) -> NonNegativeInteger
differentialVariables : % -> List S
differentiate : (%,(R -> R)) -> %
eval : (%,List S,List R) -> % if R has DIFRING
eval : (%,List S,List %) -> % if R has DIFRING
eval : (%,List Equation %) -> %
initial : % -> %
isobaric? : % -> Boolean
leader : % -> V
makeVariable : S -> (NonNegativeInteger -> %)
makeVariable : % -> (NonNegativeInteger -> %) if R has DIFRING
order : % -> NonNegativeInteger
order : (%,S) -> NonNegativeInteger
retractIfCan : % -> Union(S,"failed")
separant : % -> %
weight : % -> NonNegativeInteger
weight : (%,S) -> NonNegativeInteger
weights : (%,S) -> List NonNegativeInteger
weights : % -> List NonNegativeInteger

```

These exports come from (p1305) PolynomialCategory(R,E,V)
 where R:Ring, E:OrderedAbelianMonoidSup,
 V:DifferentialVariableCategory(S:OrderedSet):

```

0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean if R has INTDOM
binomThmExpt : (%,%,NonNegativeInteger) -> % if R has COMRING
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(%, "failed")
  if and(has($,CharacteristicNonZero),
    has(R,PolynomialFactorizationExplicit))
  or R has CHARNZ
coefficient : (%,List V,List NonNegativeInteger) -> %
coefficient : (%,V,NonNegativeInteger) -> %
coefficient : (%,E) -> R
coefficients : % -> List R
coerce : R -> %
coerce : Fraction Integer -> %
  if R has RETRACT FRAC INT
  or R has ALGEBRA FRAC INT

```

```

coerce : % -> % if R has INTDOM
coerce : Integer -> %
coerce : % -> OutputForm
coerce : V -> %
conditionP : Matrix % -> Union(Vector %, "failed")
    if and(has($, CharacteristicNonZero),
        has(R, PolynomialFactorizationExplicit))
content : % -> R if R has GCDDOM
content : (% , V) -> % if R has GCDDOM
convert : % -> Pattern Integer
    if V has KONVERT PATTERN INT
    and R has KONVERT PATTERN INT
convert : % -> Pattern Float
    if V has KONVERT PATTERN FLOAT
    and R has KONVERT PATTERN FLOAT
convert : % -> InputForm
    if V has KONVERT INFORM
    and R has KONVERT INFORM
D : (% , List V) -> %
D : (% , V) -> %
D : (% , List V, List NonNegativeInteger) -> %
D : (% , V, NonNegativeInteger) -> %
degree : % -> E
degree : (% , List V) -> List NonNegativeInteger
degree : (% , V) -> NonNegativeInteger
differentiate : (% , V) -> %
differentiate : (% , List V, List NonNegativeInteger) -> %
differentiate : (% , V, NonNegativeInteger) -> %
differentiate : (% , List V) -> %
discriminant : (% , V) -> % if R has COMRING
eval : (% , Equation %) -> %
eval : (% , List % , List %) -> %
eval : (% , % , %) -> %
eval : (% , List V, List R) -> %
eval : (% , V, R) -> %
eval : (% , List V, List %) -> %
eval : (% , V, %) -> %
exquo : (% , %) -> Union(% , "failed") if R has INTDOM
exquo : (% , R) -> Union(% , "failed") if R has INTDOM
factor : % -> Factored % if R has PFECAT
factorPolynomial :
    SparseUnivariatePolynomial % ->
        Factored SparseUnivariatePolynomial %
        if R has PFECAT
factorSquareFreePolynomial :
    SparseUnivariatePolynomial % ->
        Factored SparseUnivariatePolynomial %
        if R has PFECAT
gcd : (% , %) -> % if R has GCDDOM
gcd : List % -> % if R has GCDDOM

```

```

gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
    if R has GCDDOM
ground : % -> R
ground? : % -> Boolean
hash : % -> SingleInteger
isExpt : % ->
  Union(Record(var: V,exponent: NonNegativeInteger),"failed")
isPlus : % -> Union(List %,"failed")
isTimes : % -> Union(List %,"failed")
latex : % -> String
lcm : (%,% ) -> % if R has GCDDOM
lcm : List % -> % if R has GCDDOM
leadingCoefficient : % -> R
leadingMonomial : % -> %
mainVariable : % -> Union(V,"failed")
map : ((R -> R),%) -> %
mapExponents : ((E -> E),%) -> %
max : (%,% ) -> % if R has ORDSET
min : (%,% ) -> % if R has ORDSET
minimumDegree : % -> E
minimumDegree : (%,List V) -> List NonNegativeInteger
minimumDegree : (% ,V) -> NonNegativeInteger
monicDivide : (%,% ,V) -> Record(quotient: %,remainder: %)
monomial : (% ,V,NonNegativeInteger) -> %
monomial : (% ,List V,List NonNegativeInteger) -> %
monomial : (R,E) -> %
monomial? : % -> Boolean
monomials : % -> List %
multivariate : (SparseUnivariatePolynomial %,V) -> %
multivariate : (SparseUnivariatePolynomial R,V) -> %
numberOfMonomials : % -> NonNegativeInteger
one? : % -> Boolean
patternMatch :
  (% ,Pattern Integer,PatternMatchResult(Integer,%)) ->
    PatternMatchResult(Integer,%)
    if V has PATMAB INT
    and R has PATMAB INT
patternMatch :
  (% ,Pattern Float,PatternMatchResult(Float,%)) ->
    PatternMatchResult(Float,%)
    if V has PATMAB FLOAT
    and R has PATMAB FLOAT
pomopo! : (% ,R,E,% ) -> %
prime? : % -> Boolean if R has PFECAT
primitiveMonomials : % -> List %
primitivePart : (% ,V) -> % if R has GCDDOM
primitivePart : % -> % if R has GCDDOM

```

```

recip : % -> Union(%, "failed")
reducedSystem : Matrix % -> Matrix R
reducedSystem :
  (Matrix %, Vector %) -> Record(mat: Matrix R, vec: Vector R)
reducedSystem :
  (Matrix %, Vector %) ->
    Record(mat: Matrix Integer, vec: Vector Integer)
    if R has LINEXP INT
reducedSystem : Matrix % -> Matrix Integer
  if R has LINEXP INT
reductum : % -> %
resultant : (%, %, V) -> % if R has COMRING
retract : % -> R
retract : % -> Integer if R has RETRACT INT
retract : % -> Fraction Integer if R has RETRACT FRAC INT
retract : % -> V
retractIfCan : % -> Union(R, "failed")
retractIfCan : % -> Union(Integer, "failed")
  if R has RETRACT INT
retractIfCan : % -> Union(Fraction Integer, "failed")
  if R has RETRACT FRAC INT
retractIfCan : % -> Union(V, "failed")
sample : () -> %
solveLinearPolynomialEquation :
  (List SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    Union(List SparseUnivariatePolynomial %, "failed")
    if R has PFECAT
squareFree : % -> Factored % if R has GCDDOM
squareFreePart : % -> % if R has GCDDOM
squareFreePolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if R has PFECAT
subtractIfCan : (%, %) -> Union(%, "failed")
totalDegree : (%, List V) -> NonNegativeInteger
totalDegree : % -> NonNegativeInteger
unit? : % -> Boolean if R has INTDOM
unitCanonical : % -> % if R has INTDOM
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
  if R has INTDOM
univariate : % -> SparseUnivariatePolynomial R
univariate : (%, V) -> SparseUnivariatePolynomial %
variables : % -> List V
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (%, R) -> %
?*? : (R, %) -> %

```

```

?? : (Fraction Integer,%) -> % if R has ALGEBRA FRAC INT
?? : (%,Fraction Integer) -> % if R has ALGEBRA FRAC INT
?? : (%,%) -> %
?? : (Integer,%) -> %
?? : (PositiveInteger,%) -> %
?? : (NonNegativeInteger,%) -> %
?/? : (%,R) -> % if R has FIELD
?-? : (%,%) -> %
-? : % -> %
?? : (%,NonNegativeInteger) -> %
?? : (%,PositiveInteger) -> %
?<? : (%,%) -> Boolean if R has ORDSET
?<=? : (%,%) -> Boolean if R has ORDSET
?>? : (%,%) -> Boolean if R has ORDSET
?>=? : (%,%) -> Boolean if R has ORDSET
*** : (%,PositiveInteger) -> %
*** : (%,NonNegativeInteger) -> %

```

These exports come from (p1005) DifferentialExtension(R:Ring):

```

D : (%,(R -> R)) -> %
D : (%,(R -> R),NonNegativeInteger) -> %
D : % -> % if R has DIFRING
D : (%,NonNegativeInteger) -> % if R has DIFRING
D : (%,Symbol) -> % if R has PDRING SYMBOL
D : (%,List Symbol) -> % if R has PDRING SYMBOL
D : (%,Symbol,NonNegativeInteger) -> %
    if R has PDRING SYMBOL
D : (%,List Symbol,List NonNegativeInteger) -> %
    if R has PDRING SYMBOL
differentiate : (%,NonNegativeInteger) -> %
    if R has DIFRING
differentiate : (%,List Symbol) -> %
    if R has PDRING SYMBOL
differentiate : (%,Symbol,NonNegativeInteger) -> %
    if R has PDRING SYMBOL
differentiate : (%,List Symbol,List NonNegativeInteger) -> %
    if R has PDRING SYMBOL
differentiate : % -> % if R has DIFRING
differentiate : (%,(R -> R),NonNegativeInteger) -> %
differentiate : (%,Symbol) -> % if R has PDRING SYMBOL

```

These exports come from (p95) RetractableTo(S:OrderedSet):

```

retract : % -> S

```

These exports come from (p56) InnerEvalable(S,R)
where S:OrderedSet, R:Ring:

```

eval : (%,S,R) -> % if R has DIFRING

```

These exports come from (p56) InnerEvalable(S, where S:OrderedSet,

```
eval : (% , S , %) -> % if R has DIFRING
```

These exports come from (p129) Evalable(

— category DPOLCAT DifferentialPolynomialCategory —

```
)abbrev category DPOLCAT DifferentialPolynomialCategory
++ Author: William Sit
++ Date Created: 19 July 1990
++ Date Last Updated: 13 September 1991
++ References: Kolchin, E.R. "Differential Algebra and Algebraic Groups"
++ (Academic Press, 1973).
++ Description:
++ \spadtype{DifferentialPolynomialCategory} is a category constructor
++ specifying basic functions in an ordinary differential polynomial
++ ring with a given ordered set of differential indeterminates.
++ In addition, it implements defaults for the basic functions.
++ The functions \spadfun{order} and \spadfun{weight} are extended
++ from the set of derivatives of differential indeterminates
++ to the set of differential polynomials. Other operations
++ provided on differential polynomials are
++ \spadfun{leader}, \spadfun{initial},
++ \spadfun{separant}, \spadfun{differentialVariables}, and
++ \spadfun{isobaric?}. Furthermore, if the ground ring is
++ a differential ring, then evaluation (substitution
++ of differential indeterminates by elements of the ground ring
++ or by differential polynomials) is
++ provided by \spadfun{eval}.
++ A convenient way of referencing derivatives is provided by
++ the functions \spadfun{makeVariable}.
++
++ To construct a domain using this constructor, one needs
++ to provide a ground ring R, an ordered set S of differential
++ indeterminates, a ranking V on the set of derivatives
++ of the differential indeterminates, and a set E of
++ exponents in bijection with the set of differential monomials
++ in the given differential indeterminates.

DifferentialPolynomialCategory(R:Ring, S:OrderedSet,
  V:DifferentialVariableCategory S, E:OrderedAbelianMonoidSup):
  Category ==
  Join(PolynomialCategory(R, E, V),
    DifferentialExtension R, RetractableTo S) with
  -- Examples:
```

```

-- s:=makeVariable('s)
-- p:= 3*(s 1)**2 + s*(s 2)**3
-- all functions below have default implementations
-- using primitives from V

makeVariable: S -> (NonNegativeInteger -> $)
  ++ makeVariable(s) views s as a differential
  ++ indeterminate, in such a way that the n-th
  ++ derivative of s may be simply referenced as z.n
  ++ where z :=makeVariable(s).
  ++ Note that In the interpreter, z is
  ++ given as an internal map, which may be ignored.
  -- Example: makeVariable('s); %.5

differentialVariables: $ -> List S
  ++ differentialVariables(p) returns a list of differential
  ++ indeterminates occurring in a differential polynomial p.
order : ($, S) -> NonNegativeInteger
  ++ order(p,s) returns the order of the differential
  ++ polynomial p in differential indeterminate s.
order : $ -> NonNegativeInteger
  ++ order(p) returns the order of the differential polynomial p,
  ++ which is the maximum number of differentiations of a
  ++ differential indeterminate, among all those appearing in p.
degree: ($, S) -> NonNegativeInteger
  ++ degree(p, s) returns the maximum degree of
  ++ the differential polynomial p viewed as a differential polynomial
  ++ in the differential indeterminate s alone.
weights: $ -> List NonNegativeInteger
  ++ weights(p) returns a list of weights of differential monomials
  ++ appearing in differential polynomial p.
weight: $ -> NonNegativeInteger
  ++ weight(p) returns the maximum weight of all differential monomials
  ++ appearing in the differential polynomial p.
weights: ($, S) -> List NonNegativeInteger
  ++ weights(p, s) returns a list of
  ++ weights of differential monomials
  ++ appearing in the differential polynomial p when p is viewed
  ++ as a differential polynomial in the differential indeterminate s
  ++ alone.
weight: ($, S) -> NonNegativeInteger
  ++ weight(p, s) returns the maximum weight of all differential
  ++ monomials appearing in the differential polynomial p
  ++ when p is viewed as a differential polynomial in
  ++ the differential indeterminate s alone.
isobaric?: $ -> Boolean
  ++ isobaric?(p) returns true if every differential monomial appearing
  ++ in the differential polynomial p has same weight,
  ++ and returns false otherwise.
leader: $ -> V

```

```

    ++ leader(p) returns the derivative of the highest rank
    ++ appearing in the differential polynomial p
    ++ Note that an error occurs if p is in the ground ring.
initial:$ -> $
    ++ initial(p) returns the
    ++ leading coefficient when the differential polynomial p
    ++ is written as a univariate polynomial in its leader.
separant:$ -> $
    ++ separant(p) returns the
    ++ partial derivative of the differential polynomial p
    ++ with respect to its leader.
if R has DifferentialRing then
    InnerEvalable(S, R)
    InnerEvalable(S, $)
    Evalable $
    makeVariable: $ -> (NonNegativeInteger -> $)
    ++ makeVariable(p) views p as an element of a differential
    ++ ring, in such a way that the n-th
    ++ derivative of p may be simply referenced as z.n
    ++ where z := makeVariable(p).
    ++ Note that In the interpreter, z is
    ++ given as an internal map, which may be ignored.
    -- Example: makeVariable(p); %.5; makeVariable(%**2); %.2

add
    p:$
    s:S

    makeVariable s == n +-> makeVariable(s,n):: $

    if R has IntegralDomain then
        differentiate(p:$, d:R -> R) ==
            ans:$ := 0
            l := variables p
            while (u:=retractIfCan(p)@Union(R, "failed")) case "failed" repeat
                t := leadingMonomial p
                lc := leadingCoefficient t
                ans := ans + d(lc):: $ * (t exquo lc):: $
                    + +/[differentiate(t, v) * (differentiate v):: $ for v in l]
                p := reductum p
            ans + d(u::R):: $

    order (p:$):NonNegativeInteger ==
        ground? p => 0
        "max"/[order v for v in variables p]

    order (p:$,s:S):NonNegativeInteger ==
        ground? p => 0
        empty? (vv:= [order v for v in variables p | (variable v) = s ]) =>0
        "max"/vv

```



```

degree (p, s) ==
  d:NonNegativeInteger:=0
  for lp in monomials p repeat
    lv:= [v for v in variables lp | (variable v) = s ]
    if not empty? lv then d:= max(d, +/degree(lp, lv))
  d

weights p ==
  ws:List NonNegativeInteger := nil
  empty? (mp:=monomials p) => ws
  for lp in mp repeat
    lv:= variables lp
    if not empty? lv then
      dv:= degree(lp, lv)
      w:=+/(weight v) * d _
        for v in lv for d in dv]$(List NonNegativeInteger)
      ws:= concat(ws, w)
  ws

weight p ==
  empty? (ws:=weights p) => 0
  "max"/ws

weights (p, s) ==
  ws:List NonNegativeInteger := nil
  empty?(mp:=monomials p) => ws
  for lp in mp repeat
    lv:= [v for v in variables lp | (variable v) = s ]
    if not empty? lv then
      dv:= degree(lp, lv)
      w:=+/(weight v) * d _
        for v in lv for d in dv]$(List NonNegativeInteger)
      ws:= concat(ws, w)
  ws

weight (p,s) ==
  empty? (ws:=weights(p,s)) => 0
  "max"/ws

isobaric? p == (# removeDuplicates weights p) = 1

leader p ==          -- depends on the ranking
  vl:= variables p
  -- it's not enough just to look at leadingMonomial p
  -- the term-ordering need not respect the ranking
  empty? vl => error "leader is not defined "
  "max"/vl

initial p == leadingCoefficient univariate(p,leader p)

```

```

separant p == differentiate(p, leader p)

coerce(s:S):$ == s::V:::$

retractIfCan(p:$):Union(S, "failed") ==
  (v := retractIfCan(p)@Union(V,"failed")) case "failed" => "failed"
  retractIfCan(v::V)

differentialVariables p ==
  removeDuplicates [variable v for v in variables p]

if R has DifferentialRing then

  makeVariable p == n +-> differentiate(p, n)

  eval(p:$, sl:List S, rl:List R) ==
    ordp:= order p
    vl := concat [[makeVariable(s,j)$V for j in 0..ordp]
                  for s in sl]$List(List V)
    rrl:=nil$List(R)
    for r in rl repeat
      t:= r
      rrl:= concat(rrl,
                  concat(r, [t := differentiate t for i in 1..ordp]))
    eval(p, vl, rrl)

  eval(p:$, sl:List S, rl:List $) ==
    ordp:= order p
    vl := concat [[makeVariable(s,j)$V for j in 0..ordp]
                  for s in sl]$List(List V)
    rrl:=nil$List($)
    for r in rl repeat
      t:=r
      rrl:=concat(rrl,
                  concat(r, [t:=differentiate t for i in 1..ordp]))
    eval(p, vl, rrl)

  eval(p:$, l:List Equation $) ==
    eval(p, [retract(lhs e)@S for e in l]$List(S),
          [rhs e for e in l]$List($))

```

— DPOLCAT.dotabb —

"DPOLCAT"

[color=lightblue,href="bookvol10.2.pdf#nameddest=DPOLCAT"];

```

"DPOLCAT" -> "DIFEXT"
"DPOLCAT" -> "POLYCAT"
"DPOLCAT" -> "RETRACT"

```

— DPOLCAT.dotfull —

```

"DifferentialPolynomialCategory(a:Ring,b:OrderedSet,c:DifferentialVariableCategory(b),d:OrderedA
[ color=lightblue,href="bookvol10.2.pdf#nameddest=DPOLCAT" ] ;
"DifferentialPolynomialCategory(a:Ring,b:OrderedSet,c:DifferentialVariableCategory(b),d:OrderedA
-> "DifferentialExtension(a:Ring)"
"DifferentialPolynomialCategory(a:Ring,b:OrderedSet,c:DifferentialVariableCategory(b),d:OrderedA
-> "PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
"DifferentialPolynomialCategory(a:Ring,b:OrderedSet,c:DifferentialVariableCategory(b),d:OrderedA
-> "RetractableTo(OrderedSet)"

```

— DPOLCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

"DifferentialPolynomialCategory(a:Ring,b:OrderedSet,c:DifferentialVariableCategory(b),d:OrderedA
[ color=lightblue ];

"DifferentialPolynomialCategory(a:Ring,b:OrderedSet,c:DifferentialVariableCategory(b),d:OrderedA
-> "DifferentialExtension(a:Ring)"

"DifferentialPolynomialCategory(a:Ring,b:OrderedSet,c:DifferentialVariableCategory(b),d:OrderedA
-> "PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"

"DifferentialPolynomialCategory(a:Ring,b:OrderedSet,c:DifferentialVariableCategory(b),d:OrderedA
-> "RetractableTo(OrderedSet)"

"DifferentialExtension(a:Ring)"
[ color=lightblue,href="bookvol10.2.pdf#nameddest=DIFEXT" ];
"DifferentialExtension(a:Ring)" -> "RING..."
"DifferentialExtension(a:Ring)" -> "DIFRING..."
"DifferentialExtension(a:Ring)" -> "PDRING..."

"RetractableTo(OrderedSet)"
[ color=seagreen,href="bookvol10.2.pdf#nameddest=RETRACT" ];

```

```

"RetractableTo(OrderedSet)" -> "RETRACT..."

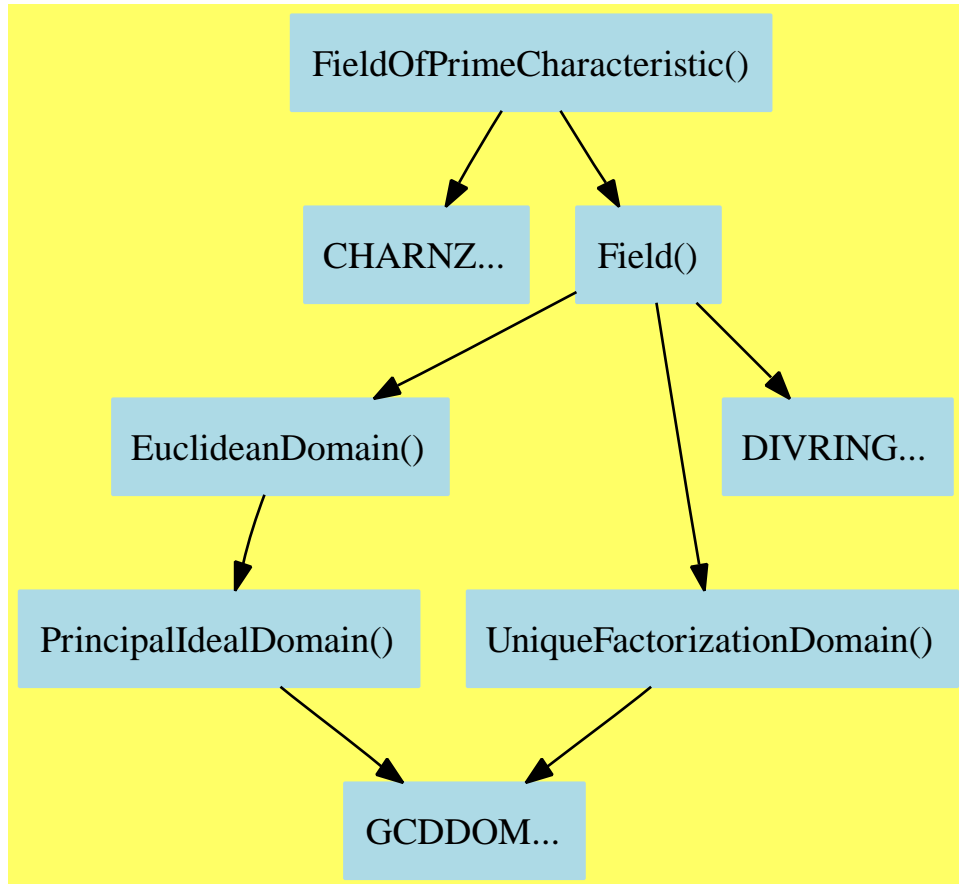
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=POLYCAT"];
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "PDRING..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "FAMR..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "EVALAB..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "IEVALAB..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "RETRACT..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "FLINEXP..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "ORDSET..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "GCDDOM..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  -> "PFECAT..."

"DIFRING..." [color=lightblue];
"RING..." [color=lightblue];
"PDRING..." [color=lightblue];
"FAMR..." [color=lightblue];
"EVALAB..." [color=lightblue];
"IEVALAB..." [color=lightblue];
"RETRACT..." [color=lightblue];
"FLINEXP..." [color=lightblue];
"ORDSET..." [color=lightblue];
"GCDDOM..." [color=lightblue];
"PFECAT..." [color=lightblue];

}

```

FieldOfPrimeCharacteristic (FPC)



— FieldOfPrimeCharacteristic.input —

```

)set break resume
)sys rm -f FieldOfPrimeCharacteristic.output
)spool FieldOfPrimeCharacteristic.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FieldOfPrimeCharacteristic
--R
--R FieldOfPrimeCharacteristic is a category constructor
--R Abbreviation for FieldOfPrimeCharacteristic is FPC
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FPC
--R
--R----- Operations -----
--R ??? : (Fraction(Integer),%) -> %      ??? : (%,Fraction(Integer)) -> %
--R ??? : (%,%) -> %                      ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %        ??? : (%,Integer) -> %
--R ??? : (%,PositiveInteger) -> %        ?+? : (%,%) -> %
--R ?-? : (%,%) -> %                      -? : % -> %
--R ?/? : (%,%) -> %                      ?=? : (%,%) -> Boolean
--R 1 : () -> %                           0 : () -> %
--R ?? : (%,Integer) -> %                  ?? : (%,PositiveInteger) -> %
--R associates? : (%,%) -> Boolean         coerce : Fraction(Integer) -> %
--R coerce : % -> %                       coerce : Integer -> %
--R coerce : % -> OutputForm              factor : % -> Factored(%)
--R gcd : List(%) -> %                    gcd : (%,%) -> %
--R hash : % -> SingleInteger              inv : % -> %
--R latex : % -> String                   lcm : List(%) -> %
--R lcm : (%,%) -> %                      one? : % -> Boolean
--R prime? : % -> Boolean                  primeFrobenius : % -> %
--R ?quo? : (%,%) -> %                    recip : % -> Union(%, "failed")
--R ?rem? : (%,%) -> %                    sample : () -> %
--R sizeLess? : (%,%) -> Boolean           squareFree : % -> Factored(%)
--R squareFreePart : % -> %                unit? : % -> Boolean
--R unitCanonical : % -> %                 zero? : % -> Boolean
--R ?^=? : (%,%) -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed")
--R discreteLog : (%,%) -> Union(NonNegativeInteger, "failed")
--R divide : (%,%) -> Record(quotient: %, remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%), "failed")
--R exquo : (%,%) -> Union(%, "failed")
--R extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
--R extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R multiEuclidean : (List(%),%) -> Union(List(%), "failed")
--R order : % -> OnePointCompletion(PositiveInteger)
--R primeFrobenius : (%,NonNegativeInteger) -> %
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— FieldOfPrimeCharacteristic.help —

```
=====
FieldOfPrimeCharacteristic examples
=====
```

FieldOfPrimeCharacteristic is the category of fields of prime characteristic, e.g. finite fields, algebraic closures of fields of prime characteristic, transcendental extensions of fields of prime characteristic.

See Also:

o)show FieldOfPrimeCharacteristic

See:

⇒ “FiniteFieldCategory” (FFIELDC) [18](#) on page [1570](#)
 ⇐ “CharacteristicNonZero” (CHARNZ) [10](#) on page [887](#)
 ⇐ “Field” (FIELD) [16](#) on page [1271](#)

Exports:

| | | | |
|----------------|--------------------|---------------|-------------------|
| 0 | 1 | associates? | characteristic |
| charthRoot | coerce | discreteLog | divide |
| euclideanSize | expressIdealMember | exquo | extendedEuclidean |
| factor | gcd | gcdPolynomial | hash |
| inv | latex | lcm | multiEuclidean |
| one? | order | prime? | primeFrobenius |
| principalIdeal | recip | sample | sizeLess? |
| squareFree | squareFreePart | subtractIfCan | unit? |
| unitCanonical | unitNormal | zero? | ?*? |
| ?**? | ?+? | ?-? | -? |
| ?/? | ?=? | ?^? | ?rem? |
| ?quo? | ?~=? | | |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **canonicalsClosed** is true if `unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**("*") is true if it has an operation " $*$ " : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return "failed" if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
order : % -> OnePointCompletion PositiveInteger
discreteLog : (%,%) -> Union(NonNegativeInteger,"failed")
```

These are implemented by this category:

```
primeFrobenius : % -> %
primeFrobenius : (%,NonNegativeInteger) -> %
```

These exports come from (p1271) Field():

```
0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
coerce : Fraction Integer -> %
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %, "failed")
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
exquo : (%,%) -> Union(%, "failed")
factor : % -> Factored %
gcd : (%,%) -> %
gcd : List % -> %
gcdPolynomial : (SparseUnivariatePolynomial %,
                  SparseUnivariatePolynomial %) ->
                  SparseUnivariatePolynomial %
hash : % -> SingleInteger
inv : % -> %
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
multiEuclidean : (List %,%) -> Union(List %, "failed")
```



```

one? : % -> Boolean
prime? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%, "failed")
sample : () -> %
sizeLess? : (%,%) -> Boolean
squareFree : % -> Factored %
squareFreePart : % -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (Fraction Integer,%) -> %
?*? : (%,Fraction Integer) -> %
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
?*?* : (%,Integer) -> %
?*?* : (%,PositiveInteger) -> %
?*?* : (%,NonNegativeInteger) -> %
?^? : (%,PositiveInteger) -> %
?^? : (%,NonNegativeInteger) -> %
?^? : (%,Integer) -> %
?/? : (%,%) -> %
?quo? : (%,%) -> %
?rem? : (%,%) -> %

```

These exports come from (p887) `CharacteristicNonZero()`:

```

charthRoot : % -> Union(%, "failed")

```

— category FPC FieldOfPrimeCharacteristic —

```

)abbrev category FPC FieldOfPrimeCharacteristic
++ Author: J. Grabmeier, A. Scheerhorn
++ Date Created: 10 March 1991
++ Date Last Updated: 31 March 1991
++ References:
++ J. Grabmeier, A. Scheerhorn: Finite Fields in AXIOM.
++ AXIOM Technical Report Series, ATR/5 NP2522.
++ Description:
++ FieldOfPrimeCharacteristic is the category of fields of prime

```

```

++ characteristic, e.g. finite fields, algebraic closures of
++ fields of prime characteristic, transcendental extensions of
++ of fields of prime characteristic.

```

```

FieldOfPrimeCharacteristic:Category == _
Join(Field,CharacteristicNonZero) with
  order: $ -> OnePointCompletion PositiveInteger
    ++ order(a) computes the order of an element in the multiplicative
    ++ group of the field.
    ++ Error: if \spad{a} is 0.
discreteLog: ($,$) -> Union(NonNegativeInteger,"failed")
  ++ discreteLog(b,a) computes s with \spad{b**s = a} if such an s exists.
primeFrobenius: $ -> $
  ++ primeFrobenius(a) returns \spad{a**p} where p is the characteristic.
primeFrobenius: ($,NonNegativeInteger) -> $
  ++ primeFrobenius(a,s) returns \spad{a**(p**s)} where p
  ++ is the characteristic.
add
  primeFrobenius(a) == a ** characteristic()
  primeFrobenius(a,s) == a ** (characteristic()**s)

```

— FPC.dotabb —

```

"FPC"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FPC"];
"FPC" -> "CHARNZ"
"FPC" -> "FIELD"

```

— FPC.dotfull —

```

"FieldOfPrimeCharacteristic()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FPC"];
"FieldOfPrimeCharacteristic()" -> "CharacteristicNonZero()"

```

— FPC.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";

```

```

node [shape=box, color=white, style=filled];

"FieldOfPrimeCharacteristic()" [color=lightblue];
"FieldOfPrimeCharacteristic()" -> "CHARNZ..."
"FieldOfPrimeCharacteristic()" -> "Field()"

"Field()" [color=lightblue];
"Field()" -> "EuclideanDomain()"
"Field()" -> "UniqueFactorizationDomain()"
"Field()" -> "DIVRING..."

"EuclideanDomain()" [color=lightblue];
"EuclideanDomain()" -> "PrincipalIdealDomain()"

"UniqueFactorizationDomain()" [color=lightblue];
"UniqueFactorizationDomain()" -> "GCDDOM..."

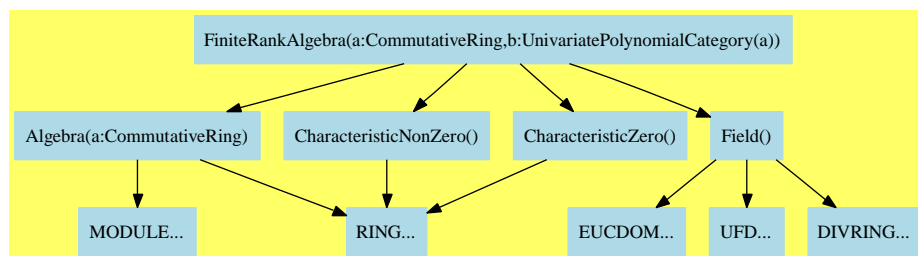
"PrincipalIdealDomain()" [color=lightblue];
"PrincipalIdealDomain()" -> "GCDDOM..."

"GCDDOM..." [color=lightblue];
"DIVRING..." [color=lightblue];
"CHARNZ..." [color=lightblue];
}

```

→

FiniteRankAlgebra (FINRALG)



— FiniteRankAlgebra.input —

```

)set break resume
)sys rm -f FiniteRankAlgebra.output
)spool FiniteRankAlgebra.output
)set message test on

```

```

)set message auto off
)clear all

--S 1 of 1
)show FiniteRankAlgebra
--R
--R FiniteRankAlgebra(R: CommutativeRing,UP: UnivariatePolynomialCategory(t#1)) is a category constructor
--R Abbreviation for FiniteRankAlgebra is FINRALG
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FINRALG
--R
--R----- Operations -----
--R ?? : (R,%) -> %           ?? : (% ,R) -> %
--R ?? : (% ,%) -> %         ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (% ,PositiveInteger) -> %
--R ?? : (% ,%) -> %         ?-? : (% ,%) -> %
--R -? : % -> %              ?=? : (% ,%) -> Boolean
--R 1 : () -> %              0 : () -> %
--R ?? : (% ,PositiveInteger) -> %   coerce : R -> %
--R coerce : Integer -> %           coerce : % -> OutputForm
--R discriminant : Vector(%) -> R     hash : % -> SingleInteger
--R latex : % -> String              norm : % -> R
--R one? : % -> Boolean              rank : () -> PositiveInteger
--R recip : % -> Union(%, "failed")   sample : () -> %
--R trace : % -> R                  zero? : % -> Boolean
--R ?^=? : (% ,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ?? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R characteristicPolynomial : % -> UP
--R charthRoot : % -> Union(%, "failed") if R has CHARNZ
--R coordinates : (Vector(%),Vector(%)) -> Matrix(R)
--R coordinates : (% ,Vector(%)) -> Vector(R)
--R minimalPolynomial : % -> UP if R has FIELD
--R regularRepresentation : (% ,Vector(%)) -> Matrix(R)
--R represents : (Vector(R),Vector(%)) -> %
--R subtractIfCan : (% ,%) -> Union(%, "failed")
--R traceMatrix : Vector(%) -> Matrix(R)
--R
--E 1

)spool
)lisp (bye)

```

```
=====
FiniteRankAlgebra examples
=====
```

A `FiniteRankAlgebra` is an algebra over a commutative ring `R` which is a free `R`-module of finite rank.

See Also:

o `)show FiniteRankAlgebra`

See:

⇒ “FramedAlgebra” (FRAMALG) [18](#) on page [1591](#)
 ⇐ “Algebra” (ALGEBRA) [11](#) on page [999](#)
 ⇐ “CharacteristicNonZero” (CHARNZ) [10](#) on page [887](#)
 ⇐ “CharacteristicZero” (CHARZ) [10](#) on page [892](#)
 ⇐ “Field” (FIELD) [16](#) on page [1271](#)

Exports:

| | | |
|---------------------------------------|--------------------------------|-----------------------------|
| <code>0</code> | <code>1</code> | <code>characteristic</code> |
| <code>characteristicPolynomial</code> | <code>charthRoot</code> | <code>coerce</code> |
| <code>coordinates</code> | <code>discriminant</code> | <code>hash</code> |
| <code>latex</code> | <code>minimalPolynomial</code> | <code>norm</code> |
| <code>one?</code> | <code>rank</code> | <code>recip</code> |
| <code>regularRepresentation</code> | <code>represents</code> | <code>sample</code> |
| <code>subtractIfCan</code> | <code>trace</code> | <code>traceMatrix</code> |
| <code>zero?</code> | <code>?*?</code> | <code>?**?</code> |
| <code>?+?</code> | <code>?-?</code> | <code>-?</code> |
| <code>?=?</code> | <code>?^?</code> | <code>?~=?</code> |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
characteristicPolynomial : % -> UP
coordinates : (% , Vector %) -> Vector R
minimalPolynomial : % -> UP if R has FIELD
norm : % -> R
```

```
rank : () -> PositiveInteger
trace : % -> R
```

These are implemented by this category:

```
coordinates : (Vector %,Vector %) -> Matrix R
discriminant : Vector % -> R
regularRepresentation : (%,Vector %) -> Matrix R
represents : (Vector R,Vector %) -> %
traceMatrix : Vector % -> Matrix R
```

These exports come from (p999) Algebra(R:CommutativeRing):

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
?*?* : (%,PositiveInteger) -> %
?*?* : (%,NonNegativeInteger) -> %
?^? : (%,PositiveInteger) -> %
?^? : (%,NonNegativeInteger) -> %
```

These exports come from (p1271) Field():

```
coerce : R -> %
?*? : (R,%) -> %
?*? : (%,R) -> %
```

These exports come from (p887) CharacteristicNonZero():

```
charthRoot : % -> Union(%, "failed") if R has CHARNZ
```

These exports come from (p892) CharacteristicZero():

— category FINRALG FiniteRankAlgebra —

```

)abbrev category FINRALG FiniteRankAlgebra
++ Author: Barry Trager
++ Description:
++ A FiniteRankAlgebra is an algebra over a commutative ring R which
++ is a free R-module of finite rank.

FiniteRankAlgebra(R:CommutativeRing, UP:UnivariatePolynomialCategory R):
Category == Algebra R with
  rank                : () -> PositiveInteger
  ++ rank() returns the rank of the algebra.
  regularRepresentation : (% , Vector %) -> Matrix R
  ++ regularRepresentation(a,basis) returns the matrix of the
  ++ linear map defined by left multiplication by \spad{a} with respect
  ++ to the basis \spad{basis}.
  trace                : % -> R
  ++ trace(a) returns the trace of the regular representation
  ++ of \spad{a} with respect to any basis.
  norm                  : % -> R
  ++ norm(a) returns the determinant of the regular representation
  ++ of \spad{a} with respect to any basis.
  coordinates           : (% , Vector %) -> Vector R
  ++ coordinates(a,basis) returns the coordinates of \spad{a} with
  ++ respect to the basis \spad{basis}.
  coordinates           : (Vector %, Vector %) -> Matrix R
  ++ coordinates([v1,...,vm], basis) returns the coordinates of the
  ++ vi's with to the basis \spad{basis}. The coordinates of vi are
  ++ contained in the ith row of the matrix returned by this
  ++ function.
  represents            : (Vector R, Vector %) -> %
  ++ represents([a1,...,an],[v1,...,vn]) returns \spad{a1*v1+...+an*vn}.
  discriminant          : Vector % -> R
  ++ discriminant([v1,...,vn]) returns
  ++ \spad{determinant(traceMatrix([v1,...,vn]))}.
  traceMatrix           : Vector % -> Matrix R
  ++ traceMatrix([v1,...,vn]) is the n-by-n matrix ( Tr(vi * vj) )
  characteristicPolynomial: % -> UP
  ++ characteristicPolynomial(a) returns the characteristic
  ++ polynomial of the regular representation of \spad{a} with respect
  ++ to any basis.
  if R has Field then minimalPolynomial : % -> UP
  ++ minimalPolynomial(a) returns the minimal polynomial of \spad{a}.
  if R has CharacteristicZero then CharacteristicZero
  if R has CharacteristicNonZero then CharacteristicNonZero

add

```

```

discriminant v == determinant traceMatrix v

coordinates(v:Vector %, b:Vector %) ==
  m := new(#v, #b, 0)$Matrix(R)
  for i in minIndex v .. maxIndex v for j in minRowIndex m .. repeat
    setRow_!(m, j, coordinates(qelt(v, i), b))
  m

represents(v, b) ==
  m := minIndex v - 1
  _+/[v(i+m) * b(i+m) for i in 1..rank()]

traceMatrix v ==
  matrix [[trace(v.i*v.j) for j in minIndex v..maxIndex v]$List(R)
    for i in minIndex v .. maxIndex v]$List(List R)

regularRepresentation(x, b) ==
  m := minIndex b - 1
  matrix
    [parts coordinates(x*b(i+m),b) for i in 1..rank()]$List(List R)

```

— FINRAlg.dotabb —

```

"FINRAlg"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FINRAlg"];
"FINRAlg" -> "ALGEBRA"
"FINRAlg" -> "FIELD"
"FINRAlg" -> "CHARNZ"
"FINRAlg" -> "CHARZ"

```

— FINRAlg.dotfull —

```

"FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FINRAlg"];
"FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "Algebra(a:CommutativeRing)"
"FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "Field()"
"FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "CharacteristicNonZero()"
"FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->

```


"CharacteristicZero()"

— FINRAlg.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"
    [color=lightblue];
  "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
    "Algebra(a:CommutativeRing)"
  "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
    "Field()"
  "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
    "CharacteristicNonZero()"
  "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
    "CharacteristicZero()"

  "Algebra(a:CommutativeRing)" [color=lightblue];
  "Algebra(a:CommutativeRing)" -> "RING..."
  "Algebra(a:CommutativeRing)" -> "MODULE..."

  "Field()" [color=lightblue];
  "Field()" -> "EUCDOM..."
  "Field()" -> "UFD..."
  "Field()" -> "DIVRING..."

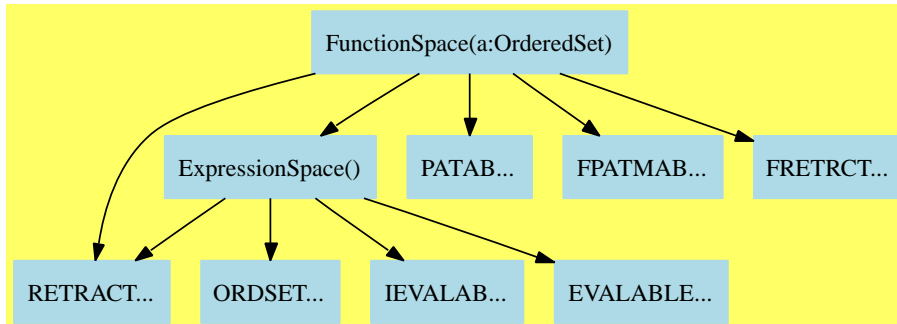
  "CharacteristicNonZero()" [color=lightblue];
  "CharacteristicNonZero()" -> "RING..."

  "CharacteristicZero()" [color=lightblue];
  "CharacteristicZero()" -> "RING..."

  "EUCDOM..." [color=lightblue];
  "UFD..." [color=lightblue];
  "DIVRING..." [color=lightblue];
  "RING..." [color=lightblue];
  "MODULE..." [color=lightblue];
}

```

FunctionSpace (FS)



— FunctionSpace.input —

```

)set break resume
)sys rm -f FunctionSpace.output
)spool FunctionSpace.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FunctionSpace
--R
--R FunctionSpace(R: OrderedSet) is a category constructor
--R Abbreviation for FunctionSpace is FS
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FS
--R
--R----- Operations -----
--R -? : % -> % if R has ABELGRP      ?<? : (%,%) -> Boolean
--R ?<=? : (%,%) -> Boolean          ?=? : (%,%) -> Boolean
--R ?>? : (%,%) -> Boolean          ?>=? : (%,%) -> Boolean
--R 1 : () -> % if R has SGROUP      0 : () -> % if R has ABELSG
--R applyQuote : (Symbol,%,%) -> %   applyQuote : (Symbol,%) -> %
--R belong? : BasicOperator -> Boolean box : List(%) -> %
--R box : % -> %                     coerce : R -> %
--R coerce : Symbol -> %              coerce : Kernel(%) -> %
--R coerce : % -> OutputForm          distribute : (%,%) -> %
--R distribute : % -> %               elt : (BasicOperator,%,%) -> %
--R elt : (BasicOperator,%) -> %      eval : (%,%,%) -> %
--R eval : (%,Equation(%)) -> %       eval : (%,Kernel(%),%) -> %
--R freeOf? : (%,Symbol) -> Boolean   freeOf? : (%,%) -> Boolean
--R ground : % -> R                   ground? : % -> Boolean
--R hash : % -> SingleInteger         height : % -> NonNegativeInteger
--R is? : (%,Symbol) -> Boolean       kernel : (BasicOperator,%) -> %

```

```

--R kernels : % -> List(Kernel(%))          latex : % -> String
--R max : (% , %) -> %                      min : (% , %) -> %
--R paren : List(%) -> %                   paren : % -> %
--R retract : % -> R                      retract : % -> Symbol
--R retract : % -> Kernel(%)              subst : (% , Equation(%)) -> %
--R tower : % -> List(Kernel(%))          variables : % -> List(Symbol)
--R ?^=? : (% , %) -> Boolean
--R ?*? : (% , %) -> % if R has SGROUP
--R ?*? : (PositiveInteger , %) -> % if R has ABELSG
--R ?*? : (NonNegativeInteger , %) -> % if R has ABELSG
--R ?*? : (Integer , %) -> % if R has ABELGRP
--R ?*? : (% , R) -> % if R has COMRING
--R ?*? : (R , %) -> % if R has COMRING
--R ?*? : (% , Fraction(Integer)) -> % if R has INTDOM
--R ?*? : (Fraction(Integer) , %) -> % if R has INTDOM
--R ??? : (% , PositiveInteger) -> % if R has SGROUP
--R ??? : (% , NonNegativeInteger) -> % if R has SGROUP
--R ??? : (% , Integer) -> % if R has GROUP or R has INTDOM
--R ?+? : (% , %) -> % if R has ABELSG
--R ?-? : (% , %) -> % if R has ABELGRP
--R ?/? : (% , %) -> % if R has GROUP or R has INTDOM
--R ?/? : (SparseMultivariatePolynomial(R , Kernel(%)) , SparseMultivariatePolynomial(R , Kernel(%)))
--R D : (% , Symbol) -> % if R has RING
--R D : (% , List(Symbol)) -> % if R has RING
--R D : (% , Symbol , NonNegativeInteger) -> % if R has RING
--R D : (% , List(Symbol) , List(NonNegativeInteger)) -> % if R has RING
--R ?? : (% , PositiveInteger) -> % if R has SGROUP
--R ?? : (% , NonNegativeInteger) -> % if R has SGROUP
--R ?? : (% , Integer) -> % if R has GROUP or R has INTDOM
--R applyQuote : (Symbol , List(%)) -> %
--R applyQuote : (Symbol , % , % , % , %) -> %
--R applyQuote : (Symbol , % , % , %) -> %
--R associates? : (% , %) -> Boolean if R has INTDOM
--R characteristic : () -> NonNegativeInteger if R has RING
--R charthRoot : % -> Union(% , "failed") if R has CHARNZ
--R coerce : Integer -> % if R has RING or R has RETRACT(INT)
--R coerce : Fraction(Integer) -> % if R has INTDOM or R has RETRACT(INT) and R has INTDOM or R
--R coerce : Polynomial(R) -> % if R has RING
--R coerce : % -> % if R has INTDOM
--R coerce : Fraction(Polynomial(R)) -> % if R has INTDOM
--R coerce : Fraction(Polynomial(Fraction(R))) -> % if R has INTDOM
--R coerce : Polynomial(Fraction(R)) -> % if R has INTDOM
--R coerce : Fraction(R) -> % if R has INTDOM
--R coerce : SparseMultivariatePolynomial(R , Kernel(%)) -> % if R has RING
--R commutator : (% , %) -> % if R has GROUP
--R conjugate : (% , %) -> % if R has GROUP
--R convert : % -> InputForm if R has KONVERT(INFORM)
--R convert : Factored(%) -> % if R has INTDOM
--R convert : % -> Pattern(Float) if R has KONVERT(PATTERN(FLOAT))
--R convert : % -> Pattern(Integer) if R has KONVERT(PATTERN(INT))

```

```

--R definingPolynomial : % -> % if $ has RING
--R denom : % -> SparseMultivariatePolynomial(R,Kernel(%)) if R has INTDOM
--R denominator : % -> % if R has INTDOM
--R differentiate : (% ,Symbol) -> % if R has RING
--R differentiate : (% ,List(Symbol)) -> % if R has RING
--R differentiate : (% ,Symbol,NonNegativeInteger) -> % if R has RING
--R differentiate : (% ,List(Symbol),List(NonNegativeInteger)) -> % if R has RING
--R divide : (% ,%) -> Record(quotient: %,remainder: %) if R has INTDOM
--R elt : (BasicOperator,List(%)) -> %
--R elt : (BasicOperator,% ,% ,% ,%) -> %
--R elt : (BasicOperator,% ,% ,%) -> %
--R euclideanSize : % -> NonNegativeInteger if R has INTDOM
--R eval : (% ,Symbol,NonNegativeInteger,(% -> %)) -> % if R has RING
--R eval : (% ,Symbol,NonNegativeInteger,(List(% ) -> %)) -> % if R has RING
--R eval : (% ,List(Symbol),List(NonNegativeInteger),List((List(% ) -> %))) -> % if R has RING
--R eval : (% ,List(Symbol),List(NonNegativeInteger),List((% -> %))) -> % if R has RING
--R eval : (% ,List(BasicOperator),List(% ),Symbol) -> % if R has KONVERT(INFORM)
--R eval : (% ,BasicOperator,% ,Symbol) -> % if R has KONVERT(INFORM)
--R eval : % -> % if R has KONVERT(INFORM)
--R eval : (% ,List(Symbol)) -> % if R has KONVERT(INFORM)
--R eval : (% ,Symbol) -> % if R has KONVERT(INFORM)
--R eval : (% ,BasicOperator,(% -> %)) -> %
--R eval : (% ,BasicOperator,(List(% ) -> %)) -> %
--R eval : (% ,List(BasicOperator),List((List(% ) -> %))) -> %
--R eval : (% ,List(BasicOperator),List((% -> %))) -> %
--R eval : (% ,Symbol,(% -> %)) -> %
--R eval : (% ,Symbol,(List(% ) -> %)) -> %
--R eval : (% ,List(Symbol),List((List(% ) -> %))) -> %
--R eval : (% ,List(Symbol),List((% -> %))) -> %
--R eval : (% ,List(% ),List(% )) -> %
--R eval : (% ,List(Equation(% ))) -> %
--R eval : (% ,List(Kernel(% )),List(% )) -> %
--R even? : % -> Boolean if $ has RETRACT(INT)
--R expressIdealMember : (List(% ),%) -> Union(List(% ),"failed") if R has INTDOM
--R exquo : (% ,%) -> Union(% ,"failed") if R has INTDOM
--R extendedEuclidean : (% ,%) -> Record(coef1: %,coef2: %,generator: %) if R has INTDOM
--R extendedEuclidean : (% ,% ,%) -> Union(Record(coef1: %,coef2: %),"failed") if R has INTDOM
--R factor : % -> Factored(%) if R has INTDOM
--R gcd : (% ,%) -> % if R has INTDOM
--R gcd : List(% ) -> % if R has INTDOM
--R gcdPolynomial : (SparseUnivariatePolynomial(% ),SparseUnivariatePolynomial(% )) -> SparseUnivariatePolynomial(R,Kernel(% )) if R has INTDOM
--R inv : % -> % if R has GROUP or R has INTDOM
--R is? : (% ,BasicOperator) -> Boolean
--R isExpt : (% ,Symbol) -> Union(Record(var: Kernel(% ),exponent: Integer),"failed") if R has RING
--R isExpt : (% ,BasicOperator) -> Union(Record(var: Kernel(% ),exponent: Integer),"failed") if R has RING
--R isExpt : % -> Union(Record(var: Kernel(% ),exponent: Integer),"failed") if R has SGROUP
--R isMult : % -> Union(Record(coef: Integer,var: Kernel(% )), "failed") if R has ABELSG
--R isPlus : % -> Union(List(% ), "failed") if R has ABELSG
--R isPower : % -> Union(Record(val: %,exponent: Integer),"failed") if R has RING
--R isTimes : % -> Union(List(% ), "failed") if R has SGROUP

```

```

--R kernel : (BasicOperator,List(%)) -> %
--R lcm : (%,% ) -> % if R has INTDOM
--R lcm : List(% ) -> % if R has INTDOM
--R mainKernel : % -> Union(Kernel(%),"failed")
--R map : ((% -> %),Kernel(%)) -> %
--R minPoly : Kernel(% ) -> SparseUnivariatePolynomial(% ) if $ has RING
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed") if R has INTDOM
--R numer : % -> SparseMultivariatePolynomial(R,Kernel(%)) if R has RING
--R numerator : % -> % if R has RING
--R odd? : % -> Boolean if $ has RETRACT(INT)
--R one? : % -> Boolean if R has SGROUP
--R operator : BasicOperator -> BasicOperator
--R operators : % -> List(BasicOperator)
--R patternMatch : (% ,Pattern(Float),PatternMatchResult(Float,%)) -> PatternMatchResult(Float,% )
--R patternMatch : (% ,Pattern(Integer),PatternMatchResult(Integer,%)) -> PatternMatchResult(Integer,% )
--R prime? : % -> Boolean if R has INTDOM
--R principalIdeal : List(% ) -> Record(coef: List(%),generator: % ) if R has INTDOM
--R ?quo? : (%,% ) -> % if R has INTDOM
--R recip : % -> Union(%,"failed") if R has SGROUP
--R reducedSystem : Matrix(% ) -> Matrix(R) if R has RING
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(R),vec: Vector(R)) if R has RING
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Integer),vec: Vector(Integer)) if R has RING
--R reducedSystem : Matrix(% ) -> Matrix(Integer) if and(has(R,LinearlyExplicitRingOver(Integer)))
--R ?rem? : (%,% ) -> % if R has INTDOM
--R retract : % -> Fraction(Integer) if R has RETRACT(INT) and R has INTDOM or R has RETRACT(FRACTION)
--R retract : % -> Polynomial(R) if R has RING
--R retract : % -> Fraction(Polynomial(R)) if R has INTDOM
--R retract : % -> Integer if R has RETRACT(INT)
--R retractIfCan : % -> Union(Fraction(Integer),"failed") if R has RETRACT(INT) and R has INTDOM
--R retractIfCan : % -> Union(Polynomial(R),"failed") if R has RING
--R retractIfCan : % -> Union(Fraction(Polynomial(R)),"failed") if R has INTDOM
--R retractIfCan : % -> Union(R,"failed")
--R retractIfCan : % -> Union(Integer,"failed") if R has RETRACT(INT)
--R retractIfCan : % -> Union(Symbol,"failed")
--R retractIfCan : % -> Union(Kernel(%),"failed")
--R sample : () -> % if R has SGROUP or R has ABELSG
--R sizeLess? : (%,% ) -> Boolean if R has INTDOM
--R squareFree : % -> Factored(% ) if R has INTDOM
--R squareFreePart : % -> % if R has INTDOM
--R subst : (% ,List(Kernel(%)),List(%)) -> %
--R subst : (% ,List(Equation(%))) -> %
--R subtractIfCan : (%,% ) -> Union(%,"failed") if R has ABELGRP
--R unit? : % -> Boolean if R has INTDOM
--R unitCanonical : % -> % if R has INTDOM
--R unitNormal : % -> Record(unit: %,canonical: %,associate: % ) if R has INTDOM
--R univariate : (% ,Kernel(%)) -> Fraction(SparseUnivariatePolynomial(%)) if R has INTDOM
--R zero? : % -> Boolean if R has ABELSG
--R
--E 1

```

```
)spool
)lisp (bye)
```

— **FunctionSpace.help** —

=====

FunctionSpace examples

=====

This is the category for formal functions.
 A space of formal functions with arguments in an arbitrary ordered set.

See Also:

o)show FunctionSpace

See:

⇐ “AbelianGroup” (ABELGRP) [7](#) on page [574](#)
 ⇐ “AbelianMonoid” (ABELMON) [5](#) on page [321](#)
 ⇐ “AbelianSemiGroup” (ABELSG) [4](#) on page [173](#)
 ⇐ “Algebra” (ALGEBRA) [11](#) on page [999](#)
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 ⇐ “CharacteristicNonZero” (CHARNZ) [10](#) on page [887](#)
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 ⇐ “IntegralDomain” (INTDOM) [12](#) on page [1097](#)
 ⇐ “Monoid” (MONOID) [5](#) on page [386](#)
 ⇐ “PartialDifferentialRing” (PDRING) [10](#) on page [939](#)
 ⇐ “Patternable” (PATAB) [2](#) on page [86](#)
 ⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)
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 ⇐ “SemiGroup” (SGROUP) [4](#) on page [292](#)

Exports:

| | | | |
|----------------|--------------------|----------------|--------------------|
| 0 | 1 | applyQuote | associates? |
| belong? | box | characteristic | charthRoot |
| coerce | commutator | conjugate | convert |
| D | definingPolynomial | denom | denominator |
| differentiate | distribute | divide | elt |
| eval | euclideanSize | even? | expressIdealMember |
| exquo | extendedEuclidean | factor | freeOf? |
| gcd | gcdPolynomial | ground | ground? |
| hash | height | inv | is? |
| isExpt | isMult | isPlus | isPower |
| isTimes | kernel | kernels | latex |
| lcm | mainKernel | map | max |
| min | minPoly | multiEuclidean | numerator |
| numerator | odd? | one? | operator |
| operators | paren | patternMatch | prime? |
| principalIdeal | recip | reducedSystem | retract |
| retractIfCan | sample | sizeLess? | squareFree |
| squareFreePart | subst | subtractIfCan | tower |
| unit? | unitCanonical | unitNormal | univariate |
| variables | zero? | -? | ?<? |
| ?<=? | ?=? | ?>? | ?>=? |
| ?~=? | ?*? | ?**? | ?+? |
| ?-? | ?/? | ?^? | ?quo? |
| ?rem? | | | |

Attributes Exported:

- if \$ has IntegralDomain then noZeroDivisors where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- if \$ has IntegralDomain then canonicalUnitNormal where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?(a,b)** returns true if and only if **unitCanonical(a) = unitCanonical(b)**.
- if \$ has IntegralDomain then canonicalsClosed where **canonicalsClosed** is true if **unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)**.
- if \$ has IntegralDomain then commutative(“*”) where **commutative(“*”)** is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- if \$ has Ring or Group then unitsKnown where **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- if \$ has CommutativeRing then leftUnitary where **leftUnitary** is true if $1 * x = x$ for all x.

- if \$ has CommutativeRing then rightUnitary where **rightUnitary** is true if $x * 1 = x$ for all x.
- nil

These are directly exported but not implemented:

```
coerce : SparseMultivariatePolynomial(R,Kernel %) -> %
  if R has RING
coerce : Fraction R -> % if R has INTDOM
coerce : Polynomial Fraction R -> % if R has INTDOM
denom : % -> SparseMultivariatePolynomial(R,Kernel %)
  if R has INTDOM
eval : (%,List BasicOperator,List %,Symbol) -> %
  if R has KONVERT INFORM
numer : % -> SparseMultivariatePolynomial(R,Kernel %)
  if R has RING
?/? :
  (SparseMultivariatePolynomial(R,Kernel %),
   SparseMultivariatePolynomial(R,Kernel %)) -> %
  if R has INTDOM
?*** : (%,NonNegativeInteger) -> % if R has SGROUP
```

These are implemented by this category:

```
applyQuote : (Symbol,%) -> %
applyQuote : (Symbol,%,%) -> %
applyQuote : (Symbol,%,%,%) -> %
applyQuote : (Symbol,%,%,%,%) -> %
applyQuote : (Symbol,List %) -> %
belong? : BasicOperator -> Boolean
characteristic : () -> NonNegativeInteger if R has RING
coerce : Symbol -> %
coerce : Kernel % -> %
coerce : % -> OutputForm
coerce : Fraction Integer -> %
  if R has INTDOM
  or R has RETRACT INT
  and R has INTDOM
  or R has RETRACT FRAC INT
coerce : Fraction Polynomial R -> % if R has INTDOM
coerce : Fraction Polynomial Fraction R -> %
  if R has INTDOM
coerce : Polynomial R -> % if R has RING
convert : % -> Pattern Float if R has KONVERT PATTERN FLOAT
convert : % -> Pattern Integer if R has KONVERT PATTERN INT
convert : Factored % -> % if R has INTDOM
denominator : % -> % if R has INTDOM
differentiate : (%,Symbol) -> % if R has RING
elt : (BasicOperator,List %) -> %
```



```

eval : (%,List Symbol) -> % if R has KONVERT INFORM
eval : % -> % if R has KONVERT INFORM
eval : (%,Symbol) -> % if R has KONVERT INFORM
eval : (%,BasicOperator,%,Symbol) -> %
    if R has KONVERT INFORM
eval : (%,Symbol,NonNegativeInteger,(% -> %)) -> %
    if R has RING
eval : (%,Symbol,NonNegativeInteger,(List % -> %)) -> %
    if R has RING
eval : (%,List Symbol,List NonNegativeInteger,List (List % -> %)) -> %
    if R has RING
eval : (%,List Symbol,List NonNegativeInteger,List (% -> %)) -> %
    if R has RING
eval : (%,List Kernel %,List %) -> %
ground : % -> R
ground? : % -> Boolean
isExpt : (%,BasicOperator) ->
    Union(Record(var: Kernel %,exponent: Integer),"failed")
    if R has RING
isExpt : % ->
    Union(Record(var: Kernel %,exponent: Integer),"failed")
    if R has SGROUP
isExpt : (%,Symbol) ->
    Union(Record(var: Kernel %,exponent: Integer),"failed")
    if R has RING
isMult : % ->
    Union(Record(coef: Integer,var: Kernel %),"failed")
    if R has ABELSG
isPlus : % -> Union(List %,"failed") if R has ABELSG
isPower : % ->
    Union(Record(val: %,exponent: Integer),"failed")
    if R has RING
isTimes : % -> Union(List %,"failed") if R has SGROUP
kernels : % -> List Kernel %
mainKernel : % -> Union(Kernel %,"failed")
numerator : % -> % if R has RING
operator : BasicOperator -> BasicOperator
retract : % -> Fraction Polynomial R if R has INTDOM
retract : % -> Polynomial R if R has RING
retract : % -> R
retract : % -> Symbol
retractIfCan : % -> Union(R,"failed")
retractIfCan : % -> Union(Fraction Polynomial R,"failed")
    if R has INTDOM
retractIfCan : % -> Union(Polynomial R,"failed")
    if R has RING
retractIfCan : % -> Union(Symbol,"failed")
subst : (%,List Kernel %,List %) -> %
univariate : (%,Kernel %) ->
    Fraction SparseUnivariatePolynomial %

```

```

    if R has INTDOM
variables : % -> List Symbol
?? : (% , R) -> % if R has COMRING
?? : (R , %) -> % if R has COMRING

```

These exports come from (p355) ExpressionSpace():

```

box : List % -> %
box : % -> %
definingPolynomial : % -> % if $ has RING
distribute : (% , %) -> %
distribute : % -> %
elt : (BasicOperator , % , % , % , %) -> %
elt : (BasicOperator , % , % , %) -> %
elt : (BasicOperator , % , %) -> %
elt : (BasicOperator , %) -> %
eval : (% , List BasicOperator , List (% -> %)) -> %
eval : (% , List Equation %) -> %
eval : (% , Symbol , (% -> %)) -> %
eval : (% , Symbol , (List % -> %)) -> %
eval : (% , BasicOperator , (% -> %)) -> %
eval : (% , BasicOperator , (List % -> %)) -> %
eval : (% , List Symbol , List (% -> %)) -> %
eval : (% , List BasicOperator , List (List % -> %)) -> %
eval : (% , List Symbol , List (List % -> %)) -> %
eval : (% , List % , List %) -> %
eval : (% , % , %) -> %
eval : (% , Equation %) -> %
eval : (% , Kernel % , %) -> %
even? : % -> Boolean if $ has RETRACT INT
freeOf? : (% , Symbol) -> Boolean
freeOf? : (% , %) -> Boolean
hash : % -> SingleInteger
height : % -> NonNegativeInteger
is? : (% , BasicOperator) -> Boolean
is? : (% , Symbol) -> Boolean
kernel : (BasicOperator , %) -> %
kernel : (BasicOperator , List %) -> %
latex : % -> String
map : ((% -> % ) , Kernel %) -> %
max : (% , %) -> %
min : (% , %) -> %
minPoly : Kernel % -> SparseUnivariatePolynomial %
    if $ has RING
odd? : % -> Boolean if $ has RETRACT INT
operators : % -> List BasicOperator
paren : List % -> %
paren : % -> %
retract : % -> Kernel %
retractIfCan : % -> Union(Kernel % , "failed")

```

```

subst : (%,List Equation %) -> %
subst : (%,Equation %) -> %
tower : % -> List Kernel %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?<? : (%,%) -> Boolean
?<=? : (%,%) -> Boolean
?>? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean

```

These exports come from (p141) FullyPatternMatchable(OrderedSet):

```

patternMatch :
  (%,Pattern Integer,PatternMatchResult(Integer,%)) ->
    PatternMatchResult(Integer,%)
    if R has PATMAB INT
patternMatch :
  (%,Pattern Float,PatternMatchResult(Float,%)) ->
    PatternMatchResult(Float,%)
    if R has PATMAB FLOAT

```

These exports come from (p136) FullyRetractableTo(OrderedSet):

```

coerce : Integer -> % if R has RING or R has RETRACT INT
coerce : R -> %

```

These exports come from (p41) ConvertibleTo(InputForm):

```

convert : % -> InputForm if R has KONVERT INFORM

```

These exports come from (p386) Monoid():

```

1 : () -> % if R has SGROUP
one? : % -> Boolean if R has SGROUP
recip : % -> Union(%, "failed") if R has SGROUP
sample : () -> % if R has SGROUP or R has ABELSG
?^? : (%,NonNegativeInteger) -> % if R has SGROUP
?*? : (%,%) -> % if R has SGROUP
***? : (%,PositiveInteger) -> % if R has SGROUP
?^? : (%,PositiveInteger) -> % if R has SGROUP

```

These exports come from (p452) Group():

```

commutator : (%,%) -> % if R has GROUP
conjugate : (%,%) -> % if R has GROUP
inv : % -> % if R has GROUP or R has INTDOM
?/? : (%,%) -> % if R has GROUP or R has INTDOM
?^? : (%,Integer) -> % if R has GROUP or R has INTDOM
***? : (%,Integer) -> % if R has GROUP or R has INTDOM

```

These exports come from (p321) AbelianMonoid():

```
0 : () -> % if R has ABELSG
zero? : % -> Boolean if R has ABELSG
?? : (PositiveInteger,%) -> % if R has ABELSG
?? : (NonNegativeInteger,%) -> % if R has ABELSG
?+? : (%,%) -> % if R has ABELSG
```

These exports come from (p574) AbelianGroup():

```
subtractIfCan : (%,%) -> Union(%, "failed") if R has ABELGRP
?? : (Integer,%) -> % if R has ABELGRP
?-? : (%,%) -> % if R has ABELGRP
-? : % -> % if R has ABELGRP
```

These exports come from (p939) PartialDifferentialRing(Symbol):

```
D : (%,Symbol) -> % if R has RING
D : (%,List Symbol) -> % if R has RING
D : (%,Symbol,NonNegativeInteger) -> % if R has RING
D : (%,List Symbol,List NonNegativeInteger) -> % if R has RING
differentiate : (%,List Symbol) -> % if R has RING
differentiate : (%,Symbol,NonNegativeInteger) -> % if R has RING
differentiate : (%,List Symbol,List NonNegativeInteger) -> %
    if R has RING
```

These exports come from (p1012) FullyLinearlyExplicitRingOver(R)
where R:OrderedSet:

```
reducedSystem : Matrix % -> Matrix R if R has RING
reducedSystem : (Matrix %,Vector %) ->
    Record(mat: Matrix R,vec: Vector R) if R has RING
reducedSystem : (Matrix %,Vector %) ->
    Record(mat: Matrix Integer,vec: Vector Integer)
    if and(has(R,LinearlyExplicitRingOver Integer),has(R, Ring))
reducedSystem : Matrix % -> Matrix Integer
    if and(has(R,LinearlyExplicitRingOver Integer),has(R, Ring))
```

These exports come from (p887) CharacteristicNonZero():

```
charthRoot : % -> Union(%, "failed") if R has CHARNZ
```

These exports come from (p1097) IntegralDomain():

```
associates? : (%,%) -> Boolean if R has INTDOM
exquo : (%,%) -> Union(%, "failed") if R has INTDOM
unit? : % -> Boolean if R has INTDOM
unitCanonical : % -> % if R has INTDOM
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
    if R has INTDOM
```

These exports come from (p1271) `Field()`:

```

coerce : % -> % if R has INTDOM
divide : (% , %) -> Record(quotient: %, remainder: %)
    if R has INTDOM
euclideanSize : % -> NonNegativeInteger if R has INTDOM
expressIdealMember : (List % , %) -> Union(List %, "failed")
    if R has INTDOM
extendedEuclidean : (% , %) -> Record(coef1: %, coef2: %, generator: %)
    if R has INTDOM
extendedEuclidean : (% , % , %) -> Union(Record(coef1: %, coef2: %), "failed")
    if R has INTDOM
factor : % -> Factored % if R has INTDOM
gcd : (% , %) -> % if R has INTDOM
gcd : List % -> % if R has INTDOM
gcdPolynomial :
    (SparseUnivariatePolynomial %,
     SparseUnivariatePolynomial %) ->
        SparseUnivariatePolynomial %
    if R has INTDOM
lcm : (% , %) -> % if R has INTDOM
lcm : List % -> % if R has INTDOM
multiEuclidean : (List % , %) -> Union(List %, "failed")
    if R has INTDOM
prime? : % -> Boolean if R has INTDOM
principalIdeal : List % -> Record(coef: List %, generator: %)
    if R has INTDOM
sizeLess? : (% , %) -> Boolean if R has INTDOM
squareFree : % -> Factored % if R has INTDOM
squareFreePart : % -> % if R has INTDOM
?quo? : (% , %) -> % if R has INTDOM
?rem? : (% , %) -> % if R has INTDOM

```

These exports come from (p95) `RetractableTo(Integer)`:

```

retract : % -> Integer if R has RETRACT INT
retractIfCan : % -> Union(Integer, "failed")
    if R has RETRACT INT

```

These exports come from (p95) `RetractableTo(Fraction(Integer))`:

```

retract : % -> Fraction Integer
    if R has RETRACT INT
    and R has INTDOM
    or R has RETRACT FRAC INT
retractIfCan : % -> Union(Fraction Integer, "failed")
    if R has RETRACT INT
    and R has INTDOM
    or R has RETRACT FRAC INT

```

```

???: (% , Fraction Integer) -> % if R has INTDOM
???: (Fraction Integer, %) -> % if R has INTDOM

```

— category FS FunctionSpace —

```

)abbrev category FS FunctionSpace
++ Author: Manuel Bronstein
++ Date Created: 22 March 1988
++ Date Last Updated: 14 February 1994
++ Description:
++ Category for formal functions
++ A space of formal functions with arguments in an arbitrary ordered set.

FunctionSpace(R:OrderedSet): Category == Definition where
  OP ==> BasicOperator
  O  ==> OutputForm
  SY ==> Symbol
  N  ==> NonNegativeInteger
  Z  ==> Integer
  K  ==> Kernel %
  Q  ==> Fraction R
  PR ==> Polynomial R
  MP ==> SparseMultivariatePolynomial(R, K)
  QF==> PolynomialCategoryQuotientFunctions(IndexedExponents K,K,R,MP,%)

  ODD ==> "odd"
  EVEN ==> "even"

  SPECIALDIFF ==> "%specialDiff"
  SPECIALDISP ==> "%specialDisp"
  SPECIALEQUAL ==> "%specialEqual"
  SPECIALINPUT ==> "%specialInput"

Definition ==> Join(ExpressionSpace, RetractableTo SY, Patternable R,
  FullyPatternMatchable R, FullyRetractableTo R) with
  ground? : % -> Boolean
    ++ ground?(f) tests if f is an element of R.
  ground : % -> R
    ++ ground(f) returns f as an element of R.
    ++ An error occurs if f is not an element of R.
  variables : % -> List SY
    ++ variables(f) returns the list of all the variables of f.
  applyQuote: (SY, %) -> %
    ++ applyQuote(foo, x) returns \spad{'foo(x)}.
  applyQuote: (SY, %, %) -> %
    ++ applyQuote(foo, x, y) returns \spad{'foo(x,y)}.
  applyQuote: (SY, %, %, %) -> %
    ++ applyQuote(foo, x, y, z) returns \spad{'foo(x,y,z)}.
  applyQuote: (SY, %, %, %, %) -> %

```

```

++ applyQuote(foo, x, y, z, t) returns \spad{'foo(x,y,z,t)}.
applyQuote: (SY, List %) -> %
++ applyQuote(foo, [x1,...,xn]) returns \spad{'foo(x1,...,xn)}.
if R has ConvertibleTo InputForm then
  ConvertibleTo InputForm
  eval      : (%, SY) -> %
  ++ eval(f, foo) unquotes all the foo's in f.
  eval      : (%, List SY) -> %
  ++ eval(f, [foo1,...,foon]) unquotes all the \spad{fooi}'s in f.
  eval      : % -> %
  ++ eval(f) unquotes all the quoted operators in f.
  eval      : (%, OP, %, SY) -> %
  ++ eval(x, s, f, y) replaces every \spad{s(a)} in x by \spad{f(y)}
  ++ with \spad{y} replaced by \spad{a} for any \spad{a}.
  eval      : (%, List OP, List %, SY) -> %
  ++ eval(x, [s1,...,sm], [f1,...,fm], y) replaces every
  ++ \spad{si(a)} in x by \spad{fi(y)}
  ++ with \spad{y} replaced by \spad{a} for any \spad{a}.
if R has SemiGroup then
  Monoid
  -- the following line is necessary because of a compiler bug
  "***"      : (%, N) -> %
  ++ x**n returns x * x * x * ... * x (n times).
  isTimes: % -> Union(List %, "failed")
  ++ isTimes(p) returns \spad{[a1,...,an]}
  ++ if \spad{p = a1*...*an} and \spad{n > 1}.
  isExpt : % -> Union(Record(var:K,exponent:Z),"failed")
  ++ isExpt(p) returns \spad{[x, n]} if \spad{p = x**n}
  ++ and \spad{n <> 0}.
if R has Group then Group
if R has AbelianSemiGroup then
  AbelianMonoid
  isPlus: % -> Union(List %, "failed")
  ++ isPlus(p) returns \spad{[m1,...,mn]}
  ++ if \spad{p = m1 +...+ mn} and \spad{n > 1}.
  isMult: % -> Union(Record(coef:Z, var:K),"failed")
  ++ isMult(p) returns \spad{[n, x]} if \spad{p = n * x}
  ++ and \spad{n <> 0}.
if R has AbelianGroup then AbelianGroup
if R has Ring then
  Ring
  RetractableTo PR
  PartialDifferentialRing SY
  FullyLinearlyExplicitRingOver R
  coerce      : MP -> %
  ++ coerce(p) returns p as an element of %.
  numer      : % -> MP
  ++ numer(f) returns the
  ++ numerator of f viewed as a polynomial in the kernels over R
  ++ if R is an integral domain. If not, then numer(f) = f viewed

```

```

    ++ as a polynomial in the kernels over R.
    -- DO NOT change this meaning of numer!  MB 1/90
numerator : % -> %
    ++ numerator(f) returns the numerator of \spad{f} converted to %.
isExpt:(%,OP) -> Union(Record(var:K,exponent:Z),"failed")
    ++ isExpt(p,op) returns \spad{[x, n]} if \spad{p = x**n}
    ++ and \spad{n <> 0} and \spad{x = op(a)}.
isExpt:(%,SY) -> Union(Record(var:K,exponent:Z),"failed")
    ++ isExpt(p,f) returns \spad{[x, n]} if \spad{p = x**n}
    ++ and \spad{n <> 0} and \spad{x = f(a)}.
isPower : % -> Union(Record(val:K,exponent:Z),"failed")
    ++ isPower(p) returns \spad{[x, n]} if \spad{p = x**n}
    ++ and \spad{n <> 0}.
eval: (%, List SY, List N, List(% -> %)) -> %
    ++ eval(x, [s1,...,sm], [n1,...,nm], [f1,...,fm]) replaces
    ++ every \spad{si(a)**ni} in x by \spad{fi(a)} for any \spad{a}.
eval: (%, List SY, List N, List(List % -> %)) -> %
    ++ eval(x, [s1,...,sm], [n1,...,nm], [f1,...,fm]) replaces
    ++ every \spad{si(a1,...,an)**ni} in x by \spad{fi(a1,...,an)}
    ++ for any a1,...,am.
eval: (%, SY, N, List % -> %) -> %
    ++ eval(x, s, n, f) replaces every \spad{s(a1,...,am)**n} in x
    ++ by \spad{f(a1,...,am)} for any a1,...,am.
eval: (%, SY, N, % -> %) -> %
    ++ eval(x, s, n, f) replaces every \spad{s(a)**n} in x
    ++ by \spad{f(a)} for any \spad{a}.
if R has CharacteristicZero then CharacteristicZero
if R has CharacteristicNonZero then CharacteristicNonZero
if R has CommutativeRing then
    Algebra R
if R has IntegralDomain then
    Field
    RetractableTo Fraction PR
    convert : Factored % -> %
        ++ convert(f1\^e1 ... fm\^em) returns \spad{(f1)\^e1 ... (fm)\^em}
        ++ as an element of %, using formal kernels
        ++ created using a \spadfunFrom{paren}{ExpressionSpace}.
    denom : % -> MP
        ++ denom(f) returns the denominator of f viewed as a
        ++ polynomial in the kernels over R.
    denominator : % -> %
        ++ denominator(f) returns the denominator of \spad{f}
        ++ converted to %.
    "/" : (MP, MP) -> %
        ++ p1/p2 returns the quotient of p1 and p2 as an element of %.
    coerce : Q -> %
        ++ coerce(q) returns q as an element of %.
    coerce : Polynomial Q -> %
        ++ coerce(p) returns p as an element of %.
    coerce : Fraction Polynomial Q -> %

```



```

    ++ coerce(f) returns f as an element of %.
    univariate: (% , K) -> Fraction SparseUnivariatePolynomial %
    ++ univariate(f, k) returns f viewed as a univariate fraction in k.
    if R has RetractableTo Z then RetractableTo Fraction Z
add
import BasicOperatorFunctions1(%)

-- these are needed in Ring only, but need to be declared here
-- because of compiler bug: if they are declared inside the Ring
-- case, then they are not visible inside the IntegralDomain case.
smpIsMult : MP -> Union(Record(coef:Z, var:K),"failed")
smpret    : MP -> Union(PR, "failed")
smpeval   : (MP, List K, List %) -> %
smpsubst  : (MP, List K, List %) -> %
smpderiv  : (MP, SY) -> %
smpunq    : (MP, List SY, Boolean) -> %
kerderiv  : (K, SY) -> %
kderiv    : K -> List %
opderiv   : (OP, N) -> List(List % -> %)
smp20     : MP -> 0
bestKernel: List K -> K
worse?    : (K, K) -> Boolean
diffArg   : (List %, OP, N) -> List %
substArg  : (OP, List %, Z, %) -> %
dispdiff  : List % -> Record(name:0, sub:0, arg:List 0, level:N)
ddiff     : List % -> 0
diffEval  : List % -> %
dfeval    : (List %, K) -> %
smprep    : (List SY, List N, List(List % -> %), MP) -> %
diffdiff  : (List %, SY) -> %
diffdiff0 : (List %, SY, %, K, List %) -> %
subs      : (% -> %, K) -> %
symsub    : (SY, Z) -> SY
kunq      : (K, List SY, Boolean) -> %
pushunq   : (List SY, List %) -> List %
notfound  : (K -> %, List K, K) -> %

equaldiff : (K,K)->Boolean
debugA: (List % ,List %,Boolean) -> Boolean
opdiff := operator("%diff"::SY)$CommonOperators()
opquote := operator("applyQuote"::SY)$CommonOperators

ground? x                == retractIfCan(x)@Union(R,"failed") case R

ground x                  == retract x

coerce(x:SY):%            == kernel(x)@K :: %

retract(x:%):SY           == symbolIfCan(retract(x)@K)::SY

```

```

applyQuote(s:SY, x:%) == applyQuote(s, [x])

applyQuote(s, x, y) == applyQuote(s, [x, y])

applyQuote(s, x, y, z) == applyQuote(s, [x, y, z])

applyQuote(s, x, y, z, t) == applyQuote(s, [x, y, z, t])

applyQuote(s:SY, l:List %) == opquote concat(s::%, l)

belong? op == op = opdiff or op = opquote

subs(fn, k) == kernel(operator k, [fn x for x in argument k]$List(%))

operator op ==
  is?(op, "%diff"::SY) => opdiff
  is?(op, "%quote"::SY) => opquote
  error "Unknown operator"

if R has ConvertibleTo InputForm then
  INP==>InputForm
  import MakeUnaryCompiledFunction(%, %, %)
  indiff: List % -> INP
  pint : List INP-> INP
  differentiad: List % -> %

  differentiad l == eval(first l, retract(second l)@K, third l)

  pint l == convert concat(convert("D"::SY)@INP, l)

  indiff l ==
    r2:= convert([convert(":"::SY)@INP,_
                  convert(third l)@INP,_
                  convert("Symbol"::SY)@INP]@List INP)@INP
    pint [convert(differentiad l)@INP, r2]

  eval(f:%, s:SY) == eval(f, [s])

  eval(f:%, s:OP, g:%, x:SY) == eval(f, [s], [g], x)

  eval(f:%, ls:List OP, lg:List %, x:SY) ==
    eval(f, ls, [compiledFunction(g, x) for g in lg])

  setProperty(opdiff, SPECIALINPUT, _
    indiff@(List % -> InputForm) pretend None)

variables x ==
  l := empty()$List(SY)
  for k in tower x repeat
    if ((s := symbolIfCan k) case SY) then l := concat(s::SY, l)

```

```

reverse_! 1

retractIfCan(x:%):Union(SY, "failed") ==
  (k := retractIfCan(x)@Union(K,"failed")) case "failed" => "failed"
  symbolIfCan(k::K)

if R has Ring then
  import UserDefinedPartialOrdering(SY)

-- cannot use new()$Symbol because of possible re-instantiation
gendiff := "%0":SY

characteristic() == characteristic()$R

coerce(k:K):% == k::MP:%

symsub(sy, i) == concat(string sy, convert(i)@String)::SY

numerator x == numer(x)::%

eval(x:%, s:SY, n:N, f:% -> %) ==
  eval(x,[s],[n],[(y:List %):% +-> f(first(y))])

eval(x:%, s:SY, n:N, f:List % -> %) == eval(x, [s], [n], [f])

eval(x:%, l:List SY, f:List(List % -> %)) == eval(x, l, new(#l, 1), f)

elt(op:OP, args:List %) ==
  unary? op and ((od? := has?(op, ODD)) or has?(op, EVEN)) and
  leadingCoefficient(numer first args) < 0 =>
    x := op(- first args)
    od? => -x
    x
  elt(op, args)$ExpressionSpace_&(&)

eval(x:%, s:List SY, n:List N, l:List(% -> %)) ==
  eval(x, s, n, [y+> f(first(y)) for f in l]$List(List % -> %))

-- op(arg)**m ==> func(arg)**(m quo n) * op(arg)**(m rem n)
smprep(lop, lexp, lfunc, p) ==
  (v := mainVariable p) case "failed" => p::%
  symbolIfCan(k := v::K) case SY => p::%
  g := (op := operator k)
  (arg := [eval(a,lop,lexp,lfunc) for a in argument k]$List(%))
  q := map(y+>eval(y::%, lop, lexp, lfunc),
    univariate(p, k))$SparseUnivariatePolynomialFunctions2(MP, %)
  (n := position(name op, lop)) < minIndex lop => q g
  a:% := 0
  f := eval((lfunc.n) arg, lop, lexp, lfunc)
  e := lexp.n

```

```

while q ^= 0 repeat
  m := degree q
  qr := divide(m, e)
  t1 := f ** (qr.quotient)::N
  t2 := g ** (qr.remainder)::N
  a := a + leadingCoefficient(q) * t1 * t2
  q := reductum q
a

dispdiff l ==
  s := second(l)::0
  t := third(l)::0
  a := argument(k := retract(first l)@K)
  is?(k, opdif) =>
    rec := dispdif a
    i := position(s, rec.arg)
    rec.arg.i := t
    [rec.name,
      hconcat(rec.sub, hconcat("::SY::0, (i+1-minIndex a)::0)),
      rec.arg, (zero?(rec.level) => 0; rec.level + 1)]
  i := position(second l, a)
  m := [x::0 for x in a]$List(0)
  m.i := t
  [name(operator k)::0, hconcat("::SY::0, (i+1-minIndex a)::0),
    m, (empty? rest a => 1; 0)]

ddiff l ==
  rec := dispdif l
  opname :=
    zero?(rec.level) => sub(rec.name, rec.sub)
    differentiate(rec.name, rec.level)
  prefix(opname, rec.arg)

substArg(op, l, i, g) ==
  z := copy l
  z.i := g
  kernel(op, z)

diffdiff(l, x) ==
  f := kernel(opdif, l)
  diffdiff0(l, x, f, retract(f)@K, empty())

diffdiff0(l, x, expr, kd, done) ==
  op := operator(k := retract(first l)@K)
  gg := second l
  u := third l
  arg := argument k
  ans:% := 0
  if (not member?(u,done)) and (ans := differentiate(u,x))^=0 then

```

```

    ans := ans * kernel(opdiff,
        [subst(expr, [kd], [kernel(opdiff, [first l, gg, gg])]),
         gg, u])
done := concat(gg, done)
is?(k, opdiff) => ans + diffdiff0(arg, x, expr, k, done)
for i in minIndex arg .. maxIndex arg for b in arg repeat
    if (not member?(b,done)) and (bp:=differentiate(b,x))^=0 then
        g := symsub(gendiff, i)::%
        ans := ans + bp * kernel(opdiff, [subst(expr, [kd],
            [kernel(opdiff, [substArg(op, arg, i, g), gg, u])]), g, b])
ans

dfeval(l, g) ==
    eval(differentiate(first l, symbolIfCan(g)::SY), g, third l)

diffEval l ==
    k:K
    g := retract(second l)@K
    ((u := retractIfCan(first l)@Union(K, "failed")) case "failed")
    or (u case K and symbolIfCan(k := u::K) case SY => dfeval(l, g)
    op := operator k
    (ud := derivative op) case "failed" =>
        -- possible trouble
        -- make sure it is a dummy var
        dumm:=symsub(gendiff,1)::%
        ss:=subst(l.1,l.2=dumm)
        -- output(nl::OutputForm)$OutputPackage
        -- output("fixed"::OutputForm)$OutputPackage
        nl:=[ss,dumm,l.3]
        kernel(opdiff, nl)
    (n := position(second l,argument k)) < minIndex l =>
        dfeval(l,g)
    d := ud::List(List % -> %)
    eval((d.n)(argument k), g, third l)

diffArg(l, op, i) ==
    n := i - 1 + minIndex l
    z := copy l
    z.n := g := symsub(gendiff, n)::%
    [kernel(op, z), g, l.n]

opderiv(op, n) ==
--    one? n =>
    (n = 1) =>
        g := symsub(gendiff, n)::%
        [x +-> kernel(opdiff,[kernel(op, g), g, first x])]
        [y +-> kernel(opdiff, diffArg(y, op, i)) for i in 1..n]

kderiv k ==
    zero?(n := #(args := argument k)) => empty()

```

```

op := operator k
grad :=
  (u := derivative op) case "failed" => opderiv(op, n)
  u::List(List % -> %)
  if #grad ^= n then grad := opderiv(op, n)
  [g args for g in grad]

-- SPECIALDIFF contains a map (List %, Symbol) -> %
-- it is used when the usual chain rule does not apply,
-- for instance with implicit algebraics.
kderderiv(k, x) ==
  (v := symbolIfCan(k)) case SY =>
    v::SY = x => 1
    0
  (fn := property(operator k, SPECIALDIFF)) case None =>
    ((fn::None) pretend ((List %, SY) -> %)) (argument k, x)
  +/[g * differentiate(y,x) for g in kderiv k for y in argument k]

smpderiv(p, x) ==
  map((s:R):R +-> retract differentiate(s::PR, x), p)::% +
  +/[differentiate(p,k)::% * kderderiv(k, x) for k in variables p]

coerce(p:PR):% ==
  map(s +-> s::%, r +-> r::%, p)$PolynomialCategoryLifting(
    IndexedExponents SY, SY, R, PR, %)

worse?(k1, k2) ==
  (u := less?(name operator k1, name operator k2)) case "failed" =>
    k1 < k2
  u::Boolean

bestKernel l ==
  empty? rest l => first l
  a := bestKernel rest l
  worse?(first l, a) => a
  first l

smp20 p ==
  (r:=retractIfCan(p)@Union(R,"failed")) case R => r::R::OutputForm
  a :=
    userOrdered?() => bestKernel variables p
    mainVariable(p)::K
  outputForm(map((x:MP):% +-> x::%, univariate(p, a))_
    $SparseUnivariatePolynomialFunctions2(MP, %), a::OutputForm)

smpsubst(p, lk, lv) ==
  map(x +-> match(lk, lv, x,
    notfound((z:K):% +-> subs(s+>subst(s, lk, lv), z), lk, x))_
    $ListToMap(K, %), y+>y::%, p)_
    $PolynomialCategoryLifting(IndexedExponents K, K, R, MP, %)

```

```

smpeval(p, lk, lv) ==
  map(x +-> match(lk, lv, x,
    notfound((z:K):%+>map(s+>eval(s,lk,lv),z),lk,x))_
    $ListToMap(K,%),y+>y:%,p)_
    $PolynomialCategoryLifting(IndexedExponents K,K,R,MP,%)

-- this is called on k when k is not a member of lk
notfound(fn, lk, k) ==
  empty? setIntersection(tower(f := k:%), lk) => f
  fn k

if R has ConvertibleTo InputForm then
  pushunq(l, arg) ==
    empty? l => [eval a for a in arg]
    [eval(a, l) for a in arg]

  kunq(k, l, givenlist?) ==
    givenlist? and empty? l => k:_%
    is?(k, opquote) and
      (member?(s:=retract(first argument k)@SY, l) or empty? l) =>
        interpret(convert(concat(convert(s)@InputForm,
          [convert a for a in pushunq(l, rest argument k)
            ]@List(InputForm)))@InputForm)$InputFormFunctions1(%)
          (operator k) pushunq(l, argument k)

  smpunq(p, l, givenlist?) ==
    givenlist? and empty? l => p:_%
    map(x +-> kunq(x, l, givenlist?), y+>y:%, p)_
    $PolynomialCategoryLifting(IndexedExponents K,K,R,MP,%)

  smpret p ==
    "or"/[symbolIfCan(k) case "failed" for k in variables p] =>
      "failed"
    map(x+>symbolIfCan(x)::SY::PR, y+>y::PR,p)_
    $PolynomialCategoryLifting(IndexedExponents K, K, R, MP, PR)

  isExpt(x:%, op:OP) ==
    (u := isExpt x) case "failed" => "failed"
    is?((u::Record(var:K, exponent:Z)).var, op) => u
    "failed"

  isExpt(x:%, sy:SY) ==
    (u := isExpt x) case "failed" => "failed"
    is?((u::Record(var:K, exponent:Z)).var, sy) => u
    "failed"

if R has RetractableTo Z then
  smpIsMult p ==
  -- (u := mainVariable p) case K and one? degree(q:=univariate(p,u::K))

```

```

(u := mainVariable p) case K and (degree(q:=univariate(p,u::K))=1)
  and zero?(leadingCoefficient reductum q)
  and ((r:=retractIfCan(leadingCoefficient q)@Union(R,"failed"))
    case R)
    and (n := retractIfCan(r::R)@Union(Z, "failed")) case Z =>
      [n::Z, u::K]
"failed"

evaluate(opdiff, diffEval)

debugA(a1,a2,t) ==
  -- uncomment for debugging
  -- output(hconcat [a1::OutputForm,_
  --               a2::OutputForm,t::OutputForm])$OutputPackage
  t

equaldiff(k1,k2) ==
  a1:=argument k1
  a2:=argument k2
  -- check the operator
  res:=operator k1 = operator k2
  not res => debugA(a1,a2,res)
  -- check the evaluation point
  res:= (a1.3 = a2.3)
  not res => debugA(a1,a2,res)
  -- check all the arguments
  res:= (a1.1 = a2.1) and (a1.2 = a2.2)
  res => debugA(a1,a2,res)
  -- check the substituted arguments
  (subst(a1.1,[retract(a1.2)@K],[a2.2]) = a2.1) => debugA(a1,a2,true)
  debugA(a1,a2,false)

setProperty(opdiff,SPECIALEQUAL,
            equaldiff@((K,K) -> Boolean) pretend None)

setProperty(opdiff, SPECIALDIFF,
            diffdiff@((List %, SY) -> %) pretend None)

setProperty(opdiff, SPECIALDISP,
            ddiff@(List % -> OutputForm) pretend None)

if not(R has IntegralDomain) then
  mainKernel x      == mainVariable numer x

  kernels x         == variables numer x

  retract(x:%):R     == retract numer x

  retract(x:%):PR    == smpret(numer x)::PR

```



```

retractIfCan(x: %): Union(R, "failed") == retract number x

retractIfCan(x: %): Union(PR, "failed") == smpret number x

eval(x: %, lk: List K, lv: List %) == smpeval(number x, lk, lv)

subst(x: %, lk: List K, lv: List %) == smpsubst(number x, lk, lv)

differentiate(x: %, s: SY) == smpderiv(number x, s)

coerce(x: %): OutputForm == smp20 number x

if R has ConvertibleTo InputForm then
  eval(f: %, l: List SY) == smpunq(number f, l, true)

  eval f == smpunq(number f, empty(), false)

eval(x: %, s: List SY, n: List N, f: List(List % -> %)) ==
  smprep(s, n, f, number x)

isPlus x ==
  (u := isPlus number x) case "failed" => "failed"
  [p: % for p in u: List(MP)]

isTimes x ==
  (u := isTimes number x) case "failed" => "failed"
  [p: % for p in u: List(MP)]

isExpt x ==
  (u := isExpt number x) case "failed" => "failed"
  r := u: Record(var: K, exponent: NonNegativeInteger)
  [r.var, r.exponent: Z]

isPower x ==
  (u := isExpt number x) case "failed" => "failed"
  r := u: Record(var: K, exponent: NonNegativeInteger)
  [r.var: %, r.exponent: Z]

if R has ConvertibleTo Pattern Z then
  convert(x: %): Pattern(Z) == convert number x

if R has ConvertibleTo Pattern Float then
  convert(x: %): Pattern(Float) == convert number x

if R has RetractableTo Z then
  isMult x == smpIsMult number x

if R has CommutativeRing then
  r: R * x: % == r: MP: % * x

```

```

if R has IntegralDomain then
  par : % -> %

  mainKernel x == mainVariable(x)$QF

  kernels x == variables(x)$QF

  univariate(x:%, k:K) == univariate(x, k)$QF

  isPlus x == isPlus(x)$QF

  isTimes x == isTimes(x)$QF

  isExpt x == isExpt(x)$QF

  isPower x == isPower(x)$QF

  denominator x == denom(x)::%

  coerce(q:Q):% == (numer q)::MP / (denom q)::MP

  coerce(q:Fraction PR):% == (numer q)::% / (denom q)::%

  coerce(q:Fraction Polynomial Q) == (numer q)::% / (denom q)::%

  retract(x:%):PR == retract(retract(x)@Fraction(PR))

  retract(x:%):Fraction(PR) == smpret(numer x)::PR / smpret(denom x)::PR

  retract(x:%):R == (retract(numer x)@R exquo retract(denom x)@R)::R

  coerce(x:%):OutputForm ==
--    one?(denom x) => smp20 numer x
    ((denom x) = 1) => smp20 numer x
    smp20(numer x) / smp20(denom x)

  retractIfCan(x:%):Union(R, "failed") ==
    (n := retractIfCan(numer x)@Union(R, "failed")) case "failed" or
    (d := retractIfCan(denom x)@Union(R, "failed")) case "failed"
    or (r := n::R exquo d::R) case "failed" => "failed"
    r::R

  eval(f:%, l:List SY) ==
    smpunq(numer f, l, true) / smpunq(denom f, l, true)

if R has ConvertibleTo InputForm then
  eval f ==
    smpunq(numer f, empty(), false) / smpunq(denom f, empty(), false)

  eval(x:%, s:List SY, n:List N, f:List(List % -> %)) ==

```

```

smprep(s, n, f, numer x) / smprep(s, n, f, denom x)

differentiate(f:%, x:SY) ==
  (smpderiv(numer f, x) * denom(f)::% -
   numer(f)::% * smpderiv(denom f, x))
  / (denom(f)::% ** 2)

eval(x:%, lk:List K, lv:List %) ==
  smpeval(numer x, lk, lv) / smpeval(denom x, lk, lv)

subst(x:%, lk:List K, lv:List %) ==
  smpsubst(numer x, lk, lv) / smpsubst(denom x, lk, lv)

par x ==
  (r := retractIfCan(x)@Union(R, "failed")) case R => x
  paren x

convert(x:Factored %):% ==
  par(unit x) * */[par(f.factor) ** f.exponent for f in factors x]

retractIfCan(x:%):Union(PR, "failed") ==
  (u := retractIfCan(x)@Union(Fraction PR, "failed")) case "failed"
  => "failed"
  retractIfCan(u::Fraction(PR))

retractIfCan(x:%):Union(Fraction PR, "failed") ==
  (n := smpret numer x) case "failed" => "failed"
  (d := smpret denom x) case "failed" => "failed"
  n::PR / d::PR

coerce(p:Polynomial Q):% ==
  map(x+>x:%, y+>y:%, p)_
  $PolynomialCategoryLifting(IndexedExponents SY, SY,
                              Q, Polynomial Q, %)

if R has RetractableTo Z then
  coerce(x:Fraction Z):% == numer(x)::MP / denom(x)::MP

isMult x ==
  (u := smpIsMult numer x) case "failed"
  or (v := retractIfCan(denom x)@Union(R, "failed")) case "failed"
  or (w := retractIfCan(v::R)@Union(Z, "failed")) case "failed"
  => "failed"
  r := u::Record(coef:Z, var:K)
  (q := r.coef exquo w::Z) case "failed" => "failed"
  [q::Z, r.var]

if R has ConvertibleTo Pattern Z then
  convert(x:%):Pattern(Z) == convert(numer x) / convert(denom x)

```

```

if R has ConvertibleTo Pattern Float then
  convert(x: %):Pattern(Float) ==
    convert(numer x) / convert(denom x)

```

— FS.dotabb —

```

"FS"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FS"];
"FS" -> "ES"
"FS" -> "FPATMAB"
"FS" -> "FRETRCT"
"FS" -> "PATAB"
"FS" -> "RETRACT"
"FS" -> "KONVERT"
"FS" -> "MONOID"
"FS" -> "GROUP"
"FS" -> "ABELMON"
"FS" -> "ABELGRP"
"FS" -> "PDRING"
"FS" -> "FLINEXP"
"FS" -> "CHARNZ"
"FS" -> "INTDOM"
"FS" -> "FIELD"

```

— FS.dotfull —

```

"FunctionSpace(a:OrderedSet)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FS"];
"FunctionSpace(a:OrderedSet)" -> "ExpressionSpace()"
"FunctionSpace(a:OrderedSet)" -> "RetractableTo(Symbol)"
"FunctionSpace(a:OrderedSet)" -> "Patternable(OrderedSet)"
"FunctionSpace(a:OrderedSet)" -> "FullyPatternMatchable(OrderedSet)"
"FunctionSpace(a:OrderedSet)" -> "FullyRetractableTo(OrderedSet)"
"FunctionSpace(a:OrderedSet)" -> "ConvertibleTo(InputForm)"
"FunctionSpace(a:OrderedSet)" -> "Monoid()"
"FunctionSpace(a:OrderedSet)" -> "Group()"
"FunctionSpace(a:OrderedSet)" -> "AbelianMonoid()"
"FunctionSpace(a:OrderedSet)" -> "AbelianGroup()"
"FunctionSpace(a:OrderedSet)" -> "PartialDifferentialRing(Symbol)"
"FunctionSpace(a:OrderedSet)" -> "FullyLinearlyExplicitRingOver(OrderedSet)"
"FunctionSpace(a:OrderedSet)" -> "CharacteristicNonZero()"
"FunctionSpace(a:OrderedSet)" -> "IntegralDomain()"

```

```

"FunctionSpace(a:OrderedSet)" -> "Field()"
"FunctionSpace(a:OrderedSet)" -> "RetractableTo(Integer)"
"FunctionSpace(a:OrderedSet)" -> "RetractableTo(Fraction(Integer))"

```

— FS.dotpic —

```

digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "FunctionSpace(a:OrderedSet)" [color=lightblue];
    "FunctionSpace(a:OrderedSet)" -> "ES..."
    "FunctionSpace(a:OrderedSet)" -> "RETRACT..."
    "FunctionSpace(a:OrderedSet)" -> "PATAB..."
    "FunctionSpace(a:OrderedSet)" -> "FPATMAB..."
    "FunctionSpace(a:OrderedSet)" -> "FRETRACT..."
    "FunctionSpace(a:OrderedSet)" -> "KONVERT..."
    "FunctionSpace(a:OrderedSet)" -> "MONOID..."
    "FunctionSpace(a:OrderedSet)" -> "GROUP..."
    "FunctionSpace(a:OrderedSet)" -> "ABELMON..."
    "FunctionSpace(a:OrderedSet)" -> "ABELGRP..."
    "FunctionSpace(a:OrderedSet)" -> "PDRING..."
    "FunctionSpace(a:OrderedSet)" -> "FLINEXP..."
    "FunctionSpace(a:OrderedSet)" -> "CHARNZ..."
    "FunctionSpace(a:OrderedSet)" -> "INTDOM..."
    "FunctionSpace(a:OrderedSet)" -> "FIELD..."
    "FunctionSpace(a:OrderedSet)" -> "RETRACT..."

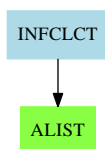
    "ES..." [color=lightblue];
    "EVALABLE..." [color=lightblue];
    "FRETRACT..." [color=lightblue];
    "FPATMAB..." [color=lightblue];
    "IEVALAB..." [color=lightblue];
    "ORDSET..." [color=lightblue];
    "PATAB..." [color=lightblue];
    "RETRACT..." [color=lightblue];
    "KONVERT..." [color=lightblue];
    "MONOID..." [color=lightblue];
    "GROUP..." [color=lightblue];
    "ABELMON..." [color=lightblue];
    "ABELGRP..." [color=lightblue];
    "PDRING..." [color=lightblue];
    "FLINEXP..." [color=lightblue];
    "CHARNZ..." [color=lightblue];
    "INTDOM..." [color=lightblue];
}

```

```
"FIELD..." [color=lightblue];
"RETRACT..." [color=lightblue];
}
```

—————

InfinitelyClosePointCategory (INFCLCT)



— InfinitelyClosePointCategory.input —

```
)set break resume
)sys rm -f InfinitelyClosePointCategory.output
)spool InfinitelyClosePointCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show InfinitelyClosePointCategory
--I InfinitelyClosePointCategory(K: Field,
--I symb: List Symbol,
--I PolyRing: PolynomialCategory(t#1,t#4,OrderedVariableList t#2),
--I E: DirectProductCategory(# t#2,NonNegativeInteger),
--I ProjPt: ProjectiveSpaceCategory t#1,
--I PCS: LocalPowerSeriesCategory t#1,
--I Plc: PlacesCategory(t#1,t#6),
--I DIVISOR: DivisorCategory t#7,
--I BLMET: BlowUpMethodCategory) is a category constructor
--I Abbreviation for InfinitelyClosePointCategory is INFCLCT
--I This constructor is exposed in this frame.
--I Issue )edit bookvol10.2.pamphlet to see algebra source code for INFCLCT
--I
--I----- Operations -----
--I ?? : (%,% ) -> Boolean          actualExtensionV : % -> K
--I chartV : % -> BLMET             coerce : % -> OutputForm
--I create : (ProjPt,PolyRing) -> % degree : % -> PositiveInteger
--I excpDivV : % -> DIVISOR          hash : % -> SingleInteger
--I latex : % -> String              localParamV : % -> List PCS
```

```

--I localPointV : % -> AffinePlane K      multV : % -> NonNegativeInteger
--I pointV : % -> ProjPt                  setchart! : (% , BLMET) -> BLMET
--I setpoint! : (% , ProjPt) -> ProjPt     symbNameV : % -> Symbol
--I ?~=? : (% , %) -> Boolean
--I create : (ProjPt,
--I   DistributedMultivariatePolynomial([construct, QUOTEX, QUOTEY], K),
--I   AffinePlane K,
--I   NonNegativeInteger,
--I   BLMET,
--I   NonNegativeInteger,
--I   DIVISOR,
--I   K,
--I   Symbol) -> %
--I curveV : % ->
--I   DistributedMultivariatePolynomial([construct, QUOTEX, QUOTEY], K)
--I setcurve! :
--I   (% , DistributedMultivariatePolynomial([construct, QUOTEX, QUOTEY], K)) ->
--I   DistributedMultivariatePolynomial([construct, QUOTEX, QUOTEY], K)
--I setexcpDiv! : (% , DIVISOR) -> DIVISOR
--I setlocalParam! : (% , List PCS) -> List PCS
--I setlocalPoint! : (% , AffinePlane K) -> AffinePlane K
--I setmult! : (% , NonNegativeInteger) -> NonNegativeInteger
--I setsubmult! : (% , NonNegativeInteger) -> NonNegativeInteger
--I setsymbName! : (% , Symbol) -> Symbol
--I subMultV : % -> NonNegativeInteger
--I
--E 1

)spool
)lisp (bye)

```

— InfinitelyClosePointCategory.help —

```

=====
InfinitelyClosePointCategory examples
=====

```

This category is part of the PAFF package

See Also:

o)show InfinitelyClosePointCategory

⇐ “SetCategoryWithDegree” (SETCATD) 4 on page 296

Exports:

| | | | |
|-------------|-------------|------------------|----------------|
| ?=? | ?~=? | actualExtensionV | chartV |
| coerce | create | curveV | degree |
| excpDivV | hash | latex | localParamV |
| localPointV | multV | pointV | setchart! |
| setcurve! | setexcpDiv! | setlocalParam! | setlocalPoint! |
| setmult! | setpoint! | setsubmult! | setsymbName! |
| subMultV | symbNameV | | |

These are directly exported but not implemented:

```

actualExtensionV : % -> K
chartV : % -> BLMET
create :
  (ProjPt,DistributedMultivariatePolynomial([construct,QUOTEX,QUOTEY],K),
   AffinePlane K,NonNegativeInteger,BLMET,NonNegativeInteger,DIVISOR,K,Symbol)
  -> %
create : (ProjPt,PolyRing) -> %
curveV : % -> DistributedMultivariatePolynomial([construct,QUOTEX,QUOTEY],K)
excpDivV : % -> DIVISOR
localParamV : % -> List PCS
localPointV : % -> AffinePlane K
multV : % -> NonNegativeInteger
pointV : % -> ProjPt
setchart! : (% ,BLMET) -> BLMET
setcurve! :
  (% ,DistributedMultivariatePolynomial([construct,QUOTEX,QUOTEY],K)) ->
    DistributedMultivariatePolynomial([construct,QUOTEX,QUOTEY],K)
setexcpDiv! : (% ,DIVISOR) -> DIVISOR
setlocalParam! : (% ,List PCS) -> List PCS
setlocalPoint! : (% ,AffinePlane K) -> AffinePlane K
setmult! : (% ,NonNegativeInteger) -> NonNegativeInteger
setpoint! : (% ,ProjPt) -> ProjPt
setsubmult! : (% ,NonNegativeInteger) -> NonNegativeInteger
setsymbName! : (% ,Symbol) -> Symbol
subMultV : % -> NonNegativeInteger
symbNameV : % -> Symbol

```

These exports come from (p296) SetCategoryWithDegree:

```

?=? : (% ,%) -> Boolean
?~=? : (% ,%) -> Boolean
coerce : % -> OutputForm
degree : % -> PositiveInteger
hash : % -> SingleInteger
latex : % -> String

```



```

)abbrev category INFCLCT InfinitelyClosePointCategory
++ Authors: Gaetan Hache
++ Date Created: may 1997
++ Date Last Updated: April 2010, by Tim Daly
++ Description:
++ This category is part of the PAFF package
InfinitelyClosePointCategory(_
  K      :Field,_
  symb   :List(Symbol),_
  PolyRing :PolynomialCategory(K,E,OrderedVariableList(symb)),_
  E      :DirectProductCategory(#symb,NonNegativeInteger),_
  ProjPt  :ProjectiveSpaceCategory(K),_
  PCS     :LocalPowerSeriesCategory(K),_
  Plc     :PlacesCategory(K,PCS),_
  DIVISOR :DivisorCategory(Plc),_
  BLMET   :BlowUpMethodCategory_
):Category == Exports where

bls      ==> ['X,'Y]
BlUpRing ==> DistributedMultivariatePolynomial(bls , K)
AFP      ==> AffinePlane(K)

Exports ==> SetCategoryWithDegree with

  create: (ProjPt , BlUpRing, AFP , NonNegativeInteger, BLMET, _
    NonNegativeInteger, DIVISOR, K, Symbol) -> %
    ++ create an infinitely close point

  create: (ProjPt, PolyRing) -> %

  setpoint_!: (% , ProjPt) -> ProjPt

  setcurve_!: (% , BlUpRing) -> BlUpRing

  setlocalPoint_!: (% , AFP) -> AFP

  setsubmult_! : (% , NonNegativeInteger) -> NonNegativeInteger

  setmult_!: (% , NonNegativeInteger) -> NonNegativeInteger

  setchart_!: (% , BLMET) -> BLMET -- CHH

  setexcpDiv_!: (% , DIVISOR) -> DIVISOR

  setlocalParam_!: (% , List PCS) -> List(PCS)

  setsymbName_!: (% , Symbol) -> Symbol

  subMultV: % -> NonNegativeInteger

```

```

localParamV: % -> List PCS

symbNameV: % -> Symbol

pointV: % -> ProjPt
  ++ pointV returns the infinitely close point.

curveV: % -> BlUpRing
  ++ curveV(p) returns the defining polynomial of the strict transform
  ++ on which lies the corresponding infinitely close point.

localPointV: % -> AFP
  ++ localPointV returns the coordinates of the local infinitely
  ++ close point

multV:      % -> NonNegativeInteger
  ++ multV returns the multiplicity of the infinitely close point.

chartV:      % -> BLMET -- CHH
  ++ chartV is the chart of the infinitely close point. The first integer
  ++ correspond to variable defining the exceptional line, the last one
  ++ the affine neighborhood and the second one is the
  ++ remaining integer. For example [1,2,3] means that
  ++ Z=1, X=X and Y=XY. [2,3,1] means that X=1, Y=Y and Z=YZ.

excpDivV:    % -> DIVISOR
  ++ excpDivV returns the exceptional divisor of the infinitely close point.

actualExtensionV: % -> K

```

— INFCLCT.dotabb —

```

"INFCLCT" [color=lightblue,href="bookvol10.2.pdf#nameddest=INFCLCT"];
"ALIST" [color="#88FF44",href="bookvol10.3.pdf#nameddest=ALIST"]
"INFCLCT" -> "ALIST"

```

— INFCLCT.dotfull —

```

"InfinitelyClosePointCategory"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=INFCLCT"];
"InfinitelyClosePointCategory" -> "AssociationList(SetCategory,SetCategory)"

```

— INFCLCT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

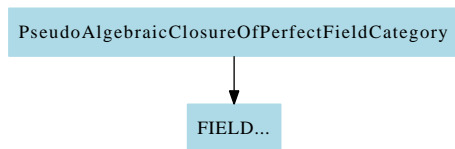
  "InfinitelyClosePointCategory" [color=lightblue];
  "InfinitelyClosePointCategory" -> "AssociationList(SetCategory,SetCategory)"

  "AssociationList(SetCategory,SetCategory)" -> "AssociationList()"

  "AssociationList()" [color=lightblue];
}

```

PseudoAlgebraicClosureOfPerfectFieldCategory (PACPERC)



— PseudoAlgebraicClosureOfPerfectFieldCategory.input —

```

)set break resume
)sys rm -f PseudoAlgebraicClosureOfPerfectFieldCategory.output
)spool PseudoAlgebraicClosureOfPerfectFieldCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PseudoAlgebraicClosureOfPerfectFieldCategory
--R
--R PseudoAlgebraicClosureOfPerfectFieldCategory is a category constructor
--R Abbreviation for PseudoAlgebraicClosureOfPerfectFieldCategory is PACPERC
--R This constructor is exposed in this frame.

```

```
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PACPERC
```

```
--R
```

```
--R----- Operations -----
```

```
--R ???: (Fraction(Integer),%) -> %      ??: (% , Fraction(Integer)) -> %
```

```
--R ??: (% , %) -> %                    ??: (Integer, %) -> %
```

```
--R ??: (PositiveInteger, %) -> %        ??: (% , Integer) -> %
```

```
--R ??: (% , PositiveInteger) -> %      ?+: (% , %) -> %
```

```
--R ?-?: (% , %) -> %                  -: % -> %
```

```
--R ?/? : (% , %) -> %                 ?=: (% , %) -> Boolean
```

```
--R 1 : () -> %                       0 : () -> %
```

```
--R ???: (% , Integer) -> %           ???: (% , PositiveInteger) -> %
```

```
--R associates?: (% , %) -> Boolean    coerce : Fraction(Integer) -> %
```

```
--R coerce : % -> %                   coerce : Integer -> %
```

```
--R coerce : % -> OutputForm          conjugate : % -> %
```

```
--R extDegree : % -> PositiveInteger   factor : % -> Factored(%)
```

```
--R fullOutput : % -> OutputForm       gcd : List(%) -> %
```

```
--R gcd : (% , %) -> %                ground?: % -> Boolean
```

```
--R hash : % -> SingleInteger          inv : % -> %
```

```
--R latex : % -> String               lcm : List(%) -> %
```

```
--R lcm : (% , %) -> %               maxTower : List(%) -> %
```

```
--R one?: % -> Boolean               previousTower : % -> %
```

```
--R prime?: % -> Boolean             ?quo?: (% , %) -> %
```

```
--R recip : % -> Union(%, "failed")   ?rem?: (% , %) -> %
```

```
--R sample : () -> %                 setTower! : % -> Void
```

```
--R sizeLess?: (% , %) -> Boolean     squareFree : % -> Factored(%)
```

```
--R squareFreePart : % -> %          unit?: % -> Boolean
```

```
--R unitCanonical : % -> %           vectorise : (% , %) -> Vector(%)
```

```
--R zero?: % -> Boolean              ?~=: (% , %) -> Boolean
```

```
--R ??: (NonNegativeInteger, %) -> %
```

```
--R ??: (% , NonNegativeInteger) -> %
```

```
--R ??: (% , NonNegativeInteger) -> %
```

```
--R characteristic : () -> NonNegativeInteger
```

```
--R definingPolynomial : % -> SparseUnivariatePolynomial(%)
```

```
--R definingPolynomial : () -> SparseUnivariatePolynomial(%)
```

```
--R distinguishedRootsOf : (SparseUnivariatePolynomial(%), %) -> List(%)
```

```
--R divide : (% , %) -> Record(quotient: %, remainder: %)
```

```
--R euclideanSize : % -> NonNegativeInteger
```

```
--R expressIdealMember : (List(%), %) -> Union(List(%), "failed")
```

```
--R exquo : (% , %) -> Union(%, "failed")
```

```
--R extendedEuclidean : (% , %, %) -> Union(Record(coef1: %, coef2: %), "failed")
```

```
--R extendedEuclidean : (% , %) -> Record(coef1: %, coef2: %, generator: %)
```

```
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
```

```
--R lift : (% , %) -> SparseUnivariatePolynomial(%)
```

```
--R lift : % -> SparseUnivariatePolynomial(%)
```

```
--R multiEuclidean : (List(%), %) -> Union(List(%), "failed")
```

```
--R newElement : (SparseUnivariatePolynomial(%), Symbol) -> %
```

```
--R newElement : (SparseUnivariatePolynomial(%), %, Symbol) -> %
```

```
--R principalIdeal : List(%) -> Record(coef: List(%), generator: %)
```

```
--R reduce : SparseUnivariatePolynomial(%) -> %
```

```
--R subtractIfCan : (% , %) -> Union(%, "failed")
```

```

--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— PseudoAlgebraicClosureOfPerfectFieldCategory.help —

```

=====
PseudoAlgebraicClosureOfPerfectFieldCategory examples
=====

```

This category exports the function for domains which implement dynamic extension using the simple notion of tower extensions. A tower extension T of the ground field K is any sequence of field extensions

($T : K_0, K_1, \dots, K_i, \dots, K_n$) where $K_0 = K$
and for
 $i = 1, 2, \dots, n$, K_i is an extension of K_{i-1} of degree > 1
and defined by an irreducible polynomial $p(Z)$ in K_{i-1} .

Two towers

($T_1 : K_{01}, K_{11}, \dots, K_{i1}, \dots, K_{n1}$)

and

($T_2 : K_{02}, K_{12}, \dots, K_{i2}, \dots, K_{n2}$)

are said to be related if

$T_1 \leq T_2$ (or $T_1 \geq T_2$),

that is if

$K_{i1} = K_{i2}$ for $i = 1, 2, \dots, n_1$ (or $i = 1, 2, \dots, n_2$).

Any algebraic operations defined for several elements are only defined if all of the concerned elements are coming from a set of related tower extensions.

See Also:

o)show PseudoAlgebraicClosureOfPerfectFieldCategory

⇐ “Field” (FIELD) [16](#) on page [1271](#)

Exports:

| | | | |
|---------------|-------------------|--------------------|----------------------|
| 0 | 1 | associates? | characteristic |
| coerce | conjugate | definingPolynomial | distinguishedRootsOf |
| divide | euclideanSize | expressIdealMember | exquo |
| extDegree | extendedEuclidean | factor | fullOutput |
| gcd | gcdPolynomial | ground? | hash |
| inv | latex | lcm | lift |
| maxTower | multiEuclidean | newElement | one? |
| previousTower | prime? | principalIdeal | ?quo? |
| recip | reduce | ?rem? | sample |
| setTower! | sizeLess? | squareFree | squareFreePart |
| subtractIfCan | unit? | unitCanonical | unitNormal |
| vectorise | zero? | ?*? | ?**? |
| ?+? | ?-? | -? | ?/? |
| ?=? | ?^? | ?~=? | |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **canonicalsClosed** is true if `unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative(“*”)** is true if it has an operation “ $*$ ” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```

conjugate: % -> %
definingPolynomial: () -> SUP(%)
definingPolynomial: % -> SUP %
distinguishedRootsOf: (SparseUnivariatePolynomial %,%) -> List %
extDegree: % -> PI
fullOutput: % -> OutputForm
ground_? : % -> Boolean
lift: % -> SUP(%)
lift: (%,%) -> SUP(%)
maxTower: List % -> %
newElement: (SUP(%), %, Symbol) -> %
newElement: (SUP(%), Symbol) -> %

```

```

previousTower: % -> %
reduce: SUP(%) -> %
setTower_!: % -> Void
vectorise: (%,%) -> Vector(%)

```

These exports come from (p1271) Field():

```

associates? : (%,%) -> Boolean
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
exquo : (%,%) -> Union(%, "failed")
factor : % -> Factored %
gcd : (%,%) -> %
inv : % -> %
prime? : % -> Boolean
squareFree : % -> Factored %
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
?/? : (%,%) -> %

```

These exports come from (p1235) EuclideanDomain():

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
expressIdealMember : (List %,%) -> Union(List %, "failed")
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
gcd : List % -> %
gcdPolynomial : (SparseUnivariatePolynomial %,
                  SparseUnivariatePolynomial %) ->
                  SparseUnivariatePolynomial %
hash : % -> SingleInteger
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
multiEuclidean : (List %,%) -> Union(List %, "failed")
one? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%, "failed")
sample : () -> %
sizeLess? : (%,%) -> Boolean
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean

```

```

?~=? : (%,% ) -> Boolean
?*? : (%,% ) -> %
?*? : (Integer,% ) -> %
?*? : (PositiveInteger,% ) -> %
?*? : (NonNegativeInteger,% ) -> %
?-? : (%,% ) -> %
-? : % -> %
***? : (% ,PositiveInteger) -> %
***? : (% ,NonNegativeInteger) -> %
?^? : (% ,PositiveInteger) -> %
?^? : (% ,NonNegativeInteger) -> %
?quo? : (%,% ) -> %
?rem? : (%,% ) -> %

```

These exports come from (p1222) UniqueFactorizationDomain():

```
squareFreePart : % -> %
```

These exports come from (p1063) DivisionRing():

```

coerce : Fraction Integer -> %
?*? : (Fraction Integer,% ) -> %
?*? : (% ,Fraction Integer) -> %
***? : (% ,Integer) -> %
?^? : (% ,Integer) -> %

```

— category PACPERC PseudoAlgebraicClosureOfPerfectFieldCategory —

```

)abbrev category PACPERC PseudoAlgebraicClosureOfPerfectFieldCategory
++ Authors: Gaetan Hache
++ Date Created: may 1997
++ Date Last Updated: April 2010, by Tim Daly
++ Description:
++ This category exports the function for domains
++ which implement dynamic extension using the simple notion of tower
++ extensions. ++ A tower extension T of the ground
++ field K is any sequence of field extension
++ (T : K_0, K_1, ..., K_i...,K_n) where K_0 = K
++ and for i =1,2,...,n, K_i is an extension of K_{i-1} of degree > 1
++ and defined by an irreducible polynomial p(Z) in K_{i-1}.
++ Two towers (T_1: K_01, K_11,...,K_i1,...,K_n1)
++ and (T_2: K_02, K_12,...,K_i2,...,K_n2)
++ are said to be related if T_1 <= T_2 (or T_1 >= T_2),
++ that is if K_i1 = K_i2 for i=1,2,...,n1 (or i=1,2,...,n2).
++ Any algebraic operations defined for several elements
++ are only defined if all of the concerned elements are coming from
++ a set of related tower extensions.

```



```

PseudoAlgebraicClosureOfPerfectFieldCategory() : Category == PUB where

INT      ==> Integer
K        ==> Fraction Integer
NNI      ==> NonNegativeInteger
SUP      ==> SparseUnivariatePolynomial
BOOLEAN  ==> Boolean
PI       ==> PositiveInteger
FFFACTSE ==> FiniteFieldFactorizationWithSizeParseBySideEffect

PUB ==> Field with

definingPolynomial: () -> SUP(%)
definingPolynomial: % -> SUP %

lift: % -> SUP(%)
lift: (%,% ) -> SUP(%)
reduce: SUP(%) -> %

distinguishedRootsOf: (SparseUnivariatePolynomial %,%) -> List %
++ distinguishedRootsOf(p,a) returns a (distinguished) root for each
++ irreducible factor of the polynomial p (factored over the field defined
++ by the element a).

ground_? : % -> Boolean
maxTower: List % -> %
++ maxTower(l) returns the tower in the list having the maximal extension
++ degree over the ground field. It has no meaning if the towers are
++ not related.
extDegree: % -> PI
++ extDegree(a) returns the extension degree of the extension tower
++ over which the element is defined.
previousTower: % -> %
++ previousTower(a) returns the previous tower extension over which
++ the element a is defined.

vectorise: (%,% ) -> Vector(%)

conjugate: % -> %
newElement: (SUP(%), %, Symbol) -> %
newElement: (SUP(%), Symbol) -> %
setTower_!: % -> Void
fullOutput: % -> OutputForm

```

```
"PACPERC" [color=lightblue,href="bookvol10.2.pdf#nameddest=PACPERC"];
"PACPERC" -> "FIELD"
```

— PACPERC.dotfull —

```
"PseudoAlgebraicClosureOfPerfectFieldCategory"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PACPERC"];
"PseudoAlgebraicClosureOfPerfectFieldCategory" -> "Field()"
```

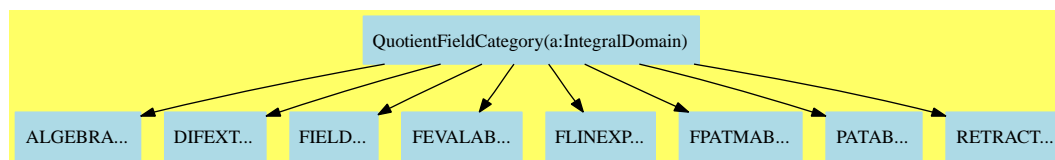
— PACPERC.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PseudoAlgebraicClosureOfPerfectFieldCategory" [color=lightblue];
  "PseudoAlgebraicClosureOfPerfectFieldCategory" -> "FIELD..."

  "FIELD..." [color=lightblue];
}
```

QuotientFieldCategory (QFCAT)



— QuotientFieldCategory.input —

```
)set break resume
```

```

)sys rm -f QuotientFieldCategory.output
)spool QuotientFieldCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show QuotientFieldCategory
--R
--R QuotientFieldCategory(S: IntegralDomain) is a category constructor
--R Abbreviation for QuotientFieldCategory is QFCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for QFCAT
--R
--R----- Operations -----
--R ???: (%,S) -> %                ???: (S,%) -> %
--R ???: (Fraction(Integer),%) -> % ???: (%,Fraction(Integer)) -> %
--R ???: (%,%) -> %                ???: (Integer,%) -> %
--R ???: (PositiveInteger,%) -> %   ????: (%,Integer) -> %
--R ????: (%,PositiveInteger) -> % ?+?: (%,%) -> %
--R ?-?: (%,%) -> %                -?: % -> %
--R ?/? : (S,S) -> %                ?/? : (%,%) -> %
--R ?=: (%,%) -> Boolean            D : (%,(S -> S)) -> %
--R D : % -> % if S has DIFRING     1 : () -> %
--R 0 : () -> %                    ?^?: (%,Integer) -> %
--R ??: (%,PositiveInteger) -> %    associates?: (%,%) -> Boolean
--R ceiling : % -> % if S has INS    coerce : S -> %
--R coerce : Fraction(Integer) -> %  coerce : % -> %
--R coerce : Integer -> %            coerce : % -> OutputForm
--R denom : % -> S                   denominator : % -> %
--R factor : % -> Factored(%)        floor : % -> % if S has INS
--R gcd : List(%) -> %               gcd : (%,%) -> %
--R hash : % -> SingleInteger        init : () -> % if S has STEP
--R inv : % -> %                     latex : % -> String
--R lcm : List(%) -> %               lcm : (%,%) -> %
--R map : ((S -> S),%) -> %          numer : % -> S
--R numerator : % -> %              one?: % -> Boolean
--R prime?: % -> Boolean              ?quo?: (%,%) -> %
--R random : () -> % if S has INS    recip : % -> Union(%, "failed")
--R ?rem?: (%,%) -> %               retract : % -> S
--R sample : () -> %                sizeLess?: (%,%) -> Boolean
--R squareFree : % -> Factored(%)    squareFreePart : % -> %
--R unit?: % -> Boolean              unitCanonical : % -> %
--R zero?: % -> Boolean              ?~=: (%,%) -> Boolean
--R ???: (NonNegativeInteger,%) -> %
--R ????: (%,NonNegativeInteger) -> %
--R ?<?: (%,%) -> Boolean if S has ORDSET
--R ?<=: (%,%) -> Boolean if S has ORDSET
--R ?>?: (%,%) -> Boolean if S has ORDSET
--R ?>=: (%,%) -> Boolean if S has ORDSET

```

```

--R D : (%,(S -> S),NonNegativeInteger) -> %
--R D : (%,List(Symbol),List(NonNegativeInteger)) -> % if S has PDRING(SYMBOL)
--R D : (%,Symbol,NonNegativeInteger) -> % if S has PDRING(SYMBOL)
--R D : (%,List(Symbol)) -> % if S has PDRING(SYMBOL)
--R D : (%,Symbol) -> % if S has PDRING(SYMBOL)
--R D : (%,NonNegativeInteger) -> % if S has DIFRING
--R ?? : (%,NonNegativeInteger) -> %
--R abs : % -> % if S has OINTDOM
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if S has CHARNZ or and(has($,CharacteristicNonZero),has(S,Polynomial))
--R coerce : Symbol -> % if S has RETRACT(SYMBOL)
--R conditionP : Matrix(%) -> Union(Vector(%), "failed") if and(has($,CharacteristicNonZero),has(S,Polynomial))
--R convert : % -> DoubleFloat if S has REAL
--R convert : % -> Float if S has REAL
--R convert : % -> InputForm if S has KONVERT(INFORM)
--R convert : % -> Pattern(Float) if S has KONVERT(PATTERN(FLOAT))
--R convert : % -> Pattern(Integer) if S has KONVERT(PATTERN(INT))
--R differentiate : (%,(S -> S)) -> %
--R differentiate : (%,(S -> S),NonNegativeInteger) -> %
--R differentiate : (%,List(Symbol),List(NonNegativeInteger)) -> % if S has PDRING(SYMBOL)
--R differentiate : (%,Symbol,NonNegativeInteger) -> % if S has PDRING(SYMBOL)
--R differentiate : (%,List(Symbol)) -> % if S has PDRING(SYMBOL)
--R differentiate : (%,Symbol) -> % if S has PDRING(SYMBOL)
--R differentiate : (%,NonNegativeInteger) -> % if S has DIFRING
--R differentiate : % -> % if S has DIFRING
--R divide : (%,%) -> Record(quotient: %,remainder: %)
--R ?? : (%,S) -> % if S has ELTAB(S,S)
--R euclideanSize : % -> NonNegativeInteger
--R eval : (%,Symbol,S) -> % if S has IEVALAB(SYMBOL,S)
--R eval : (%,List(Symbol),List(S)) -> % if S has IEVALAB(SYMBOL,S)
--R eval : (%,List(Equation(S))) -> % if S has EVALAB(S)
--R eval : (%,Equation(S)) -> % if S has EVALAB(S)
--R eval : (%,S,S) -> % if S has EVALAB(S)
--R eval : (%,List(S),List(S)) -> % if S has EVALAB(S)
--R expressIdealMember : (List(%),%) -> Union(List(%), "failed")
--R exquo : (%,%) -> Union(%, "failed")
--R extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
--R extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
--R factorPolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%)) if S has PDRING(SYMBOL)
--R factorSquareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%)) if S has PDRING(SYMBOL)
--R fractionPart : % -> % if S has EUCLDOM
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%) if S has PDRING(SYMBOL)
--R max : (%,%) -> % if S has ORDSET
--R min : (%,%) -> % if S has ORDSET
--R multiEuclidean : (List(%),%) -> Union(List(%), "failed")
--R negative? : % -> Boolean if S has OINTDOM
--R nextItem : % -> Union(%, "failed") if S has STEP
--R patternMatch : (%,Pattern(Float),PatternMatchResult(Float,%)) -> PatternMatchResult(Float,%) if S has PDRING(SYMBOL)
--R patternMatch : (%,Pattern(Integer),PatternMatchResult(Integer,%)) -> PatternMatchResult(Integer,%) if S has PDRING(SYMBOL)
--R positive? : % -> Boolean if S has OINTDOM

```

```

--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R reducedSystem : Matrix(%) -> Matrix(S)
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(S),vec: Vector(S))
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Integer),vec: Vector(Integer))
--R reducedSystem : Matrix(%) -> Matrix(Integer) if S has LINEXP(INT)
--R retract : % -> Integer if S has RETRACT(INT)
--R retract : % -> Fraction(Integer) if S has RETRACT(INT)
--R retract : % -> Symbol if S has RETRACT(SYMBOL)
--R retractIfCan : % -> Union(Integer,"failed") if S has RETRACT(INT)
--R retractIfCan : % -> Union(Fraction(Integer),"failed") if S has RETRACT(INT)
--R retractIfCan : % -> Union(Symbol,"failed") if S has RETRACT(SYMBOL)
--R retractIfCan : % -> Union(S,"failed")
--R sign : % -> Integer if S has OINTDOM
--R solveLinearPolynomialEquation : (List(SparseUnivariatePolynomial(%)),SparseUnivariatePolynomial(
--R squareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(
--R subtractIfCan : (%,%) -> Union(%,"failed")
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R wholePart : % -> S if S has EUCDOM
--R
--E 1

)spool
)lisp (bye)

```

— QuotientFieldCategory.help —

=====

QuotientFieldCategory examples

=====

QuotientField(S) is the category of fractions of an Integral Domain S.

See Also:

o)show QuotientFieldCategory

See:

- ⇐ “Algebra” (ALGEBRA) [11](#) on page [999](#)
- ⇐ “CharacteristicNonZero” (CHARNZ) [10](#) on page [887](#)
- ⇐ “CharacteristicZero” (CHARZ) [10](#) on page [892](#)
- ⇐ “ConvertibleTo” (KONVERT) [2](#) on page [41](#)
- ⇐ “DifferentialExtension” (DIFEXT) [11](#) on page [1005](#)
- ⇐ “EuclideanDomain” (EUCDOM) [15](#) on page [1235](#)
- ⇐ “Field” (FIELD) [16](#) on page [1271](#)

⇐ “FullyEvaluableOver” (FEVALAB) 4 on page 209
 ⇐ “FullyLinearlyExplicitRingOver” (FLINEXP) 11 on page 1012
 ⇐ “FullyPatternMatchable” (FPATMAB) 3 on page 141
 ⇐ “OrderedIntegralDomain” (OINTDOM) 13 on page 1185
 ⇐ “OrderedSet” (ORDSET) 4 on page 269
 ⇐ “Patternable” (PATAB) 2 on page 86
 ⇐ “PolynomialFactorizationExplicit” (PFECAT) 15 on page 1253
 ⇐ “RealConstant” (REAL) 3 on page 155
 ⇐ “RetractableTo” (RETRACT) 2 on page 95
 ⇐ “StepThrough” (STEP) 4 on page 305

Exports:

| | | |
|------------------|----------------------------|-------------------------------|
| 0 | 1 | abs |
| associates? | ceiling | characteristic |
| charthRoot | coerce | conditionP |
| convert | D | denom |
| denominator | differentiate | divide |
| euclideanSize | eval | expressIdealMember |
| exquo | extendedEuclidean | factor |
| factorPolynomial | factorSquareFreePolynomial | floor |
| fractionPart | gcd | gcdPolynomial |
| hash | init | inv |
| latex | lcm | map |
| max | min | multiEuclidean |
| negative? | nextItem | numer |
| numerator | one? | patternMatch |
| positive? | prime? | principalIdeal |
| random | recip | reducedSystem |
| retract | retractIfCan | sample |
| sign | sizeLess? | solveLinearPolynomialEquation |
| squareFree | squareFreePart | squareFreePolynomial |
| subtractIfCan | unit? | unitNormal |
| unitCanonical | wholePart | zero? |
| ?.? | ?*? | ?**? |
| ?+? | ?-? | -? |
| ?/? | ?=? | ?^? |
| ?quo? | ?rem? | ?~=? |
| ?<? | ?<=? | ?>? |
| ?>=? | | |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.

- **canonicalsClosed** is true if
`unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative("*)** is true if it has an operation $" * "$: $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return "failed" if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- **nil**

These are directly exported but not implemented:

```
ceiling : % -> S if S has INS
denom : % -> S
floor : % -> S if S has INS
numer : % -> S
wholePart : % -> S if S has EUCDOM
?/? : (S,S) -> %
```

These are implemented by this category:

```
characteristic : () -> NonNegativeInteger
coerce : Symbol -> % if S has RETRACT SYMBOL
coerce : Fraction Integer -> %
convert : % -> InputForm if S has KONVERT INFORM
convert : % -> DoubleFloat if S has REAL
convert : % -> Float if S has REAL
convert : % -> Pattern Integer if S has KONVERT PATTERN INT
convert : % -> Pattern Float if S has KONVERT PATTERN FLOAT
denominator : % -> %
differentiate : (%, (S -> S)) -> %
fractionPart : % -> % if S has EUCDOM
init : () -> % if S has STEP
map : ((S -> S), %) -> %
nextItem : % -> Union(%, "failed") if S has STEP
numerator : % -> %
patternMatch :
  (%, Pattern Float, PatternMatchResult(Float, %)) ->
    PatternMatchResult(Float, %)
    if S has PATMAB FLOAT
patternMatch :
  (%, Pattern Integer, PatternMatchResult(Integer, %)) ->
    PatternMatchResult(Integer, %)
```

```

    if S has PATMAB INT
random : () -> % if S has INS
reducedSystem : Matrix % -> Matrix S
reducedSystem : (Matrix %,Vector %) -> Record(mat: Matrix S,vec: Vector S)
retract : % -> Symbol if S has RETRACT SYMBOL
retract : % -> Integer if S has RETRACT INT
retractIfCan : % -> Union(Integer,"failed") if S has RETRACT INT
retractIfCan : % -> Union(Symbol,"failed") if S has RETRACT SYMBOL
?<? : (%,%) -> Boolean if S has ORDSET

```

These exports come from (p1271) Field():

```

0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %,"failed")
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
exquo : (%,%) -> Union(%,"failed")
factor : % -> Factored %
gcd : (%,%) -> %
gcd : List % -> %
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
   SparseUnivariatePolynomial %
hash : % -> SingleInteger
inv : % -> %
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
multiEuclidean : (List %,%) -> Union(List %,"failed")
one? : % -> Boolean
prime? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%,"failed")
sample : () -> %
sizeLess? : (%,%) -> Boolean
squareFree : % -> Factored %
squareFreePart : % -> %
subtractIfCan : (%,%) -> Union(%,"failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
zero? : % -> Boolean

```



```

?? : (Fraction Integer,%) -> %
?? : (%,Fraction Integer) -> %
***? : (%,Integer) -> %
?? : (%,Integer) -> %
+? : (%,%) -> %
=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?? : (%,%) -> %
?? : (Integer,%) -> %
?? : (PositiveInteger,%) -> %
?? : (NonNegativeInteger,%) -> %
-? : (%,%) -> %
-? : % -> %
***? : (%,PositiveInteger) -> %
***? : (%,NonNegativeInteger) -> %
?? : (%,NonNegativeInteger) -> %
?? : (%,PositiveInteger) -> %
?/? : (%,%) -> %
?quo? : (%,%) -> %
?rem? : (%,%) -> %

```

These exports come from (p999) Algebra(S:IntegralDomain):

```

coerce : S -> %
?? : (%,S) -> %
?? : (S,%) -> %

```

These exports come from (p95) RetractableTo(S:IntegralDomain):

```

retract : % -> S
retractIfCan : % -> Union(S,"failed")

```

These exports come from (p209) FullyEvalableOver(S:IntegralDomain):

```

?.? : (%,S) -> % if S has ELTAB(S,S)
eval : (%,Equation S) -> % if S has EVALAB S
eval : (%,List Symbol,List S) -> % if S has IEVALAB(SYMBOL,S)
eval : (%,List Equation S) -> % if S has EVALAB S
eval : (%,S,S) -> % if S has EVALAB S
eval : (%,List S,List S) -> % if S has EVALAB S
eval : (%,Symbol,S) -> % if S has IEVALAB(SYMBOL,S)

```

These exports come from (p1005) DifferentialExtension(S:IntegralDomain):

```

D : (%,(S -> S)) -> %
D : (%,(S -> S),NonNegativeInteger) -> %
D : % -> % if S has DIFRING
D : (%,NonNegativeInteger) -> % if S has DIFRING
D : (%,List Symbol,List NonNegativeInteger) -> %

```

```

    if S has PDRING SYMBOL
D : (%,Symbol,NonNegativeInteger) -> %
    if S has PDRING SYMBOL
D : (%,List Symbol) -> % if S has PDRING SYMBOL
D : (%,Symbol) -> % if S has PDRING SYMBOL
differentiate : (%,List Symbol) -> %
    if S has PDRING SYMBOL
differentiate : (%,Symbol,NonNegativeInteger) -> %
    if S has PDRING SYMBOL
differentiate : (%,List Symbol,List NonNegativeInteger) -> %
    if S has PDRING SYMBOL
differentiate : (%,NonNegativeInteger) -> % if S has DIFRING
differentiate : % -> % if S has DIFRING
differentiate : (%,Symbol) -> % if S has PDRING SYMBOL
differentiate : (%,(S -> S),NonNegativeInteger) -> %

```

These exports come from (p1012) FullyLinearlyExplicitRingOver(S:IntegralDomain):

```

reducedSystem : (Matrix %,Vector %) ->
  Record(mat: Matrix Integer,vec: Vector Integer)
  if S has LINEXP INT
reducedSystem : Matrix % -> Matrix Integer if S has LINEXP INT

```

These exports come from (p95) RetractableTo(Fraction(Integer)):

```

retract : % -> Fraction Integer if S has RETRACT INT
retractIfCan : % -> Union(Fraction Integer,"failed")
  if S has RETRACT INT

```

These exports come from (p269) OrderedSet():

```

max : (%,%) -> % if S has ORDSET
min : (%,%) -> % if S has ORDSET
?<=? : (%,%) -> Boolean if S has ORDSET
?>? : (%,%) -> Boolean if S has ORDSET
?>=? : (%,%) -> Boolean if S has ORDSET

```

These exports come from (p1185) OrderedIntegralDomain():

```

abs : % -> % if S has OINTDOM
negative? : % -> Boolean if S has OINTDOM
positive? : % -> Boolean if S has OINTDOM
sign : % -> Integer if S has OINTDOM

```

These exports come from (p887) CharacteristicNonZero():

```

charthRoot : % -> Union(%,"failed")
  if S has CHARNZ
  or and(has($,CharacteristicNonZero),
    has(S,PolynomialFactorizationExplicit))

```

These exports come from (p1253) PolynomialFactorizationExplicit():

```
conditionP : Matrix % -> Union(Vector %, "failed")
  if and(has($, CharacteristicNonZero),
    has(S, PolynomialFactorizationExplicit))
factorPolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if S has PFECAT
factorSquareFreePolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if S has PFECAT
solveLinearPolynomialEquation :
  (List SparseUnivariatePolynomial %,
    SparseUnivariatePolynomial %) ->
    Union(List SparseUnivariatePolynomial %, "failed")
    if S has PFECAT
squareFreePolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if S has PFECAT
```

— category QFCAT QuotientFieldCategory —

```
)abbrev category QFCAT QuotientFieldCategory
++ Date Last Updated: 5th March 1996
++ Description:
++ QuotientField(S) is the category of fractions of an Integral Domain S.

QuotientFieldCategory(S: IntegralDomain): Category ==
  Join(Field, Algebra S, RetractableTo S, FullyEvalableOver S,
    DifferentialExtension S, FullyLinearlyExplicitRingOver S,
    Patternable S, FullyPatternMatchable S) with
  _/      : (S, S) -> %
    ++ d1 / d2 returns the fraction d1 divided by d2.
  numer   : % -> S
    ++ numer(x) returns the numerator of the fraction x.
  denom   : % -> S
    ++ denom(x) returns the denominator of the fraction x.
  numerator : % -> %
    ++ numerator(x) is the numerator of the fraction x converted to %.
  denominator : % -> %
    ++ denominator(x) is the denominator of the fraction x converted to %.
  if S has StepThrough then StepThrough
  if S has RetractableTo Integer then
    RetractableTo Integer
    RetractableTo Fraction Integer
  if S has OrderedSet then OrderedSet
```

```

if S has OrderedIntegralDomain then OrderedIntegralDomain
if S has RealConstant then RealConstant
if S has ConvertibleTo InputForm then ConvertibleTo InputForm
if S has CharacteristicZero then CharacteristicZero
if S has CharacteristicNonZero then CharacteristicNonZero
if S has RetractableTo Symbol then RetractableTo Symbol
if S has EuclideanDomain then
  wholePart: % -> S
    ++ wholePart(x) returns the whole part of the fraction x
    ++ i.e. the truncated quotient of the numerator by the denominator.
  fractionPart: % -> %
    ++ fractionPart(x) returns the fractional part of x.
    ++ x = wholePart(x) + fractionPart(x)
if S has IntegerNumberSystem then
  random: () -> %
    ++ random() returns a random fraction.
  ceiling : % -> S
    ++ ceiling(x) returns the smallest integral element above x.
  floor: % -> S
    ++ floor(x) returns the largest integral element below x.
if S has PolynomialFactorizationExplicit then
  PolynomialFactorizationExplicit

add
import MatrixCommonDenominator(S, %)

numerator(x) == numer(x)::%

denominator(x) == denom(x) ::%

if S has StepThrough then
  init() == init()$S / 1$S

  nextItem(n) ==
    m:= nextItem(numer(n))
    m case "failed" =>
      error "We seem to have a Fraction of a finite object"
    m / 1

map(fn, x) == (fn numer x) / (fn denom x)

reducedSystem(m:Matrix %):Matrix S == clearDenominator m

characteristic() == characteristic()$S

differentiate(x:%, deriv:S -> S) ==
  n := numer x
  d := denom x
  (deriv n * d - n * deriv d) / (d**2)

```

```

if S has ConvertibleTo InputForm then
  convert(x:):InputForm == (convert numer x) / (convert denom x)

if S has RealConstant then
  convert(x:):Float == (convert numer x) / (convert denom x)

  convert(x:):DoubleFloat == (convert numer x) / (convert denom x)

-- Note that being a Join(OrderedSet,IntegralDomain) is not the same
-- as being an OrderedIntegralDomain.
if S has OrderedIntegralDomain then
  if S has canonicalUnitNormal then
    x: < y: ==
      (numer x * denom y) < (numer y * denom x)
  else
    x: < y: ==
      if denom(x) < 0 then (x,y):=(y,x)
      if denom(y) < 0 then (x,y):=(y,x)
      (numer x * denom y) < (numer y * denom x)
  else if S has OrderedSet then
    x: < y: ==
      (numer x * denom y) < (numer y * denom x)

if (S has EuclideanDomain) then
  fractionPart x == x - (wholePart(x)::)

if S has RetractableTo Symbol then
  coerce(s:Symbol): == s::S:

  retract(x:):Symbol == retract(retract(x)@S)

  retractIfCan(x:):Union(Symbol, "failed") ==
    (r := retractIfCan(x)@Union(S,"failed")) case "failed" =>"failed"
    retractIfCan(r::S)

if (S has ConvertibleTo Pattern Integer) then
  convert(x:):Pattern(Integer)==(convert numer x)/(convert denom x)

  if (S has PatternMatchable Integer) then
    patternMatch(x:, p:Pattern Integer,
      l:PatternMatchResult(Integer, %)) ==
      patternMatch(x, p,
        l)$PatternMatchQuotientFieldCategory(Integer, S, %)

if (S has ConvertibleTo Pattern Float) then
  convert(x:):Pattern(Float) == (convert numer x)/(convert denom x)

  if (S has PatternMatchable Float) then
    patternMatch(x:, p:Pattern Float,
      l:PatternMatchResult(Float, %)) ==

```

```

patternMatch(x, p,
             1)$PatternMatchQuotientFieldCategory(Float, S, %)

if S has RetractableTo Integer then
  coerce(x:Fraction Integer):% == numer(x)::% / denom(x)::%

if not(S is Integer) then
  retract(x:%):Integer == retract(retract(x)@S)

  retractIfCan(x:%):Union(Integer, "failed") ==
    (u := retractIfCan(x)@Union(S, "failed")) case "failed" =>
      "failed"
  retractIfCan(u::S)

if S has IntegerNumberSystem then
  random():% ==
    while zero?(d:=random()$S) repeat d
  random()$S / d

reducedSystem(m:Matrix %, v:Vector %):
  Record(mat:Matrix S, vec:Vector S) ==
    n := reducedSystem(horizConcat(v::Matrix(%), m))@Matrix(S)
    [subMatrix(n, minRowIndex n, maxRowIndex n, 1 + minColIndex n,
               maxColIndex n), column(n, minColIndex n)]

```

— QFCAT.dotabb —

```

"QFCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=QFCAT"];
"QFCAT" -> "ALGEBRA"
"QFCAT" -> "DIFEXT"
"QFCAT" -> "FIELD"
"QFCAT" -> "FEVALAB"
"QFCAT" -> "FLINEXP"
"QFCAT" -> "FPATMAB"
"QFCAT" -> "PATAB"
"QFCAT" -> "RETRACT"

```

— QFCAT.dotfull —

```

"QuotientFieldCategory(a:IntegralDomain)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=QFCAT"];

```

```

"QuotientFieldCategory(a: IntegralDomain)" -> "Field()"
"QuotientFieldCategory(a: IntegralDomain)" -> "Algebra(IntegralDomain)"
"QuotientFieldCategory(a: IntegralDomain)" -> "RetractableTo(IntegralDomain)"
"QuotientFieldCategory(a: IntegralDomain)" ->
  "FullyEvaluableOver(IntegralDomain)"
"QuotientFieldCategory(a: IntegralDomain)" ->
  "DifferentialExtension(IntegralDomain)"
"QuotientFieldCategory(a: IntegralDomain)" ->
  "FullyLinearlyExplicitRingOver(IntegralDomain)"
"QuotientFieldCategory(a: IntegralDomain)" ->
  "Patternable(IntegralDomain)"
"QuotientFieldCategory(a: IntegralDomain)" ->
  "FullyPatternMatchable(IntegralDomain)"

```

— QFCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

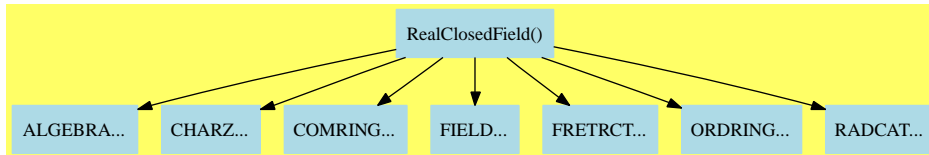
  "QuotientFieldCategory(a: IntegralDomain)" [color=lightblue];
  "QuotientFieldCategory(a: IntegralDomain)" -> "ALGEBRA..."
  "QuotientFieldCategory(a: IntegralDomain)" -> "DIFEXT..."
  "QuotientFieldCategory(a: IntegralDomain)" -> "FIELD..."
  "QuotientFieldCategory(a: IntegralDomain)" -> "FEVALAB..."
  "QuotientFieldCategory(a: IntegralDomain)" -> "FLINEXP..."
  "QuotientFieldCategory(a: IntegralDomain)" -> "FPATMAB..."
  "QuotientFieldCategory(a: IntegralDomain)" -> "PATAB..."
  "QuotientFieldCategory(a: IntegralDomain)" -> "RETRACT..."

  "ALGEBRA..." [color=lightblue];
  "DIFEXT..." [color=lightblue];
  "FIELD..." [color=lightblue];
  "FEVALAB..." [color=lightblue];
  "FLINEXP..." [color=lightblue];
  "FPATMAB..." [color=lightblue];
  "PATAB..." [color=lightblue];
  "RETRACT..." [color=lightblue];

}

```

RealClosedField (RCFIELD)



— RealClosedField.input —

```

)set break resume
)sys rm -f RealClosedField.output
)spool RealClosedField.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RealClosedField
--R
--R RealClosedField is a category constructor
--R Abbreviation for RealClosedField is RCFIELD
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RCFIELD
--R
--R----- Operations -----
--R ??? : (%,Fraction(Integer)) -> %      ??? : (Fraction(Integer),%) -> %
--R ??? : (%,Integer) -> %                ??? : (Integer,%) -> %
--R ??? : (%,Fraction(Integer)) -> %      ??? : (Fraction(Integer),%) -> %
--R ??? : (%,%) -> %                      ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %         ??? : (%,Integer) -> %
--R ??? : (%,PositiveInteger) -> %         +? : (%,%) -> %
--R ?-? : (%,%) -> %                      -? : % -> %
--R ?/? : (%,%) -> %                      ?<? : (%,%) -> Boolean
--R ?<=? : (%,%) -> Boolean                ?=? : (%,%) -> Boolean
--R ?>? : (%,%) -> Boolean                ?>=? : (%,%) -> Boolean
--R 1 : () -> %                           0 : () -> %
--R ?? : (%,Integer) -> %                  ?? : (%,PositiveInteger) -> %
--R abs : % -> %                           associates? : (%,%) -> Boolean
--R coerce : Fraction(Integer) -> %         coerce : Integer -> %
--R coerce : Fraction(Integer) -> %         coerce : % -> %
--R coerce : Fraction(Integer) -> %         coerce : Integer -> %
--R coerce : % -> OutputForm                factor : % -> Factored(%)
--R gcd : (%,%) -> %                        gcd : List(%) -> %
--R hash : % -> SingleInteger               inv : % -> %
--R latex : % -> String                     lcm : (%,%) -> %
--R lcm : List(%) -> %                      max : (%,%) -> %
--R min : (%,%) -> %                        negative? : % -> Boolean

```



```

--R nthRoot : (%,Integer) -> %
--R positive? : % -> Boolean
--R ?quo? : (%,% ) -> %
--R ?rem? : (%,% ) -> %
--R rename! : (% ,OutputForm) -> %
--R sample : () -> %
--R sizeLess? : (%,% ) -> Boolean
--R sqrt : Fraction(Integer) -> %
--R squareFree : % -> Factored(%)
--R unit? : % -> Boolean
--R zero? : % -> Boolean
--R ?? : (NonNegativeInteger,% ) -> %
--R ??? : (% ,Fraction(Integer)) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ?? : (% ,NonNegativeInteger) -> %
--R allRootsOf : Polynomial(Integer) -> List(%)
--R allRootsOf : Polynomial(Fraction(Integer)) -> List(%)
--R allRootsOf : Polynomial(%) -> List(%)
--R allRootsOf : SparseUnivariatePolynomial(Integer) -> List(%)
--R allRootsOf : SparseUnivariatePolynomial(Fraction(Integer)) -> List(%)
--R allRootsOf : SparseUnivariatePolynomial(%) -> List(%)
--R approximate : (%,% ) -> Fraction(Integer)
--R characteristic : () -> NonNegativeInteger
--R divide : (%,% ) -> Record(quotient: %,remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%),"failed")
--R exquo : (%,% ) -> Union(%,"failed")
--R extendedEuclidean : (%,% ) -> Record(coef1: %,coef2: %,generator: %)
--R extendedEuclidean : (%,% ,%) -> Union(Record(coef1: %,coef2: %),"failed")
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R mainDefiningPolynomial : % -> Union(SparseUnivariatePolynomial(%),"failed")
--R mainForm : % -> Union(OutputForm,"failed")
--R mainValue : % -> Union(SparseUnivariatePolynomial(%),"failed")
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed")
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R retract : % -> Fraction(Integer) if Fraction(Integer) has RETRACT(FRAC(INT))
--R retract : % -> Integer if Fraction(Integer) has RETRACT(INT)
--R retractIfCan : % -> Union(Fraction(Integer),"failed")
--R retractIfCan : % -> Union(Fraction(Integer),"failed") if Fraction(Integer) has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer,"failed") if Fraction(Integer) has RETRACT(INT)
--R rootOf : (SparseUnivariatePolynomial(%),PositiveInteger) -> Union(%,"failed")
--R rootOf : (SparseUnivariatePolynomial(%),PositiveInteger,OutputForm) -> Union(%,"failed")
--R sqrt : (% ,NonNegativeInteger) -> %
--R subtractIfCan : (%,% ) -> Union(%,"failed")
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— **RealClosedField.help** —

=====

RealClosedField examples

=====

RealClosedField provides common access functions for all real closed fields.
It provides computations with generic real roots of polynomials.

See Also:

o)show RealClosedField

See:

⇐ “Algebra” (ALGEBRA) [11](#) on page [999](#)
 ⇐ “CharacteristicZero” (CHARZ) [10](#) on page [892](#)
 ⇐ “CommutativeRing” (COMRING) [10](#) on page [896](#)
 ⇐ “Field” (FIELD) [16](#) on page [1271](#)
 ⇐ “FullyRetractableTo” (FRETRCT) [3](#) on page [136](#)
 ⇐ “OrderedRing” (ORDRING) [10](#) on page [933](#)
 ⇐ “RadicalCategory” (RADCAT) [2](#) on page [92](#)

Exports:

| | | | |
|------------------------|----------------|--------------------|----------------|
| 0 | 1 | abs | allRootsOf |
| approximate | associates? | characteristic | coerce |
| divide | euclideanSize | expressIdealMember | exquo |
| extendedEuclidean | factor | gcd | gcdPolynomial |
| hash | inv | latex | lcm |
| mainDefiningPolynomial | mainForm | mainValue | max |
| min | multiEuclidean | negative? | nthRoot |
| one? | positive? | prime? | principalIdeal |
| recip | rename | rename! | retract |
| retractIfCan | rootOf | sample | sign |
| sizeLess? | sqrt | squareFree | squareFreePart |
| subtractIfCan | unit? | unitCanonical | unitNormal |
| zero? | ?*? | ?**? | ?+? |
| ?-? | -? | ?/? | ?<? |
| ?<=? | ?=? | ?>? | ?>=? |
| ?^? | ?~=? | ?quo? | ?rem? |

Attributes Exported:

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?**(a, b) returns true if and only if **unitCanonical**(a) = **unitCanonical**(b).
- **canonicalsClosed** is true if
 $\text{unitCanonical}(a) * \text{unitCanonical}(b) = \text{unitCanonical}(a * b)$.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has **unitsKnown** means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.

These are directly exported but not implemented:

```
allRootsOf : SparseUnivariatePolynomial % -> List %
approximate : (% , %) -> Fraction Integer
mainDefiningPolynomial :
  % -> Union(SparseUnivariatePolynomial %, "failed")
mainForm : % -> Union(OutputForm, "failed")
mainValue : % -> Union(SparseUnivariatePolynomial %, "failed")
rename : (% , OutputForm) -> %
rename! : (% , OutputForm) -> %
```

These are implemented by this category:

```
allRootsOf : Polynomial Integer -> List %
allRootsOf : Polynomial Fraction Integer -> List %
allRootsOf : Polynomial % -> List %
allRootsOf : SparseUnivariatePolynomial Integer -> List %
allRootsOf : SparseUnivariatePolynomial Fraction Integer -> List %
characteristic : () -> NonNegativeInteger
nthRoot : (% , Integer) -> %
rootOf :
  (SparseUnivariatePolynomial %, PositiveInteger) ->
  Union(%, "failed")
rootOf :
  (SparseUnivariatePolynomial %, PositiveInteger, OutputForm) ->
  Union(%, "failed")
sqrt : (% , NonNegativeInteger) -> %
sqrt : Integer -> %
sqrt : Fraction Integer -> %
sqrt : % -> %
?*** : (% , Fraction Integer) -> %
```

These exports come from (p892) `CharacteristicZero()`:

```

0 : () -> %
1 : () -> %
coerce : Integer -> %
coerce : % -> OutputForm
hash : % -> SingleInteger
latex : % -> String
one? : % -> Boolean
recip : % -> Union(%, "failed")
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
zero? : % -> Boolean
?~=? : (%, %) -> Boolean
?^? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
?*? : (%, %) -> %
?*? : (NonNegativeInteger, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
***? : (%, PositiveInteger) -> %
***? : (%, NonNegativeInteger) -> %
+? : (%, %) -> %
-? : (%, %) -> %
-? : % -> %
?=? : (%, %) -> Boolean

```

These exports come from (p933) `OrderedRing()`:

```

abs : % -> %
coerce : Integer -> %
max : (%, %) -> %
min : (%, %) -> %
negative? : % -> Boolean
positive? : % -> Boolean
sign : % -> Integer
?<? : (%, %) -> Boolean
?<=? : (%, %) -> Boolean
?>? : (%, %) -> Boolean
?>=? : (%, %) -> Boolean
?*? : (Integer, %) -> %

```

These exports come from (p1271) `Field()`:

```

associates? : (%, %) -> Boolean
coerce : % -> %
coerce : Fraction Integer -> %
coerce : Fraction Integer -> %
coerce : Fraction Integer -> %

```

```

divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %, "failed")
exquo : (%,%) -> Union(%, "failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
factor : % -> Factored %
gcd : (%,%) -> %
gcd : List % -> %
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
inv : % -> %
lcm : (%,%) -> %
lcm : List % -> %
multiEuclidean : (List %,%) -> Union(List %, "failed")
prime? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
sizeLess? : (%,%) -> Boolean
squareFree : % -> Factored %
squareFreePart : % -> %
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
?/? : (%,%) -> %
?? : (Fraction Integer,%) -> %
?? : (Fraction Integer,%) -> %
?? : (%,Fraction Integer) -> %
?? : (%,Fraction Integer) -> %
*** : (%,Integer) -> %
?? : (%,Integer) -> %
?quo? : (%,%) -> %
?rem? : (%,%) -> %

```

These exports come from (p136) FullyRetractableTo(Fraction(Integer)):

```

retract : % -> Fraction Integer
retract : % -> Fraction Integer
  if Fraction Integer has RETRACT FRAC INT
retract : % -> Integer if Fraction Integer has RETRACT INT
retractIfCan : % -> Union(Fraction Integer, "failed")
retractIfCan : % -> Union(Fraction Integer, "failed")
  if Fraction Integer has RETRACT FRAC INT
retractIfCan : % -> Union(Integer, "failed")
  if Fraction Integer has RETRACT INT

```

These exports come from (p999) Algebra(Integer):

```

?? : (%,Integer) -> %

```

— category RCFIELD RealClosedField —

```

)abbrev category RCFIELD RealClosedField
++ Author: Renaud Rioboo
++ Date Created: may 1993
++ Date Last Updated: January 2004
++ Description:
++ \axiomType{RealClosedField} provides common access
++ functions for all real closed fields.
++ provides computations with generic real roots of polynomials

RealClosedField : Category == PUB where

  E ==> OutputForm
  SUP ==> SparseUnivariatePolynomial
  OFIELD ==> Join(OrderedRing,Field)
  PME ==> SUP($)
  N ==> NonNegativeInteger
  PI ==> PositiveInteger
  RN ==> Fraction(Integer)
  Z ==> Integer
  POLY ==> Polynomial
  PACK ==> SparseUnivariatePolynomialFunctions2

  PUB == Join(CharacteristicZero,
    OrderedRing,
    CommutativeRing,
    Field,
    FullyRetractableTo(Fraction(Integer)),
    Algebra Integer,
    Algebra(Fraction(Integer)),
    RadicalCategory) with

  mainForm : $ -> Union(E,"failed")
    ++ \axiom{mainForm(x)} is the main algebraic quantity name of
    ++ \axiom{x}

  mainDefiningPolynomial : $ -> Union(PME,"failed")
    ++ \axiom{mainDefiningPolynomial(x)} is the defining
    ++ polynomial for the main algebraic quantity of \axiom{x}

  mainValue : $ -> Union(PME,"failed")
    ++ \axiom{mainValue(x)} is the expression of \axiom{x} in terms
    ++ of \axiom{SparseUnivariatePolynomial($)}

  rootOf:      (PME,PI,E)      -> Union($,"failed")
    ++ \axiom{rootOf(pol,n,name)} creates the nth root for the order
    ++ of \axiom{pol} and names it \axiom{name}

```

```

rootOf:      (PME,PI)      -> Union($,"failed")
++ \axiom{rootOf(pol,n)} creates the nth root for the order
++ of \axiom{pol} and gives it unique name

allRootsOf:   PME      -> List $
++ \axiom{allRootsOf(pol)} creates all the roots
++ of \axiom{pol} naming each uniquely

allRootsOf:   (SUP(RN))   -> List $
++ \axiom{allRootsOf(pol)} creates all the roots
++ of \axiom{pol} naming each uniquely

allRootsOf:   (SUP(Z))    -> List $
++ \axiom{allRootsOf(pol)} creates all the roots
++ of \axiom{pol} naming each uniquely

allRootsOf:   (POLY($))   -> List $
++ \axiom{allRootsOf(pol)} creates all the roots
++ of \axiom{pol} naming each uniquely

allRootsOf:   (POLY(RN))  -> List $
++ \axiom{allRootsOf(pol)} creates all the roots
++ of \axiom{pol} naming each uniquely

allRootsOf:   (POLY(Z))   -> List $
++ \axiom{allRootsOf(pol)} creates all the roots
++ of \axiom{pol} naming each uniquely

sqrt:         ($,N)      -> $
++ \axiom{sqrt(x,n)} is \axiom{x ** (1/n)}

sqrt:         $          -> $
++ \axiom{sqrt(x)} is \axiom{x ** (1/2)}

sqrt:         RN         -> $
++ \axiom{sqrt(x)} is \axiom{x ** (1/2)}

sqrt:         Z          -> $
++ \axiom{sqrt(x)} is \axiom{x ** (1/2)}

rename! :     ($,E)      -> $
++ \axiom{rename!(x,name)} changes the way \axiom{x} is printed

rename :      ($,E)      -> $
++ \axiom{rename(x,name)} gives a new number that prints as name

approximate:  ($,$) -> RN
++ \axiom{approximate(n,p)} gives an approximation of \axiom{n}
++ that has precision \axiom{p}

```

add

```

sqrt(a:$):$ == sqrt(a,2)

sqrt(a:RN):$ == sqrt(a::$,2)

sqrt(a:Z):$ == sqrt(a::$,2)

characteristic() == 0

rootOf(pol,n,o) ==
  r := rootOf(pol,n)
  r case "failed" => "failed"
  rename!(r,o)

rootOf(pol,n) ==
  liste:List($):= allRootsOf(pol)
  # liste > n => "failed"
  liste.n

sqrt(x,n) ==
  n = 0 => 1
  n = 1 => x
  zero?(x) => 0
  one?(x) => 1
  if odd?(n)
  then
    r := rootOf(monomial(1,n) - (x :: PME), 1)
  else
    r := rootOf(monomial(1,n) - (x :: PME), 2)
  r case "failed" => error "no roots"
  n = 2 => rename(r,root(x::E)$E)
  rename(r,root(x :: E, n :: E)$E)

(x : $) ** (rn : RN) == sqrt(x**numer(rn),denom(rn)::N)

nthRoot(x, n) ==
  zero?(n) => x
  negative?(n) => inv(sqrt(x,(-n) :: N))
  sqrt(x,n :: N)

allRootsOf(p:SUP(RN)) == allRootsOf(map(z +-> z::$ ,p)$PACK(RN,$))

allRootsOf(p:SUP(Z)) == allRootsOf(map(z +-> z::$ ,p)$PACK(Z,$))

allRootsOf(p:POLY($)) == allRootsOf(univariate(p))

allRootsOf(p:POLY(RN)) == allRootsOf(univariate(p))

```



```
allRootsOf(p:POLY(Z)) == allRootsOf(univariate(p))
```

— RCFIELD.dotabb —

```
"RCFIELD"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RCFIELD"];
"RCFIELD" -> "ALGEBRA"
"RCFIELD" -> "CHARZ"
"RCFIELD" -> "COMRING"
"RCFIELD" -> "FIELD"
"RCFIELD" -> "FRETRCT"
"RCFIELD" -> "ORDRING"
"RCFIELD" -> "RADCAT"
```

— RCFIELD.dotfull —

```
"RealClosedField()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RCFIELD"];
"RealClosedField()" -> "Algebra(Integer)"
"RealClosedField()" -> "Algebra(Fraction(Integer))"
"RealClosedField()" -> "CharacteristicZero()"
"RealClosedField()" -> "CommutativeRing()"
"RealClosedField()" -> "Field()"
"RealClosedField()" -> "FullyRetractableTo(Fraction(Integer))"
"RealClosedField()" -> "OrderedRing()"
"RealClosedField()" -> "RadicalCategory()"
```

— RCFIELD.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "RealClosedField()" [color=lightblue];
  "RealClosedField()" -> "ALGEBRA..."
  "RealClosedField()" -> "CHARZ..."
  "RealClosedField()" -> "COMRING..."
  "RealClosedField()" -> "FIELD..."
```

```

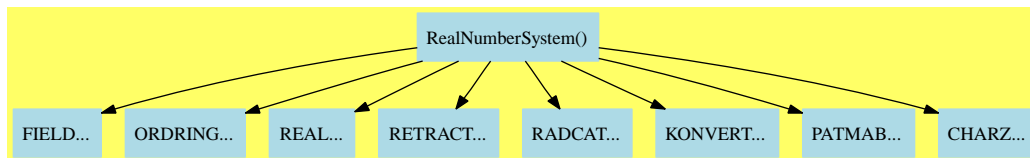
"RealClosedField()" -> "FRETRCT..."
"RealClosedField()" -> "ORDRING..."
"RealClosedField()" -> "RADCAT..."

"ALGEBRA..." [color=lightblue];
"CHARZ..." [color=lightblue];
"COMRING..." [color=lightblue];
"FIELD..." [color=lightblue];
"FRETRCT..." [color=lightblue];
"ORDRING..." [color=lightblue];
"RADCAT..." [color=lightblue];

}

```

RealNumberSystem (RNS)



— RealNumberSystem.input —

```

)set break resume
)sys rm -f RealNumberSystem.output
)spool RealNumberSystem.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RealNumberSystem
--R
--R RealNumberSystem is a category constructor
--R Abbreviation for RealNumberSystem is RNS
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RNS
--R
--R----- Operations -----
--R ??? : (Fraction(Integer),%) -> %      ??? : (%,Fraction(Integer)) -> %
--R ??? : (%,%) -> %                      ??? : (Integer,%) -> %

```

```

--R ?? : (PositiveInteger,%) -> %
--R ??? : (%,PositiveInteger) -> %
--R ?-? : (%,%) -> %
--R ?/? : (%,%) -> %
--R ?<=? : (%,%) -> Boolean
--R ?>? : (%,%) -> Boolean
--R 1 : () -> %
--R ?^? : (%,Integer) -> %
--R abs : % -> %
--R ceiling : % -> %
--R coerce : Integer -> %
--R coerce : % -> %
--R coerce : % -> OutputForm
--R convert : % -> DoubleFloat
--R factor : % -> Factored(%)
--R fractionPart : % -> %
--R gcd : (%,%) -> %
--R inv : % -> %
--R lcm : List(%) -> %
--R max : (%,%) -> %
--R negative? : % -> Boolean
--R nthRoot : (%,Integer) -> %
--R positive? : % -> Boolean
--R ?quo? : (%,%) -> %
--R ?rem? : (%,%) -> %
--R retract : % -> Integer
--R sample : () -> %
--R sizeLess? : (%,%) -> Boolean
--R squareFree : % -> Factored(%)
--R truncate : % -> %
--R unitCanonical : % -> %
--R zero? : % -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,Fraction(Integer)) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?^? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R divide : (%,%) -> Record(quotient: %,remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%),"failed")
--R exquo : (%,%) -> Union(%,"failed")
--R extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed")
--R extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed")
--R patternMatch : (%,Pattern(Float),PatternMatchResult(Float,%)) -> PatternMatchResult(Float,%)
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R retractIfCan : % -> Union(Fraction(Integer),"failed")
--R retractIfCan : % -> Union(Integer,"failed")
--R subtractIfCan : (%,%) -> Union(%,"failed")

??? : (%,Integer) -> %
?+? : (%,%) -> %
-? : % -> %
?<? : (%,%) -> Boolean
?=? : (%,%) -> Boolean
?>=? : (%,%) -> Boolean
0 : () -> %
?^? : (%,PositiveInteger) -> %
associates? : (%,%) -> Boolean
coerce : Fraction(Integer) -> %
coerce : Fraction(Integer) -> %
coerce : Integer -> %
convert : % -> Pattern(Float)
convert : % -> Float
floor : % -> %
gcd : List(%) -> %
hash : % -> SingleInteger
latex : % -> String
lcm : (%,%) -> %
min : (%,%) -> %
norm : % -> %
one? : % -> Boolean
prime? : % -> Boolean
recip : % -> Union(%,"failed")
retract : % -> Fraction(Integer)
round : % -> %
sign : % -> Integer
sqrt : % -> %
squareFreePart : % -> %
unit? : % -> Boolean
wholePart : % -> Integer
?~=? : (%,%) -> Boolean

```

```

--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— RealNumberSystem.help —

```

=====
RealNumberSystem examples
=====

```

The real number system category is intended as a model for the real numbers. The real numbers form an ordered normed field. Note that we have purposely not included `DifferentialRing` or the elementary functions (see `TranscendentalFunctionCategory`) in the definition.

See Also:

- o `)show RealNumberSystem`
- o `)show TranscendentalFunctionCategory`

See:

- ⇒ “FloatingPointSystem” (FPS) [18](#) on page [1582](#)
- ⇐ “CharacteristicZero” (CHARZ) [10](#) on page [892](#)
- ⇐ “ConvertibleTo” (KONVERT) [2](#) on page [41](#)
- ⇐ “Field” (FIELD) [16](#) on page [1271](#)
- ⇐ “OrderedRing” (ORDRING) [10](#) on page [933](#)
- ⇐ “PatternMatchable” (PATMAB) [4](#) on page [279](#)
- ⇐ “RadicalCategory” (RADCAT) [2](#) on page [92](#)
- ⇐ “RealConstant” (REAL) [3](#) on page [155](#)
- ⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

Exports:

| | | | |
|-------------------|----------------|--------------------|---------------|
| 0 | 1 | abs | associates? |
| ceiling | characteristic | coerce | convert |
| divide | euclideanSize | expressIdealMember | exquo |
| extendedEuclidean | factor | floor | fractionPart |
| gcd | gcdPolynomial | hash | inv |
| latex | lcm | max | min |
| multiEuclidean | negative? | norm | nthRoot |
| one? | patternMatch | positive? | prime? |
| principalIdeal | recip | retract | retractIfCan |
| round | sample | sign | sizeLess? |
| sqrt | squareFree | squareFreePart | subtractIfCan |
| truncate | unit? | unitCanonical | unitNormal |
| wholePart | zero? | ?*? | ?**? |
| ?+? | ?-? | -? | ?/? |
| ?<? | ?<=? | ?=? | ?>? |
| ?>=? | ?^? | ?quo? | ?rem? |
| ?~=? | | | |

These are directly exported but not implemented:

```
abs : % -> %
wholePart : % -> Integer
```

These are implemented by this category:

```
characteristic : () -> NonNegativeInteger
ceiling : % -> %
coerce : Fraction Integer -> %
convert : % -> Pattern Float
floor : % -> %
fractionPart : % -> %
norm : % -> %
patternMatch :
  (% , Pattern Float , PatternMatchResult(Float, %)) ->
    PatternMatchResult(Float, %)
round : % -> %
truncate : % -> %
```

These exports come from (p1271) Field():

```
0 : () -> %
1 : () -> %
associates? : (% , %) -> Boolean
coerce : % -> %
coerce : Integer -> %
coerce : Integer -> %
coerce : Fraction Integer -> %
coerce : % -> OutputForm
divide : (% , %) -> Record(quotient: % , remainder: %)
```

```

euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %,"failed")
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
exquo : (%,%) -> Union(%,"failed")
factor : % -> Factored %
gcd : List % -> %
gcd : (%,%) -> %
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
   SparseUnivariatePolynomial %
hash : % -> SingleInteger
inv : % -> %
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
multiEuclidean : (List %,%) -> Union(List %,"failed")
one? : % -> Boolean
prime? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%,"failed")
sample : () -> %
sizeLess? : (%,%) -> Boolean
squareFree : % -> Factored %
squareFreePart : % -> %
subtractIfCan : (%,%) -> Union(%,"failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (Fraction Integer,%) -> %
?*? : (%,Fraction Integer) -> %
?*?* : (%,Fraction Integer) -> %
?^? : (%,Integer) -> %
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
?*?* : (%,PositiveInteger) -> %
?*?* : (%,NonNegativeInteger) -> %
?^? : (%,NonNegativeInteger) -> %
?^? : (%,PositiveInteger) -> %
?/? : (%,%) -> %
?quo? : (%,%) -> %

```

```
?rem? : (%,% ) -> %
```

These exports come from (p933) `OrderedRing()`:

```
negative? : % -> Boolean
positive? : % -> Boolean
sign : % -> Integer
max : (%,% ) -> %
min : (%,% ) -> %
?<? : (%,% ) -> Boolean
?<=? : (%,% ) -> Boolean
?>? : (%,% ) -> Boolean
?>=? : (%,% ) -> Boolean
```

These exports come from (p155) `RealConstant()`:

```
convert : % -> DoubleFloat
convert : % -> Float
```

These exports come from (p95) `RetractableTo(Integer)`:

```
retract : % -> Integer
retractIfCan : % -> Union(Integer,"failed")
```

These exports come from (p95) `RetractableTo(Fraction(Integer))`:

```
retract : % -> Fraction Integer
retractIfCan : % -> Union(Fraction Integer,"failed")
```

These exports come from (p92) `RadicalCategory()`:

```
nthRoot : (%,Integer) -> %
sqrt : % -> %
```

These exports come from (p41) `ConvertibleTo(Pattern(Float))`:

These exports come from (p279) `PatternMatchable(Float)`:

These exports come from (p892) `CharacteristicZero()`:

```

)abbrev category RNS RealNumberSystem
++ Author: Michael Monagan and Stephen M. Watt
++ Date Created: January 1988
++ Description:
++ The real number system category is intended as a model for the real
++ numbers. The real numbers form an ordered normed field. Note that
++ we have purposely not included \spadtype{DifferentialRing} or
++ the elementary functions (see \spadtype{TranscendentalFunctionCategory})
++ in the definition.

RealNumberSystem(): Category ==
  Join(Field, OrderedRing, RealConstant, RetractableTo Integer,
    RetractableTo Fraction Integer, RadicalCategory,
    ConvertibleTo Pattern Float, PatternMatchable Float,
    CharacteristicZero) with
  norm : % -> %
    ++ norm x returns the same as absolute value.
  ceiling : % -> %
    ++ ceiling x returns the small integer \spad{>= x}.
  floor: % -> %
    ++ floor x returns the largest integer \spad{<= x}.
  wholePart : % -> Integer
    ++ wholePart x returns the integer part of x.
  fractionPart : % -> %
    ++ fractionPart x returns the fractional part of x.
  truncate: % -> %
    ++ truncate x returns the integer between x and 0 closest to x.
  round: % -> %
    ++ round x computes the integer closest to x.
  abs : % -> %
    ++ abs x returns the absolute value of x.
add
  characteristic() == 0

  fractionPart x == x - truncate x

  truncate x == (negative? x => -floor(-x); floor x)

  round x == (negative? x => truncate(x-1/2::%); truncate(x+1/2::%))

  norm x == abs x

  coerce(x:Fraction Integer):% == numer(x)::% / denom(x)::%

  convert(x:%):Pattern(Float) == convert(x)@Float :: Pattern(Float)

  floor x ==
    x1 := (wholePart x) :: %
    x = x1 => x
    x < 0 => (x1 - 1)

```



```

x1

ceiling x ==
  x1 := (wholePart x)::%
  x = x1 => x
  x >= 0 => (x1 + 1)
  x1

patternMatch(x, p, l) ==
  generic? p => addMatch(p, x, l)
  constant? p =>
    (r := retractIfCan(p)@Union(Float, "failed")) case Float =>
      convert(x)@Float = r::Float => l
      failed()
    failed()
  failed()

```

— RNS.dotabb —

```

"RNS"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RNS"];
"RNS" -> "FIELD"
"RNS" -> "ORDRING"
"RNS" -> "REAL"
"RNS" -> "RETRACT"
"RNS" -> "RADCAT"
"RNS" -> "KONVERT"
"RNS" -> "PATMAB"
"RNS" -> "CHARZ"

```

— RNS.dotfull —

```

"RealNumberSystem()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RNS"];
"RealNumberSystem()" -> "Field()"
"RealNumberSystem()" -> "OrderedRing()"
"RealNumberSystem()" -> "RealConstant()"
"RealNumberSystem()" -> "RetractableTo(Integer)"
"RealNumberSystem()" -> "RetractableTo(Fraction(Integer))"
"RealNumberSystem()" -> "RadicalCategory()"
"RealNumberSystem()" -> "ConvertibleTo(Pattern(Float))"
"RealNumberSystem()" -> "PatternMatchable(Float)"

```

```
"RealNumberSystem()" -> "CharacteristicZero()"
```

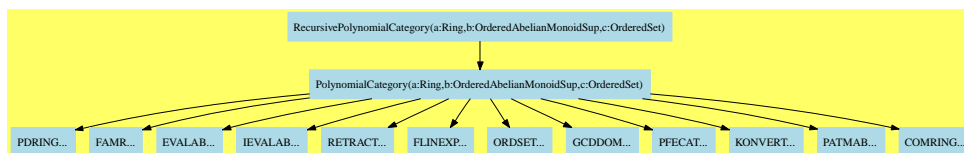
— RNS.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "RealNumberSystem()" [color=lightblue];
  "RealNumberSystem()" -> "FIELD..."
  "RealNumberSystem()" -> "ORDRING..."
  "RealNumberSystem()" -> "REAL..."
  "RealNumberSystem()" -> "RETRACT..."
  "RealNumberSystem()" -> "RADCAT..."
  "RealNumberSystem()" -> "KONVERT..."
  "RealNumberSystem()" -> "PATMAB..."
  "RealNumberSystem()" -> "CHARZ..."

  "FIELD..." [color=lightblue];
  "ORDRING..." [color=lightblue];
  "REAL..." [color=lightblue];
  "RETRACT..." [color=lightblue];
  "RADCAT..." [color=lightblue];
  "KONVERT..." [color=lightblue];
  "PATMAB..." [color=lightblue];
  "CHARZ..." [color=lightblue];
}
```

RecursivePolynomialCategory (RPOLCAT)



— RecursivePolynomialCategory.input —

```

)set break resume
)sys rm -f RecursivePolynomialCategory.output
)spool RecursivePolynomialCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show RecursivePolynomialCategory
--R
--R RecursivePolynomialCategory(R: Ring,E: OrderedAbelianMonoidSup,V: OrderedSet) is a category
--R Abbreviation for RecursivePolynomialCategory is RPOLCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for RPOLCAT
--R
--R----- Operations -----
--R ??? : (%,R) -> %
--R ??? : (%,%) -> %
--R ??? : (PositiveInteger,%) -> %
--R ?+? : (%,%) -> %
--R -? : % -> %
--R D : (%,List(V)) -> %
--R 1 : () -> %
--R ?? : (%,PositiveInteger) -> %
--R coefficients : % -> List(R)
--R coerce : R -> %
--R coerce : % -> OutputForm
--R deepestTail : % -> %
--R differentiate : (%,List(V)) -> %
--R eval : (%,List(V),List(%)) -> %
--R eval : (%,List(V),List(R)) -> %
--R eval : (%,%,%) -> %
--R ground : % -> R
--R hash : % -> SingleInteger
--R headReduce : (%,%) -> %
--R infRittWu? : (%,%) -> Boolean
--R initiallyReduce : (%,%) -> %
--R latex : % -> String
--R lazyPquo : (%,%) -> %
--R lazyPrem : (%,%) -> %
--R leadingCoefficient : % -> R
--R leastMonomial : % -> %
--R mainMonomial : % -> %
--R map : ((R -> R),%) -> %
--R mdeg : % -> NonNegativeInteger
--R monic? : % -> Boolean
--R monomial : (R,E) -> %
--R monomials : % -> List(%)
--R normalized? : (%,%) -> Boolean
--R pomopo! : (%,R,E,%) -> %
--R ??? : (R,%) -> %
--R ??? : (Integer,%) -> %
--R ??? : (%,PositiveInteger) -> %
--R ?-? : (%,%) -> %
--R ?=? : (%,%) -> Boolean
--R D : (%,V) -> %
--R 0 : () -> %
--R coefficient : (%,E) -> R
--R coerce : V -> %
--R coerce : Integer -> %
--R deepestInitial : % -> %
--R degree : % -> E
--R differentiate : (%,V) -> %
--R eval : (%,V,%) -> %
--R eval : (%,V,R) -> %
--R eval : (%,Equation(%)) -> %
--R ground? : % -> Boolean
--R head : % -> %
--R headReduced? : (%,%) -> Boolean
--R init : % -> %
--R iteratedInitials : % -> List(%)
--R lazyPquo : (%,%,V) -> %
--R lazyPrem : (%,%,V) -> %
--R leadingCoefficient : (%,V) -> %
--R leadingMonomial : % -> %
--R mainCoefficients : % -> List(%)
--R mainMonomials : % -> List(%)
--R mapExponents : ((E -> E),%) -> %
--R minimumDegree : % -> E
--R monicModulo : (%,%) -> %
--R monomial? : % -> Boolean
--R mvar : % -> V
--R one? : % -> Boolean
--R pquo : (%,%,V) -> %

```

```

--R pquo : (%,% ) -> %
--R prem : (%,% ) -> %
--R recip : % -> Union(%,"failed")
--R reductum : (% ,V) -> %
--R retract : % -> V
--R sample : () -> %
--R tail : % -> %
--R zero? : % -> Boolean
--R ?? : (Fraction(Integer),%) -> % if R has ALGEBRA(FRAC(INT))
--R ?? : (% ,Fraction(Integer)) -> % if R has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger,%) -> %
--R *** : (% ,NonNegativeInteger) -> %
--R ?/? : (% ,R) -> % if R has FIELD
--R ?<? : (% ,%) -> Boolean if R has ORDSET
--R ?<=? : (% ,%) -> Boolean if R has ORDSET
--R ?>? : (% ,%) -> Boolean if R has ORDSET
--R ?>=? : (% ,%) -> Boolean if R has ORDSET
--R D : (% ,List(V),List(NonNegativeInteger)) -> %
--R D : (% ,V,NonNegativeInteger) -> %
--R LazardQuotient : (% ,%,NonNegativeInteger) -> % if R has INTDOM
--R LazardQuotient2 : (% ,%,%,NonNegativeInteger) -> % if R has INTDOM
--R RittWuCompare : (% ,%) -> Union(Boolean,"failed")
--R ?? : (% ,NonNegativeInteger) -> %
--R associates? : (% ,%) -> Boolean if R has INTDOM
--R binomThmExpt : (% ,%,NonNegativeInteger) -> % if R has COMRING
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%,"failed") if and(has($,CharacteristicNonZero),has(R,PolynomialFactorizationExp
--R coefficient : (% ,List(V),List(NonNegativeInteger)) -> %
--R coefficient : (% ,V,NonNegativeInteger) -> %
--R coerce : % -> % if R has INTDOM
--R coerce : Fraction(Integer) -> % if R has RETRACT(FRAC(INT)) or R has ALGEBRA(FRAC(INT))
--R coerce : % -> Polynomial(R) if V has KONVERT(SYMBOL)
--R conditionP : Matrix(%) -> Union(Vector(%),"failed") if and(has($,CharacteristicNonZero),has(R,Polynomial
--R content : (% ,V) -> % if R has GCDDOM
--R content : % -> R if R has GCDDOM
--R convert : % -> Polynomial(R) if V has KONVERT(SYMBOL)
--R convert : % -> String if R has RETRACT(INT) and V has KONVERT(SYMBOL)
--R convert : Polynomial(R) -> % if V has KONVERT(SYMBOL)
--R convert : Polynomial(Integer) -> % if not(has(R,Algebra(Fraction(Integer)))) and R has ALGEBRA(INT) and
--R convert : Polynomial(Fraction(Integer)) -> % if R has ALGEBRA(FRAC(INT)) and V has KONVERT(SYMBOL)
--R convert : % -> InputForm if V has KONVERT(INFORM) and R has KONVERT(INFORM)
--R convert : % -> Pattern(Integer) if V has KONVERT(PATTERN(INT)) and R has KONVERT(PATTERN(INT))
--R convert : % -> Pattern(Float) if V has KONVERT(PATTERN(FLOAT)) and R has KONVERT(PATTERN(FLOAT))
--R degree : (% ,List(V)) -> List(NonNegativeInteger)
--R degree : (% ,V) -> NonNegativeInteger
--R differentiate : (% ,List(V),List(NonNegativeInteger)) -> %
--R differentiate : (% ,V,NonNegativeInteger) -> %
--R discriminant : (% ,V) -> % if R has COMRING
--R eval : (% ,List(%),List(%)) -> %
--R eval : (% ,List(Equation(%))) -> %

```

```

--R exactQuotient : (%,% ) -> % if R has INTDOM
--R exactQuotient : (% ,R) -> % if R has INTDOM
--R exactQuotient! : (%,% ) -> % if R has INTDOM
--R exactQuotient! : (% ,R) -> % if R has INTDOM
--R exquo : (%,% ) -> Union(%, "failed") if R has INTDOM
--R exquo : (% ,R) -> Union(%, "failed") if R has INTDOM
--R extendedSubResultantGcd : (%,% ) -> Record(gcd: %,coef1: %,coef2: %) if R has INTDOM
--R factor : % -> Factored(%) if R has PFECAT
--R factorPolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%))
--R factorSquareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%))
--R gcd : (%,% ) -> % if R has GCDDOM
--R gcd : List(%) -> % if R has GCDDOM
--R gcd : (R,% ) -> R if R has GCDDOM
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R halfExtendedSubResultantGcd1 : (%,% ) -> Record(gcd: %,coef1: %) if R has INTDOM
--R halfExtendedSubResultantGcd2 : (%,% ) -> Record(gcd: %,coef2: %) if R has INTDOM
--R headReduced? : (% ,List(%)) -> Boolean
--R initiallyReduced? : (% ,List(%)) -> Boolean
--R initiallyReduced? : (%,% ) -> Boolean
--R isExpt : % -> Union(Record(var: V,exponent: NonNegativeInteger), "failed")
--R isPlus : % -> Union(List(%), "failed")
--R isTimes : % -> Union(List(%), "failed")
--R lastSubResultant : (%,% ) -> % if R has INTDOM
--R lazyPremWithDefault : (%,% ,V) -> Record(coef: %,gap: NonNegativeInteger,remainder: %)
--R lazyPremWithDefault : (%,% ) -> Record(coef: %,gap: NonNegativeInteger,remainder: %)
--R lazyPseudoDivide : (%,% ,V) -> Record(coef: %,gap: NonNegativeInteger,quotient: %,remainder: %)
--R lazyPseudoDivide : (%,% ) -> Record(coef: %,gap: NonNegativeInteger,quotient: %,remainder: %)
--R lazyResidueClass : (%,% ) -> Record(polnum: %,polden: %,power: NonNegativeInteger)
--R lcm : (%,% ) -> % if R has GCDDOM
--R lcm : List(%) -> % if R has GCDDOM
--R mainContent : % -> % if R has GCDDOM
--R mainPrimitivePart : % -> % if R has GCDDOM
--R mainSquareFreePart : % -> % if R has GCDDOM
--R mainVariable : % -> Union(V, "failed")
--R max : (%,% ) -> % if R has ORDSET
--R min : (%,% ) -> % if R has ORDSET
--R minimumDegree : (% ,List(V)) -> List(NonNegativeInteger)
--R minimumDegree : (% ,V) -> NonNegativeInteger
--R monicDivide : (%,% ,V) -> Record(quotient: %,remainder: %)
--R monomial : (% ,List(V),List(NonNegativeInteger)) -> %
--R monomial : (% ,V,NonNegativeInteger) -> %
--R multivariate : (SparseUnivariatePolynomial(%),V) -> %
--R multivariate : (SparseUnivariatePolynomial(R),V) -> %
--R nextsubResultant2 : (%,% ,%,%) -> % if R has INTDOM
--R normalized? : (% ,List(%)) -> Boolean
--R numberOfMonomials : % -> NonNegativeInteger
--R patternMatch : (% ,Pattern(Integer),PatternMatchResult(Integer,%)) -> PatternMatchResult(Integer,% )
--R patternMatch : (% ,Pattern(Float),PatternMatchResult(Float,%)) -> PatternMatchResult(Float,% )
--R primPartElseUnitCanonical : % -> % if R has INTDOM
--R primPartElseUnitCanonical! : % -> % if R has INTDOM

```

```

--R prime? : % -> Boolean if R has PFECAT
--R primitiveMonomials : % -> List(%)
--R primitivePart : (% ,V) -> % if R has GCDDOM
--R primitivePart : % -> % if R has GCDDOM
--R primitivePart! : % -> % if R has GCDDOM
--R pseudoDivide : (% ,%) -> Record(quotient: %,remainder: %)
--R reduced? : (% ,List(%)) -> Boolean
--R reducedSystem : Matrix(%) -> Matrix(R)
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(R),vec: Vector(R))
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Integer),vec: Vector(Integer)) if R has LINE
--R reducedSystem : Matrix(%) -> Matrix(Integer) if R has LINEXP(INT)
--R resultant : (% ,%) -> % if R has INTDOM
--R resultant : (% ,%,V) -> % if R has COMRING
--R retract : Polynomial(R) -> % if not(has(R,Algebra(Fraction(Integer)))) and not(has(R,Algebra(Integer)))
--R retract : Polynomial(Integer) -> % if not(has(R,Algebra(Fraction(Integer)))) and R has ALGEBRA(INT) and
--R retract : Polynomial(Fraction(Integer)) -> % if R has ALGEBRA(FRAC(INT)) and V has KONVERT(SYMBOL)
--R retract : % -> Integer if R has RETRACT(INT)
--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retractIfCan : Polynomial(R) -> Union(%,"failed") if not(has(R,Algebra(Fraction(Integer)))) and not(has
--R retractIfCan : Polynomial(Integer) -> Union(%,"failed") if not(has(R,Algebra(Fraction(Integer)))) and R
--R retractIfCan : Polynomial(Fraction(Integer)) -> Union(%,"failed") if R has ALGEBRA(FRAC(INT)) and V has
--R retractIfCan : % -> Union(V,"failed")
--R retractIfCan : % -> Union(Integer,"failed") if R has RETRACT(INT)
--R retractIfCan : % -> Union(Fraction(Integer),"failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(R,"failed")
--R solveLinearPolynomialEquation : (List(SparseUnivariatePolynomial(%)),SparseUnivariatePolynomial(%)) -> U
--R squareFree : % -> Factored(%) if R has GCDDOM
--R squareFreePart : % -> % if R has GCDDOM
--R squareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%)) if R has
--R subResultantChain : (% ,%) -> List(%) if R has INTDOM
--R subResultantGcd : (% ,%) -> % if R has INTDOM
--R subtractIfCan : (% ,%) -> Union(%,"failed")
--R totalDegree : (% ,List(V)) -> NonNegativeInteger
--R totalDegree : % -> NonNegativeInteger
--R unit? : % -> Boolean if R has INTDOM
--R unitCanonical : % -> % if R has INTDOM
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if R has INTDOM
--R univariate : % -> SparseUnivariatePolynomial(R)
--R univariate : (% ,V) -> SparseUnivariatePolynomial(%)
--R
--E 1

)spool
)lisp (bye)

```

```
=====
RecursivePolynomialCategory examples
=====
```

A category for general multi-variate polynomials with coefficients in a ring, variables in an ordered set, and exponents from an ordered abelian monoid, with a sup operation.

When not constant, such a polynomial is viewed as a univariate polynomial in its main variable w. r. t. to the total ordering on the elements in the ordered set, so that some operations usually defined for univariate polynomials make sense here.

See Also:
o)show RecursivePolynomialCategory

See:

⇐ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)

Exports:

| | | |
|------------------------------|----------------------------|-------------------------------|
| 0 | 1 | associates? |
| binomThmExpt | characteristic | charthRoot |
| coefficient | coefficients | coerce |
| conditionP | convert | D |
| deepestInitial | deepestTail | degree |
| differentiate | discriminant | eval |
| exactQuotient | exactQuotient! | exquo |
| extendedSubResultantGcd | factor | factorPolynomial |
| factorSquareFreePolynomial | gcd | gcdPolynomial |
| ground | ground? | halfExtendedSubResultantGcd1 |
| halfExtendedSubResultantGcd2 | hash | head |
| headReduce | headReduced? | infRittWu? |
| init | initiallyReduce | initiallyReduced? |
| isExpt | isPlus | isTimes |
| iteratedInitials | lastSubResultant | latex |
| LazardQuotient | LazardQuotient2 | lazyPquo |
| lazyPrem | lazyPremWithDefault | lazyPseudoDivide |
| lazyResidueClass | lcm | leadingCoefficient |
| leadingMonomial | leastMonomial | mainCoefficients |
| mainContent | mainMonomial | mainPrimitivePart |
| mainSquareFreePart | mainVariable | map |
| mapExponents | max | mdeg |
| min | minimumDegree | monic? |
| monicDivide | monicModulo | monomial |
| monomial? | monomials | multivariate |
| mvar | nextsubResultant2 | normalized? |
| numberOfMonomials | one? | patternMatch |
| pomopo! | pquo | prem |
| primPartElseUnitCanonical | primPartElseUnitCanonical! | prime? |
| primitiveMonomials | primitivePart | primitivePart! |
| pseudoDivide | quasiMonic? | recip |
| reduced? | reducedSystem | reductum |
| resultant | retract | retractIfCan |
| RittWuCompare | sample | solveLinearPolynomialEquation |
| squareFree | squareFreePart | squareFreePolynomial |
| subResultantChain | subResultantGcd | subtractIfCan |
| supRittWu? | tail | totalDegree |
| unit? | unitCanonical | unitNormal |
| univariate | variables | zero? |
| ?*? | ?**? | ?+? |
| ?-? | -? | ?=? |
| ?^? | ?~=? | ?/? |
| ?<? | ?<=? | ?>? |
| ?>=? | | |

Attributes Exported:

- if #1 has CommutativeRing then commutative(“*”) where **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- if #1 has IntegralDomain then noZeroDivisors where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- if #1 has canonicalUnitNormal then canonicalUnitNormal where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?**(a,b) returns true if and only if **unitCanonical**(a) = **unitCanonical**(b).
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```
exactQuotient! : (% , R) -> % if R has INTDOM
extendedSubResultantGcd : (% , %) -> Record(gcd: %, coef1: %, coef2: %)
  if R has INTDOM
halfExtendedSubResultantGcd1 : (% , %) -> Record(gcd: %, coef1: %)
  if R has INTDOM
halfExtendedSubResultantGcd2 : (% , %) -> Record(gcd: %, coef2: %)
  if R has INTDOM
lastSubResultant : (% , %) -> % if R has INTDOM
LazardQuotient : (% , %, NonNegativeInteger) -> %
  if R has INTDOM
LazardQuotient2 : (% , %, %, NonNegativeInteger) -> %
  if R has INTDOM
nextsubResultant2 : (% , %, %, %) -> % if R has INTDOM
resultant : (% , %) -> % if R has INTDOM
subResultantChain : (% , %) -> List % if R has INTDOM
subResultantGcd : (% , %) -> % if R has INTDOM
```

These are implemented by this category:

```
coerce : % -> OutputForm
coerce : % -> Polynomial R if V has KONVERT SYMBOL
convert : % -> String
  if R has RETRACT INT
  and V has KONVERT SYMBOL
convert : % -> Polynomial R if V has KONVERT SYMBOL
convert : Polynomial R -> % if V has KONVERT SYMBOL
convert : Polynomial Integer -> %
  if not has(R, Algebra Fraction Integer)
  and R has ALGEBRA INT
  and V has KONVERT SYMBOL
```

```

    or R has ALGEBRA FRAC INT
    and V has KONVERT SYMBOL
convert : Polynomial Fraction Integer -> %
    if R has ALGEBRA FRAC INT
    and V has KONVERT SYMBOL
deepestInitial : % -> %
deepestTail : % -> %
exactQuotient : (% , R) -> % if R has INTDOM
exactQuotient : (% , %) -> % if R has INTDOM
exactQuotient! : (% , %) -> % if R has INTDOM
gcd : (R , %) -> R if R has GCDDOM
head : % -> %
headReduce : (% , %) -> %
headReduced? : (% , List %) -> Boolean
headReduced? : (% , %) -> Boolean
infRittWu? : (% , %) -> Boolean
init : % -> %
initiallyReduce : (% , %) -> %
initiallyReduced? : (% , %) -> Boolean
initiallyReduced? : (% , List %) -> Boolean
iteratedInitials : % -> List %
lazyPremWithDefault : (% , %) ->
    Record(coef: %, gap: NonNegativeInteger, remainder: %)
lazyPremWithDefault : (% , %, V) ->
    Record(coef: %, gap: NonNegativeInteger, remainder: %)
lazyPquo : (% , %) -> %
lazyPquo : (% , %, V) -> %
lazyPrem : (% , %, V) -> %
lazyPrem : (% , %) -> %
lazyPseudoDivide : (% , %) ->
    Record(coef: %, gap: NonNegativeInteger, quotient: %, remainder: %)
lazyPseudoDivide : (% , %, V) ->
    Record(coef: %, gap: NonNegativeInteger, quotient: %, remainder: %)
lazyResidueClass : (% , %) ->
    Record(polnum: %, polden: %, power: NonNegativeInteger)
leadingCoefficient : (% , V) -> %
leastMonomial : % -> %
mainCoefficients : % -> List %
mainContent : % -> % if R has GCDDOM
mainMonomial : % -> %
mainMonomials : % -> List %
mainPrimitivePart : % -> % if R has GCDDOM
mainSquareFreePart : % -> % if R has GCDDOM
mdeg : % -> NonNegativeInteger
monic? : % -> Boolean
monicModulo : (% , %) -> %
mvar : % -> V
normalized? : (% , %) -> Boolean
normalized? : (% , List %) -> Boolean
pquo : (% , %) -> %

```

```

pquo : (%,%,V) -> %
prem : (%,%,V) -> %
prem : (%,%) -> %
primitivePart! : % -> % if R has GCDDOM
primPartElseUnitCanonical : % -> % if R has INTDOM
primPartElseUnitCanonical! : % -> % if R has INTDOM
pseudoDivide : (%,%) -> Record(quotient: %,remainder: %)
quasiMonic? : % -> Boolean
reduced? : (%,%) -> Boolean
reduced? : (%,List %) -> Boolean
reductum : (%,V) -> %
retract : Polynomial R -> %
  if not has(R,Algebra Fraction Integer)
  and not has(R,Algebra Integer)
  and V has KONVERT SYMBOL
  or not has(R,IntegerNumberSystem)
  and not has(R,Algebra Fraction Integer)
  and R has ALGEBRA INT
  and V has KONVERT SYMBOL
  or not has(R,QuotientFieldCategory Integer)
  and R has ALGEBRA FRAC INT
  and V has KONVERT SYMBOL
retract : Polynomial Integer -> %
  if not has(R,Algebra Fraction Integer)
  and R has ALGEBRA INT
  and V has KONVERT SYMBOL
  or R has ALGEBRA FRAC INT
  and V has KONVERT SYMBOL
retract : Polynomial Fraction Integer -> %
  if R has ALGEBRA FRAC INT and V has KONVERT SYMBOL
retractIfCan : Polynomial R -> Union(%,"failed")
  if not has(R,Algebra Fraction Integer)
  and not has(R,Algebra Integer)
  and V has KONVERT SYMBOL
  or not has(R,IntegerNumberSystem)
  and not has(R,Algebra Fraction Integer)
  and R has ALGEBRA INT
  and V has KONVERT SYMBOL
  or not has(R,QuotientFieldCategory Integer)
  and R has ALGEBRA FRAC INT
  and V has KONVERT SYMBOL
retractIfCan : Polynomial Fraction Integer -> Union(%,"failed")
  if R has ALGEBRA FRAC INT
  and V has KONVERT SYMBOL
retractIfCan : Polynomial Integer -> Union(%,"failed")
  if not has(R,Algebra Fraction Integer)
  and R has ALGEBRA INT
  and V has KONVERT SYMBOL
  or R has ALGEBRA FRAC INT
  and V has KONVERT SYMBOL

```

```

RittWuCompare : (%,%) -> Union(Boolean,"failed")
supRittWu? : (%,%) -> Boolean
tail : % -> %

```

These exports come from (p1305) PolynomialCategory(R,E,V)
 where R:Ring, E:OrderedAbelianMonoidSup, V:OrderedSet:

```

0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
  if R has INTDOM
binomThmExpt : (%,%,NonNegativeInteger) -> %
  if R has COMRING
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(%, "failed")
  if and(has($,CharacteristicNonZero),
    has(R,PolynomialFactorizationExplicit))
  or R has CHARNZ
coefficient : (%,List V,List NonNegativeInteger) -> %
coefficient : (%,V,NonNegativeInteger) -> %
coefficient : (%,E) -> R
coefficients : % -> List R
coerce : R -> %
coerce : Fraction Integer -> %
  if R has RETRACT FRAC INT or R has ALGEBRA FRAC INT
coerce : V -> %
coerce : % -> % if R has INTDOM
coerce : Integer -> %
conditionP : Matrix % -> Union(Vector %, "failed")
  if and(has($,CharacteristicNonZero),
    has(R,PolynomialFactorizationExplicit))
content : % -> R if R has GCDDOM
content : (%,V) -> % if R has GCDDOM
convert : % -> Pattern Integer
  if V has KONVERT PATTERN INT and R has KONVERT PATTERN INT
convert : % -> Pattern Float
  if V has KONVERT PATTERN FLOAT and R has KONVERT PATTERN FLOAT
convert : % -> InputForm
  if V has KONVERT INFORM and R has KONVERT INFORM
D : (%,List V) -> %
D : (%,V) -> %
D : (%,List V,List NonNegativeInteger) -> %
D : (%,V,NonNegativeInteger) -> %
degree : % -> E
degree : (%,List V) -> List NonNegativeInteger
degree : (%,V) -> NonNegativeInteger
differentiate : (%,List V,List NonNegativeInteger) -> %
differentiate : (%,V,NonNegativeInteger) -> %
differentiate : (%,List V) -> %
differentiate : (%,V) -> %

```

```

discriminant : (%,V) -> % if R has COMRING
eval : (%,List Equation %) -> %
eval : (%,Equation %) -> %
eval : (%,List %,List %) -> %
eval : (%,%,%) -> %
eval : (%,V,R) -> %
eval : (%,List V,List R) -> %
eval : (%,V,%) -> %
eval : (%,List V,List %) -> %
exquo : (%,R) -> Union(%, "failed") if R has INTDOM
exquo : (%,%) -> Union(%, "failed") if R has INTDOM
factor : % -> Factored % if R has PFECAT
factorPolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if R has PFECAT
factorSquareFreePolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if R has PFECAT
gcd : (%,%) -> % if R has GCDDOM
gcd : List % -> % if R has GCDDOM
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
    if R has GCDDOM
ground : % -> R
ground? : % -> Boolean
hash : % -> SingleInteger
isExpt : % -> Union(Record(var: V,exponent: NonNegativeInteger), "failed")
isPlus : % -> Union(List %, "failed")
isTimes : % -> Union(List %, "failed")
latex : % -> String
lcm : (%,%) -> % if R has GCDDOM
lcm : List % -> % if R has GCDDOM
leadingCoefficient : % -> R
leadingMonomial : % -> %
mainVariable : % -> Union(V, "failed")
map : ((R -> R),%) -> %
mapExponents : ((E -> E),%) -> %
max : (%,%) -> % if R has ORDSET
min : (%,%) -> % if R has ORDSET
minimumDegree : % -> E
minimumDegree : (%,List V) -> List NonNegativeInteger
minimumDegree : (%,V) -> NonNegativeInteger
monicDivide : (%,%,V) -> Record(quotient: %,remainder: %)
monomial : (%,V,NonNegativeInteger) -> %
monomial : (%,List V,List NonNegativeInteger) -> %
monomial : (R,E) -> %

```

```

monomial? : % -> Boolean
monomials : % -> List %
multivariate : (SparseUnivariatePolynomial %,V) -> %
multivariate : (SparseUnivariatePolynomial R,V) -> %
numberOfMonomials : % -> NonNegativeInteger
one? : % -> Boolean
patternMatch :
  (%,Pattern Integer,PatternMatchResult(Integer,%)) ->
    PatternMatchResult(Integer,%)
    if V has PATMAB INT and R has PATMAB INT
patternMatch :
  (%,Pattern Float,PatternMatchResult(Float,%)) ->
    PatternMatchResult(Float,%)
    if V has PATMAB FLOAT and R has PATMAB FLOAT
pomopo! : (%,R,E,%) -> %
prime? : % -> Boolean if R has PFECAT
primitiveMonomials : % -> List %
primitivePart : (%,V) -> % if R has GCDDOM
primitivePart : % -> % if R has GCDDOM
recip : % -> Union(%, "failed")
reducedSystem : Matrix % -> Matrix R
reducedSystem : (Matrix %,Vector %) ->
  Record(mat: Matrix R,vec: Vector R)
reducedSystem : (Matrix %,Vector %) ->
  Record(mat: Matrix Integer,vec: Vector Integer)
  if R has LINEXP INT
reducedSystem : Matrix % -> Matrix Integer
  if R has LINEXP INT
reductum : % -> %
resultant : (%,%,V) -> % if R has COMRING
retract : % -> R
retract : % -> Integer if R has RETRACT INT
retract : % -> Fraction Integer
  if R has RETRACT FRAC INT
retract : % -> V
retractIfCan : % -> Union(R, "failed")
retractIfCan : % -> Union(Integer, "failed")
  if R has RETRACT INT
retractIfCan : % -> Union(Fraction Integer, "failed")
  if R has RETRACT FRAC INT
retractIfCan : % -> Union(V, "failed")
sample : () -> %
solveLinearPolynomialEquation :
  (List SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    Union(List SparseUnivariatePolynomial %, "failed")
    if R has PFECAT
squareFree : % -> Factored % if R has GCDDOM
squareFreePart : % -> % if R has GCDDOM
squareFreePolynomial :

```

```

SparseUnivariatePolynomial % ->
  Factored SparseUnivariatePolynomial %
  if R has PFECAT
subtractIfCan : (%,% ) -> Union(%, "failed")
totalDegree : (% , List V) -> NonNegativeInteger
totalDegree : % -> NonNegativeInteger
unit? : % -> Boolean if R has INTDOM
unitCanonical : % -> % if R has INTDOM
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
  if R has INTDOM
univariate : % -> SparseUnivariatePolynomial R
univariate : (% , V) -> SparseUnivariatePolynomial %
variables : % -> List V
zero? : % -> Boolean
?+? : (% , %) -> %
?=? : (% , %) -> Boolean
?~=? : (% , %) -> Boolean
?*? : (% , R) -> %
?*? : (R , %) -> %
?*? : (Fraction Integer , %) -> % if R has ALGEBRA FRAC INT
?*? : (% , Fraction Integer) -> % if R has ALGEBRA FRAC INT
?*? : (% , %) -> %
?*? : (Integer , %) -> %
?*? : (PositiveInteger , %) -> %
?*? : (NonNegativeInteger , %) -> %
?/? : (% , R) -> % if R has FIELD
?-? : (% , %) -> %
-? : % -> %
?*?* : (% , PositiveInteger) -> %
?*?* : (% , NonNegativeInteger) -> %
?^? : (% , NonNegativeInteger) -> %
?^? : (% , PositiveInteger) -> %
?<? : (% , %) -> Boolean if R has ORDSET
?<=? : (% , %) -> Boolean if R has ORDSET
?>? : (% , %) -> Boolean if R has ORDSET
?>=? : (% , %) -> Boolean if R has ORDSET

```

— category RPOLCAT RecursivePolynomialCategory —

```

)abbrev category RPOLCAT RecursivePolynomialCategory
++ Author: Marc Moreno Maza
++ Date Created: 04/22/1994
++ Date Last Updated: 14/12/1998
++ Description:

```

```

RecursivePolynomialCategory(R:Ring, E:OrderedAbelianMonoidSup, V:OrderedSet):_
Category ==
  PolynomialCategory(R, E, V) with
    mvar : $ -> V

```

```

++ \axiom{mvar(p)} returns an error if \axiom{p} belongs to
++ \axiom{R}, otherwise returns its main variable w. r. t. to the
++ total ordering on the elements in \axiom{V}.
mdeg : $ -> NonNegativeInteger
++ \axiom{mdeg(p)} returns an error if \axiom{p} is \axiom{0},
++ otherwise, if \axiom{p} belongs to \axiom{R} returns \axiom{0},
++ otherwise, returns the degree of \axiom{p} in its main variable.
init : $ -> $
++ \axiom{init(p)} returns an error if \axiom{p} belongs to
++ \axiom{R}, otherwise returns its leading coefficient, where
++ \axiom{p} is viewed as a univariate polynomial in its main
++ variable.
head : $ -> $
++ \axiom{head(p)} returns \axiom{p} if \axiom{p} belongs to
++ \axiom{R}, otherwise returns its leading term (monomial in the
++ AXIOM sense), where \axiom{p} is viewed as a univariate polynomial
++ in its main variable.
tail : $ -> $
++ \axiom{tail(p)} returns its reductum, where \axiom{p} is viewed
++ as a univariate polynomial in its main variable.
deepestTail : $ -> $
++ \axiom{deepestTail(p)} returns \axiom{0} if \axiom{p} belongs to
++ \axiom{R}, otherwise returns tail(p), if \axiom{tail(p)} belongs
++ to \axiom{R} or \axiom{mvar(tail(p)) < mvar(p)}, otherwise
++ returns \axiom{deepestTail(tail(p))}.
iteratedInitials : $ -> List $
++ \axiom{iteratedInitials(p)} returns \axiom{[]} if \axiom{p}
++ belongs to \axiom{R},
++ otherwise returns the list of the iterated initials of \axiom{p}.
deepestInitial : $ -> $
++ \axiom{deepestInitial(p)} returns an error if \axiom{p} belongs
++ to \axiom{R},
++ otherwise returns the last term of \axiom{iteratedInitials(p)}.
leadingCoefficient : ($,V) -> $
++ \axiom{leadingCoefficient(p,v)} returns the leading coefficient
++ of \axiom{p}, where \axiom{p} is viewed as A univariate
++ polynomial in \axiom{v}.
reductum : ($,V) -> $
++ \axiom{reductum(p,v)} returns the reductum of \axiom{p}, where
++ \axiom{p} is viewed as a univariate polynomial in \axiom{v}.
monic? : $ -> Boolean
++ \axiom{monic?(p)} returns false if \axiom{p} belongs to \axiom{R},
++ otherwise returns true iff \axiom{p} is monic as a univariate
++ polynomial in its main variable.
quasiMonic? : $ -> Boolean
++ \axiom{quasiMonic?(p)} returns false if \axiom{p} belongs to
++ \axiom{R}, otherwise returns true iff the initial of \axiom{p}
++ lies in the base ring \axiom{R}.
mainMonomial : $ -> $
++ \axiom{mainMonomial(p)} returns an error if \axiom{p} is

```



```

++ \axiom{0}, otherwise, if \axiom{p} belongs to \axiom{R} returns
++ \axiom{1}, otherwise, \axiom{mvar(p)} raised to the power
++ \axiom{mdeg(p)}.
leastMonomial : $ -> $
++ \axiom{leastMonomial(p)} returns an error if \axiom{p} is
++ \axiom{0}, otherwise, if \axiom{p} belongs to \axiom{R} returns
++ \axiom{1}, otherwise, the monomial of \axiom{p} with lowest
++ degree, where \axiom{p} is viewed as a univariate polynomial in
++ its main variable.
mainCoefficients : $ -> List $
++ \axiom{mainCoefficients(p)} returns an error if \axiom{p} is
++ \axiom{0}, otherwise, if \axiom{p} belongs to \axiom{R} returns
++ [p], otherwise returns the list of the coefficients of \axiom{p},
++ where \axiom{p} is viewed as a univariate polynomial in its main
++ variable.
mainMonomials : $ -> List $
++ \axiom{mainMonomials(p)} returns an error if \axiom{p} is
++ \axiom{0}, otherwise, if \axiom{p} belongs to \axiom{R} returns
++ [1], otherwise returns the list of the monomials of \axiom{p},
++ where \axiom{p} is viewed as a univariate polynomial in its main
++ variable.
RittWuCompare : ($, $) -> Union(Boolean,"failed")
++ \axiom{RittWuCompare(a,b)} returns \axiom{"failed"} if \axiom{a}
++ and \axiom{b} have same rank w.r.t.
++ Ritt and Wu Wen Tsun ordering using the refinement of Lazard,
++ otherwise returns \axiom{infRittWu?(a,b)}.
infRittWu? : ($, $) -> Boolean
++ \axiom{infRittWu?(a,b)} returns true if \axiom{a} is less than
++ \axiom{b} w.r.t. the Ritt and Wu Wen Tsun ordering using the
++ refinement of Lazard.
supRittWu? : ($, $) -> Boolean
++ \axiom{supRittWu?(a,b)} returns true if \axiom{a} is greater
++ than \axiom{b} w.r.t. the Ritt and Wu Wen Tsun ordering using the
++ refinement of Lazard.
reduced? : ($,$) -> Boolean
++ \axiom{reduced?(a,b)} returns true iff
++ \axiom{degree(a,mvar(b)) < mdeg(b)}.
reduced? : ($,List($)) -> Boolean
++ \axiom{reduced?(q,lp)} returns true iff \axiom{reduced?(q,p)}
++ holds for every \axiom{p} in \axiom{lp}.
headReduced? : ($,$) -> Boolean
++ \axiom{headReduced?(a,b)} returns true iff
++ \axiom{degree(head(a),mvar(b)) < mdeg(b)}.
headReduced? : ($,List($)) -> Boolean
++ \axiom{headReduced?(q,lp)} returns true iff
++ \axiom{headReduced?(q,p)} holds for every \axiom{p} in \axiom{lp}.
initiallyReduced? : ($,$) -> Boolean
++ \axiom{initiallyReduced?(a,b)} returns false iff there exists an
++ iterated initial of \axiom{a} which is not reduced w.r.t \axiom{b}.
initiallyReduced? : ($,List($)) -> Boolean

```

```

++ \axiom{initiallyReduced?(q,lp)} returns true iff
++ \axiom{initiallyReduced?(q,p)} holds for every \axiom{p} in
++ \axiom{lp}.
normalized? : ($,$) -> Boolean
++ \axiom{normalized?(a,b)} returns true iff \axiom{a} and its
++ iterated initials have degree zero w.r.t. the main variable of
++ \axiom{b}
normalized? : ($,List($)) -> Boolean
++ \axiom{normalized?(q,lp)} returns true iff
++ \axiom{normalized?(q,p)} holds
++ for every \axiom{p} in \axiom{lp}.
prem : ($, $) -> $
++ \axiom{prem(a,b)} computes the pseudo-remainder of \axiom{a} by
++ \axiom{b}, both viewed as univariate polynomials in the main
++ variable of \axiom{b}.
pquo : ($, $) -> $
++ \axiom{pquo(a,b)} computes the pseudo-quotient of \axiom{a} by
++ \axiom{b}, both viewed as univariate polynomials in the main
++ variable of \axiom{b}.
prem : ($, $, V) -> $
++ \axiom{prem(a,b,v)} computes the pseudo-remainder of \axiom{a}
++ by \axiom{b}, both viewed as univariate polynomials in \axiom{v}.
pquo : ($, $, V) -> $
++ \axiom{pquo(a,b,v)} computes the pseudo-quotient of \axiom{a} by
++ \axiom{b}, both viewed as univariate polynomials in \axiom{v}.
lazyPrem : ($, $) -> $
++ \axiom{lazyPrem(a,b)} returns the polynomial \axiom{r} reduced
++ w.r.t. \axiom{b} and such that \axiom{b} divides
++ \axiom{init(b)^e a - r} where \axiom{e}
++ is the number of steps of this pseudo-division.
lazyPquo : ($, $) -> $
++ \axiom{lazyPquo(a,b)} returns the polynomial \axiom{q} such that
++ \axiom{lazyPseudoDivide(a,b)} returns \axiom{[c,g,q,r]}.
lazyPrem : ($, $, V) -> $
++ \axiom{lazyPrem(a,b,v)} returns the polynomial \axiom{r}
++ reduced w.r.t. \axiom{b} viewed as univariate polynomials in the
++ variable \axiom{v} such that \axiom{b} divides
++ \axiom{init(b)^e a - r} where \axiom{e} is the number of steps of
++ this pseudo-division.
lazyPquo : ($, $, V) -> $
++ \axiom{lazyPquo(a,b,v)} returns the polynomial \axiom{q} such that
++ \axiom{lazyPseudoDivide(a,b,v)} returns \axiom{[c,g,q,r]}.
lazyPremWithDefault : ($, $) -> _
Record (coef : $, gap : NonNegativeInteger, remainder : $)
++ \axiom{lazyPremWithDefault(a,b)} returns \axiom{[c,g,r]}
++ such that \axiom{r = lazyPrem(a,b)} and
++ \axiom{(c*g)*r = prem(a,b)}.
lazyPremWithDefault : ($, $, V) -> _
Record (coef : $, gap : NonNegativeInteger, remainder : $)
++ \axiom{lazyPremWithDefault(a,b,v)} returns \axiom{[c,g,r]}

```

```

++ such that \axiom{r = lazyPrem(a,b,v)} and
++ \axiom{(c**g)*r = prem(a,b,v)}.
lazyPseudoDivide : ($,$) -> _
  Record(coef:$, gap: NonNegativeInteger, quotient:$, remainder:$)
  ++ \axiom{lazyPseudoDivide(a,b)} returns \axiom{[c,g,q,r]}
  ++ such that \axiom{[c,g,r] = lazyPremWithDefault(a,b)} and
  ++ \axiom{q} is the pseudo-quotient computed in this lazy
  ++ pseudo-division.
lazyPseudoDivide : ($,$,V) -> _
  Record(coef:$, gap:NonNegativeInteger, quotient:$, remainder:$)
  ++ \axiom{lazyPseudoDivide(a,b,v)} returns \axiom{[c,g,q,r]} such
  ++ that \axiom{r = lazyPrem(a,b,v)}, \axiom{(c**g)*r = prem(a,b,v)}
  ++ and \axiom{q} is the pseudo-quotient computed in this lazy
  ++ pseudo-division.
pseudoDivide : ($,$) -> Record (quotient : $, remainder : $)
  ++ \axiom{pseudoDivide(a,b)} computes \axiom{[pquo(a,b),prem(a,b)]},
  ++ both polynomials viewed as univariate polynomials in the main
  ++ variable of \axiom{b}, if \axiom{b} is not a constant polynomial.
monicModulo : ($,$) -> $
  ++ \axiom{monicModulo(a,b)} computes \axiom{a mod b}, if \axiom{b} is
  ++ monic as univariate polynomial in its main variable.
lazyResidueClass : ($,$) -> _
  Record(polnum:$, polden:$, power:NonNegativeInteger)
  ++ \axiom{lazyResidueClass(a,b)} returns \axiom{[p,q,n]} where
  ++ \axiom{p / q**n} represents the residue class of \axiom{a}
  ++ modulo \axiom{b} and \axiom{p} is reduced w.r.t. \axiom{b} and
  ++ \axiom{q} is \axiom{init(b)}.
headReduce: ($,$) -> $
  ++ \axiom{headReduce(a,b)} returns a polynomial \axiom{r} such that
  ++ \axiom{headReduced?(r,b)} holds and there exists an integer
  ++ \axiom{e} such that \axiom{init(b)^e a - r} is zero modulo
  ++ \axiom{b}.
initiallyReduce: ($,$) -> $
  ++ \axiom{initiallyReduce(a,b)} returns a polynomial \axiom{r} such
  ++ that \axiom{initiallyReduced?(r,b)} holds and there exists an
  ++ integer \axiom{e} such that \axiom{init(b)^e a - r} is zero
  ++ modulo \axiom{b}.

if (V has ConvertibleTo(Symbol))
then
  CoercibleTo(Polynomial R)
  ConvertibleTo(Polynomial R)
  if R has Algebra Fraction Integer
  then
    retractIfCan : Polynomial Fraction Integer -> Union($,"failed")
    ++ \axiom{retractIfCan(p)} returns \axiom{p} as an element of
    ++ the current domain if all its variables belong to \axiom{V}.
    retract : Polynomial Fraction Integer -> $
    ++ \axiom{retract(p)} returns \axiom{p} as an element of the
    ++ current domain if \axiom{retractIfCan(p)} does not return

```

```

    ++ "failed", otherwise an error is produced.
convert : Polynomial Fraction Integer -> $
    ++ \axiom{convert(p)} returns the same as \axiom{retract(p)}.
retractIfCan : Polynomial Integer -> Union($,"failed")
    ++ \axiom{retractIfCan(p)} returns \axiom{p} as an element of
    ++ the current domain if all its variables belong to \axiom{V}.
retract : Polynomial Integer -> $
    ++ \axiom{retract(p)} returns \axiom{p} as an element of the
    ++ current domain if \axiom{retractIfCan(p)} does not return
    ++ "failed", otherwise an error is produced.
convert : Polynomial Integer -> $
    ++ \axiom{convert(p)} returns the same as \axiom{retract(p)}
if (R has QuotientFieldCategory(Integer))
then
    retractIfCan : Polynomial R -> Union($,"failed")
        ++ \axiom{retractIfCan(p)} returns \axiom{p} as an element
        ++ of the current domain if all its variables belong to
        ++ \axiom{V}.
    retract : Polynomial R -> $
        ++ \axiom{retract(p)} returns \axiom{p} as an element of the
        ++ current domain if \axiom{retractIfCan(p)} does not
        ++ return "failed", otherwise an error is produced.
if (R has Algebra Integer) and not(R has Algebra Fraction Integer)
then
    retractIfCan : Polynomial Integer -> Union($,"failed")
        ++ \axiom{retractIfCan(p)} returns \axiom{p} as an element of
        ++ the current domain if all its variables belong to \axiom{V}.
    retract : Polynomial Integer -> $
        ++ \axiom{retract(p)} returns \axiom{p} as an element of the
        ++ current domain if \axiom{retractIfCan(p)} does not return
        ++ "failed", otherwise an error is produced.
    convert : Polynomial Integer -> $
        ++ \axiom{convert(p)} returns the same as \axiom{retract(p)}.
    if not (R has IntegerNumberSystem)
    then
        retractIfCan : Polynomial R -> Union($,"failed")
            ++ \axiom{retractIfCan(p)} returns \axiom{p} as an element
            ++ of the current domain if all its variables belong to
            ++ \axiom{V}.
        retract : Polynomial R -> $
            ++ \axiom{retract(p)} returns \axiom{p} as an element of the
            ++ current domain if \axiom{retractIfCan(p)} does not
            ++ return "failed", otherwise an error is produced.
    if not(R has Algebra Integer) and not(R has Algebra Fraction Integer)
    then
        retractIfCan : Polynomial R -> Union($,"failed")
            ++ \axiom{retractIfCan(p)} returns \axiom{p} as an element of
            ++ the current domain if all its variables belong to \axiom{V}.
        retract : Polynomial R -> $
            ++ \axiom{retract(p)} returns \axiom{p} as an element of the

```

```

    ++ current domain if \axiom{retractIfCan(p)} does not return
    ++ "failed", otherwise an error is produced.
convert : Polynomial R -> $
    ++ \axiom{convert(p)} returns \axiom{p} as an element of the current
    ++ domain if all its variables belong to \axiom{V}, otherwise an
    ++ error is produced.

if R has RetractableTo(Integer)
then
    ConvertibleTo(String)

if R has IntegralDomain
then
    primPartElseUnitCanonical : $ -> $
        ++ \axiom{primPartElseUnitCanonical(p)} returns
        ++ \axiom{primitivePart(p)} if \axiom{R} is a gcd-domain,
        ++ otherwise \axiom{unitCanonical(p)}.
    primPartElseUnitCanonical! : $ -> $
        ++ \axiom{primPartElseUnitCanonical!(p)} replaces \axiom{p}
        ++ by \axiom{primPartElseUnitCanonical(p)}.
    exactQuotient : ($,R) -> $
        ++ \axiom{exactQuotient(p,r)} computes the exact quotient of
        ++ \axiom{p} by \axiom{r}, which is assumed to be a divisor of
        ++ \axiom{p}. No error is returned if this exact quotient fails!
    exactQuotient! : ($,R) -> $
        ++ \axiom{exactQuotient!(p,r)} replaces \axiom{p} by
        ++ \axiom{exactQuotient(p,r)}.
    exactQuotient : ($,$) -> $
        ++ \axiom{exactQuotient(a,b)} computes the exact quotient of
        ++ \axiom{a} by \axiom{b}, which is assumed to be a divisor of
        ++ \axiom{a}. No error is returned if this exact quotient fails!
    exactQuotient! : ($,$) -> $
        ++ \axiom{exactQuotient!(a,b)} replaces \axiom{a} by
        ++ \axiom{exactQuotient(a,b)}
    subResultantGcd : ($, $) -> $
        ++ \axiom{subResultantGcd(a,b)} computes a gcd of \axiom{a} and
        ++ \axiom{b} where \axiom{a} and \axiom{b} are assumed to have the
        ++ same main variable \axiom{v} and are viewed as univariate
        ++ polynomials in \axiom{v} with coefficients in the fraction
        ++ field of the polynomial ring generated by their other variables
        ++ over \axiom{R}.
    extendedSubResultantGcd : ($, $) -> _
        Record (gcd : $, coef1 : $, coef2 : $)
        ++ \axiom{extendedSubResultantGcd(a,b)} returns \axiom{[ca,cb,r]}
        ++ such that \axiom{r} is \axiom{subResultantGcd(a,b)} and we have
        ++ \axiom{ca * a + cb * cb = r} .
    halfExtendedSubResultantGcd1 : ($, $) -> Record (gcd : $, coef1 : $)
        ++ \axiom{halfExtendedSubResultantGcd1(a,b)} returns \axiom{[g,ca]}
        ++ if \axiom{extendedSubResultantGcd(a,b)} returns \axiom{[g,ca,cb]}
        ++ otherwise produces an error.

```

```

halfExtendedSubResultantGcd2: ($, $) -> Record (gcd : $, coef2 : $)
  ++ \axiom{halfExtendedSubResultantGcd2(a,b)} returns \axiom{[g,cb]}
  ++ if \axiom{extendedSubResultantGcd(a,b)} returns \axiom{[g,ca,cb]}
  ++ otherwise produces an error.
resultant : ($, $) -> $
  ++ \axiom{resultant(a,b)} computes the resultant of \axiom{a} and
  ++ \axiom{b} where \axiom{a} and \axiom{b} are assumed to have the
  ++ same main variable \axiom{v} and are viewed as univariate
  ++ polynomials in \axiom{v}.
subResultantChain : ($, $) -> List $
  ++ \axiom{subResultantChain(a,b)}, where \axiom{a} and \axiom{b}
  ++ are not constant polynomials with the same main variable, returns
  ++ the subresultant chain of \axiom{a} and \axiom{b}.
lastSubResultant: ($, $) -> $
  ++ \axiom{lastSubResultant(a,b)} returns the last non-zero
  ++ subresultant of \axiom{a} and \axiom{b} where \axiom{a} and
  ++ \axiom{b} are assumed to have the same main variable \axiom{v}
  ++ and are viewed as univariate polynomials in \axiom{v}.
LazardQuotient: ($, $, NonNegativeInteger) -> $
  ++ \axiom{LazardQuotient(a,b,n)} returns \axiom{a**n exquo b**(n-1)}
  ++ assuming that this quotient does not fail.
LazardQuotient2: ($, $, $, NonNegativeInteger) -> $
  ++ \axiom{LazardQuotient2(p,a,b,n)} returns
  ++ \axiom{(a**(n-1) * p) exquo b**(n-1)}
  ++ assuming that this quotient does not fail.
next_subResultant2: ($, $, $, $) -> $
  ++ \axiom{nextsubResultant2(p,q,z,s)} is the multivariate version
  ++ of the operation
  ++ next_sousResultant2 from PseudoRemainderSequence from
  ++ the \axiomType{PseudoRemainderSequence} constructor.

if R has GcdDomain
then
  gcd : (R,$) -> R
    ++ \axiom{gcd(r,p)} returns the gcd of \axiom{r} and the content
    ++ of \axiom{p}.
  primitivePart! : $ -> $
    ++ \axiom{primitivePart!(p)} replaces \axiom{p} by its primitive
    ++ part.
  mainContent : $ -> $
    ++ \axiom{mainContent(p)} returns the content of \axiom{p} viewed
    ++ as a univariate polynomial in its main variable and with
    ++ coefficients in the polynomial ring generated by its other
    ++ variables over \axiom{R}.
  mainPrimitivePart : $ -> $
    ++ \axiom{mainPrimitivePart(p)} returns the primitive part of
    ++ \axiom{p} viewed as a univariate polynomial in its main
    ++ variable and with coefficients in the polynomial ring generated
    ++ by its other variables over \axiom{R}.
  mainSquareFreePart : $ -> $

```

```

++ \axiom{mainSquareFreePart(p)} returns the square free part of
++ \axiom{p} viewed as a univariate polynomial in its main
++ variable and with coefficients in the polynomial ring
++ generated by its other variables over \axiom{R}.

add
  0 ==> OutputForm
  NNI ==> NonNegativeInteger
  INT ==> Integer

  exactQuo : (R,R) -> R

  coerce(p:$):0 ==
    ground? (p) => (ground(p))::0
  --   if one?((ip := init(p)))
    if (((ip := init(p))) = 1)
      then
        if zero?((tp := tail(p)))
          then
            if one?((dp := mdeg(p)))
            --   if (((dp := mdeg(p))) = 1)
              then
                return((mvar(p))::0)
              else
                return(((mvar(p))::0 **$0 (dp::0)))
            else
            --   if one?((dp := mdeg(p)))
              if (((dp := mdeg(p))) = 1)
                then
                  return((mvar(p))::0 +$0 (tp::0))
                else
                  return(((mvar(p))::0 **$0 (dp::0)) +$0 (tp::0))
            else
              if zero?((tp := tail(p)))
                then
            --   if one?((dp := mdeg(p)))
              if (((dp := mdeg(p))) = 1)
                then
                  return((ip::0) *$0 (mvar(p))::0)
                else
                  return((ip::0) *$0 ((mvar(p))::0 **$0 (dp::0)))
              else
            --   if one?(mdeg(p))
              if ((mdeg(p)) = 1)
                then
                  return(((ip::0) *$0 (mvar(p))::0) +$0 (tp::0))
                  ((ip)::0 *$0 ((mvar(p))::0 **$0 ((mdeg(p)::0))) +$0 (tail(p)::0))

  mvar p ==
    ground?(p) => error"Error in mvar from RPOLCAT : #1 is constant."

```

```

mainVariable(p)::V

mdeg p ==
  ground?(p) => 0$NNI
  degree(p,mainVariable(p)::V)

init p ==
  ground?(p) => error"Error in mvar from RPOLCAT : #1 is constant."
  v := mainVariable(p)::V
  coefficient(p,v,degree(p,v))

leadingCoefficient (p,v) ==
  zero? (d := degree(p,v)) => p
  coefficient(p,v,d)

head p ==
  ground? p => p
  v := mainVariable(p)::V
  d := degree(p,v)
  monomial(coefficient(p,v,d),v,d)

reductum(p,v) ==
  zero? (d := degree(p,v)) => 0$$
  p - monomial(coefficient(p,v,d),v,d)

tail p ==
  ground? p => 0$$
  p - head(p)

deepestTail p ==
  ground? p => 0$$
  ground? tail(p) => tail(p)
  mvar(p) > mvar(tail(p)) => tail(p)
  deepestTail(tail(p))

iteratedInitials p ==
  ground? p => []
  p := init(p)
  cons(p,iteratedInitials(p))

localDeepestInitial (p : $) : $ ==
  ground? p => p
  localDeepestInitial init p

deepestInitial p ==
  ground? p => _
  error"Error in deepestInitial from RPOLCAT : #1 is constant."
  localDeepestInitial init p

monic? p ==

```



```

ground? p => false
(recip(init(p)))$$ case $)@Boolean

quasiMonic? p ==
  ground? p => false
  ground?(init(p))

mainMonomial p ==
  zero? p => error"Error in mainMonomial from RPOLCAT : #1 is zero"
  ground? p => 1$$
  v := mainVariable(p)::V
  monomial(1$$,v,degree(p,v))

leastMonomial p ==
  zero? p => error"Error in leastMonomial from RPOLCAT : #1 is zero"
  ground? p => 1$$
  v := mainVariable(p)::V
  monomial(1$$,v,minimumDegree(p,v))

mainCoefficients p ==
  zero? p => error"Error in mainCoefficients from RPOLCAT : #1 is zero"
  ground? p => [p]
  v := mainVariable(p)::V
  coefficients(univariate(p,v)@SparseUnivariatePolynomial($))

mainMonomials p ==
  zero? p => error"Error in mainMonomials from RPOLCAT : #1 is zero"
  ground? p => [1$$]
  v := mainVariable(p)::V
  lm := monomials(univariate(p,v)@SparseUnivariatePolynomial($))
  [monomial(1$$,v,degree(m)) for m in lm]

RittWuCompare (a,b) ==
  (ground? b and ground? a) => "failed"::Union(Boolean,"failed")
  ground? b => false::Union(Boolean,"failed")
  ground? a => true::Union(Boolean,"failed")
  mvar(a) < mvar(b) => true::Union(Boolean,"failed")
  mvar(a) > mvar(b) => false::Union(Boolean,"failed")
  mdeg(a) < mdeg(b) => true::Union(Boolean,"failed")
  mdeg(a) > mdeg(b) => false::Union(Boolean,"failed")
  lc := RittWuCompare(init(a),init(b))
  lc case Boolean => lc
  RittWuCompare(tail(a),tail(b))

infRittWu? (a,b) ==
  lc : Union(Boolean,"failed") := RittWuCompare(a,b)
  lc case Boolean => lc::Boolean
  false

supRittWu? (a,b) ==

```

```

infRittWu? (b,a)

prem (a:$, b:$) : $ ==
  cP := lazyPremWithDefault (a,b)
  ((cP.coef) ** (cP.gap)) * cP.remainder

pquo (a:$, b:$) : $ ==
  cPS := lazyPseudoDivide (a,b)
  c := (cPS.coef) ** (cPS.gap)
  c * cPS.quotient

prem (a:$, b:$, v:V) : $ ==
  cP := lazyPremWithDefault (a,b,v)
  ((cP.coef) ** (cP.gap)) * cP.remainder

pquo (a:$, b:$, v:V) : $ ==
  cPS := lazyPseudoDivide (a,b,v)
  c := (cPS.coef) ** (cPS.gap)
  c * cPS.quotient

lazyPrem (a:$, b:$) : $ ==
  (not ground?(b)) and (monic?(b)) => monicModulo(a,b)
  (lazyPremWithDefault (a,b)).remainder

lazyPquo (a:$, b:$) : $ ==
  (lazyPseudoDivide (a,b)).quotient

lazyPrem (a:$, b:$, v:V) : $ ==
  zero? b => _
  error"Error in lazyPrem : ($,$,V) -> $ from RPOLCAT : #2 is zero"
  ground?(b) => 0$$$
  (v = mvar(b)) => lazyPrem(a,b)
  dbv : NNI := degree(b,v)
  zero? dbv => 0$$$
  dav : NNI := degree(a,v)
  zero? dav => a
  test : INT := dav::INT - dbv
  lcbv : $ := leadingCoefficient(b,v)
  while not zero?(a) and not negative?(test) repeat
    lcav := leadingCoefficient(a,v)
    term := monomial(lcav,v,test::NNI)
    a := lcbv * a - term * b
    test := degree(a,v)::INT - dbv
  a

lazyPquo (a:$, b:$, v:V) : $ ==
  (lazyPseudoDivide (a,b,v)).quotient

headReduce (a:$,b:$) ==
  ground? b => error _

```

```

      "Error in headReduce : ($,$) -> Boolean from TSETCAT : #2 is constant"
ground? a => a
mvar(a) = mvar(b) => lazyPrem(a,b)
while not reduced?((ha := head a),b) repeat
  lrc := lazyResidueClass(ha,b)
  if zero? tail(a)
    then
      a := lrc.polnum
    else
      a := lrc.polnum + (lrc.polden)**(lrc.power) * tail(a)
a

initiallyReduce(a:$,b:$) ==
ground? b => error _
"Error in initiallyReduce : ($,$) -> Boolean from TSETCAT : #2 is constant"
ground? a => a
v := mvar(b)
mvar(a) = v => lazyPrem(a,b)
ia := a
ma := 1$$
ta := 0$$
while (not ground?(ia)) and (mvar(ia) >= mvar(b)) repeat
  if (mvar(ia) = mvar(b)) and (mdeg(ia) >= mdeg(b))
    then
      iamodb := lazyResidueClass(ia,b)
      ia := iamodb.polnum
      if not zero? ta
        then
          ta := (iamodb.polden)**(iamodb.power) * ta
  if zero? ia
    then
      ia := ta
      ma := 1$$
      ta := 0$$
    else
      if not ground?(ia)
        then
          ta := tail(ia) * ma + ta
          ma := mainMonomial(ia) * ma
          ia := init(ia)
  ia * ma + ta

lazyPremWithDefault (a,b) ==
ground?(b) => error _
"Error in lazyPremWithDefault from RPOLCAT : #2 is constant"
ground?(a) => [1$$,0$NNI,a]
xa := mvar a
xb := mvar b
xa < xb => [1$$,0$NNI,a]
lcb : $ := init b

```

```

db : NNI := mdeg b
test : INT := degree(a,xb)::INT - db
delta : INT := max(test + 1$INT, 0$INT)
if xa = xb
then
  b := tail b
  while not zero?(a) and not negative?(test) repeat
    term := monomial(init(a),xb,test::NNI)
    a := lcb * tail(a) - term * b
    delta := delta - 1$INT
    test := degree(a,xb)::INT - db
  else
    while not zero?(a) and not negative?(test) repeat
      term := monomial(leadingCoefficient(a,xb),xb,test::NNI)
      a := lcb * a - term * b
      delta := delta - 1$INT
      test := degree(a,xb)::INT - db
    [lcb, (delta::NNI), a]

lazyPremWithDefault (a,b,v) ==
  zero? b => error _
  "Error in lazyPremWithDefault : ($,$,V) -> $ from RPOLCAT : #2 is zero"
  ground?(b) => [b,1$NNI,0$$]
  (v = mvar(b)) => lazyPremWithDefault(a,b)
  dbv : NNI := degree(b,v)
  zero? dbv => [b,1$NNI,0$$]
  dav : NNI := degree(a,v)
  zero? dav => [1$$,0$NNI,a]
  test : INT := dav::INT - dbv
  delta : INT := max(test + 1$INT, 0$INT)
  lcbv : $ := leadingCoefficient(b,v)
  while not zero?(a) and not negative?(test) repeat
    lcav := leadingCoefficient(a,v)
    term := monomial(lcav,v,test::NNI)
    a := lcbv * a - term * b
    delta := delta - 1$INT
    test := degree(a,v)::INT - dbv
  [lcbv, (delta::NNI), a]

pseudoDivide (a,b) ==
  cPS := lazyPseudoDivide (a,b)
  c := (cPS.coef) ** (cPS.gap)
  [c * cPS.quotient, c * cPS.remainder]

lazyPseudoDivide (a,b) ==
  ground?(b) => error _
  "Error in lazyPseudoDivide from RPOLCAT : #2 is constant"
  ground?(a) => [1$$,0$NNI,0$$,a]
  xa := mvar a
  xb := mvar b

```

```

xa < xb => [1$$,0$NNI,0$$, a]
lcb : $ := init b
db : NNI := mdeg b
q := 0$$
test : INT := degree(a,xb)::INT - db
delta : INT := max(test + 1$INT, 0$INT)
if xa = xb
then
  b := tail b
  while not zero?(a) and not negative?(test) repeat
    term := monomial(init(a),xb,test::NNI)
    a := lcb * tail(a) - term * b
    q := lcb * q + term
    delta := delta - 1$INT
    test := degree(a,xb)::INT - db
  else
    while not zero?(a) and not negative?(test) repeat
      term := monomial(leadingCoefficient(a,xb),xb,test::NNI)
      a := lcb * a - term * b
      q := lcb * q + term
      delta := delta - 1$INT
      test := degree(a,xb)::INT - db
    [lcb, (delta::NNI), q, a]

lazyPseudoDivide (a,b,v) ==
zero? b => error _
  "Error in lazyPseudoDivide : ($,$,V) -> $ from RPOLCAT : #2 is zero"
ground?(b) => [b,1$NNI,a,0$$]
(v = mvar(b)) => lazyPseudoDivide(a,b)
dbv : NNI := degree(b,v)
zero? dbv => [b,1$NNI,a,0$$]
dav : NNI := degree(a,v)
zero? dav => [1$$,0$NNI,0$$, a]
test : INT := dav::INT - dbv
delta : INT := max(test + 1$INT, 0$INT)
lcbv : $ := leadingCoefficient(b,v)
q := 0$$
while not zero?(a) and not negative?(test) repeat
  lcav := leadingCoefficient(a,v)
  term := monomial(lcav,v,test::NNI)
  a := lcbv * a - term * b
  q := lcbv * q + term
  delta := delta - 1$INT
  test := degree(a,v)::INT - dbv
[lcbv, (delta::NNI), q, a]

monicModulo (a,b) ==
ground?(b) => error"Error in monicModulo from RPOLCAT : #2 is constant"
rec : Union($,"failed")
rec := recip((ib := init(b)))$$

```

```

(rec case "failed")@Boolean => error _
  "Error in monicModulo from RPOLCAT : #2 is not monic"
ground? a => a
ib * ((lazyPremWithDefault ((rec::$) * a,(rec::$) * b)).remainder)

lazyResidueClass(a,b) ==
  zero? b => [a,1$$,0$NNI]
  ground? b => [0$$,1$$,0$NNI]
  ground? a => [a,1$$,0$NNI]
  xa := mvar a
  xb := mvar b
  xa < xb => [a,1$$,0$NNI]
  monic?(b) => [monicModulo(a,b),1$$,0$NNI]
  lcb : $ := init b
  db : NNI := mdeg b
  test : INT := degree(a,xb)::INT - db
  pow : NNI := 0
  if xa = xb
  then
    b := tail b
    while not zero?(a) and not negative?(test) repeat
      term := monomial(init(a),xb,test::NNI)
      a := lcb * tail(a) - term * b
      pow := pow + 1$NNI
      test := degree(a,xb)::INT - db
    else
      while not zero?(a) and not negative?(test) repeat
        term := monomial(leadingCoefficient(a,xb),xb,test::NNI)
        a := lcb * a - term * b
        pow := pow + 1$NNI
        test := degree(a,xb)::INT - db
      [a,lcb,pow]

reduced? (a:$,b:$) : Boolean ==
  degree(a,mvar(b)) < mdeg(b)

reduced? (p:$, lq : List($)) : Boolean ==
  ground? p => true
  while (not empty? lq) and (reduced?(p, first lq)) repeat
    lq := rest lq
  empty? lq

headReduced? (a:$,b:$) : Boolean ==
  reduced?(head(a),b)

headReduced? (p:$, lq : List($)) : Boolean ==
  reduced?(head(p),lq)

initiallyReduced? (a:$,b:$) : Boolean ==
  ground? b => error _

```

```

"Error in initiallyReduced? : ($,$) -> Bool. from RPOLCAT : #2 is constant"
  ground?(a) => true
  mvar(a) < mvar(b) => true
  (mvar(a) = mvar(b)) => reduced?(a,b)
  initiallyReduced?(init(a),b)

initiallyReduced? (p:$, lq : List($)) : Boolean ==
  ground? p => true
  while (not empty? lq) and (initiallyReduced?(p, first lq)) repeat
    lq := rest lq
  empty? lq

normalized?(a:$,b:$) : Boolean ==
  ground? b => error _
  "Error in normalized? : ($,$) -> Boolean from TSETCAT : #2 is constant"
  ground? a => true
  mvar(a) < mvar(b) => true
  (mvar(a) = mvar(b)) => false
  normalized?(init(a),b)

normalized? (p:$, lq : List($)) : Boolean ==
  while (not empty? lq) and (normalized?(p, first lq)) repeat
    lq := rest lq
  empty? lq

if R has IntegralDomain
then

  if R has EuclideanDomain
  then
    exactQuo(r:R,s:R):R ==
      r quo$R s
  else
    exactQuo(r:R,s:R):R ==
      (r exquo$R s)::R

exactQuotient (p:$,r:R) ==
  (p exquo$$ r)::$

exactQuotient (a:$,b:$) ==
  ground? b => exactQuotient(a,ground(b))
  (a exquo$$ b)::$

exactQuotient! (a:$,b:$) ==
  ground? b => exactQuotient!(a,ground(b))
  a := (a exquo$$ b)::$

if (R has GcdDomain) and not(R has Field)
then

```

```

    primPartElseUnitCanonical p ==
      primitivePart p

    primitivePart! p ==
      zero? p => p
--      if one?(cp := content(p))
      if ((cp := content(p)) = 1)
      then
        p := unitCanonical p
      else
        p := unitCanonical exactQuotient!(p,cp)
    p

    primPartElseUnitCanonical! p ==
      primitivePart! p

  else
    primPartElseUnitCanonical p ==
      unitCanonical p

    primPartElseUnitCanonical! p ==
      p := unitCanonical p

if R has GcdDomain
then
  gcd(r:R,p:$):R ==
--    one? r => r
    (r = 1) => r
    zero? p => r
    ground? p => gcd(r,ground(p))$R
    gcd(gcd(r,init(p)),tail(p))

  mainContent p ==
    zero? p => p
    "gcd"/mainCoefficients(p)

  mainPrimitivePart p ==
    zero? p => p
    (unitNormal((p exquo$$ mainContent(p)):$)).canonical

  mainSquareFreePart p ==
    ground? p => p
    v := mainVariable(p)::V
    sfp : SparseUnivariatePolynomial($)
    sfp := squareFreePart(univariate(p,v)@SparseUnivariatePolynomial($))
    multivariate(sfp,v)

if (V has ConvertibleTo(Symbol))

```



```

then

PR ==> Polynomial R
PQ ==> Polynomial Fraction Integer
PZ ==> Polynomial Integer
IES ==> IndexedExponents(Symbol)
Q ==> Fraction Integer
Z ==> Integer

convert(p:$) : PR ==
  ground? p => (ground(p)$)$::PR
  v : V := mvar(p)
  d : NNI := mdeg(p)
  convert(init(p))@PR *$PR _
    ((convert(v)@Symbol)::PR)**d +$PR convert(tail(p))@PR

coerce(p:$) : PR ==
  convert(p)@PR

localRetract : PR -> $
localRetractPQ : PQ -> $
localRetractPZ : PZ -> $
localRetractIfCan : PR -> Union($,"failed")
localRetractIfCanPQ : PQ -> Union($,"failed")
localRetractIfCanPZ : PZ -> Union($,"failed")

if V has Finite
then

  sizeV : NNI := size()$V
  lv : List Symbol
  lv := _
    [convert(index(i::PositiveInteger)$V)@Symbol for i in 1..sizeV]

  localRetract(p : PR) : $ ==
    ground? p => (ground(p)$PR)::$
    mvp : Symbol := (mainVariable(p)$PR)::Symbol
    d : NNI
    imvp : PositiveInteger := _
      (position(mvp,lv)$(List Symbol))::PositiveInteger
    vimvp : V := index(imvp)$V
    xvimvp,c : $
    newp := 0$$
    while (not zero? (d := degree(p,mvp))) repeat
      c := localRetract(coefficient(p,mvp,d)$PR)
      xvimvp := monomial(c,vimvp,d)$$
      newp := newp +$$ xvimvp
      p := p -$PR monomial(coefficient(p,mvp,d)$PR,mvp,d)$PR
    newp +$$ localRetract(p)

```

```

if R has Algebra Fraction Integer
then
  localRetractPQ(pq:PQ):$ ==
    ground? pq => ((ground(pq)$PQ)::R)::$
    mvp : Symbol := (mainVariable(pq)$PQ)::Symbol
    d : NNI
    imvp : PositiveInteger := _
      (position(mvp,lv)$(List Symbol))::PositiveInteger
    vimvp : V := index(imvp)$V
    xvimvp,c : $
    newp := 0$$
    while (not zero? (d := degree(pq,mvp))) repeat
      c := localRetractPQ(coefficient(pq,mvp,d)$PQ)
      xvimvp := monomial(c,vimvp,d)$$
      newp := newp +$$ xvimvp
      pq := pq -$PQ monomial(coefficient(pq,mvp,d)$PQ,mvp,d)$PQ
      newp +$$ localRetractPQ(pq)

if R has Algebra Integer
then
  localRetractPZ(pz:PZ):$ ==
    ground? pz => ((ground(pz)$PZ)::R)::$
    mvp : Symbol := (mainVariable(pz)$PZ)::Symbol
    d : NNI
    imvp : PositiveInteger := _
      (position(mvp,lv)$(List Symbol))::PositiveInteger
    vimvp : V := index(imvp)$V
    xvimvp,c : $
    newp := 0$$
    while (not zero? (d := degree(pz,mvp))) repeat
      c := localRetractPZ(coefficient(pz,mvp,d)$PZ)
      xvimvp := monomial(c,vimvp,d)$$
      newp := newp +$$ xvimvp
      pz := pz -$PZ monomial(coefficient(pz,mvp,d)$PZ,mvp,d)$PZ
      newp +$$ localRetractPZ(pz)

retractable?(p:PR):Boolean ==
  lvp := variables(p)$PR
  while not empty? lvp and member?(first lvp,lv) repeat
    lvp := rest lvp
  empty? lvp

retractablePQ?(p:PQ):Boolean ==
  lvp := variables(p)$PQ
  while not empty? lvp and member?(first lvp,lv) repeat
    lvp := rest lvp
  empty? lvp

retractablePZ?(p:PZ):Boolean ==
  lvp := variables(p)$PZ

```

```

while not empty? lvp and member?(first lvp,lv) repeat
  lvp := rest lvp
empty? lvp

localRetractIfCan(p : PR): Union($,"failed") ==
  not retractable?(p) => "failed":Union($,"failed")
  localRetract(p)::Union($,"failed")

localRetractIfCanPQ(p : PQ): Union($,"failed") ==
  not retractablePQ?(p) => "failed":Union($,"failed")
  localRetractPQ(p)::Union($,"failed")

localRetractIfCanPZ(p : PZ): Union($,"failed") ==
  not retractablePZ?(p) => "failed":Union($,"failed")
  localRetractPZ(p)::Union($,"failed")

if R has Algebra Fraction Integer
then

  mpc2Z := MPolyCatFunctions2(Symbol,IES,IES,Z,R,PZ,PR)
  mpc2Q := MPolyCatFunctions2(Symbol,IES,IES,Q,R,PQ,PR)
  ZToR (z:Z):R == coerce(z)@R
  QToR (q:Q):R == coerce(q)@R
  PZToPR (pz:PZ):PR == map(ZToR,pz)$mpc2Z
  PQToPR (pq:PQ):PR == map(QToR,pq)$mpc2Q

  retract(pz:PZ) ==
    rif : Union($,"failed") := retractIfCan(pz)@Union($,"failed")
    (rif case "failed") => error _
    "failed in retract: POLY Z -> $ from RPOLCAT"
    rif::$

  convert(pz:PZ) ==
    retract(pz)@$

  retract(pq:PQ) ==
    rif : Union($,"failed") := retractIfCan(pq)@Union($,"failed")
    (rif case "failed") => error _
    "failed in retract: POLY Z -> $ from RPOLCAT"
    rif::$

  convert(pq:PQ) ==
    retract(pq)@$

if not (R has QuotientFieldCategory(Integer))
then
  -- the only operation to implement is
  -- retractIfCan : PR -> Union($,"failed")
  -- when V does not have Finite

```

```

if V has Finite
then
  retractIfCan(pr:PR) ==
    localRetractIfCan(pr)@Union($,"failed")

  retractIfCan(pq:PQ) ==
    localRetractIfCanPQ(pq)@Union($,"failed")
else
  retractIfCan(pq:PQ) ==
    pr : PR := PQToPR(pq)
    retractIfCan(pr)@Union($,"failed")

retractIfCan(pz:PZ) ==
  pr : PR := PZToPR(pz)
  retractIfCan(pr)@Union($,"failed")

retract(pr:PR) ==
  rif : Union($,"failed") := _
    retractIfCan(pr)@Union($,"failed")
  (rif case "failed") => error _
    "failed in retract: POLY Z -> $ from RPOLCAT"
  rif:: $

convert(pr:PR) ==
  retract(pr)@$

else
  -- the only operation to implement is
  -- retractIfCan : PQ -> Union($,"failed")
  -- when V does not have Finite
  mpc2ZQ := MPolyCatFunctions2(Symbol,IES,IES,Z,Q,PZ,PQ)
  mpc2RQ := MPolyCatFunctions2(Symbol,IES,IES,R,Q,PR,PQ)
  ZToQ(z:Z):Q == coerce(z)@Q
  RToQ(r:R):Q == retract(r)@Q

  PZToPQ (pz:PZ):PQ == map(ZToQ,pz)$mpc2ZQ
  PRTToPQ (pr:PR):PQ == map(RToQ,pr)$mpc2RQ

  retractIfCan(pz:PZ) ==
    pq : PQ := PZToPQ(pz)
    retractIfCan(pq)@Union($,"failed")

if V has Finite
then
  retractIfCan(pq:PQ) ==
    localRetractIfCanPQ(pq)@Union($,"failed")

  convert(pr:PR) ==
    lrif : Union($,"failed") := _
      localRetractIfCan(pr)@Union($,"failed")

```

```

        (lrif case "failed") => error _
                                "failed in convert: PR->$ from RPOLCAT"
        lrif::$
    else
        convert(pr:PR) ==
            pq : PQ := PRTToPQ(pr)
            retract(pq)@$

if (R has Algebra Integer) and not(R has Algebra Fraction Integer)
then

    mpc2Z := MPolyCatFunctions2(Symbol,IES,IES,Z,R,PZ,PR)
    ZToR (z:Z):R == coerce(z)@R
    PZToPR (pz:PZ):PR == map(ZToR,pz)$mpc2Z

    retract(pz:PZ) ==
        rif : Union($,"failed") := retractIfCan(pz)@Union($,"failed")
        (rif case "failed") => error _
                                "failed in retract: POLY Z -> $ from RPOLCAT"
        rif::$

    convert(pz:PZ) ==
        retract(pz)@$

if not (R has IntegerNumberSystem)
then
    -- the only operation to implement is
    -- retractIfCan : PR -> Union($,"failed")
    -- when V does not have Finite

    if V has Finite
    then
        retractIfCan(pr:PR) ==
            localRetractIfCan(pr)@Union($,"failed")

        retractIfCan(pz:PZ) ==
            localRetractIfCanPZ(pz)@Union($,"failed")
    else
        retractIfCan(pz:PZ) ==
            pr : PR := PZToPR(pz)
            retractIfCan(pr)@Union($,"failed")

    retract(pr:PR) ==
        rif : Union($,"failed"):=retractIfCan(pr)@Union($,"failed")
        (rif case "failed") => error _
                                "failed in retract: POLY Z -> $ from RPOLCAT"
        rif::$

    convert(pr:PR) ==
        retract(pr)@$

```

```

else
  -- the only operation to implement is
  -- retractIfCan : PZ -> Union($,"failed")
  -- when V does not have Finite

  mpc2RZ := MPolyCatFunctions2(Symbol,IES,IES,R,Z,PR,PZ)
  RToZ(r:R):Z == retract(r)@Z
  PRTToPZ (pr:PR):PZ == map(RToZ,pr)$mpc2RZ

  if V has Finite
  then
    convert(pr:PR) ==
      lrif : Union($,"failed") := _
                        localRetractIfCan(pr)@Union($,"failed")
      (lrif case "failed") => error _
                        "failed in convert: PR->$ from RPOLCAT"

      lrif:: $
    retractIfCan(pz:PZ) ==
      localRetractIfCanPZ(pz)@Union($,"failed")
  else
    convert(pr:PR) ==
      pz : PZ := PRTToPZ(pr)
      retract(pz)@$

if not(R has Algebra Integer) and not(R has Algebra Fraction Integer)
then
  -- the only operation to implement is
  -- retractIfCan : PR -> Union($,"failed")

  if V has Finite
  then
    retractIfCan(pr:PR) ==
      localRetractIfCan(pr)@Union($,"failed")

  retract(pr:PR) ==
    rif : Union($,"failed") := retractIfCan(pr)@Union($,"failed")
    (rif case "failed") => error _
    "failed in retract: POLY Z -> $ from RPOLCAT"

    rif:: $

  convert(pr:PR) ==
    retract(pr)@$

if (R has RetractableTo(INT))
then

  convert(pol:$):String ==
    ground?(pol) => convert(retract(ground(pol))@INT)@String

```

```

ipol : $ := init(pol)
vpol : V := mvar(pol)
dpol : NNI := mdeg(pol)
tpol: $ := tail(pol)
sipol,svpol,sdpol,stpol : String
--   if one? ipol
if (ipol = 1)
  then
    sipol := empty()$String
  else
--   if one?(-ipol)
    if ((-ipol) = 1)
      then
        sipol := "-"
      else
        sipol := convert(ipol)@String
        if not monomial?(ipol)
          then
            sipol := concat(["(",sipol,"*"])$String
          else
            sipol := concat(sipol,"*")$String
svpol := string(convert(vpol)@Symbol)
--   if one? dpol
if (dpol = 1)
  then
    sdpol := empty()$String
  else
    sdpol := _
      concat("**",convert(convert(dpol)@INT)@String )$String
if zero? tpol
  then
    stpol := empty()$String
  else
    if ground?(tpol)
      then
        n := retract(ground(tpol))@INT
        if n > 0
          then
            stpol := concat(" +",convert(n)@String)$String
          else
            stpol := convert(n)@String
      else
        stpol := convert(tpol)@String
        if _
          not member?((stpol.1)::String,["+","-"])$(List String)
        then
          stpol := concat(" + ",stpol)$String
concat([sipol,svpol,sdpol,stpol])$String

```

— RPOLCAT.dotabb —

```
"RPOLCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RPOLCAT"];
"RPOLCAT" -> "POLYCAT"
```

— RPOLCAT.dotfull —

```
"RecursivePolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RPOLCAT"];
"RecursivePolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
```

— RPOLCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

"RecursivePolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  [color=lightblue];
"RecursivePolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"

"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
  [color=lightblue];
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "PDRING..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "FAMR..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "EVALAB..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "IEVALAB..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "RETRACT..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "FLINEXP..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
```



```

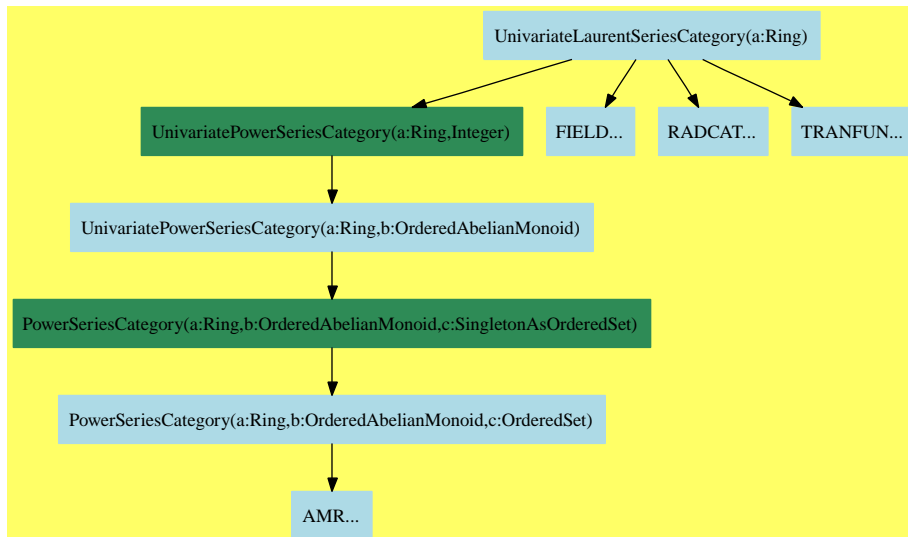
-> "ORDSET..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "GCDDOM..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "PFECAT..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "KONVERT..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "PATMAB..."
"PolynomialCategory(a:Ring,b:OrderedAbelianMonoidSup,c:OrderedSet)"
-> "COMRING..."

"PDRING..." [color=lightblue];
"FAMR..." [color=lightblue];
"EVALAB..." [color=lightblue];
"IEVALAB..." [color=lightblue];
"RETRACT..." [color=lightblue];
"FLINEXP..." [color=lightblue];
"ORDSET..." [color=lightblue];
"GCDDOM..." [color=lightblue];
"PFECAT..." [color=lightblue];
"KONVERT..." [color=lightblue];
"PATMAB..." [color=lightblue];
"COMRING..." [color=lightblue];

}

```

UnivariateLaurentSeriesCategory (ULSCAT)



— UnivariateLaurentSeriesCategory.input —

```

)set break resume
)sys rm -f UnivariateLaurentSeriesCategory.output
)spool UnivariateLaurentSeriesCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show UnivariateLaurentSeriesCategory
--R
--R UnivariateLaurentSeriesCategory(Coef: Ring) is a category constructor
--R Abbreviation for UnivariateLaurentSeriesCategory is ULSCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ULSCAT
--R
--R----- Operations -----
--R ?? : (Coef,%) -> %
--R ?? : (%,%) -> %
--R ?? : (PositiveInteger,%) -> %
--R ?? : (%,%) -> %
--R -? : % -> %
--R 1 : () -> %
--R ?? : (%,PositiveInteger) -> %
--R coefficient : (%,Integer) -> Coef
--R ?? : (%,Coef) -> %
--R ?? : (Integer,%) -> %
--R ***? : (%,PositiveInteger) -> %
--R ?-? : (%,%) -> %
--R ?? : (%,%) -> Boolean
--R 0 : () -> %
--R center : % -> Coef
--R coerce : Integer -> %

```

```

--R coerce : % -> OutputForm
--R degree : % -> Integer
--R extend : (% , Integer) -> %
--R latex : % -> String
--R leadingMonomial : % -> %
--R monomial : (Coef, Integer) -> %
--R one? : % -> Boolean
--R order : % -> Integer
--R recip : % -> Union(%, "failed")
--R sample : () -> %
--R variable : % -> Symbol
--R ~=? : (% , %) -> Boolean
--R ?? : (% , Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (Fraction(Integer), %) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger, %) -> %
--R ??? : (% , Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (% , %) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (% , Integer) -> % if Coef has FIELD
--R ??? : (% , NonNegativeInteger) -> %
--R ?/? : (% , %) -> % if Coef has FIELD
--R ?/? : (% , Coef) -> % if Coef has FIELD
--R D : % -> % if Coef has *: (Integer, Coef) -> Coef
--R D : (% , NonNegativeInteger) -> % if Coef has *: (Integer, Coef) -> Coef
--R D : (% , Symbol) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Integer, Coef) -> Coef
--R D : (% , List(Symbol)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Integer, Coef) -> Coef
--R D : (% , Symbol, NonNegativeInteger) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Integer, Coef) -> Coef
--R D : (% , List(Symbol), List(NonNegativeInteger)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Integer, Coef) -> Coef
--R ?? : (% , Integer) -> % if Coef has FIELD
--R ?? : (% , NonNegativeInteger) -> %
--R acos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acoth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R approximate : (% , Integer) -> Coef if Coef has **: (Coef, Integer) -> Coef and Coef has coerce
--R asec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asinh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R associates? : (% , %) -> Boolean if Coef has INTDOM
--R atan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R atanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
--R coerce : % -> % if Coef has INTDOM
--R coerce : Fraction(Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R coerce : Coef -> % if Coef has COMRING
--R cos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R complete : % -> %
--R ?.? : (% , Integer) -> Coef
--R hash : % -> SingleInteger
--R leadingCoefficient : % -> Coef
--R map : ((Coef -> Coef), %) -> %
--R monomial? : % -> Boolean
--R order : (% , Integer) -> Integer
--R pole? : % -> Boolean
--R reductum : % -> %
--R truncate : (% , Integer) -> %
--R zero? : % -> Boolean

```

```

--R cot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R coth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R differentiate : % -> % if Coef has *: (Integer,Coef) -> Coef
--R differentiate : (% ,NonNegativeInteger) -> % if Coef has *: (Integer,Coef) -> Coef
--R differentiate : (% ,Symbol) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Integer,Coef) -> Coef
--R differentiate : (% ,List(Symbol)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Integer,Coef) -> Coef
--R differentiate : (% ,Symbol,NonNegativeInteger) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Integer,Coef) -> Coef
--R differentiate : (% ,List(Symbol),List(NonNegativeInteger)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Integer,Coef) -> Coef
--R divide : (% ,%) -> Record(quotient: %,remainder: %) if Coef has FIELD
--R ?? : (% ,%) -> % if Integer has SGROUP
--R euclideanSize : % -> NonNegativeInteger if Coef has FIELD
--R eval : (% ,Coef) -> Stream(Coef) if Coef has **: (Coef,Integer) -> Coef
--R exp : % -> % if Coef has ALGEBRA(FRAC(INT))
--R expressIdealMember : (List(%),%) -> Union(List(%),"failed") if Coef has FIELD
--R exquo : (% ,%) -> Union(%,"failed") if Coef has INTDOM
--R extendedEuclidean : (% ,%) -> Record(coef1: %,coef2: %,generator: %) if Coef has FIELD
--R extendedEuclidean : (% ,%,%) -> Union(Record(coef1: %,coef2: %),"failed") if Coef has FIELD
--R factor : % -> Factored(%) if Coef has FIELD
--R gcd : (% ,%) -> % if Coef has FIELD
--R gcd : List(%) -> % if Coef has FIELD
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R integrate : (% ,Symbol) -> % if Coef has ACFS(INT) and Coef has PRIMCAT and Coef has TRANFUN and Coef has TRANFUN
--R integrate : % -> % if Coef has ALGEBRA(FRAC(INT))
--R inv : % -> % if Coef has FIELD
--R lcm : (% ,%) -> % if Coef has FIELD
--R lcm : List(%) -> % if Coef has FIELD
--R log : % -> % if Coef has ALGEBRA(FRAC(INT))
--R monomial : (% ,List(SingletonAsOrderedSet),List(Integer)) -> %
--R monomial : (% ,SingletonAsOrderedSet,Integer) -> %
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed") if Coef has FIELD
--R multiplyCoefficients : ((Integer -> Coef),%) -> %
--R multiplyExponents : (% ,PositiveInteger) -> %
--R nthRoot : (% ,Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R pi : () -> % if Coef has ALGEBRA(FRAC(INT))
--R prime? : % -> Boolean if Coef has FIELD
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %) if Coef has FIELD
--R ?quo? : (% ,%) -> % if Coef has FIELD
--R rationalFunction : (% ,Integer,Integer) -> Fraction(Polynomial(Coef)) if Coef has INTDOM
--R rationalFunction : (% ,Integer) -> Fraction(Polynomial(Coef)) if Coef has INTDOM
--R ?rem? : (% ,%) -> % if Coef has FIELD
--R sec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R series : Stream(Record(k: Integer,c: Coef)) -> %
--R sin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sinh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sizeLess? : (% ,%) -> Boolean if Coef has FIELD
--R sqrt : % -> % if Coef has ALGEBRA(FRAC(INT))
--R squareFree : % -> Factored(%) if Coef has FIELD

```

```

--R squareFreePart : % -> % if Coef has FIELD
--R subtractIfCan : (%,% ) -> Union(%, "failed")
--R tan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R tanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R terms : % -> Stream(Record(k: Integer, c: Coef))
--R truncate : (% , Integer, Integer) -> %
--R unit? : % -> Boolean if Coef has INTDOM
--R unitCanonical : % -> % if Coef has INTDOM
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %) if Coef has INTDOM
--R variables : % -> List(SingletonAsOrderedSet)
--R
--E 1

)spool
)lisp (bye)

```

— UnivariateLaurentSeriesCategory.help —

```

=====
UnivariateLaurentSeriesCategory examples
=====

```

UnivariateLaurentSeriesCategory is the category of Laurent series in one variable.

See Also:

- o)show UnivariateLaurentSeriesCategory

See:

- ⇒ “UnivariateLaurentSeriesConstructorCategory” (ULSCCAT) [18](#) on page [1606](#)
- ⇐ “Field” (FIELD) [16](#) on page [1271](#)
- ⇐ “RadicalCategory” (RADCAT) [2](#) on page [92](#)
- ⇐ “TranscendentalFunctionCategory” (TRANFUN) [3](#) on page [166](#)
- ⇐ “UnivariatePowerSeriesCategory” (UPSCAT) [15](#) on page [1260](#)

Exports:

| | | | |
|-----------------|----------------|----------------------|--------------------|
| 0 | 1 | acos | acosh |
| acot | acoth | acsc | acsch |
| approximate | asec | asech | asin |
| asinh | associates? | atan | atanh |
| center | characteristic | charthRoot | coefficient |
| coerce | complete | cos | cosh |
| cot | coth | csc | csch |
| D | degree | differentiate | divide |
| euclideanSize | eval | exp | expressIdealMember |
| exquo | extend | extendedEuclidean | factor |
| gcd | gcdPolynomial | hash | integrate |
| inv | latex | lcm | leadingCoefficient |
| leadingMonomial | log | map | monomial |
| monomial? | multiEuclidean | multiplyCoefficients | multiplyExponents |
| nthRoot | one? | order | pi |
| pole? | prime? | principalIdeal | rationalFunction |
| recip | reductum | sample | sec |
| sech | series | sin | sinh |
| sizeLess? | sqrt | squareFree | squareFreePart |
| subtractIfCan | tan | tanh | terms |
| truncate | unit? | unitCanonical | unitNormal |
| variable | variables | zero? | ?*? |
| ?**? | ?+? | ?-? * -? | |
| ?=? | ?^? | ?~=? | ?/? |
| ?..? | ?quo? | ?rem? | |

Attributes Exported:

- if #1 has Field then canonicalUnitNormal where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- if #1 has Field then canonicalsClosed where **canonicalsClosed** is true if `unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation `recip` can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- if #1 has IntegralDomain then noZeroDivisors where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- if #1 has CommutativeRing then commutative(“*”) where **commutative(“*”)** is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.

These are directly exported but not implemented:

```

integrate : % -> % if Coef has ALGEBRA FRAC INT
integrate : (% , Symbol) -> %
  if Coef has ACFS INT
  and Coef has PRIMCAT
  and Coef has TRANFUN
  and Coef has ALGEBRA FRAC INT
  or Coef has variables: Coef -> List Symbol
  and Coef has integrate: (Coef, Symbol) -> Coef
  and Coef has ALGEBRA FRAC INT
multiplyCoefficients : ((Integer -> Coef), %) -> %
rationalFunction : (% , Integer) -> Fraction Polynomial Coef
  if Coef has INTDOM
rationalFunction : (% , Integer, Integer) -> Fraction Polynomial Coef
  if Coef has INTDOM
series : Stream Record(k: Integer, c: Coef) -> %

```

These exports come from (p1260) `UnivariatePowerSeriesCategory(Coef,Integer)`
 where `Coef:Ring`:

```

0 : () -> %
1 : () -> %
approximate : (% , Integer) -> Coef
  if Coef has **: (Coef, Integer) -> Coef
  and Coef has coerce: Symbol -> Coef
associates? : (% , %) -> Boolean if Coef has INTDOM
center : % -> Coef
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(% , "failed") if Coef has CHARNZ
coefficient : (% , Integer) -> Coef
coerce : % -> % if Coef has INTDOM
coerce : Fraction Integer -> % if Coef has ALGEBRA FRAC INT
coerce : Coef -> % if Coef has COMRING
coerce : Integer -> %
coerce : % -> OutputForm
complete : % -> %
D : % -> % if Coef has *: (Integer, Coef) -> Coef
D : (% , NonNegativeInteger) -> %
  if Coef has *: (Integer, Coef) -> Coef
D : (% , Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Integer, Coef) -> Coef
D : (% , List Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Integer, Coef) -> Coef
D : (% , Symbol, NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Integer, Coef) -> Coef
D : (% , List Symbol, List NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Integer, Coef) -> Coef

```

```

degree : % -> Integer
differentiate : (%,Symbol) -> %
  if Coef has PDRING SYMBOL
    and Coef has *: (Integer,Coef) -> Coef
differentiate : (%,List Symbol) -> %
  if Coef has PDRING SYMBOL
    and Coef has *: (Integer,Coef) -> Coef
differentiate : (%,Symbol,NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
    and Coef has *: (Integer,Coef) -> Coef
differentiate : (%,List Symbol,List NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
    and Coef has *: (Integer,Coef) -> Coef
differentiate : % -> %
  if Coef has *: (Integer,Coef) -> Coef
differentiate : (%,NonNegativeInteger) -> %
  if Coef has *: (Integer,Coef) -> Coef
eval : (%,Coef) -> Stream Coef
  if Coef has **: (Coef,Integer) -> Coef
exquo : (%,%) -> Union(%, "failed")
  if Coef has INTDOM
extend : (%,Integer) -> %
hash : % -> SingleInteger
latex : % -> String
leadingCoefficient : % -> Coef
leadingMonomial : % -> %
map : ((Coef -> Coef),%) -> %
monomial : (%,SingletonAsOrderedSet,Integer) -> %
monomial : (%,List SingletonAsOrderedSet,List Integer) -> %
monomial : (Coef,Integer) -> %
monomial? : % -> Boolean
multiplyExponents : (%,PositiveInteger) -> %
one? : % -> Boolean
order : (%,Integer) -> Integer
order : % -> Integer
pole? : % -> Boolean
recip : % -> Union(%, "failed")
reductum : % -> %
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
terms : % -> Stream Record(k: Integer,c: Coef)
truncate : (%,Integer,Integer) -> %
truncate : (%,Integer) -> %
unit? : % -> Boolean if Coef has INTDOM
unitCanonical : % -> % if Coef has INTDOM
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
  if Coef has INTDOM
variable : % -> Symbol
variables : % -> List SingletonAsOrderedSet
zero? : % -> Boolean

```



```

?/? : (%,Integer) -> Coef
? ** ? : (% , NonNegativeInteger) -> %
? ^ ? : (% , NonNegativeInteger) -> %
? + ? : (% , %) -> %
? = ? : (% , %) -> Boolean
? ~ = ? : (% , %) -> Boolean
? * ? : (NonNegativeInteger , %) -> %
? * ? : (PositiveInteger , %) -> %
? * ? : (% , %) -> %
? - ? : (% , %) -> %
? ** ? : (% , PositiveInteger) -> %
? ^ ? : (% , PositiveInteger) -> %
? * ? : (Integer , %) -> %
? * ? : (Coef , %) -> %
? * ? : (% , Coef) -> %
? * ? : (% , Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
? * ? : (Fraction Integer , %) -> % if Coef has ALGEBRA FRAC INT
? / ? : (% , Coef) -> % if Coef has FIELD
- ? : % -> %
? . ? : (% , %) -> % if Integer has SGROUP

```

These exports come from (p166) `TranscendentalFunctionCategory()`:

```

acos : % -> % if Coef has ALGEBRA FRAC INT
acosh : % -> % if Coef has ALGEBRA FRAC INT
acot : % -> % if Coef has ALGEBRA FRAC INT
acoth : % -> % if Coef has ALGEBRA FRAC INT
acsc : % -> % if Coef has ALGEBRA FRAC INT
acsch : % -> % if Coef has ALGEBRA FRAC INT
asec : % -> % if Coef has ALGEBRA FRAC INT
asech : % -> % if Coef has ALGEBRA FRAC INT
asin : % -> % if Coef has ALGEBRA FRAC INT
asinh : % -> % if Coef has ALGEBRA FRAC INT
atanh : % -> % if Coef has ALGEBRA FRAC INT
atan : % -> % if Coef has ALGEBRA FRAC INT
cos : % -> % if Coef has ALGEBRA FRAC INT
cosh : % -> % if Coef has ALGEBRA FRAC INT
cot : % -> % if Coef has ALGEBRA FRAC INT
coth : % -> % if Coef has ALGEBRA FRAC INT
csc : % -> % if Coef has ALGEBRA FRAC INT
csch : % -> % if Coef has ALGEBRA FRAC INT
exp : % -> % if Coef has ALGEBRA FRAC INT
log : % -> % if Coef has ALGEBRA FRAC INT
pi : () -> % if Coef has ALGEBRA FRAC INT
sec : % -> % if Coef has ALGEBRA FRAC INT
sech : % -> % if Coef has ALGEBRA FRAC INT
sin : % -> % if Coef has ALGEBRA FRAC INT
sinh : % -> % if Coef has ALGEBRA FRAC INT
tan : % -> % if Coef has ALGEBRA FRAC INT
tanh : % -> % if Coef has ALGEBRA FRAC INT

```

```
***? : (%,%) -> % if Coef has ALGEBRA FRAC INT
```

These exports come from (p92) RadicalCategory():

```
nthRoot : (%,Integer) -> % if Coef has ALGEBRA FRAC INT
sqrt : % -> % if Coef has ALGEBRA FRAC INT
***? : (%,Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
```

These exports come from (p1271) Field():

```
divide : (%,%) -> Record(quotient: %,remainder: %)
  if Coef has FIELD
euclideanSize : % -> NonNegativeInteger
  if Coef has FIELD
expressIdealMember : (List %,%) -> Union(List %, "failed")
  if Coef has FIELD
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
  if Coef has FIELD
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
  if Coef has FIELD
factor : % -> Factored % if Coef has FIELD
gcd : (%,%) -> % if Coef has FIELD
gcd : List % -> % if Coef has FIELD
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
  SparseUnivariatePolynomial %
  if Coef has FIELD
inv : % -> % if Coef has FIELD
lcm : (%,%) -> % if Coef has FIELD
lcm : List % -> % if Coef has FIELD
multiEuclidean : (List %,%) -> Union(List %, "failed")
  if Coef has FIELD
prime? : % -> Boolean if Coef has FIELD
principalIdeal : List % -> Record(coef: List %,generator: %)
  if Coef has FIELD
sizeLess? : (%,%) -> Boolean if Coef has FIELD
squareFree : % -> Factored % if Coef has FIELD
squareFreePart : % -> % if Coef has FIELD
***? : (%,Integer) -> % if Coef has FIELD
?^? : (%,Integer) -> % if Coef has FIELD
?/? : (%,%) -> % if Coef has FIELD
?quo? : (%,%) -> % if Coef has FIELD
?rem? : (%,%) -> % if Coef has FIELD
```

— category ULSCAT UnivariateLaurentSeriesCategory —

```
)abbrev category ULSCAT UnivariateLaurentSeriesCategory
```

```

++ Author: Clifton J. Williamson
++ Date Created: 21 December 1989
++ Date Last Updated: 20 September 1993
++ Description:
++ \spadtype{UnivariateLaurentSeriesCategory} is the category of
++ Laurent series in one variable.

UnivariateLaurentSeriesCategory(Coef): Category == Definition where
  Coef : Ring
  I    ==> Integer
  NNI  ==> NonNegativeInteger
  Term ==> Record(k:I,c:Coef)

Definition ==> UnivariatePowerSeriesCategory(Coef,Integer) with

series: Stream Term -> %
++ \spad{series(st)} creates a series from a stream of non-zero terms,
++ where a term is an exponent-coefficient pair. The terms in the
++ stream should be ordered by increasing order of exponents.
multiplyCoefficients: (I -> Coef,%) -> %
++ \spad{multiplyCoefficients(f,sum(n = n0..infinity,a[n] * x**n)) =
++ sum(n = 0..infinity,f(n) * a[n] * x**n)}.
++ This function is used when Puiseux series are represented by
++ a Laurent series and an exponent.
if Coef has IntegralDomain then
  rationalFunction: (%,I) -> Fraction Polynomial Coef
  ++ \spad{rationalFunction(f,k)} returns a rational function
  ++ consisting of the sum of all terms of f of degree <= k.
  rationalFunction: (%,I,I) -> Fraction Polynomial Coef
  ++ \spad{rationalFunction(f,k1,k2)} returns a rational function
  ++ consisting of the sum of all terms of f of degree d with
  ++ \spad{k1 <= d <= k2}.

if Coef has Algebra Fraction Integer then
  integrate: % -> %
  ++ \spad{integrate(f(x))} returns an anti-derivative of the power
  ++ series \spad{f(x)} with constant coefficient 1.
  ++ We may integrate a series when we can divide coefficients
  ++ by integers.
if Coef has integrate: (Coef,Symbol) -> Coef and _
  Coef has variables: Coef -> List Symbol then
  integrate: (%,Symbol) -> %
  ++ \spad{integrate(f(x),y)} returns an anti-derivative of the power
  ++ series \spad{f(x)} with respect to the variable \spad{y}.
if Coef has TranscendentalFunctionCategory and _
  Coef has PrimitiveFunctionCategory and _
  Coef has AlgebraicallyClosedFunctionSpace Integer then
  integrate: (%,Symbol) -> %
  ++ \spad{integrate(f(x),y)} returns an anti-derivative of
  ++ the power series \spad{f(x)} with respect to the variable

```

```

    ++ \spad{y}.
RadicalCategory
--++ We provide rational powers when we can divide coefficients
--++ by integers.
TranscendentalFunctionCategory
--++ We provide transcendental functions when we can divide
--++ coefficients by integers.
if Coef has Field then Field
--++ Univariate Laurent series over a field form a field.
--++ In fact,  $K((x))$  is the quotient field of  $K[[x]]$ .

```

— ULSCAT.dotabb —

```

"ULSCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ULSCAT"];
"ULSCAT" -> "UPSCAT"
"ULSCAT" -> "FIELD"
"ULSCAT" -> "TRANFUN"
"ULSCAT" -> "RADCAT"

```

— ULSCAT.dotfull —

```

"UnivariateLaurentSeriesCategory(a:Ring)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ULSCAT"];
"UnivariateLaurentSeriesCategory(a:Ring)" ->
  "Field()"
"UnivariateLaurentSeriesCategory(a:Ring)" ->
  "RadicalCategory()"
"UnivariateLaurentSeriesCategory(a:Ring)" ->
  "TranscendentalFunctionCategory()"
"UnivariateLaurentSeriesCategory(a:Ring)" ->
  "UnivariatePowerSeriesCategory(a:Ring,Integer)"

```

— ULSCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

```

```

"UnivariateLaurentSeriesCategory(a:Ring)" [color=lightblue];
"UnivariateLaurentSeriesCategory(a:Ring)" ->
    "UnivariatePowerSeriesCategory(a:Ring,Integer)"
"UnivariateLaurentSeriesCategory(a:Ring)" ->
    "FIELD..."
"UnivariateLaurentSeriesCategory(a:Ring)" ->
    "RADCAT..."
"UnivariateLaurentSeriesCategory(a:Ring)" ->
    "TRANFUN..."

"UnivariatePowerSeriesCategory(a:Ring,Integer)" [color=seagreen];
"UnivariatePowerSeriesCategory(a:Ring,Integer)" ->
    "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"

"UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"
    [color=lightblue];
"UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)" ->
    "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"

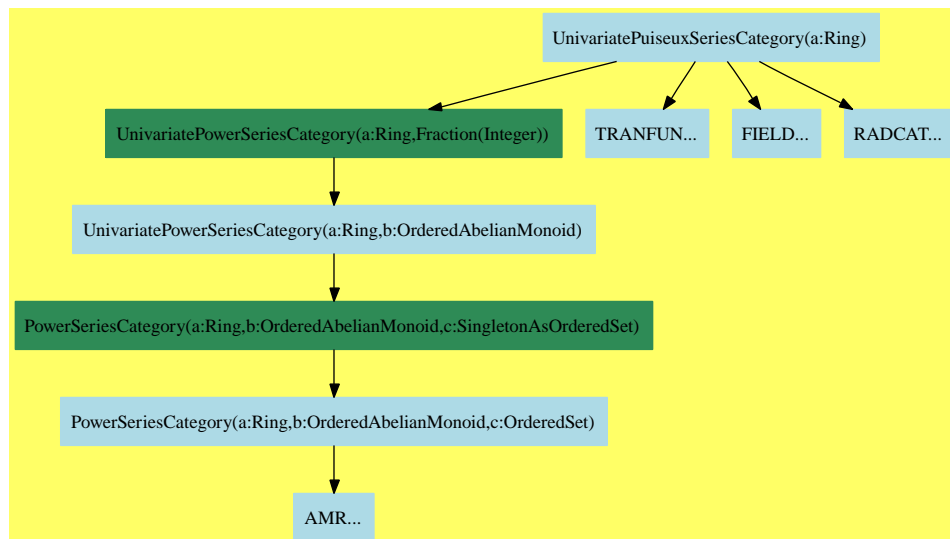
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
    [color=seagreen];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
    -> "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"

"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"
    [color=lightblue];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)" ->
    "AMR..."

"AMR..." [color=lightblue];
"FIELD..." [color=lightblue];
"TRANFUN..." [color=lightblue];
"RADCAT..." [color=lightblue];
}

```

UnivariatePuisseuxSeriesCategory (UPXSCAT)



— UnivariatePuisseuxSeriesCategory.input —

```

)set break resume
)sys rm -f UnivariatePuisseuxSeriesCategory.output
)spool UnivariatePuisseuxSeriesCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show UnivariatePuisseuxSeriesCategory
--R
--R UnivariatePuisseuxSeriesCategory(Coef: Ring) is a category constructor
--R Abbreviation for UnivariatePuisseuxSeriesCategory is UPXSCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for UPXSCAT
--R
--R----- Operations -----
--R ?? : (Coef,%) -> %
--R ?? : (%,%) -> %
--R ?? : (PositiveInteger,%) -> %
--R ?? : (%,%) -> %
--R -? : % -> %
--R 1 : () -> %
--R ?? : (%,PositiveInteger) -> %
--R coerce : Integer -> %
--R ?? : (%,Coef) -> %
--R ?? : (Integer,%) -> %
--R ***? : (%,PositiveInteger) -> %
--R ?-? : (%,%) -> %
--R ?? : (%,%) -> Boolean
--R 0 : () -> %
--R center : % -> Coef
--R coerce : % -> OutputForm

```

```

--R complete : % -> %
--R hash : % -> SingleInteger
--R leadingCoefficient : % -> Coef
--R map : ((Coef -> Coef),%) -> %
--R one? : % -> Boolean
--R pole? : % -> Boolean
--R reductum : % -> %
--R variable : % -> Symbol
--R ~=? : (%,%) -> Boolean
--R ?? : (%,Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (Fraction(Integer),%) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (%,%) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (%,Integer) -> % if Coef has FIELD
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,%) -> % if Coef has FIELD
--R ?/? : (%,Coef) -> % if Coef has FIELD
--R D : % -> % if Coef has *: (Fraction(Integer),Coef) -> Coef
--R D : (%,NonNegativeInteger) -> % if Coef has *: (Fraction(Integer),Coef) -> Coef
--R D : (%,Symbol) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> Coef
--R D : (%,List(Symbol)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> Coef
--R D : (%,Symbol,NonNegativeInteger) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> Coef
--R D : (%,List(Symbol),List(NonNegativeInteger)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> Coef
--R ?? : (%,Integer) -> % if Coef has FIELD
--R ?? : (%,NonNegativeInteger) -> %
--R acos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acoth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R approximate : (%,Fraction(Integer)) -> Coef if Coef has **: (Coef,Fraction(Integer)) -> Coef
--R asec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asinh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R associates? : (%,%) -> Boolean if Coef has INTDOM
--R atan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R atanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
--R coefficient : (%,Fraction(Integer)) -> Coef
--R coerce : % -> % if Coef has INTDOM
--R coerce : Fraction(Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R coerce : Coef -> % if Coef has COMRING
--R cos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R coth : % -> % if Coef has ALGEBRA(FRAC(INT))

```

```

--R csc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R differentiate : % -> % if Coef has *: (Fraction(Integer),Coef) -> Coef
--R differentiate : (% ,NonNegativeInteger) -> % if Coef has *: (Fraction(Integer),Coef) -> Coef
--R differentiate : (% ,Symbol) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> %
--R differentiate : (% ,List(Symbol)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> %
--R differentiate : (% ,Symbol,NonNegativeInteger) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> %
--R differentiate : (% ,List(Symbol),List(NonNegativeInteger)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> %
--R divide : (% ,%) -> Record(quotient: %,remainder: %) if Coef has FIELD
--R ?.? : (% ,%) -> % if Fraction(Integer) has SGROUP
--R ?.? : (% ,Fraction(Integer)) -> Coef
--R euclideanSize : % -> NonNegativeInteger if Coef has FIELD
--R eval : (% ,Coef) -> Stream(Coef) if Coef has **: (Coef,Fraction(Integer)) -> Coef
--R exp : % -> % if Coef has ALGEBRA(FRAC(INT))
--R expressIdealMember : (List(%),%) -> Union(List(%),"failed") if Coef has FIELD
--R exquo : (% ,%) -> Union(%,"failed") if Coef has INTDOM
--R extend : (% ,Fraction(Integer)) -> %
--R extendedEuclidean : (% ,%) -> Record(coef1: %,coef2: %,generator: %) if Coef has FIELD
--R extendedEuclidean : (% ,%,%) -> Union(Record(coef1: %,coef2: %),"failed") if Coef has FIELD
--R factor : % -> Factored(%) if Coef has FIELD
--R gcd : (% ,%) -> % if Coef has FIELD
--R gcd : List(%) -> % if Coef has FIELD
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R integrate : (% ,Symbol) -> % if Coef has ACFS(INT) and Coef has PRIMCAT and Coef has TRANFUN and Coef has ALGEBRA(FRAC(INT))
--R integrate : % -> % if Coef has ALGEBRA(FRAC(INT))
--R inv : % -> % if Coef has FIELD
--R lcm : (% ,%) -> % if Coef has FIELD
--R lcm : List(%) -> % if Coef has FIELD
--R log : % -> % if Coef has ALGEBRA(FRAC(INT))
--R monomial : (% ,List(SingletonAsOrderedSet),List(Fraction(Integer))) -> %
--R monomial : (% ,SingletonAsOrderedSet,Fraction(Integer)) -> %
--R monomial : (Coef,Fraction(Integer)) -> %
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed") if Coef has FIELD
--R multiplyExponents : (% ,Fraction(Integer)) -> %
--R multiplyExponents : (% ,PositiveInteger) -> %
--R nthRoot : (% ,Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R order : (% ,Fraction(Integer)) -> Fraction(Integer)
--R pi : () -> % if Coef has ALGEBRA(FRAC(INT))
--R prime? : % -> Boolean if Coef has FIELD
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %) if Coef has FIELD
--R ?quo? : (% ,%) -> % if Coef has FIELD
--R ?rem? : (% ,%) -> % if Coef has FIELD
--R sec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R series : (NonNegativeInteger,Stream(Record(k: Fraction(Integer),c: Coef))) -> %
--R sin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sinh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sizeLess? : (% ,%) -> Boolean if Coef has FIELD
--R sqrt : % -> % if Coef has ALGEBRA(FRAC(INT))
--R squareFree : % -> Factored(%) if Coef has FIELD

```



```

--R squareFreePart : % -> % if Coef has FIELD
--R subtractIfCan : (%,% ) -> Union(%, "failed")
--R tan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R tanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R terms : % -> Stream(Record(k: Fraction(Integer), c: Coef))
--R truncate : (% , Fraction(Integer), Fraction(Integer)) -> %
--R truncate : (% , Fraction(Integer)) -> %
--R unit? : % -> Boolean if Coef has INTDOM
--R unitCanonical : % -> % if Coef has INTDOM
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %) if Coef has INTDOM
--R variables : % -> List(SingletonAsOrderedSet)
--R
--E 1

)spool
)lisp (bye)

```

— UnivariatePuisseuxSeriesCategory.help —

```

=====
UnivariatePuisseuxSeriesCategory examples
=====

```

UnivariatePuisseuxSeriesCategory is the category of Puiseux series in one variable.

See Also:

o)show UnivariatePuisseuxSeriesCategory

See:

⇒ “UnivariatePuisseuxSeriesConstructorCategory” (UPXSCCA) [18](#) on page [1623](#)
 ⇐ “TranscendentalFunctionCategory” (TRANFUN) [3](#) on page [166](#)
 ⇐ “Field” (FIELD) [16](#) on page [1271](#)
 ⇐ “RadicalCategory” (RADCAT) [2](#) on page [92](#)
 ⇐ “UnivariatePowerSeriesCategory” (UPSCAT) [15](#) on page [1260](#)

Exports:

| | | | |
|-----------------|----------------|-------------------|--------------------|
| 0 | 1 | acos | acosh |
| acot | acoth | acsc | acsch |
| approximate | asec | asech | asin |
| asinh | associates? | atan | atanh |
| center | characteristic | charthRoot | coefficient |
| coerce | complete | cos | cosh |
| cot | coth | csc | csch |
| D | degree | differentiate | divide |
| euclideanSize | eval | exp | expressIdealMember |
| exquo | extend | extendedEuclidean | factor |
| gcd | gcdPolynomial | hash | integrate |
| inv | latex | lcm | leadingCoefficient |
| leadingMonomial | log | map | monomial |
| monomial? | multiEuclidean | multiplyExponents | nthRoot |
| one? | order | pi | pole? |
| prime? | principalIdeal | recip | reductum |
| sample | sec | sech | series |
| sin | sinh | sizeLess? | sqrt |
| squareFree | squareFreePart | subtractIfCan | tan |
| tanh | terms | truncate | unit? |
| unitCanonical | unitNormal | variable | variables |
| zero? | ?*? | ?**? | ?+? |
| ?-? | -? | ?=? | ?~=? |
| ?/? | ?^? | ?..? | ?quo? |
| ?rem? | | | |

Attributes Exported:

- if #1 has Field then canonicalUnitNormal where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- if #1 has Field then canonicalsClosed where **canonicalsClosed** is true if `unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- if #1 has IntegralDomain then noZeroDivisors where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- if #1 has CommutativeRing then commutative(“*”) where **commutative(“*”)** is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.

These are directly exported but not implemented:

```

integrate : % -> % if Coef has ALGEBRA FRAC INT
integrate : (%,Symbol) -> %
  if Coef has ACFS INT
  and Coef has PRIMCAT
  and Coef has TRANFUN
  and Coef has ALGEBRA FRAC INT
  or Coef has variables: Coef -> List Symbol
  and Coef has integrate: (Coef,Symbol) -> Coef
  and Coef has ALGEBRA FRAC INT
multiplyExponents : (%,Fraction Integer) -> %
series : (NonNegativeInteger,Stream Record(k: Fraction Integer,c: Coef)) -> %

```

These exports come from (p1260) `UnivariatePowerSeriesCategory(Coef,RN)` where `Coef:Ring` and `RN:Fraction(Integer)`:

```

0 : () -> %
1 : () -> %
approximate : (%,Fraction Integer) -> Coef
  if Coef has **: (Coef,Fraction Integer) -> Coef
  and Coef has coerce: Symbol -> Coef
associates? : (%,%) -> Boolean if Coef has INTDOM
center : % -> Coef
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
coefficient : (%,Fraction Integer) -> Coef
coerce : % -> % if Coef has INTDOM
coerce : Fraction Integer -> % if Coef has ALGEBRA FRAC INT
coerce : Coef -> % if Coef has COMRING
coerce : Integer -> %
coerce : % -> OutputForm
complete : % -> %
D : % -> % if Coef has *: (Fraction Integer,Coef) -> Coef
D : (%,NonNegativeInteger) -> %
  if Coef has *: (Fraction Integer,Coef) -> Coef
D : (%,Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer,Coef) -> Coef
D : (%,List Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer,Coef) -> Coef
D : (%,Symbol,NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer,Coef) -> Coef
D : (%,List Symbol,List NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer,Coef) -> Coef
degree : % -> Fraction Integer
differentiate : (%,Symbol) -> %

```

```

    if Coef has PDRING SYMBOL
    and Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : (% , List Symbol) -> %
    if Coef has PDRING SYMBOL
    and Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : (% , Symbol, NonNegativeInteger) -> %
    if Coef has PDRING SYMBOL
    and Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : (% , List Symbol, List NonNegativeInteger) -> %
    if Coef has PDRING SYMBOL
    and Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : % -> %
    if Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : (% , NonNegativeInteger) -> %
    if Coef has *: (Fraction Integer, Coef) -> Coef
eval : (% , Coef) -> Stream Coef
    if Coef has **: (Coef, Fraction Integer) -> Coef
exquo : (% , %) -> Union(%, "failed") if Coef has INTDOM
extend : (% , Fraction Integer) -> %
hash : % -> SingleInteger
latex : % -> String
leadingCoefficient : % -> Coef
leadingMonomial : % -> %
map : ((Coef -> Coef), %) -> %
monomial : (% , List SingletonAsOrderedSet, List Fraction Integer) -> %
monomial : (Coef, Fraction Integer) -> %
monomial : (% , SingletonAsOrderedSet, Fraction Integer) -> %
monomial? : % -> Boolean
multiplyExponents : (% , PositiveInteger) -> %
one? : % -> Boolean
order : (% , Fraction Integer) -> Fraction Integer
order : % -> Fraction Integer
pole? : % -> Boolean
recip : % -> Union(%, "failed")
reductum : % -> %
sample : () -> %
subtractIfCan : (% , %) -> Union(%, "failed")
terms : % -> Stream Record(k: Fraction Integer, c: Coef)
truncate : (% , Fraction Integer, Fraction Integer) -> %
truncate : (% , Fraction Integer) -> %
unit? : % -> Boolean if Coef has INTDOM
unitCanonical : % -> % if Coef has INTDOM
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
    if Coef has INTDOM
variable : % -> Symbol
variables : % -> List SingletonAsOrderedSet
zero? : % -> Boolean
***? : (% , NonNegativeInteger) -> %
?^? : (% , NonNegativeInteger) -> %
?+? : (% , %) -> %

```

```

?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (NonNegativeInteger,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (%,%) -> %
?-? : (%,%) -> %
***? : (%,PositiveInteger) -> %
?^? : (%,PositiveInteger) -> %
?*? : (Integer,%) -> %
?*? : (Coef,%) -> %
?*? : (%,Coef) -> %
?*? : (%,Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
?*? : (Fraction Integer,%) -> % if Coef has ALGEBRA FRAC INT
?/? : (%,Coef) -> % if Coef has FIELD
-? : % -> %
?..? : (%,%) -> % if Fraction Integer has SGROUP
?..? : (%,Fraction Integer) -> Coef

```

These exports come from (p166) TranscendentalFunctionCategory():

```

acos : % -> % if Coef has ALGEBRA FRAC INT
acosh : % -> % if Coef has ALGEBRA FRAC INT
acot : % -> % if Coef has ALGEBRA FRAC INT
acoth : % -> % if Coef has ALGEBRA FRAC INT
acsc : % -> % if Coef has ALGEBRA FRAC INT
acsch : % -> % if Coef has ALGEBRA FRAC INT
asec : % -> % if Coef has ALGEBRA FRAC INT
asech : % -> % if Coef has ALGEBRA FRAC INT
asin : % -> % if Coef has ALGEBRA FRAC INT
asinh : % -> % if Coef has ALGEBRA FRAC INT
atan : % -> % if Coef has ALGEBRA FRAC INT
atanh : % -> % if Coef has ALGEBRA FRAC INT
cos : % -> % if Coef has ALGEBRA FRAC INT
cosh : % -> % if Coef has ALGEBRA FRAC INT
cot : % -> % if Coef has ALGEBRA FRAC INT
coth : % -> % if Coef has ALGEBRA FRAC INT
csc : % -> % if Coef has ALGEBRA FRAC INT
csch : % -> % if Coef has ALGEBRA FRAC INT
exp : % -> % if Coef has ALGEBRA FRAC INT
log : % -> % if Coef has ALGEBRA FRAC INT
pi : () -> % if Coef has ALGEBRA FRAC INT
sec : % -> % if Coef has ALGEBRA FRAC INT
sech : % -> % if Coef has ALGEBRA FRAC INT
sin : % -> % if Coef has ALGEBRA FRAC INT
sinh : % -> % if Coef has ALGEBRA FRAC INT
tan : % -> % if Coef has ALGEBRA FRAC INT
tanh : % -> % if Coef has ALGEBRA FRAC INT
***? : (%,%) -> % if Coef has ALGEBRA FRAC INT

```

These exports come from (p1271) Field():

```

divide : (%,%) -> Record(quotient: %,remainder: %)
  if Coef has FIELD
euclideanSize : % -> NonNegativeInteger if Coef has FIELD
expressIdealMember : (List %,%) -> Union(List %, "failed")
  if Coef has FIELD
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
  if Coef has FIELD
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
  if Coef has FIELD
factor : % -> Factored % if Coef has FIELD
gcd : (%,%) -> % if Coef has FIELD
gcd : List % -> % if Coef has FIELD
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
  if Coef has FIELD
inv : % -> % if Coef has FIELD
lcm : (%,%) -> % if Coef has FIELD
lcm : List % -> % if Coef has FIELD
multiEuclidean : (List %,%) -> Union(List %, "failed")
  if Coef has FIELD
prime? : % -> Boolean if Coef has FIELD
principalIdeal : List % -> Record(coef: List %,generator: %)
  if Coef has FIELD
sizeLess? : (%,%) -> Boolean if Coef has FIELD
squareFree : % -> Factored % if Coef has FIELD
squareFreePart : % -> % if Coef has FIELD
?*** : (%,Integer) -> % if Coef has FIELD
?^? : (%,Integer) -> % if Coef has FIELD
?/? : (%,%) -> % if Coef has FIELD
?quo? : (%,%) -> % if Coef has FIELD
?rem? : (%,%) -> % if Coef has FIELD

```

These exports come from (p92) RadicalCategory():

```

nthRoot : (%,Integer) -> % if Coef has ALGEBRA FRAC INT
sqrt : % -> % if Coef has ALGEBRA FRAC INT
?*** : (%,Fraction Integer) -> % if Coef has ALGEBRA FRAC INT

```

— category UPXSCAT UnivariatePuisseuxSeriesCategory —

```

)abbrev category UPXSCAT UnivariatePuisseuxSeriesCategory
++ Author: Clifton J. Williamson
++ Date Created: 21 December 1989
++ Date Last Updated: 20 September 1993
++ Description:
++ \spadtype{UnivariatePuisseuxSeriesCategory} is the category of Puiseux
++ series in one variable.

```

```

UnivariatePuisseuxSeriesCategory(Coef): Category == Definition where
  Coef : Ring
  NNI ==> NonNegativeInteger
  RN ==> Fraction Integer
  Term ==> Record(k:RN,c:Coef)

Definition ==> UnivariatePowerSeriesCategory(Coef,RN) with

series: (NNI,Stream Term) -> %
  ++ \spad{series(n,st)} creates a series from a common denomiator and
  ++ a stream of non-zero terms, where a term is an exponent-coefficient
  ++ pair. The terms in the stream should be ordered by increasing order
  ++ of exponents and \spad{n} should be a common denominator for the
  ++ exponents in the stream of terms.
multiplyExponents: (%,Fraction Integer) -> %
  ++ \spad{multiplyExponents(f,r)} multiplies all exponents of the power
  ++ series f by the positive rational number r.

if Coef has Algebra Fraction Integer then
  integrate: % -> %
    ++ \spad{integrate(f(x))} returns an anti-derivative of the power
    ++ series \spad{f(x)} with constant coefficient 1.
    ++ We may integrate a series when we can divide coefficients
    ++ by rational numbers.
  if Coef has integrate: (Coef,Symbol) -> Coef and _
    Coef has variables: Coef -> List Symbol then
    integrate: (%,Symbol) -> %
      ++ \spad{integrate(f(x),var)} returns an anti-derivative of the power
      ++ series \spad{f(x)} with respect to the variable \spad{var}.
  if Coef has TranscendentalFunctionCategory and _
    Coef has PrimitiveFunctionCategory and _
    Coef has AlgebraicallyClosedFunctionSpace Integer then
    integrate: (%,Symbol) -> %
      ++ \spad{integrate(f(x),y)} returns an anti-derivative of
      ++ the power series \spad{f(x)} with respect to the variable
      ++ \spad{y}.
  RadicalCategory
    --++ We provide rational powers when we can divide coefficients
    --++ by integers.
  TranscendentalFunctionCategory
    --++ We provide transcendental functions when we can divide
    --++ coefficients by integers.
if Coef has Field then Field
  --++ Univariate Puiseux series over a field form a field.

```

— UPXSCAT.dotabb —

```
"UPXSCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=UPXSCAT"];
"UPXSCAT" -> "TRANFUN"
"UPXSCAT" -> "FIELD"
"UPXSCAT" -> "RADCAT"
"UPXSCAT" -> "UPSCAT"
```

— UPXSCAT.dotfull —

```
"UnivariatePuisseuxSeriesCategory(a:Ring)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=UPXSCAT"];
"UnivariatePuisseuxSeriesCategory(a:Ring)" ->
  "UnivariatePowerSeriesCategory(a:Ring,Fraction(Integer))"
"UnivariatePuisseuxSeriesCategory(a:Ring)" ->
  "TranscendentalFunctionCategory()"
"UnivariatePuisseuxSeriesCategory(a:Ring)" ->
  "Field()"
"UnivariatePuisseuxSeriesCategory(a:Ring)" ->
  "RadicalCategory()"
```

— UPXSCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "UnivariatePuisseuxSeriesCategory(a:Ring)" [color=lightblue];
  "UnivariatePuisseuxSeriesCategory(a:Ring)" ->
    "UnivariatePowerSeriesCategory(a:Ring,Fraction(Integer))"
  "UnivariatePuisseuxSeriesCategory(a:Ring)" ->
    "TRANFUN..."
  "UnivariatePuisseuxSeriesCategory(a:Ring)" ->
    "FIELD..."
  "UnivariatePuisseuxSeriesCategory(a:Ring)" ->
    "RADCAT..."

  "UnivariatePowerSeriesCategory(a:Ring,Fraction(Integer))" [color=seagreen];
  "UnivariatePowerSeriesCategory(a:Ring,Fraction(Integer))" ->
    "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"
```



```

"UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"
  [color=lightblue];
"UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)" ->
  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"

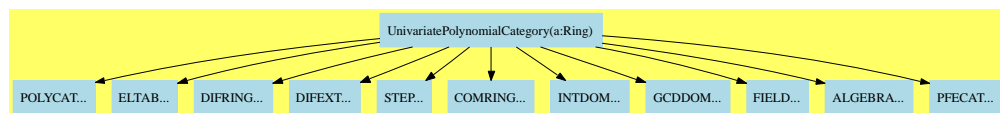
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
  [color=seagreen];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
  -> "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"

"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"
  [color=lightblue];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)" ->
  "AMR..."

"TRANFUN..." [color=lightblue];
"FIELD..." [color=lightblue];
"RADCAT..." [color=lightblue];
"AMR..." [color=lightblue];
}

```

UnivariatePolynomialCategory (UPOLYC)



— UnivariatePolynomialCategory.input —

```

)set break resume
)sys rm -f UnivariatePolynomialCategory.output
)spool UnivariatePolynomialCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 4
)show UnivariatePolynomialCategory
--R UnivariatePolynomialCategory(R: Ring) is a category constructor
--R Abbreviation for UnivariatePolynomialCategory is UPOLYC
--R This constructor is exposed in this frame.

```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for UPOLYC
--R
--R----- Operations -----
--R ??? : (%,R) -> %           ??? : (R,%) -> %
--R ??? : (%,%) -> %           ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %           ?-? : (%,%) -> %
--R -? : % -> %               ?=? : (%,%) -> Boolean
--R D : (%,(R -> R)) -> %       D : % -> %
--R D : (%,NonNegativeInteger) -> % 1 : () -> %
--R 0 : () -> %               ?? : (%,PositiveInteger) -> %
--R coefficients : % -> List(R)   coerce : R -> %
--R coerce : Integer -> %         coerce : % -> OutputForm
--R degree : % -> NonNegativeInteger  differentiate : % -> %
--R ?? : (%,%) -> %             ?? : (%,R) -> R
--R eval : (%,%,%) -> %         eval : (%,Equation(%)) -> %
--R ground : % -> R             ground? : % -> Boolean
--R hash : % -> SingleInteger     init : () -> % if R has STEP
--R latex : % -> String           leadingCoefficient : % -> R
--R leadingMonomial : % -> %      map : ((R -> R),%) -> %
--R monomial? : % -> Boolean      monomials : % -> List(%)
--R one? : % -> Boolean           pseudoRemainder : (%,%) -> %
--R recip : % -> Union(%, "failed") reductum : % -> %
--R retract : % -> R             sample : () -> %
--R unvectorise : Vector(R) -> %  zero? : % -> Boolean
--R ?=? : (%,%) -> Boolean
--R ??? : (Fraction(Integer),%) -> % if R has ALGEBRA(FRAC(INT))
--R ??? : (%,Fraction(Integer)) -> % if R has ALGEBRA(FRAC(INT))
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,R) -> % if R has FIELD
--R ?<? : (%,%) -> Boolean if R has ORDSET
--R ?<=? : (%,%) -> Boolean if R has ORDSET
--R ?>? : (%,%) -> Boolean if R has ORDSET
--R ?>=? : (%,%) -> Boolean if R has ORDSET
--R D : (%,(R -> R),NonNegativeInteger) -> %
--R D : (%,List(Symbol),List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R D : (%,Symbol,NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R D : (%,List(Symbol)) -> % if R has PDRING(SYMBOL)
--R D : (%,Symbol) -> % if R has PDRING(SYMBOL)
--R D : (%,List(SingletonAsOrderedSet),List(NonNegativeInteger)) -> %
--R D : (%,SingletonAsOrderedSet,NonNegativeInteger) -> %
--R D : (%,List(SingletonAsOrderedSet)) -> %
--R D : (%,SingletonAsOrderedSet) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R associates? : (%,%) -> Boolean if R has INTDOM
--R binomThmExpt : (%,%,NonNegativeInteger) -> % if R has COMRING
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if and(has($,CharacteristicNonZero),has(R,PolynomialFactorizationExpt))
--R coefficient : (%,List(SingletonAsOrderedSet),List(NonNegativeInteger)) -> %

```

```

--R coefficient : (%,SingletonAsOrderedSet,NonNegativeInteger) -> %
--R coefficient : (%,NonNegativeInteger) -> R
--R coerce : % -> % if R has INTDOM
--R coerce : Fraction(Integer) -> % if R has RETRACT(FRAC(INT)) or R has ALGEBRA(FRAC(INT))
--R coerce : SingletonAsOrderedSet -> %
--R composite : (Fraction(%),%) -> Union(Fraction(%),"failed") if R has INTDOM
--R composite : (%,%) -> Union(%,"failed") if R has INTDOM
--R conditionP : Matrix(%) -> Union(Vector(%),"failed") if and(has($,CharacteristicNonZero),has(
--R content : (%,SingletonAsOrderedSet) -> % if R has GCDDOM
--R content : % -> R if R has GCDDOM
--R convert : % -> InputForm if SingletonAsOrderedSet has KONVERT(INFORM) and R has KONVERT(INFO
--R convert : % -> Pattern(Integer) if SingletonAsOrderedSet has KONVERT(PATTERN(INT)) and R has
--R convert : % -> Pattern(Float) if SingletonAsOrderedSet has KONVERT(PATTERN(FLOAT)) and R has
--R degree : (%,List(SingletonAsOrderedSet)) -> List(NonNegativeInteger)
--R degree : (%,SingletonAsOrderedSet) -> NonNegativeInteger
--R differentiate : (%,(R -> R),%) -> %
--R differentiate : (%,(R -> R)) -> %
--R differentiate : (%,(R -> R),NonNegativeInteger) -> %
--R differentiate : (%,List(Symbol),List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R differentiate : (%,Symbol,NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R differentiate : (%,List(Symbol)) -> % if R has PDRING(SYMBOL)
--R differentiate : (%,Symbol) -> % if R has PDRING(SYMBOL)
--R differentiate : (%,NonNegativeInteger) -> %
--R differentiate : (%,List(SingletonAsOrderedSet),List(NonNegativeInteger)) -> %
--R differentiate : (%,SingletonAsOrderedSet,NonNegativeInteger) -> %
--R differentiate : (%,List(SingletonAsOrderedSet)) -> %
--R differentiate : (%,SingletonAsOrderedSet) -> %
--R discriminant : % -> R if R has COMRING
--R discriminant : (%,SingletonAsOrderedSet) -> % if R has COMRING
--R divide : (%,%) -> Record(quotient: %,remainder: %) if R has FIELD
--R divideExponents : (%,NonNegativeInteger) -> Union(%,"failed")
--R ? : (%,Fraction(%)) -> Fraction(%) if R has INTDOM
--R elt : (Fraction(%),R) -> R if R has FIELD
--R elt : (Fraction(%),Fraction(%)) -> Fraction(%) if R has INTDOM
--R euclideanSize : % -> NonNegativeInteger if R has FIELD
--R eval : (%,List(SingletonAsOrderedSet),List(%)) -> %
--R eval : (%,SingletonAsOrderedSet,%) -> %
--R eval : (%,List(SingletonAsOrderedSet),List(R)) -> %
--R eval : (%,SingletonAsOrderedSet,R) -> %
--R eval : (%,List(%),List(%)) -> %
--R eval : (%,List(Equation(%))) -> %
--R expressIdealMember : (List(%),%) -> Union(List(%),"failed") if R has FIELD
--R exquo : (%,%) -> Union(%,"failed") if R has INTDOM
--R exquo : (%,R) -> Union(%,"failed") if R has INTDOM
--R extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %) if R has FIELD
--R extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed") if R has FIELD
--R factor : % -> Factored(%) if R has PFECAT
--R factorPolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%))
--R factorSquareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolyn
--R gcd : (%,%) -> % if R has GCDDOM

```

```

--R gcd : List(%) -> % if R has GCDDOM
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R integrate : % -> % if R has ALGEBRA(FRAC(INT))
--R isExpt : % -> Union(Record(var: SingletonAsOrderedSet,exponent: NonNegativeInteger),"failed")
--R isPlus : % -> Union(List(%),"failed")
--R isTimes : % -> Union(List(%),"failed")
--R karatsubaDivide : (%,NonNegativeInteger) -> Record(quotient: %,remainder: %)
--R lcm : (%,%) -> % if R has GCDDOM
--R lcm : List(%) -> % if R has GCDDOM
--R lcmCoef : (%,%) -> Record(llcmres: %,coeff1: %,coeff2: %) if R has GCDDOM
--R mainVariable : % -> Union(SingletonAsOrderedSet,"failed")
--R makeSUP : % -> SparseUnivariatePolynomial(R)
--R mapExponents : ((NonNegativeInteger -> NonNegativeInteger),%) -> %
--R max : (%,%) -> % if R has ORDSET
--R min : (%,%) -> % if R has ORDSET
--R minimumDegree : (%,List(SingletonAsOrderedSet)) -> List(NonNegativeInteger)
--R minimumDegree : (%,SingletonAsOrderedSet) -> NonNegativeInteger
--R minimumDegree : % -> NonNegativeInteger
--R monicDivide : (%,%) -> Record(quotient: %,remainder: %)
--R monicDivide : (%,%,SingletonAsOrderedSet) -> Record(quotient: %,remainder: %)
--R monomial : (%,List(SingletonAsOrderedSet),List(NonNegativeInteger)) -> %
--R monomial : (%,SingletonAsOrderedSet,NonNegativeInteger) -> %
--R monomial : (R,NonNegativeInteger) -> %
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed") if R has FIELD
--R multiplyExponents : (%,NonNegativeInteger) -> %
--R multivariate : (SparseUnivariatePolynomial(%),SingletonAsOrderedSet) -> %
--R multivariate : (SparseUnivariatePolynomial(R),SingletonAsOrderedSet) -> %
--R nextItem : % -> Union(%,"failed") if R has STEP
--R numberOfMonomials : % -> NonNegativeInteger
--R order : (%,%) -> NonNegativeInteger if R has INTDOM
--R patternMatch : (%,Pattern(Integer),PatternMatchResult(Integer,%)) -> PatternMatchResult(Integer,%) if S
--R patternMatch : (%,Pattern(Float),PatternMatchResult(Float,%)) -> PatternMatchResult(Float,%) if Singleto
--R pomopo! : (%,R,NonNegativeInteger,%) -> %
--R prime? : % -> Boolean if R has PFECAT
--R primitiveMonomials : % -> List(%)
--R primitivePart : (%,SingletonAsOrderedSet) -> % if R has GCDDOM
--R primitivePart : % -> % if R has GCDDOM
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %) if R has FIELD
--R pseudoDivide : (%,%) -> Record(coef: R,quotient: %,remainder: %) if R has INTDOM
--R pseudoQuotient : (%,%) -> % if R has INTDOM
--R ?quo? : (%,%) -> % if R has FIELD
--R reducedSystem : Matrix(%) -> Matrix(R)
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(R),vec: Vector(R))
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Integer),vec: Vector(Integer)) if R has LIN
--R reducedSystem : Matrix(%) -> Matrix(Integer) if R has LINEXP(INT)
--R ?rem? : (%,%) -> % if R has FIELD
--R resultant : (%,%) -> R if R has COMRING
--R resultant : (%,%,SingletonAsOrderedSet) -> % if R has COMRING
--R retract : % -> SingletonAsOrderedSet
--R retract : % -> Integer if R has RETRACT(INT)

```

```

--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(SingletonAsOrderedSet,"failed")
--R retractIfCan : % -> Union(Integer,"failed") if R has RETRACT(INT)
--R retractIfCan : % -> Union(Fraction(Integer),"failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(R,"failed")
--R separate : (%,%) -> Record(primePart: %,commonPart: %) if R has GCDDOM
--R shiftLeft : (%,NonNegativeInteger) -> %
--R shiftRight : (%,NonNegativeInteger) -> %
--R sizeLess? : (%,%) -> Boolean if R has FIELD
--R solveLinearPolynomialEquation : (List(SparseUnivariatePolynomial(%)),SparseUnivariatePolynom
--R squareFree : % -> Factored(%) if R has GCDDOM
--R squareFreePart : % -> % if R has GCDDOM
--R squareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(
--R subResultantGcd : (%,%) -> % if R has INTDOM
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R totalDegree : (%,List(SingletonAsOrderedSet)) -> NonNegativeInteger
--R totalDegree : % -> NonNegativeInteger
--R unit? : % -> Boolean if R has INTDOM
--R unitCanonical : % -> % if R has INTDOM
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if R has INTDOM
--R univariate : % -> SparseUnivariatePolynomial(R)
--R univariate : (%,SingletonAsOrderedSet) -> SparseUnivariatePolynomial(%)
--R unmakeSUP : SparseUnivariatePolynomial(R) -> %
--R variables : % -> List(SingletonAsOrderedSet)
--R vectorise : (%,NonNegativeInteger) -> Vector(R)
--E 1

--S 2 of 4
t1:UP(x,FRAC(INT)):=3*x^3+4*x^2+5*x+6
--R
--R      3      2
--R      (1)  3x  + 4x  + 5x + 6
--R
--R                                          Type: UnivariatePolynomial(x,Fraction(Integer))
--E 2

--S 3 of 4
t2:=vectorise(t1,4)
--R
--R      (2)  [6,5,4,3]
--R
--R                                          Type: Vector(Fraction(Integer))
--E 3

--S 4 of 4
t3:UP(x,FRAC(INT)):=unvectorise(t2)
--R
--R      3      2
--R      (3)  3x  + 4x  + 5x + 6
--R
--R                                          Type: UnivariatePolynomial(x,Fraction(Integer))
--E 4

```

```
)spool
)lisp (bye)
```

— UnivariatePolynomialCategory.help —

```
=====
UnivariatePolynomialCategory examples
=====
```

The category of univariate polynomials over a ring R. No particular model is assumed - implementations can be either sparse or dense.

See Also:

```
o )show UnivariatePolynomialCategory
```

See:

⇐ “Algebra” (ALGEBRA) [11](#) on page [999](#)
 ⇐ “CommutativeRing” (COMRING) [10](#) on page [896](#)
 ⇐ “DifferentialExtension” (DIFEXT) [11](#) on page [1005](#)
 ⇐ “DifferentialRing” (DIFRING) [10](#) on page [902](#)
 ⇐ “Eltable” (ELTAB) [2](#) on page [48](#)
 ⇐ “Field” (FIELD) [16](#) on page [1271](#)
 ⇐ “GcdDomain” (GCDDOM) [13](#) on page [1179](#)
 ⇐ “IntegralDomain” (INTDOM) [12](#) on page [1097](#)
 ⇐ “PolynomialCategory” (POLYCAT) [16](#) on page [1305](#)
 ⇐ “PolynomialFactorizationExplicit” (PFECAT) [15](#) on page [1253](#)
 ⇐ “StepThrough” (STEP) [4](#) on page [305](#)

Exports:

| | | |
|-------------------------------|--------------------|--------------------|
| 0 | 1 | associates? |
| binomThmExpt | characteristic | charthRoot |
| coefficient | coefficients | coerce |
| composite | conditionP | content |
| convert | D | degree |
| differentiate | discriminant | divide |
| divideExponents | elt | euclideanSize |
| eval | expressIdealMember | exquo |
| extendedEuclidean | factor | factorPolynomial |
| factorSquareFreePolynomial | gcd | gcdPolynomial |
| ground | ground? | hash |
| init | integrate | isExpt |
| isPlus | isTimes | karatsubaDivide |
| latex | lcm | leadingCoefficient |
| leadingMonomial | mainVariable | makeSUP |
| map | mapExponents | max |
| min | minimumDegree | monicDivide |
| monomial | monomial? | monomials |
| multiEuclidean | multiplyExponents | multivariate |
| nextItem | numberOfMonomials | one? |
| order | patternMatch | pomopo! |
| prime? | primitiveMonomials | primitivePart |
| principalIdeal | pseudoDivide | pseudoQuotient |
| pseudoRemainder | recip | reducedSystem |
| reductum | resultant | retract |
| retractIfCan | sample | separate |
| shiftLeft | shiftRight | sizeLess? |
| solveLinearPolynomialEquation | squareFree | squareFreePart |
| squareFreePolynomial | subResultantGcd | subtractIfCan |
| totalDegree | unit? | unitCanonical |
| unitNormal | univariate | unmakeSUP |
| variables | vectorise | zero? |
| ?*? | ?**? | ?+? |
| ?-? | -? | ?=? |
| ?^? | ?.?? | ?~=? |
| ?/? | ?<? | ?<=? |
| ?>? | ?>=? | ?quo? |
| ?rem? | | |

Attributes exported:

- if \$ has CommutativeRing then commutative(“*”) where **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- if \$ has IntegralDomain then noZeroDivisors where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- if R has Field then additiveValuation where **additiveValuation** implies

`euclideanSize(a*b)=euclideanSize(a)+euclideanSize(b).`

- if `$` has `canonicalUnitNormal` then `canonicalUnitNormal` where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
discriminant : % -> R if R has COMRING
divideExponents : (% , NonNegativeInteger) -> Union(%, "failed")
monicDivide : (% , %) -> Record(quotient: %, remainder: %)
multiplyExponents : (% , NonNegativeInteger) -> %
pseudoRemainder : (% , %) -> %
resultant : (% , %) -> R if R has COMRING
subResultantGcd : (% , %) -> % if R has INTDOM
```

These are implemented by this category:

```
0 : () -> %
1 : () -> %
associates? : (% , %) -> Boolean if R has INTDOM
binomThmExpt : (% , %, NonNegativeInteger) -> %
    if R has COMRING
characteristic : () -> NonNegativeInteger
coefficient : (% , NonNegativeInteger) -> R
coefficients : % -> List R
coerce : R -> %
coerce : Fraction Integer -> %
    if R has RETRACT FRAC INT
    or R has ALGEBRA FRAC INT
coerce : % -> % if R has INTDOM
content : % -> R if R has GCDDOM
coerce : Integer -> %
coerce : % -> OutputForm
coerce : SingletonAsOrderedSet -> %
composite : (Fraction %, %) -> Union(Fraction %, "failed")
    if R has INTDOM
composite : (% , %) -> Union(%, "failed")
    if R has INTDOM
content : (% , SingletonAsOrderedSet) -> %
    if R has GCDDOM
D : (% , List SingletonAsOrderedSet) -> %
```



```

D : (% , SingletonAsOrderedSet) -> %
D : (% , List SingletonAsOrderedSet, List NonNegativeInteger) -> %
D : (% , SingletonAsOrderedSet, NonNegativeInteger) -> %
degree : % -> NonNegativeInteger
degree :
  (% , List SingletonAsOrderedSet) -> List NonNegativeInteger
differentiate :
  (% , List SingletonAsOrderedSet, List NonNegativeInteger) -> %
differentiate :
  (% , SingletonAsOrderedSet, NonNegativeInteger) -> %
differentiate : (% , List SingletonAsOrderedSet) -> %
differentiate : (% , (R -> R) , %) -> %
differentiate : (% , (R -> R)) -> %
differentiate : % -> %
differentiate : (% , SingletonAsOrderedSet) -> %
divide : (% , %) -> Record(quotient: % , remainder: %)
  if R has FIELD
elt : (Fraction % , Fraction %) -> Fraction %
  if R has INTDOM
elt : (Fraction % , R) -> R if R has FIELD
euclideanSize : % -> NonNegativeInteger
  if R has FIELD
eval : (% , List SingletonAsOrderedSet, List %) -> %
eval : (% , SingletonAsOrderedSet, %) -> %
eval : (% , List SingletonAsOrderedSet, List R) -> %
eval : (% , SingletonAsOrderedSet, R) -> %
eval : (% , List Equation %) -> %
eval : (% , List % , List %) -> %
eval : (% , % , %) -> %
eval : (% , Equation %) -> %
exquo : (% , R) -> Union(% , "failed")
  if R has INTDOM
exquo : (% , %) -> Union(% , "failed")
  if R has INTDOM
factor : % -> Factored % if R has PFECAT
factorPolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if R has PFECAT
factorSquareFreePolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if R has PFECAT
gcd : (% , %) -> % if R has GCDDOM
gcd : List % -> % if R has GCDDOM
gcdPolynomial :
  (SparseUnivariatePolynomial % ,
   SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
    if R has GCDDOM

```

```

ground : % -> R
ground? : % -> Boolean
hash : % -> SingleInteger
init : () -> % if R has STEP
integrate : % -> % if R has ALGEBRA FRAC INT
karatsubaDivide :
  (% , NonNegativeInteger) -> Record(quotient: % , remainder: %)
latex : % -> String
lcm : (% , %) -> % if R has GCDDOM
lcm : List % -> % if R has GCDDOM
leadingCoefficient : % -> R
leadingMonomial : % -> %
mainVariable : % -> Union(SingletonAsOrderedSet, "failed")
makeSUP : % -> SparseUnivariatePolynomial R
map : ((R -> R) , %) -> %
mapExponents :
  ((NonNegativeInteger -> NonNegativeInteger) , %) -> %
max : (% , %) -> % if R has ORDSET
min : (% , %) -> % if R has ORDSET
minimumDegree :
  (% , SingletonAsOrderedSet) -> NonNegativeInteger
minimumDegree :
  (% , List SingletonAsOrderedSet) -> List NonNegativeInteger
monomial : (R , NonNegativeInteger) -> %
monomial : (% , SingletonAsOrderedSet , NonNegativeInteger) -> %
monomial? : % -> Boolean
nextItem : % -> Union(% , "failed") if R has STEP
numberOfMonomials : % -> NonNegativeInteger
one? : % -> Boolean
order : (% , %) -> NonNegativeInteger
  if R has INTDOM
pomopo! : (% , R , NonNegativeInteger , %) -> %
prime? : % -> Boolean if R has PFECAT
pseudoDivide :
  (% , %) -> Record(coef: R , quotient: % , remainder: %)
  if R has INTDOM
pseudoQuotient : (% , %) -> % if R has INTDOM
recip : % -> Union(% , "failed")
reducedSystem : (Matrix % , Vector %) ->
  Record(mat: Matrix Integer , vec: Vector Integer)
  if R has LINEXP INT
reducedSystem : Matrix % -> Matrix Integer
  if R has LINEXP INT
reductum : % -> %
retract : % -> R
retract : % -> Integer if R has RETRACT INT
retract : % -> Fraction Integer
  if R has RETRACT FRAC INT
retractIfCan : % -> Union(Integer , "failed")
  if R has RETRACT INT

```

```

retractIfCan : % -> Union(Fraction Integer,"failed")
  if R has RETRACT FRAC INT
retractIfCan : % -> Union(R,"failed")
sample : () -> %
separate : (%,% ) -> Record(primePart: %,commonPart: %)
  if R has GCDDOM
shiftLeft : (% ,NonNegativeInteger) -> %
shiftRight : (% ,NonNegativeInteger) -> %
solveLinearPolynomialEquation :
  (List SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    Union(List SparseUnivariatePolynomial %,"failed")
  if R has PFECAT
squareFree : % -> Factored % if R has GCDDOM
squareFreePart : % -> % if R has GCDDOM
squareFreePolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
  if R has PFECAT
subtractIfCan : (%,% ) -> Union(%,"failed")
totalDegree :
  (% ,List SingletonAsOrderedSet) -> NonNegativeInteger
unit? : % -> Boolean if R has INTDOM
unitCanonical : % -> % if R has INTDOM
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
  if R has INTDOM
unmakeSUP : SparseUnivariatePolynomial R -> %
variables : % -> List SingletonAsOrderedSet
vectorise : (% ,NonNegativeInteger) -> Vector R
zero? : % -> Boolean
?<=? : (%,% ) -> Boolean if R has ORDSET
?>? : (%,% ) -> Boolean if R has ORDSET
?>=? : (%,% ) -> Boolean if R has ORDSET
?+? : (%,% ) -> %
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (% ,R) -> %
?*? : (R,% ) -> %
?*? : (Fraction Integer,% ) -> %
  if R has ALGEBRA FRAC INT
?*? : (% ,Fraction Integer) -> %
  if R has ALGEBRA FRAC INT
?*? : (%,% ) -> %
?*? : (Integer,% ) -> %
?*? : (PositiveInteger,% ) -> %
?*? : (NonNegativeInteger,% ) -> %
?/? : (% ,R) -> % if R has FIELD
?-? : (%,% ) -> %
-? : % -> %
?^? : (% ,PositiveInteger) -> %

```

```

?^? : (% , NonNegativeInteger) -> %
?**? : (% , PositiveInteger) -> %
?***? : (% , NonNegativeInteger) -> %
?.? : (% , Fraction %) -> Fraction %
    if R has INTDOM

```

These exports come from (p1305) PolynomialCategory(R,N,S)
 where R:Ring, N:NonNegativeInteger, S:SingletonAsOrderedSet:

```

charthRoot : % -> Union(%,"failed")
    if
        and(has($,CharacteristicNonZero),
            has(R,PolynomialFactorizationExplicit))
        or R has CHARNZ
coefficient :
    (% , SingletonAsOrderedSet, NonNegativeInteger) -> %
coefficient :
    (% , List SingletonAsOrderedSet, List NonNegativeInteger) -> %
conditionP : Matrix % -> Union(Vector %,"failed")
    if and(has($,CharacteristicNonZero),
        has(R,PolynomialFactorizationExplicit))
convert : % -> Pattern Integer
    if SingletonAsOrderedSet has KONVERT PATTERN INT
    and R has KONVERT PATTERN INT
convert : % -> Pattern Float
    if SingletonAsOrderedSet has KONVERT PATTERN FLOAT
    and R has KONVERT PATTERN FLOAT
convert : % -> InputForm
    if SingletonAsOrderedSet has KONVERT INFORM
    and R has KONVERT INFORM
degree : (% , SingletonAsOrderedSet) -> NonNegativeInteger
discriminant : (% , SingletonAsOrderedSet) -> %
    if R has COMRING
isExpt : % ->
    Union(
        Record(var: SingletonAsOrderedSet, exponent: NonNegativeInteger),
        "failed")
isPlus : % -> Union(List %,"failed")
isTimes : % -> Union(List %,"failed")
minimumDegree : % -> NonNegativeInteger
monicDivide :
    (% , % , SingletonAsOrderedSet) -> Record(quotient: % , remainder: %)
monomial :
    (% , List SingletonAsOrderedSet, List NonNegativeInteger) -> %
monomials : % -> List %
multivariate :
    (SparseUnivariatePolynomial % , SingletonAsOrderedSet) -> %
multivariate :
    (SparseUnivariatePolynomial R , SingletonAsOrderedSet) -> %
patternMatch :

```

```

(%,Pattern Integer,PatternMatchResult(Integer,%)) ->
  PatternMatchResult(Integer,%)
  if SingletonAsOrderedSet has PATMAB INT
  and R has PATMAB INT
patternMatch :
(%,Pattern Float,PatternMatchResult(Float,%)) ->
  PatternMatchResult(Float,%)
  if SingletonAsOrderedSet has PATMAB FLOAT
  and R has PATMAB FLOAT
primitiveMonomials : % -> List %
primitivePart : (%,SingletonAsOrderedSet) -> %
  if R has GCDDOM
primitivePart : % -> % if R has GCDDOM
reducedSystem : Matrix % -> Matrix R
reducedSystem : (Matrix %,Vector %) ->
  Record(mat: Matrix R,vec: Vector R)
resultant : (%,%,SingletonAsOrderedSet) -> %
  if R has COMRING
retract : % -> SingletonAsOrderedSet
retractIfCan : % -> Union(SingletonAsOrderedSet,"failed")
totalDegree : % -> NonNegativeInteger
univariate : % -> SparseUnivariatePolynomial R
univariate :
  (%,SingletonAsOrderedSet) -> SparseUnivariatePolynomial %
?<? : (%,%) -> Boolean if R has ORDSET

```

These exports come from (p48) Eltable(R:Ring,R:Ring):

```

?.? : (%,R) -> R

```

These exports come from (p48) Eltable(R:UPOLYC,R:UPOLYC):

```

?.? : (%,%) -> %

```

These exports come from (p902) DifferentialRing():

```

D : % -> %
D : (%,NonNegativeInteger) -> %
differentiate : (%,NonNegativeInteger) -> %

```

These exports come from (p1005) DifferentialExtension(R:Ring):

```

D : (%,(R -> R)) -> %
D : (%,(R -> R),NonNegativeInteger) -> %
D : (%,Symbol) -> % if R has PDRING SYMBOL
D : (%,List Symbol) -> % if R has PDRING SYMBOL
D : (%,Symbol,NonNegativeInteger) -> %
  if R has PDRING SYMBOL
D : (%,List Symbol,List NonNegativeInteger) -> %

```

```

    if R has PDRING SYMBOL
differentiate : (%,(R -> R),NonNegativeInteger) -> %
differentiate : (%,Symbol) -> %
    if R has PDRING SYMBOL
differentiate : (%,List Symbol) -> %
    if R has PDRING SYMBOL
differentiate : (%,Symbol,NonNegativeInteger) -> %
    if R has PDRING SYMBOL
differentiate : (%,List Symbol,List NonNegativeInteger) -> %
    if R has PDRING SYMBOL

```

These exports come from (p305) StepThrough()

These exports come from (p896) CommutativeRing()

These exports come from (p1097) IntegralDomain()

These exports come from (p1179) GcdDomain()

These exports come from (p1271) Field()

```

expressIdealMember : (List %,%) -> Union(List %,"failed")
    if R has FIELD
extendedEuclidean : (%,%) ->
    Record(coef1: %,coef2: %,generator: %)
    if R has FIELD
extendedEuclidean :
    (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed")
    if R has FIELD
multiEuclidean : (List %,%) -> Union(List %,"failed")
    if R has FIELD
principalIdeal : List % -> Record(coef: List %,generator: %)
    if R has FIELD
sizeLess? : (%,%) -> Boolean if R has FIELD
?quo? : (%,%) -> % if R has FIELD
?rem? : (%,%) -> % if R has FIELD

```

These exports come from (p999) Algebra(Fraction(Integer))

These exports come from (p1253) PolynomialFactorizationExplicit()

— category UPOLYC UnivariatePolynomialCategory —

```
)abbrev category UPOLYC UnivariatePolynomialCategory
++ Description:
++ The category of univariate polynomials over a ring R.
++ No particular model is assumed - implementations can be either
++ sparse or dense.

UnivariatePolynomialCategory(R:Ring): Category ==
Join(PolynomialCategory(R, NonNegativeInteger, SingletonAsOrderedSet),
    Eltable(R, R), Eltable(%, %), DifferentialRing,
    DifferentialExtension R) with
vectorise      : (%,NonNegativeInteger) -> Vector R
++ vectorise(p, n) returns \spad{[a0,...,a(n-1)]} where
++ \spad{p = a0 + a1*x + ... + a(n-1)*x**(n-1)} + higher order terms.
++ The degree of polynomial p can be different from \spad{n-1}.
++
++X t1:UP(x,FRAC(INT)):=3*x^3+4*x^2+5*x+6
++X t2:=vectorise(t1,4)
unvectorise : Vector R -> %
++ unvectorise(v) returns the polynomial which has for coefficients the
++ entries of v in the increasing order.
++
++X t1:UP(x,FRAC(INT)):=3*x^3+4*x^2+5*x+6
++X t2:=vectorise(t1,4)
++X t3:UP(x,FRAC(INT)):=unvectorise(t2)
makeSUP: % -> SparseUnivariatePolynomial R
++ makeSUP(p) converts the polynomial p to be of type
++ SparseUnivariatePolynomial over the same coefficients.
unmakeSUP: SparseUnivariatePolynomial R -> %
++ unmakeSUP(sup) converts sup of type
++ \spadtype{SparseUnivariatePolynomial(R)}
++ to be a member of the given type.
++ Note that converse of makeSUP.
multiplyExponents: (%,NonNegativeInteger) -> %
++ multiplyExponents(p,n) returns a new polynomial resulting from
++ multiplying all exponents of the polynomial p by the non negative
++ integer n.
divideExponents: (%,NonNegativeInteger) -> Union(%, "failed")
++ divideExponents(p,n) returns a new polynomial resulting from
++ dividing all exponents of the polynomial p by the non negative
++ integer n, or "failed" if some exponent is not exactly divisible
++ by n.
monicDivide: (%,%) -> Record(quotient:%,remainder:%)
++ monicDivide(p,q) divide the polynomial p by the monic polynomial q,
```

```

    ++ returning the pair \spad{[quotient, remainder]}.
    ++ Error: if q isn't monic.
-- These three are for Karatsuba
    karatsubaDivide: (%,NonNegativeInteger) -> Record(quotient:%,remainder:%)
    ++ \spad{karatsubaDivide(p,n)} returns the same as
    ++ \spad{monicDivide(p,monomial(1,n))}
    shiftRight: (%,NonNegativeInteger) -> %
    ++ \spad{shiftRight(p,n)} returns
    ++ \spad{monicDivide(p,monomial(1,n)).quotient}
    shiftLeft: (%,NonNegativeInteger) -> %
    ++ \spad{shiftLeft(p,n)} returns \spad{p * monomial(1,n)}
    pseudoRemainder: (%,%) -> %
    ++ pseudoRemainder(p,q) = r, for polynomials p and q, returns the
    ++ remainder when
    ++ \spad{p' := p*lc(q)**(deg p - deg q + 1)}
    ++ is pseudo right-divided by q, i.e. \spad{p' = s q + r}.
    differentiate: (%, R -> R, %) -> %
    ++ differentiate(p, d, x') extends the R-derivation d to an
    ++ extension D in \spad{R[x]} where Dx is given by x', and
    ++ returns \spad{Dp}.
    if R has StepThrough then StepThrough
    if R has CommutativeRing then
        discriminant: % -> R
        ++ discriminant(p) returns the discriminant of the polynomial p.
        resultant: (%,%) -> R
        ++ resultant(p,q) returns the resultant of the polynomials p and q.
    if R has IntegralDomain then
        Eltable(Fraction %, Fraction %)
        elt : (Fraction %, Fraction %) -> Fraction %
        ++ elt(a,b) evaluates the fraction of univariate polynomials
        ++ \spad{a} with the distinguished variable replaced by b.
        order: (%, %) -> NonNegativeInteger
        ++ order(p, q) returns the largest n such that \spad{q**n}
        ++ divides polynomial p
        ++ i.e. the order of \spad{p(x)} at \spad{q(x)=0}.
        subResultantGcd: (%,%) -> %
        ++ subResultantGcd(p,q) computes the gcd of the polynomials p
        ++ and q using the SubResultant GCD algorithm.
        composite: (%, %) -> Union(%, "failed")
        ++ composite(p, q) returns h if \spad{p = h(q)}, and "failed"
        ++ no such h exists.
        composite: (Fraction %, %) -> Union(Fraction %, "failed")
        ++ composite(f, q) returns h if f = h(q), and "failed" is
        ++ no such h exists.
        pseudoQuotient: (%,%) -> %
        ++ pseudoQuotient(p,q) returns r, the quotient when
        ++ \spad{p' := p*lc(q)**(deg p - deg q + 1)}
        ++ is pseudo right-divided by q, i.e. \spad{p' = s q + r}.
        pseudoDivide: (%, %) -> Record(coef:R, quotient: %, remainder:%)
        ++ pseudoDivide(p,q) returns \spad{[c, q, r]}, when

```



```

    ++ \spad{p}' := p*lc(q)**(deg p - deg q + 1) = c * p}
    ++ is pseudo right-divided by q, i.e. \spad{p}' = s q + r}.
if R has GcdDomain then
    separate: (% , %) -> Record(primePart:%, commonPart: %)
    ++ separate(p, q) returns \spad{[a, b]} such that polynomial
    ++ \spad{p = a b} and \spad{a} is relatively prime to q.
if R has Field then
    EuclideanDomain
    additiveValuation
    ++ euclideanSize(a*b) = euclideanSize(a) + euclideanSize(b)
    elt      : (Fraction %, R) -> R
    ++ elt(a,r) evaluates the fraction of univariate polynomials
    ++ \spad{a} with the distinguished variable replaced by the
    ++ constant r.
if R has Algebra Fraction Integer then
    integrate: % -> %
    ++ integrate(p) integrates the univariate polynomial p with respect
    ++ to its distinguished variable.
add
pp,qq: SparseUnivariatePolynomial %

variables(p) ==
    zero? p or zero?(degree p) => []
    [create()]

degree(p:%,v:SingletonAsOrderedSet) == degree p

totalDegree(p:%,lv:List SingletonAsOrderedSet) ==
    empty? lv => 0
    totalDegree p

degree(p:%,lv:List SingletonAsOrderedSet) ==
    empty? lv => []
    [degree p]

eval(p:%,lv: List SingletonAsOrderedSet,lq: List %):% ==
    empty? lv => p
    not empty? rest lv => _
        error "can only eval a univariate polynomial once"
    eval(p,first lv,first lq)$%

eval(p:%,v:SingletonAsOrderedSet,q:%):% == p(q)

eval(p:%,lv: List SingletonAsOrderedSet,lr: List R):% ==
    empty? lv => p
    not empty? rest lv => _
        error "can only eval a univariate polynomial once"
    eval(p,first lv,first lr)$%

eval(p:%,v:SingletonAsOrderedSet,r:R):% == p(r)::%

```

```

eval(p:%,le:List Equation %):% ==
  empty? le => p
  not empty? rest le => _
    error "can only eval a univariate polynomial once"
  mainVariable(lhs first le) case "failed" => p
  p(rhs first le)

mainVariable(p:%) ==
  zero? degree p => "failed"
  create()$SingletonAsOrderedSet

minimumDegree(p:%,v:SingletonAsOrderedSet) == minimumDegree p

minimumDegree(p:%,lv:List SingletonAsOrderedSet) ==
  empty? lv => []
  [minimumDegree p]

monomial(p:%,v:SingletonAsOrderedSet,n:NonNegativeInteger) ==
  mapExponents(x1+->x1+n,p)

coerce(v:SingletonAsOrderedSet):% == monomial(1,1)

makeSUP p ==
  zero? p => 0
  monomial(leadingCoefficient p,degree p) + makeSUP reductum p

unmakeSUP sp ==
  zero? sp => 0
  monomial(leadingCoefficient sp,degree sp) + unmakeSUP reductum sp

karatsubaDivide(p:%,n:NonNegativeInteger) == monicDivide(p,monomial(1,n))

shiftRight(p:%,n:NonNegativeInteger) ==
  monicDivide(p,monomial(1,n)).quotient

shiftLeft(p:%,n:NonNegativeInteger) == p * monomial(1,n)

if R has PolynomialFactorizationExplicit then
  PFBURU ==> PolynomialFactorizationByRecursionUnivariate(R,%)
  pp,qq: SparseUnivariatePolynomial %
  lpp:List SparseUnivariatePolynomial %
  SupR ==> SparseUnivariatePolynomial R
  sp:SupR

  solveLinearPolynomialEquation(lpp,pp) ==
    solveLinearPolynomialEquationByRecursion(lpp,pp)$PFBURU

  factorPolynomial(pp) ==
    factorByRecursion(pp)$PFBURU

```

```

factorSquareFreePolynomial(pp) ==
  factorSquareFreeByRecursion(pp)$PFBRU

import FactoredFunctions2(SupR,S)

factor p ==
  zero? degree p =>
    ansR:=factor leadingCoefficient p
    makeFR(unit(ansR)::%,
      [[w.flg,w.fctr::%,w.xpnt] for w in factorList ansR])
    map(unmakeSUP,factorPolynomial(makeSUP p)$R)

vectorise(p, n) ==
  m := minIndex(v := new(n, 0)$Vector(R))
  for i in minIndex v .. maxIndex v repeat
    qsetelt_!(v, i, coefficient(p, (i - m)::NonNegativeInteger))
  v

unvectorise(v : Vector R) : % ==
  p : % := 0
  for i in 1..#v repeat
    p := p + monomial(v(i), (i-1)::NonNegativeInteger)
  p

retract(p:%):R ==
  zero? p => 0
  zero? degree p => leadingCoefficient p
  error "Polynomial is not of degree 0"

retractIfCan(p:%):Union(R, "failed") ==
  zero? p => 0
  zero? degree p => leadingCoefficient p
  "failed"

if R has StepThrough then
  init() == init()$R::%

  nextItemInner: % -> Union(%, "failed")

  nextItemInner(n) ==
    zero? n => nextItem(0$R)::R::% -- assumed not to fail
    zero? degree n =>
      nn:=nextItem leadingCoefficient n
      nn case "failed" => "failed"
      nn::R::%
    n1:=reductum n
    n2:=nextItemInner n1 -- try stepping the reductum
    n2 case % => monomial(leadingCoefficient n,degree n) + n2
    1+degree n1 < degree n => -- there was a hole between lt n and n1

```

```

        monomial(leadingCoefficient n, degree n) +
        monomial(nextItem(init()$R)::R, 1 + degree n1)
    n3 := nextItem leadingCoefficient n
    n3 case "failed" => "failed"
    monomial(n3, degree n)

nextItem(n) ==
    n1 := nextItemInner n
    n1 case "failed" => monomial(nextItem(init()$R)::R, 1 + degree(n))
    n1

if R has GcdDomain then

    content(p:%, v:SingletonAsOrderedSet) == content(p)::%

    primeFactor: (% , %) -> %

    primeFactor(p, q) ==
        (p1 := (p exquo gcd(p, q))::%) = p => p
        primeFactor(p1, q)

    separate(p, q) ==
        a := primeFactor(p, q)
        [a, (p exquo a)::%]

if R has CommutativeRing then
    differentiate(x:%, deriv:R -> R, x':%) ==
        d:% := 0
        while (dg := degree x) > 0 repeat
            lc := leadingCoefficient x
            d := d + x' * monomial(dg * lc, (dg - 1)::NonNegativeInteger)
                + monomial(deriv lc, dg)
            x := reductum x
        d + deriv(leadingCoefficient x)::%
    else
        ncdiff: (NonNegativeInteger, %) -> %
        -- computes d(x**n) given dx = x', non-commutative case
        ncdiff(n, x') ==
            zero? n => 0
            zero?(n1 := (n - 1)::NonNegativeInteger) => x'
            x' * monomial(1, n1) + monomial(1, 1) * ncdiff(n1, x')

    differentiate(x:%, deriv:R -> R, x':%) ==
        d:% := 0
        while (dg := degree x) > 0 repeat
            lc := leadingCoefficient x
            d := d + monomial(deriv lc, dg) + lc * ncdiff(dg, x')
            x := reductum x
        d + deriv(leadingCoefficient x)::%

```

```

differentiate(x:%, deriv:R -> R) == differentiate(x, deriv, 1$%)$%

differentiate(x:%) ==
  d:% := 0
  while (dg := degree x) > 0 repeat
    d:=d+monomial(dg*leadingCoefficient x,(dg-1)::NonNegativeInteger)
    x := reductum x
  d

differentiate(x:%,v:SingletonAsOrderedSet) == differentiate x

if R has IntegralDomain then

  elt(g:Fraction %, f:Fraction %) == ((numer g) f) / ((denom g) f)

  pseudoQuotient(p, q) ==
    (n := degree(p)::Integer - degree q + 1) < 1 => 0
    ((leadingCoefficient(q)**(n::NonNegativeInteger) * p
    - pseudoRemainder(p, q)) exquo q)::%

  pseudoDivide(p, q) ==
    (n := degree(p)::Integer - degree q + 1) < 1 => [1, 0, p]
    prem := pseudoRemainder(p, q)
    lc := leadingCoefficient(q)**(n::NonNegativeInteger)
    [lc,((lc*p - prem) exquo q)::%, prem]

  composite(f:Fraction %, q:%) ==
    (n := composite(numer f, q)) case "failed" => "failed"
    (d := composite(denom f, q)) case "failed" => "failed"
    n::% / d::%

  composite(p:%, q:%) ==
    ground? p => p
    cqr := pseudoDivide(p, q)
    ground?(cqr.remainder) and
      ((v := cqr.remainder exquo cqr.coef) case %) and
      ((u := composite(cqr.quotient, q)) case %) and
      ((w := (u::%) exquo cqr.coef) case %) =>
        v::% + monomial(1, 1) * w::%
    "failed"

  elt(p:%, f:Fraction %) ==
    zero? p => 0
    ans:Fraction(%) := (leadingCoefficient p)::%::Fraction(%)
    n := degree p
    while not zero?(p:=reductum p) repeat
      ans := ans * f ** (n - (n := degree p))::NonNegativeInteger +
        (leadingCoefficient p)::%::Fraction(%)
    zero? n => ans
    ans * f ** n

```

```

order(p, q) ==
  zero? p => error "order: arguments must be nonzero"
  degree(q) < 1 => error "order: place must be non-trivial"
  ans:NonNegativeInteger := 0
  repeat
    (u := p exquo q) case "failed" => return ans
    p := u::%
    ans := ans + 1

if R has GcdDomain then
  squareFree(p:%) ==
    squareFree(p)$UnivariatePolynomialSquareFree(R, %)

  squareFreePart(p:%) ==
    squareFreePart(p)$UnivariatePolynomialSquareFree(R, %)

if R has PolynomialFactorizationExplicit then

  gcdPolynomial(pp,qq) ==
    zero? pp => unitCanonical qq -- subResultantGcd can't handle 0
    zero? qq => unitCanonical pp
    unitCanonical(gcd(content (pp),content(qq))*
      primitivePart
      subResultantGcd(primitivePart pp,primitivePart qq))

  squareFreePolynomial pp ==
    squareFree(pp)$UnivariatePolynomialSquareFree(%,
      SparseUnivariatePolynomial %)

if R has Field then
  elt(f:Fraction %, r:R) == ((numer f) r) / ((denom f) r)

  euclideanSize x ==
    zero? x =>
      error "euclideanSize called on 0 in Univariate Polynomial"
    degree x

  divide(x,y) ==
    zero? y => error "division by 0 in Univariate Polynomials"
    quot:=0
    lc := inv leadingCoefficient y
    while not zero?(x) and (degree x >= degree y) repeat
      f:=lc*leadingCoefficient x
      n:=(degree x - degree y)::NonNegativeInteger
      quot:=quot+monomial(f,n)
      x:=x-monomial(f,n)*y
    [quot,x]

if R has Algebra Fraction Integer then

```

```

integrate p ==
  ans:% := 0
  while p ^= 0 repeat
    l := leadingCoefficient p
    d := 1 + degree p
    ans := ans + inv(d::Fraction(Integer)) * monomial(l, d)
    p := reductum p
  ans

```

— UPOLYC.dotabb —

```

"UPOLYC"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=UPOLYC"];
"UPOLYC" -> "POLYCAT"
"UPOLYC" -> "ELTAB"
"UPOLYC" -> "DIFRING"
"UPOLYC" -> "DIFEXT"
"UPOLYC" -> "STEP"
"UPOLYC" -> "COMRING"
"UPOLYC" -> "INTDOM"
"UPOLYC" -> "GCDDOM"
"UPOLYC" -> "FIELD"
"UPOLYC" -> "ALGEBRA"
"UPOLYC" -> "PFECAT"

```

— UPOLYC.dotfull —

```

"UnivariatePolynomialCategory(a:Ring)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=UPOLYC"];
"UnivariatePolynomialCategory(a:Ring)" ->
  "PolynomialCategory(a:Ring,b:NonNegativeInteger,c:SingletonAsOrderedSet)"
"UnivariatePolynomialCategory(a:Ring)" ->
  "Eltable(a:Ring,b:Ring)"
"UnivariatePolynomialCategory(a:Ring)" ->
  "Eltable(a:UnivariatePolynomialCategory(a:Ring),b:UnivariatePolynomialCategory(a:Ring))"
"UnivariatePolynomialCategory(a:Ring)" ->
  "DifferentialRing()"
"UnivariatePolynomialCategory(a:Ring)" ->
  "DifferentialExtension(a:Ring)"
"UnivariatePolynomialCategory(a:Ring)" ->
  "StepThrough()"

```

```

"UnivariatePolynomialCategory(a:Ring)" ->
  "CommutativeRing()"
"UnivariatePolynomialCategory(a:Ring)" ->
  "IntegralDomain()"
"UnivariatePolynomialCategory(a:Ring)" ->
  "GcdDomain()"
"UnivariatePolynomialCategory(a:Ring)" ->
  "Field()"
"UnivariatePolynomialCategory(a:Ring)" ->
  "Algebra(Fraction(Integer))"
"UnivariatePolynomialCategory(a:Ring)" ->
  "PolynomialFactorizationExplicit()"

```

— UPOLYC.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "UnivariatePolynomialCategory(a:Ring)" [color=lightblue];
  "UnivariatePolynomialCategory(a:Ring)" -> "POLYCAT..."
  "UnivariatePolynomialCategory(a:Ring)" -> "ELTAB..."
  "UnivariatePolynomialCategory(a:Ring)" -> "DIFRING..."
  "UnivariatePolynomialCategory(a:Ring)" -> "DIFEXT..."
  "UnivariatePolynomialCategory(a:Ring)" -> "STEP..."
  "UnivariatePolynomialCategory(a:Ring)" -> "COMRING..."
  "UnivariatePolynomialCategory(a:Ring)" -> "INTDOM..."
  "UnivariatePolynomialCategory(a:Ring)" -> "GCDDOM..."
  "UnivariatePolynomialCategory(a:Ring)" -> "FIELD..."
  "UnivariatePolynomialCategory(a:Ring)" -> "ALGEBRA..."
  "UnivariatePolynomialCategory(a:Ring)" -> "PFECAT..."

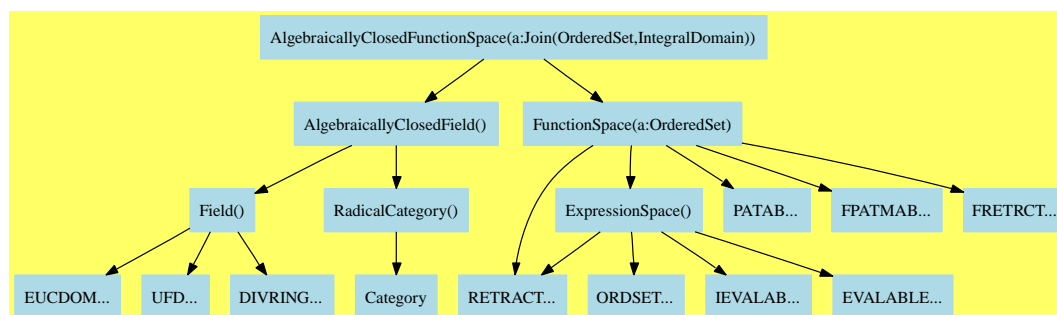
  "POLYCAT..." [color=lightblue];
  "ELTAB..." [color=lightblue];
  "DIFRING..." [color=lightblue];
  "DIFEXT..." [color=lightblue];
  "STEP..." [color=lightblue];
  "COMRING..." [color=lightblue];
  "INTDOM..." [color=lightblue];
  "GCDDOM..." [color=lightblue];
  "FIELD..." [color=lightblue];
  "ALGEBRA..." [color=lightblue];
  "PFECAT..." [color=lightblue];
}

```

Chapter 18

Category Layer 17

AlgebraicallyClosedFunctionSpace (ACFS)



— AlgebraicallyClosedFunctionSpace.input —

```

)set break resume
)sys rm -f AlgebraicallyClosedFunctionSpace.output
)spool AlgebraicallyClosedFunctionSpace.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show AlgebraicallyClosedFunctionSpace
--R
--R AlgebraicallyClosedFunctionSpace(R: Join(OrderedSet,IntegralDomain)) is a category constructor
--R Abbreviation for AlgebraicallyClosedFunctionSpace is ACFS
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ACFS
--R

```

```

--R----- Operations -----
--R ?? : (Fraction(Integer),%) -> %      ?? : (% , Fraction(Integer)) -> %
--R ?? : (% , %) -> %                    ?? : (Integer , %) -> %
--R ?? : (PositiveInteger , %) -> %      ??? : (% , Integer) -> %
--R ??? : (% , PositiveInteger) -> %     ?+? : (% , %) -> %
--R ?-? : (% , %) -> %                  -? : % -> %
--R ?/? : (% , %) -> %                  ?<? : (% , %) -> Boolean
--R ?<=? : (% , %) -> Boolean           ?=? : (% , %) -> Boolean
--R ?>? : (% , %) -> Boolean           ?>=? : (% , %) -> Boolean
--R 1 : () -> %                         0 : () -> %
--R ?? : (% , Integer) -> %             ?? : (% , PositiveInteger) -> %
--R applyQuote : (Symbol , %) -> %      applyQuote : (Symbol , % , %) -> %
--R associates? : (% , %) -> Boolean    belong? : BasicOperator -> Boolean
--R box : % -> %                        box : List(%) -> %
--R coerce : Kernel(%) -> %             coerce : Symbol -> %
--R coerce : R -> %                     coerce : Fraction(Integer) -> %
--R coerce : % -> %                     coerce : Integer -> %
--R coerce : % -> OutputForm            distribute : % -> %
--R distribute : (% , %) -> %           elt : (BasicOperator , %) -> %
--R elt : (BasicOperator , % , %) -> %   eval : (% , Kernel(%) , %) -> %
--R eval : (% , Equation(%)) -> %       eval : (% , % , %) -> %
--R factor : % -> Factored(%)           freeOf? : (% , %) -> Boolean
--R freeOf? : (% , Symbol) -> Boolean    gcd : List(%) -> %
--R gcd : (% , %) -> %                  ground : % -> R
--R ground? : % -> Boolean              hash : % -> SingleInteger
--R height : % -> NonNegativeInteger    inv : % -> %
--R is? : (% , Symbol) -> Boolean        kernel : (BasicOperator , %) -> %
--R kernels : % -> List(Kernel(%))      latex : % -> String
--R lcm : List(%) -> %                  lcm : (% , %) -> %
--R max : (% , %) -> %                  min : (% , %) -> %
--R nthRoot : (% , Integer) -> %         one? : % -> Boolean
--R paren : % -> %                      paren : List(%) -> %
--R prime? : % -> Boolean                ?quo? : (% , %) -> %
--R recip : % -> Union(%, "failed")      ?rem? : (% , %) -> %
--R retract : % -> Kernel(%)            retract : % -> Symbol
--R retract : % -> R                    rootOf : (% , Symbol) -> %
--R rootOf : % -> %                     rootOf : Polynomial(%) -> %
--R rootsOf : (% , Symbol) -> List(%)    rootsOf : % -> List(%)
--R sample : () -> %                    sizeLess? : (% , %) -> Boolean
--R sqrt : % -> %                       squareFree : % -> Factored(%)
--R squareFreePart : % -> %              subst : (% , Equation(%)) -> %
--R tower : % -> List(Kernel(%))         unit? : % -> Boolean
--R unitCanonical : % -> %               variables : % -> List(Symbol)
--R zero? : % -> Boolean                 zeroOf : (% , Symbol) -> %
--R zeroOf : % -> %                     zeroOf : Polynomial(%) -> %
--R zerosOf : (% , Symbol) -> List(%)    zerosOf : % -> List(%)
--R ?^=? : (% , %) -> Boolean
--R ?? : (R , %) -> % if R has COMRING
--R ?? : (% , R) -> % if R has COMRING
--R ?? : (NonNegativeInteger , %) -> %

```



```

--R eval : % -> % if R has KONVERT(INFORM)
--R eval : (% , BasicOperator , % , Symbol) -> % if R has KONVERT(INFORM)
--R eval : (% , List(BasicOperator) , List(% ) , Symbol) -> % if R has KONVERT(INFORM)
--R eval : (% , List(Symbol) , List(NonNegativeInteger) , List((% -> %))) -> % if R has RING
--R eval : (% , List(Symbol) , List(NonNegativeInteger) , List((List(% ) -> %))) -> % if R has RING
--R eval : (% , Symbol , NonNegativeInteger , (List(% ) -> %)) -> % if R has RING
--R eval : (% , Symbol , NonNegativeInteger , (% -> %)) -> % if R has RING
--R even? : % -> Boolean if $ has RETRACT(INT)
--R expressIdealMember : (List(% ) , %) -> Union(List(% ) , "failed")
--R exquo : (% , %) -> Union(% , "failed")
--R extendedEuclidean : (% , % , %) -> Union(Record(coef1: % , coef2: % ) , "failed")
--R extendedEuclidean : (% , %) -> Record(coef1: % , coef2: % , generator: % )
--R gcdPolynomial : (SparseUnivariatePolynomial(% ) , SparseUnivariatePolynomial(% )) -> SparseUnivariatePolynomial(% )
--R is? : (% , BasicOperator) -> Boolean
--R isExpt : % -> Union(Record(var: Kernel(% ) , exponent: Integer) , "failed") if R has SGROUP
--R isExpt : (% , BasicOperator) -> Union(Record(var: Kernel(% ) , exponent: Integer) , "failed") if R has SGROUP
--R isExpt : (% , Symbol) -> Union(Record(var: Kernel(% ) , exponent: Integer) , "failed") if R has SGROUP
--R isMult : % -> Union(Record(coef: Integer , var: Kernel(% )) , "failed") if R has ABELSG
--R isPlus : % -> Union(List(% ) , "failed") if R has ABELSG
--R isPower : % -> Union(Record(val: % , exponent: Integer) , "failed") if R has RING
--R isTimes : % -> Union(List(% ) , "failed") if R has SGROUP
--R kernel : (BasicOperator , List(% )) -> %
--R mainKernel : % -> Union(Kernel(% ) , "failed")
--R map : ((% -> % ) , Kernel(% )) -> %
--R minPoly : Kernel(% ) -> SparseUnivariatePolynomial(% ) if $ has RING
--R multiEuclidean : (List(% ) , %) -> Union(List(% ) , "failed")
--R numer : % -> SparseMultivariatePolynomial(R , Kernel(% )) if R has RING
--R numerator : % -> % if R has RING
--R odd? : % -> Boolean if $ has RETRACT(INT)
--R operator : BasicOperator -> BasicOperator
--R operators : % -> List(BasicOperator)
--R patternMatch : (% , Pattern(Integer) , PatternMatchResult(Integer , % )) -> PatternMatchResult(Integer , % )
--R patternMatch : (% , Pattern(Float) , PatternMatchResult(Float , % )) -> PatternMatchResult(Float , % )
--R principalIdeal : List(% ) -> Record(coef: List(% ) , generator: % )
--R reducedSystem : Matrix(% ) -> Matrix(Integer) if and(has(R , Ring) , has(R , LinearlyExplicitRingOver(Integer)))
--R reducedSystem : (Matrix(% ) , Vector(% )) -> Record(mat: Matrix(Integer) , vec: Vector(Integer)) if R has RING
--R reducedSystem : (Matrix(% ) , Vector(% )) -> Record(mat: Matrix(R) , vec: Vector(R)) if R has RING
--R reducedSystem : Matrix(% ) -> Matrix(R) if R has RING
--R retract : % -> Fraction(Integer) if R has RETRACT(INT) and R has INTDOM or R has RETRACT(FRACTION)
--R retract : % -> Integer if R has RETRACT(INT)
--R retract : % -> Fraction(Polynomial(R)) if R has INTDOM
--R retract : % -> Polynomial(R) if R has RING
--R retractIfCan : % -> Union(Fraction(Integer) , "failed") if R has RETRACT(INT) and R has INTDOM
--R retractIfCan : % -> Union(Kernel(% ) , "failed")
--R retractIfCan : % -> Union(Symbol , "failed")
--R retractIfCan : % -> Union(Integer , "failed") if R has RETRACT(INT)
--R retractIfCan : % -> Union(R , "failed")
--R retractIfCan : % -> Union(Fraction(Polynomial(R)) , "failed") if R has INTDOM
--R retractIfCan : % -> Union(Polynomial(R) , "failed") if R has RING
--R rootOf : (SparseUnivariatePolynomial(% ) , Symbol) -> %

```

```

--R rootOf : SparseUnivariatePolynomial(%) -> %
--R rootsOf : (SparseUnivariatePolynomial(%),Symbol) -> List(%)
--R rootsOf : SparseUnivariatePolynomial(%) -> List(%)
--R rootsOf : Polynomial(%) -> List(%)
--R subst : (%,List(Equation(%))) -> %
--R subst : (%,List(Kernel(%)),List(%)) -> %
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R univariate : (%,Kernel(%)) -> Fraction(SparseUnivariatePolynomial(%)) if R has INTDOM
--R zeroOf : (SparseUnivariatePolynomial(%),Symbol) -> %
--R zeroOf : SparseUnivariatePolynomial(%) -> %
--R zerosOf : (SparseUnivariatePolynomial(%),Symbol) -> List(%)
--R zerosOf : SparseUnivariatePolynomial(%) -> List(%)
--R zerosOf : Polynomial(%) -> List(%)
--R
--E 1

```

```

)spool
)lisp (bye)

```

— AlgebraicallyClosedFunctionSpace.help —

```

=====
AlgebraicallyClosedFunctionSpace examples
=====

```

Model for algebraically closed function spaces.

See Also:

o)show AlgebraicallyClosedFunctionSpace

See:

⇐ “AlgebraicallyClosedField” (ACF) [17](#) on page [1343](#)

⇐ “FunctionSpace” (FS) [17](#) on page [1387](#)

Exports:

| | | | |
|----------------|--------------------|----------------|--------------------|
| 0 | 1 | applyQuote | associates? |
| belong? | box | characteristic | charthRoot |
| coerce | commutator | conjugate | convert |
| D | definingPolynomial | denom | denominator |
| differentiate | distribute | divide | elt |
| euclideanSize | eval | even? | expressIdealMember |
| exquo | extendedEuclidean | factor | freeOf? |
| gcd | gcdPolynomial | ground | ground? |
| hash | height | inv | is? |
| isExpt | isMult | isPlus | isPower |
| isTimes | kernel | kernels | latex |
| lcm | mainKernel | map | max |
| min | minPoly | multiEuclidean | nthRoot |
| numer | numerator | odd? | one? |
| operator | operators | paren | patternMatch |
| prime? | principalIdeal | recip | reducedSystem |
| retract | retractIfCan | rootOf | rootsOf |
| sample | sizeLess? | sqrt | squareFree |
| squareFreePart | subst | subtractIfCan | tower |
| unit? | unitCanonical | unitNormal | univariate |
| variables | zero? | zeroOf | zerosOf |
| ?*? | ?**? | ?+? | ?-? |
| ~? | ?/? | ?<? | ?<=? |
| ?=? | ?>? | ?>=? | ?^? |
| ?~=? | ?quo? | ?rem? | |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?(a,b)** returns true if and only if **unitCanonical(a) = unitCanonical(b)**.
- **canonicalsClosed** is true if
 unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b).
- **commutative(“*”)** is true if it has an operation “*” : $(D,D) \rightarrow D$ which is commutative.
- **nil**

These are implemented by this category:

```

rootOf : % -> %
rootOf : (%,Symbol) -> %
rootsOf : % -> List %
rootsOf : (%,Symbol) -> List %
rootsOf : (SparseUnivariatePolynomial %,Symbol) -> List %
zeroOf : % -> %
zeroOf : (%,Symbol) -> %
zeroOf : (SparseUnivariatePolynomial %,Symbol) -> %
zerosOf : % -> List %
zerosOf : (%,Symbol) -> List %
zerosOf : (SparseUnivariatePolynomial %,Symbol) -> List %

```

These exports come from (p1343) AlgebraicallyClosedField():

```

0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
coerce : Fraction Integer -> %
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %, "failed")
exquo : (%,%) -> Union(%, "failed")
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
factor : % -> Factored %
gcd : List % -> %
gcd : (%,%) -> %
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
hash : % -> SingleInteger
inv : % -> %
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
multiEuclidean : (List %,%) -> Union(List %, "failed")
nthRoot : (%,Integer) -> %
one? : % -> Boolean
prime? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%, "failed")
rootOf : SparseUnivariatePolynomial % -> %
rootOf : Polynomial % -> %

```



```

rootOf : (SparseUnivariatePolynomial %,Symbol) -> %
rootsOf : SparseUnivariatePolynomial % -> List %
rootsOf : Polynomial % -> List %
sample : () -> %
sizeLess? : (%,%) -> Boolean
sqrt : % -> %
squareFree : % -> Factored %
squareFreePart : % -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
zero? : % -> Boolean
zeroOf : Polynomial % -> %
zeroOf : SparseUnivariatePolynomial % -> %
zerosOf : Polynomial % -> List %
zerosOf : SparseUnivariatePolynomial % -> List %
?*? : (Fraction Integer, %) -> %
?*? : (%, Fraction Integer) -> %
?*?* : (%, Fraction Integer) -> %
?*?* : (%, Integer) -> %
?*? : (%, Integer) -> %
?*? : (%, %) -> %
?*? : (%, %) -> Boolean
?*=? : (%, %) -> Boolean
?*? : (%, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (NonNegativeInteger, %) -> %
?*? : (%, %) -> %
-*? : % -> %
?*?* : (%, PositiveInteger) -> %
?*?* : (%, NonNegativeInteger) -> %
?*? : (%, PositiveInteger) -> %
?*? : (%, NonNegativeInteger) -> %
?/? : (%, %) -> %
?quo? : (%, %) -> %
?rem? : (%, %) -> %

```

These exports come from (p1387) `FunctionSpace(R)`
 where `R:Join(OrderedSet, IntegralDomain)`:

```

applyQuote : (Symbol, %) -> %
applyQuote : (Symbol, %, %) -> %
applyQuote : (Symbol, %, %, %) -> %
applyQuote : (Symbol, %, %, %, %) -> %
applyQuote : (Symbol, List %) -> %
belong? : BasicOperator -> Boolean
box : % -> %
box : List % -> %

```

```

charthRoot : % -> Union(%, "failed") if R has CHARNZ
coerce : R -> %
coerce : Symbol -> %
coerce : Kernel % -> %
coerce : Fraction Polynomial R -> % if R has INTDOM
coerce : Fraction Polynomial Fraction R -> % if R has INTDOM
coerce : SparseMultivariatePolynomial(R, Kernel %) -> %
    if R has RING
coerce : Fraction R -> % if R has INTDOM
coerce : Polynomial Fraction R -> % if R has INTDOM
coerce : Polynomial R -> % if R has RING
commutator : (%, %) -> % if R has GROUP
conjugate : (%, %) -> % if R has GROUP
convert : % -> InputForm if R has KONVERT INFORM
convert : % -> Pattern Integer if R has KONVERT PATTERN INT
convert : % -> Pattern Float if R has KONVERT PATTERN FLOAT
convert : Factored % -> % if R has INTDOM
D : (%, List Symbol, List NonNegativeInteger) -> % if R has RING
D : (%, Symbol, NonNegativeInteger) -> % if R has RING
D : (%, List Symbol) -> % if R has RING
D : (%, Symbol) -> % if R has RING
definingPolynomial : % -> % if $ has RING
denom : % -> SparseMultivariatePolynomial(R, Kernel %) if R has INTDOM
denominator : % -> % if R has INTDOM
differentiate : (%, List Symbol, List NonNegativeInteger) -> %
    if R has RING
differentiate : (%, Symbol, NonNegativeInteger) -> % if R has RING
differentiate : (%, List Symbol) -> % if R has RING
distribute : % -> %
distribute : (%, %) -> %
differentiate : (%, Symbol) -> % if R has RING
elt : (BasicOperator, %, %, %) -> %
elt : (BasicOperator, %, %, %, %) -> %
elt : (BasicOperator, %) -> %
elt : (BasicOperator, %, %) -> %
elt : (BasicOperator, List %) -> %
eval : (%, List BasicOperator, List (% -> %)) -> %
eval : (%, List Equation %) -> %
eval : (%, Symbol, (% -> %)) -> %
eval : (%, Symbol, (List % -> %)) -> %
eval : (%, BasicOperator, %, Symbol) -> % if R has KONVERT INFORM
eval : (%, BasicOperator, (List % -> %)) -> %
eval : (%, BasicOperator, (% -> %)) -> %
eval : (%, List Symbol, List (% -> %)) -> %
eval : (%, List BasicOperator, List (List % -> %)) -> %
eval : (%, List Symbol, List (List % -> %)) -> %
eval : (%, List %, List %) -> %
eval : (%, %, %) -> %
eval : (%, Equation %) -> %
eval : (%, Kernel %, %) -> %

```

```

eval : (%,List Symbol) -> % if R has KONVERT INFORM
eval : % -> % if R has KONVERT INFORM
eval : (%,Symbol) -> % if R has KONVERT INFORM
eval : (%,Symbol,NonNegativeInteger,(% -> %)) -> % if R has RING
eval : (%,Symbol,NonNegativeInteger,(List % -> %)) -> % if R has RING
eval :
  (%,List Symbol,List NonNegativeInteger,List (List % -> %)) -> %
  if R has RING
eval :
  (%,List Symbol,List NonNegativeInteger,List (% -> %)) -> %
  if R has RING
eval : (%,List Kernel %,List %) -> %
eval : (%,List BasicOperator,List %,Symbol) -> %
  if R has KONVERT INFORM
even? : % -> Boolean if $ has RETRACT INT
freeOf? : (%,%) -> Boolean
freeOf? : (%,Symbol) -> Boolean
ground : % -> R
ground? : % -> Boolean
height : % -> NonNegativeInteger
is? : (%,BasicOperator) -> Boolean
is? : (%,Symbol) -> Boolean
isExpt : % ->
  Union(Record(var: Kernel %,exponent: Integer),"failed")
  if R has SGROUP
isExpt :
  (%,BasicOperator) ->
    Union(Record(var: Kernel %,exponent: Integer),"failed")
    if R has RING
isExpt :
  (%,Symbol) ->
    Union(Record(var: Kernel %,exponent: Integer),"failed")
    if R has RING
isMult : % ->
  Union(Record(coef: Integer,var: Kernel %),"failed")
  if R has ABELSG
isPlus : % -> Union(List %,"failed") if R has ABELSG
isPower : % -> Union(Record(val: %,exponent: Integer),"failed")
  if R has RING
isTimes : % -> Union(List %,"failed") if R has SGROUP
kernel : (BasicOperator,List %) -> %
kernel : (BasicOperator,%) -> %
kernels : % -> List Kernel %
mainKernel : % -> Union(Kernel %,"failed")
map : ((% -> %),Kernel %) -> %
max : (%,%) -> %
min : (%,%) -> %
minPoly : Kernel % -> SparseUnivariatePolynomial % if $ has RING
num : % -> SparseMultivariatePolynomial(R,Kernel %) if R has RING
numerator : % -> % if R has RING

```

```

odd? : % -> Boolean if $ has RETRACT INT
operator : BasicOperator -> BasicOperator
operators : % -> List BasicOperator
paren : % -> %
paren : List % -> %
patternMatch :
  (% , Pattern Integer , PatternMatchResult(Integer, %)) ->
    PatternMatchResult(Integer, %)
    if R has PATMAB INT
patternMatch :
  (% , Pattern Float , PatternMatchResult(Float, %)) ->
    PatternMatchResult(Float, %)
    if R has PATMAB FLOAT
reducedSystem : Matrix % -> Matrix Integer
  if and(has(R, Ring), has(R, LinearlyExplicitRingOver Integer))
  or and(has(R, LinearlyExplicitRingOver Integer), has(R, Ring))
reducedSystem :
  (Matrix %, Vector %) ->
    Record(mat: Matrix Integer, vec: Vector Integer)
    if and(has(R, Ring), has(R, LinearlyExplicitRingOver Integer))
    or and(has(R, LinearlyExplicitRingOver Integer), has(R, Ring))
reducedSystem :
  (Matrix %, Vector %) -> Record(mat: Matrix R, vec: Vector R)
  if R has RING
reducedSystem : Matrix % -> Matrix R if R has RING
retract : % -> Kernel %
retract : % -> Fraction Polynomial R if R has INTDOM
retract : % -> Polynomial R if R has RING
retract : % -> R
retract : % -> Symbol
retract : % -> Integer if R has RETRACT INT
retract : % -> Fraction Integer
  if R has RETRACT INT
  and R has INTDOM
  or R has RETRACT FRAC INT
retractIfCan : % -> Union(Integer, "failed") if R has RETRACT INT
retractIfCan : % -> Union(Fraction Integer, "failed")
  if R has RETRACT INT
  and R has INTDOM
  or R has RETRACT FRAC INT
retractIfCan : % -> Union(Kernel %, "failed")
retractIfCan : % -> Union(R, "failed")
retractIfCan : % -> Union(Fraction Polynomial R, "failed")
  if R has INTDOM
retractIfCan : % -> Union(Polynomial R, "failed") if R has RING
retractIfCan : % -> Union(Symbol, "failed")
subst : (% , List Kernel %, List %) -> %
subst : (% , List Equation %) -> %
subst : (% , Equation %) -> %
tower : % -> List Kernel %

```

```

univariate : (% , Kernel %) -> Fraction SparseUnivariatePolynomial %
  if R has INTDOM
variables : % -> List Symbol
?<? : (% , %) -> Boolean
?<=? : (% , %) -> Boolean
?>? : (% , %) -> Boolean
?>=? : (% , %) -> Boolean
?*? : (R , %) -> % if R has COMRING
?*? : (% , R) -> % if R has COMRING
?/? :
  (SparseMultivariatePolynomial(R , Kernel %),
   SparseMultivariatePolynomial(R , Kernel %)) -> %
  if R has INTDOM

```

— category ACFS AlgebraicallyClosedFunctionSpace —

```

)abbrev category ACFS AlgebraicallyClosedFunctionSpace
++ Author: Manuel Bronstein
++ Date Created: 31 October 1988
++ Date Last Updated: 7 October 1991
++ Description:
++ Model for algebraically closed function spaces.

AlgebraicallyClosedFunctionSpace(R:Join(OrderedSet, IntegralDomain)):
Category == Join(AlgebraicallyClosedField, FunctionSpace R) with
  rootOf : $ -> $
    ++ rootOf(p) returns y such that \spad{p(y) = 0}.
    ++ Error: if p has more than one variable y.
  rootsOf : $ -> List $
    ++ rootsOf(p, y) returns \spad{[y1,...,yn]} such that \spad{p(yi) = 0};
    ++ Note that the returned symbols y1,...,yn are bound in the interpreter
    ++ to respective root values.
    ++ Error: if p has more than one variable y.
  rootOf : ($, Symbol) -> $
    ++ rootOf(p,y) returns y such that \spad{p(y) = 0}.
    ++ The object returned displays as \spad{'y}.
  rootsOf : ($, Symbol) -> List $
    ++ rootsOf(p, y) returns \spad{[y1,...,yn]} such that \spad{p(yi) = 0};
    ++ The returned roots display as \spad{'y1},..., \spad{'yn}.
    ++ Note that the returned symbols y1,...,yn are bound in the interpreter
    ++ to respective root values.
  zeroOf : $ -> $
    ++ zeroOf(p) returns y such that \spad{p(y) = 0}.
    ++ The value y is expressed in terms of radicals if possible, and otherwise
    ++ as an implicit algebraic quantity.
    ++ Error: if p has more than one variable.
  zerosOf : $ -> List $
    ++ zerosOf(p) returns \spad{[y1,...,yn]} such that \spad{p(yi) = 0}.
    ++ The yi's are expressed in radicals if possible.

```

```

++ The returned symbols y1,...,yn are bound in the interpreter
++ to respective root values.
++ Error: if p has more than one variable.
zeroOf : ($, Symbol) -> $
++ zeroOf(p, y) returns y such that \spad{p(y) = 0}.
++ The value y is expressed in terms of radicals if possible, and otherwise
++ as an implicit algebraic quantity
++ which displays as \spad{'y}.
zerosOf: ($, Symbol) -> List $
++ zerosOf(p, y) returns \spad{[y1,...,yn]} such that \spad{p(yi) = 0}.
++ The yi's are expressed in radicals if possible, and otherwise
++ as implicit algebraic quantities
++ which display as \spad{'yi}.
++ The returned symbols y1,...,yn are bound in the interpreter
++ to respective root values.
add
rootOf(p:$) ==
  empty?(l := variables p) => error "rootOf: constant expression"
  rootOf(p, first l)

rootsOf(p:$) ==
  empty?(l := variables p) => error "rootsOf: constant expression"
  rootsOf(p, first l)

zeroOf(p:$) ==
  empty?(l := variables p) => error "zeroOf: constant expression"
  zeroOf(p, first l)

zerosOf(p:$) ==
  empty?(l := variables p) => error "zerosOf: constant expression"
  zerosOf(p, first l)

zeroOf(p:$, x:Symbol) ==
  n := numer(f := univariate(p, kernel(x)$Kernel($)))
  degree denom f > 0 => error "zeroOf: variable appears in denom"
  degree n = 0 => error "zeroOf: constant expression"
  zeroOf(n, x)

rootOf(p:$, x:Symbol) ==
  n := numer(f := univariate(p, kernel(x)$Kernel($)))
  degree denom f > 0 => error "rootOf: variable appears in denom"
  degree n = 0 => error "rootOf: constant expression"
  rootOf(n, x)

zerosOf(p:$, x:Symbol) ==
  n := numer(f := univariate(p, kernel(x)$Kernel($)))
  degree denom f > 0 => error "zerosOf: variable appears in denom"
  degree n = 0 => empty()
  zerosOf(n, x)

```

```

rootsOf(p:$, x:Symbol) ==
  n := numer(f := univariate(p, kernel(x)$Kernel($)))
  degree denom f > 0 => error "rootsOf: variable appears in denom"
  degree n = 0 => empty()
  rootsOf(n, x)

rootsOf(p: SparseUnivariatePolynomial $, y:Symbol) ==
  (r := retractIfCan(p)@Union($,"failed")) case $ => rootsOf(r::$,y)
  rootsOf(p, y)$AlgebraicallyClosedField_&($)

zerosOf(p: SparseUnivariatePolynomial $, y:Symbol) ==
  (r := retractIfCan(p)@Union($,"failed")) case $ => zerosOf(r::$,y)
  zerosOf(p, y)$AlgebraicallyClosedField_&($)

zeroOf(p: SparseUnivariatePolynomial $, y:Symbol) ==
  (r := retractIfCan(p)@Union($,"failed")) case $ => zeroOf(r::$, y)
  zeroOf(p, y)$AlgebraicallyClosedField_&($)

```

— ACFS.dotabb —

```

"ACFS"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ACFS" ];
"ACFS" -> "ACF"
"ACFS" -> "FS"

```

— ACFS.dotfull —

```

"AlgebraicallyClosedFunctionSpace(a:Join(OrderedSet,IntegralDomain))"
[ color=lightblue, href="bookvol10.2.pdf#nameddest=ACFS" ];
"AlgebraicallyClosedFunctionSpace(a:Join(OrderedSet,IntegralDomain))"
-> "AlgebraicallyClosedField()"
"AlgebraicallyClosedFunctionSpace(a:Join(OrderedSet,IntegralDomain))"
-> "FunctionSpace(a:OrderedSet)"

```

— ACFS.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";

```

```

node [shape=box, color=white, style=filled];

"AlgebraicallyClosedFunctionSpace(a:Join(OrderedSet,IntegralDomain))"
  [color=lightblue];
"AlgebraicallyClosedFunctionSpace(a:Join(OrderedSet,IntegralDomain))"
  -> "AlgebraicallyClosedField()"
"AlgebraicallyClosedFunctionSpace(a:Join(OrderedSet,IntegralDomain))"
  -> "FunctionSpace(a:OrderedSet)"

"AlgebraicallyClosedField()" [color=lightblue];
"AlgebraicallyClosedField()" -> "Field()"
"AlgebraicallyClosedField()" -> "RadicalCategory()"

"Field()" [color=lightblue];
"Field()" -> "EUCDOM..."
"Field()" -> "UFD..."
"Field()" -> "DIVRING..."

"RadicalCategory()" [color=lightblue];
"RadicalCategory()" -> "Category"

"Category" [color=lightblue];

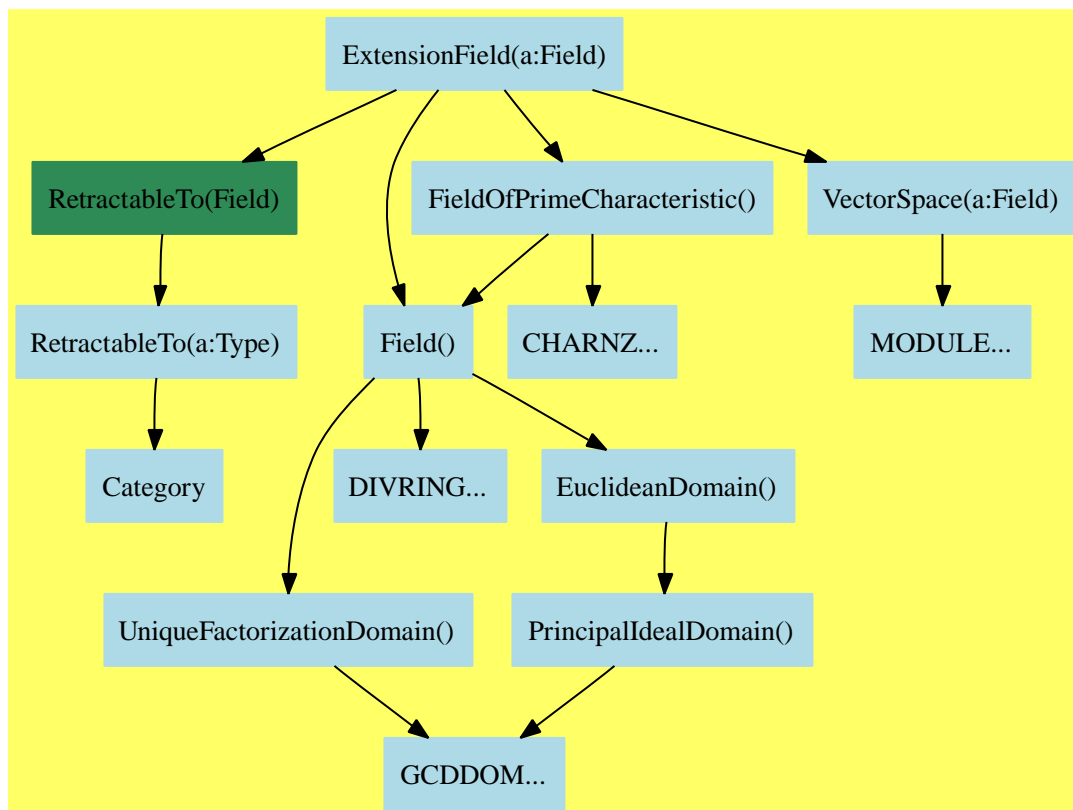
"FunctionSpace(a:OrderedSet)" [color=lightblue];
"FunctionSpace(a:OrderedSet)" -> "ExpressionSpace()"
"FunctionSpace(a:OrderedSet)" -> "RETRACT..."
"FunctionSpace(a:OrderedSet)" -> "PATAB..."
"FunctionSpace(a:OrderedSet)" -> "FPATMAB..."
"FunctionSpace(a:OrderedSet)" -> "FRETRACT..."

"ExpressionSpace()" [color=lightblue];
"ExpressionSpace()" -> "ORDSET..."
"ExpressionSpace()" -> "RETRACT..."
"ExpressionSpace()" -> "IEVALAB..."
"ExpressionSpace()" -> "EVALABLE..."

"UFD..." [color=lightblue];
"EUCDOM..." [color=lightblue];
"DIVRING..." [color=lightblue];
"EVALABLE..." [color=lightblue];
"FRETRACT..." [color=lightblue];
"FPATMAB..." [color=lightblue];
"IEVALAB..." [color=lightblue];
"ORDSET..." [color=lightblue];
"PATAB..." [color=lightblue];
"RETRACT..." [color=lightblue];
}

```

ExtensionField (XF)



— ExtensionField.input —

```

)set break resume
)sys rm -f ExtensionField.output
)spool ExtensionField.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ExtensionField
--R
--R ExtensionField(F: Field) is a category constructor
--R Abbreviation for ExtensionField is XF

```

```

--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for XF
--R
--R----- Operations -----
--R ?? : (F,%) -> %           ?? : (%,F) -> %
--R ?? : (Fraction(Integer),%) -> %   ?? : (%,Fraction(Integer)) -> %
--R ?? : (%,%) -> %           ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %     ??? : (%,Integer) -> %
--R ??? : (%,PositiveInteger) -> %    ?+? : (%,%) -> %
--R ?-? : (%,%) -> %           -? : % -> %
--R ?/? : (%,F) -> %          ?/? : (%,%) -> %
--R ?=? : (%,%) -> Boolean        1 : () -> %
--R 0 : () -> %                ?? : (%,Integer) -> %
--R ?? : (%,PositiveInteger) -> %    algebraic? : % -> Boolean
--R associates? : (%,%) -> Boolean   coerce : F -> %
--R coerce : Fraction(Integer) -> %   coerce : % -> %
--R coerce : Integer -> %            coerce : % -> OutputForm
--R dimension : () -> CardinalNumber  factor : % -> Factored(%)
--R gcd : List(%) -> %              gcd : (%,%) -> %
--R hash : % -> SingleInteger        inGroundField? : % -> Boolean
--R inv : % -> %                   latex : % -> String
--R lcm : List(%) -> %             lcm : (%,%) -> %
--R one? : % -> Boolean             prime? : % -> Boolean
--R ?quo? : (%,%) -> %             recip : % -> Union(%, "failed")
--R ?rem? : (%,%) -> %             retract : % -> F
--R sample : () -> %               sizeLess? : (%,%) -> Boolean
--R squareFree : % -> Factored(%)    squareFreePart : % -> %
--R transcendent? : % -> Boolean     unit? : % -> Boolean
--R unitCanonical : % -> %          zero? : % -> Boolean
--R ?^=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R Frobenius : (%,NonNegativeInteger) -> % if F has FINITE
--R Frobenius : % -> % if F has FINITE
--R ?? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if F has CHARNZ or F has FINITE
--R degree : % -> OnePointCompletion(PositiveInteger)
--R discreteLog : (%,%) -> Union(NonNegativeInteger, "failed") if F has CHARNZ or F has FINITE
--R divide : (%,%) -> Record(quotient: %, remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%,%) -> Union(List(%), "failed")
--R exquo : (%,%) -> Union(%, "failed")
--R extendedEuclidean : (%,%,%) -> Union(Record(coef1: %, coef2: %), "failed")
--R extendedEuclidean : (%,%) -> Record(coef1: %, coef2: %, generator: %)
--R extensionDegree : () -> OnePointCompletion(PositiveInteger)
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R multiEuclidean : (List(%,%) -> Union(List(%), "failed")
--R order : % -> OnePointCompletion(PositiveInteger) if F has CHARNZ or F has FINITE
--R primeFrobenius : % -> % if F has CHARNZ or F has FINITE

```

```

--R primeFrobenius : (% , NonNegativeInteger) -> % if F has CHARNZ or F has FINITE
--R principalIdeal : List(%) -> Record(coef: List(%) , generator: %)
--R retractIfCan : % -> Union(F, "failed")
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R transcendenceDegree : () -> NonNegativeInteger
--R unitNormal : % -> Record(unit: % , canonical: % , associate: %)
--R
--E 1

```

```

)spool
)lisp (bye)

```

— **ExtensionField.help** —

```

=====
ExtensionField examples
=====

```

ExtensionField F is the category of fields which extend the field F

See Also:

o)show ExtensionField

See:

⇒ “FiniteAlgebraicExtensionField” (FAXF) [19](#) on page [1635](#)

⇐ “Field” (FIELD) [16](#) on page [1271](#)

⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

⇐ “VectorSpace” (VSPACE) [11](#) on page [1038](#)

Exports:

| | | | |
|----------------|-------------------|-----------------|---------------------|
| 0 | 1 | algebraic? | associates? |
| characteristic | charthRoot | coerce | degree |
| discreteLog | divide | euclideanSize | expressIdealMember |
| exquo | extendedEuclidean | extensionDegree | dimension |
| factor | Frobenius | gcd | gcdPolynomial |
| hash | inGroundField? | inv | latex |
| lcm | multiEuclidean | one? | order |
| prime? | primeFrbenius | principalIdeal | recip |
| retract | retractIfCan | sample | sizeLess? |
| squareFree | squareFreePart | subtractIfCan | transcendenceDegree |
| transcendent? | unit? | unitCanonical | unitNormal |
| zero? | ?*? | ?**? | ?+? |
| ?-? | -? | ?/? | ?=? |
| ?^? | ?quo? | ?rem? | ?~=? |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **canonicalsClosed** is true if `unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative("*)** is true if it has an operation $*$: $(D,D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
inGroundField? : % -> Boolean
degree : % -> OnePointCompletion PositiveInteger
extensionDegree : () -> OnePointCompletion PositiveInteger
transcendenceDegree : () -> NonNegativeInteger
```

These are implemented by this category:

```
algebraic? : % -> Boolean
Frobenius : % -> % if F has FINITE
Frobenius : (% , NonNegativeInteger) -> % if F has FINITE
transcendent? : % -> Boolean
```

These exports come from (p1271) `Field()`:

```

0 : () -> %
1 : () -> %
associates? : (%,% ) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
coerce : Fraction Integer -> %
divide : (%,% ) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,% ) -> Union(List %,"failed")
exquo : (%,% ) -> Union(%,"failed")
extendedEuclidean : (%,%,% ) ->
  Union(Record(coef1: %,coef2: %),"failed")
extendedEuclidean : (%,% ) ->
  Record(coef1: %,coef2: %,generator: %)
factor : % -> Factored %
gcd : List % -> %
gcd : (%,% ) -> %
gcdPolynomial : (SparseUnivariatePolynomial %,
  SparseUnivariatePolynomial %) ->
  SparseUnivariatePolynomial %
hash : % -> SingleInteger
inv : % -> %
latex : % -> String
lcm : List % -> %
lcm : (%,% ) -> %
multiEuclidean : (List %,% ) -> Union(List %,"failed")
one? : % -> Boolean
prime? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%,"failed")
sample : () -> %
squareFree : % -> Factored %
squareFreePart : % -> %
sizeLess? : (%,% ) -> Boolean
subtractIfCan : (%,% ) -> Union(%,"failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
zero? : % -> Boolean
?/? : (%,% ) -> %
?+? : (%,% ) -> %
?=? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
?*? : (%,% ) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %

```

```

?? : (NonNegativeInteger,%) -> %
?? : (Fraction Integer,%) -> %
?? : (%,Fraction Integer) -> %
?? : (F,%) -> %
?? : (%,F) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%,NonNegativeInteger) -> %
***? : (%,PositiveInteger) -> %
***? : (%,Integer) -> %
?? : (%,Integer) -> %
?? : (%,PositiveInteger) -> %
?? : (%,NonNegativeInteger) -> %
?quo? : (%,%) -> %
?rem? : (%,%) -> %

```

These exports come from (p95) `RetractableTo(F:Field)`:

```

coerce : F -> %
retract : % -> F
retractIfCan : % -> Union(F,"failed")

```

These exports come from (p1038) `VectorSpace(F:Field)`:

```

dimension : () -> CardinalNumber
?/? : (%,F) -> %

```

These exports come from (p1374) `FieldOfPrimeCharacteristic()`:

```

charthRoot : % -> Union(%, "failed")
  if F has CHARNZ or F has FINITE
discreteLog : (%,%) -> Union(NonNegativeInteger, "failed")
  if F has CHARNZ or F has FINITE
order : % -> OnePointCompletion PositiveInteger
  if F has CHARNZ or F has FINITE
primeFrobenius : % -> %
  if F has CHARNZ or F has FINITE
primeFrobenius : (%,NonNegativeInteger) -> %
  if F has CHARNZ or F has FINITE

```

— category XF ExtensionField —

```

)abbrev category XF ExtensionField
++ Author: J. Grabmeier, A. Scheerhorn
++ Date Created: 10 March 1991
++ Date Last Updated: 31 March 1991
++ References:
++ J. Grabmeier, A. Scheerhorn: Finite Fields in AXIOM.

```

```

++ AXIOM Technical Report Series, ATR/5 NP2522.
++ Description:
++ ExtensionField F is the category of fields which extend the field F

ExtensionField(F:Field) : Category == _
Join(Field,RetractableTo F,VectorSpace F) with
  if F has CharacteristicZero then CharacteristicZero
  if F has CharacteristicNonZero then FieldOfPrimeCharacteristic
  algebraic? : $ -> Boolean
    ++ algebraic?(a) tests whether an element \spad{a} is algebraic with
    ++ respect to the ground field F.
  transcendent? : $ -> Boolean
    ++ transcendent?(a) tests whether an element \spad{a} is transcendent
    ++ with respect to the ground field F.
  inGroundField?: $ -> Boolean
    ++ inGroundField?(a) tests whether an element \spad{a}
    ++ is already in the ground field F.
  degree : $ -> OnePointCompletion PositiveInteger
    ++ degree(a) returns the degree of minimal polynomial of an element
    ++ \spad{a} if \spad{a} is algebraic
    ++ with respect to the ground field F, and \spad{infinity} otherwise.
  extensionDegree : () -> OnePointCompletion PositiveInteger
    ++ extensionDegree() returns the degree of the field extension if the
    ++ extension is algebraic, and \spad{infinity} if it is not.
  transcendenceDegree : () -> NonNegativeInteger
    ++ transcendenceDegree() returns the transcendence degree of the
    ++ field extension, 0 if the extension is algebraic.
-- perhaps more absolute degree functions
if F has Finite then
  FieldOfPrimeCharacteristic
  Frobenius: $ -> $
    ++ Frobenius(a) returns \spad{a ** q} where q is the \spad{size()$F}.
  Frobenius: ($,NonNegativeInteger) -> $
    ++ Frobenius(a,s) returns \spad{a**(q**s)} where q is the size()$F.
add
  algebraic?(a) == not infinite? (degree(a)@OnePointCompletion_
    (PositiveInteger))$OnePointCompletion(PositiveInteger)
  transcendent? a == infinite?(degree(a)@OnePointCompletion _
    (PositiveInteger))$OnePointCompletion(PositiveInteger)
  if F has Finite then
    Frobenius(a) == a ** size()$F
    Frobenius(a,s) == a ** (size()$F ** s)

```

— XF.dotabb —

"XF"

```

[color=lightblue,href="bookvol10.2.pdf#nameddest=XF"];
"XF" -> "FIELD"
"XF" -> "RETRACT"
"XF" -> "VSPACE"
"XF" -> "FPC"

```

— XF.dotfull —

```

"ExtensionField(a:Field)"
[color=lightblue,href="bookvol10.2.pdf#nameddest=XF"];
"ExtensionField(a:Field)" -> "Field()"
"ExtensionField(a:Field)" -> "RetractableTo(Field)"
"ExtensionField(a:Field)" -> "VectorSpace(a:Field)"
"ExtensionField(a:Field)" -> "FieldOfPrimeCharacteristic()"

```

— XF.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "ExtensionField(a:Field)" [color=lightblue];
  "ExtensionField(a:Field)" -> "Field()"
  "ExtensionField(a:Field)" -> "RetractableTo(Field)"
  "ExtensionField(a:Field)" -> "VectorSpace(a:Field)"

  "FieldOfPrimeCharacteristic()" [color=lightblue];
  "FieldOfPrimeCharacteristic()" -> "CHARNZ..."
  "FieldOfPrimeCharacteristic()" -> "Field()"

  "Field()" [color=lightblue];
  "Field()" -> "EuclideanDomain()"
  "Field()" -> "UniqueFactorizationDomain()"
  "Field()" -> "DIVRING..."

  "EuclideanDomain()" [color=lightblue];
  "EuclideanDomain()" -> "PrincipalIdealDomain()"

  "UniqueFactorizationDomain()" [color=lightblue];
  "UniqueFactorizationDomain()" -> "GCDDOM..."

```



```

"PrincipalIdealDomain()" [color=lightblue];
"PrincipalIdealDomain()" -> "GCDDOM..."

"RetractableTo(Field)" [color=seagreen];
"RetractableTo(Field)" -> "RetractableTo(a:Type)"

"RetractableTo(a:Type)" [color=lightblue];
"RetractableTo(a:Type)" -> "Category"

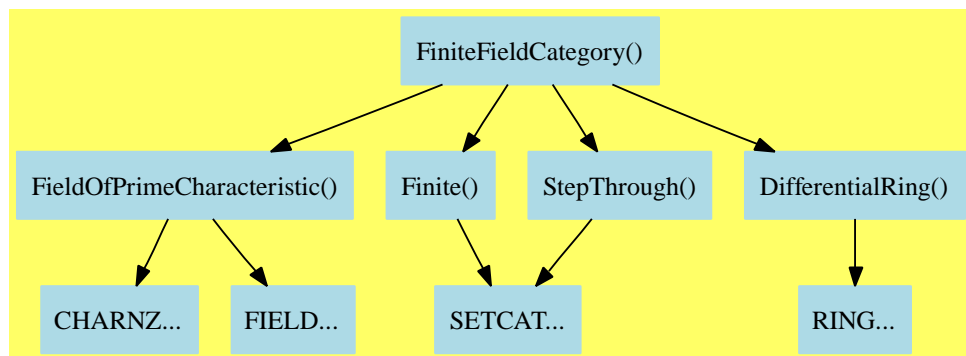
"VectorSpace(a:Field)" [color=lightblue];
"VectorSpace(a:Field)" -> "MODULE..."

"MODULE..." [color=lightblue];
"DIVRING..." [color=lightblue];
"GCDDOM..." [color=lightblue];
"CHARNZ..." [color=lightblue];
"Category" [color=lightblue];
}

```

—————

FiniteFieldCategory (FFIELDC)



— FiniteFieldCategory.input —

```

)set break resume
)sys rm -f FiniteFieldCategory.output
)spool FiniteFieldCategory.output
)set message test on
)set message auto off
)clear all

```

```

--S 1 of 1
)show FiniteFieldCategory
--R FiniteFieldCategory is a category constructor
--R Abbreviation for FiniteFieldCategory is FFIELDC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FFIELDC
--R
--R----- Operations -----
--R ?? : (Fraction(Integer),%) -> %      ?? : (%,Fraction(Integer)) -> %
--R ?? : (%,%) -> %                      ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %        ??? : (%,Integer) -> %
--R ??? : (%,PositiveInteger) -> %      ?+? : (%,%) -> %
--R ?-? : (%,%) -> %                     -? : % -> %
--R ?/? : (%,%) -> %                     ?? : (%,%) -> Boolean
--R D : % -> %                           D : (%,NonNegativeInteger) -> %
--R 1 : () -> %                           0 : () -> %
--R ?? : (%,Integer) -> %                 ?? : (%,PositiveInteger) -> %
--R associates? : (%,%) -> Boolean        charthRoot : % -> %
--R coerce : Fraction(Integer) -> %       coerce : % -> %
--R coerce : Integer -> %                 coerce : % -> OutputForm
--R createPrimitiveElement : () -> %       differentiate : % -> %
--R enumerate : () -> List(%)             factor : % -> Factored(%)
--R gcd : List(%) -> %                    gcd : (%,%) -> %
--R hash : % -> SingleInteger              index : PositiveInteger -> %
--R init : () -> %                        inv : % -> %
--R latex : % -> String                   lcm : List(%) -> %
--R lcm : (%,%) -> %                      lookup : % -> PositiveInteger
--R one? : % -> Boolean                   order : % -> PositiveInteger
--R prime? : % -> Boolean                  primeFrobenius : % -> %
--R primitive? : % -> Boolean              primitiveElement : () -> %
--R ?quo? : (%,%) -> %                    random : () -> %
--R recip : % -> Union(%, "failed")        ?rem? : (%,%) -> %
--R sample : () -> %                      size : () -> NonNegativeInteger
--R sizeLess? : (%,%) -> Boolean            squareFree : % -> Factored(%)
--R squareFreePart : % -> %                unit? : % -> Boolean
--R unitCanonical : % -> %                 zero? : % -> Boolean
--R ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed")
--R conditionP : Matrix(%) -> Union(Vector(%), "failed")
--R differentiate : (%,NonNegativeInteger) -> %
--R discreteLog : % -> NonNegativeInteger
--R discreteLog : (%,%) -> Union(NonNegativeInteger, "failed")
--R divide : (%,%) -> Record(quotient: %, remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%), "failed")

```

```

--R exquo : (%,% ) -> Union(%, "failed")
--R extendedEuclidean : (%,%,% ) -> Union(Record(coef1: %,coef2: %), "failed")
--R extendedEuclidean : (%,% ) -> Record(coef1: %,coef2: %,generator: %)
--R factorsOfCyclicGroupSize : () -> List(Record(factor: Integer,exponent: Integer))
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R multiEuclidean : (List(%),%) -> Union(List(%), "failed")
--R nextItem : % -> Union(%, "failed")
--R order : % -> OnePointCompletion(PositiveInteger)
--R primeFrobenius : (% ,NonNegativeInteger) -> %
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R representationType : () -> Union("prime",polynomial,normal,cyclic)
--R subtractIfCan : (%,% ) -> Union(%, "failed")
--R tableForDiscreteLogarithm : Integer -> Table(PositiveInteger,NonNegativeInteger)
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— FiniteFieldCategory.help —

=====

FiniteFieldCategory examples

=====

FiniteFieldCategory is the category of finite fields

See Also:

o)show FiniteFieldCategory

See:

- ⇐ “DifferentialRing” (DIFRING) [10](#) on page [902](#)
- ⇐ “FieldOfPrimeCharacteristic” (FPC) [17](#) on page [1374](#)
- ⇐ “Finite” (FINITE) [4](#) on page [218](#)
- ⇐ “StepThrough” (STEP) [4](#) on page [305](#)

Exports:

| | | |
|---------------------------|------------------------|--------------------------|
| 0 | 1 | associates? |
| characteristic | charthRoot | coerce |
| conditionP | createPrimitiveElement | D |
| differentiate | discreteLog | divide |
| euclideanSize | expressIdealMember | exquo |
| extendedEuclidean | factor | factorsOfCyclicGroupSize |
| gcd | gcdPolynomial | hash |
| index | init | inv |
| latex | lcm | lookup |
| multiEuclidean | nextItem | one? |
| order | prime? | primeFrobenius |
| primitive? | primitiveElement | principalIdeal |
| random | recip | representationType |
| sample | size | sizeLess? |
| squareFree | squareFreePart | subtractIfCan |
| tableForDiscreteLogarithm | unit? | unitCanonical |
| unitNormal | zero? | ?*? |
| ?*?* | ?+? | ?-? |
| -? | ?/? | ?=? |
| ?^? | ?quo? | ?rem? |
| ?~=? | | |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **canonicalsClosed** is true if `unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative("*)** is true if it has an operation " $*$ " : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return "failed" if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
factorsOfCyclicGroupSize : () ->
  List Record(factor: Integer,exponent: Integer)
primitiveElement : () -> %
representationType : () -> Union("prime",polynomial,normal,cyclic)
```

```
tableForDiscreteLogarithm : Integer ->
  Table(PositiveInteger, NonNegativeInteger)
```

These are implemented by this category:

```
charthRoot : % -> %
charthRoot : % -> Union(%, "failed")
conditionP : Matrix % -> Union(Vector %, "failed")
createPrimitiveElement : () -> %
differentiate : % -> %
discreteLog : % -> NonNegativeInteger
discreteLog : (%, %) -> Union(NonNegativeInteger, "failed")
gcdPolynomial : (SparseUnivariatePolynomial %,
  SparseUnivariatePolynomial %) ->
  SparseUnivariatePolynomial %
init : () -> %
nextItem : % -> Union(%, "failed")
order : % -> OnePointCompletion PositiveInteger
order : % -> PositiveInteger
primitive? : % -> Boolean
```

These exports come from (p1374) FieldOfPrimeCharacteristic():

```
0 : () -> %
1 : () -> %
associates? : (%, %) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
coerce : Fraction Integer -> %
divide : (%, %) -> Record(quotient: %, remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %, %) -> Union(List %, "failed")
extendedEuclidean : (%, %, %) -> Union(Record(coef1: %, coef2: %), "failed")
extendedEuclidean : (%, %) -> Record(coef1: %, coef2: %, generator: %)
exquo : (%, %) -> Union(%, "failed")
factor : % -> Factored %
gcd : List % -> %
gcd : (%, %) -> %
hash : % -> SingleInteger
inv : % -> %
latex : % -> String
lcm : List % -> %
lcm : (%, %) -> %
multiEuclidean : (List %, %) -> Union(List %, "failed")
one? : % -> Boolean
prime? : % -> Boolean
primeFrobenius : % -> %
primeFrobenius : (%, NonNegativeInteger) -> %
```

```

principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%, "failed")
sample : () -> %
sizeLess? : (%,%) -> Boolean
squareFree : % -> Factored %
squareFreePart : % -> %
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (Fraction Integer,%) -> %
?*? : (%,Fraction Integer) -> %
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?-? : (%,%) -> %
-? : % -> %
?***? : (%,Integer) -> %
?***? : (%,PositiveInteger) -> %
?***? : (%,NonNegativeInteger) -> %
?^? : (%,PositiveInteger) -> %
?^? : (%,NonNegativeInteger) -> %
?^? : (%,Integer) -> %
?/? : (%,%) -> %
?quo? : (%,%) -> %
?rem? : (%,%) -> %

```

These exports come from (p218) `Finite()`:

```

index : PositiveInteger -> %
lookup : % -> PositiveInteger
random : () -> %
size : () -> NonNegativeInteger

```

These exports come from (p305) `StepThrough()`:

These exports come from (p902) `DifferentialRing()`:

```

D : % -> %
D : (%,NonNegativeInteger) -> %
differentiate : (%,NonNegativeInteger) -> %

```

```

)abbrev category FFIELDC FiniteFieldCategory
++ Author: J. Grabmeier, A. Scheerhorn
++ Date Created: 11 March 1991
++ Date Last Updated: 31 March 1991
++ References:
++ D.Lipson, Elements of Algebra and Algebraic Computing, The
++ Benjamin/Cummings Publishing Company, Inc.-Menlo Park, California, 1981.
++ J. Grabmeier, A. Scheerhorn: Finite Fields in AXIOM.
++ AXIOM Technical Report Series, ATR/5 NP2522.
++ Description:
++ FiniteFieldCategory is the category of finite fields

FiniteFieldCategory() : Category ==_
  Join(FieldOfPrimeCharacteristic,Finite,StepThrough,DifferentialRing) with
--      ,PolynomialFactorizationExplicit) with
  charthRoot: $ -> $
    ++ charthRoot(a) takes the characteristic'th root of a.
    ++ Note that such a root is alway defined in finite fields.
  conditionP: Matrix $ -> Union(Vector $,"failed")
    ++ conditionP(mat), given a matrix representing a homogeneous system
    ++ of equations, returns a vector whose characteristic'th powers
    ++ is a non-trivial solution, or "failed" if no such vector exists.
-- the reason for implementing the following function is that we
-- can implement the functions order, getGenerator and primitive? on
-- category level without computing the, may be time intensive,
-- factorization of size()-1 at every function call again.
  factorsOfCyclicGroupSize:_
    () -> List Record(factor:Integer,exponent:Integer)
    ++ factorsOfCyclicGroupSize() returns the factorization of size()-1
-- the reason for implementing the function tableForDiscreteLogarithm
-- is that we can implement the functions discreteLog and
-- shanksDiscLogAlgorithm on category level
-- computing the necessary exponentiation tables in the respective
-- domains once and for all
-- absoluteDegree : $ -> PositiveInteger
-- ++ degree of minimal polynomial, if algebraic with respect
-- ++ to the prime subfield
  tableForDiscreteLogarithm: Integer -> _
    Table(PositiveInteger,NonNegativeInteger)
    ++ tableForDiscreteLogarithm(a,n) returns a table of the discrete
    ++ logarithms of \spad{a**0} up to \spad{a**(n-1)} which, called with
    ++ key \spad{lookup(a**i)} returns i for i in \spad{0..n-1}.
    ++ Error: if not called for prime divisors of order of
    ++      multiplicative group.
  createPrimitiveElement: () -> $
    ++ createPrimitiveElement() computes a generator of the (cyclic)
    ++ multiplicative group of the field.
-- RDJ: Are these next lines to be included?
-- we run through the field and test, algorithms which construct
-- elements of larger order were found to be too slow

```

```

primitiveElement: () -> $
  ++ primitiveElement() returns a primitive element stored in a global
  ++ variable in the domain.
  ++ At first call, the primitive element is computed
  ++ by calling \spadfun{createPrimitiveElement}.
primitive?: $ -> Boolean
  ++ primitive?(b) tests whether the element b is a generator of the
  ++ (cyclic) multiplicative group of the field, i.e. is a primitive
  ++ element.
  ++ Implementation Note that see ch.IX.1.3, th.2 in D. Lipson.
discreteLog: $ -> NonNegativeInteger
  ++ discreteLog(a) computes the discrete logarithm of \spad{a}
  ++ with respect to \spad{primitiveElement()} of the field.
order: $ -> PositiveInteger
  ++ order(b) computes the order of an element b in the multiplicative
  ++ group of the field.
  ++ Error: if b equals 0.
representationType: () -> Union("prime","polynomial","normal","cyclic")
  ++ representationType() returns the type of the representation, one of:
  ++ \spad{prime}, \spad{polynomial}, \spad{normal}, or \spad{cyclic}.
add
  I ==> Integer
  PI ==> PositiveInteger
  NNI ==> NonNegativeInteger
  SUP ==> SparseUnivariatePolynomial
  DLP ==> DiscreteLogarithmPackage

-- exported functions

differentiate x == 0

init() == 0

nextItem(a) ==
  zero?(a:=index(lookup(a)+1)) => "failed"
  a

order(e):OnePointCompletion(PositiveInteger) ==
  (order(e)@PI)::OnePointCompletion(PositiveInteger)

conditionP(mat:Matrix $) ==
  l:=nullSpace mat
  empty? l or every?(zero?, first l) => "failed"
  map(charthRoot,first l)

charthRoot(x:$):$ == x**(size() quo characteristic())

charthRoot(x:%):Union($,"failed") ==
  (charthRoot(x)@$)::Union($,"failed")

```



```

createPrimitiveElement() ==
  sm1 : PositiveInteger := (size()$$-1) pretend PositiveInteger
  start : Integer :=
    -- in the polynomial case, index from 1 to characteristic-1
    -- gives prime field elements
    representationType = "polynomial" => characteristic():Integer
    1
  found : Boolean := false
  for i in start.. while not found repeat
    e : $ := index(i::PositiveInteger)
    found := (order(e) = sm1)
  e

primitive? a ==
  -- add special implementation for prime field case
  zero?(a) => false
  explist := factorsOfCyclicGroupSize()
  q:=(size()-1)@Integer
  equalone : Boolean := false
  for exp in explist while not equalone repeat
    -- equalone := one?(a**(q quo exp.factor))
    equalone := ((a**(q quo exp.factor)) = 1)
  not equalone

order e ==
  e = 0 => error "order(0) is not defined "
  ord:Integer:= size()-1 -- order e divides ord
  a:Integer:= 0
  lof:=factorsOfCyclicGroupSize()
  for rec in lof repeat -- run through prime divisors
    a := ord quo (primeDivisor := rec.factor)
    -- goon := one?(e**a)
    goon := ((e**a) = 1)
    -- run through exponents of the prime divisors
    for j in 0..(rec.exponent)-2 while goon repeat
      -- as long as we get (e**ord = 1) we
      -- continue dividing by primeDivisor
      ord := a
      a := ord quo primeDivisor
    -- goon := one?(e**a)
    goon := ((e**a) = 1)
    if goon then ord := a
    -- as we do a top down search we have found the
    -- correct exponent of primeDivisor in order e
    -- and continue with next prime divisor
  ord pretend PositiveInteger

discreteLog(b) ==
  zero?(b) => error "discreteLog: logarithm of zero"
  faclist:=factorsOfCyclicGroupSize()

```

```

a:=b
gen:=primitiveElement()
-- in GF(2) its necessary to have discreteLog(1) = 1
b = gen => 1
disclog:Integer:=0
mult:Integer:=1
groupord := (size() - 1)@Integer
exp:Integer:=groupord
for f in faclist repeat
  fac:=f.factor
  for t in 0..f.exponent-1 repeat
    exp:=exp quo fac
    -- shanks discrete logarithm algorithm
    exptable:=tableForDiscreteLogarithm(fac)
    n:=#exptable
    c:=a**exp
    end:=(fac - 1) quo n
    found:=false
    disc1:Integer:=0
    for i in 0..end while not found repeat
      rho:= search(lookup(c),exptable)_
        $Table(PositiveInteger,NNI)
      rho case NNI =>
        found := true
        disc1:=((n * i + rho)@Integer) * mult
        c:=c* gen**((groupord quo fac) * (-n))
    not found => error "discreteLog: ?? discrete logarithm"
    -- end of shanks discrete logarithm algorithm
    mult := mult * fac
    disclog:=disclog+disc1
    a:=a * (gen ** (-disc1))
  disclog pretend NonNegativeInteger

discreteLog(logbase,b) ==
  zero?(b) =>
    messagePrint("discreteLog: logarithm of zero")$OutputForm
    "failed"
  zero?(logbase) =>
    messagePrint("discreteLog: logarithm to base zero")$OutputForm
    "failed"
  b = logbase => 1
  not zero?((groupord:=order(logbase)@PI) rem order(b)@PI) =>
    messagePrint("discreteLog: second argument not in cyclic group_
generated by first argument")$OutputForm
    "failed"
  faclist:=factors factor groupord
  a:=b
  disclog:Integer:=0
  mult:Integer:=1
  exp:Integer:= groupord

```

```

for f in faclist repeat
  fac:=f.factor
  primroot:= logbase ** (groupord quo fac)
  for t in 0..f.exponent-1 repeat
    exp:=exp quo fac
    rhoHelp:= shanksDiscLogAlgorithm(primroot, _
      a**exp, fac pretend NonNegativeInteger)$DLP($)
    rhoHelp case "failed" => return "failed"
    rho := (rhoHelp :: NNI) * mult
    disclog := disclog + rho
    mult := mult * fac
    a:=a * (logbase ** (-rho))
  disclog pretend NonNegativeInteger

FP ==> SparseUnivariatePolynomial($)
FRP ==> Factored FP
f,g:FP

squareFreePolynomial(f:FP):FRP ==
  squareFree(f)$UnivariatePolynomialSquareFree($,FP)

factorPolynomial(f:FP):FRP == factor(f)$DistinctDegreeFactorize($,FP)

factorSquareFreePolynomial(f:FP):FRP ==
  f = 0 => 0
  flist := distdfact(f,true)$DistinctDegreeFactorize($,FP)
  (flist.cont :: FP) *
    (*/[primeFactor(u.irr,u.pow) for u in flist.factors])

gcdPolynomial(f:FP,g:FP):FP ==
  gcd(f,g)$EuclideanDomain_&(FP)

```

— **FFIELDC.dotabb** —

```

"FFIELDC"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FFIELDC"];
"FFIELDC" -> "FPC"
"FFIELDC" -> "FINITE"
"FFIELDC" -> "STEP"
"FFIELDC" -> "DIFRING"

```

— **FFIELDC.dotfull** —

```

"FiniteFieldCategory()"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FFIELDC"];
"FiniteFieldCategory()" -> "FieldOfPrimeCharacteristic()"
"FiniteFieldCategory()" -> "Finite()"
"FiniteFieldCategory()" -> "StepThrough()"
"FiniteFieldCategory()" -> "DifferentialRing()"

```

— **FFIELDC.dotpic** —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FiniteFieldCategory()" [color=lightblue];
  "FiniteFieldCategory()" -> "FieldOfPrimeCharacteristic()"
  "FiniteFieldCategory()" -> "Finite()"
  "FiniteFieldCategory()" -> "StepThrough()"
  "FiniteFieldCategory()" -> "DifferentialRing()"

  "FieldOfPrimeCharacteristic()" [color=lightblue];
  "FieldOfPrimeCharacteristic()" -> "CHARNZ..."
  "FieldOfPrimeCharacteristic()" -> "FIELD..."

  "Finite()" [color=lightblue];
  "Finite()" -> "SETCAT..."

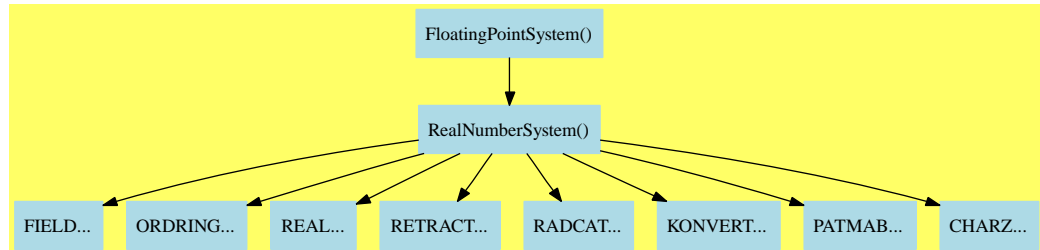
  "StepThrough()" [color=lightblue];
  "StepThrough()" -> "SETCAT..."

  "DifferentialRing()" [color=lightblue];
  "DifferentialRing()" -> "RING..."

  "RING..." [color=lightblue];
  "FIELD..." [color=lightblue];
  "CHARNZ..." [color=lightblue];
  "SETCAT..." [color=lightblue];
}

```

FloatingPointSystem (FPS)



— FloatingPointSystem.input —

```

)set break resume
)sys rm -f FloatingPointSystem.output
)spool FloatingPointSystem.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FloatingPointSystem
--R
--R FloatingPointSystem is a category constructor
--R Abbreviation for FloatingPointSystem is FPS
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FPS
--R
--R----- Operations -----
--R ?? : (Fraction(Integer),%) -> %      ?? : (%,Fraction(Integer)) -> %
--R ?? : (%,%) -> %                      ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %        ??? : (%,Integer) -> %
--R ??? : (%,PositiveInteger) -> %      ?+? : (%,%) -> %
--R ?-? : (%,%) -> %                    -? : % -> %
--R ?/? : (%,%) -> %                   ?<? : (%,%) -> Boolean
--R ?<=? : (%,%) -> Boolean              ?=? : (%,%) -> Boolean
--R ?>? : (%,%) -> Boolean              ?>=? : (%,%) -> Boolean
--R 1 : () -> %                         0 : () -> %
--R ?? : (%,Integer) -> %               ?? : (%,PositiveInteger) -> %
--R abs : % -> %                        associates? : (%,%) -> Boolean
--R base : () -> PositiveInteger         bits : () -> PositiveInteger
--R ceiling : % -> %                    coerce : Fraction(Integer) -> %
--R coerce : Integer -> %                coerce : Fraction(Integer) -> %
--R coerce : % -> %                     coerce : Integer -> %
--R coerce : % -> OutputForm             convert : % -> Pattern(Float)
--R convert : % -> DoubleFloat           convert : % -> Float
--R digits : () -> PositiveInteger       exponent : % -> Integer

```

```

--R factor : % -> Factored(%)
--R floor : % -> %
--R gcd : List(%) -> %
--R hash : % -> SingleInteger
--R latex : % -> String
--R lcm : (%,%) -> %
--R max : (%,%) -> %
--R negative? : % -> Boolean
--R nthRoot : (%,Integer) -> %
--R order : % -> Integer
--R precision : () -> PositiveInteger
--R ?quo? : (%,%) -> %
--R ?rem? : (%,%) -> %
--R retract : % -> Integer
--R sample : () -> %
--R sizeLess? : (%,%) -> Boolean
--R squareFree : % -> Factored(%)
--R truncate : % -> %
--R unitCanonical : % -> %
--R zero? : % -> Boolean
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,Fraction(Integer)) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R ?? : (%,NonNegativeInteger) -> %
--R bits : PositiveInteger -> PositiveInteger if $ has arbitraryPrecision
--R characteristic : () -> NonNegativeInteger
--R decreasePrecision : Integer -> PositiveInteger if $ has arbitraryPrecision
--R digits : PositiveInteger -> PositiveInteger if $ has arbitraryPrecision
--R divide : (%,%) -> Record(quotient: %,remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%),"failed")
--R exquo : (%,%) -> Union(%,"failed")
--R extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed")
--R extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
--R float : (Integer,Integer,PositiveInteger) -> %
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R increasePrecision : Integer -> PositiveInteger if $ has arbitraryPrecision
--R max : () -> % if not(has($,arbitraryPrecision)) and not(has($,arbitraryExponent))
--R min : () -> % if not(has($,arbitraryPrecision)) and not(has($,arbitraryExponent))
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed")
--R patternMatch : (%,Pattern(Float),PatternMatchResult(Float,%)) -> PatternMatchResult(Float,%)
--R precision : PositiveInteger -> PositiveInteger if $ has arbitraryPrecision
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R retractIfCan : % -> Union(Fraction(Integer),"failed")
--R retractIfCan : % -> Union(Integer,"failed")
--R subtractIfCan : (%,%) -> Union(%,"failed")
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

```

```
)spool
)lisp (bye)
```

— FloatingPointSystem.help —

=====

FloatingPointSystem examples

=====

This category is intended as a model for floating point systems. A floating point system is a model for the real numbers. In fact, it is an approximation in the sense that not all real numbers are exactly representable by floating point numbers.

A floating point system is characterized by the following:

- 1: base of the exponent where the actual implementations are usually binary or decimal)
- 2: precision of the mantissa (arbitrary or fixed)
- 3: rounding error for operations
- 4: when, and what happens if exponent overflow/underflow occurs

Because a Float is an approximation to the real numbers, even though it is defined to be a join of a Field and OrderedRing, some of the attributes do not hold. In particular associative("+") does not hold. Algorithms defined over a field need special considerations when the field is a floating point system.

See Also:

o)show FloatingPointSystem

See:

⇐ “RealNumberSystem” (RNS) [17](#) on page [1451](#)

Exports:

| | | | |
|----------------|-------------------|-------------------|--------------------|
| 0 | 1 | abs | associates? |
| base | bits | characteristic | ceiling |
| coerce | convert | decreasePrecision | digits |
| divide | euclideanSize | exponent | expressIdealMember |
| exquo | extendedEuclidean | factor | float |
| floor | fractionPart | gcd | gcdPolynomial |
| hash | increasePrecision | inv | latex |
| lcm | mantissa | max | min |
| multiEuclidean | negative? | norm | nthRoot |
| one? | order | patternMatch | positive? |
| precision | prime? | principalIdeal | recip |
| retract | retractIfCan | round | sample |
| sign | sizeLess? | sqrt | squareFree |
| squareFreePart | subtractIfCan | truncate | unit? |
| unitCanonical | unitNormal | wholePart | zero? |
| ?*? | ?**? | ?+? | ?-? |
| ~? | ?/? | ?<? | ?<=? |
| ?=? | ?>? | ?>=? | ?^? |
| ?~=? | ?quo? | ?rem? | |

Attributes Exported:

- **approximate** means “is an approximation to the real numbers”.
- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **canonicalsClosed** is true if `unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative(“*”)** is true if it has an operation “ $*$ ” : $(D,D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
base : () -> PositiveInteger
bits : () -> PositiveInteger
bits : PositiveInteger -> PositiveInteger
  if $ has arbitraryPrecision
```



```

decreasePrecision : Integer -> PositiveInteger
  if $ has arbitraryPrecision
digits : PositiveInteger -> PositiveInteger
  if $ has arbitraryPrecision
exponent : % -> Integer
float : (Integer,Integer,PositiveInteger) -> %
increasePrecision : Integer -> PositiveInteger
  if $ has arbitraryPrecision
mantissa : % -> Integer
max : () -> %
  if not has($,arbitraryPrecision)
  and not has($,arbitraryExponent)
min : () -> %
  if not has($,arbitraryPrecision)
  and not has($,arbitraryExponent)
order : % -> Integer
precision : () -> PositiveInteger
precision : PositiveInteger -> PositiveInteger
  if $ has arbitraryPrecision

```

These are implemented by this category:

```

digits : () -> PositiveInteger
float : (Integer,Integer) -> %

```

These exports come from (p1451) RealNumberSystem():

```

0 : () -> %
1 : () -> %
abs : % -> %
associates? : (%,% ) -> Boolean
characteristic : () -> NonNegativeInteger
ceiling : % -> %
coerce : Fraction Integer -> %
coerce : Integer -> %
coerce : Fraction Integer -> %
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
convert : % -> Pattern Float
convert : % -> DoubleFloat
convert : % -> Float
divide : (%,% ) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,% ) -> Union(List %, "failed")
exquo : (%,% ) -> Union(%,"failed")
extendedEuclidean : (%,%,% ) -> Union(Record(coef1: %,coef2: %),"failed")
extendedEuclidean : (%,%,% ) -> Record(coef1: %,coef2: %,generator: %)
factor : % -> Factored %
floor : % -> %

```

```

fractionPart : % -> %
gcd : List % -> %
gcd : (%,%) -> %
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    SparseUnivariatePolynomial %
hash : % -> SingleInteger
inv : % -> %
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
max : (%,%) -> %
min : (%,%) -> %
multiEuclidean : (List %,%) -> Union(List %, "failed")
negative? : % -> Boolean
norm : % -> %
nthRoot : (%, Integer) -> %
one? : % -> Boolean
patternMatch :
  (%, Pattern Float, PatternMatchResult(Float, %)) ->
    PatternMatchResult(Float, %)
positive? : % -> Boolean
prime? : % -> Boolean
principalIdeal : List % -> Record(coef: List %, generator: %)
recip : % -> Union(%, "failed")
retract : % -> Fraction Integer
retract : % -> Integer
retractIfCan : % -> Union(Fraction Integer, "failed")
retractIfCan : % -> Union(Integer, "failed")
round : % -> %
sample : () -> %
sign : % -> Integer
sizeLess? : (%,%) -> Boolean
sqrt : % -> %
squareFree : % -> Factored %
squareFreePart : % -> %
subtractIfCan : (%,%) -> Union(%, "failed")
truncate : % -> %
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
wholePart : % -> Integer
zero? : % -> Boolean
?? : (Fraction Integer, %) -> %
?? : (%, Fraction Integer) -> %
?? : (%,%) -> %
?? : (Integer, %) -> %
?? : (PositiveInteger, %) -> %
??? : (%, Fraction Integer) -> %

```

```

***? : (%,Integer) -> %
***? : (%,PositiveInteger) -> %
?+? : (%,% ) -> %
?-? : (%,% ) -> %
-? : % -> %
?/? : (%,% ) -> %
?<? : (%,% ) -> Boolean
?<=? : (%,% ) -> Boolean
?=? : (%,% ) -> Boolean
?>? : (%,% ) -> Boolean
?>=? : (%,% ) -> Boolean
?^? : (%,Integer) -> %
?^? : (%,PositiveInteger) -> %
?~=? : (%,% ) -> Boolean
?*? : (NonNegativeInteger,% ) -> %
***? : (% ,NonNegativeInteger) -> %
?^? : (% ,NonNegativeInteger) -> %
?quo? : (%,% ) -> %
?rem? : (%,% ) -> %

```

— category FPS FloatingPointSystem —

```

)abbrev category FPS FloatingPointSystem
++ Description:
++ This category is intended as a model for floating point systems.
++ A floating point system is a model for the real numbers. In fact,
++ it is an approximation in the sense that not all real numbers are
++ exactly representable by floating point numbers.
++ A floating point system is characterized by the following:
++
++ 1: base of the exponent where the actual implemenations are
++ usually binary or decimal)\br
++ 2: precision of the mantissa (arbitrary or fixed)\br
++ 3: rounding error for operations
--++ 4: when, and what happens if exponent overflow/underflow occurs
++
++ Because a Float is an approximation to the real numbers, even though
++ it is defined to be a join of a Field and OrderedRing, some of
++ the attributes do not hold. In particular associative("+")
++ does not hold. Algorithms defined over a field need special
++ considerations when the field is a floating point system.

FloatingPointSystem(): Category == RealNumberSystem() with
  approximate
  ++\spad{approximate} means "is an approximation to the real numbers".
  float: (Integer,Integer) -> %
  ++float(a,e) returns \spad{a * base() ** e}.
  float: (Integer,Integer,PositiveInteger) -> %
  ++float(a,e,b) returns \spad{a * b ** e}.

```

```

order: % -> Integer
    ++order x is the order of magnitude of x.
    ++Note that \spad{base ** order x <= |x| < base ** (1 + order x)}.
base: () -> PositiveInteger
    ++base() returns the base of the
    ++\spadfunFrom{exponent}{FloatingPointSystem}.

exponent: % -> Integer
    ++ exponent(x) returns the
    ++ \spadfunFrom{exponent}{FloatingPointSystem} part of x.

mantissa: % -> Integer
    ++ mantissa(x) returns the mantissa part of x.
-- round?: () -> B
--    ++ round?() returns the rounding or chopping.

bits: () -> PositiveInteger
    ++ bits() returns ceiling's precision in bits.
digits: () -> PositiveInteger
    ++ digits() returns ceiling's precision in decimal digits.
precision: () -> PositiveInteger
    ++ precision() returns the precision in digits base.

if % has arbitraryPrecision then
    bits: PositiveInteger -> PositiveInteger
        ++ bits(n) set the \spadfunFrom{precision}{FloatingPointSystem}
        ++ to n bits.

    digits: PositiveInteger -> PositiveInteger
        ++ digits(d) set the \spadfunFrom{precision}{FloatingPointSystem}
        ++ to d digits.

    precision: PositiveInteger -> PositiveInteger
        ++ precision(n) set the precision in the base to n decimal digits.

    increasePrecision: Integer -> PositiveInteger
        ++ increasePrecision(n) increases the current
        ++ \spadfunFrom{precision}{FloatingPointSystem} by n decimal digits.

    decreasePrecision: Integer -> PositiveInteger
        ++ decreasePrecision(n) decreases the current
        ++ \spadfunFrom{precision}{FloatingPointSystem} precision
        ++ by n decimal digits.

if not (% has arbitraryExponent) then
    -- overflow: (()->Exit) -> Void
    --    ++ overflow() returns the Exponent overflow of float
    -- underflow: (()->Exit) -> Void
    --    ++ underflow() returns the Exponent underflow of float
    -- maxExponent: () -> Integer

```

```

--      ++ maxExponent() returns the max Exponent of float
      if not (% has arbitraryPrecision) then
        min: () -> %
        ++ min() returns the minimum floating point number.
        max: () -> %
        ++ max() returns the maximum floating point number.
add
float(ma, ex) == float(ma, ex, base())
digits() == max(1,4004 * (bits()-1) quo 13301)::PositiveInteger

```

— FPS.dotabb —

```

"FPS"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FPS"];
"FPS" -> "RNS"

```

— FPS.dotfull —

```

"FloatingPointSystem()"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FPS"];
"FloatingPointSystem()" -> "RealNumberSystem()"

```

— FPS.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FloatingPointSystem()" [color=lightblue];
  "FloatingPointSystem()" -> "RealNumberSystem()"

  "RealNumberSystem()" [color=lightblue];
  "RealNumberSystem()" -> "FIELD..."
  "RealNumberSystem()" -> "ORDRING..."
  "RealNumberSystem()" -> "REAL..."
  "RealNumberSystem()" -> "RETRACT..."
  "RealNumberSystem()" -> "RADCAT..."
  "RealNumberSystem()" -> "KONVERT..."

```

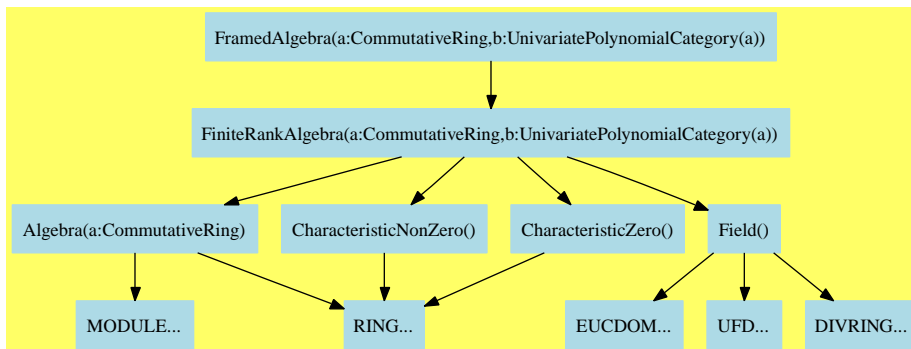
```

"RealNumberSystem()" -> "PATMAB..."
"RealNumberSystem()" -> "CHARZ..."

"FIELD..." [color=lightblue];
"ORDRING..." [color=lightblue];
"REAL..." [color=lightblue];
"RETRACT..." [color=lightblue];
"RADCAT..." [color=lightblue];
"KONVERT..." [color=lightblue];
"PATMAB..." [color=lightblue];
"CHARZ..." [color=lightblue];
}

```

FramedAlgebra (FRAMALG)



— FramedAlgebra.input —

```

)set break resume
)sys rm -f FramedAlgebra.output
)spool FramedAlgebra.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FramedAlgebra
--R
--R FramedAlgebra(R: CommutativeRing,UP: UnivariatePolynomialCategory(t#1)) is a category constructor
--R Abbreviation for FramedAlgebra is FRAMALG

```

```

--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FRAMALG
--R
--R----- Operations -----
--R ?? : (R,%) -> %           ?? : (% ,R) -> %
--R ?? : (% ,%) -> %           ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (% ,PositiveInteger) -> %
--R ?+? : (% ,%) -> %           ?-? : (% ,%) -> %
--R -? : % -> %                 ?=? : (% ,%) -> Boolean
--R 1 : () -> %                 0 : () -> %
--R ?? : (% ,PositiveInteger) -> %   basis : () -> Vector(%)
--R coerce : R -> %               coerce : Integer -> %
--R coerce : % -> OutputForm       convert : Vector(R) -> %
--R convert : % -> Vector(R)       coordinates : % -> Vector(R)
--R discriminant : () -> R         discriminant : Vector(%) -> R
--R hash : % -> SingleInteger      latex : % -> String
--R norm : % -> R                  one? : % -> Boolean
--R rank : () -> PositiveInteger    recip : % -> Union(%, "failed")
--R represents : Vector(R) -> %    sample : () -> %
--R trace : % -> R                 traceMatrix : () -> Matrix(R)
--R zero? : % -> Boolean           ?~=? : (% ,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (% ,NonNegativeInteger) -> %
--R ?? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R characteristicPolynomial : % -> UP
--R charthRoot : % -> Union(%, "failed") if R has CHARNZ
--R coordinates : Vector(%) -> Matrix(R)
--R coordinates : (Vector(%) , Vector(%)) -> Matrix(R)
--R coordinates : (% , Vector(%)) -> Vector(R)
--R minimalPolynomial : % -> UP if R has FIELD
--R regularRepresentation : % -> Matrix(R)
--R regularRepresentation : (% , Vector(%)) -> Matrix(R)
--R represents : (Vector(R) , Vector(%)) -> %
--R subtractIfCan : (% ,%) -> Union(%, "failed")
--R traceMatrix : Vector(%) -> Matrix(R)
--R
--E 1

)spool
)lisp (bye)

```

— FramedAlgebra.help —

```

=====
FramedAlgebra examples
=====

```

A `FramedAlgebra` is a `FiniteRankAlgebra` together with a fixed `R`-module basis.

See Also:

o `)show FramedAlgebra`

See:

⇒ “`MonogenicAlgebra`” (`MONOGEN`) [19](#) on page [1651](#)

⇐ “`FiniteRankAlgebra`” (`FINRALG`) [17](#) on page [1380](#)

Exports:

| | | |
|--------------------------------|---------------------------------------|------------------------------------|
| <code>0</code> | <code>1</code> | <code>basis</code> |
| <code>characteristic</code> | <code>characteristicPolynomial</code> | <code>charthRoot</code> |
| <code>coerce</code> | <code>convert</code> | <code>coordinates</code> |
| <code>discriminant</code> | <code>hash</code> | <code>latex</code> |
| <code>minimalPolynomial</code> | <code>norm</code> | <code>one?</code> |
| <code>rank</code> | <code>recip</code> | <code>regularRepresentation</code> |
| <code>represents</code> | <code>sample</code> | <code>subtractIfCan</code> |
| <code>trace</code> | <code>traceMatrix</code> | <code>zero?</code> |
| <code>?*?</code> | <code>?**?</code> | <code>?+?</code> |
| <code>?-?</code> | <code>-?</code> | <code>?=?</code> |
| <code>?^?</code> | <code>?~=?</code> | |

Attributes Exported:

- **`unitsKnown`** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **`leftUnitary`** is true if $1 * x = x$ for all x .
- **`rightUnitary`** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
basis : () -> Vector %
represents : Vector R -> %
```

These are implemented by this category:

```
convert : Vector R -> %
convert : % -> Vector R
coordinates : Vector % -> Matrix R
coordinates : % -> Vector R
discriminant : () -> R
regularRepresentation : % -> Matrix R
traceMatrix : () -> Matrix R
```


These exports come from (p1380) `FiniteRankAlgebra(R, UP)`
 where `R:CommutativeRing` and `UP:UnivariatePolynomialCategory R`:

```

0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
characteristicPolynomial : % -> UP
charthRoot : % -> Union(%, "failed") if R has CHARNZ
coerce : R -> %
coerce : Integer -> %
coerce : % -> OutputForm
coordinates : (%, Vector %) -> Vector R
coordinates : (Vector %, Vector %) -> Matrix R
discriminant : Vector % -> R
hash : % -> SingleInteger
latex : % -> String
minimalPolynomial : % -> UP if R has FIELD
norm : % -> R
one? : % -> Boolean
rank : () -> PositiveInteger
recip : % -> Union(%, "failed")
regularRepresentation : (%, Vector %) -> Matrix R
represents : (Vector R, Vector %) -> %
sample : () -> %
subtractIfCan : (%, %) -> Union(%, "failed")
trace : % -> R
traceMatrix : Vector % -> Matrix R
zero? : % -> Boolean
?+? : (%, %) -> %
?=? : (%, %) -> Boolean
?~=? : (%, %) -> Boolean
?*? : (%, %) -> %
?*? : (Integer, %) -> %
?*? : (PositiveInteger, %) -> %
?*? : (NonNegativeInteger, %) -> %
?*? : (R, %) -> %
?*? : (%, R) -> %
?-? : (%, %) -> %
-? : % -> %
***? : (%, PositiveInteger) -> %
***? : (%, NonNegativeInteger) -> %
?^? : (%, PositiveInteger) -> %
?^? : (%, NonNegativeInteger) -> %

```

— category FRAMALG FramedAlgebra —

```

)abbrev category FRAMALG FramedAlgebra
++ Author: Barry Trager
++ Description:

```

```

++ A \spadtype{FramedAlgebra} is a \spadtype{FiniteRankAlgebra} together
++ with a fixed R-module basis.

FramedAlgebra(R:CommutativeRing, UP:UnivariatePolynomialCategory R):
Category == FiniteRankAlgebra(R, UP) with
  basis          : () -> Vector %
  ++ basis() returns the fixed R-module basis.
  coordinates    : % -> Vector R
  ++ coordinates(a) returns the coordinates of \spad{a} with
  ++ respect to the fixed R-module basis.
  coordinates    : Vector % -> Matrix R
  ++ coordinates([v1,...,vm]) returns the coordinates of the
  ++ vi's with to the fixed basis. The coordinates of vi are
  ++ contained in the ith row of the matrix returned by this
  ++ function.
  represents     : Vector R -> %
  ++ represents([a1,...,an]) returns \spad{a1*v1 + ... + an*vn}, where
  ++ v1, ..., vn are the elements of the fixed basis.
  convert        : % -> Vector R
  ++ convert(a) returns the coordinates of \spad{a} with respect to the
  ++ fixed R-module basis.
  convert        : Vector R -> %
  ++ convert([a1,...,an]) returns \spad{a1*v1 + ... + an*vn}, where
  ++ v1, ..., vn are the elements of the fixed basis.
  traceMatrix    : () -> Matrix R
  ++ traceMatrix() is the n-by-n matrix ( \spad{Tr(vi * vj)} ), where
  ++ v1, ..., vn are the elements of the fixed basis.
  discriminant   : () -> R
  ++ discriminant() = determinant(traceMatrix()).
  regularRepresentation : % -> Matrix R
  ++ regularRepresentation(a) returns the matrix of the linear
  ++ map defined by left multiplication by \spad{a} with respect
  ++ to the fixed basis.
--attributes
--separable <=> discriminant() ^= 0
add
convert(x:%):Vector(R) == coordinates(x)
convert(v:Vector R):% == represents(v)
traceMatrix() == traceMatrix basis()
discriminant() == discriminant basis()
regularRepresentation x == regularRepresentation(x, basis())
coordinates x == coordinates(x, basis())
represents x == represents(x, basis())

coordinates(v:Vector %) ==
  m := new(#v, rank(), 0)$Matrix(R)
  for i in minIndex v .. maxIndex v for j in minRowIndex m .. repeat
    setRow_!(m, j, coordinates qelt(v, i))
  m

```

```

regularRepresentation x ==
  m := new(n := rank(), n, 0)$Matrix(R)
  b := basis()
  for i in minIndex b .. maxIndex b for j in minRowIndex m .. repeat
    setRow_!(m, j, coordinates(x * qelt(b, i)))
  m

characteristicPolynomial x ==
  mat00 := (regularRepresentation x)
  mat0 := map(y+>y::UP,mat00)$MatrixCategoryFunctions2(R, Vector R,
    Vector R, Matrix R, UP, Vector UP,Vector UP, Matrix UP)
  mat1 : Matrix UP := scalarMatrix(rank(),monomial(1,1)$UP)
  determinant(mat1 - mat0)

if R has Field then
  -- depends on the ordering of results from nullSpace, also see FFP
  minimalPolynomial(x:%):UP ==
    y:%:=1
    n:=rank()
    m:Matrix R:=zero(n,n+1)
    for i in 1..n+1 repeat
      setColumn_!(m,i,coordinates(y))
    y:=y*x
    v:=first nullSpace(m)
    +/[monomial(v.(i+1),i) for i in 0..#v-1]



---


— FRAMALG.dotabb —

"FRAMALG"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FRAMALG"];
"FRAMALG" -> "FINRALG"



---



— FRAMALG.dotfull —

"FramedAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"
[color=lightblue,href="bookvol10.2.pdf#nameddest=FRAMALG"];
"FramedAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"



---



— FRAMALG.dotpic —

```

```

digraph pic {
    fontsize=10;
    bgcolor="#ECEA81";
    node [shape=box, color=white, style=filled];

    "FramedAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"
    [color=lightblue];
    "FramedAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
        "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"

    "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"
    [color=lightblue];
    "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
        "Algebra(a:CommutativeRing)"
    "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
        "Field()"
    "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
        "CharacteristicNonZero()"
    "FiniteRankAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
        "CharacteristicZero()"

    "Algebra(a:CommutativeRing)" [color=lightblue];
    "Algebra(a:CommutativeRing)" -> "RING..."
    "Algebra(a:CommutativeRing)" -> "MODULE..."

    "Field()" [color=lightblue];
    "Field()" -> "EUCDOM..."
    "Field()" -> "UFD..."
    "Field()" -> "DIVRING..."

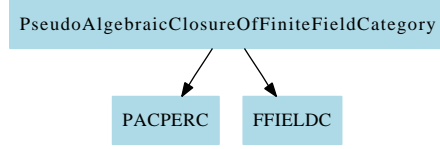
    "CharacteristicNonZero()" [color=lightblue];
    "CharacteristicNonZero()" -> "RING..."

    "CharacteristicZero()" [color=lightblue];
    "CharacteristicZero()" -> "RING..."

    "EUCDOM..." [color=lightblue];
    "UFD..." [color=lightblue];
    "DIVRING..." [color=lightblue];
    "RING..." [color=lightblue];
    "MODULE..." [color=lightblue];
}

```

PseudoAlgebraicClosureOfFiniteFieldCategory (PACFFC)



— PseudoAlgebraicClosureOfFiniteFieldCategory.input —

```

)set break resume
)sys rm -f PseudoAlgebraicClosureOfFiniteFieldCategory.output
)spool PseudoAlgebraicClosureOfFiniteFieldCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PseudoAlgebraicClosureOfFiniteFieldCategory
--R PseudoAlgebraicClosureOfFiniteFieldCategory is a category constructor
--R Abbreviation for PseudoAlgebraicClosureOfFiniteFieldCategory is PACFFC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PACFFC
--R
--R----- Operations -----
--R ???: (Fraction(Integer),%) -> %      ??? : (%,Fraction(Integer)) -> %
--R ??? : (%,%) -> %                    ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %      ??? : (%,Integer) -> %
--R ??? : (%,PositiveInteger) -> %     ?+? : (%,%) -> %
--R ?-? : (%,%) -> %                   -? : % -> %
--R ?/? : (%,%) -> %                   ?=? : (%,%) -> Boolean
--R D : % -> %                         D : (%,NonNegativeInteger) -> %
--R 1 : () -> %                        0 : () -> %
--R ?? : (%,Integer) -> %              ?^? : (%,PositiveInteger) -> %
--R associates? : (%,%) -> Boolean     charthRoot : % -> %
--R coerce : Fraction(Integer) -> %    coerce : % -> %
--R coerce : Integer -> %              coerce : % -> OutputForm
--R conjugate : % -> %                 createPrimitiveElement : () -> %
--R differentiate : % -> %             enumerate : () -> List(%)
--R extDegree : % -> PositiveInteger    factor : % -> Factored(%)
--R fullOutput : % -> OutputForm        gcd : List(%) -> %
--R gcd : (%,%) -> %                   ground? : % -> Boolean
--R hash : % -> SingleInteger           index : PositiveInteger -> %
--R init : () -> %                     inv : % -> %
--R latex : % -> String                 lcm : List(%) -> %
--R lcm : (%,%) -> %                   lookup : % -> PositiveInteger
--R maxTower : List(%) -> %             one? : % -> Boolean
--R order : % -> PositiveInteger         previousTower : % -> %

```

```

--R prime? : % -> Boolean
--R primitive? : % -> Boolean
--R ?quo? : (%,%)->%
--R recip : % -> Union(%,"failed")
--R sample : () -> %
--R size : () -> NonNegativeInteger
--R squareFree : % -> Factored(%)
--R unit? : % -> Boolean
--R vectorise : (%,%)-> Vector(%)
--R ?~=? : (%,%)-> Boolean
--R ?*? : (NonNegativeInteger,%)->%
--R ??? : (%NonNegativeInteger)->%
--R ?? : (%NonNegativeInteger)->%
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%,"failed")
--R conditionP : Matrix(%) -> Union(Vector(%),"failed")
--R definingPolynomial : () -> SparseUnivariatePolynomial(%)
--R definingPolynomial : % -> SparseUnivariatePolynomial(%)
--R differentiate : (%NonNegativeInteger)->%
--R discreteLog : % -> NonNegativeInteger
--R discreteLog : (%,%)-> Union(NonNegativeInteger,"failed")
--R distinguishedRootsOf : (SparseUnivariatePolynomial(%),%) -> List(%)
--R divide : (%,%)-> Record(quotient: %,remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%),"failed")
--R exquo : (%,%)-> Union(%,"failed")
--R extendedEuclidean : (%,%,%)-> Union(Record(coef1: %,coef2: %),"failed")
--R extendedEuclidean : (%,%)-> Record(coef1: %,coef2: %,generator: %)
--R factorsOfCyclicGroupSize : () -> List(Record(factor: Integer,exponent: Integer))
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R lift : % -> SparseUnivariatePolynomial(%)
--R lift : (%,%)-> SparseUnivariatePolynomial(%)
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed")
--R newElement : (SparseUnivariatePolynomial(%),%,Symbol) -> %
--R newElement : (SparseUnivariatePolynomial(%),Symbol) -> %
--R nextItem : % -> Union(%,"failed")
--R order : % -> OnePointCompletion(PositiveInteger)
--R primeFrobenius : (%NonNegativeInteger)->%
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R reduce : SparseUnivariatePolynomial(%) -> %
--R representationType : () -> Union("prime",polynomial,normal,cyclic)
--R subtractIfCan : (%,%)-> Union(%,"failed")
--R tableForDiscreteLogarithm : Integer -> Table(PositiveInteger,NonNegativeInteger)
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— PseudoAlgebraicClosureOfFiniteFieldCategory.help —

```
=====
PseudoAlgebraicClosureOfFiniteFieldCategory examples
=====
```

This category exports the function for the domain
PseudoAlgebraicClosureOfFiniteField which implement dynamic extension
using the simple notion of tower extensions.

A tower extension T of the ground field K is any sequence of field extension
 $(T : K_0, K_1, \dots, K_i, \dots, K_n)$
where $K_0 = K$ and for $i = 1, 2, \dots, n$, K_i is an extension
of K_{i-1} of degree > 1 and defined by an irreducible polynomial
 $p(Z)$ in K_{i-1} .

Two towers

$(T_1: K_{01}, K_{11}, \dots, K_{i1}, \dots, K_{n1})$

and

$(T_2: K_{02}, K_{12}, \dots, K_{i2}, \dots, K_{n2})$

are said to be related if

$T_1 \leq T_2$ (or $T_1 \geq T_2$),

that is if

$K_{i1} = K_{i2}$ for $i = 1, 2, \dots, n_1$

(or $i = 1, 2, \dots, n_2$). Any algebraic operations defined for several elements
are only defined if all of the concerned elements are coming from
a set of related tower extensions.

See Also:

o)show PseudoAlgebraicClosureOfFiniteFieldCategory

⇐ “FieldOfPrimeCharacteristic” (FPC) [17](#) on page [1374](#)

⇐ “PseudoAlgebraicClosureOfPerfectFieldCategory” (PACPERC) [17](#) on page [1420](#)

Exports:

| | | |
|--------------------------|----------------------|---------------------------|
| 0 | 1 | associates? |
| characteristic | charthRoot | conditionP |
| coerce | conjugate | createPrimitiveElement |
| D | definingPolynomial | differentiate |
| discreteLog | distinguishedRootsOf | divide |
| euclideanSize | extendedEuclidean | expressIdealMember |
| exquo | extDegree | factor |
| factorsOfCyclicGroupSize | fullOutput | gcd |
| gcdPolynomial | ground? | hash |
| index | init | inv |
| latex | lcm | lift |
| lookup | maxTower | multiEuclidean |
| newElement | nextItem | one? |
| order | previousTower | prime? |
| primeFrobenius | primitive? | primitiveElement |
| principalIdeal | ?quo? | random |
| recip | reduce | ?rem? |
| representationType | sample | setTower! |
| size | sizeLess? | squareFree |
| squareFreePart | subtractIfCan | tableForDiscreteLogarithm |
| unit? | unitCanonical | unitNormal |
| vectorise | zero? | ?*? |
| ?**? | ?+? | ?-? |
| -? | ?/? | ?=? |
| ?^? | ?~=? | |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **canonicalsClosed** is true if `unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative(“*”)** is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These exports come from (p1420) `PseudoAlgebraicClosureOfPerfectFieldCategory()`:


```

?? : (Fraction Integer,%) -> %
?? : (%,Fraction Integer) -> %
?? : (%,%) -> %
?? : (Integer,%) -> %
?? : (PositiveInteger,%) -> %
?? : (NonNegativeInteger,%) -> %
***? : (%,Integer) -> %
***? : (%,PositiveInteger) -> %
***? : (%,NonNegativeInteger) -> %
?+? : (%,%) -> %
?-? : (%,%) -> %
-? : % -> %
?/? : (%,%) -> %
=? : (%,%) -> Boolean
1 : () -> %
0 : () -> %
?? : (%,Integer) -> %
?? : (%,PositiveInteger) -> %
?? : (%,NonNegativeInteger) -> %
?~=? : (%,%) -> Boolean
associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : Fraction Integer -> %
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
conjugate : % -> %
definingPolynomial : () -> SUP %
definingPolynomial : % -> SUP %
distinguishedRootsOf : (SparseUnivariatePolynomial %,%) -> List %
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %, "failed")
exquo : (%,%) -> Union(%, "failed")
extDegree : % -> PI
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
factor : % -> Factored %
fullOutput : % -> OutputForm
gcd : List % -> %
gcd : (%,%) -> %
gcdPolynomial : (SparseUnivariatePolynomial %,SparseUnivariatePolynomial %) -> SparseUnivariate
ground? : % -> Boolean
hash : % -> SingleInteger
inv : % -> %
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
lift : % -> SUP %
lift : (%,%) -> SUP %

```

```

maxTower : List % -> %
multiEuclidean : (List %,%) -> Union(List %,"failed")
newElement : (SUP %,Symbol) -> %
newElement : (SUP %,%,Symbol) -> %
one? : % -> Boolean
previousTower : % -> %
prime? : % -> Boolean
principalIdeal : List % -> Record(coef: List %,generator: %)
?quo? : (%,%) -> %
recip : % -> Union(%,"failed")
reduce : SUP % -> %
?rem? : (%,%) -> %
sample : () -> %
setTower! : % -> Void
sizeLess? : (%,%) -> Boolean
squareFree : % -> Factored %
squareFreePart : % -> %
subtractIfCan : (%,%) -> Union(%,"failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
vectorise : (%,%) -> Vector %
zero? : % -> Boolean

```

These exports come from (p1570) `FiniteFieldCategory()`:

```

charthRoot : % -> %
charthRoot : % -> Union(%,"failed")
conditionP : Matrix % -> Union(Vector %,"failed")
createPrimitiveElement : () -> %
D : % -> %
D : (%,NonNegativeInteger) -> %
differentiate : % -> %
differentiate : (%,NonNegativeInteger) -> %
discreteLog : % -> NonNegativeInteger
discreteLog : (%,%) -> Union(NonNegativeInteger,"failed")
factorsOfCyclicGroupSize : () ->
  List Record(factor: Integer,exponent: Integer)
index : PositiveInteger -> %
init : () -> %
lookup : % -> PositiveInteger
nextItem : % -> Union(%,"failed")
order : % -> OnePointCompletion PositiveInteger
order : % -> PositiveInteger
primeFrobenius : (%,NonNegativeInteger) -> %
primeFrobenius : % -> %
primitive? : % -> Boolean
primitiveElement : () -> %
random : () -> %
representationType : () -> Union("prime",polynomial,normal,cyclic)

```

```

size : () -> NonNegativeInteger
tableForDiscreteLogarithm : Integer ->
    Table(PositiveInteger, NonNegativeInteger)

```

— category PACFFC PseudoAlgebraicClosureOfFiniteFieldCategory

```

)abbrev category PACFFC PseudoAlgebraicClosureOfFiniteFieldCategory
-- PseudoAlgebraicClosureOfFiniteFieldCategory
++ Authors: Gaetan Hache
++ Date Created: june 1996
++ Description:
++ This category exports the function for the domain
++ PseudoAlgebraicClosureOfFiniteField which implement dynamic extension
++ using the simple notion of tower extensions.
++ A tower extension T of the ground
++ field K is any sequence of field extension (T : K_0, K_1, ..., K_i..., K_n)
++ where K_0 = K and for i =1,2,...,n, K_i is an extension
++ of K_{i-1} of degree > 1 and defined by an irreducible polynomial
++ p(Z) in K_{i-1}.
++ Two towers (T_1: K_01, K_11,...,K_i1,...,K_n1)
++ and (T_2: K_02, K_12,...,K_i2,...,K_n2)
++ are said to be related if T_1 <= T_2 (or T_1 >= T_2),
++ that is if K_i1 = K_i2 for i=1,2,...,n1
++ (or i=1,2,...,n2). Any algebraic operations defined for several elements
++ are only defined if all of the concerned elements are coming from
++ a set of related tower extensions.
PseudoAlgebraicClosureOfFiniteFieldCategory:Category ==
    Join(FiniteFieldCategory, PseudoAlgebraicClosureOfPerfectFieldCategory)

```

— PACFFC.dotabb —

```

"PACFFC" [color=lightblue,href="bookvol10.2.pdf#nameddest=PACFFC"];
"PACFFC" -> "PACPERC"

```

— PACFFC.dotfull —

```

"PseudoAlgebraicClosureOfFiniteFieldCategory"
[color=lightblue,href="bookvol10.2.pdf#nameddest=PACFFC"];
"PseudoAlgebraicClosureOfFiniteFieldCategory" ->
    "PseudoAlgebraicClosureOfPerfectFieldCategory()"

```

```
"PseudoAlgebraicClosureOfFiniteFieldCategory" ->
  "FiniteFieldCategory"
```

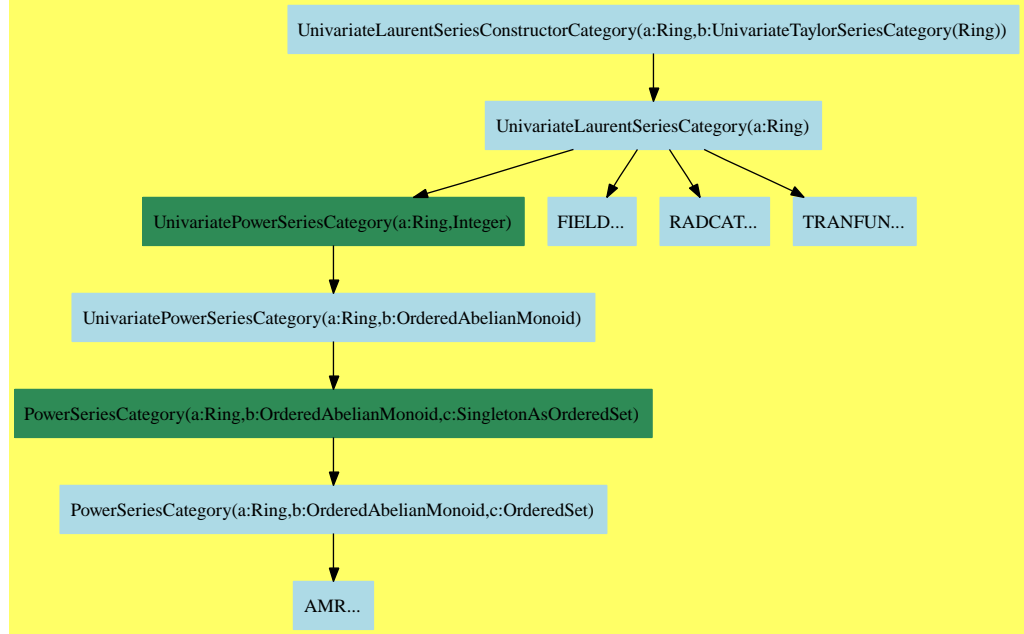
— PACFFC.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "PseudoAlgebraicClosureOfFiniteFieldCategory" [color=lightblue];
  "PseudoAlgebraicClosureOfFiniteFieldCategory" -> "PACPERC"
  "PseudoAlgebraicClosureOfFiniteFieldCategory" -> "FFIELDC"

  "PACPERC" [color=lightblue];
  "FFIELDC" [color=lightblue];
}
```

UnivariateLaurentSeriesConstructorCategory (ULSCCAT)



— UnivariateLaurentSeriesConstructorCategory.input —

```

)set break resume
)sys rm -f UnivariateLaurentSeriesConstructorCategory.output
)spool UnivariateLaurentSeriesConstructorCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show UnivariateLaurentSeriesConstructorCategory
--R
--R UnivariateLaurentSeriesConstructorCategory(Coef: Ring,UTS: UnivariateTaylorSeriesCategory(t#
--R Abbreviation for UnivariateLaurentSeriesConstructorCategory is ULSCCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for ULSCCAT
--R
--R----- Operations -----
--R ?? : (Coef,%) -> %
--R ?? : (%,%) -> %
--R ?? : (PositiveInteger,%) -> %
--R ?+? : (%,%) -> %
--R -? : % -> %
--R ?? : (%,Coef) -> %
--R ?? : (Integer,%) -> %
--R ***? : (%,PositiveInteger) -> %
--R ?-? : (%,%) -> %
--R ?=? : (%,%) -> Boolean

```

```

--R 1 : () -> %
--R ?? : (% , PositiveInteger) -> %
--R coefficient : (% , Integer) -> Coef
--R coerce : Integer -> %
--R complete : % -> %
--R ?? : (% , Integer) -> Coef
--R hash : % -> SingleInteger
--R laurent : (Integer , UTS) -> %
--R leadingMonomial : % -> %
--R monomial : (Coef , Integer) -> %
--R one? : % -> Boolean
--R order : % -> Integer
--R recip : % -> Union(% , "failed")
--R removeZeroes : (Integer , %) -> %
--R retract : % -> UTS
--R taylor : % -> UTS
--R truncate : (% , Integer) -> %
--R zero? : % -> Boolean
--R ?? : (% , Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (Fraction(Integer) , %) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (UTS , %) -> % if Coef has FIELD
--R ?? : (% , UTS) -> % if Coef has FIELD
--R ?? : (NonNegativeInteger , %) -> %
--R ??? : (% , Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (% , %) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (% , Integer) -> % if Coef has FIELD
--R ??? : (% , NonNegativeInteger) -> %
--R ?/? : (UTS , UTS) -> % if Coef has FIELD
--R ?/? : (% , %) -> % if Coef has FIELD
--R ?/? : (% , Coef) -> % if Coef has FIELD
--R ?<? : (% , %) -> Boolean if and(has(UTS , OrderedSet) , has(Coef , Field))
--R ?<=? : (% , %) -> Boolean if and(has(UTS , OrderedSet) , has(Coef , Field))
--R ?>? : (% , %) -> Boolean if and(has(UTS , OrderedSet) , has(Coef , Field))
--R ?>=? : (% , %) -> Boolean if and(has(UTS , OrderedSet) , has(Coef , Field))
--R D : (% , Symbol) -> % if and(has(UTS , PartialDifferentialRing(Symbol)) , has(Coef , Field)) or Coef has PDRING
--R D : (% , List(Symbol)) -> % if and(has(UTS , PartialDifferentialRing(Symbol)) , has(Coef , Field)) or Coef has PDRING
--R D : (% , Symbol , NonNegativeInteger) -> % if and(has(UTS , PartialDifferentialRing(Symbol)) , has(Coef , Field))
--R D : (% , List(Symbol) , List(NonNegativeInteger)) -> % if and(has(UTS , PartialDifferentialRing(Symbol)) , has(Coef , Field))
--R D : % -> % if and(has(UTS , DifferentialRing) , has(Coef , Field)) or Coef has *: (Integer , Coef) -> Coef
--R D : (% , NonNegativeInteger) -> % if and(has(UTS , DifferentialRing) , has(Coef , Field)) or Coef has *: (Integer , Coef) -> Coef
--R D : (% , (UTS -> UTS) , NonNegativeInteger) -> % if Coef has FIELD
--R D : (% , (UTS -> UTS)) -> % if Coef has FIELD
--R ?? : (% , Integer) -> % if Coef has FIELD
--R ?? : (% , NonNegativeInteger) -> %
--R abs : % -> % if and(has(UTS , OrderedIntegralDomain) , has(Coef , Field))
--R acos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acoth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R 0 : () -> %
--R center : % -> Coef
--R coerce : UTS -> %
--R coerce : % -> OutputForm
--R degree : % -> Integer
--R extend : (% , Integer) -> %
--R latex : % -> String
--R leadingCoefficient : % -> Coef
--R map : ((Coef -> Coef) , %) -> %
--R monomial? : % -> Boolean
--R order : (% , Integer) -> Integer
--R pole? : % -> Boolean
--R reductum : % -> %
--R removeZeroes : % -> %
--R sample : () -> %
--R taylorRep : % -> UTS
--R variable : % -> Symbol
--R ~=? : (% , %) -> Boolean

```

```

--R acsch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R approximate : (%,Integer) -> Coef if Coef has **: (Coef,Integer) -> Coef and Coef has coerce
--R asec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asinh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R associates? : (%,%) -> Boolean if Coef has INTDOM
--R atan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R atanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R ceiling : % -> UTS if and(has(UTS,IntegerNumberSystem),has(Coef,Field))
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if and(OR(has(UTS,CharacteristicNonZero),and(has($,Chara
--R coerce : % -> % if Coef has INTDOM
--R coerce : Fraction(Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R coerce : Symbol -> % if and(has(UTS,RetractableTo(Symbol)),has(Coef,Field))
--R coerce : Coef -> % if Coef has COMRING
--R conditionP : Matrix(%) -> Union(Vector(%), "failed") if and(and(has($,CharacteristicNonZero),
--R convert : % -> Pattern(Integer) if and(has(UTS,ConvertibleTo(Pattern(Integer))),has(Coef,Field))
--R convert : % -> Pattern(Float) if and(has(UTS,ConvertibleTo(Pattern(Float))),has(Coef,Field))
--R convert : % -> InputForm if and(has(UTS,ConvertibleTo(InputForm)),has(Coef,Field))
--R convert : % -> Float if and(has(UTS,RealConstant),has(Coef,Field))
--R convert : % -> DoubleFloat if and(has(UTS,RealConstant),has(Coef,Field))
--R cos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R coth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R denom : % -> UTS if Coef has FIELD
--R denominator : % -> % if Coef has FIELD
--R differentiate : (%,Symbol) -> % if and(has(UTS,PartialDifferentialRing(Symbol)),has(Coef,Field))
--R differentiate : (%,List(Symbol)) -> % if and(has(UTS,PartialDifferentialRing(Symbol)),has(Coef,Field))
--R differentiate : (%,Symbol,NonNegativeInteger) -> % if and(has(UTS,PartialDifferentialRing(Symbol)),has(Coef,Field))
--R differentiate : (%,List(Symbol),List(NonNegativeInteger)) -> % if and(has(UTS,PartialDifferentialRing(Symbol)),has(Coef,Field))
--R differentiate : % -> % if and(has(UTS,DifferentialRing),has(Coef,Field)) or Coef has *: (Int
--R differentiate : (%,NonNegativeInteger) -> % if and(has(UTS,DifferentialRing),has(Coef,Field))
--R differentiate : (%,(UTS -> UTS),NonNegativeInteger) -> % if Coef has FIELD
--R differentiate : (%,(UTS -> UTS)) -> % if Coef has FIELD
--R divide : (%,%) -> Record(quotient: %,remainder: %) if Coef has FIELD
--R ?? : (%,UTS) -> % if and(has(UTS,Eltable(UTS,UTS)),has(Coef,Field))
--R ?? : (%,%) -> % if Integer has SGROUP
--R euclideanSize : % -> NonNegativeInteger if Coef has FIELD
--R eval : (%,List(UTS),List(UTS)) -> % if and(has(UTS,Evaluable(UTS)),has(Coef,Field))
--R eval : (%,UTS,UTS) -> % if and(has(UTS,Evaluable(UTS)),has(Coef,Field))
--R eval : (%,Equation(UTS)) -> % if and(has(UTS,Evaluable(UTS)),has(Coef,Field))
--R eval : (%,List(Equation(UTS))) -> % if and(has(UTS,Evaluable(UTS)),has(Coef,Field))
--R eval : (%,List(Symbol),List(UTS)) -> % if and(has(UTS,InnerEvaluable(Symbol,UTS)),has(Coef,Field))
--R eval : (%,Symbol,UTS) -> % if and(has(UTS,InnerEvaluable(Symbol,UTS)),has(Coef,Field))
--R eval : (%,Coef) -> Stream(Coef) if Coef has **: (Coef,Integer) -> Coef
--R exp : % -> % if Coef has ALGEBRA(FRAC(INT))

```

```

--R expressIdealMember : (List(%),%) -> Union(List(%),"failed") if Coef has FIELD
--R exquo : (%,%)-> Union(%,"failed") if Coef has INTDOM
--R extendedEuclidean : (%,%)-> Record(coef1: %,coef2: %,generator: %) if Coef has FIELD
--R extendedEuclidean : (%,%,%)-> Union(Record(coef1: %,coef2: %),"failed") if Coef has FIELD
--R factor : % -> Factored(%) if Coef has FIELD
--R factorPolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%)) if and(has(
--R factorSquareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%)) if
--R floor : % -> UTS if and(has(UTS,IntegerNumberSystem),has(Coef,Field))
--R fractionPart : % -> % if and(has(UTS,EuclideanDomain),has(Coef,Field))
--R gcd : (%,%)-> % if Coef has FIELD
--R gcd : List(%) -> % if Coef has FIELD
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynom
--R init : () -> % if and(has(UTS,StepThrough),has(Coef,Field))
--R integrate : (%Symbol)-> % if Coef has ACFS(INT) and Coef has PRIMCAT and Coef has TRANFUN and Coef has
--R integrate : % -> % if Coef has ALGEBRA(FRAC(INT))
--R inv : % -> % if Coef has FIELD
--R lcm : (%,%)-> % if Coef has FIELD
--R lcm : List(%) -> % if Coef has FIELD
--R log : % -> % if Coef has ALGEBRA(FRAC(INT))
--R map : ((UTS -> UTS),%) -> % if Coef has FIELD
--R max : (%,%)-> % if and(has(UTS,OrderedSet),has(Coef,Field))
--R min : (%,%)-> % if and(has(UTS,OrderedSet),has(Coef,Field))
--R monomial : (%List(SingletonAsOrderedSet),List(Integer))-> %
--R monomial : (%SingletonAsOrderedSet,Integer)-> %
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed") if Coef has FIELD
--R multiplyCoefficients : ((Integer -> Coef),%) -> %
--R multiplyExponents : (%PositiveInteger)-> %
--R negative? : % -> Boolean if and(has(UTS,OrderedIntegralDomain),has(Coef,Field))
--R nextItem : % -> Union(%,"failed") if and(has(UTS,StepThrough),has(Coef,Field))
--R nthRoot : (%Integer)-> % if Coef has ALGEBRA(FRAC(INT))
--R numer : % -> UTS if Coef has FIELD
--R numerator : % -> % if Coef has FIELD
--R patternMatch : (%Pattern(Integer),PatternMatchResult(Integer,%)) -> PatternMatchResult(Integer,%) if a
--R patternMatch : (%Pattern(Float),PatternMatchResult(Float,%)) -> PatternMatchResult(Float,%) if and(has
--R pi : () -> % if Coef has ALGEBRA(FRAC(INT))
--R positive? : % -> Boolean if and(has(UTS,OrderedIntegralDomain),has(Coef,Field))
--R prime? : % -> Boolean if Coef has FIELD
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %) if Coef has FIELD
--R ?quo? : (%,%)-> % if Coef has FIELD
--R random : () -> % if and(has(UTS,IntegerNumberSystem),has(Coef,Field))
--R rationalFunction : (%Integer,Integer)-> Fraction(Polynomial(Coef)) if Coef has INTDOM
--R rationalFunction : (%Integer)-> Fraction(Polynomial(Coef)) if Coef has INTDOM
--R reducedSystem : Matrix(%) -> Matrix(Integer) if and(has(UTS,LinearlyExplicitRingOver(Integer)),has(Coef
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Integer),vec: Vector(Integer)) if and(has(U
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(UTS),vec: Vector(UTS)) if Coef has FIELD
--R reducedSystem : Matrix(%) -> Matrix(UTS) if Coef has FIELD
--R ?rem? : (%,%)-> % if Coef has FIELD
--R retract : % -> Symbol if and(has(UTS,RetractableTo(Symbol)),has(Coef,Field))
--R retract : % -> Fraction(Integer) if and(has(UTS,RetractableTo(Integer)),has(Coef,Field))
--R retract : % -> Integer if and(has(UTS,RetractableTo(Integer)),has(Coef,Field))

```



```

--R retractIfCan : % -> Union(Symbol,"failed") if and(has(UTS,RetractableTo(Symbol)),has(Coef,Fi
--R retractIfCan : % -> Union(Fraction(Integer),"failed") if and(has(UTS,RetractableTo(Integer))
--R retractIfCan : % -> Union(Integer,"failed") if and(has(UTS,RetractableTo(Integer)),has(Coef,
--R retractIfCan : % -> Union(UTS,"failed")
--R sec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R series : Stream(Record(k: Integer,c: Coef)) -> %
--R sign : % -> Integer if and(has(UTS,OrderedIntegralDomain),has(Coef,Field))
--R sin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sinh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sizeLess? : (%,%) -> Boolean if Coef has FIELD
--R solveLinearPolynomialEquation : (List(SparseUnivariatePolynomial(%)),SparseUnivariatePolynom
--R sqrt : % -> % if Coef has ALGEBRA(FRAC(INT))
--R squareFree : % -> Factored(%) if Coef has FIELD
--R squareFreePart : % -> % if Coef has FIELD
--R squareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R tan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R tanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R taylorIfCan : % -> Union(UTS,"failed")
--R terms : % -> Stream(Record(k: Integer,c: Coef))
--R truncate : (%,Integer,Integer) -> %
--R unit? : % -> Boolean if Coef has INTDOM
--R unitCanonical : % -> % if Coef has INTDOM
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if Coef has INTDOM
--R variables : % -> List(SingletonAsOrderedSet)
--R wholePart : % -> UTS if and(has(UTS,EuclideanDomain),has(Coef,Field))
--R
--E 1

```

```

)spool
)lisp (bye)

```

— UnivariateLaurentSeriesConstructorCategory.help —

```

=====
UnivariateLaurentSeriesConstructorCategory examples
=====

```

This is a category of univariate Laurent series constructed from univariate Taylor series. A Laurent series is represented by a pair $[n, f(x)]$, where n is an arbitrary integer and $f(x)$ is a Taylor series. This pair represents the Laurent series $x^{**n} * f(x)$.

See Also:

```
o )show UnivariateLaurentSeriesConstructorCategory
```

See:

⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

⇐ “UnivariateLaurentSeriesCategory” (ULSCAT) [17](#) on page [1499](#)

Exports:

| | | |
|-------------------------------|----------------------|----------------------------|
| 0 | 1 | abs |
| acos | acosh | acot |
| acoth | acsc | acsch |
| approximate | asec | asech |
| asin | asinh | associates? |
| atan | atanh | ceiling |
| center | characteristic | charthRoot |
| coefficient | coerce | complete |
| conditionP | convert | cos |
| cosh | cot | coth |
| csc | csch | D |
| degree | denom | denominator |
| differentiate | divide | euclideanSize |
| eval | exp | expressIdealMember |
| exquo | extend | extendedEuclidean |
| factor | factorPolynomial | factorSquareFreePolynomial |
| floor | fractionPart | gcd |
| gcdPolynomial | hash | init |
| integrate | inv | latex |
| laurent | lcm | leadingCoefficient |
| leadingMonomial | log | map |
| max | min | monomial |
| monomial? | multiEuclidean | multiplyCoefficients |
| multiplyExponents | negative? | nextItem |
| nthRoot | numer | numerator |
| one? | order | patternMatch |
| pi | pole? | positive? |
| prime? | principalIdeal | random |
| rationalFunction | recip | reducedSystem |
| reductum | removeZeroes | retract |
| retractIfCan | sample | sec |
| sech | series | sign |
| sin | sinh | sizeLess? |
| solveLinearPolynomialEquation | sqrt | squareFree |
| squareFreePart | squareFreePolynomial | subtractIfCan |
| tan | tanh | taylor |
| taylorIfCan | taylorRep | terms |
| truncate | unit? | unitCanonical |
| unitNormal | variable | variables |
| wholePart | zero? | ?*? |
| ***? | ?+? | ?-? |
| -? | ?=? | ?^? |
| ?~=? | ?/? | ?<? |
| ?<=? | ?>? | ?>=? |
| ?.? | ?quo? | ?rem? |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- if #1 has Field then canonicalClosed where **canonicalsClosed** is true if $\text{unitCanonical}(a) * \text{unitCanonical}(b) = \text{unitCanonical}(a * b)$.
- if #1 has Field then canonicalUnitNormal where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is $\text{associates?}(a, b)$ returns true if and only if $\text{unitCanonical}(a) = \text{unitCanonical}(b)$.
- if #1 has CommutativeRing then commutative(“*”) where **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- if #1 has IntegralDomain then noZeroDivisors where **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- if #1 has Field then nil

These are directly exported but not implemented:

```
coerce : UTS -> %
degree : % -> Integer
laurent : (Integer,UTS) -> %
removeZeroes : % -> %
removeZeroes : (Integer,%) -> %
taylor : % -> UTS
taylorIfCan : % -> Union(UTS,"failed")
taylorRep : % -> UTS
```

These are implemented by this category:

```
retract : % -> UTS
retractIfCan : % -> Union(UTS,"failed")
zero? : % -> Boolean
```

These exports come from (p1499) UnivariateLaurentSeriesCategory(Coef:Ring)

```
0 : () -> %
1 : () -> %
acos : % -> % if Coef has ALGEBRA FRAC INT
acosh : % -> % if Coef has ALGEBRA FRAC INT
acot : % -> % if Coef has ALGEBRA FRAC INT
acoth : % -> % if Coef has ALGEBRA FRAC INT
acsc : % -> % if Coef has ALGEBRA FRAC INT
```

```

acsch : % -> % if Coef has ALGEBRA FRAC INT
approximate : (%,Integer) -> Coef
  if Coef has **: (Coef,Integer) -> Coef
    and Coef has coerce: Symbol -> Coef
asec : % -> % if Coef has ALGEBRA FRAC INT
asech : % -> % if Coef has ALGEBRA FRAC INT
asin : % -> % if Coef has ALGEBRA FRAC INT
asinh : % -> % if Coef has ALGEBRA FRAC INT
associates? : (%,% ) -> Boolean if Coef has INTDOM
atan : % -> % if Coef has ALGEBRA FRAC INT
atanh : % -> % if Coef has ALGEBRA FRAC INT
center : % -> Coef
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(%, "failed")
  if and(OR(has(UTS,CharacteristicNonZero),
    and(has($,CharacteristicNonZero),
      has(UTS,PolynomialFactorizationExplicit))),
    has(Coef,Field))
  or Coef has CHARNZ
coefficient : (%,Integer) -> Coef
coerce : % -> % if Coef has INTDOM
coerce : Fraction Integer -> % if Coef has ALGEBRA FRAC INT
coerce : Coef -> % if Coef has COMRING
coerce : Integer -> %
coerce : % -> OutputForm
complete : % -> %
cos : % -> % if Coef has ALGEBRA FRAC INT
cosh : % -> % if Coef has ALGEBRA FRAC INT
cot : % -> % if Coef has ALGEBRA FRAC INT
coth : % -> % if Coef has ALGEBRA FRAC INT
csc : % -> % if Coef has ALGEBRA FRAC INT
csch : % -> % if Coef has ALGEBRA FRAC INT
D : % -> %
  if and(has(UTS,DifferentialRing),has(Coef,Field))
  or Coef has *: (Integer,Coef) -> Coef
D : (% , NonNegativeInteger) -> %
  if and(has(UTS,DifferentialRing),has(Coef,Field))
  or Coef has *: (Integer,Coef) -> Coef
D : (% , Symbol) -> %
  if and(has(UTS,PartialDifferentialRing Symbol),has(Coef,Field))
  or Coef has PDRING SYMBOL
  and Coef has *: (Integer,Coef) -> Coef
D : (% , List Symbol) -> %
  if and(has(UTS,PartialDifferentialRing Symbol),has(Coef,Field))
  or Coef has PDRING SYMBOL
  and Coef has *: (Integer,Coef) -> Coef
D : (% , Symbol, NonNegativeInteger) -> %
  if and(has(UTS,PartialDifferentialRing Symbol),has(Coef,Field))
  or Coef has PDRING SYMBOL
  and Coef has *: (Integer,Coef) -> Coef

```

```

D : (% , List Symbol , List NonNegativeInteger) -> %
  if and(has(UTS,PartialDifferentialRing Symbol),has(Coef,Field))
  or Coef has PDRING SYMBOL
  and Coef has *: (Integer,Coef) -> Coef
differentiate : (% , Symbol) -> %
  if and(has(UTS,PartialDifferentialRing Symbol),has(Coef,Field))
  or Coef has PDRING SYMBOL
  and Coef has *: (Integer,Coef) -> Coef
differentiate : (% , List Symbol) -> %
  if and(has(UTS,PartialDifferentialRing Symbol),has(Coef,Field))
  or Coef has PDRING SYMBOL
  and Coef has *: (Integer,Coef) -> Coef
differentiate : (% , Symbol , NonNegativeInteger) -> %
  if and(has(UTS,PartialDifferentialRing Symbol),has(Coef,Field))
  or Coef has PDRING SYMBOL
  and Coef has *: (Integer,Coef) -> Coef
differentiate : (% , List Symbol , List NonNegativeInteger) -> %
  if and(has(UTS,PartialDifferentialRing Symbol),has(Coef,Field))
  or Coef has PDRING SYMBOL
  and Coef has *: (Integer,Coef) -> Coef
differentiate : % -> %
  if and(has(UTS,DifferentialRing),has(Coef,Field))
  or Coef has *: (Integer,Coef) -> Coef
differentiate : (% , NonNegativeInteger) -> %
  if and(has(UTS,DifferentialRing),has(Coef,Field))
  or Coef has *: (Integer,Coef) -> Coef
divide : (% , %) -> Record(quotient: % , remainder: %)
  if Coef has FIELD
euclideanSize : % -> NonNegativeInteger if Coef has FIELD
eval : (% , Coef) -> Stream Coef
  if Coef has **: (Coef,Integer) -> Coef
exp : % -> % if Coef has ALGEBRA FRAC INT
expressIdealMember : (List % , %) -> Union(List % , "failed")
  if Coef has FIELD
exquo : (% , %) -> Union(% , "failed") if Coef has INTDOM
extend : (% , Integer) -> %
extendedEuclidean : (% , %) -> Record(coef1: % , coef2: % , generator: %)
  if Coef has FIELD
extendedEuclidean : (% , % , %) -> Union(Record(coef1: % , coef2: % ) , "failed")
  if Coef has FIELD
factor : % -> Factored % if Coef has FIELD
gcd : (% , %) -> % if Coef has FIELD
gcd : List % -> % if Coef has FIELD
gcdPolynomial :
  (SparseUnivariatePolynomial % ,
   SparseUnivariatePolynomial %) ->
  SparseUnivariatePolynomial %
  if Coef has FIELD
hash : % -> SingleInteger
integrate : (% , Symbol) -> %

```

```

    if Coef has ACFS INT
    and Coef has PRIMCAT
    and Coef has TRANFUN
    and Coef has ALGEBRA FRAC INT
    or Coef has variables: Coef -> List Symbol
    and Coef has integrate: (Coef,Symbol) -> Coef
    and Coef has ALGEBRA FRAC INT
integrate : % -> % if Coef has ALGEBRA FRAC INT
inv : % -> % if Coef has FIELD
latex : % -> String
lcm : (%,%) -> % if Coef has FIELD
lcm : List % -> % if Coef has FIELD
leadingCoefficient : % -> Coef
leadingMonomial : % -> %
log : % -> % if Coef has ALGEBRA FRAC INT
map : ((Coef -> Coef),%) -> %
monomial : (%,List SingletonAsOrderedSet,List Integer) -> %
monomial : (%,SingletonAsOrderedSet,Integer) -> %
monomial : (Coef,Integer) -> %
monomial? : % -> Boolean
multiEuclidean : (List %,%) -> Union(List %,"failed")
    if Coef has FIELD
multiplyCoefficients : ((Integer -> Coef),%) -> %
multiplyExponents : (%,PositiveInteger) -> %
nthRoot : (%,Integer) -> % if Coef has ALGEBRA FRAC INT
one? : % -> Boolean
order : (%,Integer) -> Integer
order : % -> Integer
pi : () -> % if Coef has ALGEBRA FRAC INT
pole? : % -> Boolean
prime? : % -> Boolean if Coef has FIELD
principalIdeal : List % -> Record(coef: List %,generator: %)
    if Coef has FIELD
rationalFunction : (%,Integer) -> Fraction Polynomial Coef
    if Coef has INTDOM
rationalFunction : (%,Integer,Integer) -> Fraction Polynomial Coef
    if Coef has INTDOM
recip : % -> Union(%,"failed")
reductum : % -> %
sample : () -> %
sec : % -> % if Coef has ALGEBRA FRAC INT
sech : % -> % if Coef has ALGEBRA FRAC INT
series : Stream Record(k: Integer,c: Coef) -> %
sin : % -> % if Coef has ALGEBRA FRAC INT
sinh : % -> % if Coef has ALGEBRA FRAC INT
sizeLess? : (%,%) -> Boolean if Coef has FIELD
squareFree : % -> Factored % if Coef has FIELD
squareFreePart : % -> % if Coef has FIELD
sqrt : % -> % if Coef has ALGEBRA FRAC INT
subtractIfCan : (%,%) -> Union(%,"failed")

```

```

tan : % -> % if Coef has ALGEBRA FRAC INT
tanh : % -> % if Coef has ALGEBRA FRAC INT
terms : % -> Stream Record(k: Integer,c: Coef)
truncate : (%,Integer,Integer) -> %
truncate : (%,Integer) -> %
unit? : % -> Boolean if Coef has INTDOM
unitCanonical : % -> % if Coef has INTDOM
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
  if Coef has INTDOM
variable : % -> Symbol
variables : % -> List SingletonAsOrderedSet
?.? : (%,Integer) -> Coef
?*?: (%,Integer) -> % if Coef has FIELD
***? : (%,Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
***? : (%,NonNegativeInteger) -> %
?^? : (%,Integer) -> % if Coef has FIELD
?^? : (%,NonNegativeInteger) -> %
?/? : (%,% ) -> % if Coef has FIELD
?+? : (%,% ) -> %
?= ? : (%,% ) -> Boolean
?~=? : (%,% ) -> Boolean
*? : (NonNegativeInteger,% ) -> %
*? : (PositiveInteger,% ) -> %
*? : (%,% ) -> %
?-? : (%,% ) -> %
-? : % -> %
***? : (%,PositiveInteger) -> %
***? : (%,% ) -> % if Coef has ALGEBRA FRAC INT
?^? : (%,PositiveInteger) -> %
*? : (Integer,% ) -> %
*? : (Coef,% ) -> %
*? : (% ,Coef) -> %
*? : (% ,Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
*? : (Fraction Integer,% ) -> % if Coef has ALGEBRA FRAC INT
?/? : (% ,Coef) -> % if Coef has FIELD
?.? : (%,% ) -> % if Integer has SGROUP
?quo? : (%,% ) -> % if Coef has FIELD
?rem? : (%,% ) -> % if Coef has FIELD

```

These exports come from (p1427) QuotientFieldCategory(UTS)
 where UTS:UnivariateLaurentSeriesCategory(Coef:Ring)

```

abs : % -> %
  if and(has(UTS,OrderedIntegralDomain),has(Coef,Field))
ceiling : % -> UTS
  if and(has(UTS,IntegerNumberSystem),has(Coef,Field))
conditionP : Matrix % -> Union(Vector %, "failed")
  if and(and(has($,CharacteristicNonZero),
    has(UTS,PolynomialFactorizationExplicit)),
    has(Coef,Field))

```



```

coerce : Symbol -> %
  if and(has(UTS,RetractableTo Symbol),has(Coef,Field))
convert : % -> Pattern Integer
  if and(has(UTS,ConvertibleTo Pattern Integer),has(Coef,Field))
convert : % -> Pattern Float
  if and(has(UTS,ConvertibleTo Pattern Float),has(Coef,Field)\hfill\
convert : % -> InputForm
  if and(has(UTS,ConvertibleTo InputForm),has(Coef,Field))
convert : % -> Float
  if and(has(UTS,RealConstant),has(Coef,Field))
convert : % -> DoubleFloat
  if and(has(UTS,RealConstant),has(Coef,Field))
D : (%,(UTS -> UTS),NonNegativeInteger) -> %
  if Coef has FIELD
D : (%,(UTS -> UTS)) -> % if Coef has FIELD
denom : % -> UTS if Coef has FIELD
denominator : % -> % if Coef has FIELD
differentiate : (%,(UTS -> UTS)) -> % if Coef has FIELD
differentiate : (%,(UTS -> UTS),NonNegativeInteger) -> %
  if Coef has FIELD
eval : (% ,Equation UTS) -> %
  if and(has(UTS,Evalable UTS),has(Coef,Field))
eval : (% ,List Symbol,List UTS) -> %
  if and(has(UTS,InnerEvalable(Symbol,UTS)),has(Coef,Field))
eval : (% ,List Equation UTS) -> %
  if and(has(UTS,Evalable UTS),has(Coef,Field))
eval : (% ,UTS,UTS) -> %
  if and(has(UTS,Evalable UTS),has(Coef,Field))
eval : (% ,List UTS,List UTS) -> %
  if and(has(UTS,Evalable UTS),has(Coef,Field))
eval : (% ,Symbol,UTS) -> %
  if and(has(UTS,InnerEvalable(Symbol,UTS)),has(Coef,Field))
factorPolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if and(has(UTS,PolynomialFactorizationExplicit),has(Coef,Field))
factorSquareFreePolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if and(has(UTS,PolynomialFactorizationExplicit),has(Coef,Field))
floor : % -> UTS
  if and(has(UTS,IntegerNumberSystem),has(Coef,Field))
fractionPart : % -> %
  if and(has(UTS,EuclideanDomain),has(Coef,Field))
init : () -> % if and(has(UTS,StepThrough),has(Coef,Field))
map : ((UTS -> UTS),%) -> % if Coef has FIELD
max : (% ,%) -> % if and(has(UTS,OrderedSet),has(Coef,Field))
min : (% ,%) -> % if and(has(UTS,OrderedSet),has(Coef,Field))
negative? : % -> Boolean
  if and(has(UTS,OrderedIntegralDomain),has(Coef,Field))

```

```

nextItem : % -> Union(%, "failed")
  if and(has(UTS, StepThrough), has(Coef, Field))
numer : % -> UTS if Coef has FIELD
numerator : % -> % if Coef has FIELD
patternMatch :
  (%, Pattern Integer, PatternMatchResult(Integer, %)) ->
    PatternMatchResult(Integer, %)
    if and(has(UTS, PatternMatchable Integer), has(Coef, Field))
patternMatch :
  (%, Pattern Float, PatternMatchResult(Float, %)) ->
    PatternMatchResult(Float, %)
    if and(has(UTS, PatternMatchable Float), has(Coef, Field))
positive? : % -> Boolean
  if and(has(UTS, OrderedIntegralDomain), has(Coef, Field))
random : () -> %
  if and(has(UTS, IntegerNumberSystem), has(Coef, Field))
reducedSystem :
  (Matrix %, Vector %) -> Record(mat: Matrix Integer, vec: Vector Integer)
  if and(has(UTS, LinearlyExplicitRingOver Integer), has(Coef, Field))
reducedSystem : Matrix % -> Matrix Integer
  if and(has(UTS, LinearlyExplicitRingOver Integer), has(Coef, Field))
reducedSystem :
  (Matrix %, Vector %) -> Record(mat: Matrix UTS, vec: Vector UTS)
  if Coef has FIELD
reducedSystem : Matrix % -> Matrix UTS if Coef has FIELD
retract : % -> Symbol
  if and(has(UTS, RetractableTo Symbol), has(Coef, Field))
retract : % -> Integer
  if and(has(UTS, RetractableTo Integer), has(Coef, Field))
retract : % -> Fraction Integer
  if and(has(UTS, RetractableTo Integer), has(Coef, Field))
retractIfCan : % -> Union(Fraction Integer, "failed")
  if and(has(UTS, RetractableTo Integer), has(Coef, Field))
retractIfCan : % -> Union(Symbol, "failed")
  if and(has(UTS, RetractableTo Symbol), has(Coef, Field))
retractIfCan : % -> Union(Integer, "failed")
  if and(has(UTS, RetractableTo Integer), has(Coef, Field))
sign : % -> Integer
  if and(has(UTS, OrderedIntegralDomain), has(Coef, Field))
solveLinearPolynomialEquation :
  (List SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
    Union(List SparseUnivariatePolynomial %, "failed")
    if and(has(UTS, PolynomialFactorizationExplicit), has(Coef, Field))
squareFreePolynomial :
  SparseUnivariatePolynomial % ->
    Factored SparseUnivariatePolynomial %
    if and(has(UTS, PolynomialFactorizationExplicit), has(Coef, Field))
wholePart : % -> UTS
  if and(has(UTS, EuclideanDomain), has(Coef, Field))

```

```

?? : (UTS,%) -> % if Coef has FIELD
?? : (% ,UTS) -> % if Coef has FIELD
?? : (% ,%) -> Boolean if and(has(UTS,OrderedSet),has(Coef,Field))
?? : (UTS,UTS) -> % if Coef has FIELD
?.? : (% ,UTS) -> % if and(has(UTS,Eltable(UTS,UTS)),has(Coef,Field))
?<=? : (% ,%) -> Boolean if and(has(UTS,OrderedSet),has(Coef,Field))
?>? : (% ,%) -> Boolean if and(has(UTS,OrderedSet),has(Coef,Field))
?>=? : (% ,%) -> Boolean if and(has(UTS,OrderedSet),has(Coef,Field))

```

— category ULSCCAT UnivariateLaurentSeriesConstructorCategory

```

)abbrev category ULSCCAT UnivariateLaurentSeriesConstructorCategory
++ Author: Clifton J. Williamson
++ Date Created: 6 February 1990
++ Date Last Updated: 10 May 1990
++ Description:
++ This is a category of univariate Laurent series constructed from
++ univariate Taylor series. A Laurent series is represented by a pair
++ \spad{[n,f(x)]}, where n is an arbitrary integer and \spad{f(x)}
++ is a Taylor series. This pair represents the Laurent series
++ \spad{x**n * f(x)}.

UnivariateLaurentSeriesConstructorCategory(Coef,UTS):_
Category == Definition where
  Coef: Ring
  UTS : UnivariateTaylorSeriesCategory Coef
  I ==> Integer

Definition ==> Join(UnivariateLaurentSeriesCategory(Coef),_
  RetractableTo UTS) with
  laurent: (I,UTS) -> %
    ++ \spad{laurent(n,f(x))} returns \spad{x**n * f(x)}.
  degree: % -> I
    ++ \spad{degree(f(x))} returns the degree of the lowest order term of
    ++ \spad{f(x)}, which may have zero as a coefficient.
  taylorRep: % -> UTS
    ++ \spad{taylorRep(f(x))} returns \spad{g(x)}, where
    ++ \spad{f = x**n * g(x)} is represented by \spad{[n,g(x)]}.
  removeZeroes: % -> %
    ++ \spad{removeZeroes(f(x))} removes leading zeroes from the
    ++ representation of the Laurent series \spad{f(x)}.
    ++ A Laurent series is represented by (1) an exponent and
    ++ (2) a Taylor series which may have leading zero coefficients.
    ++ When the Taylor series has a leading zero coefficient, the
    ++ 'leading zero' is removed from the Laurent series as follows:
    ++ the series is rewritten by increasing the exponent by 1 and
    ++ dividing the Taylor series by its variable.
    ++ Note that \spad{removeZeroes(f)} removes all leading zeroes from f

```

```

removeZeroes: (I,%) -> %
  ++ \spad{removeZeroes(n,f(x))} removes up to n leading zeroes from
  ++ the Laurent series \spad{f(x)}.
  ++ A Laurent series is represented by (1) an exponent and
  ++ (2) a Taylor series which may have leading zero coefficients.
  ++ When the Taylor series has a leading zero coefficient, the
  ++ 'leading zero' is removed from the Laurent series as follows:
  ++ the series is rewritten by increasing the exponent by 1 and
  ++ dividing the Taylor series by its variable.
coerce: UTS -> %
  ++ \spad{coerce(f(x))} converts the Taylor series \spad{f(x)} to a
  ++ Laurent series.
taylor: % -> UTS
  ++ taylor(f(x)) converts the Laurent series f(x) to a Taylor series,
  ++ if possible. Error: if this is not possible.
taylorIfCan: % -> Union(UTS,"failed")
  ++ \spad{taylorIfCan(f(x))} converts the Laurent series \spad{f(x)}
  ++ to a Taylor series, if possible. If this is not possible,
  ++ "failed" is returned.
if Coef has Field then QuotientFieldCategory(UTS)
  --++ the quotient field of univariate Taylor series over a field is
  --++ the field of Laurent series

add

zero? x == zero? taylorRep x

retract(x:%):UTS == taylor x

retractIfCan(x:%):Union(UTS,"failed") == taylorIfCan x

-----

— ULSCCAT.dotabb —

"ULSCCAT"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ULSCCAT"];
"ULSCCAT" -> "ULSCAT"

-----

— ULSCCAT.dotfull —

"UnivariateLaurentSeriesConstructorCategory(a:Ring,b:UnivariateTaylorSeriesCategory(Ring))"
[color=lightblue,href="bookvol10.2.pdf#nameddest=ULSCCAT"];
"UnivariateLaurentSeriesConstructorCategory(a:Ring,b:UnivariateTaylorSeriesCategory(Ring))"

```

```
-> "UnivariateLaurentSeriesCategory(a:Ring)"
```

— ULSCCAT.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "UnivariateLaurentSeriesConstructorCategory(a:Ring,b:UnivariateTaylorSeriesCategory(Ring))"
    [color=lightblue];
  "UnivariateLaurentSeriesConstructorCategory(a:Ring,b:UnivariateTaylorSeriesCategory(Ring))"
    -> "UnivariateLaurentSeriesCategory(a:Ring)"

  "UnivariateLaurentSeriesCategory(a:Ring)" [color=lightblue];
  "UnivariateLaurentSeriesCategory(a:Ring)" ->
    "UnivariatePowerSeriesCategory(a:Ring,Integer)"
  "UnivariateLaurentSeriesCategory(a:Ring)" ->
    "FIELD..."
  "UnivariateLaurentSeriesCategory(a:Ring)" ->
    "RADCAT..."
  "UnivariateLaurentSeriesCategory(a:Ring)" ->
    "TRANFUN..."

  "UnivariatePowerSeriesCategory(a:Ring,Integer)" [color=seagreen];
  "UnivariatePowerSeriesCategory(a:Ring,Integer)" ->
    "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"

  "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"
    [color=lightblue];
  "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)" ->
    "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"

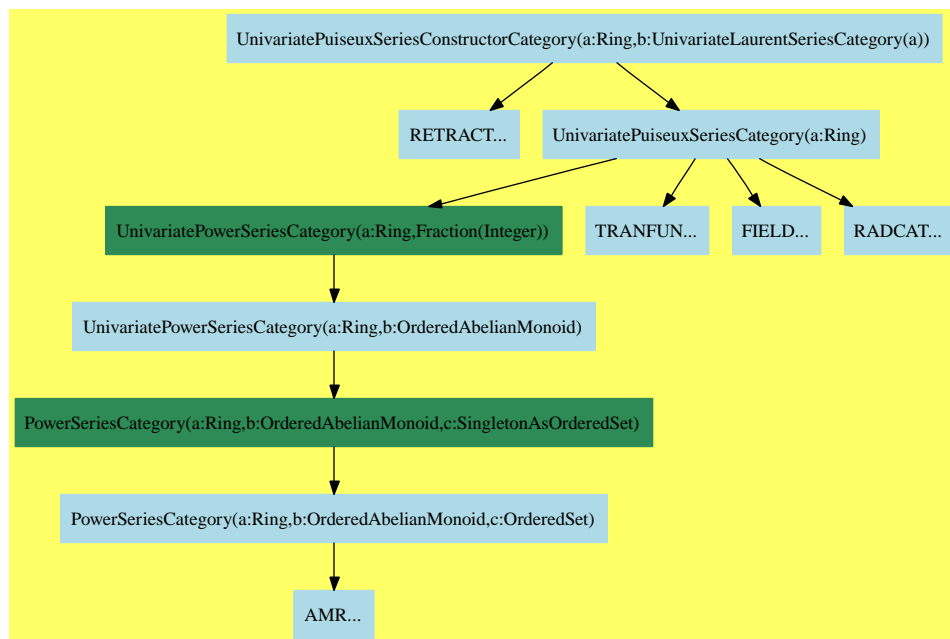
  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
    [color=seagreen];
  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
    -> "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"

  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"
    [color=lightblue];
  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)" ->
    "AMR..."

  "AMR..." [color=lightblue];
  "FIELD..." [color=lightblue];
  "TRANFUN..." [color=lightblue];
```

```
"RADCAT..." [color=lightblue];
}
```

UnivariatePuisseuxSeriesConstructorCategory (UPXSCCA)



— UnivariatePuisseuxSeriesConstructorCategory.input —

```
)set break resume
)sys rm -f UnivariatePuisseuxSeriesConstructorCategory.output
)spool UnivariatePuisseuxSeriesConstructorCategory.output
)set message test on
)set message auto off
)clear all
```

```
--S 1 of 1
```

```
)show UnivariatePuisseuxSeriesConstructorCategory
```

```
--R
```

```
--R UnivariatePuisseuxSeriesConstructorCategory(Coef: Ring,ULS: UnivariateLaurentSeriesCategory(t#1)) is a
```

```
--R Abbreviation for UnivariatePuisseuxSeriesConstructorCategory is UPXSCCA
```

```
--R This constructor is exposed in this frame.
```

```

--R Issue )edit bookvol10.2.pamphlet to see algebra source code for UPXSCCA
--R
--R----- Operations -----
--R ?? : (Coef,%) -> %           ?? : (%,Coef) -> %
--R ?? : (%,%) -> %             ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,PositiveInteger) -> %
--R +? : (%,%) -> %             ?-? : (%,%) -> %
--R -? : % -> %                 ?=? : (%,%) -> Boolean
--R 1 : () -> %                 0 : () -> %
--R ?? : (%,PositiveInteger) -> %   center : % -> Coef
--R coerce : ULS -> %             coerce : Integer -> %
--R coerce : % -> OutputForm       complete : % -> %
--R degree : % -> Fraction(Integer) hash : % -> SingleInteger
--R latex : % -> String           laurent : % -> ULS
--R laurentRep : % -> ULS         leadingCoefficient : % -> Coef
--R leadingMonomial : % -> %       map : ((Coef -> Coef),%) -> %
--R monomial? : % -> Boolean       one? : % -> Boolean
--R order : % -> Fraction(Integer) pole? : % -> Boolean
--R recip : % -> Union(%, "failed") reductum : % -> %
--R retract : % -> ULS           sample : () -> %
--R variable : % -> Symbol        zero? : % -> Boolean
--R ~=? : (%,%) -> Boolean
--R ?? : (%,Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (Fraction(Integer),%) -> % if Coef has ALGEBRA(FRAC(INT))
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,Fraction(Integer)) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (%,%) -> % if Coef has ALGEBRA(FRAC(INT))
--R ??? : (%,Integer) -> % if Coef has FIELD
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,%) -> % if Coef has FIELD
--R ?/? : (%,Coef) -> % if Coef has FIELD
--R D : % -> % if Coef has *: (Fraction(Integer),Coef) -> Coef
--R D : (%,NonNegativeInteger) -> % if Coef has *: (Fraction(Integer),Coef) -> Coef
--R D : (%,Symbol) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> Coef
--R D : (%,List(Symbol)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> Coef
--R D : (%,Symbol,NonNegativeInteger) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> Coef
--R D : (%,List(Symbol),List(NonNegativeInteger)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer),Coef) -> Coef
--R ?? : (%,Integer) -> % if Coef has FIELD
--R ?? : (%,NonNegativeInteger) -> %
--R acos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acoth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R acsch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R approximate : (%,Fraction(Integer)) -> Coef if Coef has **: (Coef,Fraction(Integer)) -> Coef
--R asec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R asinh : % -> % if Coef has ALGEBRA(FRAC(INT))

```

```

--R associates? : (%,%) -> Boolean if Coef has INTDOM
--R atan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R atanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
--R coefficient : (%, Fraction(Integer)) -> Coef
--R coerce : % -> % if Coef has INTDOM
--R coerce : Fraction(Integer) -> % if Coef has ALGEBRA(FRAC(INT))
--R coerce : Coef -> % if Coef has COMRING
--R cos : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cosh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R cot : % -> % if Coef has ALGEBRA(FRAC(INT))
--R coth : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csc : % -> % if Coef has ALGEBRA(FRAC(INT))
--R csch : % -> % if Coef has ALGEBRA(FRAC(INT))
--R differentiate : % -> % if Coef has *: (Fraction(Integer), Coef) -> Coef
--R differentiate : (%, NonNegativeInteger) -> % if Coef has *: (Fraction(Integer), Coef) -> Coef
--R differentiate : (%, Symbol) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer), Coef) -> %
--R differentiate : (%, List(Symbol)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer), Coef) -> %
--R differentiate : (%, Symbol, NonNegativeInteger) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer), Coef) -> %
--R differentiate : (%, List(Symbol), List(NonNegativeInteger)) -> % if Coef has PDRING(SYMBOL) and Coef has *: (Fraction(Integer), Coef) -> %
--R divide : (%,%) -> Record(quotient: %, remainder: %) if Coef has FIELD
--R ?? : (%,%) -> % if Fraction(Integer) has SGROUP
--R ?? : (%, Fraction(Integer)) -> Coef
--R euclideanSize : % -> NonNegativeInteger if Coef has FIELD
--R eval : (%, Coef) -> Stream(Coef) if Coef has **: (Coef, Fraction(Integer)) -> Coef
--R exp : % -> % if Coef has ALGEBRA(FRAC(INT))
--R expressIdealMember : (List(%), %) -> Union(List(%), "failed") if Coef has FIELD
--R exquo : (%,%) -> Union(%, "failed") if Coef has INTDOM
--R extend : (%, Fraction(Integer)) -> %
--R extendedEuclidean : (%,%) -> Record(coef1: %, coef2: %, generator: %) if Coef has FIELD
--R extendedEuclidean : (%,%,%) -> Union(Record(coef1: %, coef2: %), "failed") if Coef has FIELD
--R factor : % -> Factored(%) if Coef has FIELD
--R gcd : (%,%) -> % if Coef has FIELD
--R gcd : List(%) -> % if Coef has FIELD
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R integrate : (%, Symbol) -> % if Coef has ACFS(INT) and Coef has PRIMCAT and Coef has TRANFUN and Coef has INTDOM
--R integrate : % -> % if Coef has ALGEBRA(FRAC(INT))
--R inv : % -> % if Coef has FIELD
--R laurentIfCan : % -> Union(ULS, "failed")
--R lcm : (%,%) -> % if Coef has FIELD
--R lcm : List(%) -> % if Coef has FIELD
--R log : % -> % if Coef has ALGEBRA(FRAC(INT))
--R monomial : (%, List(SingletonAsOrderedSet), List(Fraction(Integer))) -> %
--R monomial : (%, SingletonAsOrderedSet, Fraction(Integer)) -> %
--R monomial : (Coef, Fraction(Integer)) -> %
--R multiEuclidean : (List(%), %) -> Union(List(%), "failed") if Coef has FIELD
--R multiplyExponents : (%, Fraction(Integer)) -> %
--R multiplyExponents : (%, PositiveInteger) -> %
--R nthRoot : (%, Integer) -> % if Coef has ALGEBRA(FRAC(INT))

```



```

--R order : (% , Fraction(Integer)) -> Fraction(Integer)
--R pi : () -> % if Coef has ALGEBRA(FRAC(INT))
--R prime? : % -> Boolean if Coef has FIELD
--R principalIdeal : List(%) -> Record(coef: List(%), generator: %) if Coef has FIELD
--R puiseux : (Fraction(Integer), ULS) -> %
--R ?quo? : (% , %) -> % if Coef has FIELD
--R rationalPower : % -> Fraction(Integer)
--R ?rem? : (% , %) -> % if Coef has FIELD
--R retractIfCan : % -> Union(ULS, "failed")
--R sec : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sech : % -> % if Coef has ALGEBRA(FRAC(INT))
--R series : (NonNegativeInteger, Stream(Record(k: Fraction(Integer), c: Coef))) -> %
--R sin : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sinh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R sizeLess? : (% , %) -> Boolean if Coef has FIELD
--R sqrt : % -> % if Coef has ALGEBRA(FRAC(INT))
--R squareFree : % -> Factored(%) if Coef has FIELD
--R squareFreePart : % -> % if Coef has FIELD
--R subtractIfCan : (% , %) -> Union(%, "failed")
--R tan : % -> % if Coef has ALGEBRA(FRAC(INT))
--R tanh : % -> % if Coef has ALGEBRA(FRAC(INT))
--R terms : % -> Stream(Record(k: Fraction(Integer), c: Coef))
--R truncate : (% , Fraction(Integer), Fraction(Integer)) -> %
--R truncate : (% , Fraction(Integer)) -> %
--R unit? : % -> Boolean if Coef has INTDOM
--R unitCanonical : % -> % if Coef has INTDOM
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %) if Coef has INTDOM
--R variables : % -> List(SingletonAsOrderedSet)
--R
--E 1

)spool
)lisp (bye)

```

— UnivariatePuisseuxSeriesConstructorCategory.help —

=====

UnivariatePuisseuxSeriesConstructorCategory examples

=====

This is a category of univariate Puiseux series constructed from univariate Laurent series. A Puiseux series is represented by a pair $[r, f(x)]$, where r is a positive rational number and $f(x)$ is a Laurent series. This pair represents the Puiseux series $f(x^r)$.

See Also:

o)show UnivariatePuisseuxSeriesConstructorCategory

See:

⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

⇐ “UnivariatePuisseuxSeriesCategory” (UPXSCAT) [17](#) on page [1511](#)

Exports:

| | | | |
|----------------|-------------------|--------------------|--------------------|
| 0 | 1 | acos | acosh |
| acot | acoth | acsc | acsch |
| approximate | asec | asech | asin |
| asinh | associates? | atan | atanh |
| center | characteristic | charthRoot | coefficient |
| coerce | complete | cos | cosh |
| cot | coth | csc | csch |
| D | degree | differentiate | divide |
| euclideanSize | eval | exp | expressIdealMember |
| exquo | extend | extendedEuclidean | factor |
| gcd | gcdPolynomial | hash | integrate |
| inv | latex | laurent | laurentIfCan |
| laurentRep | lcm | leadingCoefficient | leadingMonomial |
| log | map | monomial | monomial? |
| multiEuclidean | multiplyExponents | nthRoot | one? |
| order | pi | pole? | prime? |
| principalIdeal | puisseux | rationalPower | recip |
| reductum | retract | retractIfCan | sample |
| sec | sech | series | sin |
| sinh | sizeLess? | sqrt | squareFree |
| squareFreePart | subtractIfCan | tan | tanh |
| terms | truncate | unit? | unitCanonical |
| unitNormal | variable | variables | zero? |
| ?..? | ?*? | ?**? | ?+? |
| ?-? | -? | ?=? | ?^? |
| ?~=? | ?/? | ?quo? | ?rem? |

Attributes Exported:

- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .
- if $\#1$ has Field then canonicalsClosed where

- **canonicalsClosed** is true if
`unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- if #1 has **Field** then **canonicalUnitNormal** where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- if #1 has **IntegralDomain** then **noZeroDivisors** where **noZeroDivisors** is true if $x*y \neq 0$ implies both x and y are non-zero.
- if #1 has **CommutativeRing** then `commutative("**")` where **commutative("**")** is true if it has an operation $"*": (D, D) \rightarrow D$ which is commutative.

These are directly exported but not implemented:

```
coerce : ULS -> %
degree : % -> Fraction Integer
laurent : % -> ULS
laurentIfCan : % -> Union(ULS,"failed")
laurentRep : % -> ULS
puiseux : (Fraction Integer,ULS) -> %
rationalPower : % -> Fraction Integer
```

These are implemented by this category:

```
retract : % -> ULS
retractIfCan : % -> Union(ULS,"failed")
zero? : % -> Boolean
```

These exports come from (p1511) `UnivariatePuisseuxSeriesCategory(Coef:Ring)`:

```
0 : () -> %
1 : () -> %
approximate : (% , Fraction Integer) -> Coef
  if Coef has **: (Coef, Fraction Integer) -> Coef
  and Coef has coerce: Symbol -> Coef
associates? : (% , %) -> Boolean if Coef has INTDOM
acos : % -> % if Coef has ALGEBRA FRAC INT
acosh : % -> % if Coef has ALGEBRA FRAC INT
acot : % -> % if Coef has ALGEBRA FRAC INT
acoth : % -> % if Coef has ALGEBRA FRAC INT
acsc : % -> % if Coef has ALGEBRA FRAC INT
acsch : % -> % if Coef has ALGEBRA FRAC INT
asec : % -> % if Coef has ALGEBRA FRAC INT
asech : % -> % if Coef has ALGEBRA FRAC INT
asin : % -> % if Coef has ALGEBRA FRAC INT
asinh : % -> % if Coef has ALGEBRA FRAC INT
atan : % -> % if Coef has ALGEBRA FRAC INT
atanh : % -> % if Coef has ALGEBRA FRAC INT
```

```

center : % -> Coef
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(%, "failed") if Coef has CHARNZ
coefficient : (%, Fraction Integer) -> Coef
coerce : % -> % if Coef has INTDOM
coerce : Fraction Integer -> % if Coef has ALGEBRA FRAC INT
coerce : Coef -> % if Coef has COMRING
coerce : Integer -> %
coerce : % -> OutputForm
complete : % -> %
cos : % -> % if Coef has ALGEBRA FRAC INT
cosh : % -> % if Coef has ALGEBRA FRAC INT
cot : % -> % if Coef has ALGEBRA FRAC INT
coth : % -> % if Coef has ALGEBRA FRAC INT
csc : % -> % if Coef has ALGEBRA FRAC INT
csch : % -> % if Coef has ALGEBRA FRAC INT
D : % -> % if Coef has *: (Fraction Integer, Coef) -> Coef
D : (%, NonNegativeInteger) -> %
  if Coef has *: (Fraction Integer, Coef) -> Coef
D : (%, Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer, Coef) -> Coef
D : (%, List Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer, Coef) -> Coef
D : (%, Symbol, NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer, Coef) -> Coef
D : (%, List Symbol, List NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : (%, Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : (%, List Symbol) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : (%, Symbol, NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : (%, List Symbol, List NonNegativeInteger) -> %
  if Coef has PDRING SYMBOL
  and Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : % -> % if Coef has *: (Fraction Integer, Coef) -> Coef
differentiate : (%, NonNegativeInteger) -> %
  if Coef has *: (Fraction Integer, Coef) -> Coef
divide : (%, %) -> Record(quotient: %, remainder: %) if Coef has FIELD
euclideanSize : % -> NonNegativeInteger if Coef has FIELD
eval : (%, Coef) -> Stream Coef
  if Coef has **: (Coef, Fraction Integer) -> Coef

```

```

exp : % -> % if Coef has ALGEBRA FRAC INT
expressIdealMember : (List %,%) -> Union(List %,"failed")
  if Coef has FIELD
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
  if Coef has FIELD
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed")
  if Coef has FIELD
exquo : (%,%) -> Union(%,"failed") if Coef has INTDOM
extend : (%,Fraction Integer) -> %
factor : % -> Factored % if Coef has FIELD
gcd : (%,%) -> % if Coef has FIELD
gcd : List % -> % if Coef has FIELD
gcdPolynomial :
  (SparseUnivariatePolynomial %,
   SparseUnivariatePolynomial %) ->
   SparseUnivariatePolynomial %
  if Coef has FIELD
hash : % -> SingleInteger
integrate : (%,Symbol) -> %
  if Coef has ACFS INT
  and Coef has PRIMCAT
  and Coef has TRANFUN
  and Coef has ALGEBRA FRAC INT
  or Coef has variables: Coef -> List Symbol
  and Coef has integrate: (Coef,Symbol) -> Coef
  and Coef has ALGEBRA FRAC INT
integrate : % -> % if Coef has ALGEBRA FRAC INT
inv : % -> % if Coef has FIELD
latex : % -> String
lcm : (%,%) -> % if Coef has FIELD
lcm : List % -> % if Coef has FIELD
leadingCoefficient : % -> Coef
leadingMonomial : % -> %
log : % -> % if Coef has ALGEBRA FRAC INT
map : ((Coef -> Coef),%) -> %
monomial : (%,List SingletonAsOrderedSet,List Fraction Integer) -> %
monomial : (%,SingletonAsOrderedSet,Fraction Integer) -> %
monomial : (Coef,Fraction Integer) -> %
monomial? : % -> Boolean
multiEuclidean : (List %,%) -> Union(List %,"failed") if Coef has FIELD
multiplyExponents : (%,PositiveInteger) -> %
multiplyExponents : (%,Fraction Integer) -> %
nthRoot : (%,Integer) -> % if Coef has ALGEBRA FRAC INT
one? : % -> Boolean
order : (%,Fraction Integer) -> Fraction Integer
order : % -> Fraction Integer
pi : () -> % if Coef has ALGEBRA FRAC INT
pole? : % -> Boolean
prime? : % -> Boolean if Coef has FIELD
principalIdeal : List % -> Record(coef: List %,generator: %)

```

```

    if Coef has FIELD
  recip : % -> Union(%, "failed")
  reductum : % -> %
  sample : () -> %
  sec : % -> % if Coef has ALGEBRA FRAC INT
  sech : % -> % if Coef has ALGEBRA FRAC INT
  series :
    (NonNegativeInteger, Stream Record(k: Fraction Integer, c: Coef)) -> %
  sin : % -> % if Coef has ALGEBRA FRAC INT
  sinh : % -> % if Coef has ALGEBRA FRAC INT
  sizeLess? : (%, %) -> Boolean if Coef has FIELD
  sqrt : % -> % if Coef has ALGEBRA FRAC INT
  squareFree : % -> Factored % if Coef has FIELD
  squareFreePart : % -> % if Coef has FIELD
  subtractIfCan : (%, %) -> Union(%, "failed")
  tan : % -> % if Coef has ALGEBRA FRAC INT
  tanh : % -> % if Coef has ALGEBRA FRAC INT
  terms : % -> Stream Record(k: Fraction Integer, c: Coef)
  truncate : (%, Fraction Integer, Fraction Integer) -> %
  truncate : (%, Fraction Integer) -> %
  unit? : % -> Boolean if Coef has INTDOM
  unitCanonical : % -> % if Coef has INTDOM
  unitNormal : % -> Record(unit: %, canonical: %, associate: %)
    if Coef has INTDOM
  variable : % -> Symbol
  variables : % -> List SingletonAsOrderedSet
  ??? : (%, Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
  ??? : (%, Integer) -> % if Coef has FIELD
  ?? : (%, Integer) -> % if Coef has FIELD
  ?/? : (%, %) -> % if Coef has FIELD
  ??? : (%, %) -> % if Coef has ALGEBRA FRAC INT
  ??? : (%, NonNegativeInteger) -> %
  ?? : (%, NonNegativeInteger) -> %
  ?+? : (%, %) -> %
  ?? : (%, %) -> Boolean
  ?? : (%, %) -> Boolean
  ?? : (NonNegativeInteger, %) -> %
  ?? : (PositiveInteger, %) -> %
  ?? : (%, %) -> %
  ?? : (%, %) -> %
  ??? : (%, PositiveInteger) -> %
  ?? : (%, PositiveInteger) -> %
  ?? : (Integer, %) -> %
  ?? : (Coef, %) -> %
  ?? : (%, Coef) -> %
  ?? : (%, Fraction Integer) -> % if Coef has ALGEBRA FRAC INT
  ?? : (Fraction Integer, %) -> % if Coef has ALGEBRA FRAC INT
  ?/? : (%, Coef) -> % if Coef has FIELD
  -? : % -> %
  ?.? : (%, %) -> % if Fraction Integer has SGROUP

```

```

?.? : (% , Fraction Integer) -> Coef
?quo? : (% , %) -> % if Coef has FIELD
?rem? : (% , %) -> % if Coef has FIELD

```

— category UPXSCCA UnivariatePuisseuxSeriesConstructorCategory

```

)abbrev category UPXSCCA UnivariatePuisseuxSeriesConstructorCategory
++ Author: Clifton J. Williamson
++ Date Created: 6 February 1990
++ Date Last Updated: 22 March 1990
++ Description:
++ This is a category of univariate Puiseux series constructed
++ from univariate Laurent series. A Puiseux series is represented
++ by a pair \spad{[r,f(x)]}, where r is a positive rational number and
++ \spad{f(x)} is a Laurent series. This pair represents the Puiseux
++ series \spad{f(x^r)}.

UnivariatePuisseuxSeriesConstructorCategory(Coef, ULS):_
Category == Definition where
  Coef : Ring
  ULS : UnivariateLaurentSeriesCategory Coef
  I ==> Integer
  RN ==> Fraction Integer

Definition ==> Join(UnivariatePuisseuxSeriesCategory(Coef),_
  RetractableTo ULS) with
  puiseux: (RN, ULS) -> %
    ++ \spad{puiseux(r,f(x))} returns \spad{f(x^r)}.
  rationalPower: % -> RN
    ++ \spad{rationalPower(f(x))} returns r where the Puiseux series
    ++ \spad{f(x) = g(x^r)}.
  laurentRep : % -> ULS
    ++ \spad{laurentRep(f(x))} returns \spad{g(x)} where the Puiseux series
    ++ \spad{f(x) = g(x^r)} is represented by \spad{[r,g(x)]}.
  degree: % -> RN
    ++ \spad{degree(f(x))} returns the degree of the leading term of the
    ++ Puiseux series \spad{f(x)}, which may have zero as a coefficient.
  coerce: ULS -> %
    ++ \spad{coerce(f(x))} converts the Laurent series \spad{f(x)} to a
    ++ Puiseux series.
  laurent: % -> ULS
    ++ \spad{laurent(f(x))} converts the Puiseux series \spad{f(x)} to a
    ++ Laurent series if possible. Error: if this is not possible.
  laurentIfCan: % -> Union(ULS, "failed")
    ++ \spad{laurentIfCan(f(x))} converts the Puiseux series \spad{f(x)}
    ++ to a Laurent series if possible.
    ++ If this is not possible, "failed" is returned.

```

add

```
zero? x == zero? laurentRep x
```

```
retract(x:%):ULS == laurent x
```

```
retractIfCan(x:%):Union(ULS,"failed") == laurentIfCan x
```

— UPXSCCA.dotabb —

```
"UPXSCCA"
```

```
  [color=lightblue,href="bookvol10.2.pdf#nameddest=UPXSCCA"];
```

```
"UPXSCCA" -> "RETRACT"
```

```
"UPXSCCA" -> "UPXSCAT"
```

— UPXSCCA.dotfull —

```
"UnivariatePuisseuxSeriesConstructorCategory(a:Ring,b:UnivariateLaurentSeriesCategory(a))"
```

```
  [color=lightblue,href="bookvol10.2.pdf#nameddest=UPXSCCA"];
```

```
"UnivariatePuisseuxSeriesConstructorCategory(a:Ring,b:UnivariateLaurentSeriesCategory(a))"
```

```
  -> "RetractableTo(UnivariatePuisseuxSeriesCategory(Ring))"
```

```
"UnivariatePuisseuxSeriesConstructorCategory(a:Ring,b:UnivariateLaurentSeriesCategory(a))"
```

```
  -> "UnivariatePuisseuxSeriesCategory(a:Ring)"
```

— UPXSCCA.dotpic —

```
digraph pic {
```

```
  fontsize=10;
```

```
  bgcolor="#ECEA81";
```

```
  node [shape=box, color=white, style=filled];
```

```
"UnivariatePuisseuxSeriesConstructorCategory(a:Ring,b:UnivariateLaurentSeriesCategory(a))"
```

```
  [color=lightblue,href="bookvol10.2.pdf#nameddest=UPXSCCA"];
```

```
"UnivariatePuisseuxSeriesConstructorCategory(a:Ring,b:UnivariateLaurentSeriesCategory(a))"
```

```
  -> "RETRACT..."
```

```
"UnivariatePuisseuxSeriesConstructorCategory(a:Ring,b:UnivariateLaurentSeriesCategory(a))"
```

```
  -> "UnivariatePuisseuxSeriesCategory(a:Ring)"
```

```
"UnivariatePuisseuxSeriesCategory(a:Ring)" [color=lightblue];
```



```

"UnivariatePuisseuxSeriesCategory(a:Ring)" ->
  "UnivariatePowerSeriesCategory(a:Ring,Fraction(Integer))"
"UnivariatePuisseuxSeriesCategory(a:Ring)" ->
  "TRANFUN..."
"UnivariatePuisseuxSeriesCategory(a:Ring)" ->
  "FIELD..."
"UnivariatePuisseuxSeriesCategory(a:Ring)" ->
  "RADCAT..."

"UnivariatePowerSeriesCategory(a:Ring,Fraction(Integer))" [color=seagreen];
"UnivariatePowerSeriesCategory(a:Ring,Fraction(Integer))" ->
  "UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"

"UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)"
  [color=lightblue];
"UnivariatePowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid)" ->
  "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"

"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
  [color=seagreen];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:SingletonAsOrderedSet)"
  -> "PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"

"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)"
  [color=lightblue];
"PowerSeriesCategory(a:Ring,b:OrderedAbelianMonoid,c:OrderedSet)" ->
  "AMR..."

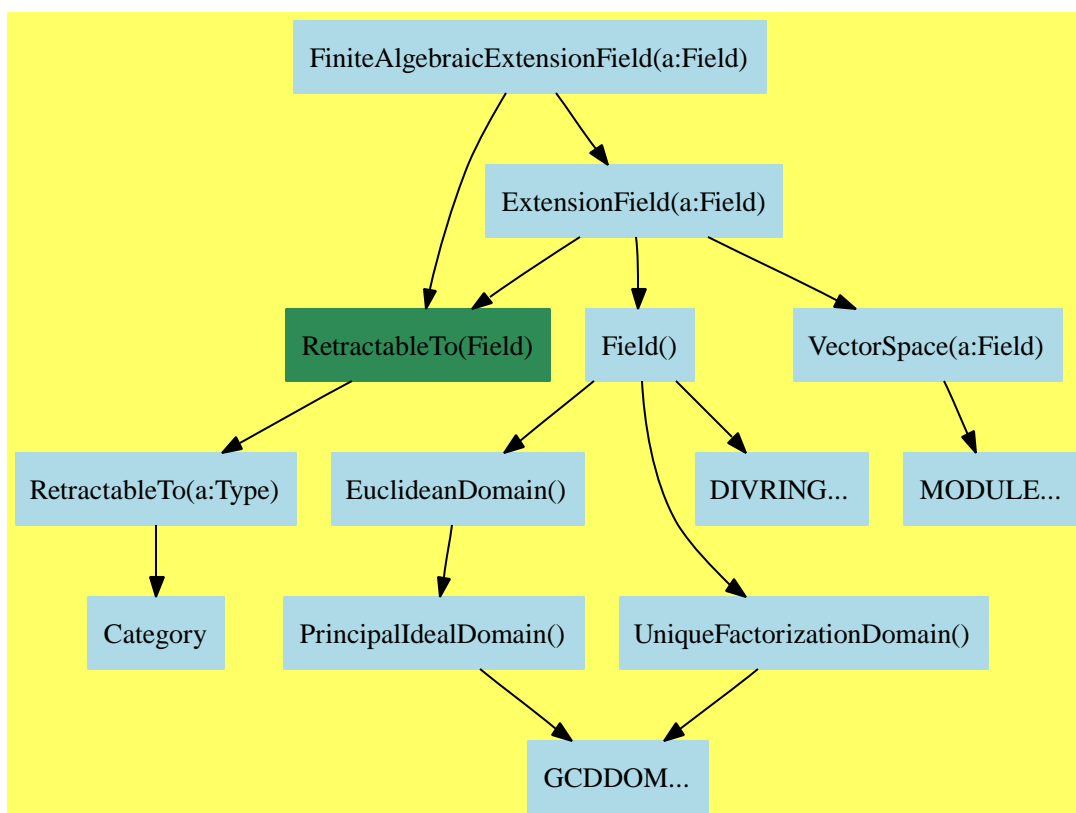
"RETRACT..." [color=lightblue];
"TRANFUN..." [color=lightblue];
"FIELD..." [color=lightblue];
"RADCAT..." [color=lightblue];
"AMR..." [color=lightblue];
}

```

Chapter 19

Category Layer 18

FiniteAlgebraicExtensionField (FAXF)



— FiniteAlgebraicExtensionField.input —

```

)set break resume
)sys rm -f FiniteAlgebraicExtensionField.output
)spool FiniteAlgebraicExtensionField.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FiniteAlgebraicExtensionField
--R FiniteAlgebraicExtensionField(F: Field) is a category constructor
--R Abbreviation for FiniteAlgebraicExtensionField is FAXF
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FAXF
--R
--R----- Operations -----
--R ?? : (F,%) -> %           ?? : (%,F) -> %
--R ?? : (Fraction(Integer),%) -> %   ?? : (%,Fraction(Integer)) -> %
--R ?? : (%,%) -> %           ?? : (Integer,%) -> %
--R ?? : (PositiveInteger,%) -> %   ??? : (%,Integer) -> %
--R ??? : (%,PositiveInteger) -> %   ?+? : (%,%) -> %
--R ?-? : (%,%) -> %           -? : % -> %
--R ?/? : (%,F) -> %           ?/? : (%,%) -> %
--R ?=? : (%,%) -> Boolean       D : % -> % if F has FINITE
--R 1 : () -> %                 0 : () -> %
--R ?? : (%,Integer) -> %       ?~? : (%,PositiveInteger) -> %
--R algebraic? : % -> Boolean    associates? : (%,%) -> Boolean
--R basis : () -> Vector(%)      coerce : F -> %
--R coerce : Fraction(Integer) -> %   coerce : % -> %
--R coerce : Integer -> %         coerce : % -> OutputForm
--R coordinates : % -> Vector(F)    degree : % -> PositiveInteger
--R dimension : () -> CardinalNumber factor : % -> Factored(%)
--R gcd : List(%) -> %           gcd : (%,%) -> %
--R hash : % -> SingleInteger      inGroundField? : % -> Boolean
--R inv : % -> %                 latex : % -> String
--R lcm : List(%) -> %           lcm : (%,%) -> %
--R norm : % -> F                one? : % -> Boolean
--R prime? : % -> Boolean         ?quo? : (%,%) -> %
--R recip : % -> Union(%, "failed") ?rem? : (%,%) -> %
--R represents : Vector(F) -> %    retract : % -> F
--R sample : () -> %             sizeLess? : (%,%) -> Boolean
--R squareFree : % -> Factored(%)   squareFreePart : % -> %
--R trace : % -> F                transcendent? : % -> Boolean
--R unit? : % -> Boolean           unitCanonical : % -> %
--R zero? : % -> Boolean          ?~=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R D : (%,NonNegativeInteger) -> % if F has FINITE
--R Frobenius : (%,NonNegativeInteger) -> % if F has FINITE

```

```

--R Frobenius : % -> % if F has FINITE
--R ?? : (% , NonNegativeInteger) -> %
--R basis : PositiveInteger -> Vector(%)
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if F has CHARNZ or F has FINITE
--R charthRoot : % -> % if F has FINITE
--R conditionP : Matrix(%) -> Union(Vector(%), "failed") if F has FINITE
--R coordinates : Vector(%) -> Matrix(F)
--R createNormalElement : () -> % if F has FINITE
--R createPrimitiveElement : () -> % if F has FINITE
--R definingPolynomial : () -> SparseUnivariatePolynomial(F)
--R degree : % -> OnePointCompletion(PositiveInteger)
--R differentiate : (% , NonNegativeInteger) -> % if F has FINITE
--R differentiate : % -> % if F has FINITE
--R discreteLog : (% , %) -> Union(NonNegativeInteger, "failed") if F has CHARNZ or F has FINITE
--R discreteLog : % -> NonNegativeInteger if F has FINITE
--R divide : (% , %) -> Record(quotient: %, remainder: %)
--R enumerate : () -> List(%) if F has FINITE
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%) , %) -> Union(List(%), "failed")
--R exquo : (% , %) -> Union(%, "failed")
--R extendedEuclidean : (% , %, %) -> Union(Record(coef1: %, coef2: %), "failed")
--R extendedEuclidean : (% , %) -> Record(coef1: %, coef2: %, generator: %)
--R extensionDegree : () -> PositiveInteger
--R extensionDegree : () -> OnePointCompletion(PositiveInteger)
--R factorsOfCyclicGroupSize : () -> List(Record(factor: Integer, exponent: Integer)) if F has FINITE
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(F)
--R generator : () -> % if F has FINITE
--R index : PositiveInteger -> % if F has FINITE
--R init : () -> % if F has FINITE
--R linearAssociatedExp : (% , SparseUnivariatePolynomial(F)) -> % if F has FINITE
--R linearAssociatedLog : (% , %) -> Union(SparseUnivariatePolynomial(F), "failed") if F has FINITE
--R linearAssociatedLog : % -> SparseUnivariatePolynomial(F) if F has FINITE
--R linearAssociatedOrder : % -> SparseUnivariatePolynomial(F) if F has FINITE
--R lookup : % -> PositiveInteger if F has FINITE
--R minimalPolynomial : (% , PositiveInteger) -> SparseUnivariatePolynomial(%) if F has FINITE
--R minimalPolynomial : % -> SparseUnivariatePolynomial(F)
--R multiEuclidean : (List(%) , %) -> Union(List(%), "failed")
--R nextItem : % -> Union(%, "failed") if F has FINITE
--R norm : (% , PositiveInteger) -> % if F has FINITE
--R normal? : % -> Boolean if F has FINITE
--R normalElement : () -> % if F has FINITE
--R order : % -> OnePointCompletion(PositiveInteger) if F has CHARNZ or F has FINITE
--R order : % -> PositiveInteger if F has FINITE
--R primeFrobenius : % -> % if F has CHARNZ or F has FINITE
--R primeFrobenius : (% , NonNegativeInteger) -> % if F has CHARNZ or F has FINITE
--R primitive? : % -> Boolean if F has FINITE
--R primitiveElement : () -> % if F has FINITE
--R principalIdeal : List(%) -> Record(coef: List(%), generator: %)
--R random : () -> % if F has FINITE

```

```

--R representationType : () -> Union("prime",polynomial,normal,cyclic) if F has FINITE
--R retractIfCan : % -> Union(F,"failed")
--R size : () -> NonNegativeInteger if F has FINITE
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R tableForDiscreteLogarithm : Integer -> Table(PositiveInteger,NonNegativeInteger) if F has FI
--R trace : (%,PositiveInteger) -> % if F has FINITE
--R transcendenceDegree : () -> NonNegativeInteger
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— FiniteAlgebraicExtensionField.help —

```

=====
FiniteAlgebraicExtensionField examples
=====

```

FiniteAlgebraicExtensionField F is the category of fields
which are finite algebraic extensions of the field F.

If F is finite then any finite algebraic extension of F is finite, too.
Let K be a finite algebraic extension of the finite field F. The
exponentiation of elements of K defines a Z-module structure on the
multiplicative group of K.

The additive group of K becomes a module over the ring of polynomials
over F via the operation

```

linearAssociatedExp(a:K,f:SparseUnivariatePolynomial F)

```

which is linear over F, i.e. for elements a from K, c,d from F and
f,g univariate polynomials over F we have `linearAssociatedExp}(a,cf+dg)`
equals c times `linearAssociatedExp}(a,f)` plus d times
`linearAssociatedExp}(a,g)`.

Therefore `linearAssociatedExp` is defined completely by its action on
monomials from $F[X]$: `linearAssociatedExp(a,monomial(1,k)\$SUP(F))` is
defined to be `Frobenius(a,k)` which is a^{q^k} where $q=\text{size}()\$F$.

The operations `order` and `discreteLog` associated with the multiplicative
exponentiation have additive analogues associated to the operation
`linearAssociatedExp`. These are the functions `linearAssociatedOrder`
and `linearAssociatedLog`, respectively.

See Also:

```

o )show FiniteAlgebraicExtensionField

```

See:

⇐ “ExtensionField” (XF) [18](#) on page [1562](#)
 ⇐ “RetractableTo” (RETRACT) [2](#) on page [95](#)

Exports:

| | | |
|---------------------------|--------------------------|------------------------|
| 0 | 1 | algebraic? |
| associates? | basis | characteristic |
| charthRoot | coerce | conditionP |
| coordinates | createNormalElement | createPrimitiveElement |
| D | definingPolynomial | degree |
| differentiate | dimension | discreteLog |
| divide | euclideanSize | expressIdealMember |
| exquo | extendedEuclidean | extensionDegree |
| factor | factorsOfCyclicGroupSize | Frobenius |
| gcd | gcdPolynomial | generator |
| hash | index | inGroundField? |
| init | inv | latex |
| lcm | linearAssociatedExp | linearAssociatedLog |
| linearAssociatedOrder | lookup | minimalPolynomial |
| multiEuclidean | nextItem | norm |
| normal? | normalElement | one? |
| order | prime? | primeFrobenius |
| primitive? | primitiveElement | principalIdeal |
| random | recip | representationType |
| represents | retract | retractIfCan |
| sample | size | sizeLess? |
| squareFree | squareFreePart | subtractIfCan |
| tableForDiscreteLogarithm | trace | transcendenceDegree |
| transcendent? | unit? | unitCanonical |
| unitNormal | zero? | ?*? |
| ?**? | ?+? | ?-? |
| -? | ?/? | ?=? |
| ?^? | ?quo? | ?rem? |
| ?~=? | | |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **canonicalsClosed** is true if

`unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b).`

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**("*") is true if it has an operation " $*$ " : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has `unitsKnown` means that the operation `recip` can only return "failed" if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These are directly exported but not implemented:

```
basis : () -> Vector %
basis : PositiveInteger -> Vector %
coordinates : % -> Vector F
definingPolynomial : () -> SparseUnivariatePolynomial F
generator : () -> % if F has FINITE
minimalPolynomial : (% , PositiveInteger) ->
    SparseUnivariatePolynomial %
    if F has FINITE
normalElement : () -> % if F has FINITE
```

These are implemented by this category:

```
algebraic? : % -> Boolean
charthRoot : % -> Union(% , "failed")
    if F has CHARNZ or F has FINITE
coordinates : Vector % -> Matrix F
createNormalElement : () -> % if F has FINITE
degree : % -> PositiveInteger
dimension : () -> CardinalNumber
extensionDegree : () -> PositiveInteger
linearAssociatedExp : (% , SparseUnivariatePolynomial F) -> %
    if F has FINITE
linearAssociatedLog : (% , %) ->
    Union(SparseUnivariatePolynomial F , "failed")
    if F has FINITE
linearAssociatedLog : % -> SparseUnivariatePolynomial F
    if F has FINITE
linearAssociatedOrder : % -> SparseUnivariatePolynomial F
    if F has FINITE
minimalPolynomial : % -> SparseUnivariatePolynomial F
norm : % -> F
norm : (% , PositiveInteger) -> % if F has FINITE
normal? : % -> Boolean if F has FINITE
represents : Vector F -> %
```

```

size : () -> NonNegativeInteger if F has FINITE
trace : % -> F
trace : (%,PositiveInteger) -> % if F has FINITE
transcendenceDegree : () -> NonNegativeInteger
transcendent? : % -> Boolean

```

These exports come from (p1562) `ExtensionField(F:Field)`:

```

0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : F -> %
coerce : % -> %
coerce : Integer -> %
coerce : % -> OutputForm
coerce : Fraction Integer -> %
discreteLog : (%,%) ->
  Union(NonNegativeInteger,"failed")
  if F has CHARNZ or F has FINITE
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %,"failed")
exquo : (%,%) -> Union(%,"failed")
extendedEuclidean : (%,%,%) ->
  Union(Record(coef1: %,coef2: %),"failed")
extendedEuclidean : (%,%) ->
  Record(coef1: %,coef2: %,generator: %)
factor : % -> Factored %
Frobenius : (%,NonNegativeInteger) -> % if F has FINITE
Frobenius : % -> % if F has FINITE
gcd : List % -> %
gcd : (%,%) -> %
gcdPolynomial : (SparseUnivariatePolynomial %,
  SparseUnivariatePolynomial %) ->
  SparseUnivariatePolynomial %
hash : % -> SingleInteger
inGroundField? : % -> Boolean
inv : % -> %
latex : % -> String
lcm : List % -> %
lcm : (%,%) -> %
multiEuclidean : (List %,%) -> Union(List %,"failed")
one? : % -> Boolean
order : % -> OnePointCompletion PositiveInteger
  if F has CHARNZ or F has FINITE
prime? : % -> Boolean
primeFrobenius : % -> %
  if F has CHARNZ or F has FINITE
primeFrobenius : (%,NonNegativeInteger) -> %

```



```

    if F has CHARNZ or F has FINITE
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%, "failed")
retract : % -> F
retractIfCan : % -> Union(F, "failed")
sample : () -> %
squareFree : % -> Factored %
squareFreePart : % -> %
sizeLess? : (%,%) -> Boolean
subtractIfCan : (%,%) -> Union(%, "failed")
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
zero? : % -> Boolean
?/? : (%,%) -> %
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?*? : (Fraction Integer,%) -> %
?*? : (%,Fraction Integer) -> %
?*? : (F,%) -> %
?*? : (%,F) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%,NonNegativeInteger) -> %
***? : (%,PositiveInteger) -> %
***? : (%,Integer) -> %
?^? : (%,Integer) -> %
?^? : (%,PositiveInteger) -> %
?^? : (%,NonNegativeInteger) -> %
?quo? : (%,%) -> %
?rem? : (%,%) -> %
?/? : (%,F) -> %

```

These exports come from (p95) `RetractableTo(F:Field)`:

These exports come from (p1570) `FiniteFieldCategory()`:

```

charthRoot : % -> % if F has FINITE
conditionP : Matrix % -> Union(Vector %, "failed")
    if F has FINITE
createPrimitiveElement : () -> % if F has FINITE
D : % -> % if F has FINITE
D : (%,NonNegativeInteger) -> % if F has FINITE

```

```

differentiate : % -> % if F has FINITE
differentiate : (% , NonNegativeInteger) -> %
    if F has FINITE
discreteLog : % -> NonNegativeInteger if F has FINITE
factorsOfCyclicGroupSize : () ->
    List Record(factor: Integer, exponent: Integer)
    if F has FINITE
index : PositiveInteger -> % if F has FINITE
init : () -> % if F has FINITE
lookup : % -> PositiveInteger if F has FINITE
nextItem : % -> Union(%, "failed") if F has FINITE
order : % -> PositiveInteger if F has FINITE
primitive? : % -> Boolean if F has FINITE
primitiveElement : () -> % if F has FINITE
random : () -> % if F has FINITE
representationType : () ->
    Union("prime", polynomial, normal, cyclic)
    if F has FINITE
tableForDiscreteLogarithm : Integer ->
    Table(PositiveInteger, NonNegativeInteger)
    if F has FINITE

```

— category FAXF FiniteAlgebraicExtensionField —

```

)abbrev category FAXF FiniteAlgebraicExtensionField
++ Author: J. Grabmeier, A. Scheerhorn
++ Date Created: 11 March 1991
++ Date Last Updated: 31 March 1991
++ References:
++ R.Lidl, H.Niederreiter: Finite Field, Encycoldia of Mathematics and
++ Its Applications, Vol. 20, Cambridge Univ. Press, 1983,
++ ISBN 0 521 30240 4 J. Grabmeier, A. Scheerhorn: Finite Fields in AXIOM.
++ AXIOM Technical Report Series, ATR/5 NP2522.
++ Description:
++ FiniteAlgebraicExtensionField F is the category of fields
++ which are finite algebraic extensions of the field F.
++ If F is finite then any finite algebraic extension of F
++ is finite, too. Let K be a finite algebraic extension of the
++ finite field F. The exponentiation of elements of K
++ defines a Z-module structure on the multiplicative group of K.
++ The additive group of K becomes a module over the ring of
++ polynomials over F via the operation
++ \spadfun{linearAssociatedExp}(a:K,f: SparseUnivariatePolynomial F)
++ which is linear over F, that is, for elements a from K,
++ c,d from F and f,g univariate polynomials over F
++ we have \spadfun{linearAssociatedExp}(a,cf+dg) equals c times
++ \spadfun{linearAssociatedExp}(a,f) plus d times
++ \spadfun{linearAssociatedExp}(a,g).
++ Therefore \spadfun{linearAssociatedExp} is defined completely by

```

```

++ its action on monomials from F[X]:
++ \spadfun{linearAssociatedExp}(a,monomial(1,k)\$SUP(F)) is defined to be
++ \spadfun{Frobenius}(a,k) which is a**(q**k) where q=size()\$F.
++ The operations order and discreteLog associated with the multiplicative
++ exponentiation have additive analogues associated to the operation
++ \spadfun{linearAssociatedExp}. These are the functions
++ \spadfun{linearAssociatedOrder} and \spadfun{linearAssociatedLog},
++ respectively.

FiniteAlgebraicExtensionField(F : Field) : Category == _
  Join(ExtensionField F, RetractableTo F) with
  -- should be unified with algebras
  -- Join(ExtensionField F, FramedAlgebra F, RetractableTo F) with

  basis : () -> Vector $
    ++ basis() returns a fixed basis of \$ as \spad{F}-vectorspace.

  basis : PositiveInteger -> Vector $
    ++ basis(n) returns a fixed basis of a subfield of \$ as
    ++ \spad{F}-vectorspace.

  coordinates : $ -> Vector F
    ++ coordinates(a) returns the coordinates of \spad{a} with respect
    ++ to the fixed \spad{F}-vectorspace basis.

  coordinates : Vector $ -> Matrix F
    ++ coordinates([v1,...,vm]) returns the coordinates of the
    ++ vi's with to the fixed basis. The coordinates of vi are
    ++ contained in the ith row of the matrix returned by this
    ++ function.

  represents: Vector F -> $
    ++ represents([a1,...,an]) returns \spad{a1*v1 + ... + an*vn}, where
    ++ v1,...,vn are the elements of the fixed basis.

  minimalPolynomial: $ -> SparseUnivariatePolynomial F
    ++ minimalPolynomial(a) returns the minimal polynomial of an
    ++ element \spad{a} over the ground field F.

  definingPolynomial: () -> SparseUnivariatePolynomial F
    ++ definingPolynomial() returns the polynomial used to define
    ++ the field extension.

  extensionDegree : () -> PositiveInteger
    ++ extensionDegree() returns the degree of field extension.

  degree : $ -> PositiveInteger
    ++ degree(a) returns the degree of the minimal polynomial of an
    ++ element \spad{a} over the ground field F.

```

```

norm: $ -> F
++ norm(a) computes the norm of \spad{a} with respect to the
++ field considered as an algebra with 1 over the ground field F.

trace: $ -> F
++ trace(a) computes the trace of \spad{a} with respect to
++ the field considered as an algebra with 1 over the ground field F.

if F has Finite then

FiniteFieldCategory

minimalPolynomial: ($,PositiveInteger) -> SparseUnivariatePolynomial $
++ minimalPolynomial(x,n) computes the minimal polynomial of x over
++ the field of extension degree n over the ground field F.

norm: ($,PositiveInteger) -> $
++ norm(a,d) computes the norm of \spad{a} with respect to the field
++ of extension degree d over the ground field of size.
++ Error: if d does not divide the extension degree of \spad{a}.
++ Note that norm(a,d) = reduce(*,[a**(q**(d*i)) for i in 0..n/d])

trace: ($,PositiveInteger) -> $
++ trace(a,d) computes the trace of \spad{a} with respect to the
++ field of extension degree d over the ground field of size q.
++ Error: if d does not divide the extension degree of \spad{a}.
++ Note that
++ \spad{trace(a,d)=reduce(+,[a**(q**(d*i)) for i in 0..n/d])}.

createNormalElement: () -> $
++ createNormalElement() computes a normal element over the ground
++ field F, that is,
++ \spad{a**(q**i), 0 <= i < extensionDegree()} is an F-basis,
++ where \spad{q = size()\$F}.
++ Reference: Such an element exists Lidl/Niederreiter: Theorem 2.35.

normalElement: () -> $
++ normalElement() returns a element, normal over the ground field F,
++ thus \spad{a**(q**i), 0 <= i < extensionDegree()} is an F-basis,
++ where \spad{q = size()\$F}.
++ At the first call, the element is computed by
++ \spadfunFrom{createNormalElement}{FiniteAlgebraicExtensionField}
++ then cached in a global variable.
++ On subsequent calls, the element is retrieved by referencing the
++ global variable.

normal?: $ -> Boolean
++ normal?(a) tests whether the element \spad{a} is normal over the
++ ground field F, that is,
++ \spad{a**(q**i), 0 <= i <= extensionDegree()-1} is an F-basis,

```

```

++ where \spad{q = size()\$F}.
++ Implementation according to Lidl/Niederreiter: Theorem 2.39.

generator: () -> $
++ generator() returns a root of the defining polynomial.
++ This element generates the field as an algebra over the ground
++ field.

linearAssociatedExp: ($, SparseUnivariatePolynomial F) -> $
++ linearAssociatedExp(a,f) is linear over F, that is,
++ for elements a from \$, c,d form F and
++ f,g univariate polynomials over F we have
++ \spadfun{linearAssociatedExp}(a,cf+dg) equals c times
++ \spadfun{linearAssociatedExp}(a,f) plus d times
++ \spadfun{linearAssociatedExp}(a,g). Therefore
++ \spadfun{linearAssociatedExp} is defined completely by its
++ action on monomials from F[X]:
++ \spadfun{linearAssociatedExp}(a,monomial(1,k)\$SUP(F)) is
++ defined to be \spadfun{Frobenius}(a,k) which is a**(q**k),
++ where q=size()\$F.

linearAssociatedOrder: $ -> SparseUnivariatePolynomial F
++ linearAssociatedOrder(a) retruns the monic polynomial g of
++ least degree, such that \spadfun{linearAssociatedExp}(a,g) is 0.

linearAssociatedLog: $ -> SparseUnivariatePolynomial F
++ linearAssociatedLog(a) returns a polynomial g, such that
++ \spadfun{linearAssociatedExp}(normalElement(),g) equals a.

linearAssociatedLog: ($,$) -> _
Union(SparseUnivariatePolynomial F,"failed")
++ linearAssociatedLog(b,a) returns a polynomial g, such
++ that the \spadfun{linearAssociatedExp}(b,g) equals a.
++ If there is no such polynomial g, then
++ \spadfun{linearAssociatedLog} fails.

add
I ==> Integer
PI ==> PositiveInteger
NNI ==> NonNegativeInteger
SUP ==> SparseUnivariatePolynomial
DLP ==> DiscreteLogarithmPackage

represents(v) ==
a: $:=0
b:=basis()
for i in 1..extensionDegree()@PI repeat
a:=a+(v.i)*(b.i)
a

transcendenceDegree() == 0$NNI

```

```

dimension() == (#basis()) :: NonNegativeInteger :: CardinalNumber

coordinates(v:Vector $) ==
  m := new(#v, extensionDegree(), 0)$Matrix(F)
  for i in minIndex v .. maxIndex v for j in minRowIndex m .. repeat
    setRow_!(m, j, coordinates qelt(v, i))
  m

algebraic? a == true

transcendent? a == false

-- This definition is a duplicate and has been removed
-- extensionDegree():OnePointCompletion(PositiveInteger) ==
--   (#basis()) :: PositiveInteger :: OnePointCompletion(PositiveInteger)

extensionDegree() == (#basis()) :: PositiveInteger

-- These definitions are duplicates and have been removed
-- degree(a):OnePointCompletion(PositiveInteger) ==
--   degree(a)@PI :: OnePointCompletion(PositiveInteger)

-- degree a == degree(minimalPolynomial a)$SUP(F) :: PI

trace a ==
  b := basis()
  abs : F := 0
  for i in 1..#b repeat
    abs := abs + coordinates(a*b.i).i
  abs

norm a ==
  b := basis()
  m := new(#b,#b, 0)$Matrix(F)
  for i in 1..#b repeat
    setRow_!(m,i, coordinates(a*b.i))
  determinant(m)

if F has Finite then
  linearAssociatedExp(x,f) ==
    erg: := 0
    y:=x
    for i in 0..degree(f) repeat
      erg:=erg + coefficient(f,i) * y
      y:=Frobenius(y)
    erg

  linearAssociatedLog(b,x) ==
    x=0 => 0

```

```

l>List List F:=[entries coordinates b]
a:$:=b
extdeg:NNI:=extensionDegree()@PI
for i in 2..extdeg repeat
  a:=Frobenius(a)
  l:=concat(l,entries coordinates a)$(List List F)
l:=concat(l,entries coordinates x)$(List List F)
m1:=rowEchelon transpose matrix(l)$(Matrix F)
v:=zero(extdeg)$(Vector F)
rown:I:=1
for i in 1..extdeg repeat
  if qelt(m1,rown,i) = 1$F then
    v.i:=qelt(m1,rown,extdeg+1)
    rown:=rown+1
p:=+/[monomial(v.(i+1),i::NNI) for i in 0..(#v-1)]
p=0 =>
  messagePrint("linearAssociatedLog: second argument not in_
               group generated by first argument")$OutputForm
  "failed"
p

linearAssociatedLog(x) == linearAssociatedLog(normalElement(),x) ::
  SparseUnivariatePolynomial(F)

linearAssociatedOrder(x) ==
  x=0 => 0
  l>List List F:=[entries coordinates x]
  a:$:=x
  for i in 1..extensionDegree()@PI repeat
    a:=Frobenius(a)
    l:=concat(l,entries coordinates a)$(List List F)
  v:=first nullSpace transpose matrix(l)$(Matrix F)
  +/[monomial(v.(i+1),i::NNI) for i in 0..(#v-1)]

charthRoot(x):Union($,"failed") ==
  (charthRoot(x)@$):Union($,"failed")
-- norm(e) == norm(e,1) pretend F
-- trace(e) == trace(e,1) pretend F

minimalPolynomial(a,n) ==
  extensionDegree()@PI rem n ^= 0 =>
    error "minimalPolynomial: 2. argument must divide extension degree"
  f:SUP $:=monomial(1,1)$(SUP $) - monomial(a,0)$(SUP $)
  u:$:=Frobenius(a,n)
  while not(u = a) repeat
    f:=f * (monomial(1,1)$(SUP $) - monomial(u,0)$(SUP $))
    u:=Frobenius(u,n)
  f

norm(e,s) ==

```

```

qr := divide(extensionDegree(), s)
zero?(qr.remainder) =>
  pow := (size()-1) quo (size())$F ** s - 1)
  e ** (pow::NonNegativeInteger)
error "norm: second argument must divide degree of extension"

trace(e,s) ==
qr:=divide(extensionDegree(),s)
q:=size()$F
zero?(qr.remainder) =>
  a:=$:=0
  for i in 0..qr.quotient-1 repeat
    a:=a + e**(q**(s*i))
  a
  error "trace: second argument must divide degree of extension"

size() == size()$F ** extensionDegree()

createNormalElement() ==
characteristic() = size() => 1
res : $
for i in 1.. repeat
  res := index(i :: PI)
  not inGroundField? res =>
    normal? res => return res
-- theorem: there exists a normal element, this theorem is
-- unknown to the compiler
res

normal?(x:$) ==
p:SUP $:=(monomial(1,extensionDegree()) - monomial(1,0))@(SUP $)
f:SUP $:= +/[monomial(Frobenius(x,i),i)$ (SUP $) _
              for i in 0..extensionDegree()-1]
gcd(p,f) = 1 => true
false

degree a ==
y:=$:=Frobenius a
deg:PI:=1
while y^=a repeat
  y := Frobenius(y)
  deg:=deg+1
deg

```



```

"FAXF"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FAXF"];
"FAXF" -> "XF"
"FAXF" -> "RETRACT"

```

— FAXF.dotfull —

```

"FiniteAlgebraicExtensionField(a:Field)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FAXF"];
"FiniteAlgebraicExtensionField(a:Field)" -> "ExtensionField(a:Field)"
"FiniteAlgebraicExtensionField(a:Field)" -> "RetractableTo(a:Field)"

```

— FAXF.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FiniteAlgebraicExtensionField(a:Field)"
    [color=lightblue,href="bookvol10.2.pdf#nameddest=FAXF"];
  "FiniteAlgebraicExtensionField(a:Field)" -> "ExtensionField(a:Field)"
  "FiniteAlgebraicExtensionField(a:Field)" -> "RetractableTo(Field)"

  "ExtensionField(a:Field)" [color=lightblue];
  "ExtensionField(a:Field)" -> "Field()"
  "ExtensionField(a:Field)" -> "RetractableTo(Field)"
  "ExtensionField(a:Field)" -> "VectorSpace(a:Field)"

  "Field()" [color=lightblue];
  "Field()" -> "EuclideanDomain()"
  "Field()" -> "UniqueFactorizationDomain()"
  "Field()" -> "DIVRING..."

  "EuclideanDomain()" [color=lightblue];
  "EuclideanDomain()" -> "PrincipalIdealDomain()"

  "UniqueFactorizationDomain()" [color=lightblue];
  "UniqueFactorizationDomain()" -> "GCDDOM..."

  "PrincipalIdealDomain()" [color=lightblue];
  "PrincipalIdealDomain()" -> "GCDDOM..."

```

```

"RetractableTo(Field)" [color=seagreen];
"RetractableTo(Field)" -> "RetractableTo(a:Type)"

"RetractableTo(a:Type)" [color=lightblue];
"RetractableTo(a:Type)" -> "Category"

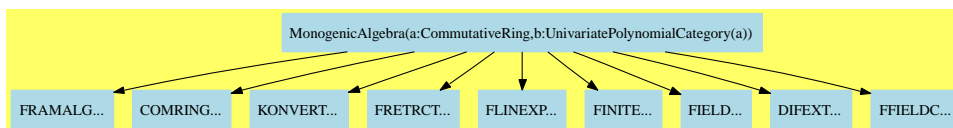
"VectorSpace(a:Field)" [color=lightblue];
"VectorSpace(a:Field)" -> "MODULE..."

"MODULE..." [color=lightblue];
"DIVRING..." [color=lightblue];
"GCDDOM..." [color=lightblue];
"Category" [color=lightblue];
}

```

—————→

MonogenicAlgebra (MONOGEN)



— MonogenicAlgebra.input —

```

)set break resume
)sys rm -f MonogenicAlgebra.output
)spool MonogenicAlgebra.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show MonogenicAlgebra
--R MonogenicAlgebra(R: CommutativeRing,UP: UnivariatePolynomialCategory(t#1)) is a category constructor
--R Abbreviation for MonogenicAlgebra is MONOGEN
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for MONOGEN
--R
--R----- Operations -----
--R ??? : (R,%) -> %           ??? : (%,R) -> %
--R ??? : (%,%) -> %          ??? : (Integer,%) -> %

```

```

--R ?? : (PositiveInteger,%) -> %
--R ?+? : (%,%) -> %
--R -? : % -> %
--R 1 : () -> %
--R ?? : (%,PositiveInteger) -> %
--R coerce : R -> %
--R coerce : % -> OutputForm
--R convert : % -> UP
--R convert : % -> Vector(R)
--R definingPolynomial : () -> UP
--R discriminant : Vector(%) -> R
--R hash : % -> SingleInteger
--R latex : % -> String
--R norm : % -> R
--R rank : () -> PositiveInteger
--R reduce : UP -> %
--R retract : % -> R
--R trace : % -> R
--R zero? : % -> Boolean
--R ?? : (%,Fraction(Integer)) -> % if R has FIELD
--R ?? : (Fraction(Integer),%) -> % if R has FIELD
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,Integer) -> % if R has FIELD
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,%) -> % if R has FIELD
--R D : (%,(R -> R)) -> % if R has FIELD
--R D : (%,(R -> R),NonNegativeInteger) -> % if R has FIELD
--R D : (%,List(Symbol),List(NonNegativeInteger)) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Field))
--R D : (%,Symbol,NonNegativeInteger) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Field))
--R D : (%,List(Symbol)) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Field))
--R D : (%,Symbol) -> % if and(has(R,PartialDifferentialRing(Symbol)),has(R,Field))
--R D : (%,NonNegativeInteger) -> % if and(has(R,DifferentialRing),has(R,Field)) or R has FFIELDC
--R D : % -> % if and(has(R,DifferentialRing),has(R,Field)) or R has FFIELDC
--R ?? : (%,Integer) -> % if R has FIELD
--R ?? : (%,NonNegativeInteger) -> %
--R associates? : (%,%) -> Boolean if R has FIELD
--R characteristic : () -> NonNegativeInteger
--R characteristicPolynomial : % -> UP
--R charthRoot : % -> Union(%, "failed") if R has CHARNZ
--R charthRoot : % -> % if R has FFIELDC
--R coerce : Fraction(Integer) -> % if R has FIELD or R has RETRACT(FRAC(INT))
--R coerce : % -> % if R has FIELD
--R conditionP : Matrix(%) -> Union(Vector(%), "failed") if R has FFIELDC
--R coordinates : Vector(%) -> Matrix(R)
--R coordinates : (Vector(%),Vector(%%)) -> Matrix(R)
--R coordinates : (%,Vector(%%)) -> Vector(R)
--R createPrimitiveElement : () -> % if R has FFIELDC
--R derivationCoordinates : (Vector(%),(R -> R)) -> Matrix(R) if R has FIELD
--R differentiate : (%,(R -> R)) -> % if R has FIELD
--R differentiate : (%,(R -> R),NonNegativeInteger) -> % if R has FIELD

```

```

--R differentiate : (% , List(Symbol), List(NonNegativeInteger)) -> % if and(has(R, PartialDifferentialRing(Symbol)), has(R,
--R differentiate : (% , Symbol, NonNegativeInteger) -> % if and(has(R, PartialDifferentialRing(Symbol)), has(R,
--R differentiate : (% , List(Symbol)) -> % if and(has(R, PartialDifferentialRing(Symbol)), has(R, Field))
--R differentiate : (% , Symbol) -> % if and(has(R, PartialDifferentialRing(Symbol)), has(R, Field))
--R differentiate : (% , NonNegativeInteger) -> % if and(has(R, DifferentialRing), has(R, Field)) or R has FFIELDC
--R differentiate : % -> % if and(has(R, DifferentialRing), has(R, Field)) or R has FFIELDC
--R discreteLog : (% , %) -> Union(NonNegativeInteger, "failed") if R has FFIELDC
--R discreteLog : % -> NonNegativeInteger if R has FFIELDC
--R divide : (% , %) -> Record(quotient: %, remainder: %) if R has FIELD
--R enumerate : () -> List(%) if R has FINITE
--R euclideanSize : % -> NonNegativeInteger if R has FIELD
--R expressIdealMember : (List(%), %) -> Union(List(%), "failed") if R has FIELD
--R exquo : (% , %) -> Union(% , "failed") if R has FIELD
--R extendedEuclidean : (% , %) -> Record(coef1: %, coef2: %, generator: %) if R has FIELD
--R extendedEuclidean : (% , %, %) -> Union(Record(coef1: %, coef2: %), "failed") if R has FIELD
--R factor : % -> Factored(%) if R has FIELD
--R factorsOfCyclicGroupSize : () -> List(Record(factor: Integer, exponent: Integer)) if R has FFIELDC
--R gcd : (% , %) -> % if R has FIELD
--R gcd : List(%) -> % if R has FIELD
--R gcdPolynomial : (SparseUnivariatePolynomial(%), SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R index : PositiveInteger -> % if R has FINITE
--R init : () -> % if R has FFIELDC
--R lcm : (% , %) -> % if R has FIELD
--R lcm : List(%) -> % if R has FIELD
--R lookup : % -> PositiveInteger if R has FINITE
--R minimalPolynomial : % -> UP if R has FIELD
--R multiEuclidean : (List(%), %) -> Union(List(%), "failed") if R has FIELD
--R nextItem : % -> Union(% , "failed") if R has FFIELDC
--R order : % -> OnePointCompletion(PositiveInteger) if R has FFIELDC
--R order : % -> PositiveInteger if R has FFIELDC
--R prime? : % -> Boolean if R has FIELD
--R primeFrobenius : % -> % if R has FFIELDC
--R primeFrobenius : (% , NonNegativeInteger) -> % if R has FFIELDC
--R primitive? : % -> Boolean if R has FFIELDC
--R primitiveElement : () -> % if R has FFIELDC
--R principalIdeal : List(%) -> Record(coef: List(%), generator: %) if R has FIELD
--R ?quo? : (% , %) -> % if R has FIELD
--R random : () -> % if R has FINITE
--R reduce : Fraction(UP) -> Union(% , "failed") if R has FIELD
--R reducedSystem : Matrix(%) -> Matrix(R)
--R reducedSystem : (Matrix(%), Vector(%)) -> Record(mat: Matrix(R), vec: Vector(R))
--R reducedSystem : (Matrix(%), Vector(%)) -> Record(mat: Matrix(Integer), vec: Vector(Integer)) if R has LINEAR
--R reducedSystem : Matrix(%) -> Matrix(Integer) if R has LINEAR
--R regularRepresentation : % -> Matrix(R)
--R regularRepresentation : (% , Vector(%)) -> Matrix(R)
--R ?rem? : (% , %) -> % if R has FIELD
--R representationType : () -> Union("prime", "polynomial", "normal", "cyclic") if R has FFIELDC
--R represents : (Vector(R), Vector(%)) -> %
--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retract : % -> Integer if R has RETRACT(INT)

```

```

--R retractIfCan : % -> Union(R,"failed")
--R retractIfCan : % -> Union(Fraction(Integer),"failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer,"failed") if R has RETRACT(INT)
--R size : () -> NonNegativeInteger if R has FINITE
--R sizeLess? : (%,%) -> Boolean if R has FIELD
--R squareFree : % -> Factored(%) if R has FIELD
--R squareFreePart : % -> % if R has FIELD
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R tableForDiscreteLogarithm : Integer -> Table(PositiveInteger,NonNegativeInteger) if R has FF
--R traceMatrix : Vector(%) -> Matrix(R)
--R unit? : % -> Boolean if R has FIELD
--R unitCanonical : % -> % if R has FIELD
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if R has FIELD
--R
--E 1

)spool
)lisp (bye)

```

— MonogenicAlgebra.help —

=====

MonogenicAlgebra examples

=====

A MonogenicAlgebra is an algebra of finite rank which can be generated by a single element.

See Also:

o)show MonogenicAlgebra

See:

⇒ “FunctionFieldCategory” (FFCAT) [20](#) on page [1693](#)
 ⇐ “CommutativeRing” (COMRING) [10](#) on page [896](#)
 ⇐ “ConvertibleTo” (KONVERT) [2](#) on page [41](#)
 ⇐ “FramedAlgebra” (FRAMALG) [18](#) on page [1591](#)
 ⇐ “FullyRetractableTo” (FRETRCT) [3](#) on page [136](#)
 ⇐ “LinearlyExplicitRingOver” (LINEXP) [10](#) on page [923](#)

Exports:

| | | |
|---------------------------|-----------------------|--------------------------|
| 0 | 1 | associates? |
| basis | characteristic | characteristicPolynomial |
| charthRoot | coerce | conditionP |
| convert | coordinates | createPrimitiveElement |
| D | definingPolynomial | derivationCoordinates |
| differentiate | discreteLog | discriminant |
| divide | euclideanSize | expressIdealMember |
| exquo | extendedEuclidean | factor |
| factorsOfCyclicGroupSize | generator | gcd |
| gcdPolynomial | hash | index |
| init | inv | latex |
| lcm | lift | lookup |
| minimalPolynomial | multiEuclidean | nextItem |
| norm | one? | order |
| prime? | primeFrobenius | primitive? |
| primitiveElement | principalIdeal | random |
| rank | recip | reduce |
| reducedSystem | regularRepresentation | represents |
| representationType | retract | retractIfCan |
| sample | size | sizeLess? |
| squareFree | squareFreePart | subtractIfCan |
| tableForDiscreteLogarithm | trace | traceMatrix |
| unit? | unitCanonical | unitNormal |
| zero? | ?*? | ?**? |
| ?+? | ?-? | -? |
| ?=? | ?^? | ?~=? |
| ?/? | ?quo? | ?rem? |

Attributes Exported:

- if \$ has Field then canonicalUnitNormal where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?(a,b)** returns true if and only if **unitCanonical(a) = unitCanonical(b)**.
- if \$ has Field then canonicalClosed where **canonicalsClosed** is true if **unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)**.
- if \$ has Field then noZeroDivisors where **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative("“*”) is true if it has an operation " * " : $(D, D) \rightarrow D$ which is commutative.**
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```
definingPolynomial : () -> UP
lift : % -> UP
reduce : UP -> %
```

These are implemented by this category:

```
basis : () -> Vector %
characteristicPolynomial : % -> UP
convert : % -> UP
convert : UP -> %
derivationCoordinates : (Vector %, (R -> R)) -> Matrix R
  if R has FIELD
differentiate : (%, (R -> R)) -> % if R has FIELD
generator : () -> %
norm : % -> R
random : () -> % if R has FINITE
recip : % -> Union(%, "failed")
reduce : Fraction UP -> Union(%, "failed") if R has FIELD
retract : % -> R
retractIfCan : % -> Union(R, "failed")
size : () -> NonNegativeInteger if R has FINITE
```

These exports come from (p1591) `FramedAlgebra(R,UP)`
 where `R:CommutativeRing` and `UP:UnivariatePolynomialCategory(a)`

```
0 : () -> %
1 : () -> %
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(%, "failed") if R has CHARNZ
coerce : R -> %
coerce : Integer -> %
coerce : % -> OutputForm
convert : Vector R -> %
convert : % -> Vector R
coordinates : (%, Vector %) -> Vector R
coordinates : (Vector %, Vector %) -> Matrix R
coordinates : Vector % -> Matrix R
coordinates : % -> Vector R
discriminant : Vector % -> R
discriminant : () -> R
hash : % -> SingleInteger
latex : % -> String
minimalPolynomial : % -> UP if R has FIELD
one? : % -> Boolean
rank : () -> PositiveInteger
regularRepresentation : (%, Vector %) -> Matrix R
regularRepresentation : % -> Matrix R
```

```

represents : (Vector R,Vector %) -> %
represents : Vector R -> %
sample : () -> %
subtractIfCan : (%,%) -> Union(%, "failed")
trace : % -> R
traceMatrix : Vector % -> Matrix R
traceMatrix : () -> Matrix R
zero? : % -> Boolean
?+? : (%,%) -> %
?=? : (%,%) -> Boolean
?~=? : (%,%) -> Boolean
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
?*? : (NonNegativeInteger,%) -> %
?*? : (R,%) -> %
?*? : (%,R) -> %
?-? : (%,%) -> %
-? : % -> %
***? : (%,PositiveInteger) -> %
***? : (%,NonNegativeInteger) -> %
?^? : (%,PositiveInteger) -> %
?^? : (%,NonNegativeInteger) -> %

```

These exports come from (p136) FullyRetractableTo(R)
 where R:CommutativeRing

```

coerce : Fraction Integer -> %
  if R has FIELD or R has RETRACT FRAC INT
retract : % -> Integer if R has RETRACT INT
retract : % -> Fraction Integer
  if R has RETRACT FRAC INT
retractIfCan : % -> Union(Fraction Integer, "failed")
  if R has RETRACT FRAC INT
retractIfCan : % -> Union(Integer, "failed")
  if R has RETRACT INT

```

These exports come from (p1012) FullyLinearlyExplicitRingOver(R)
 where R:CommutativeRing

```

reducedSystem : Matrix % -> Matrix R
reducedSystem :
  (Matrix %,Vector %) -> Record(mat: Matrix R,vec: Vector R)
reducedSystem :
  (Matrix %,Vector %) ->
    Record(mat: Matrix Integer,vec: Vector Integer)
    if R has LINEXP INT
reducedSystem : Matrix % -> Matrix Integer if R has LINEXP INT

```

These exports come from (p218) Finite()


```

index : PositiveInteger -> % if R has FINITE
lookup : % -> PositiveInteger if R has FINITE

```

These exports come from (p1271) Field()

```

associates? : (%,% ) -> Boolean if R has FIELD
coerce : % -> % if R has FIELD
divide : (%,% ) -> Record(quotient: %,remainder: %)
    if R has FIELD
euclideanSize : % -> NonNegativeInteger if R has FIELD
expressIdealMember : (List %,% ) -> Union(List %,"failed")
    if R has FIELD
exquo : (%,% ) -> Union(%,"failed") if R has FIELD
extendedEuclidean : (%,% ) -> Record(coef1: %,coef2: %,generator: %)
    if R has FIELD
extendedEuclidean : (%,%,% ) -> Union(Record(coef1: %,coef2: %),"failed")
    if R has FIELD
factor : % -> Factored % if R has FIELD
gcd : (%,% ) -> % if R has FIELD
gcd : List % -> % if R has FIELD
gcdPolynomial :
    (SparseUnivariatePolynomial %,
     SparseUnivariatePolynomial %) ->
        SparseUnivariatePolynomial % if R has FIELD
inv : % -> % if R has FIELD
lcm : (%,% ) -> % if R has FIELD
lcm : List % -> % if R has FIELD
multiEuclidean : (List %,% ) -> Union(List %,"failed")
    if R has FIELD
prime? : % -> Boolean if R has FIELD
principalIdeal : List % -> Record(coef: List %,generator: %)
    if R has FIELD
sizeLess? : (%,% ) -> Boolean if R has FIELD
squareFree : % -> Factored % if R has FIELD
squareFreePart : % -> % if R has FIELD
unit? : % -> Boolean if R has FIELD
unitCanonical : % -> % if R has FIELD
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
    if R has FIELD
?/? : (%,% ) -> % if R has FIELD
?*? : (% ,Fraction Integer) -> % if R has FIELD
?*? : (Fraction Integer,% ) -> % if R has FIELD
***? : (% ,Integer) -> % if R has FIELD
?^? : (% ,Integer) -> % if R has FIELD
?quo? : (%,% ) -> % if R has FIELD
?rem? : (%,% ) -> % if R has FIELD

```

These exports come from (p1005) DifferentialExtension(R)
where R:CommutativeRing

```

D : (%,(R -> R)) -> % if R has FIELD
D : (%,(R -> R),NonNegativeInteger) -> % if R has FIELD
D : % -> %
    if and(has(R,DifferentialRing),has(R,Field))
    or R has FFIELDC
D : (%,(NonNegativeInteger) -> %
    if and(has(R,DifferentialRing),has(R,Field))
    or R has FFIELDC
D : (%,(List Symbol,List NonNegativeInteger) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Field))
D : (%,(Symbol,NonNegativeInteger) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Field))
D : (%,(List Symbol) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Field))
D : (%,(Symbol) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Field))
differentiate : % -> %
    if and(has(R,DifferentialRing),has(R,Field))
    or R has FFIELDC
differentiate : (%,(NonNegativeInteger) -> %
    if and(has(R,DifferentialRing),has(R,Field))
    or R has FFIELDC
differentiate : (%,(List Symbol) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Field))
differentiate : (%,(Symbol,NonNegativeInteger) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Field))
differentiate : (%,(List Symbol,List NonNegativeInteger) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Field))
differentiate : (%,(R -> R),NonNegativeInteger) -> %
    if R has FIELD
differentiate : (%,(Symbol) -> %
    if and(has(R,PartialDifferentialRing Symbol),has(R,Field))

```

These exports come from (p1570) FiniteFieldCategory():

```

charthRoot : % -> % if R has FFIELDC
conditionP : Matrix % -> Union(Vector %,"failed")
    if R has FFIELDC
createPrimitiveElement : () -> % if R has FFIELDC
discreteLog : % -> NonNegativeInteger if R has FFIELDC
discreteLog : (%,(%) -> Union(NonNegativeInteger,"failed")
    if R has FFIELDC
factorsOfCyclicGroupSize : () ->
    List Record(factor: Integer,exponent: Integer)
    if R has FFIELDC
init : () -> % if R has FFIELDC
nextItem : % -> Union(%,"failed") if R has FFIELDC
order : % -> OnePointCompletion PositiveInteger
    if R has FFIELDC
order : % -> PositiveInteger if R has FFIELDC

```

```

primeFrobenius : % -> % if R has FFIELDC
primeFrobenius : (% , NonNegativeInteger) -> % if R has FFIELDC
primitive? : % -> Boolean if R has FFIELDC
primitiveElement : () -> % if R has FFIELDC
representationType : () ->
    Union("prime", polynomial, normal, cyclic)
    if R has FFIELDC
tableForDiscreteLogarithm :
    Integer -> Table(PositiveInteger, NonNegativeInteger)
    if R has FFIELDC

```

— category MONOGEN MonogenicAlgebra —

```

)abbrev category MONOGEN MonogenicAlgebra
++ Author: Barry Trager
++ Description:
++ A \spadtype{MonogenicAlgebra} is an algebra of finite rank which
++ can be generated by a single element.

MonogenicAlgebra(R:CommutativeRing, UP:UnivariatePolynomialCategory R):
Category ==
    Join(FramedAlgebra(R, UP), CommutativeRing, ConvertibleTo UP,
        FullyRetractableTo R, FullyLinearlyExplicitRingOver R) with
generator      : () -> %
    ++ generator() returns the generator for this domain.
definingPolynomial: () -> UP
    ++ definingPolynomial() returns the minimal polynomial which
    ++ \spad{generator()} satisfies.
reduce         : UP -> %
    ++ reduce(up) converts the univariate polynomial up to an algebra
    ++ element, reducing by the \spad{definingPolynomial()} if necessary.
convert        : UP -> %
    ++ convert(up) converts the univariate polynomial up to an algebra
    ++ element, reducing by the \spad{definingPolynomial()} if necessary.
lift           : % -> UP
    ++ lift(z) returns a minimal degree univariate polynomial up such that
    ++ \spad{z=reduce up}.
if R has Finite then Finite
if R has Field then
    Field
    DifferentialExtension R
    reduce      : Fraction UP -> Union(% , "failed")
    ++ reduce(frac) converts the fraction frac to an algebra element.
    derivationCoordinates: (Vector % , R -> R) -> Matrix R
    ++ derivationCoordinates(b, ') returns M such that \spad{b' = M b}.
    if R has FiniteFieldCategory then FiniteFieldCategory
add
convert(x:%):UP == lift x
convert(p:UP):% == reduce p

```

```

generator()      == reduce monomial(1, 1)$UP
norm x           == resultant(definingPolynomial(), lift x)
retract(x:%):R   == retract lift x
retractIfCan(x:%):Union(R, "failed") == retractIfCan lift x

basis() ==
  [reduce monomial(1,i)$UP for i in 0..(rank()-1)::NonNegativeInteger]

characteristicPolynomial(x:%):UP ==
  characteristicPolynomial(x)$CharacteristicPolynomialInMonogenicalAlgebra(R,UP,%)

if R has Finite then
  size() == size()$R ** rank()
  random() == represents [random()$R for i in 1..rank()],$Vector(R)

if R has Field then
  reduce(x:Fraction UP) == reduce(numer x) exquo reduce(denom x)

  differentiate(x:%, d:R -> R) ==
    p := definingPolynomial()
    yprime := - reduce(map(d, p)) / reduce(differentiate p)
    reduce(map(d, lift x)) + yprime * reduce differentiate lift x

  derivationCoordinates(b, d) ==
    coordinates(map(x +-> differentiate(x, d), b), b)

  recip x ==
    (bc := extendedEuclidean(lift x, definingPolynomial(), 1))
    case "failed" => "failed"
    reduce(bc.coef1)

```

— MONOGEN.dotabb —

```

"MONOGEN"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MONOGEN"];
"MONOGEN" -> "FRAMALG"
"MONOGEN" -> "COMRING"
"MONOGEN" -> "KONVERT"
"MONOGEN" -> "FRETRCT"
"MONOGEN" -> "FLINEXP"
"MONOGEN" -> "FINITE"
"MONOGEN" -> "FIELD"
"MONOGEN" -> "DIFEXT"
"MONOGEN" -> "FFIELDC"

```

— MONOGEN.dotfull —

```

"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=MONOGEN"];
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "FramedAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "CommutativeRing()"
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "ConvertibleTo(UnivariatePolynomialCategory(CommutativeRing))"
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "FullyRetractableTo(a:CommutativeRing)"
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "FullyLinearlyExplicitRingOver(a:CommutativeRing)"

"MonogenicAlgebra(a:FRAC(UPOLYC(UFD)),b:UPOLYC(FRAC(UPOLYC(UFD))))"
  [color=seagreen,href="bookvol10.2.pdf#nameddest=MONOGEN"];
"MonogenicAlgebra(a:FRAC(UPOLYC(UFD)),b:UPOLYC(FRAC(UPOLYC(UFD))))" ->
  "MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"

```

— MONOGEN.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"
  [color=lightblue];
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "FRAMALG..."
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "COMRING..."
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "KONVERT..."
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "FRETRCT..."
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "FLINEXP..."
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "FINITE..."
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "FIELD..."
"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "DIFEXT..."

```

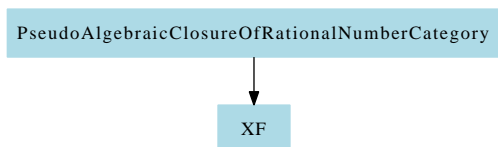
```

"MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
  "FFIELDC..."

"FRAMALG..." [color=lightblue];
"COMRING..." [color=lightblue];
"KONVERT..." [color=lightblue];
"FRETRCT..." [color=lightblue];
"FLINEXP..." [color=lightblue];
"FINITE..." [color=lightblue];
"FIELD..." [color=lightblue];
"DIFEXT..." [color=lightblue];
"FFIELDC..." [color=lightblue];
}

```

PseudoAlgebraicClosureOfRationalNumberCategory (PACRATC)



— PseudoAlgebraicClosureOfRationalNumberCategory.input —

```

)set break resume
)sys rm -f PseudoAlgebraicClosureOfRationalNumberCategory.output
)spool PseudoAlgebraicClosureOfRationalNumberCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PseudoAlgebraicClosureOfRationalNumberCategory
--R
--R PseudoAlgebraicClosureOfRationalNumberCategory is a category constructor
--R Abbreviation for PseudoAlgebraicClosureOfRationalNumberCategory is PACRATC
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PACRATC
--R
--R----- Operations -----
--R ??? : (%,Fraction(Integer)) -> %      ??? : (Fraction(Integer),%) -> %
--R ??? : (Fraction(Integer),%) -> %      ??? : (%,Fraction(Integer)) -> %

```

```

--R ?? : (%,%) -> %
--R ?? : (PositiveInteger,%) -> %
--R ??? : (%,PositiveInteger) -> %
--R ?-? : (%,%) -> %
--R ?/? : (%,Fraction(Integer)) -> %
--R ==? : (%,%) -> Boolean
--R 0 : () -> %
--R ?? : (%,PositiveInteger) -> %
--R associates? : (%,%) -> Boolean
--R coerce : Fraction(Integer) -> %
--R coerce : Fraction(Integer) -> %
--R coerce : Integer -> %
--R conjugate : % -> %
--R extDegree : % -> PositiveInteger
--R fullOutput : % -> OutputForm
--R gcd : (%,%) -> %
--R hash : % -> SingleInteger
--R inv : % -> %
--R lcm : List(%) -> %
--R maxTower : List(%) -> %
--R previousTower : % -> %
--R ?quo? : (%,%) -> %
--R ?rem? : (%,%) -> %
--R retract : % -> Fraction(Integer)
--R sample : () -> %
--R sizeLess? : (%,%) -> Boolean
--R squareFreePart : % -> %
--R unit? : % -> Boolean
--R vectorise : (%,%) -> Vector(%)
--R ^=? : (%,%) -> Boolean
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,NonNegativeInteger) -> %
--R Frobenius : % -> % if Fraction(Integer) has FINITE
--R Frobenius : (%,NonNegativeInteger) -> % if Fraction(Integer) has FINITE
--R ?? : (%,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if Fraction(Integer) has CHARNZ or Fraction(Integer) has
--R definingPolynomial : % -> SparseUnivariatePolynomial(%)
--R definingPolynomial : () -> SparseUnivariatePolynomial(%)
--R degree : % -> OnePointCompletion(PositiveInteger)
--R discreteLog : (%,%) -> Union(NonNegativeInteger, "failed") if Fraction(Integer) has CHARNZ or
--R distinguishedRootsOf : (SparseUnivariatePolynomial(%),%) -> List(%)
--R divide : (%,%) -> Record(quotient: %,remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%), "failed")
--R exquo : (%,%) -> Union(%, "failed")
--R extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
--R extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
--R extensionDegree : () -> OnePointCompletion(PositiveInteger)
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUniva
?? : (Integer,%) -> %
??? : (%,Integer) -> %
?+? : (%,%) -> %
-? : % -> %
?/? : (%,%) -> %
1 : () -> %
?^? : (%,Integer) -> %
algebraic? : % -> Boolean
coerce : Fraction(Integer) -> %
coerce : Integer -> %
coerce : % -> %
coerce : % -> OutputForm
dimension : () -> CardinalNumber
factor : % -> Factored(%)
gcd : List(%) -> %
ground? : % -> Boolean
inGroundField? : % -> Boolean
latex : % -> String
lcm : (%,%) -> %
one? : % -> Boolean
prime? : % -> Boolean
recip : % -> Union(%, "failed")
retract : % -> Fraction(Integer)
retract : % -> Integer
setTower! : % -> Void
squareFree : % -> Factored(%)
transcendent? : % -> Boolean
unitCanonical : % -> %
zero? : % -> Boolean

```

```

--R lift : (%,% ) -> SparseUnivariatePolynomial(%)
--R lift : % -> SparseUnivariatePolynomial(%)
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed")
--R newElement : (SparseUnivariatePolynomial(%),Symbol) -> %
--R newElement : (SparseUnivariatePolynomial(%),%,Symbol) -> %
--R order : % -> OnePointCompletion(PositiveInteger) if Fraction(Integer) has CHARNZ or Fraction(Integer) has FINITE
--R primeFrobenius : % -> % if Fraction(Integer) has CHARNZ or Fraction(Integer) has FINITE
--R primeFrobenius : (% ,NonNegativeInteger) -> % if Fraction(Integer) has CHARNZ or Fraction(Integer) has FINITE
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R reduce : SparseUnivariatePolynomial(%) -> %
--R retractIfCan : % -> Union(Fraction(Integer),"failed")
--R retractIfCan : % -> Union(Fraction(Integer),"failed")
--R retractIfCan : % -> Union(Integer,"failed")
--R subtractIfCan : (% ,%) -> Union(%,"failed")
--R transcendenceDegree : () -> NonNegativeInteger
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— PseudoAlgebraicClosureOfRationalNumberCategory.help —

=====

PseudoAlgebraicClosureOfRationalNumberCategory examples

=====

This category exports the function for the domain
PseudoAlgebraicClosureOfRationalNumber which implement dynamic extension
using the simple notion of tower extensions. A tower extension T of the
ground field K is any sequence of field extension

$$(T : K_0, K_1, \dots, K_i, \dots, K_n)$$

where $K_0 = K$ and for $i = 1, 2, \dots, n$, K_i is an extension
of K_{i-1} of degree > 1 and defined by an irreducible polynomial
 $p(Z)$ in K_{i-1} .

Two towers

$(T_1: K_{01}, K_{11}, \dots, K_{i1}, \dots, K_{n1})$

and

$(T_2: K_{02}, K_{12}, \dots, K_{i2}, \dots, K_{n2})$

are said to be related if

$T_1 \leq T_2$ (or $T_1 \geq T_2$),

that is if

$K_{i1} = K_{i2}$ for $i=1, 2, \dots, n1$

(or $i=1, 2, \dots, n2$). Any algebraic operations defined for several elements
are only defined if all of the concerned elements are coming from

a set of related tour extensions.

See Also:

o)show PseudoAlgebraicClosureOfRationalNumberCategory

See:

⇒ “PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory” (PACEXTC) [20](#) on page [1717](#)

⇐ “ExtensionField” (XF) [18](#) on page [1562](#)

Exports:

| | | |
|----------------------|-----------------|---------------------|
| 0 | 1 | algebraic? |
| associates? | characteristic | charthRoot |
| coerce | conjugate | definingPolynomial |
| degree | dimension | discreteLog |
| distinguishedRootsOf | divide | euclideanSize |
| expressIdealMember | exquo | extDegree |
| extendedEuclidean | extensionDegree | factor |
| Frobenius | fullOutput | gcd |
| gcdPolynomial | ground? | hash |
| inGroundField? | inv | latex |
| lcm | lift | maxTower |
| multiEuclidean | newElement | one? |
| order | previousTower | prime? |
| primeFrobenius | principalIdeal | ?quo? |
| recip | reduce | ?rem? |
| retract | retractIfCan | sample |
| setTower! | sizeLess? | squareFree |
| squareFreePart | subtractIfCan | transcendenceDegree |
| transcendent? | unit? | unitCanonical |
| unitNormal | vectorise | zero? |
| ?*? | ?**? | ?+? |
| ?-? | -? | ?/? |
| ?=? | ?~=? | ?^? |

Attributes Exported:

- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is `associates?(a,b)` returns true if and only if `unitCanonical(a) = unitCanonical(b)`.
- **canonicalsClosed** is true if `unitCanonical(a)*unitCanonical(b) = unitCanonical(a*b)`.
- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.

- **commutative**("*") is true if it has an operation " $*$ " : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return "failed" if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

These exports come from (p1420) PseudoAlgebraicClosureOfPerfectFieldCategory():

```

?*? : (Fraction Integer,%) -> %
?*? : (%,Fraction Integer) -> %
?*? : (%,%) -> %
?*? : (Integer,%) -> %
?*? : (PositiveInteger,%) -> %
***? : (%,Integer) -> %
***? : (%,PositiveInteger) -> %
?+? : (%,%) -> %
?-? : (%,%) -> %
-? : % -> %
?/? : (%,%) -> %
?=?: (%,%) -> Boolean
1 : () -> %
0 : () -> %
?^? : (%,Integer) -> %
?^? : (%,PositiveInteger) -> %
associates? : (%,%) -> Boolean
characteristic : () -> NonNegativeInteger
coerce : Fraction Integer -> %
coerce : Integer -> %
coerce : % -> %
coerce : % -> OutputForm
conjugate : % -> %
definingPolynomial : % -> SUP %
definingPolynomial : () -> SUP %
distinguishedRootsOf : (SparseUnivariatePolynomial %,%) -> List %
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %, "failed")
exquo : (%,%) -> Union(%, "failed")
extDegree : % -> PI
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %), "failed")
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
factor : % -> Factored %
fullOutput : % -> OutputForm
gcd : List % -> %
gcd : (%,%) -> %
gcdPolynomial :

```

```

    (SparseUnivariatePolynomial %, SparseUnivariatePolynomial %) ->
      SparseUnivariatePolynomial %
  ground? : % -> Boolean
  hash : % -> SingleInteger
  inv : % -> %
  latex : % -> String
  lcm : List % -> %
  lcm : (% , %) -> %
  lift : (% , %) -> SUP %
  lift : % -> SUP %
  maxTower : List % -> %
  multiEuclidean : (List % , %) -> Union(List % , "failed")
  newElement : (SUP % , Symbol) -> %
  newElement : (SUP % , % , Symbol) -> %
  one? : % -> Boolean
  previousTower : % -> %
  prime? : % -> Boolean
  principalIdeal : List % -> Record(coef: List % , generator: %)
  ?quo? : (% , %) -> %
  recip : % -> Union(% , "failed")
  reduce : SUP % -> %
  ?rem? : (% , %) -> %
  sample : () -> %
  setTower! : % -> Void
  sizeLess? : (% , %) -> Boolean
  squareFree : % -> Factored %
  squareFreePart : % -> %
  subtractIfCan : (% , %) -> Union(% , "failed")
  unit? : % -> Boolean
  unitCanonical : % -> %
  unitNormal : % -> Record(unit: % , canonical: % , associate: %)
  vectorise : (% , %) -> Vector %
  zero? : % -> Boolean
  ?~=? : (% , %) -> Boolean
  ?*? : (NonNegativeInteger , %) -> %
  ?**? : (% , NonNegativeInteger) -> %
  ?^? : (% , NonNegativeInteger) -> %

```

These exports come from (p892) `CharacteristicZero()`:

These exports come from (p95) `RetractableTo(Integer)`:

```

  retract : % -> Integer
  retractIfCan : % -> Union(Integer , "failed")

```

These exports come from (p95) `RetractableTo(Fraction(Integer))`:

```

  retract : % -> Fraction Integer

```

```
retractIfCan : % -> Union(Fraction Integer,"failed")
```

These exports come from (p1562) ExtensionField(Fraction(Integer)):

```

?/? : (% , Fraction Integer) -> %
algebraic? : % -> Boolean
charthRoot : % -> Union(%,"failed")
  if Fraction Integer has CHARNZ or Fraction Integer has FINITE
degree : % -> OnePointCompletion PositiveInteger
dimension : () -> CardinalNumber
discreteLog : (% , %) -> Union(NonNegativeInteger,"failed")
  if Fraction Integer has CHARNZ or Fraction Integer has FINITE
extensionDegree : () -> OnePointCompletion PositiveInteger
Frobenius : % -> % if Fraction Integer has FINITE
Frobenius : (% , NonNegativeInteger) -> % if Fraction Integer has FINITE
inGroundField? : % -> Boolean
order : % -> OnePointCompletion PositiveInteger
  if Fraction Integer has CHARNZ or Fraction Integer has FINITE
primeFrobenius : % -> %
  if Fraction Integer has CHARNZ or Fraction Integer has FINITE
transcendent? : % -> Boolean
primeFrobenius : (% , NonNegativeInteger) -> %
  if Fraction Integer has CHARNZ or Fraction Integer has FINITE
retractIfCan : % -> Union(Fraction Integer,"failed")
transcendenceDegree : () -> NonNegativeInteger

```

— category PACRATC PseudoAlgebraicClosureOfRationalNumber-
Category —

```

)abbrev category PACRATC PseudoAlgebraicClosureOfRationalNumberCategory
++ Authors: Gaetan Hache
++ Date Created: feb 1997
++ Description:
++ This category exports the function for the domain
++ PseudoAlgebraicClosureOfRationalNumber
++ which implement dynamic extension using the simple notion of tower
++ extensions. A tower extension T of the ground
++ field K is any sequence of field extension (T : K_0, K_1, ..., K_i...,K_n)
++ where K_0 = K and for i =1,2,...,n, K_i is an extension
++ of K_{i-1} of degree > 1 and defined by an irreducible polynomial
++ p(Z) in K_{i-1}.
++ Two towers (T_1: K_01, K_11,...,K_i1,...,K_n1)
++ and (T_2: K_02, K_12,...,K_i2,...,K_n2)
++ are said to be related if T_1 <= T_2 (or T_1 >= T_2),
++ that is if K_i1 = K_i2 for i=1,2,...,n1
++ (or i=1,2,...,n2). Any algebraic operations defined for several elements
++ are only defined if all of the concerned elements are coming from
++ a set of related tower extensions.

```

```
PseudoAlgebraicClosureOfRationalNumberCategory:Category ==
  Join(PseudoAlgebraicClosureOfPerfectFieldCategory,
        CharacteristicZero,RetractableTo(Integer),
        RetractableTo(Fraction(Integer)),ExtensionField(Fraction(Integer)))
```

— PACRATC.dotabb —

```
"PACRATC" [color=lightblue,href="bookvol10.2.pdf#nameddest=PACRATC"];
"PACRATC" -> "XF"
```

— PACRATC.dotfull —

```
"PseudoAlgebraicClosureOfRationalNumberCategory"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PACRATC"];
"PseudoAlgebraicClosureOfRationalNumberCategory" -> "ExtensionField(F:Field)"
```

— PACRATC.dotpic —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

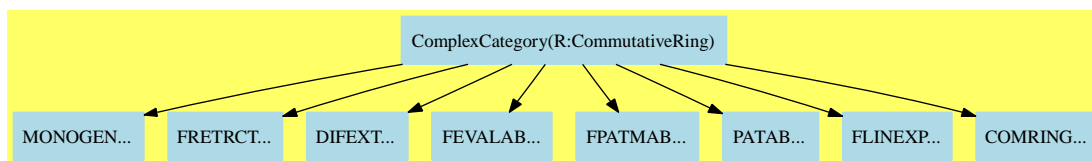
  "PseudoAlgebraicClosureOfRationalNumberCategory" [color=lightblue];
  "PseudoAlgebraicClosureOfRationalNumberCategory" -> "XF"

  "XF" [color=lightblue];
}
```

Chapter 20

Category Layer 19

ComplexCategory (COMPCAT)



— ComplexCategory.input —

```

)set break resume
)sys rm -f ComplexCategory.output
)spool ComplexCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show ComplexCategory
--R ComplexCategory(R: CommutativeRing) is a category constructor
--R Abbreviation for ComplexCategory is COMPCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for COMPCAT
--R
--R----- Operations -----
--R ?? : (R,%) -> %
--R ?? : (%,%) -> %
--R ?? : (PositiveInteger,%) -> %
--R ?+? : (%,%) -> %
--R -? : % -> %
--R ?? : (%,R) -> %
--R ?? : (Integer,%) -> %
--R ??? : (%,PositiveInteger) -> %
--R ?-? : (%,%) -> %
--R ?=? : (%,%) -> Boolean

```

```

--R D : (%,(R -> R)) -> %
--R 0 : () -> %
--R abs : % -> % if R has RNS
--R coerce : R -> %
--R coerce : % -> OutputForm
--R conjugate : % -> %
--R convert : % -> Vector(R)
--R discriminant : () -> R
--R generator : () -> %
--R imag : % -> R
--R inv : % -> % if R has FIELD
--R map : ((R -> R),%) -> %
--R one? : % -> Boolean
--R rank : () -> PositiveInteger
--R recip : % -> Union(%,"failed")
--R retract : % -> R
--R trace : % -> R
--R zero? : % -> Boolean
--R ?? : (%,Fraction(Integer)) -> % if R has FIELD
--R ?? : (Fraction(Integer),%) -> % if R has FIELD
--R ?? : (NonNegativeInteger,%) -> %
--R ??? : (%,Integer) -> % if R has FIELD
--R ??? : (%,% ) -> % if R has TRANFUN
--R ??? : (% ,Fraction(Integer)) -> % if R has RADCAT and R has TRANFUN
--R ??? : (% ,NonNegativeInteger) -> %
--R ?/? : (%,% ) -> % if R has FIELD
--R ?<? : (%,% ) -> Boolean if R has ORDSET
--R ?<=? : (%,% ) -> Boolean if R has ORDSET
--R ?>? : (%,% ) -> Boolean if R has ORDSET
--R ?>=? : (%,% ) -> Boolean if R has ORDSET
--R D : % -> % if and(has(R,Field),has(R,DifferentialRing)) or R has DIFRING or and(has(R,Differen
--R D : (% ,NonNegativeInteger) -> % if and(has(R,Field),has(R,DifferentialRing)) or R has DIFRING
--R D : (% ,Symbol) -> % if R has PDRING(SYMBOL)
--R D : (% ,List(Symbol)) -> % if R has PDRING(SYMBOL)
--R D : (% ,Symbol,NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R D : (% ,List(Symbol),List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R D : (% ,(R -> R),NonNegativeInteger) -> %
--R ?? : (% ,Integer) -> % if R has FIELD
--R ?? : (% ,NonNegativeInteger) -> %
--R acos : % -> % if R has TRANFUN
--R acosh : % -> % if R has TRANFUN
--R acot : % -> % if R has TRANFUN
--R acoth : % -> % if R has TRANFUN
--R acsc : % -> % if R has TRANFUN
--R acsch : % -> % if R has TRANFUN
--R argument : % -> R if R has TRANFUN
--R asec : % -> % if R has TRANFUN
--R asech : % -> % if R has TRANFUN
--R asin : % -> % if R has TRANFUN
--R asinh : % -> % if R has TRANFUN
1 : () -> %
?? : (% ,PositiveInteger) -> %
basis : () -> Vector(% )
coerce : Integer -> %
complex : (R,R) -> %
convert : Vector(R) -> %
coordinates : % -> Vector(R)
discriminant : Vector(% ) -> R
hash : % -> SingleInteger
imaginary : () -> %
latex : % -> String
norm : % -> R
pi : () -> % if R has TRANFUN
real : % -> R
represents : Vector(R) -> %
sample : () -> %
traceMatrix : () -> Matrix(R)
?~? : (%,% ) -> Boolean

```

```

--R associates? : (% , %) -> Boolean if R has INTDOM or R has EUCDOM and R has PFECAT
--R atan : % -> % if R has TRANFUN
--R atanh : % -> % if R has TRANFUN
--R characteristic : () -> NonNegativeInteger
--R characteristicPolynomial : % -> SparseUnivariatePolynomial(R)
--R charthRoot : % -> Union(% , "failed") if and(has($ , CharacteristicNonZero) , AND(has(R , EuclideanDomain) , has(
--R charthRoot : % -> % if R has FFIELDC
--R coerce : % -> % if R has INTDOM or R has EUCDOM and R has PFECAT
--R coerce : Fraction(Integer) -> % if R has FIELD or R has RETRACT(FRAC(INT))
--R conditionP : Matrix(% ) -> Union(Vector(% ) , "failed") if and(has($ , CharacteristicNonZero) , AND(has(R , Euclid
--R convert : % -> InputForm if R has KONVERT(INFORM)
--R convert : % -> Complex(DoubleFloat) if R has REAL
--R convert : % -> Complex(Float) if R has REAL
--R convert : % -> Pattern(Float) if R has KONVERT(PATTERN(FLOAT))
--R convert : % -> Pattern(Integer) if R has KONVERT(PATTERN(INT))
--R convert : SparseUnivariatePolynomial(R) -> %
--R convert : % -> SparseUnivariatePolynomial(R)
--R coordinates : Vector(% ) -> Matrix(R)
--R coordinates : (Vector(% ) , Vector(% )) -> Matrix(R)
--R coordinates : (% , Vector(% )) -> Vector(R)
--R cos : % -> % if R has TRANFUN
--R cosh : % -> % if R has TRANFUN
--R cot : % -> % if R has TRANFUN
--R coth : % -> % if R has TRANFUN
--R createPrimitiveElement : () -> % if R has FFIELDC
--R csc : % -> % if R has TRANFUN
--R csch : % -> % if R has TRANFUN
--R definingPolynomial : () -> SparseUnivariatePolynomial(R)
--R derivationCoordinates : (Vector(% ) , (R -> R)) -> Matrix(R) if R has FIELD
--R differentiate : % -> % if and(has(R , Field) , has(R , DifferentialRing)) or R has DIFRING or and(has(R , Differ
--R differentiate : (% , NonNegativeInteger) -> % if and(has(R , Field) , has(R , DifferentialRing)) or R has DIFRI
--R differentiate : (% , Symbol) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , List(Symbol)) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , Symbol , NonNegativeInteger) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , List(Symbol) , List(NonNegativeInteger)) -> % if R has PDRING(SYMBOL)
--R differentiate : (% , (R -> R)) -> %
--R differentiate : (% , (R -> R) , NonNegativeInteger) -> %
--R discreteLog : (% , %) -> Union(NonNegativeInteger , "failed") if R has FFIELDC
--R discreteLog : % -> NonNegativeInteger if R has FFIELDC
--R divide : (% , %) -> Record(quotient : % , remainder : %) if R has EUCDOM
--R ?? : (% , R) -> % if R has ELTAB(R , R)
--R enumerate : () -> List(% ) if R has FINITE
--R euclideanSize : % -> NonNegativeInteger if R has EUCDOM
--R eval : (% , Symbol , R) -> % if R has IEVALAB(SYMBOL , R)
--R eval : (% , List(Symbol) , List(R)) -> % if R has IEVALAB(SYMBOL , R)
--R eval : (% , List(Equation(R))) -> % if R has EVALAB(R)
--R eval : (% , Equation(R)) -> % if R has EVALAB(R)
--R eval : (% , R , R) -> % if R has EVALAB(R)
--R eval : (% , List(R) , List(R)) -> % if R has EVALAB(R)
--R exp : % -> % if R has TRANFUN

```



```

--R expressIdealMember : (List(%),%) -> Union(List(%),"failed") if R has EUCDOM
--R exquo : (%,%)-> Union(%,"failed") if R has INTDOM or R has EUCDOM and R has PFECAT
--R exquo : (% ,R) -> Union(%,"failed") if R has INTDOM
--R extendedEuclidean : (%,%)-> Record(coef1: %,coef2: %,generator: %) if R has EUCDOM
--R extendedEuclidean : (%,%,%)-> Union(Record(coef1: %,coef2: %),"failed") if R has EUCDOM
--R factor : % -> Factored(%) if R has EUCDOM and R has PFECAT or R has FIELD
--R factorPolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%))
--R factorSquareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%))
--R factorsOfCyclicGroupSize : () -> List(Record(factor: Integer,exponent: Integer)) if R has FFIELDC
--R gcd : (%,%)-> % if R has EUCDOM or R has EUCDOM and R has PFECAT
--R gcd : List(%) -> % if R has EUCDOM or R has EUCDOM and R has PFECAT
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
--R index : PositiveInteger -> % if R has FINITE
--R init : () -> % if R has FFIELDC
--R lcm : (%,%)-> % if R has EUCDOM or R has EUCDOM and R has PFECAT
--R lcm : List(%) -> % if R has EUCDOM or R has EUCDOM and R has PFECAT
--R lift : % -> SparseUnivariatePolynomial(R)
--R log : % -> % if R has TRANFUN
--R lookup : % -> PositiveInteger if R has FINITE
--R max : (%,%)-> % if R has ORDSET
--R min : (%,%)-> % if R has ORDSET
--R minimalPolynomial : % -> SparseUnivariatePolynomial(R) if R has FIELD
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed") if R has EUCDOM
--R nextItem : % -> Union(%,"failed") if R has FFIELDC
--R nthRoot : (% ,Integer) -> % if R has RADCAT and R has TRANFUN
--R order : % -> OnePointCompletion(PositiveInteger) if R has FFIELDC
--R order : % -> PositiveInteger if R has FFIELDC
--R patternMatch : (% ,Pattern(Float),PatternMatchResult(Float,%)) -> PatternMatchResult(Float,%)
--R patternMatch : (% ,Pattern(Integer),PatternMatchResult(Integer,%)) -> PatternMatchResult(Integer,%)
--R polarCoordinates : % -> Record(r: R,phi: R) if R has RNS and R has TRANFUN
--R prime? : % -> Boolean if R has EUCDOM and R has PFECAT or R has FIELD
--R primeFrobenius : % -> % if R has FFIELDC
--R primeFrobenius : (% ,NonNegativeInteger) -> % if R has FFIELDC
--R primitive? : % -> Boolean if R has FFIELDC
--R primitiveElement : () -> % if R has FFIELDC
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %) if R has EUCDOM
--R ?quo? : (%,%)-> % if R has EUCDOM
--R random : () -> % if R has FINITE
--R rational : % -> Fraction(Integer) if R has INS
--R rational? : % -> Boolean if R has INS
--R rationalIfCan : % -> Union(Fraction(Integer),"failed") if R has INS
--R reduce : Fraction(SparseUnivariatePolynomial(R)) -> Union(%,"failed") if R has FIELD
--R reduce : SparseUnivariatePolynomial(R) -> %
--R reducedSystem : Matrix(%) -> Matrix(R)
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(R),vec: Vector(R))
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Integer),vec: Vector(Integer)) if R has LINEXP(INT)
--R reducedSystem : Matrix(%) -> Matrix(Integer) if R has LINEXP(INT)
--R regularRepresentation : % -> Matrix(R)
--R regularRepresentation : (% ,Vector(%)) -> Matrix(R)
--R ?rem? : (%,%)-> % if R has EUCDOM

```

```

--R representationType : () -> Union("prime",polynomial,normal,cyclic) if R has FFIELDC
--R represents : (Vector(R),Vector(%)) -> %
--R retract : % -> Fraction(Integer) if R has RETRACT(FRAC(INT))
--R retract : % -> Integer if R has RETRACT(INT)
--R retractIfCan : % -> Union(R,"failed")
--R retractIfCan : % -> Union(Fraction(Integer),"failed") if R has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer,"failed") if R has RETRACT(INT)
--R sec : % -> % if R has TRANFUN
--R sech : % -> % if R has TRANFUN
--R sin : % -> % if R has TRANFUN
--R sinh : % -> % if R has TRANFUN
--R size : () -> NonNegativeInteger if R has FINITE
--R sizeLess? : (%,%) -> Boolean if R has EUCDOM
--R solveLinearPolynomialEquation : (List(SparseUnivariatePolynomial(%)),SparseUnivariatePolynomial(%)) -> U
--R sqrt : % -> % if R has RADCAT and R has TRANFUN
--R squareFree : % -> Factored(%) if R has EUCDOM and R has PFECAT or R has FIELD
--R squareFreePart : % -> % if R has EUCDOM and R has PFECAT or R has FIELD
--R squareFreePolynomial : SparseUnivariatePolynomial(%) -> Factored(SparseUnivariatePolynomial(%)) if R has
--R subtractIfCan : (%,%) -> Union(%, "failed")
--R tableForDiscreteLogarithm : Integer -> Table(PositiveInteger,NonNegativeInteger) if R has FFIELDC
--R tan : % -> % if R has TRANFUN
--R tanh : % -> % if R has TRANFUN
--R traceMatrix : Vector(%) -> Matrix(R)
--R unit? : % -> Boolean if R has INTDOM or R has EUCDOM and R has PFECAT
--R unitCanonical : % -> % if R has INTDOM or R has EUCDOM and R has PFECAT
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %) if R has INTDOM or R has EUCDOM and R has PI
--R
--E 1

)spool
)lisp (bye)

```

— ComplexCategory.help —

```

=====
ComplexCategory examples
=====

```

This category represents the extension of a ring by a square root of -1.

See Also:

o)show ComplexCategory

See:

- ⇐ “CommutativeRing” (COMRING) [10](#) on page [896](#)
- ⇐ “DifferentialExtension” (DIFEXT) [11](#) on page [1005](#)
- ⇐ “FullyEvalableOver” (FEVALAB) [4](#) on page [209](#)
- ⇐ “FullyPatternMatchable” (FPATMAB) [3](#) on page [141](#)
- ⇐ “FullyRetractableTo” (FRETRCT) [3](#) on page [136](#)
- ⇐ “MonogenicAlgebra” (MONOGEN) [19](#) on page [1651](#)
- ⇐ “Patternable” (PATAB) [2](#) on page [86](#)
- ⇐ “FullyLinearlyExplicitRingOver” (FLINEXP) [11](#) on page [1012](#)

Exports:

| | | |
|-----------------------|----------------------------|-------------------------------|
| 0 | 1 | abs |
| acos | acosh | acot |
| acoth | acsc | acsch |
| argument | asec | asech |
| asin | asinh | associates? |
| atan | atanh | basis |
| characteristic | characteristicPolynomial | charthRoot |
| coerce | complex | conditionP |
| conjugate | convert | coordinates |
| cos | cosh | cot |
| coth | createPrimitiveElement | csc |
| csch | D | definingPolynomial |
| derivationCoordinates | differentiate | discreteLog |
| discriminant | divide | euclideanSize |
| eval | exp | expressIdealMember |
| exquo | extendedEuclidean | factor |
| factorPolynomial | factorSquareFreePolynomial | factorsOfCyclicGroupSize |
| gcd | gcdPolynomial | generator |
| hash | imag | imaginary |
| index | init | inv |
| latex | lcm | lift |
| log | lookup | map |
| max | min | minimalPolynomial |
| multiEuclidean | nextItem | norm |
| nthRoot | one? | order |
| patternMatch | pi | polarCoordinates |
| prime? | primeFrobenius | primitive? |
| primitiveElement | principalIdeal | random |
| rank | rational | rational? |
| rationalIfCan | real | recip |
| reduce | reducedSystem | regularRepresentation |
| represents | representationType | retract |
| retractIfCan | sample | sec |
| sech | sin | sinh |
| size | sizeLess? | solveLinearPolynomialEquation |
| sqrt | squareFree | squareFreePart |
| squareFreePolynomial | subtractIfCan | tableForDiscreteLogarithm |
| tan | tanh | trace |
| traceMatrix | unit? | unitCanonical |
| unitNormal | zero? | ?*? |
| ?**? | ?+? | ?-? |
| -? | ?=? | ?^? |
| ?~=? | ?/? | ?<? |
| ?<=? | ?>? | ?>=? |
| ?..? | ?quo? | ?rem? |

Attributes Exported:

- if #1 has multiplicativeValuation then multiplicativeValuation where **multiplicativeValuation** implies $\text{euclideanSize}(a*b) = \text{euclideanSize}(a) * \text{euclideanSize}(b)$.
- if #1 has additiveValuation then additiveValuation where **additiveValuation** implies $\text{euclideanSize}(a*b) = \text{euclideanSize}(a) + \text{euclideanSize}(b)$.
- if #1 has Field then canonicalsClosed where **canonicalsClosed** is true if $\text{unitCanonical}(a) * \text{unitCanonical}(b) = \text{unitCanonical}(a*b)$.
- if #1 has Field then canonicalUnitNormal where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is $\text{associates?}(a,b)$ returns true if and only if $\text{unitCanonical}(a) = \text{unitCanonical}(b)$.
- if #1 has IntegralDomain or #1 has both EuclideanDomain and PolynomialFactorizationExplicit then noZeroDivisors where **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **commutative**("*") is true if it has an operation " * " : $(D,D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation recip can only return "failed" if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.
- **complex** means that this domain has $\sqrt{-1}$
- **nil**

These are directly exported but not implemented:

```

abs : % -> % if R has RNS
argument : % -> R if R has TRANFUN
complex : (R,R) -> %
conjugate : % -> %
exquo : (% ,R) -> Union(%,"failed") if R has INTDOM
imag : % -> R
imaginary : () -> %
norm : % -> R
polarCoordinates : % -> Record(r: R,phi: R) if R has RNS and R has TRANFUN
rational : % -> Fraction Integer if R has INS
rational? : % -> Boolean if R has INS
rationalIfCan : % -> Union(Fraction Integer,"failed") if R has INS
real : % -> R

```

These are implemented by this category:

```

acos : % -> % if R has TRANFUN
acosh : % -> % if R has TRANFUN
asin : % -> % if R has TRANFUN
asinh : % -> % if R has TRANFUN
atan : % -> % if R has TRANFUN
atanh : % -> % if R has TRANFUN
characteristic : () -> NonNegativeInteger
characteristicPolynomial : % -> SparseUnivariatePolynomial R
coerce : % -> OutputForm
convert : % -> Complex DoubleFloat if R has REAL
convert : % -> Complex Float if R has REAL
convert : % -> InputForm if R has KONVERT INFORM
convert : % -> Pattern Float if R has KONVERT PATTERN FLOAT
convert : % -> Pattern Integer if R has KONVERT PATTERN INT
coordinates : % -> Vector R
coordinates : (%,Vector %) -> Vector R
cos : % -> % if R has TRANFUN
cosh : % -> % if R has TRANFUN
definingPolynomial : () -> SparseUnivariatePolynomial R
differentiate : (%,(R -> R)) -> %
discriminant : () -> R
divide : (%,%) -> Record(quotient: %,remainder: %) if R has EUCDOM
euclideanSize : % -> NonNegativeInteger if R has EUCDOM
exp : % -> % if R has TRANFUN
exquo : (%,%) -> Union(%, "failed") if R has INTDOM or R has EUCDOM and R has PFECAT
factorPolynomial : SparseUnivariatePolynomial % -> Factored SparseUnivariatePolynomial % if R has EUCDOM and R has PFECAT
factorSquareFreePolynomial : SparseUnivariatePolynomial % -> Factored SparseUnivariatePolynomial % if R has EUCDOM and R has PFECAT
inv : % -> % if R has FIELD
lift : % -> SparseUnivariatePolynomial R
log : % -> % if R has TRANFUN
map : ((R -> R),%) -> %
minimalPolynomial : % -> SparseUnivariatePolynomial R if R has FIELD
patternMatch : (%,Pattern Integer,PatternMatchResult(Integer,%)) -> PatternMatchResult(Integer,%) if R has PATMATCH
patternMatch : (%,Pattern Float,PatternMatchResult(Float,%)) -> PatternMatchResult(Float,%) if R has PATMATCH
pi : () -> % if R has TRANFUN
rank : () -> PositiveInteger
recip : % -> Union(%, "failed")
reduce : SparseUnivariatePolynomial R -> %
reducedSystem : Matrix % -> Matrix R
reducedSystem : Matrix % -> Matrix Integer if R has LINEXP INT
retract : % -> R
retractIfCan : % -> Union(R, "failed")
sin : % -> % if R has TRANFUN
sinh : % -> % if R has TRANFUN
solveLinearPolynomialEquation : (List SparseUnivariatePolynomial %,SparseUnivariatePolynomial %) -> Union(%, "failed")
tan : % -> % if R has TRANFUN
tanh : % -> % if R has TRANFUN
trace : % -> R
unitNormal : % -> Record(unit: %,canonical: %,associate: %) if R has INTDOM or R has EUCDOM and R has PFECAT
?=? : (%,%) -> Boolean

```

```

?+? : (%,% ) -> %
-? : % -> %
?*? : (%,% ) -> %
?*? : (R,% ) -> %
?*? : (Integer,% ) -> %
?<? : (%,% ) -> Boolean if R has ORDSET
?*?* : (% ,Fraction Integer) -> % if R has RADCAT and R has TRANFUN
?rem? : (%,% ) -> % if R has EUCDOM
?quo? : (%,% ) -> % if R has EUCDOM

```

These exports come from (p1651) MonogenicAlgebra(R,S)
 where R:CommutativeRing and S:SparseUnivariatePolynomial(R):

```

0 : () -> %
1 : () -> %
associates? : (%,% ) -> Boolean if R has INTDOM or R has EUCDOM and R has PFECAT
basis : () -> Vector %
charthRoot : % -> Union(%,"failed") if and(has($,CharacteristicNonZero),AND(has(R,EuclideanDomain),AND(has(R,Field),has(R,DifferentialRing)))) or R has DIFRING or and(has(R,DifferentialRing),has(R,Field))
charthRoot : % -> % if R has FFIELDC
coerce : R -> %
coerce : % -> % if R has INTDOM or R has EUCDOM and R has PFECAT
coerce : Integer -> %
coerce : Fraction Integer -> % if R has FIELD or R has RETRACT FRAC INT
conditionP : Matrix % -> Union(Vector %,"failed") if and(has($,CharacteristicNonZero),AND(has(R,EuclideanDomain),AND(has(R,Field),has(R,DifferentialRing)))) or R has DIFRING or and(has(R,DifferentialRing),has(R,Field))
convert : SparseUnivariatePolynomial R -> %
convert : Vector R -> %
convert : % -> Vector R
convert : % -> SparseUnivariatePolynomial R
coordinates : Vector % -> Matrix R
coordinates : (Vector %,Vector %) -> Matrix R
createPrimitiveElement : () -> % if R has FFIELDC
D : (%,(R -> R)) -> %
D : (%,(R -> R),NonNegativeInteger) -> %
D : % -> % if and(has(R,Field),has(R,DifferentialRing)) or R has DIFRING or and(has(R,DifferentialRing),has(R,Field))
D : (% ,NonNegativeInteger) -> % if and(has(R,Field),has(R,DifferentialRing)) or R has DIFRING or and(has(R,DifferentialRing),has(R,Field))
D : (% ,List Symbol,List NonNegativeInteger) -> % if R has PDRING SYMBOL
D : (% ,Symbol,NonNegativeInteger) -> % if R has PDRING SYMBOL
D : (% ,List Symbol) -> % if R has PDRING SYMBOL
D : (% ,Symbol) -> % if R has PDRING SYMBOL
derivationCoordinates : (Vector %,(R -> R)) -> Matrix R if R has FIELD
differentiate : (% ,NonNegativeInteger) -> % if and(has(R,Field),has(R,DifferentialRing)) or R has DIFRING or and(has(R,DifferentialRing),has(R,Field))
differentiate : (% ,List Symbol) -> % if R has PDRING SYMBOL
differentiate : (% ,Symbol,NonNegativeInteger) -> % if R has PDRING SYMBOL
differentiate : (% ,List Symbol,List NonNegativeInteger) -> % if R has PDRING SYMBOL
differentiate : (% ,(R -> R),NonNegativeInteger) -> %
differentiate : % -> % if and(has(R,Field),has(R,DifferentialRing)) or R has DIFRING or and(has(R,DifferentialRing),has(R,Field))
differentiate : (% ,Symbol) -> % if R has PDRING SYMBOL
discreteLog : (%,% ) -> Union(NonNegativeInteger,"failed") if R has FFIELDC
discreteLog : % -> NonNegativeInteger if R has FFIELDC
discriminant : Vector % -> R

```

```

expressIdealMember : (List %,%) -> Union(List %,"failed") if R has EUCDOM
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %) if R has EUCDOM
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed") if R has EUCDOM
factor : % -> Factored % if R has EUCDOM and R has PFECAT or R has FIELD
factorsOfCyclicGroupSize : () -> List Record(factor: Integer,exponent: Integer) if R has FFIELDC
gcd : (%,%) -> % if R has EUCDOM or R has EUCDOM and R has PFECAT
gcd : List % -> % if R has EUCDOM or R has EUCDOM and R has PFECAT
gcdPolynomial : (SparseUnivariatePolynomial %,SparseUnivariatePolynomial %) -> SparseUnivariatePolynomial %
generator : () -> %
hash : % -> SingleInteger
index : PositiveInteger -> % if R has FINITE
init : () -> % if R has FFIELDC
latex : % -> String
lcm : (%,%) -> % if R has EUCDOM or R has EUCDOM and R has PFECAT
lcm : List % -> % if R has EUCDOM or R has EUCDOM and R has PFECAT
lookup : % -> PositiveInteger if R has FINITE
multiEuclidean : (List %,%) -> Union(List %,"failed") if R has EUCDOM
nextItem : % -> Union(%,"failed") if R has FFIELDC
one? : % -> Boolean
order : % -> OnePointCompletion PositiveInteger if R has FFIELDC
order : % -> PositiveInteger if R has FFIELDC
prime? : % -> Boolean if R has EUCDOM and R has PFECAT or R has FIELD
primeFrobenius : % -> % if R has FFIELDC
primeFrobenius : (%,NonNegativeInteger) -> % if R has FFIELDC
primitive? : % -> Boolean if R has FFIELDC
primitiveElement : () -> % if R has FFIELDC
principalIdeal : List % -> Record(coef: List %,generator: %) if R has EUCDOM
random : () -> % if R has FINITE
reduce : Fraction SparseUnivariatePolynomial R -> Union(%,"failed") if R has FIELD
reducedSystem : (Matrix %,Vector %) -> Record(mat: Matrix R,vec: Vector R)
reducedSystem : (Matrix %,Vector %) -> Record(mat: Matrix Integer,vec: Vector Integer) if R has LINEXP INT
regularRepresentation : % -> Matrix R
regularRepresentation : (%,Vector %) -> Matrix R
representationType : () -> Union("prime",polynomial,normal,cyclic) if R has FFIELDC
represents : (Vector R,Vector %) -> %
represents : Vector R -> %
retract : % -> Fraction Integer if R has RETRACT FRAC INT
retract : % -> Integer if R has RETRACT INT
retractIfCan : % -> Union(Fraction Integer,"failed") if R has RETRACT FRAC INT
retractIfCan : % -> Union(Integer,"failed") if R has RETRACT INT
sample : () -> %
size : () -> NonNegativeInteger if R has FINITE
sizeLess? : (%,%) -> Boolean if R has EUCDOM
subtractIfCan : (%,%) -> Union(%,"failed")
squareFree : % -> Factored % if R has EUCDOM and R has PFECAT or R has FIELD
squareFreePart : % -> % if R has EUCDOM and R has PFECAT or R has FIELD
tableForDiscreteLogarithm : Integer -> Table(PositiveInteger,NonNegativeInteger) if R has FFIELDC
traceMatrix : () -> Matrix R
traceMatrix : Vector % -> Matrix R
unit? : % -> Boolean if R has INTDOM or R has EUCDOM and R has PFECAT

```



```

unitCanonical : % -> % if R has INTDOM or R has EUCDOM and R has PFECAT
zero? : % -> Boolean
?/? : (%,% ) -> % if R has FIELD
?*? : (% ,Fraction Integer) -> % if R has FIELD
?*? : (Fraction Integer,% ) -> % if R has FIELD
***? : (% ,Integer) -> % if R has FIELD
?^? : (% ,Integer) -> % if R has FIELD
?*? : (PositiveInteger,% ) -> %
?*? : (NonNegativeInteger,% ) -> %
?*? : (% ,R) -> %
?~? : (% ,%) -> %
?*? : (% ,NonNegativeInteger) -> %
?*? : (% ,PositiveInteger) -> %
?^? : (% ,NonNegativeInteger) -> %
?^? : (% ,PositiveInteger) -> %

```

These exports come from (p209) FullyEvalableOver(R:CommutativeRing)

```

?.? : (% ,R) -> % if R has ELTAB(R,R)
eval : (% ,Equation R) -> % if R has EVALAB R
eval : (% ,List Symbol,List R) -> % if R has IEVALAB(SYMBOL,R)
eval : (% ,List Equation R) -> % if R has EVALAB R
eval : (% ,R,R) -> % if R has EVALAB R
eval : (% ,List R,List R) -> % if R has EVALAB R
eval : (% ,Symbol,R) -> % if R has IEVALAB(SYMBOL,R)

```

These exports come from (p896) CommutativeRing():

```

?~=? : (% ,%) -> Boolean

```

These exports come from (p269) OrderedSet():

```

max : (% ,%) -> % if R has ORDSET
min : (% ,%) -> % if R has ORDSET
?<=? : (% ,%) -> Boolean if R has ORDSET
?>? : (% ,%) -> Boolean if R has ORDSET
?>=? : (% ,%) -> Boolean if R has ORDSET

```

These exports come from (p92) RadicalCategory():

```

nthRoot : (% ,Integer) -> % if R has RADCAT and R has TRANFUN
sqrt : % -> % if R has RADCAT and R has TRANFUN

```

These exports come from (p166) TranscendentalFunctionCategory():

```

acot : % -> % if R has TRANFUN
acoth : % -> % if R has TRANFUN
acsc : % -> % if R has TRANFUN
acsch : % -> % if R has TRANFUN

```

```

asec : % -> % if R has TRANFUN
asech : % -> % if R has TRANFUN
cot : % -> % if R has TRANFUN
coth : % -> % if R has TRANFUN
csc : % -> % if R has TRANFUN
csch : % -> % if R has TRANFUN
sec : % -> % if R has TRANFUN
sech : % -> % if R has TRANFUN
?*** : (%,% ) -> % if R has TRANFUN

```

These exports come from (p1253) PolynomialFactorizationExplicit():

```

squareFreePolynomial : SparseUnivariatePolynomial % ->
  Factored SparseUnivariatePolynomial % if R has EUCDOM and R has PFECAT

```

— category COMPCAT ComplexCategory —

```

)abbrev category COMPCAT ComplexCategory
++ Date Last Updated: 18 March 1994
++ Description:
++ This category represents the extension of a ring by a square root of -1.

ComplexCategory(R:CommutativeRing): Category ==
  Join(MonogenicAlgebra(R, SparseUnivariatePolynomial R), FullyRetractableTo R,
    DifferentialExtension R, FullyEvaluableOver R, FullyPatternMatchable(R),
    Patternable(R), FullyLinearlyExplicitRingOver R, CommutativeRing) with
    complex                ++ indicates that % has sqrt(-1)
    imaginary:  () -> %      ++ imaginary() = sqrt(-1) = %i.
    conjugate:  % -> %       ++ conjugate(x + %i y) returns x - %i y.
    complex :   (R, R) -> %   ++ complex(x,y) constructs x + %i*y.
    imag      :  % -> R       ++ imag(x) returns imaginary part of x.
    real      :  % -> R       ++ real(x) returns real part of x.
    norm      :  % -> R       ++ norm(x) returns x * conjugate(x)
    if R has OrderedSet then OrderedSet
    if R has IntegralDomain then
      IntegralDomain
      _exquo : (% ,R) -> Union(%,"failed")
      ++ exquo(x, r) returns the exact quotient of x by r, or
      ++ "failed" if r does not divide x exactly.
    if R has EuclideanDomain then EuclideanDomain
    if R has multiplicativeValuation then multiplicativeValuation
    if R has additiveValuation then additiveValuation
    if R has Field then
      -- this is a lie; we must know that
      Field
      -- x**2+1 is irreducible in R
    if R has ConvertibleTo InputForm then ConvertibleTo InputForm
    if R has CharacteristicZero then CharacteristicZero
    if R has CharacteristicNonZero then CharacteristicNonZero
    if R has RealConstant then
      ConvertibleTo Complex DoubleFloat

```

```

    ConvertibleTo Complex Float
if R has RealNumberSystem then
  abs: % -> %
    ++ abs(x) returns the absolute value of x = sqrt(norm(x)).
if R has TranscendentalFunctionCategory then
  TranscendentalFunctionCategory
  argument: % -> R
    ++ argument(x) returns the angle made by (0,1) and (0,x).
if R has RadicalCategory then RadicalCategory
if R has RealNumberSystem then
  polarCoordinates: % -> Record(r:R, phi:R)
    ++ polarCoordinates(x) returns (r, phi) such that
    ++ x = r * exp(%i * phi).
if R has IntegerNumberSystem then
  rational? : % -> Boolean
    ++ rational?(x) tests if x is a rational number.
  rational : % -> Fraction Integer
    ++ rational(x) returns x as a rational number.
    ++ Error: if x is not a rational number.
  rationalIfCan: % -> Union(Fraction Integer, "failed")
    ++ rationalIfCan(x) returns x as a rational number, or
    ++ "failed" if x is not a rational number.
if R has PolynomialFactorizationExplicit and R has EuclideanDomain then
  PolynomialFactorizationExplicit
add
  import MatrixCategoryFunctions2(% , Vector % , Vector % , Matrix % ,
                                R , Vector R , Vector R , Matrix R)
  SUP ==> SparseUnivariatePolynomial
  characteristicPolynomial x ==
    v := monomial(1,1)$SUP(R)
    v**2 - trace(x)*v**1 + norm(x)*v**0
if R has PolynomialFactorizationExplicit and R has EuclideanDomain then
  SupR ==> SparseUnivariatePolynomial R
  Sup ==> SparseUnivariatePolynomial %
  import FactoredFunctionUtilities Sup
  import UnivariatePolynomialCategoryFunctions2(R,SupR,%,Sup)
  import UnivariatePolynomialCategoryFunctions2(% ,Sup ,R ,SupR)
  pp,qq:Sup
  if R has IntegerNumberSystem then
    myNextPrime: (% ,NonNegativeInteger) -> %
    myNextPrime(x,n ) == -- prime is actually in R, and = 3(mod 4)
      xr:=real(x)-4::R
      while not prime? xr repeat
        xr:=xr-4::R
      complex(xr,0)
    --!TT:=InnerModularGcd(% ,Sup,32719 :: % ,myNextPrime)
    --!gcdPolynomial(pp,qq) == modularGcd(pp,qq)$TT
    solveLinearPolynomialEquation(lp:List Sup,p:Sup) ==
      solveLinearPolynomialEquation(lp,p)$ComplexIntegerSolveLinearPolynomialEquation(R)
  normPolynomial: Sup -> SupR

```

```

normPolynomial pp ==
  map(z+>retract(z@%)::R,pp * map(conjugate,pp))
factorPolynomial pp ==
  refine(squareFree pp,factorSquareFreePolynomial)
factorSquareFreePolynomial pp ==
  pnorm:=normPolynomial pp
  k:=0
  while degree gcd(pnorm,differentiate pnorm)>0 repeat
    k:=k+1
    pnorm:=normPolynomial
      elt(pp,monomial(1,1)-monomial(complex(0,k),0))
  fR:=factorSquareFreePolynomial pnorm
  numberOfFactors fR = 1 =>
    makeFR(1,["irred",pp,1])
  lF>List Record(flg:Union("nil", "sqfr", "irred", "prime"),
    fctr:Sup, xpnt:Integer):=[]
  for u in factorList fR repeat
    p1:=map((z:R):%+>z::%,u.fctr)
    if not zero? k then
      p1:=elt(p1,monomial(1,1)+monomial(complex(0,k),0))
      p2:=gcd(p1,pp)
      lF:=cons(["irred",p2,1],lF)
      pp:=(pp exquo p2)::Sup
  makeFR(pp,lF)
rank() == 2
discriminant() == -4 :: R
norm x == real(x)**2 + imag(x)**2
trace x == 2 * real x
imaginary() == complex(0, 1)
conjugate x == complex(real x, - imag x)
characteristic() == characteristic()$R
map(fn, x) == complex(fn real x, fn imag x)
x = y == real(x) = real(y) and imag(x) = imag(y)
x + y == complex(real x + real y, imag x + imag y)
- x == complex(- real x, - imag x)
r:R * x:% == complex(r * real x, r * imag x)
coordinates(x:%) == [real x, imag x]
n:Integer * x:% == complex(n * real x, n * imag x)
differentiate(x:%, d:R -> R) == complex(d real x, d imag x)

definingPolynomial() ==
  monomial(1,2)$(SUP R) + monomial(1,0)$(SUP R)

reduce(pol:SUP R) ==
  part:= (monicDivide(pol,definingPolynomial()))remainder
  complex(coefficient(part,0),coefficient(part,1))

lift(x) == monomial(real x,0)$(SUP R)+monomial(imag x,1)$(SUP R)

minimalPolynomial x ==

```

```

zero? imag x =>
  monomial(1, 1)$(SUP R) - monomial(real x, 0)$(SUP R)
monomial(1, 2)$(SUP R) - monomial(trace x, 1)$(SUP R)
  + monomial(norm x, 0)$(SUP R)

coordinates(x:%, v:Vector %):Vector(R) ==
  ra := real(a := v(minIndex v))
  rb := real(b := v(maxIndex v))
  (#v ^= 2) or
    ((d := recip(ra * (ib := imag b) - (ia := imag a) * rb))
     case "failed") =>error "coordinates: vector is not a basis"
  rx := real x
  ix := imag x
  [d::R * (rx * ib - ix * rb), d::R * (ra * ix - ia * rx)]

coerce(x:%):OutputForm ==
  re := (r := real x)::OutputForm
  ie := (i := imag x)::OutputForm
  zero? i => re
  outi := "%i"::Symbol::OutputForm
  ip :=
--      one? i => outi
--      (i = 1) => outi
--      one?(-i) => -outi
--      ((-i) = 1) => -outi
  ie * outi
  zero? r => ip
  re + ip

retract(x:%):R ==
  not zero?(imag x) =>
    error "Imaginary part is nonzero. Cannot retract."
  real x

retractIfCan(x:%):Union(R, "failed") ==
  not zero?(imag x) => "failed"
  real x

x:% * y:% ==
  complex(real x * real y - imag x * imag y,
    imag x * real y + imag y * real x)

reducedSystem(m:Matrix %):Matrix R ==
  vertConcat(map(real, m), map(imag, m))

reducedSystem(m:Matrix %, v:Vector %):
Record(mat:Matrix R, vec:Vector R) ==
  rh := reducedSystem(v::Matrix %)%Matrix(R)
  [reducedSystem(m)%Matrix(R), column(rh, minColIndex rh)]

```

```

if R has RealNumberSystem then
  abs(x:%):% == (sqrt norm x)::%

if R has RealConstant then
  convert(x:%):Complex(DoubleFloat) ==
    complex(convert(real x)@DoubleFloat, convert(imag x)@DoubleFloat)

  convert(x:%):Complex(Float) ==
    complex(convert(real x)@Float, convert(imag x)@Float)

if R has ConvertibleTo InputForm then
  convert(x:%):InputForm ==
    convert([convert("complex"::Symbol), convert real x,
      convert imag x]$List(InputForm))@InputForm

if R has ConvertibleTo Pattern Integer then
  convert(x:%):Pattern Integer ==
    convert(x)$ComplexPattern(Integer, R, %)
if R has ConvertibleTo Pattern Float then
  convert(x:%):Pattern Float ==
    convert(x)$ComplexPattern(Float, R, %)

if R has PatternMatchable Integer then
  patternMatch(x:%, p:Pattern Integer,
    l:PatternMatchResult(Integer, %)) ==
    patternMatch(x, p, l)$ComplexPatternMatch(Integer, R, %)

if R has PatternMatchable Float then
  patternMatch(x:%, p:Pattern Float,
    l:PatternMatchResult(Float, %)) ==
    patternMatch(x, p, l)$ComplexPatternMatch(Float, R, %)

if R has OrderedSet then
  x < y ==
    real x = real y => imag x < imag y
    real x < real y

if R has IntegerNumberSystem then
  rational? x == zero? imag x

  rational x ==
    zero? imag x => rational real x
    error "Not a rational number"

  rationalIfCan x ==
    zero? imag x => rational real x
    "failed"

if R has Field then

```



```

    euclideanSize x == euclideanSize(real(x)**2 + imag(x)**2)$R
if R has IntegerNumberSystem then
  x rem y ==
    zero? imag y =>
      yr:=real y
      complex(symmetricRemainder(real(x), yr),
              symmetricRemainder(imag(x), yr))
    divide(x, y).remainder
  x quo y ==
    zero? imag y =>
      yr:= real y
      xr:= real x
      xi:= imag x
      complex((xr-symmetricRemainder(xr,yr)) quo yr,
              (xi-symmetricRemainder(xi,yr)) quo yr)
    divide(x, y).quotient

else
  x rem y ==
    zero? imag y =>
      yr:=real y
      complex(real(x) rem yr,imag(x) rem yr)
    divide(x, y).remainder
  x quo y ==
    zero? imag y => complex(real x quo real y,imag x quo real y)
    divide(x, y).quotient

divide(x, y) ==
  r := norm y
  y1 := conjugate y
  xx := x * y1
  x1 := real(xx) rem r
  a := x1
  if x1^=0 and sizeLess?(r, 2 * x1) then
    a := x1 - r
    if sizeLess?(x1, a) then a := x1 + r
  x2 := imag(xx) rem r
  b := x2
  if x2^=0 and sizeLess?(r, 2 * x2) then
    b := x2 - r
    if sizeLess?(x2, b) then b := x2 + r
  y1 := (complex(a, b) exquo y1)::%
  [((x - y1) exquo y)::%, y1]

if R has TranscendentalFunctionCategory then
  half := recip(2::R)::R

if R has RealNumberSystem then
  atan2loc(y: R, x: R): R ==
    pi1 := pi()$R

```



```

pi2 := pi1 * half
x = 0 => if y >= 0 then pi2 else -pi2

-- Atan in (-pi/2,pi/2]
theta := atan(y * recip(x)::R)
while theta <= -pi2 repeat theta := theta + pi1
while theta > pi2 repeat theta := theta - pi1

x >= 0 => theta      -- I or IV

if y >= 0 then
  theta + pi1      -- II
else
  theta - pi1      -- III

argument x == atan2loc(imag x, real x)

else
-- Not ordered so dictate two quadrants
argument x ==
  zero? real x => pi()$R * half
  atan(imag(x) * recip(real x)::R)

pi() == pi()$R :: %

if R is DoubleFloat then
  stoc ==> S_-TO_-C$Lisp
  ctos ==> C_-TO_-S$Lisp

  exp  x == ctos EXP(stoc x)$Lisp
  log  x == ctos LOG(stoc x)$Lisp

  sin  x == ctos SIN(stoc x)$Lisp
  cos  x == ctos COS(stoc x)$Lisp
  tan  x == ctos TAN(stoc x)$Lisp
  asin x == ctos ASIN(stoc x)$Lisp
  acos x == ctos ACOS(stoc x)$Lisp
  atan x == ctos ATAN(stoc x)$Lisp

  sinh x == ctos SINH(stoc x)$Lisp
  cosh x == ctos COSH(stoc x)$Lisp
  tanh x == ctos TANH(stoc x)$Lisp
  asinh x == ctos ASINH(stoc x)$Lisp
  acosh x == ctos ACOSH(stoc x)$Lisp
  atanh x == ctos ATANH(stoc x)$Lisp

else
  atan x ==
    ix := imaginary()*x
    - imaginary() * half * (log(1 + ix) - log(1 - ix))

```

```

log x ==
  complex(log(norm x) * half, argument x)

exp x ==
  e := exp real x
  complex(e * cos imag x, e * sin imag x)

cos x ==
  e := exp(imaginary() * x)
  half * (e + recip(e)::%)

sin x ==
  e := exp(imaginary() * x)
  - imaginary() * half * (e - recip(e)::%)

if R has RealNumberSystem then
  polarCoordinates x ==
    [sqrt norm x, (negative?(t := argument x) => t + 2 * pi(); t)]

x:% ** q:Fraction(Integer) ==
  zero? q =>
    zero? x => error "0 ** 0 is undefined"
    1
  zero? x => 0
  rx := real x
  zero? imag x and positive? rx => (rx ** q)::%
  zero? imag x and denom q = 2 => complex(0, (-rx)**q)
  ax := sqrt(norm x) ** q
  tx := q::R * argument x
  complex(ax * cos tx, ax * sin tx)

else if R has RadicalCategory then
  x:% ** q:Fraction(Integer) ==
    zero? q =>
      zero? x => error "0 ** 0 is undefined"
      1
    r := real x
    zero?(i := imag x) => (r ** q)::%
    t := numer(q) * recip(denom(q)::R)::R * argument x
    e:R :=
      zero? r => i ** q
      norm(x) ** (q / (2::Fraction(Integer)))
    complex(e * cos t, e * sin t)

```

```

"COMPCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=COMPCAT"];
"COMPCAT" -> "COMRING"
"COMPCAT" -> "DIFEXT"
"COMPCAT" -> "FEVALAB"
"COMPCAT" -> "FPATMAB"
"COMPCAT" -> "FRETRCT"
"COMPCAT" -> "MONOGEN"
"COMPCAT" -> "PATAB"
"COMPCAT" -> "FLINEXP"
"COMPCAT" -> "ORDSET"

```

— COMPCAT.dotfull —

```

"ComplexCategory(R:CommutativeRing)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=COMPCAT"];
"ComplexCategory(R:CommutativeRing)" ->
  "MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"
"ComplexCategory(R:CommutativeRing)" ->
  "FullyRetractableTo(a:CommutativeRing)"
"ComplexCategory(R:CommutativeRing)" ->
  "DifferentialExtension(CommutativeRing)"
"ComplexCategory(R:CommutativeRing)" ->
  "FullyEvaluableOver(CommutativeRing)"
"ComplexCategory(R:CommutativeRing)" ->
  "FullyPatternMatchable(CommutativeRing)"
"ComplexCategory(R:CommutativeRing)" ->
  "Patternable(CommutativeRing)"
"ComplexCategory(R:CommutativeRing)" ->
  "FullyLinearlyExplicitRingOver(a:CommutativeRing)"
"ComplexCategory(R:CommutativeRing)" ->
  "CommutativeRing()"
"ComplexCategory(R:CommutativeRing)" ->
  "OrderedSet()"

```

— COMPCAT.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

```

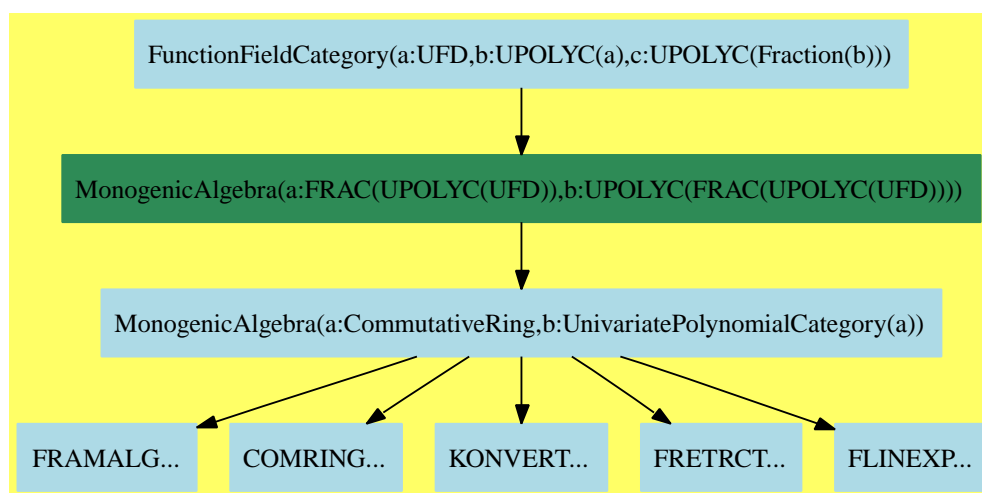
```

"ComplexCategory(R:CommutativeRing)" [color=lightblue];
"ComplexCategory(R:CommutativeRing)" -> "MONOGEN..."
"ComplexCategory(R:CommutativeRing)" -> "FRETRCT..."
"ComplexCategory(R:CommutativeRing)" -> "DIFEXT..."
"ComplexCategory(R:CommutativeRing)" -> "FEVALAB..."
"ComplexCategory(R:CommutativeRing)" -> "FPATMAB..."
"ComplexCategory(R:CommutativeRing)" -> "PATAB..."
"ComplexCategory(R:CommutativeRing)" -> "FLINEXP..."
"ComplexCategory(R:CommutativeRing)" -> "COMRING..."
"ComplexCategory(R:CommutativeRing)" -> "ORDSET..."

"MONOGEN..." [color=lightblue];
"FRETRCT..." [color=lightblue];
"DIFEXT..." [color=lightblue];
"FEVALAB..." [color=lightblue];
"COMRING..." [color=lightblue];
"FPATMAB..." [color=lightblue];
"PATAB..." [color=lightblue];
"FLINEXP..." [color=lightblue];
"ORDSET..." [color=lightblue];
}

```

FunctionFieldCategory (FFCAT)



— FunctionFieldCategory.input —

```

)set break resume
)sys rm -f FunctionFieldCategory.output
)spool FunctionFieldCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show FunctionFieldCategory
--R FunctionFieldCategory(F: UniqueFactorizationDomain,UP: UnivariatePolynomialCategory(t#1),UPU
--R Abbreviation for FunctionFieldCategory is FFCAT
--R This constructor is exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for FFCAT
--R
--R----- Operations -----
--R ??? : (Fraction(UP),%) -> %          ??? : (%,Fraction(UP)) -> %
--R ??? : (%,%) -> %                    ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %      ??? : (%,PositiveInteger) -> %
--R ?+? : (%,%) -> %                    ?-? : (%,%) -> %
--R -? : % -> %                        ?=? : (%,%) -> Boolean
--R 1 : () -> %                        0 : () -> %
--R ?? : (%,PositiveInteger) -> %      basis : () -> Vector(%)
--R branchPoint? : UP -> Boolean        branchPoint? : F -> Boolean
--R coerce : Fraction(UP) -> %          coerce : Integer -> %
--R coerce : % -> OutputForm            convert : UPUP -> %
--R convert : % -> UPUP                 definingPolynomial : () -> UPUP
--R discriminant : () -> Fraction(UP)  elt : (%,F,F) -> F
--R generator : () -> %                 genus : () -> NonNegativeInteger
--R hash : % -> SingleInteger            integral? : (%,UP) -> Boolean
--R integral? : (%,F) -> Boolean         integral? : % -> Boolean
--R integralBasis : () -> Vector(%)     latex : % -> String
--R lift : % -> UPUP                    norm : % -> Fraction(UP)
--R one? : % -> Boolean                 primitivePart : % -> %
--R ramified? : UP -> Boolean            ramified? : F -> Boolean
--R rank : () -> PositiveInteger         rationalPoint? : (F,F) -> Boolean
--R recip : % -> Union(%, "failed")      reduce : UPUP -> %
--R represents : (Vector(UP),UP) -> %    retract : % -> Fraction(UP)
--R sample : () -> %                    singular? : UP -> Boolean
--R singular? : F -> Boolean             trace : % -> Fraction(UP)
--R zero? : % -> Boolean                 ?~=? : (%,%) -> Boolean
--R ??? : (%,Fraction(Integer)) -> % if Fraction(UP) has FIELD
--R ??? : (Fraction(Integer),%) -> % if Fraction(UP) has FIELD
--R ??? : (NonNegativeInteger,%) -> %
--R ??? : (%,Integer) -> % if Fraction(UP) has FIELD
--R ??? : (%,NonNegativeInteger) -> %
--R ?/? : (%,%) -> % if Fraction(UP) has FIELD
--R D : % -> % if and(has(Fraction(UP),Field),has(Fraction(UP),DifferentialRing)) or and(has(Fra
--R D : (%,NonNegativeInteger) -> % if and(has(Fraction(UP),Field),has(Fraction(UP),Differential
--R D : (%,Symbol) -> % if and(has(Fraction(UP),Field),has(Fraction(UP),PartialDifferentialRing(
--R D : (%,List(Symbol)) -> % if and(has(Fraction(UP),Field),has(Fraction(UP),PartialDifferential

```

```

--R D : (% , Symbol, NonNegativeInteger) -> % if and(has(Fraction(UP), Field), has(Fraction(UP), PartialDifferentialRing))
--R D : (% , List(Symbol), List(NonNegativeInteger)) -> % if and(has(Fraction(UP), Field), has(Fraction(UP), PartialDifferentialRing))
--R D : (% , (Fraction(UP) -> Fraction(UP))) -> % if Fraction(UP) has FIELD
--R D : (% , (Fraction(UP) -> Fraction(UP)), NonNegativeInteger) -> % if Fraction(UP) has FIELD
--R ??? : (% , Integer) -> % if Fraction(UP) has FIELD
--R ??? : (% , NonNegativeInteger) -> %
--R absolutelyIrreducible? : () -> Boolean
--R algSplitSimple : (% , (UP -> UP)) -> Record(num: %, den: UP, derivden: UP, gd: UP)
--R associates? : (% , %) -> Boolean if Fraction(UP) has FIELD
--R branchPointAtInfinity? : () -> Boolean
--R characteristic : () -> NonNegativeInteger
--R characteristicPolynomial : % -> UPUP
--R charthRoot : % -> Union(%, "failed") if Fraction(UP) has CHARNZ
--R charthRoot : % -> % if Fraction(UP) has FFIELDC
--R coerce : % -> % if Fraction(UP) has FIELD
--R coerce : Fraction(Integer) -> % if Fraction(UP) has FIELD or Fraction(UP) has RETRACT(FRAC(INT))
--R complementaryBasis : Vector(%) -> Vector(%)
--R conditionP : Matrix(%) -> Union(Vector(%, "failed") if Fraction(UP) has FFIELDC
--R convert : Vector(Fraction(UP)) -> %
--R convert : % -> Vector(Fraction(UP))
--R coordinates : Vector(%) -> Matrix(Fraction(UP))
--R coordinates : % -> Vector(Fraction(UP))
--R coordinates : (Vector(%, Vector(%)) -> Matrix(Fraction(UP))
--R coordinates : (% , Vector(%)) -> Vector(Fraction(UP))
--R createPrimitiveElement : () -> % if Fraction(UP) has FFIELDC
--R derivationCoordinates : (Vector(%, (Fraction(UP) -> Fraction(UP))) -> Matrix(Fraction(UP)) if Fraction(UP) has FIELD
--R differentiate : % -> % if and(has(Fraction(UP), Field), has(Fraction(UP), DifferentialRing)) or and(has(Fraction(UP), Field), has(Fraction(UP), PartialDifferentialRing))
--R differentiate : (% , NonNegativeInteger) -> % if and(has(Fraction(UP), Field), has(Fraction(UP), DifferentialRing))
--R differentiate : (% , Symbol) -> % if and(has(Fraction(UP), Field), has(Fraction(UP), PartialDifferentialRing))
--R differentiate : (% , List(Symbol)) -> % if and(has(Fraction(UP), Field), has(Fraction(UP), PartialDifferentialRing))
--R differentiate : (% , Symbol, NonNegativeInteger) -> % if and(has(Fraction(UP), Field), has(Fraction(UP), PartialDifferentialRing))
--R differentiate : (% , List(Symbol), List(NonNegativeInteger)) -> % if and(has(Fraction(UP), Field), has(Fraction(UP), PartialDifferentialRing))
--R differentiate : (% , (UP -> UP)) -> %
--R differentiate : (% , (Fraction(UP) -> Fraction(UP))) -> % if Fraction(UP) has FIELD
--R differentiate : (% , (Fraction(UP) -> Fraction(UP)), NonNegativeInteger) -> % if Fraction(UP) has FIELD
--R discreteLog : (% , %) -> Union(NonNegativeInteger, "failed") if Fraction(UP) has FFIELDC
--R discreteLog : % -> NonNegativeInteger if Fraction(UP) has FFIELDC
--R discriminant : Vector(%) -> Fraction(UP)
--R divide : (% , %) -> Record(quotient: %, remainder: %) if Fraction(UP) has FIELD
--R elliptic : () -> Union(UP, "failed")
--R enumerate : () -> List(%) if Fraction(UP) has FINITE
--R euclideanSize : % -> NonNegativeInteger if Fraction(UP) has FIELD
--R expressIdealMember : (List(%), %) -> Union(List(%, "failed") if Fraction(UP) has FIELD
--R exquo : (% , %) -> Union(%, "failed") if Fraction(UP) has FIELD
--R extendedEuclidean : (% , %) -> Record(coef1: %, coef2: %, generator: %) if Fraction(UP) has FIELD
--R extendedEuclidean : (% , %, %) -> Union(Record(coef1: %, coef2: %), "failed") if Fraction(UP) has FIELD
--R factor : % -> Factored(%) if Fraction(UP) has FIELD
--R factorsOfCyclicGroupSize : () -> List(Record(factor: Integer, exponent: Integer)) if Fraction(UP) has FIELD
--R gcd : (% , %) -> % if Fraction(UP) has FIELD
--R gcd : List(%) -> % if Fraction(UP) has FIELD

```

```

--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUniva
--R hyperelliptic : () -> Union(UP,"failed")
--R index : PositiveInteger -> % if Fraction(UP) has FINITE
--R init : () -> % if Fraction(UP) has FFIELDC
--R integralAtInfinity? : % -> Boolean
--R integralBasisAtInfinity : () -> Vector(%)
--R integralCoordinates : % -> Record(num: Vector(UP),den: UP)
--R integralDerivationMatrix : (UP -> UP) -> Record(num: Matrix(UP),den: UP)
--R integralMatrix : () -> Matrix(Fraction(UP))
--R integralMatrixAtInfinity : () -> Matrix(Fraction(UP))
--R integralRepresents : (Vector(UP),UP) -> %
--R inv : % -> % if Fraction(UP) has FIELD
--R inverseIntegralMatrix : () -> Matrix(Fraction(UP))
--R inverseIntegralMatrixAtInfinity : () -> Matrix(Fraction(UP))
--R lcm : (%,% ) -> % if Fraction(UP) has FIELD
--R lcm : List(%) -> % if Fraction(UP) has FIELD
--R lookup : % -> PositiveInteger if Fraction(UP) has FINITE
--R minimalPolynomial : % -> UPUP if Fraction(UP) has FIELD
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed") if Fraction(UP) has FIELD
--R nextItem : % -> Union(%,"failed") if Fraction(UP) has FFIELDC
--R nonSingularModel : Symbol -> List(Polynomial(F)) if F has FIELD
--R normalizeAtInfinity : Vector(%) -> Vector(%)
--R numberOfComponents : () -> NonNegativeInteger
--R order : % -> OnePointCompletion(PositiveInteger) if Fraction(UP) has FFIELDC
--R order : % -> PositiveInteger if Fraction(UP) has FFIELDC
--R prime? : % -> Boolean if Fraction(UP) has FIELD
--R primeFrobenius : % -> % if Fraction(UP) has FFIELDC
--R primeFrobenius : (% ,NonNegativeInteger) -> % if Fraction(UP) has FFIELDC
--R primitive? : % -> Boolean if Fraction(UP) has FFIELDC
--R primitiveElement : () -> % if Fraction(UP) has FFIELDC
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %) if Fraction(UP) has FIELD
--R ?quo? : (%,% ) -> % if Fraction(UP) has FIELD
--R ramifiedAtInfinity? : () -> Boolean
--R random : () -> % if Fraction(UP) has FINITE
--R rationalPoints : () -> List(List(F)) if F has FINITE
--R reduce : Fraction(UPUP) -> Union(%,"failed") if Fraction(UP) has FIELD
--R reduceBasisAtInfinity : Vector(%) -> Vector(%)
--R reducedSystem : Matrix(%) -> Matrix(Fraction(UP))
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Fraction(UP)),vec: Vector(Fraction(UP)))
--R reducedSystem : (Matrix(%),Vector(%)) -> Record(mat: Matrix(Integer),vec: Vector(Integer)) if Fraction(UP) has FIELD
--R reducedSystem : Matrix(%) -> Matrix(Integer) if Fraction(UP) has LINEXP(INT)
--R regularRepresentation : % -> Matrix(Fraction(UP))
--R regularRepresentation : (% ,Vector(%)) -> Matrix(Fraction(UP))
--R ?rem? : (%,% ) -> % if Fraction(UP) has FIELD
--R representationType : () -> Union("prime",polynomial,normal,cyclic) if Fraction(UP) has FFIELDC
--R represents : Vector(Fraction(UP)) -> %
--R represents : (Vector(Fraction(UP)),Vector(%)) -> %
--R retract : % -> Fraction(Integer) if Fraction(UP) has RETRACT(FRAC(INT))
--R retract : % -> Integer if Fraction(UP) has RETRACT(INT)
--R retractIfCan : % -> Union(Fraction(UP),"failed")

```

```

--R retractIfCan : % -> Union(Fraction(Integer),"failed") if Fraction(UP) has RETRACT(FRAC(INT))
--R retractIfCan : % -> Union(Integer,"failed") if Fraction(UP) has RETRACT(INT)
--R singularAtInfinity? : () -> Boolean
--R size : () -> NonNegativeInteger if Fraction(UP) has FINITE
--R sizeLess? : (%,% ) -> Boolean if Fraction(UP) has FIELD
--R squareFree : % -> Factored(%) if Fraction(UP) has FIELD
--R squareFreePart : % -> % if Fraction(UP) has FIELD
--R subtractIfCan : (%,% ) -> Union(%, "failed")
--R tableForDiscreteLogarithm : Integer -> Table(PositiveInteger, NonNegativeInteger) if Fraction(UP) has FF
--R traceMatrix : () -> Matrix(Fraction(UP))
--R traceMatrix : Vector(%) -> Matrix(Fraction(UP))
--R unit? : % -> Boolean if Fraction(UP) has FIELD
--R unitCanonical : % -> % if Fraction(UP) has FIELD
--R unitNormal : % -> Record(unit: %, canonical: %, associate: %) if Fraction(UP) has FIELD
--R yCoordinates : % -> Record(num: Vector(UP), den: UP)
--R
--E 1

```

```

)spool
)lisp (bye)

```

— FunctionFieldCategory.help —

```

=====
FunctionFieldCategory examples
=====

```

This category is a model for the function field of a plane algebraic curve.

See Also:

- o)show FunctionFieldCategory

See:

⇐ “MonogenicAlgebra” (MONOGEN) [19](#) on page [1651](#)

Exports:

| | |
|---------------------------|---------------------------------|
| 0 | 1 |
| absolutelyIrreducible? | algSplitSimple |
| associates? | basis |
| branchPoint? | branchPointAtInfinity? |
| characteristic | characteristicPolynomial |
| charthRoot | coerce |
| complementaryBasis | conditionP |
| convert | coordinates |
| createPrimitiveElement | D |
| definingPolynomial | derivationCoordinates |
| differentiate | discreteLog |
| discriminant | divide |
| elliptic | elt |
| euclideanSize | expressIdealMember |
| exquo | extendedEuclidean |
| factor | factorsOfCyclicGroupSize |
| gcd | gcdPolynomial |
| generator | genus |
| hash | hyperelliptic |
| index | init |
| integral? | integralAtInfinity? |
| integralBasis | integralBasisAtInfinity |
| integralCoordinates | integralDerivationMatrix |
| integralMatrix | integralMatrixAtInfinity |
| integralRepresents | inv |
| inverseIntegralMatrix | inverseIntegralMatrixAtInfinity |
| latex | lcm |
| lift | lookup |
| minimalPolynomial | multiEuclidean |
| nextItem | nonSingularModel |
| norm | normalizeAtInfinity |
| numberOfComponents | one? |
| order | prime? |
| primeFrobenius | primitive? |
| primitiveElement | primitivePart |
| principalIdeal | ramified? |
| ramifiedAtInfinity? | rank |
| random | rationalPoints |
| rationalPoint? | recip |
| reduce | reduceBasisAtInfinity |
| reducedSystem | regularRepresentation |
| representationType | represents |
| retract | retractIfCan |
| sample | singular? |
| singularAtInfinity? | size |
| sizeLess? | squareFree |
| squareFreePart | subtractIfCan |
| tableForDiscreteLogarithm | trace |
| traceMatrix | unit? |
| unitCanonical | unitNormal |
| yCoordinates | zero? |
| ?*? | ***? |
| ?+? | ?-? |
| -? | ?=? |
| ?^? | ?~=? |
| ?/? | ?quo? |

Attributes Exported:

- if \$ has Fraction(UPOLYC(UFD)) and Field then noZeroDivisors where **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- if \$ has Fraction(UPOLYC(UFD)) and Field then canonicalUnitNormal where **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?(a,b)** returns true if and only if **unitCanonical(a) = unitCanonical(b)**.
- if \$ has Fraction(UPOLYC(UFD)) and Field then canonicalsClosed where **canonicalsClosed** is true if $\text{unitCanonical}(a) * \text{unitCanonical}(b) = \text{unitCanonical}(a * b)$.
- **commutative("*)** is true if it has an operation " $*$ " : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return "failed" if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x.
- **rightUnitary** is true if $x * 1 = x$ for all x.

These are directly exported but not implemented:

```
branchPointAtInfinity? : () -> Boolean
branchPoint? : UP -> Boolean
branchPoint? : F -> Boolean
integralBasis : () -> Vector %
integralBasisAtInfinity : () -> Vector %
ramifiedAtInfinity? : () -> Boolean
ramified? : UP -> Boolean
ramified? : F -> Boolean
singularAtInfinity? : () -> Boolean
singular? : F -> Boolean
singular? : UP -> Boolean
```

These are implemented by this category:

```
absolutelyIrreducible? : () -> Boolean
algSplitSimple : (%,(UP -> UP)) ->
  Record(num: %,den: UP,derivden: UP,gd: UP)
complementaryBasis : Vector % -> Vector %
differentiate : (%,(UP -> UP)) -> %
elliptic : () -> Union(UP,"failed")
elt : (%,(F,F)) -> F
genus : () -> NonNegativeInteger
hyperelliptic : () -> Union(UP,"failed")
integral? : % -> Boolean
```

```

integral? : (%,F) -> Boolean
integral? : (%,UP) -> Boolean
integralAtInfinity? : % -> Boolean
normalizeAtInfinity : Vector % -> Vector %
numberOfComponents : () -> NonNegativeInteger
primitivePart : % -> %
rationalPoint? : (F,F) -> Boolean
rationalPoints : () -> List List F if F has FINITE
reduceBasisAtInfinity : Vector % -> Vector %
represents : (Vector UP,UP) -> %
yCoordinates : % -> Record(num: Vector UP,den: UP)

```

These exports come from (p1651) MonogenicAlgebra(RF, UPUP)
 where RF:Fraction UP, UP:UnivariatePolynomialCategory F
 F:UniqueFactorizationDomain, and
 UPUP:UnivariatePolynomialCategory Fraction UP

```

0 : () -> %
1 : () -> %
associates? : (%,%) -> Boolean
  if Fraction UP has FIELD
basis : () -> Vector %
characteristic : () -> NonNegativeInteger
characteristicPolynomial : % -> UPUP
charthRoot : % -> Union(%, "failed")
  if Fraction UP has CHARNZ
charthRoot : % -> %
  if Fraction UP has FFIELDC
coerce : % -> %
  if Fraction UP has FIELD
coerce : Fraction Integer -> %
  if Fraction UP has FIELD
  or Fraction UP has RETRACT FRAC INT
coerce : Fraction UP -> %
coerce : Integer -> %
coerce : % -> OutputForm
conditionP : Matrix % -> Union(Vector %, "failed")
  if Fraction UP has FFIELDC
convert : UPUP -> %
convert : % -> UPUP
convert : Vector Fraction UP -> %
convert : % -> Vector Fraction UP
coordinates : Vector % -> Matrix Fraction UP
coordinates : % -> Vector Fraction UP
coordinates : (Vector %,Vector %) -> Matrix Fraction UP
coordinates : (%,Vector %) -> Vector Fraction UP
createPrimitiveElement : () -> %
  if Fraction UP has FFIELDC
D : % -> %
  if

```

```

    and(
      has(Fraction UP,Field),
      has(Fraction UP,DifferentialRing))
  or
    and(
      has(Fraction UP,DifferentialRing),
      has(Fraction UP,Field))
  or Fraction UP has FFIELDC
D : (%,NonNegativeInteger) -> %
if
  and(
    has(Fraction UP,Field),
    has(Fraction UP,DifferentialRing))
  or
    and(
      has(Fraction UP,DifferentialRing),
      has(Fraction UP,Field))
  or Fraction UP has FFIELDC
D : (%,Symbol) -> %
if
  and(
    has(Fraction UP,Field),
    has(Fraction UP,PartialDifferentialRing Symbol))
  or
    and(
      has(Fraction UP,PartialDifferentialRing Symbol),
      has(Fraction UP,Field))
D : (%,List Symbol) -> %
if
  and(
    has(Fraction UP,Field),
    has(Fraction UP,PartialDifferentialRing Symbol))
  or
    and(
      has(Fraction UP,PartialDifferentialRing Symbol),
      has(Fraction UP,Field))
D : (%,Symbol,NonNegativeInteger) -> %
if
  and(
    has(Fraction UP,Field),
    has(Fraction UP,PartialDifferentialRing Symbol))
  or
    and(
      has(Fraction UP,PartialDifferentialRing Symbol),
      has(Fraction UP,Field))
D : (%,List Symbol,List NonNegativeInteger) -> %
if
  and(
    has(Fraction UP,Field),
    has(Fraction UP,PartialDifferentialRing Symbol))

```

```

or
  and(
    has(Fraction UP,PartialDifferentialRing Symbol),
    has(Fraction UP,Field))
D : (%,(Fraction UP -> Fraction UP)) -> %
  if Fraction UP has FIELD
D : (%,(Fraction UP -> Fraction UP),NonNegativeInteger) -> %
  if Fraction UP has FIELD
definingPolynomial : () -> UPUP
derivationCoordinates : (Vector %, (Fraction UP -> Fraction UP))
  -> Matrix Fraction UP
  if Fraction UP has FIELD
differentiate : % -> %
  if
    and(
      has(Fraction UP,Field),
      has(Fraction UP,DifferentialRing))
or
  and(
    has(Fraction UP,DifferentialRing),
    has(Fraction UP,Field))
or Fraction UP has FFIELDC
differentiate : (%,NonNegativeInteger) -> %
  if
    and(
      has(Fraction UP,Field),
      has(Fraction UP,DifferentialRing))
or
  and(
    has(Fraction UP,DifferentialRing),
    has(Fraction UP,Field))
or Fraction UP has FFIELDC
differentiate : (%,Symbol) -> %
  if
    and(
      has(Fraction UP,Field),
      has(Fraction UP,PartialDifferentialRing Symbol))
or
  and(
    has(Fraction UP,PartialDifferentialRing Symbol),
    has(Fraction UP,Field))
differentiate : (%,List Symbol) -> %
  if
    and(
      has(Fraction UP,Field),
      has(Fraction UP,PartialDifferentialRing Symbol))
or
  and(
    has(Fraction UP,PartialDifferentialRing Symbol),
    has(Fraction UP,Field))

```

```

differentiate : (%,Symbol,NonNegativeInteger) -> %
  if
    and(
      has(Fraction UP,Field),
      has(Fraction UP,PartialDifferentialRing Symbol))
  or
    and(
      has(Fraction UP,PartialDifferentialRing Symbol),
      has(Fraction UP,Field))
differentiate : (%,List Symbol,List NonNegativeInteger) -> %
  if
    and(
      has(Fraction UP,Field),
      has(Fraction UP,PartialDifferentialRing Symbol))
  or
    and(
      has(Fraction UP,PartialDifferentialRing Symbol),
      has(Fraction UP,Field))
differentiate : (%,(Fraction UP -> Fraction UP)) -> %
  if Fraction UP has FIELD
differentiate :
  (%,(Fraction UP -> Fraction UP),NonNegativeInteger) -> %
  if Fraction UP has FIELD
discreteLog : (%,%) -> Union(NonNegativeInteger,"failed")
  if Fraction UP has FFIELDC
discreteLog : % -> NonNegativeInteger
  if Fraction UP has FFIELDC
discriminant : Vector % -> Fraction UP
discriminant : () -> Fraction UP
divide : (%,%) -> Record(quotient: %,remainder: %)
  if Fraction UP has FIELD
euclideanSize : % -> NonNegativeInteger
  if Fraction UP has FIELD
expressIdealMember : (List %,%) -> Union(List %,"failed")
  if Fraction UP has FIELD
exquo : (%,%) -> Union(%,"failed")
  if Fraction UP has FIELD
extendedEuclidean : (%,%) ->
  Record(coef1: %,coef2: %,generator: %)
  if Fraction UP has FIELD
extendedEuclidean : (%,%,%) ->
  Union(Record(coef1: %,coef2: %),"failed")
  if Fraction UP has FIELD
factor : % -> Factored %
  if Fraction UP has FIELD
factorsOfCyclicGroupSize : () ->
  List Record(factor: Integer,exponent: Integer)
  if Fraction UP has FFIELDC
gcd : (%,%) -> %
  if Fraction UP has FIELD

```

```

gcd : List % -> %
  if Fraction UP has FIELD
gcdPolynomial : (SparseUnivariatePolynomial %,
                  SparseUnivariatePolynomial %) ->
                  SparseUnivariatePolynomial %
  if Fraction UP has FIELD
generator : () -> %
hash : % -> SingleInteger
index : PositiveInteger -> %
  if Fraction UP has FINITE
init : () -> %
  if Fraction UP has FFIELDC
integralCoordinates : % ->
  Record(num: Vector UP,den: UP)
integralDerivationMatrix : (UP -> UP) ->
  Record(num: Matrix UP,den: UP)
integralMatrix : () -> Matrix Fraction UP
integralMatrixAtInfinity : () -> Matrix Fraction UP
integralRepresents : (Vector UP,UP) -> %
inv : % -> %
  if Fraction UP has FIELD
inverseIntegralMatrix : () -> Matrix Fraction UP
inverseIntegralMatrixAtInfinity : () ->
  Matrix Fraction UP
latex : % -> String
lcm : (%,%) -> %
  if Fraction UP has FIELD
lcm : List % -> %
  if Fraction UP has FIELD
lift : % -> UPUP
lookup : % -> PositiveInteger
  if Fraction UP has FINITE
minimalPolynomial : % -> UPUP
  if Fraction UP has FIELD
multiEuclidean : (List %,%) -> Union(List %,"failed")
  if Fraction UP has FIELD
nextItem : % -> Union(%,"failed")
  if Fraction UP has FFIELDC
nonSingularModel : Symbol -> List Polynomial F
  if F has FIELD
norm : % -> Fraction UP
one? : % -> Boolean
order : % -> OnePointCompletion PositiveInteger
  if Fraction UP has FFIELDC
order : % -> PositiveInteger
  if Fraction UP has FFIELDC
prime? : % -> Boolean
  if Fraction UP has FIELD
primeFrobenius : % -> %
  if Fraction UP has FFIELDC

```

```

primeFrobenius : (%,NonNegativeInteger) -> %
  if Fraction UP has FFIELDC
primitive? : % -> Boolean
  if Fraction UP has FFIELDC
primitiveElement : () -> %
  if Fraction UP has FFIELDC
principalIdeal : List % ->
  Record(coef: List %,generator: %)
  if Fraction UP has FIELD
rank : () -> PositiveInteger
random : () -> %
  if Fraction UP has FINITE
recip : % -> Union(%, "failed")
reduce : UPUP -> %
reduce : Fraction UPUP -> Union(%, "failed")
  if Fraction UP has FIELD
reducedSystem : Matrix % -> Matrix Fraction UP
reducedSystem : (Matrix %,Vector %) ->
  Record(mat: Matrix Fraction UP,vec: Vector Fraction UP)
reducedSystem : (Matrix %,Vector %) ->
  Record(mat: Matrix Integer,vec: Vector Integer)
  if Fraction UP has LINEXP INT
reducedSystem : Matrix % -> Matrix Integer
  if Fraction UP has LINEXP INT
regularRepresentation : % -> Matrix Fraction UP
regularRepresentation : (%,Vector %) -> Matrix Fraction UP
representationType : () ->
  Union("prime",polynomial,normal,cyclic)
  if Fraction UP has FFIELDC
represents : Vector Fraction UP -> %
represents : (Vector Fraction UP,Vector %) -> %
retract : % -> Fraction Integer
  if Fraction UP has RETRACT FRAC INT
retract : % -> Integer
  if Fraction UP has RETRACT INT
retract : % -> Fraction UP
retractIfCan : % -> Union(Fraction UP, "failed")
retractIfCan : % -> Union(Fraction Integer, "failed")
  if Fraction UP has RETRACT FRAC INT
retractIfCan : % -> Union(Integer, "failed")
  if Fraction UP has RETRACT INT
sample : () -> %
size : () -> NonNegativeInteger
  if Fraction UP has FINITE
sizeLess? : (%,%) -> Boolean
  if Fraction UP has FIELD
squareFree : % -> Factored %
  if Fraction UP has FIELD
squareFreePart : % -> %
  if Fraction UP has FIELD

```



```

subtractIfCan : (%,%) -> Union(%, "failed")
tableForDiscreteLogarithm : Integer ->
  Table(PositiveInteger, NonNegativeInteger)
  if Fraction UP has FFIELD
trace : % -> Fraction UP
traceMatrix : () -> Matrix Fraction UP
traceMatrix : Vector % -> Matrix Fraction UP
unit? : % -> Boolean
  if Fraction UP has FIELD
unitCanonical : % -> %
  if Fraction UP has FIELD
unitNormal : % -> Record(unit: %, canonical: %, associate: %)
  if Fraction UP has FIELD
zero? : % -> Boolean
?? : (Fraction UP, %) -> %
?? : (%, Fraction UP) -> %
?? : (%, %) -> %
?? : (Integer, %) -> %
?? : (PositiveInteger, %) -> %
***? : (%, PositiveInteger) -> %
?+? : (%, %) -> %
?-? : (%, %) -> %
-? : % -> %
=? : (%, %) -> Boolean
?^? : (%, PositiveInteger) -> %
?~=? : (%, %) -> Boolean
?? : (%, Fraction Integer) -> % if Fraction UP has FIELD
?? : (Fraction Integer, %) -> % if Fraction UP has FIELD
?? : (NonNegativeInteger, %) -> %
***? : (%, Integer) -> % if Fraction UP has FIELD
***? : (%, NonNegativeInteger) -> %
?/? : (%, %) -> % if Fraction UP has FIELD
?^? : (%, Integer) -> % if Fraction UP has FIELD
?^? : (%, NonNegativeInteger) -> %
?quo? : (%, %) -> % if Fraction UP has FIELD
?rem? : (%, %) -> % if Fraction UP has FIELD

```

— category FFCAT FunctionFieldCategory —

```

)abbrev category FFCAT FunctionFieldCategory
++ Author: Manuel Bronstein
++ Date Created: 1987
++ Date Last Updated: 19 Mai 1993
++ Description:
++ Function field of a curve
++ This category is a model for the function field of a
++ plane algebraic curve.

```

FunctionFieldCategory(F, UP, UPUP): Category == Definition where

```

F : UniqueFactorizationDomain
UP : UnivariatePolynomialCategory F
UPUP: UnivariatePolynomialCategory Fraction UP

Z ==> Integer
Q ==> Fraction F
P ==> Polynomial F
RF ==> Fraction UP
QF ==> Fraction UPUP
SY ==> Symbol
REC ==> Record(num:$, den:UP, derivden:UP, gd:UP)

```

Definition ==> MonogenicAlgebra(RF, UPUP) with

```

numberOfComponents      : () -> NonNegativeInteger
++numberOfComponents() returns the number of absolutely irreducible
++ components.
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R := RadicalFunctionField(INT, P0, P1, 1 - x**20, 20)
++X numberOfComponents()$R

genus                    : () -> NonNegativeInteger
++genus() returns the genus of one absolutely irreducible component
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R := RadicalFunctionField(INT, P0, P1, 1 - x**20, 20)
++X genus()$R

absolutelyIrreducible? : () -> Boolean
++absolutelyIrreducible?() tests if the curve absolutely irreducible?
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R2 := RadicalFunctionField(INT, P0, P1, 2 * x**2, 4)
++X absolutelyIrreducible()$R2

rationalPoint?          : (F, F) -> Boolean
++rationalPoint?(a, b) tests if \spad{(x=a,y=b)} is on the curve.
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R := RadicalFunctionField(INT, P0, P1, 1 - x**20, 20)
++X rationalPoint?(0,0)$R
++X R2 := RadicalFunctionField(INT, P0, P1, 2 * x**2, 4)
++X rationalPoint?(0,0)$R2

branchPointAtInfinity? : () -> Boolean

```

```

++branchPointAtInfinity?() tests if there is a branch point
++ at infinity.
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R := RadicalFunctionField(INT, P0, P1, 1 - x**20, 20)
++X branchPointAtInfinity?()$R
++X R2 := RadicalFunctionField(INT, P0, P1, 2 * x**2, 4)
++X branchPointAtInfinity?()$R

branchPoint?      : F -> Boolean
++branchPoint?(a) tests whether \spad{x = a} is a branch point.

branchPoint?      : UP -> Boolean
++branchPoint?(p) tests whether \spad{p(x) = 0} is a branch point.

singularAtInfinity? : () -> Boolean
++singularAtInfinity?() tests if there is a singularity at infinity.

singular?         : F -> Boolean
++singular?(a) tests whether \spad{x = a} is singular.

singular?         : UP -> Boolean
++singular?(p) tests whether \spad{p(x) = 0} is singular.

ramifiedAtInfinity? : () -> Boolean
++ramifiedAtInfinity?() tests if infinity is ramified.

ramified?        : F -> Boolean
++ramified?(a) tests whether \spad{x = a} is ramified.

ramified?        : UP -> Boolean
++ramified?(p) tests whether \spad{p(x) = 0} is ramified.

integralBasis      : () -> Vector $
++integralBasis() returns the integral basis for the curve.
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R := RadicalFunctionField(INT, P0, P1, 1 - x**20, 20)
++X integralBasis()$R

integralBasisAtInfinity: () -> Vector $
++integralBasisAtInfinity() returns the local integral basis
++ at infinity
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R := RadicalFunctionField(INT, P0, P1, 1 - x**20, 20)
++X integralBasisAtInfinity()$R

```

```

integralAtInfinity?      : $ -> Boolean
++integralAtInfinity?() tests if f is locally integral at infinity.

integral?                : $ -> Boolean
++integral?() tests if f is integral over \spad{k[x]}.

complementaryBasis       : Vector $ -> Vector $
++complementaryBasis(b1,...,bn) returns the complementary basis
++ \spad{(b1',...,bn')} of \spad{(b1,...,bn)}.

normalizeAtInfinity       : Vector $ -> Vector $
++normalizeAtInfinity(v) makes v normal at infinity.

reduceBasisAtInfinity    : Vector $ -> Vector $
++reduceBasisAtInfinity(b1,...,bn) returns \spad{(x**i * bj)}
++ for all i,j such that \spad{x**i*bj} is locally integral
++ at infinity.

integralMatrix           : () -> Matrix RF
++integralMatrix() returns M such that
++ \spad{(w1,...,wn) = M (1, y, ..., y**(n-1))},
++ where \spad{(w1,...,wn)} is the integral basis of
++ \spadfunFrom{integralBasis}{FunctionFieldCategory}.
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R := RadicalFunctionField(INT, P0, P1, 1 - x**20, 20)
++X integralMatrix()$R

inverseIntegralMatrix    : () -> Matrix RF
++inverseIntegralMatrix() returns M such that
++ \spad{M (w1,...,wn) = (1, y, ..., y**(n-1))}
++ where \spad{(w1,...,wn)} is the integral basis of
++ \spadfunFrom{integralBasis}{FunctionFieldCategory}.
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R := RadicalFunctionField(INT, P0, P1, 1 - x**20, 20)
++X inverseIntegralMatrix()$R

integralMatrixAtInfinity : () -> Matrix RF
++integralMatrixAtInfinity() returns M such that
++ \spad{(v1,...,vn) = M (1, y, ..., y**(n-1))}
++ where \spad{(v1,...,vn)} is the local integral basis at infinity
++ returned by \spad{infIntBasis()}.
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R := RadicalFunctionField(INT, P0, P1, 1 - x**20, 20)

```

```

++X integralMatrixAtInfinity()$R

inverseIntegralMatrixAtInfinity: () -> Matrix RF
++inverseIntegralMatrixAtInfinity() returns M such
++ that \spad{M (v1,...,vn) = (1, y, ..., y**(n-1))}
++ where \spad{(v1,...,vn)} is the local integral basis at infinity
++ returned by \spad{infIntBasis()}.
++
++X P0 := UnivariatePolynomial(x, Integer)
++X P1 := UnivariatePolynomial(y, Fraction P0)
++X R := RadicalFunctionField(INT, P0, P1, 1 - x**20, 20)
++X inverseIntegralMatrixAtInfinity()$R

yCoordinates          : $ -> Record(num:Vector(UP), den:UP)
++yCoordinates(f) returns \spad{[[A1,...,An], D]} such that
++ \spad{f = (A1 + A2 y +...+ An y**(n-1)) / D}.

represents            : (Vector UP, UP) -> $
++represents([A0,...,A(n-1)],D) returns
++ \spad{(A0 + A1 y +...+ A(n-1)*y**(n-1))/D}.

integralCoordinates   : $ -> Record(num:Vector(UP), den:UP)
++integralCoordinates(f) returns \spad{[[A1,...,An], D]} such that
++ \spad{f = (A1 w1 +...+ An wn) / D} where \spad{(w1,...,wn)} is the
++ integral basis returned by \spad{integralBasis()}.

integralRepresents    : (Vector UP, UP) -> $
++integralRepresents([A1,...,An], D) returns
++ \spad{(A1 w1+...+An wn)/D}
++ where \spad{(w1,...,wn)} is the integral
++ basis of \spad{integralBasis()}.

integralDerivationMatrix:(UP -> UP) -> Record(num:Matrix(UP),den:UP)
++integralDerivationMatrix(d) extends the derivation d from UP to $
++ and returns (M, Q) such that the ith row of M divided by Q form
++ the coordinates of \spad{d(wi)} with respect to \spad{(w1,...,wn)}
++ where \spad{(w1,...,wn)} is the integral basis returned
++ by integralBasis().

integral?             : ($, F) -> Boolean
++integral?(f, a) tests whether f is locally integral at \spad{x = a}.

integral?             : ($, UP) -> Boolean
++integral?(f, p) tests whether f is locally integral at
++ \spad{p(x) = 0}

differentiate         : ($, UP -> UP) -> $
++differentiate(x, d) extends the derivation d from UP to $ and
++ applies it to x.

```

```

represents          : (Vector UP, UP) -> $
++represents([A0,...,A(n-1)],D) returns
++ \spad{(A0 + A1 y +...+ A(n-1)*y**(n-1))/D}.

primitivePart       : $ -> $
++primitivePart(f) removes the content of the denominator and
++ the common content of the numerator of f.

elt                 : ($, F, F) -> F
++elt(f,a,b) or f(a, b) returns the value of f
++ at the point \spad{(x = a, y = b)}
++ if it is not singular.

elliptic            : () -> Union(UP, "failed")
++elliptic() returns \spad{p(x)} if the curve is the elliptic
++ defined by \spad{y**2 = p(x)}, "failed" otherwise.

hyperelliptic       : () -> Union(UP, "failed")
++hyperelliptic() returns \spad{p(x)} if the curve is the
++ hyperelliptic
++ defined by \spad{y**2 = p(x)}, "failed" otherwise.

algSplitSimple      : ($, UP -> UP) -> REC
++algSplitSimple(f, D) returns \spad{[h,d,d',g]} such that
++ \spad{f=h/d},
++ \spad{h} is integral at all the normal places w.r.t. \spad{D},
++ \spad{d' = Dd}, \spad{g = gcd(d, discriminant())} and \spad{D}
++ is the derivation to use. \spad{f} must have at most simple finite
++ poles.

if F has Field then

    nonSingularModel: SY -> List Polynomial F
    ++nonSingularModel(u) returns the equations in u1,...,un of
    ++ an affine non-singular model for the curve.

if F has Finite then

    rationalPoints: () -> List List F
    ++rationalPoints() returns the list of all the affine
    ++rational points.
add
import InnerCommonDenominator(UP, RF, Vector UP, Vector RF)
import UnivariatePolynomialCommonDenominator(UP, RF, UPUP)

repOrder: (Matrix RF, Z) -> Z
Q2RF      : Q  -> RF
infOrder: RF -> Z
infValue: RF -> Fraction F
intvalue: (Vector UP, F, F) -> F

```

[illegible]

```

nonSingularModel u ==
  d := commonDenominator(coordinates(w := integralBasis()))::RF
  vars := [concat(string u, string i)::SY for i in 1..(n := #w)]
  x := "%dummy1"::SY
  y := "%dummy2"::SY
  select_!(s+>zero?(degree(s, x)) and zero?(degree(s, y)),
    lexGroebner([v::P - UPUP2P(lift(d * w.i), x::P, y::P)
      for v in vars for i in 1..n], concat([x, y], vars)))

if F has Finite then
  ispoint: (UPUP, F, F) -> List F

-- must use the 'elt' function explicitly or the compiler takes 45 mins
-- on that function MB 5/90
-- still takes ages : I split the expression up. JHD 6/Aug/90
ispoint(p, x, y) ==
  jhd:RF:=p(y::UP::RF)
  zero?(jhd (x::UP::RF)) => [x, y]
  empty()

rationalPoints() ==
  p := definingPolynomial()
  concat [[pt for y in 1..size()$F | not empty?(pt :=
    ispoint(p, index(x::PositiveInteger)$F,
      index(y::PositiveInteger)$F)]]$List(List F)
    for x in 1..size()$F]$List(List(List F))

intvalue(v, x, y) ==
  singular? x => error "Point is singular"
  mini := minIndex(w := integralBasis())
  rec := yCoordinates(+/[qelt(v, i)::RF * qelt(w, i)
    for i in mini .. maxIndex w])
  n := +/[qelt(rec.num, i) x) *
    (y ** ((i - mini)::NonNegativeInteger))
    for i in mini .. maxIndex w]
  zero?(d := (rec.den) x) =>
    zero? n => error "0/0 -- cannot compute value yet"
    error "Shouldn't happen"
  (n exquo d)::F

elt(f, x, y) ==
  rec := integralCoordinates f
  n := intvalue(rec.num, x, y)
  zero?(d := (rec.den) x) =>
    zero? n => error "0/0 -- cannot compute value yet"
    error "Function has a pole at the given point"
  (n exquo d)::F

primitivePart f ==

```



```

cd := yCoordinates f
d := gcd([content qelt(cd.num, i)
          for i in minIndex(cd.num) .. maxIndex(cd.num)]$List(F))
      * primitivePart(cd.den)
represents [qelt(cd.num, i) / d
            for i in minIndex(cd.num) .. maxIndex(cd.num)]$Vector(RF)

reduceBasisAtInfinity b ==
  x := monomial(1, 1)$UP :: RF
  concat([[f for j in 0.. while
            integralAtInfinity?(f := x**j * qelt(b, i))]]$Vector($
            for i in minIndex b .. maxIndex b]$List(Vector $))

complementaryBasis b ==
  m := inverse(traceMatrix b)::Matrix(RF)
  [represents row(m, i) for i in minRowIndex m .. maxRowIndex m]

integralAtInfinity? f ==
  not any?(s +-> infOrder(s) < 0,
           coordinates(f) * inverseIntegralMatrixAtInfinity())$Vector(RF)

numberOfComponents() ==
  count(integralAtInfinity?, integralBasis())$Vector($)

represents(v:Vector UP, d:UP) ==
  represents
    [qelt(v, i) / d for i in minIndex v .. maxIndex v]$Vector(RF)

genus() ==
  ds := discriminant()
  d := degree(retract(ds)$UP) + infOrder(ds * determinant(
    integralMatrixAtInfinity() * inverseIntegralMatrix()) ** 2)
  dd := ((d exquo 2)::Z - rank()) exquo numberOfComponents()::Z
  (dd + 1)::NonNegativeInteger

repOrder(m, i) ==
  nostart:Boolean := true
  ans:Z := 0
  r := row(m, i)
  for j in minIndex r .. maxIndex r | qelt(r, j) ^= 0 repeat
    ans :=
      nostart => (nostart := false; infOrder qelt(r, j))
      min(ans, infOrder qelt(r, j))
  nostart => error "Null row"
  ans

infValue f ==
  zero? f => 0
  (n := infOrder f) > 0 => 0
  zero? n =>

```

```

    (leadingCoefficient numer f) / (leadingCoefficient denom f)
  error "f not locally integral at infinity"

rfmonom n ==
  n < 0 => inv(monomial(1, (-n)::NonNegativeInteger)$UP :: RF)
  monomial(1, n::NonNegativeInteger)$UP :: RF

kmin(m, v) ==
  nostart:Boolean := true
  k:Z := 0
  ii := minRowIndex m - (i0 := minIndex v)
  for i in minIndex v .. maxIndex v | qelt(v, i) ^= 0 repeat
    nk := repOrder(m, i + ii)
    if nostart then (nostart := false; k := nk; i0 := i)
    else
      if nk < k then (k := nk; i0 := i)
  nostart => "failed"
  [i0, k]

normalizeAtInfinity w ==
  ans := copy w
  infm := inverseIntegralMatrixAtInfinity()
  mhat := zero(rank(), rank())$Matrix(RF)
  ii := minIndex w - minRowIndex mhat
  repeat
    m := coordinates(ans) * infm
    r := [rfmonom repOrder(m, i)
          for i in minRowIndex m .. maxRowIndex m]$Vector(RF)
    for i in minRowIndex m .. maxRowIndex m repeat
      for j in minColIndex m .. maxColIndex m repeat
        qsetelt_!(mhat, i, j, qelt(r, i + ii) * qelt(m, i, j))
    sol := first nullSpace transpose map(infValue,
      mhat)$MatrixCategoryFunctions2(RF, Vector RF, Vector RF,
      Matrix RF, Q, Vector Q, Vector Q, Matrix Q)
    (pr := kmin(m, sol)) case "failed" => return ans
    qsetelt_!(ans, pr.pos,
      +/[Q2RF(qelt(sol, i)) * rfmonom(repOrder(m, i - ii) - pr.km)
        * qelt(ans, i) for i in minIndex sol .. maxIndex sol])

integral?(f:$, p:UP) ==
  (r:=retractIfCan(p)@Union(F,"failed")) case F => integral?(f,r::F)
  (integralCoordinates(f).den exquo p) case "failed"

differentiate(f:$, d:UP -> UP) ==
  differentiate(f, x +-> differentiate(x, d)$RF)

```

— **FFCAT.dotabb** —

```
"FFCAT"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FFCAT"];
"FFCAT" -> "MONOGEN"
```

— **FFCAT.dotfull** —

```
"FunctionFieldCategory(a:UFD,b:UPOLYC(a),c:UPOLYC(Fraction(b)))"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=FFCAT"];
"FunctionFieldCategory(a:UFD,b:UPOLYC(a),c:UPOLYC(Fraction(b)))"
  -> "MonogenicAlgebra(a:FRAC(UPOLYC(UFD)),b:UPOLYC(FRAC(UPOLYC(UFD))))"
```

— **FFCAT.dotpic** —

```
digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

  "FunctionFieldCategory(a:UFD,b:UPOLYC(a),c:UPOLYC(Fraction(b)))"
    [color=lightblue];
  "FunctionFieldCategory(a:UFD,b:UPOLYC(a),c:UPOLYC(Fraction(b)))"
    -> "MonogenicAlgebra(a:FRAC(UPOLYC(UFD)),b:UPOLYC(FRAC(UPOLYC(UFD))))"

  "MonogenicAlgebra(a:FRAC(UPOLYC(UFD)),b:UPOLYC(FRAC(UPOLYC(UFD))))"
    [color=seagreen];
  "MonogenicAlgebra(a:FRAC(UPOLYC(UFD)),b:UPOLYC(FRAC(UPOLYC(UFD))))" ->
    "MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"

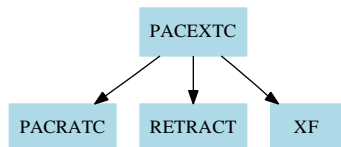
  "MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))"
    [color=lightblue];
  "MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
    "FRAMALG..."
  "MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
    "COMRING..."
  "MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
    "KONVERT..."
  "MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
    "FRETRCT..."
  "MonogenicAlgebra(a:CommutativeRing,b:UnivariatePolynomialCategory(a))" ->
    "FLINEXP..."
```

```

"FRAMALG..." [color=lightblue];
"COMRING..." [color=lightblue];
"KONVERT..." [color=lightblue];
"FRETRACT..." [color=lightblue];
"FLINEXP..." [color=lightblue];
}

```

PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory (PACEXTC)



— PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory.input

```

)set break resume
)sys rm -f PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory.output
)spool PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory.output
)set message test on
)set message auto off
)clear all

--S 1 of 1
)show PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory
--R
--R PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory is a category constructor
--R Abbreviation for PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory is PACEXTC
--R This constructor is not exposed in this frame.
--R Issue )edit bookvol10.2.pamphlet to see algebra source code for PACEXTC
--R
--R----- Operations -----
--R ??? : (%,Fraction(Integer)) -> %      ??? : (Fraction(Integer),%) -> %
--R ??? : (Fraction(Integer),%) -> %      ??? : (%,Fraction(Integer)) -> %
--R ??? : (%,%) -> %                      ??? : (Integer,%) -> %
--R ??? : (PositiveInteger,%) -> %         ??? : (%,Integer) -> %
--R ??? : (%,PositiveInteger) -> %         +? : (%,%) -> %
--R ?-? : (%,%) -> %                      -? : % -> %
--R ?/? : (%,Fraction(Integer)) -> %      ?/? : (%,%) -> %

```

```

--R ?=? : (%,% ) -> Boolean
--R 0 : () -> %
--R ?? : (% ,PositiveInteger) -> %
--R associates? : (%,% ) -> Boolean
--R coerce : Fraction(Integer) -> %
--R coerce : Fraction(Integer) -> %
--R coerce : Integer -> %
--R conjugate : % -> %
--R extDegree : % -> PositiveInteger
--R fullOutput : % -> OutputForm
--R gcd : (%,% ) -> %
--R hash : % -> SingleInteger
--R inv : % -> %
--R lcm : List(%) -> %
--R maxTower : List(%) -> %
--R previousTower : % -> %
--R ?quo? : (%,% ) -> %
--R ?rem? : (%,% ) -> %
--R retract : % -> Fraction(Integer)
--R sample : () -> %
--R sizeLess? : (%,% ) -> Boolean
--R squareFreePart : % -> %
--R unit? : % -> Boolean
--R vectorise : (%,% ) -> Vector(%)
--R ?~=? : (%,% ) -> Boolean
--R ?*? : (% ,PseudoAlgebraicClosureOfRationalNumber) -> %
--R ?*? : (PseudoAlgebraicClosureOfRationalNumber,% ) -> %
--R ?*? : (NonNegativeInteger,% ) -> %
--R ?**? : (% ,NonNegativeInteger) -> %
--R ?/? : (% ,PseudoAlgebraicClosureOfRationalNumber) -> %
--R Frobenius : % -> % if PseudoAlgebraicClosureOfRationalNumber has FINITE or Fraction(Integer)
--R Frobenius : (% ,NonNegativeInteger) -> % if PseudoAlgebraicClosureOfRationalNumber has FINITE
--R ?? : (% ,NonNegativeInteger) -> %
--R characteristic : () -> NonNegativeInteger
--R charthRoot : % -> Union(%, "failed") if PseudoAlgebraicClosureOfRationalNumber has CHARNZ or
--R coerce : PseudoAlgebraicClosureOfRationalNumber -> %
--R coerce : PseudoAlgebraicClosureOfRationalNumber -> %
--R definingPolynomial : % -> SparseUnivariatePolynomial(%)
--R definingPolynomial : () -> SparseUnivariatePolynomial(%)
--R degree : % -> OnePointCompletion(PositiveInteger)
--R discreteLog : (%,% ) -> Union(NonNegativeInteger, "failed") if PseudoAlgebraicClosureOfRationalNumber
--R distinguishedRootsOf : (SparseUnivariatePolynomial(%),%) -> List(%)
--R divide : (%,% ) -> Record(quotient: %,remainder: %)
--R euclideanSize : % -> NonNegativeInteger
--R expressIdealMember : (List(%),%) -> Union(List(%), "failed")
--R exquo : (%,% ) -> Union(%, "failed")
--R extendedEuclidean : (%,% ,%) -> Union(Record(coef1: %,coef2: %), "failed")
--R extendedEuclidean : (%,% ) -> Record(coef1: %,coef2: %,generator: %)
--R extensionDegree : () -> OnePointCompletion(PositiveInteger)
--R gcdPolynomial : (SparseUnivariatePolynomial(%),SparseUnivariatePolynomial(%)) -> SparseUnivariatePolynomial(%)
1 : () -> %
?? : (% ,Integer) -> %
algebraic? : % -> Boolean
coerce : Fraction(Integer) -> %
coerce : Integer -> %
coerce : % -> %
coerce : % -> OutputForm
dimension : () -> CardinalNumber
factor : % -> Factored(%)
gcd : List(%) -> %
ground? : % -> Boolean
inGroundField? : % -> Boolean
latex : % -> String
lcm : (%,% ) -> %
one? : % -> Boolean
prime? : % -> Boolean
recip : % -> Union(%, "failed")
retract : % -> Fraction(Integer)
retract : % -> Integer
setTower! : % -> Void
squareFree : % -> Factored(%)
transcendent? : % -> Boolean
unitCanonical : % -> %
zero? : % -> Boolean

```

```

--R lift : (%,% ) -> SparseUnivariatePolynomial(%)
--R lift : % -> SparseUnivariatePolynomial(%)
--R multiEuclidean : (List(%),%) -> Union(List(%),"failed")
--R newElement : (SparseUnivariatePolynomial(%),Symbol) -> %
--R newElement : (SparseUnivariatePolynomial(%),%,Symbol) -> %
--R order : % -> OnePointCompletion(PositiveInteger) if PseudoAlgebraicClosureOfRationalNumber has CHARNZ or
--R primeFrobenius : % -> % if PseudoAlgebraicClosureOfRationalNumber has CHARNZ or PseudoAlgebraicClosureOfRationalNumber
--R primeFrobenius : (% ,NonNegativeInteger) -> % if PseudoAlgebraicClosureOfRationalNumber has CHARNZ or PseudoAlgebraicClosureOfRationalNumber
--R principalIdeal : List(%) -> Record(coef: List(%),generator: %)
--R reduce : SparseUnivariatePolynomial(%) -> %
--R retract : % -> PseudoAlgebraicClosureOfRationalNumber
--R retract : % -> PseudoAlgebraicClosureOfRationalNumber
--R retractIfCan : % -> Union(PseudoAlgebraicClosureOfRationalNumber,"failed")
--R retractIfCan : % -> Union(PseudoAlgebraicClosureOfRationalNumber,"failed")
--R retractIfCan : % -> Union(Fraction(Integer),"failed")
--R retractIfCan : % -> Union(Fraction(Integer),"failed")
--R retractIfCan : % -> Union(Integer,"failed")
--R subtractIfCan : (% ,%) -> Union(%,"failed")
--R transcendenceDegree : () -> NonNegativeInteger
--R unitNormal : % -> Record(unit: %,canonical: %,associate: %)
--R
--E 1

)spool
)lisp (bye)

```

— PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory.help

```

=====
PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory examples
=====

```

This category exports the function for the domain
PseudoAlgebraicClosureOfAlgExtOfRationalNumber which implement dynamic
extension using the simple notion of tower extensions. A tower extension
T of the ground field K is any sequence of field extension
 $(T : K_0, K_1, \dots, K_i, \dots, K_n)$
where $K_0 = K$ and for $i = 1, 2, \dots, n$,
 K_i is an extension of K_{i-1} of degree > 1
and defined by an irreducible polynomial $p(Z)$ in K_{i-1} .

Two towers
 $(T_1: K_{01}, K_{11}, \dots, K_{i1}, \dots, K_{n1})$
and
 $(T_2: K_{02}, K_{12}, \dots, K_{i2}, \dots, K_{n2})$
are said to be related if

$T_1 \leq T_2$ (or $T_1 \geq T_2$),
 that is if
 $K_{i1} = K_{i2}$ for $i=1,2,\dots,n_1$ (or $i=1,2,\dots,n_2$).
 Any algebraic operations defined for several elements
 are only defined if all of the concerned elements are coming from
 a set of related tower extensions.

See Also:

o)show PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory

See:

\Leftarrow “PseudoAlgebraicClosureOfRationalNumberCategory” (PACRATC) 19 on page 1663

Exports:

| | | | |
|----------------|-------------------|---------------------|----------------------|
| 0 | 1 | -? | ?**? |
| ?*? | ?+? | ?-? | ?/? |
| ?=? | ?^? | ?~=? | ?quo? |
| ?rem? | algebraic? | associates? | characteristic |
| charthRoot | coerce | conjugate | definingPolynomial |
| degree | dimension | discreteLog | distinguishedRootsOf |
| divide | euclideanSize | expressIdealMember | exquo |
| extDegree | extendedEuclidean | extensionDegree | factor |
| Frobenius | fullOutput | gcd | gcdPolynomial |
| ground? | hash | inGroundField? | inv |
| latex | lcm | lift | maxTower |
| multiEuclidean | newElement | one? | order |
| previousTower | prime? | primeFrobenius | principalIdeal |
| recip | reduce | retract | retractIfCan |
| sample | setTower! | sizeLess? | squareFree |
| squareFreePart | subtractIfCan | transcendenceDegree | transcendent? |
| unit? | unitCanonical | unitNormal | vectorise |
| zero? | | | |

Attributes Exported:

- **commutative**(“*”) is true if it has an operation “*” : $(D, D) \rightarrow D$ which is commutative.
- **unitsKnown** is true if a monoid (a multiplicative semigroup with a 1) has unitsKnown means that the operation **recip** can only return “failed” if its argument is not a unit.
- **leftUnitary** is true if $1 * x = x$ for all x .
- **rightUnitary** is true if $x * 1 = x$ for all x .

- **noZeroDivisors** is true if $x * y \neq 0$ implies both x and y are non-zero.
- **canonicalUnitNormal** is true if we can choose a canonical representative for each class of associate elements, that is **associates?**(a,b) returns true if and only if **unitCanonical**(a) = **unitCanonical**(b).
- **canonicalsClosed** is true if
 unitCanonical(a)***unitCanonical**(b) = **unitCanonical**($a*b$).

These exports come from (p1663) **PseudoAlgebraicClosureOfRationalNumberCategory**

```

-? : % -> %
0 : () -> %
1 : () -> %
***? : (%,Integer) -> %
***? : (%,NonNegativeInteger) -> %
***? : (%,PositiveInteger) -> %
**? : (%,% ) -> %
**? : (% ,Fraction Integer) -> %
**? : (% ,Fraction Integer) -> %
**? : (Fraction Integer,% ) -> %
**? : (Fraction Integer,% ) -> %
**? : (Integer,% ) -> %
**? : (NonNegativeInteger,% ) -> %
**? : (PositiveInteger,% ) -> %
+? : (%,% ) -> %
-? : (%,% ) -> %
/? : (%,% ) -> %
/? : (% ,Fraction Integer) -> %
=? : (%,% ) -> Boolean
^? : (% ,Integer) -> %
^? : (% ,NonNegativeInteger) -> %
^? : (% ,PositiveInteger) -> %
quo? : (%,% ) -> %
rem? : (%,% ) -> %
~=? : (%,% ) -> Boolean
Frobenius : % -> % if Fraction Integer has FINITE
Frobenius : (% ,NonNegativeInteger) -> % if Fraction Integer has FINITE
algebraic? : % -> Boolean
associates? : (%,% ) -> Boolean
characteristic : () -> NonNegativeInteger
charthRoot : % -> Union(% , "failed")
  if Fraction Integer has CHARNZ or Fraction Integer has FINITE
coerce : % -> %
coerce : % -> OutputForm
coerce : Fraction Integer -> %
coerce : Fraction Integer -> %
coerce : Fraction Integer -> %
coerce : Integer -> %
coerce : Integer -> %

```



```

conjugate : % -> %
definingPolynomial : % -> SparseUnivariatePolynomial %
definingPolynomial : () -> SparseUnivariatePolynomial %
degree : % -> OnePointCompletion PositiveInteger
dimension : () -> CardinalNumber
discreteLog : (%,%) -> Union(NonNegativeInteger,"failed")
    if Fraction Integer has CHARNZ or Fraction Integer has FINITE
distinguishedRootsOf : (SparseUnivariatePolynomial %,%) -> List %
divide : (%,%) -> Record(quotient: %,remainder: %)
euclideanSize : % -> NonNegativeInteger
expressIdealMember : (List %,%) -> Union(List %,"failed")
exquo : (%,%) -> Union(%,"failed")
extDegree : % -> PositiveInteger
extendedEuclidean : (%,%) -> Record(coef1: %,coef2: %,generator: %)
extendedEuclidean : (%,%,%) -> Union(Record(coef1: %,coef2: %),"failed")
extensionDegree : () -> OnePointCompletion PositiveInteger
factor : % -> Factored %
fullOutput : % -> OutputForm
gcd : (%,%) -> %
gcd : List % -> %
gcdPolynomial : (SparseUnivariatePolynomial %,
    SparseUnivariatePolynomial %) -> SparseUnivariatePolynomial %
ground? : % -> Boolean
hash : % -> SingleInteger
inGroundField? : % -> Boolean
inv : % -> %
latex : % -> String
lcm : (%,%) -> %
lcm : List % -> %
lift : % -> SparseUnivariatePolynomial %
lift : (%,%) -> SparseUnivariatePolynomial %
maxTower : List % -> %
multiEuclidean : (List %,%) -> Union(List %,"failed")
newElement : (SparseUnivariatePolynomial %,%,Symbol) -> %
newElement : (SparseUnivariatePolynomial %,Symbol) -> %
one? : % -> Boolean
order : % -> OnePointCompletion PositiveInteger
    if Fraction Integer has CHARNZ or Fraction Integer has FINITE
previousTower : % -> %
prime? : % -> Boolean
primeFrobenius : % -> %
    if Fraction Integer has CHARNZ or Fraction Integer has FINITE
primeFrobenius : (%,NonNegativeInteger) -> %
    if Fraction Integer has CHARNZ or Fraction Integer has FINITE
principalIdeal : List % -> Record(coef: List %,generator: %)
recip : % -> Union(%,"failed")
reduce : SparseUnivariatePolynomial % -> %
retract : % -> Fraction Integer
retract : % -> Fraction Integer
retract : % -> Integer

```

```

retractIfCan : % -> Union(Fraction Integer,"failed")
retractIfCan : % -> Union(Fraction Integer,"failed")
retractIfCan : % -> Union(Integer,"failed")
sample : () -> %
setTower! : % -> Void
sizeLess? : (%,%) -> Boolean
squareFree : % -> Factored %
squareFreePart : % -> %
subtractIfCan : (%,%) -> Union(%, "failed")
transcendenceDegree : () -> NonNegativeInteger
transcendent? : % -> Boolean
unit? : % -> Boolean
unitCanonical : % -> %
unitNormal : % -> Record(unit: %,canonical: %,associate: %)
vectorise : (%,%) -> Vector %
zero? : % -> Boolean

```

These exports come from \ref{RetractableTo}

```

\begin{verbatim}
coerce : PseudoAlgebraicClosureOfRationalNumber -> %
coerce : PseudoAlgebraicClosureOfRationalNumber -> %
retract : % -> PseudoAlgebraicClosureOfRationalNumber
retract : % -> PseudoAlgebraicClosureOfRationalNumber
retractIfCan : % -> Union(PseudoAlgebraicClosureOfRationalNumber,"failed")
retractIfCan : % -> Union(PseudoAlgebraicClosureOfRationalNumber,"failed")

```

These exports come from (p1562) ExtensionField

```

?? : (%,PseudoAlgebraicClosureOfRationalNumber) -> %
?? : (PseudoAlgebraicClosureOfRationalNumber,%) -> %
?/? : (%,PseudoAlgebraicClosureOfRationalNumber) -> %
charthRoot : % -> Union(%, "failed") if PseudoAlgebraicClosureOfRationalNumber has CHARNZ or PseudoAlgebraicClosureOfRationalNumber has CHARNZ
discreteLog : (%,%) -> Union(NonNegativeInteger,"failed") if PseudoAlgebraicClosureOfRationalNumber has CHARNZ or PseudoAlgebraicClosureOfRationalNumber has CHARNZ
Frobenius : % -> % if PseudoAlgebraicClosureOfRationalNumber has FINITE or Fraction Integer has FINITE
Frobenius : (%,NonNegativeInteger) -> % if PseudoAlgebraicClosureOfRationalNumber has FINITE or Fraction Integer has FINITE
order : % -> OnePointCompletion PositiveInteger if PseudoAlgebraicClosureOfRationalNumber has CHARNZ or PseudoAlgebraicClosureOfRationalNumber has CHARNZ
primeFrobenius : % -> % if PseudoAlgebraicClosureOfRationalNumber has CHARNZ or PseudoAlgebraicClosureOfRationalNumber has CHARNZ
primeFrobenius : (%,NonNegativeInteger) -> % if PseudoAlgebraicClosureOfRationalNumber has CHARNZ or PseudoAlgebraicClosureOfRationalNumber has CHARNZ

```

— category PACEXTC PseudoAlgebraicClosureOfAlgExtOfRational-
NumberCategory —

```

)abbrev category PACEXTC PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory
++ Authors: Gaetan Hache
++ Date Created: jan 1998
++ Date Last Updated: May 2010 by Tim Daly
++ Description:
++ This category exports the function for the domain

```

```

++ PseudoAlgebraicClosureOfAlgExtOfRationalNumber which implement dynamic
++ extension using the simple notion of tower extensions. A tower extension
++ T of the ground field K is any sequence of field extension
++ (T : K_0, K_1, ..., K_i...,K_n) where K_0 = K and for i =1,2,...,n,
++ K_i is an extension of K_{i-1} of degree > 1 and defined by an
++ irreducible polynomial p(Z) in K_{i-1}.
++ Two towers (T_1: K_01, K_11,...,K_i1,...,K_n1) and
++ (T_2: K_02, K_12,...,K_i2,...,K_n2)
++ are said to be related if T_1 <= T_2 (or T_1 >= T_2),
++ that is if K_i1 = K_i2 for i=1,2,...,n1 (or i=1,2,...,n2).
++ Any algebraic operations defined for several elements
++ are only defined if all of the concerned elements are coming from
++ a set of related tower extensions.
PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory:Category == Impl where
  Q    ==> PseudoAlgebraicClosureOfRationalNumber
  Impl ==>
    Join(PseudoAlgebraicClosureOfRationalNumberCategory, _
      RetractableTo(Q), ExtensionField(Q))

```

— PACEXTC.dotabb —

```

"PACEXTC" [color=lightblue,href="bookvol10.2.pdf#nameddest=PACEXTC"];
"PACEXTC" -> "PACRATC"
"PACEXTC" -> "RETRACT"
"PACEXTC" -> "XF"

```

— PACEXTC.dotfull —

```

"PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory"
[ color=lightblue,href="bookvol10.2.pdf#nameddest=PACEXTC"];
-> "PseudoAlgebraicClosureOfRationalNumberCategory"
"PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory"
-> "RetractableTo(PseudoAlgebraicClosureOfRationalNumber)"
"PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory"
-> "ExtensionField(PseudoAlgebraicClosureOfRationalNumber)"

"PseudoAlgebraicClosureOfRationalNumberCategory"
[ color=lightblue,href="bookvol10.2.pdf#nameddest=PACRATC"];

"RetractableTo(PseudoAlgebraicClosureOfRationalNumber)"
[ color=lightblue,href="bookvol10.2.pdf#nameddest=RETRACT"];
-> "RetractableTo(a:Type)"

```

```

"RetractableTo(a:Type)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RETRACT"];

"ExtensionField(PseudoAlgebraicClosureOfRationalNumber)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=XF"];
"ExtensionField(PseudoAlgebraicClosureOfRationalNumber)" ->
-> "ExtensionField(a:Field)"

"ExtensionField(a:Field)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=XF"];

```

— PACEXTC.dotpic —

```

digraph pic {
  fontsize=10;
  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

"PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=PACEXTC"];
  -> "PseudoAlgebraicClosureOfRationalNumberCategory"
"PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory"
  -> "RetractableTo(PseudoAlgebraicClosureOfRationalNumber)"
"PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory"
  -> "ExtensionField(PseudoAlgebraicClosureOfRationalNumber)"

"RetractableTo(PseudoAlgebraicClosureOfRationalNumber)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=RETRACT"];
"RetractableTo(PseudoAlgebraicClosureOfRationalNumber)"
  -> "RETRACT..."

"ExtensionField(PseudoAlgebraicClosureOfRationalNumber)"
  [color=lightblue,href="bookvol10.2.pdf#nameddest=XF"];
"ExtensionField(PseudoAlgebraicClosureOfRationalNumber)" ->
-> "XF..."

"XF..." [color=lightblue];
"RETRACT..." [color=lightblue];
}

```


Chapter 21

The bootstrap code

21.1 ABELGRP.lsp BOOTSTRAP

ABELGRP depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ABELGRP** category which we can write into the **MID** directory. We compile the lisp code and copy the **ABELGRP.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ABELGRP.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |AbelianGroup;AL| (QUOTE NIL))

(DEFUN |AbelianGroup| NIL
  (LET (#:G82664)
    (COND
      (|AbelianGroup;AL|)
      (T (SETQ |AbelianGroup;AL| (|AbelianGroup;|))))))

(DEFUN |AbelianGroup;| NIL
  (PROG (#1= #:G82662)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|CancellationAbelianMonoid|)
            (|mkCategory|
              (QUOTE |domain|))
```

```

(QUOTE (
  ((|-| (|$| |$|)) T)
  ((|-| (|$| |$| |$|)) T)
  ((|*| (|$| (|Integer|) |$|)) T)))
NIL
(QUOTE ((|Integer|)))
NIL))
|AbelianGroup|)
(SETELT #1# 0 (QUOTE (|AbelianGroup|))))))

(setf (get (quote |AbelianGroup|) (quote niladic)) t)

```

21.2 ABELGRP-.lsp BOOTSTRAP

ABELGRP- depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ABELGRP-** category which we can write into the **MID** directory. We compile the lisp code and copy the **ABELGRP-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ABELGRP-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |ABELGRP-;-;3S;1| (|x| |y| |$|)
  (SPADCALL |x| (SPADCALL |y| (QREFELT |$| 7)) (QREFELT |$| 8)))

(DEFUN |ABELGRP-;subtractIfCan;2SU;2| (|x| |y| |$|)
  (CONS 0 (SPADCALL |x| |y| (QREFELT |$| 10))))

(DEFUN |ABELGRP-;*;Nni2S;3| (|n| |x| |$|)
  (SPADCALL |n| |x| (QREFELT |$| 14)))

(DEFUN |ABELGRP-;*;I2S;4| (|n| |x| |$|)
  (COND
    ((ZEROP |n|) (|spadConstant| |$| 17))
    ((|<| 0 |n|) (SPADCALL |n| |x| (QREFELT |$| 20)))
    ((QUOTE T)
      (SPADCALL (|-| |n|) (SPADCALL |x| (QREFELT |$| 7)) (QREFELT |$| 20)))))

(DEFUN |AbelianGroup&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN

```

```

(PROGN
  (LETT |DV$1| (|devalue| |#1|) . #1=(|AbelianGroup&|))
  (LETT |dv$| (LIST (QUOTE |AbelianGroup&|) |DV$1|) . #1#)
  (LETT |$| (make-array 22) . #1#)
  (QSETREFV |$| 0 |dv$|)
  (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
  (|stuffDomainSlots| |$|)
  (QSETREFV |$| 6 |#1|)
  (COND
    ((|HasCategory| |#1| (QUOTE (|Ring|))))
    ((QUOTE T)
      (QSETREFV |$| 21
        (CONS (|dispatchFunction| |ABELGRP-;*;I2S;4|) |$|))))
    |$|)))

(setf (get
  (QUOTE |AbelianGroup&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (0 . |-|)
        (5 . |+|)
        |ABELGRP-;-;3S;1|
        (11 . |-|)
        (|Union| |$| (QUOTE "failed")))
        |ABELGRP-;subtractIfCan;2SU;2|
        (|Integer|)
        (17 . |*|)
        (|NonNegativeInteger|)
        |ABELGRP-;*;Nni2S;3|
        (23 . |Zero|)
        (|PositiveInteger|)
        (|RepeatedDoubling| 6)
        (27 . |double|)
        (33 . |*|)))
    (QUOTE #(|subtractIfCan| 39 |-| 45 |*| 51))
    (QUOTE NIL)
    (CONS
      (|makeByteWordVec2| 1 (QUOTE NIL))
      (CONS
        (QUOTE #())
        (CONS
          (QUOTE #())
          (|makeByteWordVec2| 21
            (QUOTE (1 6 0 0 7 2 6 0 0 0 8 2 6 0 0 0 10 2 6 0 13 0 14 0 6 0 17
              2 19 6 18 6 20 2 0 0 13 0 21 2 0 11 0 0 12 2 0 0 0 9 2
              0 0 13 0 21 2 0 0 15 0 16)))))))
    (QUOTE |lookupComplete|)))

```


21.3 ABELMON.lsp BOOTSTRAP

ABELMON which needs **ABELSG** which needs **SETCAT** which needs **SINT** which needs **UFD** which needs **GCDDOM** which needs **COMRING** which needs **RING** which needs **RNG** which needs **ABELGRP** which needs **CABMON** which needs **ABELMON**. We break this chain with **ABELMON.lsp** which we cache here. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ABELMON** category which we can write into the **MID** directory. We compile the lisp code and copy the **ABELMON.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ABELMON.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |AbelianMonoid;AL| (QUOTE NIL))

(DEFUN |AbelianMonoid| NIL
  (LET (#:G82597)
    (COND
      (|AbelianMonoid;AL|)
      (T (SETQ |AbelianMonoid;AL| (|AbelianMonoid;|))))))

(DEFUN |AbelianMonoid;| NIL
  (PROG (#1= #:G82595)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|AbelianSemiGroup|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE (
                ((|Zero| (|$|) |constant|) T)
                ((|sample| (|$|) |constant|) T)
                ((|zero?| ((|Boolean|) |$|)) T)
                ((|*| (|$| (|NonNegativeInteger|) |$|)) T)))
              NIL
              (QUOTE ((|NonNegativeInteger|) (|Boolean|)))
              NIL))
          |AbelianMonoid|)
```

```
(SETELT #1# 0 (QUOTE (|AbelianMonoid|))))))

(setf (get (QUOTE |AbelianMonoid|) (QUOTE NILADIC)) T)
```

21.4 ABELMON-.lsp BOOTSTRAP

ABELMON- which needs **ABELSG** which needs **SETCAT** which needs **SINT** which needs **UFD** which needs **GCDDOM** which needs **COMRING** which needs **RING** which needs **RNG** which needs **ABELGRP** which needs **CABMON** which needs **ABELMON-**. We break this chain with **ABELMON-.lsp** which we cache here. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ABELMON-** category which we can write into the **MID** directory. We compile the lisp code and copy the **ABELMON-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ABELMON-.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(DEFUN |ABELMON-;zero?;SB;1| (|x| |$|)
  (SPADCALL |x| (|spadConstant| |$| 7) (QREFELT |$| 9)))

(DEFUN |ABELMON-;*;Pi2S;2| (|n| |x| |$|)
  (SPADCALL |n| |x| (QREFELT |$| 12)))

(DEFUN |ABELMON-;sample;S;3| (|$|)
  (|spadConstant| |$| 7))

(DEFUN |ABELMON-;*;Nni2S;4| (|n| |x| |$|)
  (COND
    ((ZEROP |n|) (|spadConstant| |$| 7))
    ((QUOTE T) (SPADCALL |n| |x| (QREFELT |$| 17)))))

(DEFUN |AbelianMonoid&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|AbelianMonoid&|))
        (LETT |dv$| (LIST (QUOTE |AbelianMonoid&|) |DV$1|) . #1#)
        (LETT |$| (make-array 19) . #1#)
        (QSETREFV |$| 0 |dv$|)
```

```

(QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
(|stuffDomainSlots| |$|)
(QSETREFV |$| 6 |#1|)
(COND
  ((|HasCategory| |#1| (QUOTE (|Ring|))))
  ((QUOTE T)
    (QSETREFV |$| 18
      (CONS (|dispatchFunction| |ABELMON-;*;Nni2S;4|) |$|)))) |$|))))

(setf (get
  (QUOTE |AbelianMonoid&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (0 . |Zero|)
        (|Boolean|)
        (4 . |=|)
        |ABELMON-;zero?;SB;1|
        (|NonNegativeInteger|)
        (10 . |*|)
        (|PositiveInteger|)
        |ABELMON-;*;Pi2S;2|
        |ABELMON-;sample;S;3|
        (|RepeatedDoubling| 6)
        (16 . |double|)
        (22 . |*|)))
    (QUOTE #(|zero?| 28 |sample| 33 |*| 37))
    (QUOTE NIL)
    (CONS
      (|makeByteWordVec2| 1 (QUOTE NIL))
      (CONS
        (QUOTE #())
        (CONS
          (QUOTE #())
          (|makeByteWordVec2| 18
            (QUOTE (0 6 0 7 2 6 8 0 0 9 2 6 0 11 0 12 2 16 6 13 6 17 2 0 0 11
              0 18 1 0 8 0 10 0 0 0 15 2 0 0 11 0 18 2 0 0 13 0 14)))))))
    (QUOTE |lookupComplete|)))

```

21.5 ABELSG.lsp BOOTSTRAP

ABELSG needs **SETCAT** which needs **SINT** which needs **UFD** which needs **GCDDOM** which needs **COMRING** which needs **RING** which needs **RNG** which needs **ABELGRP**

which needs **CABMON** which needs **ABELMON** which needs **ABELSG**. We break this chain with **ABELSG.lsp** which we cache here. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ABELSG** category which we can write into the **MID** directory. We compile the lisp code and copy the **ABELSG.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ABELSG.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |AbelianSemiGroup;AL| (QUOTE NIL))

(DEFUN |AbelianSemiGroup| NIL
  (LET (#:G82568)
    (COND
      (|AbelianSemiGroup;AL|)
      (T (SETQ |AbelianSemiGroup;AL| (|AbelianSemiGroup;|))))))

(DEFUN |AbelianSemiGroup;| NIL
  (PROG (#1= #:G82566)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|SetCategory|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE (
                ((|+| (|$| |$| |$|)) T)
                ((|*| (|$| (|PositiveInteger|) |$|)) T)))
              NIL
              (QUOTE ((|PositiveInteger|)))
              NIL))
          |AbelianSemiGroup|)
        (SETELT #1# 0 (QUOTE (|AbelianSemiGroup|)))))))

(setf (get (QUOTE |AbelianSemiGroup|) (QUOTE NILADIC)) T)
```

21.6 ABELSG-.lsp BOOTSTRAP

ABELSG- needs **SETCAT** which needs **SINT** which needs **UFD** which needs **GCDDOM** which needs **COMRING** which needs **RING** which needs **RNG** which needs **ABELGRP**

which needs **CABMON** which needs **ABELMON** which needs **ABELSG-**. We break this chain with **ABELSG-.lsp** which we cache here. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ABELSG-** category which we can write into the **MID** directory. We compile the lisp code and copy the **ABELSG-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— **ABELSG-.lsp BOOTSTRAP** —

```
(|/VERSIONCHECK| 2)

(DEFUN |ABELSG-;*;Pi2S;1| (|n| |x| |$|) (SPADCALL |n| |x| (QREFELT |$| 9)))

(DEFUN |AbelianSemiGroup&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|AbelianSemiGroup&|))
        (LETT |dv$| (LIST (QUOTE |AbelianSemiGroup&|) |DV$1|) . #1#)
        (LETT |$| (make-array 11) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        (COND
          ((|HasCategory| |#1| (QUOTE (|Ring|))))
          ((QUOTE T)
            (QSETREFV |$| 10
              (CONS (|dispatchFunction| |ABELSG-;*;Pi2S;1|) |$|))))
          |$|))))

(setf (get
  (QUOTE |AbelianSemiGroup&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (|PositiveInteger|)
        (|RepeatedDoubling| 6)
        (0 . |double|)
        (6 . |*|)))
    (QUOTE #(|*| 12))
    (QUOTE NIL)
    (CONS
      (|makeByteWordVec2| 1 (QUOTE NIL))
      (CONS
```

```

(QUOTE #())
(CONS
  (QUOTE #())
  (|makeByteWordVec2| 10
    (QUOTE (2 8 6 7 6 9 2 0 0 7 0 10 2 0 0 7 0 10))))))
(QUOTE |lookupComplete|))

```

21.7 ALAGG.lsp BOOTSTRAP

ALAGG depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ALAGG** category which we can write into the **MID** directory. We compile the lisp code and copy the **ALAGG.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ALAGG.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |AssociationListAggregate;CAT| (QUOTE NIL))

(SETQ |AssociationListAggregate;AL| (QUOTE NIL))

(DEFUN |AssociationListAggregate|
  (|&REST| #1=#:G88404 |&AUX| #2=#:G88402)
  (DSETQ #2# #1#)
  (LET (#3=#:G88403)
    (COND
      ((SETQ #3# (|assoc| (|devalueList| #2#) |AssociationListAggregate;AL|))
        (CDR #3#))
      (T
        (SETQ |AssociationListAggregate;AL|
          (|cons5|
            (CONS
              (|devalueList| #2#)
              (SETQ #3# (APPLY (FUNCTION |AssociationListAggregate;|) #2#)))
              |AssociationListAggregate;AL|)) #3#))))))

(DEFUN |AssociationListAggregate;| (|t#1| |t#2|)
  (PROG (#1=#:G88401)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|

```

```

(PAIR
  (QUOTE (|t#1| |t#2|)) (LIST (|devaluate| |t#1|) (|devaluate| |t#2|)))
(|sublisV|
  (PAIR
    (QUOTE (#2=:G88400))
    (LIST (QUOTE (|Record| (|:| |key| |t#1|) (|:| |entry| |t#2|)))))
  (COND
    (|AssociationListAggregate;CAT|)
    ((QUOTE T)
      (LETT |AssociationListAggregate;CAT|
        (|Join|
          (|TableAggregate| (QUOTE |t#1|) (QUOTE |t#2|))
          (|ListAggregate| (QUOTE #2#))
          (|mkCategory|
            (QUOTE |domain|)
            (QUOTE
              (((|assoc|
                ((|Union|
                  (|Record| (|:| |key| |t#1|) (|:| |entry| |t#2|)) "failed")
                  |t#1| |$|))
                T)))
              NIL (QUOTE NIL) NIL))
            . #3=(|AssociationListAggregate|))))))
    . #3#)
  (SETELT #1# 0
    (LIST
      (QUOTE |AssociationListAggregate|)
      (|devaluate| |t#1|)
      (|devaluate| |t#2|))))))

```

21.8 CABMON.lsp BOOTSTRAP

CABMON which needs **ABELMON** which needs **ABELSG** which needs **SETCAT** which needs **SINT** which needs **UFD** which needs **GCDDOM** which needs **COMRING** which needs **RING** which needs **RNG** which needs **ABELGRP** which needs **CABMON**. We break this chain with **CABMON.lsp** which we cache here. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **CABMON** category which we can write into the **MID** directory. We compile the lisp code and copy the **CABMON.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— CABMON.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |CancellationAbelianMonoid;AL| (QUOTE NIL))

(DEFUN |CancellationAbelianMonoid| NIL
  (LET (#:G82646)
    (COND
      (|CancellationAbelianMonoid;AL|)
      (T
        (SETQ
          |CancellationAbelianMonoid;AL|
          (|CancellationAbelianMonoid;|))))))

(DEFUN |CancellationAbelianMonoid;| NIL
  (PROG (#1= #:G82644)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|AbelianMonoid|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE
                (((|subtractIfCan| ((|Union| |$| "failed") |$| |$|)) T)))
                NIL
                (QUOTE NIL)
                NIL))
            |CancellationAbelianMonoid|)
          (SETELT #1# 0 (QUOTE (|CancellationAbelianMonoid|)))))))

(setf (get (QUOTE |CancellationAbelianMonoid|) (QUOTE NILADIC)) T)

```

21.9 CLAGG.lsp BOOTSTRAP

CLAGG depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **CLAGG** category which we can write into the **MID** directory. We compile the lisp code and copy the **CLAGG.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— CLAGG.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

```



```

(SETQ |Collection;CAT| (QUOTE NIL))

(SETQ |Collection;AL| (QUOTE NIL))

(DEFUN |Collection| (#1=#:G82618)
  (LET (#2=#:G82619)
    (COND
      ((SETQ #2# (|assoc| (|devalue| #1#) |Collection;AL|)) (CDR #2#))
      (T
        (SETQ |Collection;AL|
          (|cons5|
            (CONS
              (|devalue| #1#)
              (SETQ #2# (|Collection;| #1#)))
              |Collection;AL|))
          #2#))))))

(DEFUN |Collection;| (|t#1|)
  (PROG (#1=#:G82617)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR (QUOTE (|t#1|)) (LIST (|devalue| |t#1|))))
          (COND
            (|Collection;CAT|)
            ((QUOTE T)
              (LETT |Collection;CAT|
                (|Join|
                  (|HomogeneousAggregate| (QUOTE |t#1|))
                  (|mkCategory|
                    (QUOTE |domain|)
                    (QUOTE (
                      ((|construct| (|$| (|List| |t#1|)))) T)
                      ((|find| ((|Union| |t#1| "failed")
                        (|Mapping| (|Boolean|) |t#1|) |$|))
                        T)
                      ((|reduce| (|t#1| (|Mapping| |t#1| |t#1| |t#1|) |$|))
                        (|has| |$| (ATTRIBUTE |finiteAggregate|)))
                      ((|reduce| (|t#1| (|Mapping| |t#1| |t#1| |t#1|) |$| |t#1|))
                        (|has| |$| (ATTRIBUTE |finiteAggregate|)))
                      ((|remove| (|$| (|Mapping| (|Boolean|) |t#1|) |$|))
                        (|has| |$| (ATTRIBUTE |finiteAggregate|)))
                      ((|select| (|$| (|Mapping| (|Boolean|) |t#1|) |$|))
                        (|has| |$| (ATTRIBUTE |finiteAggregate|)))
                      ((|reduce| (|t#1| (|Mapping| |t#1| |t#1| |t#1|) |$| |t#1| |t#1|))
                        (AND
                          (|has| |t#1| (|SetCategory|))
                          (|has| |$| (ATTRIBUTE |finiteAggregate|))))
                    )
                  )
                )
              )
            )
          )
        )
      )
    )
  )

```

```

((|remove| (|$| |t#1| |$|))
 (AND
  (|has| |t#1| (|SetCategory|))
  (|has| |$| (ATTRIBUTE |finiteAggregate|))))
(|removeDuplicates| (|$| |$|))
 (AND
  (|has| |t#1| (|SetCategory|))
  (|has| |$| (ATTRIBUTE |finiteAggregate|))))))
(QUOTE (((|ConvertibleTo| (|InputForm|))
          (|has| |t#1| (|ConvertibleTo| (|InputForm|))))))
(QUOTE ((|List| |t#1|)) NIL))
. #2#)
. #2#)
(SETELT #1# 0 (LIST (QUOTE |Collection|) (|devaluate| |t#1|))))))

```

21.10 CLAGG-.lsp BOOTSTRAP

CLAGG- depends on **CLAGG**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **CLAGG-** category which we can write into the **MID** directory. We compile the lisp code and copy the **CLAGG-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— CLAGG-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |CLAGG-;#;ANni;1| (|c| |$|) (LENGTH (SPADCALL |c| (QREFELT |$| 9))))

(DEFUN |CLAGG-;count;MANni;2| (|f| |c| |$|)
 (PROG (|x| #1=#:G82637 #2=#:G82634 #3=#:G82632 #4=#:G82633)
 (RETURN
 (SEQ
 (PROGN
 (LETT #4# NIL |CLAGG-;count;MANni;2|)
 (SEQ
 (LETT |x| NIL |CLAGG-;count;MANni;2|)
 (LETT #1# (SPADCALL |c| (QREFELT |$| 9)) |CLAGG-;count;MANni;2|)
 G190
 (COND
 ((OR (ATOM #1#) (PROGN (LETT |x| (CAR #1#) |CLAGG-;count;MANni;2|) NIL))
 (GO G191)))
 (SEQ
 (EXIT

```

```

(COND
  ((SPADCALL |x| |f|)
   (PROGN
    (LETT #2# 1 |CLAGG-;count;MANni;2|)
    (COND
     (#4# (LETT #3# (|+| #3# #2#) |CLAGG-;count;MANni;2|))
     ((QUOTE T)
      (PROGN
       (LETT #3# #2# |CLAGG-;count;MANni;2|)
       (LETT #4# (QUOTE T) |CLAGG-;count;MANni;2|))))))
    (LETT #1# (CDR #1#) |CLAGG-;count;MANni;2|)
    (GO G190)
    G191
    (EXIT NIL))
  (COND (#4# #3#) ((QUOTE T) 0))))))

(DEFUN |CLAGG-;any?;MAB;3| (|f| |c| |$|)
  (PROG (|x| #1=#:G82642 #2=#:G82640 #3=#:G82638 #4=#:G82639)
    (RETURN
     (SEQ
      (PROGN
       (LETT #4# NIL |CLAGG-;any?;MAB;3|)
       (SEQ
        (LETT |x| NIL |CLAGG-;any?;MAB;3|)
        (LETT #1# (SPADCALL |c| (QREFELT |$| 9)) |CLAGG-;any?;MAB;3|)
        G190
        (COND
         ((OR (ATOM #1#) (PROGN (LETT |x| (CAR #1#) |CLAGG-;any?;MAB;3|) NIL))
          (GO G191)))
        (SEQ
         (EXIT
          (PROGN
           (LETT #2# (SPADCALL |x| |f|) |CLAGG-;any?;MAB;3|)
           (COND
            (#4#
             (LETT #3#
              (COND (#3# (QUOTE T)) ((QUOTE T) #2#))
              |CLAGG-;any?;MAB;3|))
            ((QUOTE T)
             (PROGN
              (LETT #3# #2# |CLAGG-;any?;MAB;3|)
              (LETT #4# (QUOTE T) |CLAGG-;any?;MAB;3|))))))
           (LETT #1# (CDR #1#) |CLAGG-;any?;MAB;3|)
           (GO G190)
           G191
           (EXIT NIL))
            (COND (#4# #3#) ((QUOTE T) (QUOTE NIL)))))))))

(DEFUN |CLAGG-;every?;MAB;4| (|f| |c| |$|)
  (PROG (|x| #1=#:G82647 #2=#:G82645 #3=#:G82643 #4=#:G82644)

```

```

(RETURN
  (SEQ
    (PROGN
      (LETT #4# NIL |CLAGG-;every?;MAB;4|)
      (SEQ
        (LETT |x| NIL |CLAGG-;every?;MAB;4|)
        (LETT #1# (SPADCALL |c| (QREFELT |$| 9)) |CLAGG-;every?;MAB;4|)
        G190
        (COND
          ((OR (ATOM #1#) (PROGN (LETT |x| (CAR #1#) |CLAGG-;every?;MAB;4|) NIL))
            (GO G191)))
        (SEQ
          (EXIT
            (PROGN
              (LETT #2# (SPADCALL |x| |f|) |CLAGG-;every?;MAB;4|)
              (COND
                (#4#
                  (LETT #3#
                    (COND (#3# #2#) ((QUOTE T) (QUOTE NIL)))
                    |CLAGG-;every?;MAB;4|))
                ((QUOTE T)
                  (PROGN
                    (LETT #3# #2# |CLAGG-;every?;MAB;4|)
                    (LETT #4# (QUOTE T) |CLAGG-;every?;MAB;4|))))))
              (LETT #1# (CDR #1#) |CLAGG-;every?;MAB;4|)
              (GO G190)
              G191
              (EXIT NIL))
            (COND (#4# #3#) ((QUOTE T) (QUOTE T)))))))
      (DEFUN |CLAGG-;find;MAU;5| (|f| |c| |$|)
        (SPADCALL |f| (SPADCALL |c| (QREFELT |$| 9)) (QREFELT |$| 18)))
      (DEFUN |CLAGG-;reduce;MAS;6| (|f| |x| |$|)
        (SPADCALL |f| (SPADCALL |x| (QREFELT |$| 9)) (QREFELT |$| 21)))
      (DEFUN |CLAGG-;reduce;MA2S;7| (|f| |x| |s| |$|)
        (SPADCALL |f| (SPADCALL |x| (QREFELT |$| 9)) |s| (QREFELT |$| 23)))
      (DEFUN |CLAGG-;remove;M2A;8| (|f| |x| |$|)
        (SPADCALL
          (SPADCALL |f| (SPADCALL |x| (QREFELT |$| 9)) (QREFELT |$| 25))
          (QREFELT |$| 26)))
      (DEFUN |CLAGG-;select;M2A;9| (|f| |x| |$|)
        (SPADCALL
          (SPADCALL |f| (SPADCALL |x| (QREFELT |$| 9)) (QREFELT |$| 28))
          (QREFELT |$| 26)))
      (DEFUN |CLAGG-;remove;S2A;10| (|s| |x| |$|)

```

```

(SPADCALL
  (CONS (FUNCTION |CLAGG-;remove;S2A;10!0|) (VECTOR |$| |s|))
  |x|
  (QREFELT |$| 31)))

(DEFUN |CLAGG-;remove;S2A;10!0| (|#1| |$$|)
  (SPADCALL |#1| (QREFELT |$$| 1) (QREFELT (QREFELT |$$| 0) 30)))

(DEFUN |CLAGG-;reduce;MA3S;11| (|f| |x| |s1| |s2| |$|)
  (SPADCALL |f| (SPADCALL |x| (QREFELT |$| 9)) |s1| |s2| (QREFELT |$| 33)))

(DEFUN |CLAGG-;removeDuplicates;2A;12| (|x| |$|)
  (SPADCALL
    (SPADCALL (SPADCALL |x| (QREFELT |$| 9)) (QREFELT |$| 35))
    (QREFELT |$| 26)))

(DEFUN |Collection&| (|#1| |#2|)
  (PROG (|DV$1| |DV$2| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|Collection&|))
        (LETT |DV$2| (|devaluate| |#2|) . #1#)
        (LETT |dv$| (LIST (QUOTE |Collection&|) |DV$1| |DV$2|) . #1#)
        (LETT |$| (make-array 37) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3
          (LETT |pv$|
            (|buildPredVector| 0 0
              (LIST
                (|HasCategory| |#2| (QUOTE (|ConvertibleTo| (|InputForm|))))
                (|HasCategory| |#2| (QUOTE (|SetCategory|)))
                (|HasAttribute| |#1| (QUOTE |finiteAggregate|))))
              . #1#))
            (|stuffDomainSlots| |$|)
            (QSETREFV |$| 6 |#1|)
            (QSETREFV |$| 7 |#2|)
            (COND
              ((|testBitVector| |pv$| 3)
                (PROGN
                  (QSETREFV |$| 11 (CONS (|dispatchFunction| |CLAGG-;#;ANni;1|) |$|))
                  (QSETREFV |$| 13 (CONS (|dispatchFunction| |CLAGG-;count;MANni;2|) |$|))
                  (QSETREFV |$| 15 (CONS (|dispatchFunction| |CLAGG-;any?;MAB;3|) |$|))
                  (QSETREFV |$| 16 (CONS (|dispatchFunction| |CLAGG-;every?;MAB;4|) |$|))
                  (QSETREFV |$| 19 (CONS (|dispatchFunction| |CLAGG-;find;MAU;5|) |$|))
                  (QSETREFV |$| 22 (CONS (|dispatchFunction| |CLAGG-;reduce;MAS;6|) |$|))
                  (QSETREFV |$| 24 (CONS (|dispatchFunction| |CLAGG-;reduce;MA2S;7|) |$|))
                  (QSETREFV |$| 27 (CONS (|dispatchFunction| |CLAGG-;remove;M2A;8|) |$|))
                  (QSETREFV |$| 29 (CONS (|dispatchFunction| |CLAGG-;select;M2A;9|) |$|))
                  (COND
                    ((|testBitVector| |pv$| 2)

```

```

(PROGN
  (QSETREFV |$| 32
    (CONS (|dispatchFunction| |CLAGG-;remove;S2A;10|) |$|))
  (QSETREFV |$| 34
    (CONS (|dispatchFunction| |CLAGG-;reduce;MA3S;11|) |$|))
  (QSETREFV |$| 36
    (CONS (|dispatchFunction| |CLAGG-;removeDuplicates;2A;12|)
      |$|))))))
|$|)))

(setf (get
  (QUOTE |Collection&|)
  (QUOTE |infovec|))
  (LIST (QUOTE
    # (NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|) (|List| 7)
      (0 . |parts|) (|NonNegativeInteger|) (5 . |#|) (|Mapping| 14 7)
      (10 . |count|) (|Boolean|) (16 . |any?|) (22 . |every?|)
      (|Union| 7 (QUOTE "failed")) (28 . |find|) (34 . |find|)
      (|Mapping| 7 7 7) (40 . |reduce|) (46 . |reduce|) (52 . |reduce|)
      (59 . |reduce|) (66 . |remove|) (72 . |construct|) (77 . |remove|)
      (83 . |select|) (89 . |select|) (95 . |=|) (101 . |remove|)
      (107 . |remove|) (113 . |reduce|) (121 . |reduce|)
      (129 . |removeDuplicates|) (134 . |removeDuplicates|)))
    (QUOTE #(|select| 139 |removeDuplicates| 145 |remove| 150 |reduce|
      162 |find| 183 |every?| 189 |count| 195 |any?| 201 |#| 207))
    (QUOTE NIL)
    (CONS
      (|makeByteWordVec2| 1 (QUOTE NIL))
      (CONS
        (QUOTE #())
        (CONS
          (QUOTE #())
          (|makeByteWordVec2| 36
            (QUOTE (1 6 8 0 9 1 0 10 0 11 2 0 10 12 0 13 2 0 14 12 0 15 2 0 14
              12 0 16 2 8 17 12 0 18 2 0 17 12 0 19 2 8 7 20 0 21 2 0 7 20 0 22
              3 8 7 20 0 7 23 3 0 7 20 0 7 24 2 8 0 12 0 25 1 6 0 8 26 2 0 0 12
              0 27 2 8 0 12 0 28 2 0 0 12 0 29 2 7 14 0 0 30 2 6 0 12 0 31 2 0 0
              7 0 32 4 8 7 20 0 7 7 33 4 0 7 20 0 7 7 34 1 8 0 0 35 1 0 0 0 36 2
              0 0 12 0 29 1 0 0 0 36 2 0 0 7 0 32 2 0 0 12 0 27 4 0 7 20 0 7 7 34
              3 0 7 20 0 7 24 2 0 7 20 0 22 2 0 17 12 0 19 2 0 14 12 0 16 2 0 10
              12 0 13 2 0 14 12 0 15 1 0 10 0 11))))))
    (QUOTE |lookupComplete|)))

```

21.11 COMRING.lsp BOOTSTRAP

COMRING depends on itself. We need to break this cycle to build the algebra. So we keep

a cached copy of the translated **COMRING** category which we can write into the **MID** directory. We compile the lisp code and copy the **COMRING.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— **COMRING.lsp BOOTSTRAP** —

```
(|/VERSIONCHECK| 2)

(SETQ |CommutativeRing;AL| (QUOTE NIL))

(DEFUN |CommutativeRing| NIL
  (LET (#:G82892)
    (COND
      (|CommutativeRing;AL|)
      (T (SETQ |CommutativeRing;AL| (|CommutativeRing;|))))))

(DEFUN |CommutativeRing;| NIL
  (PROG (#1= #:G82890)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|Ring|)
            (|BiModule| (QUOTE |$|) (QUOTE |$|))
            (|mkCategory|
              (QUOTE |package|)
              NIL
              (QUOTE (((|commutative| "*" ) T)))
              (QUOTE NIL)
              NIL))
          |CommutativeRing|)
        (SETELT #1# 0 (QUOTE (|CommutativeRing|)))))))

(setf (get (QUOTE |CommutativeRing|) (QUOTE NILADIC)) T)
```

21.12 DIFRING.lsp BOOTSTRAP

DIFRING needs **INT** which needs **DIFRING**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **DIFRING** category which we can write into the **MID** directory. We compile the lisp code and copy the **DIFRING.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— DIFRING.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |DifferentialRing;AL| (QUOTE NIL))

(DEFUN |DifferentialRing| NIL
  (LET (#:G84565)
    (COND
      (|DifferentialRing;AL|)
      (T (SETQ |DifferentialRing;AL| (|DifferentialRing;|))))))

(DEFUN |DifferentialRing;| NIL
  (PROG (#1= #:G84563)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|Ring|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE
                (((|differentiate| (|$| |$|)) T)
                 ((D (|$| |$|)) T)
                 ((|differentiate| (|$| |$| (|NonNegativeInteger|))) T)
                 ((D (|$| |$| (|NonNegativeInteger|))) T)))
                NIL
                (QUOTE ((|NonNegativeInteger|))
                NIL))
          |DifferentialRing|)
        (SETELT #1# 0 (QUOTE (|DifferentialRing|))))))

(setf (get (QUOTE |DifferentialRing|) (QUOTE NILADIC)) T)
```

21.13 DIFRING-.lsp BOOTSTRAP

DIFRING- needs **DIFRING**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **DIFRING-** category which we can write into the **MID** directory. We compile the lisp code and copy the **DIFRING-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— DIFRING-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |DIFRING-;D;2S;1| (|r| |$|)
  (SPADCALL |r| (QREFELT |$| 7)))

(DEFUN |DIFRING-;differentiate;SNniS;2| (|r| |n| |$|)
  (PROG (|i|)
    (RETURN
      (SEQ
        (SEQ
          (LETT |i| 1 |DIFRING-;differentiate;SNniS;2|)
          G190
          (COND ((QSGREATERP |i| |n|) (GO G191)))
          (SEQ
            (EXIT
              (LETT |r|
                (SPADCALL |r| (QREFELT |$| 7))
                |DIFRING-;differentiate;SNniS;2|)))
            (LETT |i| (QSADD1 |i|) |DIFRING-;differentiate;SNniS;2|)
            (GO G190)
            G191
            (EXIT NIL))
            (EXIT |r|))))))

(DEFUN |DIFRING-;D;SNniS;3| (|r| |n| |$|)
  (SPADCALL |r| |n| (QREFELT |$| 11)))

(DEFUN |DifferentialRing&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|DifferentialRing&|))
        (LETT |dv$| (LIST (QUOTE |DifferentialRing&|) |DV$1|) . #1#)
        (LETT |$| (make-array 13) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        |$|))))))

(setf (get
  (QUOTE |DifferentialRing&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL

```

```

(|local| |#1|)
(0 . |differentiate|)
|DIFRING-;D;2S;1|
(|NonNegativeInteger|)
|DIFRING-;differentiate;SNniS;2|
(5 . |differentiate|)
|DIFRING-;D;SNniS;3|))
(QUOTE #(|differentiate| 11 D 17))
(QUOTE NIL)
(CONS
  (|makeByteWordVec2| 1 (QUOTE NIL))
  (CONS
    (QUOTE #())
    (CONS
      (QUOTE #())
      (|makeByteWordVec2| 12
        (QUOTE
          (1 6 0 0 7 2 6 0 0 9 11 2 0 0 0 9 10 2 0 0 0 9 12 1 0 0 0 8)))))))
(QUOTE |lookupComplete|)))

```

21.14 DIVRING.lsp BOOTSTRAP

DIVRING depends on **QFCAT** which eventually depends on **DIVRING**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **DIVRING** category which we can write into the **MID** directory. We compile the lisp code and copy the **DIVRING.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— DIVRING.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |DivisionRing;AL| (QUOTE NIL))

(DEFUN |DivisionRing| NIL
  (LET (#:G84035)
    (COND
      (|DivisionRing;AL|)
      (T (SETQ |DivisionRing;AL| (|DivisionRing;|))))))

(DEFUN |DivisionRing;| NIL
  (PROG (#1= #:G84033)

```

```

(RETURN
  (PROG1
    (LETT #1#
      (|sublisV|
        (PAIR
          (QUOTE (#2=#:G84032))
          (LIST (QUOTE (|Fraction| (|Integer|))))))
      (|Join|
        (|EntireRing|)
        (|Algebra| (QUOTE #2#))
        (|mkCategory|
          (QUOTE |domain|)
          (QUOTE (
            ((|**| (|$| |$| (|Integer|))) T)
            ((|^| (|$| |$| (|Integer|))) T)
            ((|inv| (|$| |$|)) T)))
          NIL
          (QUOTE ((|Integer|))
            NIL)))
        |DivisionRing|)
      (SETELT #1# 0 (QUOTE (|DivisionRing|))))))

(setf (get (QUOTE |DivisionRing|) (QUOTE NILADIC)) T)

```

21.15 DIVRING-.lsp BOOTSTRAP

DIVRING- depends on **DIVRING**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **DIVRING-** category which we can write into the **MID** directory. We compile the lisp code and copy the **DIVRING-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— DIVRING-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |DIVRING-;^;SIS;1| (|x| |n| |$|)
  (SPADCALL |x| |n| (QREFELT |$| 8)))

(DEFUN |DIVRING-;**;SIS;2| (|x| |n| |$|)
  (COND
    ((ZEROP |n|) (|spadConstant| |$| 10))
    ((SPADCALL |x| (QREFELT |$| 12))

```

```

(COND
  ((|<| |n| 0) (|error| "division by zero"))
  ((QUOTE T) |x|)))
(|<| |n| 0)
  (SPADCALL (SPADCALL |x| (QREFELT |$| 14)) (|-| |n|) (QREFELT |$| 17)))
  ((QUOTE T) (SPADCALL |x| |n| (QREFELT |$| 17))))))

(DEFUN |DIVRING-;*;F2S;3| (|q| |x| |$|)
  (SPADCALL
    (SPADCALL
      (SPADCALL |q| (QREFELT |$| 20))
      (SPADCALL
        (SPADCALL (SPADCALL |q| (QREFELT |$| 21)) (QREFELT |$| 22))
        (QREFELT |$| 14))
        (QREFELT |$| 23))
      |x|
      (QREFELT |$| 24)))

(DEFUN |DivisionRing&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|DivisionRing&|))
        (LETT |dv$| (LIST (QUOTE |DivisionRing&|) |DV$1|) . #1#)
        (LETT |$| (make-array 27) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        |$|))))))

(setf (get
  (QUOTE |DivisionRing&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (|Integer|)
        (0 . |**|)
        |DIVRING-;^;SIS;1|
        (6 . |One|)
        (|Boolean|)
        (10 . |zero?|)
        (15 . |Zero|)
        (19 . |inv|)
        (|PositiveInteger|)
        (|RepeatedSquaring| 6)
        (24 . |expt|)
        |DIVRING-;**;SIS;2|
```

```

(|Fraction| 7)
(30 . |number|)
(35 . |denom|)
(40 . |coerce|)
(45 . |*|)
(51 . |*|)
|DIVRING-;*;F2S;3|
(|NonNegativeInteger|))
(QUOTE #(|^| 57 |**| 63 |*| 69))
(QUOTE NIL)
(CONS
  (|makeByteWordVec2| 1 (QUOTE NIL))
  (CONS
    (QUOTE #())
    (CONS
      (QUOTE #())
      (|makeByteWordVec2| 25
        (QUOTE
          (2 6 0 0 7 8 0 6 0 10 1 6 11 0 12 0 6 0 13 1 6 0 0 14 2 16 6
            6 15 17 1 19 7 0 20 1 19 7 0 21 1 6 0 7 22 2 6 0 7 0 23 2 6
            0 0 0 24 2 0 0 0 7 9 2 0 0 0 7 18 2 0 0 19 0 25))))))
  (QUOTE |lookupComplete|)))

```

21.16 ES.lsp BOOTSTRAP

ES depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ES** category which we can write into the **MID** directory. We compile the lisp code and copy the **ES.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ES.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |ExpressionSpace;AL| (QUOTE NIL))

(DEFUN |ExpressionSpace| NIL
  (LET (#:G82344)
    (COND
      (|ExpressionSpace;AL|)
      (T (SETQ |ExpressionSpace;AL| (|ExpressionSpace;|))))))

```

```

(DEFUN |ExpressionSpace;| NIL
  (PROG (#1=#:G82342)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR
              (QUOTE (#2=#:G82340 #3=#:G82341))
              (LIST (QUOTE (|Kernel| |$|)) (QUOTE (|Kernel| |$|))))
            (|Join|
              (|OrderedSet|
                (|RetractableTo| (QUOTE #2#))
                (|InnerEvalable| (QUOTE #3#) (QUOTE |$|))
                (|Evalable| (QUOTE |$|))
                (|mkCategory|
                  (QUOTE |domain|)
                  (QUOTE (
                    ((|elt| (|$| (|BasicOperator|) |$|)) T)
                    ((|elt| (|$| (|BasicOperator|) |$| |$|)) T)
                    ((|elt| (|$| (|BasicOperator|) |$| |$| |$|)) T)
                    ((|elt| (|$| (|BasicOperator|) |$| |$| |$| |$|)) T)
                    ((|elt| (|$| (|BasicOperator|) (|List| |$|)) T)
                    ((|subst| (|$| |$| (|Equation| |$|)) T)
                    ((|subst| (|$| |$| (|List| (|Equation| |$|))) T)
                    ((|subst| (|$| |$| (|List| (|Kernel| |$|)) (|List| |$|)) T)
                    ((|box| (|$| |$|)) T)
                    ((|box| (|$| (|List| |$|)) T)
                    ((|paren| (|$| |$|)) T)
                    ((|paren| (|$| (|List| |$|)) T)
                    ((|distribute| (|$| |$|)) T)
                    ((|distribute| (|$| |$| |$|)) T)
                    ((|height| ((|NonNegativeInteger|) |$|)) T)
                    ((|mainKernel| ((|Union| (|Kernel| |$|) "failed") |$|)) T)
                    ((|kernels| ((|List| (|Kernel| |$|)) |$|)) T)
                    ((|tower| ((|List| (|Kernel| |$|)) |$|)) T)
                    ((|operators| ((|List| (|BasicOperator|)) |$|)) T)
                    ((|operator| ((|BasicOperator|) (|BasicOperator|)) T)
                    ((|belong?| ((|Boolean|) (|BasicOperator|)) T)
                    ((|is?| ((|Boolean|) |$| (|BasicOperator|)) T)
                    ((|is?| ((|Boolean|) |$| (|Symbol|)) T)
                    ((|kernel| (|$| (|BasicOperator|) |$|)) T)
                    ((|kernel| (|$| (|BasicOperator|) (|List| |$|)) T)
                    ((|imap| (|$| (|Mapping| |$| |$|) (|Kernel| |$|)) T)
                    ((|freeOf?| ((|Boolean|) |$| |$|)) T)
                    ((|freeOf?| ((|Boolean|) |$| (|Symbol|)) T)
                    ((|eval| (|$| |$| (|List| (|Symbol|)) (|List| (|Mapping| |$| |$|)))
                      T)
                    ((|eval|
                      (|$| |$| (|List| (|Symbol|)) (|List| (|Mapping| |$| (|List| |$|))))
                      T)

```

```

((|eval| (|$| |$| (|Symbol|) (|Mapping| |$| (|List| |$|)))) T)
((|eval| (|$| |$| (|Symbol|) (|Mapping| |$| |$|))) T)
((|eval|
  (|$| |$| (|List| (|BasicOperator|)) (|List| (|Mapping| |$| |$|))))
  T)
((|eval|
  (|$| |$| (|List| (|BasicOperator|))
    (|List| (|Mapping| |$| (|List| |$|))))
  T)
((|eval| (|$| |$| (|BasicOperator|) (|Mapping| |$| (|List| |$|)))) T)
((|eval| (|$| |$| (|BasicOperator|) (|Mapping| |$| |$|))) T)
((|minPoly|
  ((|SparseUnivariatePolynomial| |$|) (|Kernel| |$|))
  (|has| |$| (|Ring|)))
  ((|definingPolynomial| (|$| |$|)) (|has| |$| (|Ring|)))
  ((|even?|
    ((|Boolean|) |$|)) (|has| |$| (|RetractableTo| (|Integer|))))
  ((|odd?|
    ((|Boolean|) |$|)) (|has| |$| (|RetractableTo| (|Integer|)))))
  NIL
  (QUOTE (
    (|Boolean|)
    (|SparseUnivariatePolynomial| |$|)
    (|Kernel| |$|)
    (|BasicOperator|)
    (|List| (|BasicOperator|))
    (|List| (|Mapping| |$| (|List| |$|)))
    (|List| (|Mapping| |$| |$|))
    (|Symbol|)
    (|List| (|Symbol|))
    (|List| |$|)
    (|List| (|Kernel| |$|))
    (|NonNegativeInteger|)
    (|List| (|Equation| |$|))
    (|Equation| |$|))
    NIL))
  (|ExpressionSpace|)
  (SETELT #1# 0 (QUOTE (|ExpressionSpace|))))))

(setf (get (QUOTE |ExpressionSpace|) (QUOTE NILADIC)) T)

```

21.17 ES-.lsp BOOTSTRAP

ES- depends on **ES**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ES-** category which we can write into the **MID** directory. We compile the lisp code and copy the **ES-.o** file to the **OUT** directory. This is eventually forcibly

replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ES-.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(DEFUN |ES-;box;2S;1| (|x| |$|)
  (SPADCALL (LIST |x|) (QREFELT |$| 16)))

(DEFUN |ES-;paren;2S;2| (|x| |$|)
  (SPADCALL (LIST |x|) (QREFELT |$| 18)))

(DEFUN |ES-;belong?;BoB;3| (|op| |$|)
  (COND
    ((SPADCALL |op| (QREFELT |$| 13) (QREFELT |$| 21)) (QUOTE T))
    ((QUOTE T) (SPADCALL |op| (QREFELT |$| 14) (QREFELT |$| 21)))))

(DEFUN |ES-;listk| (|f| |$|)
  (SPADCALL (|ES-;allKernels| |f| |$|) (QREFELT |$| 25)))

(DEFUN |ES-;tower;SL;5| (|f| |$|)
  (SPADCALL (|ES-;listk| |f| |$|) (QREFELT |$| 26)))

(DEFUN |ES-;allk| (|l| |$|)
  (PROG (#1=#:G82361 |f| #2=#:G82362)
    (RETURN
      (SEQ
        (SPADCALL
          (ELT |$| 30)
          (PROGN
            (LETT #1# NIL |ES-;allk|)
            (SEQ
              (LETT |f| NIL |ES-;allk|)
              (LETT #2# |l| |ES-;allk|)
              G190
              (COND
                ((OR (ATOM #2#)
                  (PROGN (LETT |f| (CAR #2#) |ES-;allk|) NIL))
                  (GO G191)))
              (SEQ (EXIT (LETT #1# (CONS (|ES-;allKernels| |f| |$|) #1#) |ES-;allk|)))
              (LETT #2# (CDR #2#) |ES-;allk|) (GO G190) G191 (EXIT (NREVERSEO #1#))))
          (SPADCALL NIL (QREFELT |$| 29))
          (QREFELT |$| 33))))))

(DEFUN |ES-;operators;SL;7| (|f| |$|)
  (PROG (#1=#:G82365 |k| #2=#:G82366)
    (RETURN
```



```

(SEQ
  (PROGN
    (LETT #1# NIL |ES-;operators;SL;7|)
    (SEQ
      (LETT |k| NIL |ES-;operators;SL;7|)
      (LETT #2# (|ES-;listk| |f| |$|) |ES-;operators;SL;7|)
      G190
      (COND
        ((OR (ATOM #2#) (PROGN (LETT |k| (CAR #2#) |ES-;operators;SL;7|) NIL))
          (GO G191)))
      (SEQ
        (EXIT
          (LETT #1#
            (CONS (SPADCALL |k| (QREFELT |$| 35)) #1#) |ES-;operators;SL;7|)))
        (LETT #2# (CDR #2#) |ES-;operators;SL;7|)
        (GO G190)
        G191
        (EXIT (NREVERSEO #1#))))))

(DEFUN |ES-;height;SNni;8| (|f| |$|)
  (PROG (#1=#:G82371 |k| #2=#:G82372)
    (RETURN
      (SEQ
        (SPADCALL
          (ELT |$| 41)
          (PROGN
            (LETT #1# NIL |ES-;height;SNni;8|)
            (SEQ
              (LETT |k| NIL |ES-;height;SNni;8|)
              (LETT #2# (SPADCALL |f| (QREFELT |$| 38)) |ES-;height;SNni;8|)
              G190
              (COND
                ((OR (ATOM #2#) (PROGN (LETT |k| (CAR #2#) |ES-;height;SNni;8|) NIL))
                  (GO G191)))
              (SEQ
                (EXIT
                  (LETT #1#
                    (CONS (SPADCALL |k| (QREFELT |$| 40)) #1#) |ES-;height;SNni;8|)))
                (LETT #2# (CDR #2#) |ES-;height;SNni;8|)
                (GO G190)
                G191
                (EXIT (NREVERSEO #1#))))
              0
              (QREFELT |$| 44))))))

(DEFUN |ES-;freeOf?;SSB;9| (|x| |s| |$|)
  (PROG (#1=#:G82377 |k| #2=#:G82378)
    (RETURN
      (SEQ
        (COND

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((SPADCALL |s|
 (PROGN
  (LETT #1# NIL |ES-;freeOf?;SSB;9|)
  (SEQ
   (LETT |k| NIL |ES-;freeOf?;SSB;9|)
   (LETT #2# (|ES-;listk| |x| |$|) |ES-;freeOf?;SSB;9|)
   G190
   (COND
    ((OR (ATOM #2#) (PROGN (LETT |k| (CAR #2#) |ES-;freeOf?;SSB;9|) NIL))
     (GO G191)))
   (SEQ
    (EXIT
     (LETT #1#
      (CONS (SPADCALL |k| (QREFELT |$| 46)) #1#) |ES-;freeOf?;SSB;9|)))
    (LETT #2# (CDR #2#) |ES-;freeOf?;SSB;9|)
    (GO G190)
    G191
    (EXIT (NREVERSEO #1#))))
   (QREFELT |$| 48))
  (QUOTE NIL))
 ((QUOTE T) (QUOTE T))))))

(DEFUN |ES-;distribute;2S;10| (|x| |$|)
 (PROG (#1=:G82381 |k| #2=:G82382)
 (RETURN
  (SEQ
   (|ES-;unwrap|
    (PROGN (LETT #1# NIL |ES-;distribute;2S;10|)
    (SEQ
     (LETT |k| NIL |ES-;distribute;2S;10|)
     (LETT #2# (|ES-;listk| |x| |$|) |ES-;distribute;2S;10|)
     G190
     (COND
      ((OR
       (ATOM #2#)
       (PROGN (LETT |k| (CAR #2#) |ES-;distribute;2S;10|) NIL))
       (GO G191)))
      (SEQ
       (EXIT
        (COND
         ((SPADCALL |k| (QREFELT |$| 13) (QREFELT |$| 50))
          (LETT #1# (CONS |k| #1#) |ES-;distribute;2S;10|))))
        (LETT #2# (CDR #2#) |ES-;distribute;2S;10|)
        (GO G190)
        G191
        (EXIT (NREVERSEO #1#))))
       |x|
       |$|))))))

(DEFUN |ES-;box;LS;11| (|l| |$|)

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```

(SPADCALL (QREFELT |$| 14) |l| (QREFELT |$| 52)))

(DEFUN |ES-;paren;LS;12| (|l| |$|)
  (SPADCALL (QREFELT |$| 13) |l| (QREFELT |$| 52)))

(DEFUN |ES-;freeOf?;2SB;13| (|x| |k| |$|)
  (COND
    ((SPADCALL
      (SPADCALL |k| (QREFELT |$| 56))
      (|ES-;listk| |x| |$|)
      (QREFELT |$| 57))
      (QUOTE NIL))
    ((QUOTE T) (QUOTE T))))

(DEFUN |ES-;kernel;Bo2S;14| (|op| |arg| |$|)
  (SPADCALL |op| (LIST |arg|) (QREFELT |$| 59)))

(DEFUN |ES-;elt;Bo2S;15| (|op| |x| |$|)
  (SPADCALL |op| (LIST |x|) (QREFELT |$| 52)))

(DEFUN |ES-;elt;Bo3S;16| (|op| |x| |y| |$|)
  (SPADCALL |op| (LIST |x| |y|) (QREFELT |$| 52)))

(DEFUN |ES-;elt;Bo4S;17| (|op| |x| |y| |z| |$|)
  (SPADCALL |op| (LIST |x| |y| |z|) (QREFELT |$| 52)))

(DEFUN |ES-;elt;Bo5S;18| (|op| |x| |y| |z| |t| |$|)
  (SPADCALL |op| (LIST |x| |y| |z| |t|) (QREFELT |$| 52)))

(DEFUN |ES-;eval;SSMS;19| (|x| |s| |f| |$|)
  (SPADCALL |x| (LIST |s|) (LIST |f|) (QREFELT |$| 67)))

(DEFUN |ES-;eval;SBoMS;20| (|x| |s| |f| |$|)
  (SPADCALL
    |x|
    (LIST (SPADCALL |s| (QREFELT |$| 69)))
    (LIST |f|)
    (QREFELT |$| 67)))

(DEFUN |ES-;eval;SSMS;21| (|x| |s| |f| |$|)
  (SPADCALL
    |x|
    (LIST |s|)
    (LIST (CONS (FUNCTION |ES-;eval;SSMS;21!0|) (VECTOR |f| |$|)))
    (QREFELT |$| 67)))

(DEFUN |ES-;eval;SSMS;21!0| (|#1| |$$|)
  (SPADCALL (SPADCALL |#1| (QREFELT (QREFELT |$$| 1) 72)) (QREFELT |$$| 0)))

(DEFUN |ES-;eval;SBoMS;22| (|x| |s| |f| |$|)

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(SPADCALL
  |x|
  (LIST |s|)
  (LIST (CONS (FUNCTION |ES-;eval;SBoMS;22!0|) (VECTOR |f| |$|)))
  (QREFELT |$| 75)))

(DEFUN |ES-;eval;SBoMS;22!0| (|#1| |$$|)
  (SPADCALL (SPADCALL |#1| (QREFELT (QREFELT |$$| 1) 72)) (QREFELT |$$| 0)))

(DEFUN |ES-;subst;SES;23| (|x| |e| |$|)
  (SPADCALL |x| (LIST |e|) (QREFELT |$| 78)))

(DEFUN |ES-;eval;SLLS;24| (|x| |ls| |lf| |$|)
  (PROG (#1=#:G82403 |f| #2=#:G82404)
    (RETURN
      (SEQ
        (SPADCALL
          |x|
          |ls|
          (PROGN
            (LETT #1# NIL |ES-;eval;SLLS;24|)
            (SEQ
              (LETT |f| NIL |ES-;eval;SLLS;24|)
              (LETT #2# |lf| |ES-;eval;SLLS;24|)
              G190
              (COND
                ((OR (ATOM #2#) (PROGN (LETT |f| (CAR #2#) |ES-;eval;SLLS;24|) NIL))
                 (GO G191)))
              (SEQ
                (EXIT
                  (LETT #1#
                    (CONS (CONS (FUNCTION |ES-;eval;SLLS;24!0|) (VECTOR |f| |$|)) #1#)
                    |ES-;eval;SLLS;24|)))
                (LETT #2# (CDR #2#) |ES-;eval;SLLS;24|)
                (GO G190)
                G191
                (EXIT (NREVERSE0 #1#))))
              (QREFELT |$| 75)))))))

(DEFUN |ES-;eval;SLLS;24!0| (|#1| |$$|)
  (SPADCALL (SPADCALL |#1| (QREFELT (QREFELT |$$| 1) 72)) (QREFELT |$$| 0)))

(DEFUN |ES-;eval;SLLS;25| (|x| |ls| |lf| |$|)
  (PROG (#1=#:G82407 |f| #2=#:G82408)
    (RETURN
      (SEQ
        (SPADCALL
          |x|
          |ls|
          (PROGN

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(LETT #1# NIL |ES-;eval;SLLS;25|)
(SEQ
  (LETT |f| NIL |ES-;eval;SLLS;25|)
  (LETT #2# |lf| |ES-;eval;SLLS;25|)
  G190
  (COND
    ((OR (ATOM #2#) (PROGN (LETT |f| (CAR #2#) |ES-;eval;SLLS;25|) NIL))
      (GO G191)))
  (SEQ
    (EXIT
      (LETT #1#
        (CONS (CONS (FUNCTION |ES-;eval;SLLS;25!0|) (VECTOR |f| |$|)) #1#)
          |ES-;eval;SLLS;25|)))
    (LETT #2# (CDR #2#) |ES-;eval;SLLS;25|)
    (GO G190)
    G191
    (EXIT (NREVERSEO #1#))))
(QREFELT |$| 67))))))

(DEFUN |ES-;eval;SLLS;25!0| (|#1| |$$|)
  (SPADCALL (SPADCALL |#1| (QREFELT (QREFELT |$$| 1) 72)) (QREFELT |$$| 0)))

(DEFUN |ES-;eval;SLLS;26| (|x| |ls| |lf| |$|)
  (PROG (#1=#:G82412 |s| #2=#:G82413)
    (RETURN
      (SEQ
        (SPADCALL
          |x|
          (PROGN
            (LETT #1# NIL |ES-;eval;SLLS;26|)
            (SEQ
              (LETT |s| NIL |ES-;eval;SLLS;26|)
              (LETT #2# |ls| |ES-;eval;SLLS;26|)
              G190
              (COND
                ((OR (ATOM #2#) (PROGN (LETT |s| (CAR #2#) |ES-;eval;SLLS;26|) NIL))
                  (GO G191)))
              (SEQ
                (EXIT
                  (LETT #1#
                    (CONS (SPADCALL |s| (QREFELT |$| 69)) #1#) |ES-;eval;SLLS;26|)))
                (LETT #2# (CDR #2#) |ES-;eval;SLLS;26|)
                (GO G190)
                G191
                (EXIT (NREVERSEO #1#))))
              |lf|
              (QREFELT |$| 67))))))

(DEFUN |ES-;map;MKS;27| (|fn| |k| |$|)
  (PROG (#1=#:G82428 |x| #2=#:G82429 |l|)

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(RETURN
  (SEQ
    (COND
      ((SPADCALL
        (LETT |l|
          (PROGN
            (LETT #1# NIL |ES-;map;MKS;27|)
            (SEQ
              (LETT |x| NIL |ES-;map;MKS;27|)
              (LETT #2# (SPADCALL |k| (QREFELT |$| 85)) |ES-;map;MKS;27|)
              G190
              (COND
                ((OR (ATOM #2#) (PROGN (LETT |x| (CAR #2#) |ES-;map;MKS;27|) NIL))
                  (GO G191)))
              (SEQ
                (EXIT
                  (LETT #1# (CONS (SPADCALL |x| |fn|) #1#) |ES-;map;MKS;27|)))
                (LETT #2# (CDR #2#) |ES-;map;MKS;27|)
                (GO G190)
                G191
                (EXIT (NREVERSEO #1#))))
            |ES-;map;MKS;27|)
            (SPADCALL |k| (QREFELT |$| 85)) (QREFELT |$| 86))
            (SPADCALL |k| (QREFELT |$| 87)))
          ((QUOTE T)
            (SPADCALL (SPADCALL |k| (QREFELT |$| 35)) |l| (QREFELT |$| 52)))))))

(DEFUN |ES-;operator;2Bo;28| (|op| |$|)
  (COND
    ((SPADCALL |op| (SPADCALL "%paren" (QREFELT |$| 9)) (QREFELT |$| 89))
      (QREFELT |$| 13))
    ((SPADCALL |op| (SPADCALL "%box" (QREFELT |$| 9)) (QREFELT |$| 89))
      (QREFELT |$| 14))
    ((QUOTE T) (|error| "Unknown operator"))))

(DEFUN |ES-;mainKernel;SU;29| (|x| |$|)
  (PROG (|l| |kk| #1=#:G82445 |n| |k|)
    (RETURN
      (SEQ
        (COND
          ((NULL (LETT |l| (SPADCALL |x| (QREFELT |$| 38)) |ES-;mainKernel;SU;29|))
            (CONS 1 "failed"))
          ((QUOTE T)
            (SEQ
              (LETT |n|
                (SPADCALL
                  (LETT |k| (|SPADfirst| |l|) |ES-;mainKernel;SU;29|) (QREFELT |$| 40))
                  |ES-;mainKernel;SU;29|)
              (SEQ
                (LETT |kk| NIL |ES-;mainKernel;SU;29|)

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(LETT #1# (CDR |l|) |ES-;mainKernel;SU;29|)
G190
(COND
  ((OR
    (ATOM #1#)
    (PROGN (LETT |kk| (CAR #1#) |ES-;mainKernel;SU;29|) NIL))
    (GO G191)))
  (SEQ
    (EXIT
      (COND
        ((|<| |n| (SPADCALL |kk| (QREFELT |$| 40)))
          (SEQ
            (LETT |n| (SPADCALL |kk| (QREFELT |$| 40)) |ES-;mainKernel;SU;29|)
            (EXIT (LETT |k| |kk| |ES-;mainKernel;SU;29|))))))
        (LETT #1# (CDR #1#) |ES-;mainKernel;SU;29|) (GO G190) G191 (EXIT NIL))
      (EXIT (CONS 0 |k|)))))))))

(DEFUN |ES-;allKernels| (|f| |$|)
  (PROG (|l| |k| #1#:#:G82458 |u| |s0| |n| |arg| |t| |s|)
    (RETURN
      (SEQ
        (LETT |s|
          (SPADCALL
            (LETT |l|
              (SPADCALL |f| (QREFELT |$| 38))
              |ES-;allKernels|)
            (QREFELT |$| 29))
          |ES-;allKernels|)
        (SEQ
          (LETT |k| NIL |ES-;allKernels|)
          (LETT #1# |l| |ES-;allKernels|)
          G190
          (COND
            ((OR (ATOM #1#) (PROGN (LETT |k| (CAR #1#) |ES-;allKernels|) NIL))
              (GO G191)))
          (SEQ
            (LETT |t|
              (SEQ
                (LETT |u|
                  (SPADCALL
                    (SPADCALL |k| (QREFELT |$| 35))
                    "%dummyVar"
                    (QREFELT |$| 94))
                  |ES-;allKernels|)
                (EXIT
                  (COND
                    ((EQCAR |u| 0)
                      (SEQ
                        (LETT |arg| (SPADCALL |k| (QREFELT |$| 85)) |ES-;allKernels|)
                        (LETT |s0|

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      (SPADCALL
        (SPADCALL
          (SPADCALL |arg| (QREFELT |$| 95))
          (QREFELT |$| 56))
        (|ES-;allKernels| (|SPADfirst| |arg|) |$|)
        (QREFELT |$| 96))
      |ES-;allKernels|)
    (LETT |arg| (CDR (CDR |arg|)) |ES-;allKernels|)
    (LETT |n| (QCDR |u|) |ES-;allKernels|)
    (COND ((|<| 1 |n|) (LETT |arg| (CDR |arg|) |ES-;allKernels|)))
    (EXIT (SPADCALL |s0| (|ES-;allk| |arg| |$|) (QREFELT |$| 30))))))
  ((QUOTE T) (|ES-;allk| (SPADCALL |k| (QREFELT |$| 85)) |$|))))
|ES-;allKernels|)
(EXIT
  (LETT |s| (SPADCALL |s| |t| (QREFELT |$| 30)) |ES-;allKernels|)))
(LETT #1# (CDR #1#) |ES-;allKernels|)
(GO G190)
G191
(EXIT NIL))
(EXIT |s|))))))

(DEFUN |ES-;kernel;BoLS;31| (|op| |args| |$|)
  (COND
    ((NULL (SPADCALL |op| (QREFELT |$| 97))) (|error| "Unknown operator"))
    ((QUOTE T) (|ES-;okkernel| |op| |args| |$|))))))

(DEFUN |ES-;okkernel| (|op| |l| |$|)
  (PROG (#1#:#:G82465 |f| #2#:#:G82466)
    (RETURN
      (SEQ
        (SPADCALL
          (SPADCALL |op| |l|
            (|+| 1
              (SPADCALL
                (ELT |$| 41)
                (PROGN
                  (LETT #1# NIL |ES-;okkernel|)
                  (SEQ
                    (LETT |f| NIL |ES-;okkernel|)
                    (LETT #2# |l| |ES-;okkernel|)
                    G190
                    (COND
                      ((OR (ATOM #2#) (PROGN (LETT |f| (CAR #2#) |ES-;okkernel|) NIL))
                        (GO G191))))
                  (SEQ
                    (EXIT
                      (LETT #1#
                        (CONS (SPADCALL |f| (QREFELT |$| 99)) #1#) |ES-;okkernel|)))
                    (LETT #2# (CDR #2#) |ES-;okkernel|)
                    (GO G190))
                  )
                )
              )
            )
          )
        )
      )
    )
  )

```



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G191
  (EXIT (NREVERSEO #1#)))
0
  (QREFELT |$| 44)))
  (QREFELT |$| 100))
  (QREFELT |$| 87))))))

(DEFUN |ES-;elt;BoLS;33| (|op| |args| |$|)
  (PROG (|u| #1=#:G82482 |v|)
    (RETURN
      (SEQ
        (EXIT
          (COND
            ((NULL (SPADCALL |op| (QREFELT |$| 97))) (|error| "Unknown operator"))
            ((QUOTE T)
              (SEQ
                (SEQ
                  (LETT |u| (SPADCALL |op| (QREFELT |$| 102)) |ES-;elt;BoLS;33|)
                  (EXIT
                    (COND
                      ((QEQCAR |u| 0)
                        (COND
                          ((NULL (EQL (LENGTH |args|) (QCDR |u|)))
                            (PROGN
                              (LETT #1#
                                (|error| "Wrong number of arguments")
                                |ES-;elt;BoLS;33|)
                                (GO #1#))))))
                      (LETT |v| (SPADCALL |op| |args| (QREFELT |$| 105)) |ES-;elt;BoLS;33|)
                      (EXIT
                        (COND
                          ((QEQCAR |v| 0) (QCDR |v|))
                          ((QUOTE T) (|ES-;okkernel| |op| |args| |$|))))))
                    #1#
                    (EXIT #1#))))))
            ))
    ))

(DEFUN |ES-;retract;SK;34| (|f| |$|)
  (PROG (|k|)
    (RETURN
      (SEQ
        (LETT |k| (SPADCALL |f| (QREFELT |$| 107)) |ES-;retract;SK;34|)
        (EXIT
          (COND
            ((OR
              (QEQCAR |k| 1)
              (NULL
                (SPADCALL
                  (SPADCALL (QCDR |k|) (QREFELT |$| 87))
                  |f|
                  (QREFELT |$| 108))))
            ))
        ))
    ))

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      (|error| "not a kernel"))
      ((QUOTE T) (QCDR |k|)))))))))

(DEFUN |ES-;retractIfCan;SU;35| (|f| |$|)
  (PROG (|k|)
    (RETURN
      (SEQ
        (LETT |k| (SPADCALL |f| (QREFELT |$| 107)) |ES-;retractIfCan;SU;35|)
        (EXIT
          (COND
            ((OR
              (QEQCAR |k| 1)
              (NULL
                (SPADCALL
                  (SPADCALL (QCDR |k|) (QREFELT |$| 87))
                  |f|
                  (QREFELT |$| 108))))
              (CONS 1 "failed")))
            ((QUOTE T) |k|)))))))))

(DEFUN |ES-;is?;SSB;36| (|f| |s| |$|)
  (PROG (|k|)
    (RETURN
      (SEQ
        (LETT |k| (SPADCALL |f| (QREFELT |$| 111)) |ES-;is?;SSB;36|)
        (EXIT
          (COND
            ((QEQCAR |k| 1) (QUOTE NIL))
            ((QUOTE T) (SPADCALL (QCDR |k|) |s| (QREFELT |$| 112)))))))))

(DEFUN |ES-;is?;SBoB;37| (|f| |op| |$|)
  (PROG (|k|)
    (RETURN
      (SEQ
        (LETT |k| (SPADCALL |f| (QREFELT |$| 111)) |ES-;is?;SBoB;37|)
        (EXIT
          (COND
            ((QEQCAR |k| 1) (QUOTE NIL))
            ((QUOTE T) (SPADCALL (QCDR |k|) |op| (QREFELT |$| 50)))))))))

(DEFUN |ES-;unwrap| (|l| |x| |$|)
  (PROG (|k| #1=#:G82507)
    (RETURN
      (SEQ
        (SEQ
          (LETT |k| NIL |ES-;unwrap|)
          (LETT #1# (NREVERSE |l|) |ES-;unwrap|)
          G190
          (COND
            ((OR (ATOM #1#) (PROGN (LETT |k| (CAR #1#) |ES-;unwrap|) NIL))

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      (GO G191)))
    (SEQ
      (EXIT
        (LETT |x|
          (SPADCALL |x| |k|
            (|SPADfirst| (SPADCALL |k| (QREFELT |$| 85)))
            (QREFELT |$| 115))
          |ES-;unwrap|)))
      (LETT #1# (CDR #1#) |ES-;unwrap|)
      (GO G190)
      G191
      (EXIT NIL))
    (EXIT |x|))))))

(DEFUN |ES-;distribute;3S;39| (|x| |y| |$|)
  (PROG (|ky| #1=#:G82512 |k| #2=#:G82513)
    (RETURN
      (SEQ
        (LETT |ky| (SPADCALL |y| (QREFELT |$| 56)) |ES-;distribute;3S;39|)
        (EXIT
          (|ES-;unwrap|
            (PROGN
              (LETT #1# NIL |ES-;distribute;3S;39|)
              (SEQ
                (LETT |k| NIL |ES-;distribute;3S;39|)
                (LETT #2# (|ES-;listk| |x| |$|) |ES-;distribute;3S;39|)
                G190
                (COND
                  ((OR
                    (ATOM #2#)
                    (PROGN (LETT |k| (CAR #2#) |ES-;distribute;3S;39|) NIL))
                    (GO G191)))
                (SEQ
                  (EXIT
                    (COND
                      ((COND
                        ((SPADCALL |k|
                          (SPADCALL "%paren" (QREFELT |$| 9))
                          (QREFELT |$| 112))
                        (SPADCALL |ky|
                          (|ES-;listk| (SPADCALL |k| (QREFELT |$| 87)) |$|)
                          (QREFELT |$| 57)))
                        ((QUOTE T) (QUOTE NIL)))
                      (LETT #1# (CONS |k| #1#) |ES-;distribute;3S;39|))))))
                  (LETT #2# (CDR #2#) |ES-;distribute;3S;39|)
                  (GO G190)
                  G191
                  (EXIT (NREVERSEO #1#))))
                |x|
                |$|))))))

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```

(DEFUN |ES-;eval;SLS;40| (|f| |leq| |$|)
  (PROG (|rec|)
    (RETURN
      (SEQ
        (LETT |rec| (|ES-;mkKerLists| |leq| |$|) |ES-;eval;SLS;40|)
        (EXIT (SPADCALL |f| (QCAR |rec|) (QCDR |rec|) (QREFELT |$| 117)))))))

(DEFUN |ES-;subst;SLS;41| (|f| |leq| |$|)
  (PROG (|rec|)
    (RETURN
      (SEQ
        (LETT |rec| (|ES-;mkKerLists| |leq| |$|) |ES-;subst;SLS;41|)
        (EXIT (SPADCALL |f| (QCAR |rec|) (QCDR |rec|) (QREFELT |$| 119)))))))

(DEFUN |ES-;mkKerLists| (|leq| |$|)
  (PROG (|eq| #1=#:G82530 |k| |lk| |lv|)
    (RETURN
      (SEQ
        (LETT |lk| NIL |ES-;mkKerLists|)
        (LETT |lv| NIL |ES-;mkKerLists|)
        (SEQ
          (LETT |eq| NIL |ES-;mkKerLists|)
          (LETT #1# |leq| |ES-;mkKerLists|)
          G190
          (COND
            ((OR (ATOM #1#) (PROGN (LETT |eq| (CAR #1#) |ES-;mkKerLists|) NIL))
              (GO G191)))
          (SEQ
            (LETT |k|
              (SPADCALL (SPADCALL |eq| (QREFELT |$| 122)) (QREFELT |$| 111))
              |ES-;mkKerLists|)
            (EXIT
              (COND
                ((QEQCAR |k| 1) (|error| "left hand side must be a single kernel"))
                (NULL (SPADCALL (QCDR |k|) |lk| (QREFELT |$| 57)))
                (SEQ
                  (LETT |lk| (CONS (QCDR |k|) |lk|) |ES-;mkKerLists|)
                  (EXIT
                    (LETT |lv|
                      (CONS (SPADCALL |eq| (QREFELT |$| 123)) |lv|)
                      |ES-;mkKerLists|))))))
            (LETT #1# (CDR #1#) |ES-;mkKerLists|)
            (GO G190)
            G191
            (EXIT NIL))
            (EXIT (CONS |lk| |lv|)))))))

(DEFUN |ES-;even?;SB;43| (|x| |$|)
  (|ES-;intpred?| |x| (ELT |$| 125) |$|))

```

```

(DEFUN |ES-;odd?;SB;44| (|x| |$|)
  (|ES-;intpred?| |x| (ELT |$| 127) |$|))

(DEFUN |ES-;intpred?| (|x| |pred?| |$|)
  (PROG (|u|)
    (RETURN
      (SEQ
        (LETT |u| (SPADCALL |x| (QREFELT |$| 130)) |ES-;intpred?|)
        (EXIT
          (COND
            ((QEQCAR |u| 0) (SPADCALL (QCDR |u|) |pred?|))
            ((QUOTE T) (QUOTE NIL)))))))

(DEFUN |ExpressionSpace&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|ExpressionSpace&|))
        (LETT |dv$| (LIST (QUOTE |ExpressionSpace&|) |DV$1|) . #1#)
        (LETT |$| (make-array 131) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3
          (LETT |pv$|
            (|buildPredVector| 0 0
              (LIST
                (|HasCategory| |#1| (QUOTE (|RetractableTo| (|Integer|))))
                (|HasCategory| |#1| (QUOTE (|Ring|))))) . #1#))
            (|stuffDomainSlots| |$|)
            (QSETREFV |$| 6 |#1|)
            (QSETREFV |$| 13
              (SPADCALL (SPADCALL "%paren" (QREFELT |$| 9)) (QREFELT |$| 12)))
            (QSETREFV |$| 14
              (SPADCALL (SPADCALL "%box" (QREFELT |$| 9)) (QREFELT |$| 12)))
            (COND
              ((|testBitVector| |pv$| 1)
                (PROGN
                  (QSETREFV |$| 126 (CONS (|dispatchFunction| |ES-;even?;SB;43|) |$|))
                  (QSETREFV |$| 128 (CONS (|dispatchFunction| |ES-;odd?;SB;44|) |$|))))
              |$|))))
        |$|))))

(setf (get
  (QUOTE |ExpressionSpace&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE #(
      NIL NIL NIL NIL NIL (|local| |#1|) (|String|) (|Symbol|)
      (0 . |coerce|) (|BasicOperator|) (|CommonOperators|) (5 . |operator|)
      (QUOTE |oppren|) (QUOTE |opbox|) (|List| |$|) (10 . |box|)
      |ES-;box;2S;1| (15 . |paren|) |ES-;paren;2S;2| (|Boolean|)

```

```

(20 . |=|) |ES-;belong?;BoB;3| (|List| 34) (|Set| 34)
(26 . |parts|) (31 . |sort!|) (|List| 55) |ES-;tower;SL;5|
(36 . |brace|) (41 . |union|) (|Mapping| 24 24 24) (|List| 24)
(47 . |reduce|) (|Kernel| 6) (54 . |operator|) (|List| 10)
|ES-;operators;SL;7| (59 . |kernels|) (|NonNegativeInteger|)
(64 . |height|) (69 . |max|) (|Mapping| 39 39 39) (|List| 39)
(75 . |reduce|) |ES-;height;SNni;8| (82 . |name|) (|List| 8)
(87 . |member?|) |ES-;freeOf?;SSB;9| (93 . |is?|)
|ES-;distribute;2S;10| (99 . |elt|) |ES-;box;LS;11|
|ES-;paren;LS;12| (|Kernel| |$|) (105 . |retract|)
(110 . |member?|) |ES-;freeOf?;2SB;13| (116 . |kernel|)
|ES-;kernel;Bo2S;14| |ES-;elt;Bo2S;15| |ES-;elt;Bo3S;16|
|ES-;elt;Bo4S;17| |ES-;elt;Bo5S;18| (|Mapping| |$| 15)
(|List| 65) (122 . |eval|) |ES-;eval;SSMS;19| (129 . |name|)
|ES-;eval;SBoMS;20| (|List| 6) (134 . |first|)
(|Mapping| |$| |$|) |ES-;eval;SSMS;21| (139 . |eval|)
|ES-;eval;SBoMS;22| (|List| 79) (146 . |subst|) (|Equation| |$|)
|ES-;subst;SES;23| (|List| 73) |ES-;eval;SLLS;24|
|ES-;eval;SLLS;25| |ES-;eval;SLLS;26| (152 . |argument|)
(157 . |=|) (163 . |coerce|) |ES-;map;MKS;27| (168 . |is?|)
|ES-;operator;2Bo;28| (|Union| 55 (QUOTE "failed"))
|ES-;mainKernel;SU;29| (|Union| (|None|) (QUOTE "failed"))
(174 . |property|) (180 . |second|) (185 . |remove!|)
(191 . |belong?|) |ES-;kernel;BoLS;31| (196 . |height|)
(201 . |kernel|) (|Union| 39 (QUOTE "failed")) (208 . |arity|)
(|Union| 6 (QUOTE "failed")) (|BasicOperatorFunctions1| 6)
(213 . |evaluate|) |ES-;elt;BoLS;33| (219 . |mainKernel|)
(224 . |=|) |ES-;retract;SK;34| |ES-;retractIfCan;SU;35|
(230 . |retractIfCan|) (235 . |is?|) |ES-;is?;SSB;36|
|ES-;is?;SBoB;37| (241 . |eval|) |ES-;distribute;3S;39|
(248 . |eval|) |ES-;eval;SLS;40| (255 . |subst|)
|ES-;subst;SLS;41| (|Equation| 6) (262 . |lhs|) (267 . |rhs|)
(|Integer|) (272 . |even?|) (277 . |even?|) (282 . |odd?|)
(287 . |odd?|) (|Union| 124 (QUOTE "failed")) (292 . |retractIfCan|))
(QUOTE #(
|tower| 297 |subst| 302 |retractIfCan| 314 |retract| 319 |paren| 324
|operators| 334 |operator| 339 |odd?| 344 |map| 349 |mainKernel| 355
|kernel| 360 |is?| 372 |height| 384 |freeOf?| 389 |even?| 401 |eval| 406
|elt| 461 |distribute| 497 |box| 508 |belong?| 518))
(QUOTE NIL)
(CONS
(|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
(QUOTE #())
(CONS
(QUOTE #())
(|makeByteWordVec2| 130 (QUOTE
(1 8 0 7 9 1 11 10 8 12 1 6 0 15 16 1 6 0 15 18 2 10 20 0 0 21 1 24
23 0 25 1 23 0 0 26 1 24 0 23 29 2 24 0 0 0 30 3 32 24 31 0 24 33
1 34 10 0 35 1 6 27 0 38 1 34 39 0 40 2 39 0 0 0 41 3 43 39 42 0

```

```

39 44 1 34 8 0 46 2 47 20 8 0 48 2 34 20 0 10 50 2 6 0 10 15 52 1
6 55 0 56 2 23 20 34 0 57 2 6 0 10 15 59 3 6 0 0 47 66 67 1 10 8
0 69 1 71 6 0 72 3 6 0 0 36 66 75 2 6 0 0 77 78 1 34 71 0 85 2 71
20 0 0 86 1 6 0 55 87 2 10 20 0 8 89 2 10 93 0 7 94 1 71 6 0 95
2 24 0 34 0 96 1 6 20 10 97 1 6 39 0 99 3 34 0 10 71 39 100 1 10
101 0 102 2 104 103 10 71 105 1 6 91 0 107 2 6 20 0 0 108 1 6 91
0 111 2 34 20 0 8 112 3 6 0 0 55 0 115 3 6 0 0 27 15 117 3 6 0 0
27 15 119 1 121 6 0 122 1 121 6 0 123 1 124 20 0 125 1 0 20 0 126
1 124 20 0 127 1 0 20 0 128 1 6 129 0 130 1 0 27 0 28 2 0 0 0 77
120 2 0 0 0 79 80 1 0 91 0 110 1 0 55 0 109 1 0 0 0 19 1 0 0 15
54 1 0 36 0 37 1 0 10 10 90 1 0 20 0 128 2 0 0 73 55 88 1 0 91 0
92 2 0 0 10 15 98 2 0 0 10 0 60 2 0 20 0 8 113 2 0 20 0 10 114 1
0 39 0 45 2 0 20 0 8 49 2 0 20 0 0 58 1 0 20 0 126 3 0 0 0 10 73
76 3 0 0 0 36 66 84 3 0 0 0 10 65 70 3 0 0 0 36 81 82 3 0 0 0 8
65 68 3 0 0 0 8 73 74 3 0 0 0 47 81 83 2 0 0 0 77 118 2 0 0 10
15 106 5 0 0 10 0 0 0 64 3 0 0 10 0 0 62 4 0 0 10 0 0 63 2
0 0 10 0 61 2 0 0 0 116 1 0 0 0 51 1 0 0 15 53 1 0 0 0 17 1 0
20 10 22))))))
(QUOTE |lookupComplete|))

```

21.18 EUCDOM.lsp BOOTSTRAP

EUCDOM depends on **INT** which depends on **EUCDOM**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **EUCDOM** category which we can write into the **MID** directory. We compile the lisp code and copy the **EUCDOM.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

The Lisp Implementation

EUCDOM;VersionCheck

This implements the bootstrap code for **EuclideanDomain**. The call to **VERSIONCHECK** is a legacy check to ensure that we did not load algebra code from a previous system version (which would not run due to major surgical changes in the system) without recompiling.

— **EUCDOM;VersionCheck** —

```
(|/VERSIONCHECK| 2)
```

The Domain Cache Variable

We create a variable which is formed by concatenating the string “;AL” to the domain name forming, in this case, “**EuclideanDomain;AL**”. The variable has the initial value at load time of a list of one element, **NIL**. This list is a data structure that will be modified to hold an executable function. This function is created the first time the domain is used which it replaces the **NIL**.

— **EuclideanDomain;AL** —

```
(SETQ |EuclideanDomain;AL| (QUOTE NIL))
```

The Domain Function

When you call a domain the code is pretty simple at the top level. This code will check to see if this domain has ever been used. It does this by checking the value of the cached domain variable (which is the domain name **EuclideanDomain** concatenated with the string “;AL” to form the cache variable name which is **EuclideanDomain;AL**).

If this value is **NIL** we have never executed this function before. If it is not **NIL** we have executed this function before and we need only return the cached function which was stored in the cache variable.

If this is the first time this function is called, the cache variable is **NIL** and we execute the other branch of the conditional. This calls a function which

1. creates a procedure
2. returns the procedure as a value.

This procedure replaces the cached variable **EuclideanDomain;AL** value so it will be non-**NIL** the second time this domain is used. Thus the work of building the domain only happens once.

If this function has never been called before we call the

— **EuclideanDomain** —

```
(DEFUN |EuclideanDomain| NIL
  (LET (#:G83585)
    (COND
      (|EuclideanDomain;AL|)
      (T (SETQ |EuclideanDomain;AL| (|EuclideanDomain;|))))))
```

The First Call Domain Function

— EuclideanDomain; —

```

(DEFUN |EuclideanDomain;| NIL
  (PROG (#1=#:G83583)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|PrincipalIdealDomain|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE (
                ((|sizeLess?| ((|Boolean|) |$| |$|)) T)
                ((|euclideanSize| ((|NonNegativeInteger|) |$|)) T)
                ((|divide|
                  ((|Record|
                    (|:| |quotient| |$|)
                    (|:| |remainder| |$|))
                  |$| |$|)) T)
                ((|quo| (|$| |$| |$|)) T)
                ((|rem| (|$| |$| |$|)) T)
                ((|extendedEuclidean|
                  ((|Record|
                    (|:| |coef1| |$|)
                    (|:| |coef2| |$|)
                    (|:| |generator| |$|))
                  |$| |$|)) T)
                ((|extendedEuclidean|
                  ((|Union|
                    (|Record| (|:| |coef1| |$|) (|:| |coef2| |$|))
                    "failed")
                    |$| |$| |$|)) T)
                ((|multiEuclidean|
                  ((|Union|
                    (|List| |$|)
                    "failed")
                    (|List| |$|) |$|)) T)))
          NIL
          (QUOTE ((|List| |$|) (|NonNegativeInteger|) (|Boolean|)))
          NIL))
        |EuclideanDomain|)
    (SETELT #1# 0 (QUOTE (|EuclideanDomain|))))))

```

EUCDOM;NILADIC

— **EUCDOM;NILADIC** —

```
(setf (get (QUOTE |EuclideanDomain|) (QUOTE NILADIC)) T)
```

—————

— **EUCDOM.lsp BOOTSTRAP** —

```
\getchunk{EUCDOM;VersionCheck}
\getchunk{EuclideanDomain;AL}
\getchunk{EuclideanDomain}
\getchunk{EuclideanDomain;}
\getchunk{EUCDOM;NILADIC}
```

—————

21.19 EUCDOM-.lsp BOOTSTRAP

EUCDOM- depends on **EUCDOM**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **EUCDOM-** category which we can write into the **MID** directory. We compile the lisp code and copy the **EUCDOM-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

The Lisp Implementation

EUCDOM-;VersionCheck

This implements the bootstrap code for **EuclideanDomain**. The call to **VERSIONCHECK** is a legacy check to ensure that we did not load algebra code from a previous system version (which would not run due to major surgical changes in the system) without recompiling.

— **EUCDOM-;VersionCheck** —

```
(|/VERSIONCHECK| 2)
```

—————

EUCDOM-;sizeLess?;2SB;1

— **EUCDOM-;sizeLess?;2SB;1** —

```
(DEFUN |EUCDOM-;sizeLess?;2SB;1| (|x| |y| $)
  (COND
    ((SPADCALL |y| (QREFELT $ 8)) (QUOTE NIL))
    ((SPADCALL |x| (QREFELT $ 8)) (QUOTE T))
    ((QUOTE T)
     (< (SPADCALL |x| (QREFELT $ 10)) (SPADCALL |y| (QREFELT $ 10))))))
```

—————

EUCDOM-;quo;3S;2

— **EUCDOM-;quo;3S;2** —

```
(DEFUN |EUCDOM-;quo;3S;2| (|x| |y| $)
  (QCAR (SPADCALL |x| |y| (QREFELT $ 13))))
```

—————

EUCDOM-;rem;3S;3

— **EUCDOM-;rem;3S;3** —

```
(DEFUN |EUCDOM-;rem;3S;3| (|x| |y| $)
  (QCDR (SPADCALL |x| |y| (QREFELT $ 13))))
```

—————

EUCDOM-;exquo;2SU;4

— **EUCDOM-;exquo;2SU;4** —

```
(DEFUN |EUCDOM-;exquo;2SU;4| (|x| |y| $)
  (PROG (|qr|)
    (RETURN
     (SEQ
```

```

(COND
  ((SPADCALL |x| (QREFELT $ 8)) (CONS 0 (|spadConstant| $ 16)))
  ((SPADCALL |y| (QREFELT $ 8)) (CONS 1 "failed")))
(QUOTE T)
(SEQ
  (LETT |qr|
    (SPADCALL |x| |y| (QREFELT $ 13))
    |EUCDOM-;exquo;2SU;4|)
  (EXIT
    (COND
      ((SPADCALL (QCDR |qr|) (QREFELT $ 8)) (CONS 0 (QCAR |qr|)))
      ((QUOTE T) (CONS 1 "failed"))))))))

```

EUCDOM-;gcd;3S;5

— **EUCDOM-;gcd;3S;5** —

```

(DEFUN |EUCDOM-;gcd;3S;5| (|x| |y| $)
  (PROG (|#G13| |#G14|)
    (RETURN
      (SEQ
        (LETT |x| (SPADCALL |x| (QREFELT $ 19)) |EUCDOM-;gcd;3S;5|)
        (LETT |y| (SPADCALL |y| (QREFELT $ 19)) |EUCDOM-;gcd;3S;5|)
        (SEQ G190
          (COND
            ((NULL
              (COND
                ((SPADCALL |y| (QREFELT $ 8)) (QUOTE NIL))
                ((QUOTE T) (QUOTE T))))
              (GO G191)))
          (SEQ
            (PROGN
              (LETT |#G13| |y| |EUCDOM-;gcd;3S;5|)
              (LETT |#G14| (SPADCALL |x| |y| (QREFELT $ 20)) |EUCDOM-;gcd;3S;5|)
              (LETT |x| |#G13| |EUCDOM-;gcd;3S;5|)
              (LETT |y| |#G14| |EUCDOM-;gcd;3S;5|))
            (EXIT
              (LETT |y| (SPADCALL |y| (QREFELT $ 19)) |EUCDOM-;gcd;3S;5|)))
          NIL
          (GO G190)
          G191
          (EXIT NIL))
        (EXIT |x|))))))

```

EUCDOM-;unitNormalizeIdealElt

— EUCDOM-;unitNormalizeIdealElt —

```

(DEFUN |EUCDOM-;unitNormalizeIdealElt| (|s| $)
  (PROG (|#G16| |u| |c| |a|)
    (RETURN
      (SEQ
        (PROGN
          (LETT |#G16|
            (SPADCALL (QVELT |s| 2) (QREFELT $ 23))
            |EUCDOM-;unitNormalizeIdealElt|)
          (LETT |u| (QVELT |#G16| 0) |EUCDOM-;unitNormalizeIdealElt|)
          (LETT |c| (QVELT |#G16| 1) |EUCDOM-;unitNormalizeIdealElt|)
          (LETT |a| (QVELT |#G16| 2) |EUCDOM-;unitNormalizeIdealElt|)
          |#G16|)
        (EXIT
          (COND
            ((SPADCALL |a| (|spadConstant| $ 24) (QREFELT $ 25)) |s|)
            ((QUOTE T)
              (VECTOR
                (SPADCALL |a| (QVELT |s| 0) (QREFELT $ 26))
                (SPADCALL |a| (QVELT |s| 1) (QREFELT $ 26))
                |c|))))))))))

```

EUCDOM-;extendedEuclidean;2SR;7

— EUCDOM-;extendedEuclidean;2SR;7 —

```

(DEFUN |EUCDOM-;extendedEuclidean;2SR;7| (|x| |y| $)
  (PROG (|s3| |s2| |qr| |s1|)
    (RETURN
      (SEQ
        (LETT |s1|
          (|EUCDOM-;unitNormalizeIdealElt|
            (VECTOR (|spadConstant| $ 24) (|spadConstant| $ 16) |x|)
            $)
          |EUCDOM-;extendedEuclidean;2SR;7|)
        (LETT |s2|
          (|EUCDOM-;unitNormalizeIdealElt|
            (VECTOR (|spadConstant| $ 16) (|spadConstant| $ 24) |y|)

```

```

$)
|EUCDOM-;extendedEuclidean;2SR;7|)
(EXIT
(COND
((SPADCALL |y| (QREFELT $ 8)) |s1|)
((SPADCALL |x| (QREFELT $ 8)) |s2|)
((QUOTE T)
(SEQ
(SEQ
G190
(COND
(NULL
(COND
((SPADCALL (QVELT |s2| 2) (QREFELT $ 8)) (QUOTE NIL))
((QUOTE T) (QUOTE T))))
(GO G191)))
(SEQ
(LETT |qr|
(SPADCALL (QVELT |s1| 2) (QVELT |s2| 2) (QREFELT $ 13))
|EUCDOM-;extendedEuclidean;2SR;7|)
(LETT |s3|
(VECTOR
(SPADCALL (QVELT |s1| 0)
(SPADCALL (QCAR |qr|) (QVELT |s2| 0) (QREFELT $ 26))
(QREFELT $ 27))
(SPADCALL (QVELT |s1| 1)
(SPADCALL (QCAR |qr|) (QVELT |s2| 1) (QREFELT $ 26))
(QREFELT $ 27))
(QCDR |qr|))
|EUCDOM-;extendedEuclidean;2SR;7|)
(LETT |s1| |s2| |EUCDOM-;extendedEuclidean;2SR;7|)
(EXIT
(LETT |s2|
(|EUCDOM-;unitNormalizeIdealElt| |s3| $)
|EUCDOM-;extendedEuclidean;2SR;7|)))
NIL
(GO G190)
G191
(EXIT NIL))
(COND
(NULL (SPADCALL (QVELT |s1| 0) (QREFELT $ 8)))
(COND
(NULL (SPADCALL (QVELT |s1| 0) |y| (QREFELT $ 28)))
(SEQ
(LETT |qr|
(SPADCALL (QVELT |s1| 0) |y| (QREFELT $ 13))
|EUCDOM-;extendedEuclidean;2SR;7|)
(QSETVELT |s1| 0 (QCDR |qr|))
(QSETVELT |s1| 1
(SPADCALL (QVELT |s1| 1)

```

```

      (SPADCALL (QCAR |qr|) |x| (QREFELT $ 26)) (QREFELT $ 29))
    (EXIT
      (LETT |s1|
        (|EUCDOM-;unitNormalizeIdealElt| |s1| $)
        |EUCDOM-;extendedEuclidean;2SR;7|))))))
  (EXIT |s1|))))))

```

EUCDOM-;extendedEuclidean;3SU;8

— **EUCDOM-;extendedEuclidean;3SU;8** —

```

(DEFUN |EUCDOM-;extendedEuclidean;3SU;8| (|x| |y| |z| $)
  (PROG (|s| |w| |qr|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |z| (QREFELT $ 8))
            (CONS 0 (CONS (|spadConstant| $ 16) (|spadConstant| $ 16))))
          ((QUOTE T)
            (SEQ
              (LETT |s|
                (SPADCALL |x| |y| (QREFELT $ 32))
                |EUCDOM-;extendedEuclidean;3SU;8|)
              (LETT |w|
                (SPADCALL |z| (QVELT |s| 2) (QREFELT $ 33))
                |EUCDOM-;extendedEuclidean;3SU;8|)
              (EXIT
                (COND
                  ((QEQCAR |w| 1) (CONS 1 "failed"))
                  ((SPADCALL |y| (QREFELT $ 8))
                    (CONS 0
                      (CONS (SPADCALL (QVELT |s| 0) (QCDR |w|) (QREFELT $ 26))
                        (SPADCALL (QVELT |s| 1) (QCDR |w|) (QREFELT $ 26))))
                    ((QUOTE T)
                      (SEQ
                        (LETT |qr|
                          (SPADCALL
                            (SPADCALL (QVELT |s| 0) (QCDR |w|) (QREFELT $ 26))
                            |y|
                            (QREFELT $ 13))
                          |EUCDOM-;extendedEuclidean;3SU;8|)
                        (EXIT
                          (CONS 0
                            (CONS (QCDR |qr|)
                              (SPADCALL

```

```

(SPADCALL (QVELT |s| 1) (QCDR |w|) (QREFELT $ 26))
(SPADCALL (QCAR |qr|) |x| (QREFELT $ 26))
(QREFELT $ 29)))))))))))))

```

EUCDOM-;principalIdeal;LR;9

— **EUCDOM-;principalIdeal;LR;9** —

```

(DEFUN |EUCDOM-;principalIdeal;LR;9| (|l| $)
  (PROG (|uca| |v| |u| #0=:G1497 |vv| #1=:G1498)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |l| NIL (QREFELT $ 38))
            (|error| "empty list passed to principalIdeal"))
          ((SPADCALL (CDR |l|) NIL (QREFELT $ 38))
            (SEQ
              (LETT |uca|
                (SPADCALL (|SPADfirst| |l|) (QREFELT $ 23))
                |EUCDOM-;principalIdeal;LR;9|)
              (EXIT (CONS (LIST (QVELT |uca| 0)) (QVELT |uca| 1))))))
            ((SPADCALL (CDR (CDR |l|)) NIL (QREFELT $ 38))
              (SEQ
                (LETT |u|
                  (SPADCALL (|SPADfirst| |l|)
                    (SPADCALL |l| (QREFELT $ 39)) (QREFELT $ 32))
                    |EUCDOM-;principalIdeal;LR;9|)
                  (EXIT (CONS (LIST (QVELT |u| 0) (QVELT |u| 1)) (QVELT |u| 2))))))
              ((QUOTE T)
                (SEQ
                  (LETT |v|
                    (SPADCALL (CDR |l|) (QREFELT $ 42))
                    |EUCDOM-;principalIdeal;LR;9|)
                  (LETT |u|
                    (SPADCALL (|SPADfirst| |l|) (QCDR |v|) (QREFELT $ 32))
                    |EUCDOM-;principalIdeal;LR;9|)
                  (EXIT
                    (CONS
                      (CONS (QVELT |u| 0)
                        (PROGN
                          (LETT #0# NIL |EUCDOM-;principalIdeal;LR;9|)
                          (SEQ
                            (LETT |vv| NIL |EUCDOM-;principalIdeal;LR;9|)
                            (LETT #1# (QCAR |v|) |EUCDOM-;principalIdeal;LR;9|)
                            G190

```



```

(COND
  ((OR (ATOM #1#)
        (PROGN
          (LETT |vv| (CAR #1#) |EUCDOM-;principalIdeal;LR;9|) NIL))
        (GO G191)))
(SEQ
  (EXIT
    (LETT #0#
      (CONS (SPADCALL (QVELT |u| 1) |vv| (QREFELT $ 26))
        #0#)
      |EUCDOM-;principalIdeal;LR;9|)))
  (LETT #1# (CDR #1#)
    |EUCDOM-;principalIdeal;LR;9|)
  (GO G190)
  G191
  (EXIT (NREVERSEO #0#))))))
(QVELT |u| 2)))))))))

```

EUCDOM-;expressIdealMember;LSU;10

— **EUCDOM-;expressIdealMember;LSU;10** —

```

(DEFUN |EUCDOM-;expressIdealMember;LSU;10| (|l| |z| $)
  (PROG (#0=:G1513 #1=:G1514 |pid| |q| #2=:G1515 |v| #3=:G1516)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |z| (|spadConstant| $ 16) (QREFELT $ 25))
            (CONS 0
              (PROGN
                (LETT #0# NIL |EUCDOM-;expressIdealMember;LSU;10|)
                (SEQ
                  (LETT |v| NIL |EUCDOM-;expressIdealMember;LSU;10|)
                  (LETT #1# |l| |EUCDOM-;expressIdealMember;LSU;10|)
                  G190
                  (COND
                    ((OR (ATOM #1#)
                          (PROGN
                            (LETT |v| (CAR #1#) |EUCDOM-;expressIdealMember;LSU;10|) NIL))
                      (GO G191)))
                (SEQ
                  (EXIT
                    (LETT #0#
                      (CONS (|spadConstant| $ 16) #0#)
                      |EUCDOM-;expressIdealMember;LSU;10|)))

```

```

(LETT #1# (CDR #1#) |EUCDOM-;expressIdealMember;LSU;10|)
(GO G190)
G191
(EXIT (NREVERSEO #0#))))))
((QUOTE T)
 (SEQ
  (LETT |pid|
   (SPADCALL |l| (QREFELT $ 42))
   |EUCDOM-;expressIdealMember;LSU;10|)
  (LETT |q|
   (SPADCALL |z| (QCDR |pid|) (QREFELT $ 33))
   |EUCDOM-;expressIdealMember;LSU;10|)
  (EXIT
   (COND
    ((QEQCAR |q| 1) (CONS 1 "failed"))
    ((QUOTE T)
     (CONS 0
      (PROGN
       (LETT #2# NIL |EUCDOM-;expressIdealMember;LSU;10|)
       (SEQ
        (LETT |v| NIL |EUCDOM-;expressIdealMember;LSU;10|)
        (LETT #3# (QCAR |pid|) |EUCDOM-;expressIdealMember;LSU;10|)
        G190
        (COND
         ((OR (ATOM #3#)
          (PROGN
           (LETT |v| (CAR #3#) |EUCDOM-;expressIdealMember;LSU;10|)
           NIL))
          (GO G191)))
        (SEQ
         (EXIT
          (LETT #2#
           (CONS (SPADCALL (QCDR |q|) |v| (QREFELT $ 26))
            #2#)
           |EUCDOM-;expressIdealMember;LSU;10|)))
          (LETT #3# (CDR #3#) |EUCDOM-;expressIdealMember;LSU;10|)
          (GO G190)
          G191
          (EXIT (NREVERSEO #2#))))))))))))))

```

EUCDOM-;multiEuclidean;LSU;11

— EUCDOM-;multiEuclidean;LSU;11 —

```
(DEFUN |EUCDOM-;multiEuclidean;LSU;11| (|l| |z| $)
```

```

(PROG (|n| |l1| |l2| #0=:G1405 #1=:G1535 #2=:G1522 #3=:G1520
      #4=:G1521 #5=:G1406 #6=:G1536 #7=:G1525 #8=:G1523 #9=:G1524
      |u| |v1| |v2|)
(RETURN
 (SEQ
  (LETT |n| (LENGTH |l1|) |EUCDOM-;multiEuclidean;LSU;11|)
  (EXIT
   (COND
    ((ZEROP |n|) (|error| "empty list passed to multiEuclidean"))
    ((EQL |n| 1) (CONS 0 (LIST |z|)))
    ((QUOTE T)
     (SEQ
      (LETT |l1|
       (SPADCALL |l1| (QREFELT $ 46)) |EUCDOM-;multiEuclidean;LSU;11|)
      (LETT |l2|
       (SPADCALL |l1| (QUOTIENT2 |n| 2) (QREFELT $ 48))
       |EUCDOM-;multiEuclidean;LSU;11|)
      (LETT |u|
       (SPADCALL
        (PROGN
         (LETT #4# NIL |EUCDOM-;multiEuclidean;LSU;11|)
         (SEQ
          (LETT #0# NIL |EUCDOM-;multiEuclidean;LSU;11|)
          (LETT #1# |l1| |EUCDOM-;multiEuclidean;LSU;11|)
          G190
          (COND
           ((OR (ATOM #1#)
            (PROGN
             (LETT #0# (CAR #1#) |EUCDOM-;multiEuclidean;LSU;11|)
             NIL))
            (GO G191))))
          (SEQ
           (EXIT
            (PROGN
             (LETT #2# #0# |EUCDOM-;multiEuclidean;LSU;11|)
             (COND
              (#4#
               (LETT #3#
                (SPADCALL #3# #2# (QREFELT $ 26))
                |EUCDOM-;multiEuclidean;LSU;11|))
              ((QUOTE T)
               (PROGN
                (LETT #3# #2# |EUCDOM-;multiEuclidean;LSU;11|)
                (LETT #4# (QUOTE T) |EUCDOM-;multiEuclidean;LSU;11|))))))
              (LETT #1# (CDR #1#) |EUCDOM-;multiEuclidean;LSU;11|)
              (GO G190)
              G191
              (EXIT NIL))
              (COND (#4# #3#) ((QUOTE T) (|spadConstant| $ 24))))
            (PROGN

```



```
((QUOTE T)
 (CONS 0
  (SPADCALL
   (QCDR |v1|)
   (QCDR |v2|)
   (QREFELT $ 51))))))))))))))
```

EuclideanDomain&

— **EuclideanDomainAmp** —

```
(DEFUN |EuclideanDomain&| (|#1|)
 (PROG (DV$1 |dv$| $ |pv$|)
 (RETURN
 (PROGN
  (LETT DV$1 (|devaluate| |#1|) . #0=(|EuclideanDomain&|))
  (LETT |dv$| (LIST (QUOTE |EuclideanDomain&|) DV$1) . #0#)
  (LETT $ (make-array 53) . #0#)
  (QSETREFV $ 0 |dv$|)
  (QSETREFV $ 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #0#))
  (|stuffDomainSlots| $)
  (QSETREFV $ 6 |#1|)
  $))))
```

EUCDOM-;INFOVEC

— **EUCDOM-;INFOVEC** —

```
(setf (get
 (QUOTE |EuclideanDomain&|)
 (QUOTE |infovec|))
 (LIST
  (QUOTE #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|Boolean|) (0 . |zero?|)
   (|NonNegativeInteger|) (5 . |euclideanSize|) |EUCDOM-;sizeLess?;2SB;1|
   (|Record| (|:| |quotient| $) (|:| |remainder| $)) (10 . |divide|)
   |EUCDOM-;quo;3S;2| |EUCDOM-;rem;3S;3| (16 . |Zero|)
   (|Union| $ (QUOTE "failed")) |EUCDOM-;exquo;2SU;4| (20 . |unitCanonical|)
   (25 . |rem|) |EUCDOM-;gcd;3S;5|
   (|Record| (|:| |unit| $) (|:| |canonical| $) (|:| |associate| $))
   (31 . |unitNormal|) (36 . |One|) (40 . =) (46 . *) (52 . -)
```

```

(58 . |sizeLess?|) (64 . +)
(|Record| (|:| |coef1| $) (|:| |coef2| $) (|:| |generator| $))
|EUCDOM-;extendedEuclidean;2SR;7|
(70 . |extendedEuclidean|) (76 . |exquo|)
(|Record| (|:| |coef1| $) (|:| |coef2| $))
(|Union| 34 (QUOTE "failed")) |EUCDOM-;extendedEuclidean;3SU;8|
(|List| 6) (82 . =) (88 . |second|)
(|Record| (|:| |coef| 41) (|:| |generator| $))
(|List| $) (93 . |principalIdeal|) |EUCDOM-;principalIdeal;LR;9|
(|Union| 41 (QUOTE "failed")) |EUCDOM-;expressIdealMember;LSU;10|
(98 . |copy|) (|Integer|) (103 . |split!|) (109 . |extendedEuclidean|)
(116 . |multiEuclidean|) (122 . |concat|) |EUCDOM-;multiEuclidean;LSU;11|))
(QUOTE
  #(|sizeLess?| 128 |rem| 134 |quo| 140 |principalIdeal| 146
    |multiEuclidean| 151 |gcd| 157 |extendedEuclidean| 163
    |exquo| 176 |expressIdealMember| 182))
(QUOTE NIL)
(CONS (|makeByteWordVec2| 1 (QUOTE NIL))
  (CONS (QUOTE #())
    (CONS (QUOTE #())
      (|makeByteWordVec2| 52 (QUOTE (1 6 7 0 8 1 6 9 0 10 2 6 12 0 0 13 0
        6 0 16 1 6 0 0 19 2 6 0 0 0 20 1 6 22 0 23 0 6 0 24 2 6 7 0 0 25 2 6 0
        0 0 26 2 6 0 0 0 27 2 6 7 0 0 28 2 6 0 0 0 29 2 6 30 0 0 32 2 6 17 0 0
        33 2 37 7 0 0 38 1 37 6 0 39 1 6 40 41 42 1 37 0 0 46 2 37 0 0 47 48 3
        6 35 0 0 0 49 2 6 44 41 0 50 2 37 0 0 0 51 2 0 7 0 0 11 2 0 0 0 0 15 2
        0 0 0 0 14 1 0 40 41 43 2 0 44 41 0 52 2 0 0 0 0 21 3 0 35 0 0 0 36 2 0
        30 0 0 31 2 0 17 0 0 18 2 0 44 41 0 45))))))
(QUOTE |lookupComplete|)))

```

— EUCDOM-.lsp BOOTSTRAP —

```

\getchunk{EUCDOM-;VersionCheck}
\getchunk{EUCDOM-;sizeLess?;2SB;1}
\getchunk{EUCDOM-;quo;3S;2}
\getchunk{EUCDOM-;rem;3S;3}
\getchunk{EUCDOM-;exquo;2SU;4}
\getchunk{EUCDOM-;gcd;3S;5}
\getchunk{EUCDOM-;unitNormalizeIdealElt}
\getchunk{EUCDOM-;extendedEuclidean;2SR;7}
\getchunk{EUCDOM-;extendedEuclidean;3SU;8}
\getchunk{EUCDOM-;principalIdeal;LR;9}
\getchunk{EUCDOM-;expressIdealMember;LSU;10}
\getchunk{EUCDOM-;multiEuclidean;LSU;11}
\getchunk{EuclideanDomainAmp}
\getchunk{EUCDOM-;INFOVEC}

```

21.20 ENTIRER.lsp BOOTSTRAP

ENTIRER depends on itself. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ENTIRER** category which we can write into the **MID** directory. We compile the lisp code and copy the **ENTIRER.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ENTIRER.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |EntireRing;AL| (QUOTE NIL))

(DEFUN |EntireRing| NIL
  (LET (#:G82841)
    (COND
      (|EntireRing;AL|)
      (T (SETQ |EntireRing;AL| (|EntireRing;|))))))

(DEFUN |EntireRing;| NIL
  (PROG (#1= #:G82839)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|Ring|)
            (|BiModule| (QUOTE |$|) (QUOTE |$|))
            (|mkCategory|
              (QUOTE |package|)
              NIL
              (QUOTE ((|noZeroDivisors| T)))
              (QUOTE NIL)
              NIL))
          |EntireRing|)
        (SETELT #1# 0 (QUOTE (|EntireRing|))))))

(setf (get (QUOTE |EntireRing|) (QUOTE NILADIC)) T)
```

21.21 FFIELDC.lsp BOOTSTRAP

FFIELDC depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **FFIELDC** category which we can write into the **MID** directory. We compile the lisp code and copy the **FFIELDC.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— FFIELDC.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |FiniteFieldCategory;AL| (QUOTE NIL))

(DEFUN |FiniteFieldCategory| NIL
  (LET (#:G83129)
    (COND
      (|FiniteFieldCategory;AL|)
      (T (SETQ |FiniteFieldCategory;AL| (|FiniteFieldCategory;|)))))

(DEFUN |FiniteFieldCategory;| NIL
  (PROG (#1= #:G83127)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|FieldOfPrimeCharacteristic|)
            (|Finite|)
            (|StepThrough|)
            (|DifferentialRing|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE (
                ((|charthRoot| (|$| |$|)) T)
                ((|conditionP| ((|Union| (|Vector| |$|) "failed") (|Matrix| |$|))) T)
                ((|factorsOfCyclicGroupSize|
                  ((|List| (|Record|
                    (|:| |factor| (|Integer|))
                    (|:| |exponent| (|Integer|))))))
                  T)
                ((|tableForDiscreteLogarithm|
                  ((|Table| (|PositiveInteger|) (|NonNegativeInteger|)
                    (|Integer|))) T)
                ((|createPrimitiveElement| (|$|)) T)
                ((|primitiveElement| (|$|)) T)
                ((|primitive?| ((|Boolean|) |$|)) T)
                ((|discreteLog| ((|NonNegativeInteger|) |$|)) T)
              ))
          ))
      ))
  )
```



```

((|order| ((|PositiveInteger|) |$|)) T)
((|representationType|
  ((|Union| "prime" "polynomial" "normal" "cyclic")) T)))
NIL
(QUOTE (
  (|PositiveInteger|)
  (|NonNegativeInteger|)
  (|Boolean|)
  (|Table| (|PositiveInteger|) (|NonNegativeInteger|))
  (|Integer|)
  (|List|
    (|Record| (|:| |factor| (|Integer|)) (|:| |exponent| (|Integer|))))
  (|Matrix| |$|)))
NIL))
|FiniteFieldCategory|)
(SETELT #1# 0 (QUOTE (|FiniteFieldCategory|))))))

(setf (get (QUOTE |FiniteFieldCategory|) (QUOTE NILADIC)) T)

```

21.22 FFIELD- .lsp BOOTSTRAP

FFIELD- depends on **FFIELDC**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **FFIELDC-** category which we can write into the **MID** directory. We compile the lisp code and copy the **FFIELDC-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— FFIELD- .lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |FFIELD-;differentiate;2S;1| (|x| |$|) (|spadConstant| |$| 7))

(DEFUN |FFIELD-;init;S;2| (|$|) (|spadConstant| |$| 7))

(DEFUN |FFIELD-;nextItem;SU;3| (|a| |$|)
  (COND
    ((SPADCALL
      (LETT |a|
        (SPADCALL (|+| (SPADCALL |a| (QREFELT |$| 11)) 1) (QREFELT |$| 12))
        |FFIELD-;nextItem;SU;3|)
      (QREFELT |$| 14))
      (CONS 1 "failed"))

```

```

((QUOTE T) (CONS 0 |a|)))

(DEFUN |FFIELD-;order;SOpc;4| (|e| |$|)
  (SPADCALL (SPADCALL |e| (QREFELT |$| 17)) (QREFELT |$| 20)))

(DEFUN |FFIELD-;conditionP;MU;5| (|mat| |$|)
  (PROG (|l|)
    (RETURN
      (SEQ
        (LETT |l| (SPADCALL |mat| (QREFELT |$| 24)) |FFIELD-;conditionP;MU;5|)
        (COND
          ((OR
            (NULL |l|)
            (SPADCALL (ELT |$| 14) (|SPADfirst| |l|) (QREFELT |$| 27)))
            (EXIT (CONS 1 "failed"))))
          (EXIT
            (CONS 0
              (SPADCALL (ELT |$| 28) (|SPADfirst| |l|) (QREFELT |$| 30)))))))

(DEFUN |FFIELD-;charthRoot;2S;6| (|x| |$|)
  (SPADCALL |x|
    (QUOTIENT2 (SPADCALL (QREFELT |$| 35)) (SPADCALL (QREFELT |$| 36)))
    (QREFELT |$| 37)))

(DEFUN |FFIELD-;charthRoot;SU;7| (|x| |$|)
  (CONS 0 (SPADCALL |x| (QREFELT |$| 28))))

(DEFUN |FFIELD-;createPrimitiveElement;S;8| (|$|)
  (PROG (|sm1| |start| |i| #1=#:G83175 |e| |found|)
    (RETURN
      (SEQ
        (LETT |sm1|
          (|-| (SPADCALL (QREFELT |$| 35)) 1)
          |FFIELD-;createPrimitiveElement;S;8|)
        (LETT |start|
          (COND
            ((SPADCALL
              (SPADCALL (QREFELT |$| 42))
              (CONS 1 "polynomial")
              (QREFELT |$| 43))
              (SPADCALL (QREFELT |$| 36)))
            ((QUOTE T) 1))
          |FFIELD-;createPrimitiveElement;S;8|)
        (LETT |found| (QUOTE NIL) |FFIELD-;createPrimitiveElement;S;8|)
        (SEQ
          (LETT |i| |start| |FFIELD-;createPrimitiveElement;S;8|)
          G190
          (COND
            ((NULL (COND (|found| (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
            (GO G191))))

```

```

(SEQ
  (LETT |e|
    (SPADCALL
      (PROG1
        (LETT #1# |i| |FFIELDC-;createPrimitiveElement;S;8|)
        (|check-subtype| (|>| #1# 0) (QUOTE (|PositiveInteger|)) #1#))
        (QREFELT |$| 12))
        |FFIELDC-;createPrimitiveElement;S;8|)
      (EXIT
        (LETT |found|
          (EQL (SPADCALL |e| (QREFELT |$| 17)) |sm1|)
          |FFIELDC-;createPrimitiveElement;S;8|)))
        (LETT |i| (|+| |i| 1) |FFIELDC-;createPrimitiveElement;S;8|)
        (GO G190)
      G191
      (EXIT NIL))
    (EXIT |e|))))))

(DEFUN |FFIELDC-;primitive?;SB;9| (|a| |$|)
  (PROG (|explist| |q| |exp| #1=#:G83187 |equalone|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |a| (QREFELT |$| 14)) (QUOTE NIL))
          ((QUOTE T)
            (SEQ
              (LETT |explist|
                (SPADCALL (QREFELT |$| 47)) |FFIELDC-;primitive?;SB;9|)
              (LETT |q|
                (|-| (SPADCALL (QREFELT |$| 35)) 1) |FFIELDC-;primitive?;SB;9|)
              (LETT |equalone| (QUOTE NIL) |FFIELDC-;primitive?;SB;9|)
              (SEQ
                (LETT |exp| NIL |FFIELDC-;primitive?;SB;9|)
                (LETT #1# |explist| |FFIELDC-;primitive?;SB;9|)
                G190
                (COND
                  ((OR
                    (ATOM #1#)
                    (PROGN (LETT |exp| (CAR #1#) |FFIELDC-;primitive?;SB;9|) NIL)
                    (NULL (COND (|equalone| (QUOTE NIL)) ((QUOTE T) (QUOTE T)))))
                    (GO G191)))
                (SEQ
                  (EXIT
                    (LETT |equalone|
                      (SPADCALL
                        (SPADCALL |a| (QUOTIENT2 |q| (QCAR |exp|)) (QREFELT |$| 48))
                        (QREFELT |$| 49))
                      |FFIELDC-;primitive?;SB;9|)))
                    (LETT #1# (CDR #1#) |FFIELDC-;primitive?;SB;9|)
                    (GO G190)

```

```

G191
  (EXIT NIL))
  (EXIT (COND (|equalone| (QUOTE NIL)) ((QUOTE T) (QUOTE T)))))))))

(DEFUN |FFIELDC-;order;SPi;10| (|e| |$|)
  (PROG (|lof| |rec| #1=:G83195 |primeDivisor|
    |j| #2=:G83196 |a| |goon| |ord|)
  (RETURN
  (SEQ
  (COND
    ((SPADCALL |e| (|spadConstant| |$| 7) (QREFELT |$| 51))
    (|error| "order(0) is not defined "))
    ((QUOTE T)
    (SEQ
    (LETT |ord|
      (|-| (SPADCALL (QREFELT |$| 35)) 1) |FFIELDC-;order;SPi;10|)
    (LETT |a| 0 |FFIELDC-;order;SPi;10|)
    (LETT |lof| (SPADCALL (QREFELT |$| 47)) |FFIELDC-;order;SPi;10|)
    (SEQ
      (LETT |rec| NIL |FFIELDC-;order;SPi;10|)
      (LETT #1# |lof| |FFIELDC-;order;SPi;10|)
      G190
      (COND
        ((OR
          (ATOM #1#)
          (PROGN (LETT |rec| (CAR #1#) |FFIELDC-;order;SPi;10|) NIL))
          (GO G191)))
        (SEQ
          (LETT |a|
            (QUOTIENT2 |ord|
              (LETT |primeDivisor| (QCAR |rec|) |FFIELDC-;order;SPi;10|)
              |FFIELDC-;order;SPi;10|)
            (LETT |goon|
              (SPADCALL (SPADCALL |e| |a| (QREFELT |$| 48)) (QREFELT |$| 49))
              |FFIELDC-;order;SPi;10|)
            (SEQ
              (LETT |j| 0 |FFIELDC-;order;SPi;10|)
              (LETT #2# (|-| (QCDR |rec|) 2) |FFIELDC-;order;SPi;10|)
              G190
              (COND ((OR (QSGREATERP |j| #2#) (NULL |goon|)) (GO G191)))
              (SEQ
                (LETT |ord| |a| |FFIELDC-;order;SPi;10|)
                (LETT |a|
                  (QUOTIENT2 |ord| |primeDivisor|)
                  |FFIELDC-;order;SPi;10|)
                (EXIT
                  (LETT |goon|
                    (SPADCALL (SPADCALL |e| |a| (QREFELT |$| 48)) (QREFELT |$| 49))
                    |FFIELDC-;order;SPi;10|)))
                (LETT |j| (QSADD1 |j|) |FFIELDC-;order;SPi;10|)

```

```

(GO G190)
G191
(EXIT NIL))
(EXIT (COND (|goon| (LETT |ord| |a| |FFIELDC-;order;SPi;10|))))))
(LETT #1# (CDR #1#) |FFIELDC-;order;SPi;10|)
(GO G190)
G191
(EXIT NIL))
(EXIT |ord|)))))))))

(DEFUN |FFIELDC-;discreteLog;SNni;11| (|b| |$|)
  (PROG (|faclist| |gen| |groupord| |f| #1=:G83216 |fac| |t| #2=:G83217
    |exp| |exptable| |n| |end| |i| |rho| |found| |disc1| |c| |mult|
    |disclog| |a|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |b| (QREFELT |$| 14))
            (|error| "discreteLog: logarithm of zero"))
          ((QUOTE T)
            (SEQ
              (LETT |faclist|
                (SPADCALL (QREFELT |$| 47))
                |FFIELDC-;discreteLog;SNni;11|)
              (LETT |a| |b| |FFIELDC-;discreteLog;SNni;11|)
              (LETT |gen|
                (SPADCALL (QREFELT |$| 53))
                |FFIELDC-;discreteLog;SNni;11|)
              (EXIT
                (COND
                  ((SPADCALL |b| |gen| (QREFELT |$| 51)) 1)
                  ((QUOTE T)
                    (SEQ
                      (LETT |disclog| 0 |FFIELDC-;discreteLog;SNni;11|)
                      (LETT |mult| 1 |FFIELDC-;discreteLog;SNni;11|)
                      (LETT |groupord|
                        (|-| (SPADCALL (QREFELT |$| 35)) 1)
                        |FFIELDC-;discreteLog;SNni;11|)
                      (LETT |exp| |groupord| |FFIELDC-;discreteLog;SNni;11|)
                      (SEQ
                        (LETT |f| NIL |FFIELDC-;discreteLog;SNni;11|)
                        (LETT #1# |faclist| |FFIELDC-;discreteLog;SNni;11|)
                        G190
                        (COND
                          ((OR
                            (ATOM #1#)
                            (PROGN
                              (LETT |f| (CAR #1#) |FFIELDC-;discreteLog;SNni;11|)
                              NIL))
                            (GO G191)))

```

```

(SEQ
  (LETT |fac| (QCAR |f|) |FFIELDC-;discreteLog;SNni;11|)
  (EXIT
    (SEQ
      (LETT |t| 0 |FFIELDC-;discreteLog;SNni;11|)
      (LETT #2# (|-| (QCDR |f|) 1) |FFIELDC-;discreteLog;SNni;11|)
      G190
      (COND ((QSGREATERP |t| #2#) (GO G191)))
      (SEQ
        (LETT |exp|
          (QUOTIENT2 |exp| |fac|)
          |FFIELDC-;discreteLog;SNni;11|)
        (LETT |exptable|
          (SPADCALL |fac| (QREFELT |$| 55))
          |FFIELDC-;discreteLog;SNni;11|)
        (LETT |n|
          (SPADCALL |exptable| (QREFELT |$| 56))
          |FFIELDC-;discreteLog;SNni;11|)
        (LETT |c|
          (SPADCALL |a| |exp| (QREFELT |$| 48))
          |FFIELDC-;discreteLog;SNni;11|)
        (LETT |end|
          (QUOTIENT2 (|-| |fac| 1) |n|)
          |FFIELDC-;discreteLog;SNni;11|)
        (LETT |found| (QUOTE NIL) |FFIELDC-;discreteLog;SNni;11|)
        (LETT |disc1| 0 |FFIELDC-;discreteLog;SNni;11|)
        (SEQ
          (LETT |i| 0 |FFIELDC-;discreteLog;SNni;11|)
          G190
          (COND
            ((OR
              (QSGREATERP |i| |end|)
              (NULL
                (COND (|found| (QUOTE NIL)) ((QUOTE T) (QUOTE T)))))
              (GO G191)))
          (SEQ
            (LETT |rho|
              (SPADCALL
                (SPADCALL |c| (QREFELT |$| 11))
                |exptable|
                (QREFELT |$| 58))
              |FFIELDC-;discreteLog;SNni;11|)
            (EXIT
              (COND
                ((QEQCAR |rho| 0)
                  (SEQ
                    (LETT |found| (QUOTE T) |FFIELDC-;discreteLog;SNni;11|)
                    (EXIT
                      (LETT |disc1|
                        (|*| (|+| (|*| |n| |i|) (QCDR |rho|)) |mult|)

```

```

        |FFIELDC-;discreteLog;SNni;11|))))
((QUOTE T)
(LETT |c|
(SPADCALL |c|
(SPADCALL |gen|
(|*| (QUOTIENT2 |groupord| |fac|) (|-| |n|))
(QREFELT |$| 48))
(QREFELT |$| 59))
|FFIELDC-;discreteLog;SNni;11|))))
(LETT |i| (QSADD1 |i|) |FFIELDC-;discreteLog;SNni;11|)
(GO G190)
G191
(EXIT NIL))
(EXIT
(COND
(|found|
(SEQ
(LETT |mult|
(|*| |mult| |fac|)
|FFIELDC-;discreteLog;SNni;11|)
(LETT |disclog|
(|+| |disclog| |disc1|)
|FFIELDC-;discreteLog;SNni;11|)
(EXIT
(LETT |a|
(SPADCALL |a|
(SPADCALL |gen| (|-| |disc1|) (QREFELT |$| 48))
(QREFELT |$| 59))
|FFIELDC-;discreteLog;SNni;11|))))
(|error| "discreteLog: ?? discrete logarithm"))))
(LETT |t|
(QSADD1 |t|)
|FFIELDC-;discreteLog;SNni;11|)
(GO G190)
G191
(EXIT NIL)))
(LETT #1#
(CDR #1#)
|FFIELDC-;discreteLog;SNni;11|)
(GO G190)
G191
(EXIT NIL))
(EXIT |disclog|))))))))))

(DEFUN |FFIELDC-;discreteLog;2SU;12| (|logbase| |b| |$|)
(PROG (|groupord| |fac| |f| #1=:G83235 |fac| |primroot|
|t| #2=:G83236 |exp| |rhoHelp| #3=:G83234 |rho| |disclog|
|mult| |a|)
(RETURN

```

```

(SEQ
  (EXIT
    (COND
      ((SPADCALL |b| (QREFELT |$| 14))
        (SEQ
          (SPADCALL "discreteLog: logarithm of zero" (QREFELT |$| 64))
          (EXIT (CONS 1 "failed"))))
      ((SPADCALL |logbase| (QREFELT |$| 14))
        (SEQ
          (SPADCALL "discreteLog: logarithm to base zero" (QREFELT |$| 64))
          (EXIT (CONS 1 "failed"))))
      ((SPADCALL |b| |logbase| (QREFELT |$| 51)) (CONS 0 1))
      ((QUOTE T)
        (COND
          ((NULL
            (ZEROP
              (REMAINDER2
                (LETT |groupord|
                  (SPADCALL |logbase| (QREFELT |$| 17))
                  |FFIELD-;discreteLog;2SU;12|)
                  (SPADCALL |b| (QREFELT |$| 17))))))
            (SEQ
              (SPADCALL
                "discreteLog: second argument not in cyclic group generated by first argument"
                (QREFELT |$| 64))
              (EXIT (CONS 1 "failed"))))
            ((QUOTE T)
              (SEQ
                (LETT |faclist|
                  (SPADCALL (SPADCALL |groupord| (QREFELT |$| 66)) (QREFELT |$| 68))
                  |FFIELD-;discreteLog;2SU;12|)
                (LETT |a| |b| |FFIELD-;discreteLog;2SU;12|)
                (LETT |disclog| 0 |FFIELD-;discreteLog;2SU;12|)
                (LETT |mult| 1 |FFIELD-;discreteLog;2SU;12|)
                (LETT |exp| |groupord| |FFIELD-;discreteLog;2SU;12|)
                (SEQ
                  (LETT |f| NIL |FFIELD-;discreteLog;2SU;12|)
                  (LETT #1# |faclist| |FFIELD-;discreteLog;2SU;12|)
                  G190
                  (COND
                    ((OR
                      (ATOM #1#)
                      (PROGN (LETT |f| (CAR #1#) |FFIELD-;discreteLog;2SU;12|) NIL))
                     (GO G191)))
                  (SEQ
                    (LETT |fac| (QCAR |f|) |FFIELD-;discreteLog;2SU;12|)
                    (LETT |primroot|
                      (SPADCALL |logbase|
                        (QUOTIENT2 |groupord| |fac|)
                        (QREFELT |$| 48))

```



```

|FFIELDC-;discreteLog;2SU;12|)
(EXIT
  (SEQ
    (LETT |t| 0 |FFIELDC-;discreteLog;2SU;12|)
    (LETT #2# (|-| (QCDR |f|) 1) |FFIELDC-;discreteLog;2SU;12|)
    G190
    (COND ((QSGREATERP |t| #2#) (GO G191)))
    (SEQ
      (LETT |exp|
        (QUOTIENT2 |exp| |fac|)
        |FFIELDC-;discreteLog;2SU;12|)
      (LETT |rhoHelp|
        (SPADCALL |primroot|
          (SPADCALL |a| |exp| (QREFELT |$| 48))
          |fac|
          (QREFELT |$| 70))
        |FFIELDC-;discreteLog;2SU;12|)
      (EXIT
        (COND
          ((QEQCAR |rhoHelp| 1)
            (PROGN
              (LETT #3# (CONS 1 "failed") |FFIELDC-;discreteLog;2SU;12|)
              (GO #3#)))
          ((QUOTE T)
            (SEQ
              (LETT |rho|
                (|*| (QCDR |rhoHelp|) |mult|)
                |FFIELDC-;discreteLog;2SU;12|)
              (LETT |disclog|
                (|+| |disclog| |rho|)
                |FFIELDC-;discreteLog;2SU;12|)
              (LETT |mult|
                (|*| |mult| |fac|)
                |FFIELDC-;discreteLog;2SU;12|)
              (EXIT
                (LETT |a|
                  (SPADCALL |a|
                    (SPADCALL |logbase| (|-| |rho|) (QREFELT |$| 48))
                    (QREFELT |$| 59))
                  |FFIELDC-;discreteLog;2SU;12|))))))
              (LETT |t| (QSADD1 |t|) |FFIELDC-;discreteLog;2SU;12|)
              (GO G190)
            G191
            (EXIT NIL))))
          (LETT #1# (CDR #1#) |FFIELDC-;discreteLog;2SU;12|)
          (GO G190)
        G191
        (EXIT NIL))
      (EXIT (CONS 0 |disclog|))))))
#3#

```

```

(EXIT #3#))))))

(DEFUN |FFIELD-;squareFreePolynomial| (|f| |$|)
  (SPADCALL |f| (QREFELT |$| 75)))

(DEFUN |FFIELD-;factorPolynomial| (|f| |$|)
  (SPADCALL |f| (QREFELT |$| 77)))

(DEFUN |FFIELD-;factorSquareFreePolynomial| (|f| |$|)
  (PROG (|flist| |u| #1=#:G83248 #2=#:G83245 #3=#:G83243 #4=#:G83244)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |f| (|spadConstant| |$| 78) (QREFELT |$| 79))
            (|spadConstant| |$| 80))
          ((QUOTE T)
            (SEQ
              (LETT |flist|
                (SPADCALL |f| (QUOTE T) (QREFELT |$| 83))
                |FFIELD-;factorSquareFreePolynomial|)
              (EXIT
                (SPADCALL
                  (SPADCALL (QCAR |flist|) (QREFELT |$| 84))
                  (PROGN
                    (LETT #4# NIL |FFIELD-;factorSquareFreePolynomial|)
                    (SEQ
                      (LETT |u| NIL |FFIELD-;factorSquareFreePolynomial|)
                      (LETT #1# (QCDR |flist|) |FFIELD-;factorSquareFreePolynomial|)
                      G190
                      (COND
                        ((OR
                          (ATOM #1#)
                          (PROGN
                            (LETT |u| (CAR #1#) |FFIELD-;factorSquareFreePolynomial|)
                            NIL))
                          (GO G191))))
                    (SEQ
                      (EXIT
                        (PROGN
                          (LETT #2#
                            (SPADCALL (QCAR |u|) (QCDR |u|) (QREFELT |$| 85))
                            |FFIELD-;factorSquareFreePolynomial|)
                          (COND
                            (#4#
                              (LETT #3#
                                (SPADCALL #3# #2# (QREFELT |$| 86))
                                |FFIELD-;factorSquareFreePolynomial|)
                              ((QUOTE T)
                                (PROGN
                                  (LETT #3# #2# |FFIELD-;factorSquareFreePolynomial|)

```

```

(LETT #4#
  (QUOTE T)
  |FFIELDC-;factorSquareFreePolynomial|))))))
(LETT #1# (CDR #1#) |FFIELDC-;factorSquareFreePolynomial|)
(GO G190)
G191
(EXIT NIL))
(COND (#4# #3#) ((QUOTE T) (|spadConstant| |$| 87))))
(QREFELT |$| 88)))))))))

(DEFUN |FFIELDC-;gcdPolynomial;3Sup;16| (|f| |g| |$|)
  (SPADCALL |f| |g| (QREFELT |$| 90)))

(DEFUN |FiniteFieldCategory&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|FiniteFieldCategory&|))
        (LETT |dv$| (LIST (QUOTE |FiniteFieldCategory&|) |DV$1|) . #1#)
        (LETT |$| (make-array 93) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|) |$|))))))

(setf (get
  (QUOTE |FiniteFieldCategory&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (0 . |Zero|)
        |FFIELDC-;differentiate;2S;1| |FFIELDC-;init;S;2| (|PositiveInteger|)
        (4 . |lookup|) (9 . |index|) (|Boolean|) (14 . |zero?|)
        (|Union| |$| (QUOTE "failed")) |FFIELDC-;nextItem;SU;3| (19 . |order|)
        (|Integer|) (|OnePointCompletion| 10) (24 . |coerce|)
        |FFIELDC-;order;S0pc;4| (|List| 26) (|Matrix| 6) (29 . |nullSpace|)
        (|Mapping| 13 6) (|Vector| 6) (34 . |every?|) (40 . |charthRoot|)
        (|Mapping| 6 6) (45 . |map|) (|Union| (|Vector| |$|) (QUOTE "failed"))
        (|Matrix| |$|) |FFIELDC-;conditionP;MU;5| (|NonNegativeInteger|)
        (51 . |size|) (55 . |characteristic|) (59 . |**|)
        |FFIELDC-;charthRoot;2S;6| |FFIELDC-;charthRoot;SU;7| (65 . |One|)
        (|Union| (QUOTE "prime") (QUOTE "polynomial") (QUOTE "normal")
          (QUOTE "cyclic")) (69 . |representationType|) (73 . |=|)
        |FFIELDC-;createPrimitiveElement;S;8| (|Record| (|:| |factor| 18)
          (|:| |exponent| 18)) (|List| 45) (79 . |factorsOfCyclicGroupSize|)
        (83 . |**|) (89 . |one?|) |FFIELDC-;primitive?;SB;9| (94 . |=|)
        |FFIELDC-;order;SPi;10| (100 . |primitiveElement|) (|Table| 10 34)
        (104 . |tableForDiscreteLogarithm|) (109 . |#|)
        (|Union| 34 (QUOTE "failed")) (114 . |search|) (120 . |*|)
        |FFIELDC-;discreteLog;SNni;11| (|Void|) (|String|) (|OutputForm|)

```

```

(126 . |messagePrint|) (|Factored| |$|) (131 . |factor|)
(|Factored| 18) (136 . |factors|) (|DiscreteLogarithmPackage| 6)
(141 . |shanksDiscLogAlgorithm|) |FFIELDC-;discreteLog;2SU;12|
(|Factored| 73) (|SparseUnivariatePolynomial| 6)
(|UnivariatePolynomialSquareFree| 6 73) (148 . |squareFree|)
(|DistinctDegreeFactorize| 6 73) (153 . |factor|) (158 . |Zero|)
(162 . |=|) (168 . |Zero|) (|Record| (|:| |irr| 73) (|:| |pow| 18))
(|Record| (|:| |cont| 6) (|:| |factors| (|List| 81)))
(172 . |distdfact|) (178 . |coerce|) (183 . |primeFactor|)
(189 . |*|) (195 . |One|) (199 . |*|) (|EuclideanDomain&| 73)
(205 . |gcd|) (|SparseUnivariatePolynomial| |$|)
|FFIELDC-;gcdPolynomial;3Sup;16|))
(QUOTE
#(|primitive?| 211 |order| 216 |nextItem| 226 |init| 231
|gcdPolynomial| 235 |discreteLog| 241 |differentiate| 252
|createPrimitiveElement| 257 |conditionP| 261 |charthRoot| 266))
(QUOTE NIL)
(CONS
(|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
(QUOTE #())
(CONS
(QUOTE #())
(|makeByteWordVec2| 92
(QUOTE
(0 6 0 7 1 6 10 0 11 1 6 0 10 12 1 6 13 0 14 1 6 10 0 17 1 19
0 18 20 1 23 22 0 24 2 26 13 25 0 27 1 6 0 0 28 2 26 0 29 0 30
0 6 34 35 0 6 34 36 2 6 0 0 34 37 0 6 0 40 0 6 41 42 2 41 13
0 0 43 0 6 46 47 2 6 0 0 18 48 1 6 13 0 49 2 6 13 0 0 51 0 6 0
53 1 6 54 18 55 1 54 34 0 56 2 54 57 10 0 58 2 6 0 0 0 59 1
63 61 62 64 1 18 65 0 66 1 67 46 0 68 3 69 57 6 6 34 70 1 74
72 73 75 1 76 72 73 77 0 73 0 78 2 73 13 0 0 79 0 72 0 80 2
76 82 73 13 83 1 73 0 6 84 2 72 0 73 18 85 2 72 0 0 0 86 0 72
0 87 2 72 0 73 0 88 2 89 0 0 0 90 1 0 13 0 50 1 0 10 0 52 1 0
19 0 21 1 0 15 0 16 0 0 0 9 2 0 91 91 91 92 1 0 34 0 60 2 0 57
0 0 71 1 0 0 8 0 0 44 1 0 31 32 33 1 0 0 0 38 1 0 15 0 39))))))
(QUOTE |lookupComplete|)))

```

21.23 FPS.lsp BOOTSTRAP

FPS depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **FPS** category which we can write into the **MID** directory. We compile the lisp code and copy the **FPS.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— FPS.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |FloatingPointSystem;AL| (QUOTE NIL))

(DEFUN |FloatingPointSystem| NIL
  (LET (#:G105645)
    (COND
      (|FloatingPointSystem;AL|)
      (T (SETQ |FloatingPointSystem;AL| (|FloatingPointSystem;|))))))

(DEFUN |FloatingPointSystem;| NIL
  (PROG (#1= #:G105643)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|RealNumberSystem|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE (
                ((|float| (|$| (|Integer|) (|Integer|))) T)
                ((|float| (|$| (|Integer|) (|Integer|) (|PositiveInteger|))) T)
                ((|order| ((|Integer|) |$|)) T)
                ((|base| ((|PositiveInteger|))) T)
                ((|exponent| ((|Integer|) |$|)) T)
                ((|mantissa| ((|Integer|) |$|)) T)
                ((|bits| ((|PositiveInteger|))) T)
                ((|digits| ((|PositiveInteger|))) T)
                ((|precision| ((|PositiveInteger|))) T)
                ((|bits| ((|PositiveInteger|) (|PositiveInteger|)))
                  (|has| |$| (ATTRIBUTE |arbitraryPrecision|)))
                ((|digits| ((|PositiveInteger|) (|PositiveInteger|)))
                  (|has| |$| (ATTRIBUTE |arbitraryPrecision|)))
                ((|precision| ((|PositiveInteger|) (|PositiveInteger|)))
                  (|has| |$| (ATTRIBUTE |arbitraryPrecision|)))
                ((|increasePrecision| ((|PositiveInteger|) (|Integer|)))
                  (|has| |$| (ATTRIBUTE |arbitraryPrecision|)))
                ((|decreasePrecision| ((|PositiveInteger|) (|Integer|)))
                  (|has| |$| (ATTRIBUTE |arbitraryPrecision|)))
                ((|min| (|$|))
                  (AND
                    (|not| (|has| |$| (ATTRIBUTE |arbitraryPrecision|)))
                    (|not| (|has| |$| (ATTRIBUTE |arbitraryExponent|))))))
                ((|max| (|$|))
                  (AND
                    (|not| (|has| |$| (ATTRIBUTE |arbitraryPrecision|)))

```

```

        (|not| (|has| |$| (ATTRIBUTE |arbitraryExponent|))))))
      (QUOTE ((|approximate| T)))
      (QUOTE ((|PositiveInteger|) (|Integer|)))
      NIL))
    |FloatingPointSystem|)
  (SETELT #1# 0 (QUOTE (|FloatingPointSystem|))))))

(setf (get (QUOTE |FloatingPointSystem|) (QUOTE NILADIC)) T)

```

21.24 FPS-.lsp BOOTSTRAP

FPS- depends **FPS**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **FPS-** category which we can write into the **MID** directory. We compile the lisp code and copy the **FPS-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— FPS-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |FPS-;float;2IS;1| (|ma| |ex| |$|)
  (SPADCALL |ma| |ex| (SPADCALL (QREFELT |$| 8)) (QREFELT |$| 10)))

(DEFUN |FPS-;digits;Pi;2| (|$|)
  (PROG (#1#=:G105654)
    (RETURN
      (PROG1
        (LETT #1#
          (MAX 1
            (QUOTIENT2
              (SPADCALL 4004
                (|-| (SPADCALL (QREFELT |$| 13)) 1)
                (QREFELT |$| 14))
              13301))
          |FPS-;digits;Pi;2|)
        (|check-subtype| (|>| #1# 0) (QUOTE (|PositiveInteger|)) #1#))))))

(DEFUN |FloatingPointSystem&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|FloatingPointSystem&|))

```

```

(LETT |dv$| (LIST (QUOTE |FloatingPointSystem&|) |DV$1|) . #1#)
(LETT |$| (make-array 17) . #1#)
(QSETREFV |$| 0 |dv$|)
(QSETREFV |$| 3
  (LETT |pv$|
    (|buildPredVector| 0 0
      (LIST
        (|HasAttribute| |#1| (QUOTE |arbitraryExponent|))
        (|HasAttribute| |#1| (QUOTE |arbitraryPrecision|)))) . #1#))
(|stuffDomainSlots| |$|)
(QSETREFV |$| 6 |#1|)
|$|))))

(setf (get
  (QUOTE |FloatingPointSystem&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (|PositiveInteger|)
        (0 . |base|)
        (|Integer|)
        (4 . |float|)
        |FPS-;float;2IS;1|
        (11 . |One|)
        (15 . |bits|)
        (19 . |*|)
        (25 . |max|)
        |FPS-;digits;Pi;2|))
    (QUOTE #(|float| 29 |digits| 35))
    (QUOTE NIL)
    (CONS
      (|makeByteWordVec2| 1 (QUOTE NIL))
      (CONS
        (QUOTE #())
        (CONS
          (QUOTE #())
          (|makeByteWordVec2| 16
            (QUOTE
              (0 6 7 8 3 6 0 9 9 7 10 0 6 0 12 0 6 7 13 2 9 0 7 0 14 0 6 0 15
                2 0 0 9 9 11 0 0 7 16))))))
    (QUOTE |lookupComplete|)))

```

21.25 GCDDOM.lsp BOOTSTRAP

GCDDOM needs **COMRING** which needs **RING** which needs **RNG** which needs **ABELGRP** which needs **CABMON** which needs **ABELMON** which needs **ABELSG** which needs **SETCAT** which needs **SINT** which needs **UFD** which needs **GCDDOM**. We break this chain with **GCDDOM.lsp** which we cache here. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **GCDDOM** category which we can write into the **MID** directory. We compile the lisp code and copy the **GCDDOM.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— GCDDOM.lsp BOOTSTRAP —

```
(/VERSIONCHECK 2)

(SETQ |GcdDomain;AL| (QUOTE NIL))

(DEFUN |GcdDomain| NIL
  (LET (#:G22291)
    (COND (|GcdDomain;AL|) (T (SETQ |GcdDomain;AL| (|GcdDomain;|))))))

(DEFUN |GcdDomain;| NIL
  (PROG (#0= #:G22289)
    (RETURN
      (PROG1
        (LETT #0#
          (|Join|
            (|IntegralDomain|)
            (|LeftOreRing|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE (
                ((|gcd| ($ $ $)) T)
                ((|gcd| ($ (|List| $))) T)
                ((|lcm| ($ $ $)) T)
                ((|lcm| ($ (|List| $))) T)
                ((|gcdPolynomial|
                  (|SparseUnivariatePolynomial| $)
                  (|SparseUnivariatePolynomial| $)
                  (|SparseUnivariatePolynomial| $))) T)))
          NIL
          (QUOTE ((|SparseUnivariatePolynomial| $) (|List| $)))
          NIL))
        |GcdDomain|)
      (SETELT #0# 0 (QUOTE (|GcdDomain;|))))))

(SETF (GET (QUOTE |GcdDomain|) (QUOTE NILADIC)) T)
```


21.26 GCDDOM-.lsp BOOTSTRAP

GCDDOM- depends on **GCDDOM**. We break this chain with **GCDDOM-.lsp** which we cache here. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **GCDDOM-** category which we can write into the **MID** directory. We compile the lisp code and copy the **GCDDOM-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— GCDDOM-.lsp BOOTSTRAP —

```
(/VERSIONCHECK 2)

(DEFUN |GCDDOM-;lcm;3S;1| (|x| |y| $)
  (PROG (LCM)
    (RETURN
      (SEQ
        (COND
          ((OR (SPADCALL |y| (|spadConstant| $ 7) (QREFELT $ 9))
              (SPADCALL |x| (|spadConstant| $ 7) (QREFELT $ 9)))
            (|spadConstant| $ 7))
          ((QUOTE T)
            (SEQ
              (LETT LCM
                (SPADCALL |y| (SPADCALL |x| |y| (QREFELT $ 10)) (QREFELT $ 12))
                |GCDDOM-;lcm;3S;1|)
              (EXIT
                (COND
                  ((QEQCAR LCM 0) (SPADCALL |x| (QCDR LCM) (QREFELT $ 13)))
                  ((QUOTE T) (|error| "bad gcd in lcm computation")))))))))

(DEFUN |GCDDOM-;lcm;LS;2| (|l| $)
  (SPADCALL (ELT $ 15) |l| (|spadConstant| $ 16) (|spadConstant| $ 7)
    (QREFELT $ 19)))

(DEFUN |GCDDOM-;gcd;LS;3| (|l| $)
  (SPADCALL (ELT $ 10) |l| (|spadConstant| $ 7) (|spadConstant| $ 16)
    (QREFELT $ 19)))

(DEFUN |GCDDOM-;gcdPolynomial;3Sup;4| (|p1| |p2| $)
  (PROG (|e2| |e1| |c1| |p| |c2| #0=:G22304)
    (RETURN
```

```

(SEQ
(COND
  ((SPADCALL |p1| (QREFELT $ 24)) (SPADCALL |p2| (QREFELT $ 25)))
  ((SPADCALL |p2| (QREFELT $ 24)) (SPADCALL |p1| (QREFELT $ 25)))
  ((QUOTE T)
  (SEQ
    (LETT |c1|
      (SPADCALL |p1| (QREFELT $ 26)) |GCDDOM-;gcdPolynomial;3Sup;4|)
    (LETT |c2|
      (SPADCALL |p2| (QREFELT $ 26)) |GCDDOM-;gcdPolynomial;3Sup;4|)
    (LETT |p1|
      (PROG2
        (LETT #0# (SPADCALL |p1| |c1| (QREFELT $ 27)) |GCDDOM-;gcdPolynomial;3Sup;4|)
        (QCDR #0#)
        (|check-union| (QEQCAR #0# 0)
          (|SparseUnivariatePolynomial| (QREFELT $ 6)) #0#))
        |GCDDOM-;gcdPolynomial;3Sup;4|)
      (LETT |p2|
        (PROG2
          (LETT #0#
            (SPADCALL |p2| |c2| (QREFELT $ 27))
            |GCDDOM-;gcdPolynomial;3Sup;4|)
          (QCDR #0#)
          (|check-union| (QEQCAR #0# 0)
            (|SparseUnivariatePolynomial| (QREFELT $ 6)) #0#))
          |GCDDOM-;gcdPolynomial;3Sup;4|)
        (SEQ
          (LETT |e1|
            (SPADCALL |p1| (QREFELT $ 29))
            |GCDDOM-;gcdPolynomial;3Sup;4|)
          (EXIT
            (COND
              ((< 0 |e1|)
                (LETT |p1|
                  (PROG2
                    (LETT #0#
                      (SPADCALL |p1|
                        (SPADCALL (|spadConstant| $ 16) |e1| (QREFELT $ 32))
                        (QREFELT $ 33))
                      |GCDDOM-;gcdPolynomial;3Sup;4|)
                    (QCDR #0#)
                    (|check-union| (QEQCAR #0# 0)
                      (|SparseUnivariatePolynomial| (QREFELT $ 6)) #0#))
                      |GCDDOM-;gcdPolynomial;3Sup;4|))))))
                (SEQ
                  (LETT |e2|
                    (SPADCALL |p2| (QREFELT $ 29))
                    |GCDDOM-;gcdPolynomial;3Sup;4|)
                  (EXIT
                    (COND

```

```

((< 0 |e2|)
(LETT |p2|
(PROG2
(LETT #0#
(SPADCALL |p2|
(SPADCALL (|spadConstant| $ 16) |e2| (QREFELT $ 32))
(QREFELT $ 33))
|GCDDOM-;gcdPolynomial;3Sup;4|)
(QCDR #0#)
(|check-union| (QEQCAR #0# 0)
(|SparseUnivariatePolynomial| (QREFELT $ 6)) #0#))
|GCDDOM-;gcdPolynomial;3Sup;4|))))
(LETT |e1| (MIN |e1| |e2|) |GCDDOM-;gcdPolynomial;3Sup;4|)
(LETT |c1|
(SPADCALL |c1| |c2| (QREFELT $ 10))
|GCDDOM-;gcdPolynomial;3Sup;4|)
(LETT |p1|
(COND
((OR (EQL (SPADCALL |p1| (QREFELT $ 34)) 0)
(EQL (SPADCALL |p2| (QREFELT $ 34)) 0))
(SPADCALL |c1| 0 (QREFELT $ 32)))
((QUOTE T)
(SEQ
(LETT |p|
(SPADCALL |p1| |p2| (QREFELT $ 35))
|GCDDOM-;gcdPolynomial;3Sup;4|)
(EXIT
(COND
((EQL (SPADCALL |p| (QREFELT $ 34)) 0)
(SPADCALL |c1| 0 (QREFELT $ 32)))
((QUOTE T)
(SEQ
(LETT |c2|
(SPADCALL
(SPADCALL |p1| (QREFELT $ 36))
(SPADCALL |p2| (QREFELT $ 36))
(QREFELT $ 10))
|GCDDOM-;gcdPolynomial;3Sup;4|)
(EXIT
(SPADCALL
(SPADCALL |c1|
(SPADCALL
(PROG2
(LETT #0#
(SPADCALL
(SPADCALL |c2| |p| (QREFELT $ 37))
(SPADCALL |p| (QREFELT $ 36))
(QREFELT $ 27))
|GCDDOM-;gcdPolynomial;3Sup;4|)
(QCDR #0#)

```

```

        (|check-union| (QEQCAR #0# 0)
          (|SparseUnivariatePolynomial| (QREFELT $ 6)) #0#))
      (QREFELT $ 38))
    (QREFELT $ 37))
  (QREFELT $ 25)))))))))
|GCDDOM-;gcdPolynomial;3Sup;4|)
(EXIT
  (COND
    ((ZEROP |e1|) |p1|)
    ((QUOTE T)
      (SPADCALL
        (SPADCALL (|spadConstant| $ 16) |e1| (QREFELT $ 32))
        |p1| (QREFELT $ 39)))))))))

(DEFUN |GCDDOM-;lcmCoef;2SR;5| (|c1| |c2| $)
  (PROG (|g| |cc1| #0#:#:G22318 |cc2|)
    (RETURN
      (SEQ
        (LETT |g| (SPADCALL |c1| |c2| (QREFELT $ 10)) |GCDDOM-;lcmCoef;2SR;5|)
        (LETT |cc1|
          (PROG2
            (LETT #0# (SPADCALL |c2| |g| (QREFELT $ 12)) |GCDDOM-;lcmCoef;2SR;5|)
            (QCDR #0#)
            (|check-union| (QEQCAR #0# 0) (QREFELT $ 6) #0#))
            |GCDDOM-;lcmCoef;2SR;5|)
          (LETT |cc2|
            (PROG2
              (LETT #0#
                (SPADCALL |c1| |g| (QREFELT $ 12))
                |GCDDOM-;lcmCoef;2SR;5|)
              (QCDR #0#)
              (|check-union| (QEQCAR #0# 0) (QREFELT $ 6) #0#))
              |GCDDOM-;lcmCoef;2SR;5|)
            (EXIT (VECTOR (SPADCALL |cc1| |c1| (QREFELT $ 13)) |cc1| |cc2|)))))))

(DEFUN |GcdDomain&| (|#1|)
  (PROG (DV$1 |dv$| $ |pv$|)
    (RETURN
      (PROGN
        (LETT DV$1 (|devaluate| |#1|) . #0=(|GcdDomain&|))
        (LETT |dv$| (LIST (QUOTE |GcdDomain&|) DV$1) . #0#)
        (LETT $ (MAKE-ARRAY 44) . #0#)
        (QSETREFV $ 0 |dv$|)
        (QSETREFV $ 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #0#))
        (|stuffDomainSlots| $)
        (QSETREFV $ 6 |#1|)
        $))))

(SETF (GET (QUOTE |GcdDomain&|) (QUOTE |infovec|))
  (LIST

```

```

(QUOTE #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (0 . |Zero|) (|Boolean|)
(4 . =) (10 . |gcd|) (|Union| $ (QUOTE "failed")) (16 . |exquo|)
(22 . *) |GCDDOM-;lcm;3S;1| (28 . |lcm|) (34 . |One|) (|Mapping| 6 6 6)
(|List| 6) (38 . |reduce|) (|List| $) |GCDDOM-;lcm;LS;2|
|GCDDOM-;gcd;LS;3| (|SparseUnivariatePolynomial| 6) (46 . |zero?|)
(51 . |unitCanonical|) (56 . |content|) (61 . |exquo|)
(|NonNegativeInteger|) (67 . |minimumDegree|) (72 . |Zero|) (76 . |One|)
(80 . |monomial|) (86 . |exquo|) (92 . |degree|) (97 . |subResultantGcd|)
(103 . |leadingCoefficient|) (108 . *) (114 . |primitivePart|) (119 . *)
(|SparseUnivariatePolynomial| $) |GCDDOM-;gcdPolynomial;3Sup;4|
(|Record| (|:| |lcmres| $) (|:| |coeff1| $) (|:| |coeff2| $))
|GCDDOM-;lcmCoef;2SR;5|))
(QUOTE #(|lcmCoef| 125 |lcm| 131 |gcdPolynomial| 142 |gcd| 148))
(QUOTE NIL)
(CONS
(|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
(QUOTE #())
(CONS
(QUOTE #())
(|makeByteWordVec2| 43 (QUOTE (0 6 0 7 2 6 8 0 0 9 2 6 0 0 0 10 2 6
11 0 0 12 2 6 0 0 0 13 2 6 0 0 0 15 0 6 0 16 4 18 6 17 0 6 6 19 1
23 8 0 24 1 23 0 0 25 1 23 6 0 26 2 23 11 0 6 27 1 23 28 0 29 0
23 0 30 0 23 0 31 2 23 0 6 28 32 2 23 11 0 0 33 1 23 28 0 34 2
23 0 0 0 35 1 23 6 0 36 2 23 0 6 0 37 1 23 0 0 38 2 23 0 0 0 39
2 0 42 0 0 43 2 0 0 0 0 14 1 0 0 20 21 2 0 40 40 40 41 1 0 0 20 22))))))
(QUOTE |lookupComplete|)))

```

21.27 HOAGG.lsp BOOTSTRAP

HOAGG depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **HOAGG** category which we can write into the **MID** directory. We compile the lisp code and copy the **HOAGG.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— HOAGG.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |HomogeneousAggregate;CAT| (QUOTE NIL))

(SETQ |HomogeneousAggregate;AL| (QUOTE NIL))

```

```

(DEFUN |HomogeneousAggregate| (#1=#:G82375)
  (LET (#2=#:G82376)
    (COND
      ((SETQ #2# (|assoc| (|devalue| #1#) |HomogeneousAggregate;AL|))
        (CDR #2#))
      (T
        (SETQ |HomogeneousAggregate;AL|
          (|cons5|
            (CONS (|devalue| #1#) (SETQ #2# (|HomogeneousAggregate;| #1#)))
            |HomogeneousAggregate;AL|))
          #2#))))))

(DEFUN |HomogeneousAggregate;| (|t#1|)
  (PROG (#1=#:G82374)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR (QUOTE (|t#1|)) (LIST (|devalue| |t#1|)))
            (COND
              (|HomogeneousAggregate;CAT|)
              ((QUOTE T)
                (LETT |HomogeneousAggregate;CAT|
                  (|Join|
                    (|Aggregate|)
                    (|mkCategory|
                      (QUOTE |domain|)
                      (QUOTE (
                        ((|map| (|$| (|Mapping| |t#1| |t#1|) |$|)) T)
                        ((|map!| (|$| (|Mapping| |t#1| |t#1|) |$|))
                          (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
                        ((|any?|
                          ((|Boolean|) (|Mapping| (|Boolean|) |t#1|) |$|))
                          (|has| |$| (ATTRIBUTE |finiteAggregate|)))
                        ((|every?|
                          ((|Boolean|) (|Mapping| (|Boolean|) |t#1|) |$|))
                          (|has| |$| (ATTRIBUTE |finiteAggregate|)))
                        ((|count|
                          ((|NonNegativeInteger|)
                            (|Mapping| (|Boolean|) |t#1|) |$|))
                          (|has| |$| (ATTRIBUTE |finiteAggregate|)))
                        ((|parts| ((|List| |t#1|) |$|))
                          (|has| |$| (ATTRIBUTE |finiteAggregate|)))
                        ((|members| ((|List| |t#1|) |$|))
                          (|has| |$| (ATTRIBUTE |finiteAggregate|)))
                        ((|count| ((|NonNegativeInteger|) |t#1| |$|))
                          (AND
                            (|has| |t#1| (|SetCategory|))
                            (|has| |$| (ATTRIBUTE |finiteAggregate|))))
                        ))
                      ))
                    ))
                  ))
                ))
              ))
            ))
          ))
        ))
      ))
    ))
  )

```

```

((|member?| ((|Boolean|) |t#1| |$|))
 (AND
  (|has| |t#1| (|SetCategory|))
  (|has| |$| (ATTRIBUTE |finiteAggregate|))))))
(QUOTE (
  ((|SetCategory|) (|has| |t#1| (|SetCategory|)))
  ((|Evalable| |t#1|)
   (AND
    (|has| |t#1| (|Evalable| |t#1|))
    (|has| |t#1| (|SetCategory|))))))
(QUOTE (
  (|Boolean|)
  (|NonNegativeInteger|)
  (|List| |t#1|)))
NIL))
. #2=(|HomogeneousAggregate|))))) . #2#)
(SETELT #1# 0
 (LIST (QUOTE |HomogeneousAggregate|) (|devaluate| |t#1|))))))

```

21.28 HOAGG-.lsp BOOTSTRAP

HOAGG- depends on **HOAGG**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **HOAGG-** category which we can write into the **MID** directory. We compile the lisp code and copy the **HOAGG-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— HOAGG-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |HOAGG-;eval;ALA;1| (|u| |l| |$|)
 (SPADCALL
  (CONS (FUNCTION |HOAGG-;eval;ALA;1!0|) (VECTOR |$| |l|))
  |u|
  (QREFELT |$| 11)))

(DEFUN |HOAGG-;eval;ALA;1!0| (|#1| |$$|)
 (SPADCALL |#1| (QREFELT |$$| 1) (QREFELT (QREFELT |$$| 0) 9)))

(DEFUN |HOAGG-;#;ANni;2| (|c| |$|)
 (LENGTH (SPADCALL |c| (QREFELT |$| 14))))

```



```

        (LETT #3#
          (COND (#3# #2#) ((QUOTE T) (QUOTE NIL)))
          |HOAGG-;every?;MAB;4|))
      ((QUOTE T)
        (PROGN
          (LETT #3# #2# |HOAGG-;every?;MAB;4|)
          (LETT #4# (QUOTE T) |HOAGG-;every?;MAB;4|))))))
    (LETT #1# (CDR #1#) |HOAGG-;every?;MAB;4|)
    (GO G190)
  G191
  (EXIT NIL))
(COND (#4# #3#) ((QUOTE T) (QUOTE T))))))

(DEFUN |HOAGG-;count;MANni;5| (|f| |c| |$|)
  (PROG (|x| #1=#:G82406 #2=#:G82404 #3=#:G82402 #4=#:G82403)
    (RETURN
      (SEQ
        (PROGN
          (LETT #4# NIL |HOAGG-;count;MANni;5|)
          (SEQ
            (LETT |x| NIL |HOAGG-;count;MANni;5|)
            (LETT #1# (SPADCALL |c| (QREFELT |$| 14)) |HOAGG-;count;MANni;5|)
            G190
            (COND
              ((OR (ATOM #1#) (PROGN (LETT |x| (CAR #1#) |HOAGG-;count;MANni;5|) NIL))
                (GO G191)))
            (SEQ
              (EXIT
                (COND
                  ((SPADCALL |x| |f|)
                    (PROGN
                      (LETT #2# 1 |HOAGG-;count;MANni;5|)
                      (COND
                        (#4# (LETT #3# (|+| #3# #2#) |HOAGG-;count;MANni;5|))
                        ((QUOTE T)
                          (PROGN
                            (LETT #3# #2# |HOAGG-;count;MANni;5|)
                            (LETT #4# (QUOTE T) |HOAGG-;count;MANni;5|))))))))
                    (LETT #1# (CDR #1#) |HOAGG-;count;MANni;5|)
                    (GO G190)
                    G191
                    (EXIT NIL))
                  (COND (#4# #3#) ((QUOTE T) 0)))))))
          (SPADCALL |x| (QREFELT |$| 14)))
      (DEFUN |HOAGG-;count;SANni;7| (|s| |x| |$|)
        (SPADCALL
          (CONS (FUNCTION |HOAGG-;count;SANni;7!0|) (VECTOR |$| |s|))
            |x|

```

```

(QREFELT |$| 24)))

(DEFUN |HOAGG-;count;SANni;7!0| (|#1| |$$|)
  (SPADCALL (QREFELT |$$| 1) |#1| (QREFELT (QREFELT |$$| 0) 23)))

(DEFUN |HOAGG-;member?;SAB;8!0| (|e| |c| |$|)
  (SPADCALL
    (CONS (FUNCTION |HOAGG-;member?;SAB;8!0|) (VECTOR |$| |e|))
    |c|
    (QREFELT |$| 26)))

(DEFUN |HOAGG-;member?;SAB;8!0| (|#1| |$$|)
  (SPADCALL (QREFELT |$$| 1) |#1| (QREFELT (QREFELT |$$| 0) 23)))

(DEFUN |HOAGG-;=;2AB;9| (|x| |y| |$|)
  (PROG (|b| #1=#:G82416 |a| #2=#:G82415 #3=#:G82412 #4=#:G82410 #5=#:G82411)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |x| (SPADCALL |y| (QREFELT |$| 28)) (QREFELT |$| 29))
            (PROGN
              (LETT #5# NIL |HOAGG-;=;2AB;9|)
              (SEQ
                (LETT |b| NIL |HOAGG-;=;2AB;9|)
                (LETT #1# (SPADCALL |y| (QREFELT |$| 14)) |HOAGG-;=;2AB;9|)
                (LETT |a| NIL |HOAGG-;=;2AB;9|)
                (LETT #2# (SPADCALL |x| (QREFELT |$| 14)) |HOAGG-;=;2AB;9|)
                G190
                (COND
                  ((OR
                    (ATOM #2#)
                    (PROGN (LETT |a| (CAR #2#) |HOAGG-;=;2AB;9|) NIL)
                    (ATOM #1#)
                    (PROGN (LETT |b| (CAR #1#) |HOAGG-;=;2AB;9|) NIL))
                    (GO G191)))
                (SEQ
                  (EXIT
                    (PROGN
                      (LETT #3# (SPADCALL |a| |b| (QREFELT |$| 23)) |HOAGG-;=;2AB;9|)
                      (COND
                        (#5#
                          (LETT #4#
                            (COND (#4# #3#) ((QUOTE T) (QUOTE NIL)))
                            |HOAGG-;=;2AB;9|))
                        ((QUOTE T)
                          (PROGN
                            (LETT #4# #3# |HOAGG-;=;2AB;9|)
                            (LETT #5# (QUOTE T) |HOAGG-;=;2AB;9|))))))
                      (LETT #2#
                        (PROG1

```

```

(CDR #2#)
(LETT #1# (CDR #1#) |HOAGG-;=;2AB;9|))
|HOAGG-;=;2AB;9|)
(GO G190)
G191
(EXIT NIL))
(COND (#5# #4#) ((QUOTE T) (QUOTE T))))
((QUOTE T) (QUOTE NIL))))))

(DEFUN |HOAGG-;coerce;AOf;10| (|x| |$|)
  (PROG (#1=#:G82420 |a| #2=#:G82421)
    (RETURN
      (SEQ
        (SPADCALL
          (SPADCALL
            (PROGN
              (LETT #1# NIL |HOAGG-;coerce;AOf;10|)
              (SEQ
                (LETT |a| NIL |HOAGG-;coerce;AOf;10|)
                (LETT #2# (SPADCALL |x| (QREFELT |$| 14)) |HOAGG-;coerce;AOf;10|)
                G190
                (COND
                  ((OR
                    (ATOM #2#)
                    (PROGN (LETT |a| (CAR #2#) |HOAGG-;coerce;AOf;10|) NIL))
                    (GO G191)))
                  (SEQ
                    (EXIT
                      (LETT #1#
                        (CONS (SPADCALL |a| (QREFELT |$| 32)) #1#)
                        |HOAGG-;coerce;AOf;10|)))
                      (LETT #2# (CDR #2#) |HOAGG-;coerce;AOf;10|)
                      (GO G190)
                      G191
                      (EXIT (NREVERSEO #1#))))
                    (QREFELT |$| 34))
                    (QREFELT |$| 35))))))
          )
        )
      )
    )
  )
  (DEFUN |HomogeneousAggregate&| (|#1| |#2|)
    (PROG (|DV$1| |DV$2| |dv$| |$| |pv$|)
      (RETURN
        (PROGN
          (LETT |DV$1| (|devaluate| |#1|) . #1=(|HomogeneousAggregate&|))
          (LETT |DV$2| (|devaluate| |#2|) . #1#)
          (LETT |dv$| (LIST (QUOTE |HomogeneousAggregate&|) |DV$1| |DV$2|) . #1#)
          (LETT |$| (make-array 38) . #1#)
          (QSETREFV |$| 0 |dv$|)
          (QSETREFV |$| 3
            (LETT |pv$|
              (|buildPredVector| 0 0

```

```

(LIST
  (|HasAttribute| |#1| (QUOTE |finiteAggregate|))
  (|HasAttribute| |#1| (QUOTE |shallowlyMutable|))
  (|HasCategory| |#2| (LIST (QUOTE |Evalable|) (|devaluate| |#2|)))
  (|HasCategory| |#2| (QUOTE (|SetCategory|))))
. #1#)
(|stuffDomainSlots| |$|)
(QSETREFV |$| 6 |#1|)
(QSETREFV |$| 7 |#2|)
(COND
  ((|testBitVector| |pv$| 3)
   (QSETREFV |$| 12 (CONS (|dispatchFunction| |HOAGG-;eval;ALA;1|) |$|))))
(COND
  ((|testBitVector| |pv$| 1)
   (PROGN
    (QSETREFV |$| 16 (CONS (|dispatchFunction| |HOAGG-;#;ANni;2|) |$|))
    (QSETREFV |$| 19 (CONS (|dispatchFunction| |HOAGG-;any?;MAB;3|) |$|))
    (QSETREFV |$| 20 (CONS (|dispatchFunction| |HOAGG-;every?;MAB;4|) |$|))
    (QSETREFV |$| 21 (CONS (|dispatchFunction| |HOAGG-;count;MANni;5|) |$|))
    (QSETREFV |$| 22 (CONS (|dispatchFunction| |HOAGG-;members;AL;6|) |$|))
    (COND
      ((|testBitVector| |pv$| 4)
       (PROGN
        (QSETREFV |$| 25
          (CONS (|dispatchFunction| |HOAGG-;count;SANni;7|) |$|))
        (QSETREFV |$| 27
          (CONS (|dispatchFunction| |HOAGG-;member?;SAB;8|) |$|))
        (QSETREFV |$| 30
          (CONS (|dispatchFunction| |HOAGG-;=;2AB;9|) |$|))
        (QSETREFV |$| 36
          (CONS (|dispatchFunction| |HOAGG-;coerce;AOf;10|) |$|)))))))
    |$|))))
(setf (get
  (QUOTE |HomogeneousAggregate&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|) (|List| 37)
      (0 . |eval|) (|Mapping| 7 7) (6 . |map|) (12 . |eval|) (|List| 7)
      (18 . |parts|) (|NonNegativeInteger|) (23 . |#|) (|Boolean|)
      (|Mapping| 17 7) (28 . |any?|) (34 . |every?|) (40 . |count|)
      (46 . |members|) (51 . |=|) (57 . |count|) (63 . |count|) (69 . |any?|)
      (75 . |member?|) (81 . |#|) (86 . |size?|) (92 . |=|) (|OutputForm|)
      (98 . |coerce|) (|List| |$|) (103 . |commaSeparate|) (108 . |bracket|)
      (113 . |coerce|) (|Equation| 7)))
    (QUOTE #(|members| 118 |member?| 123 |every?| 129 |eval| 135 |count| 141
      |coerce| 153 |any?| 158 |=| 164 |#| 170))
    (QUOTE NIL)
    (CONS
      (|makeByteWordVec2| 1 (QUOTE NIL))

```

```

(CONS
  (QUOTE #())
  (CONS
    (QUOTE #())
    (|makeByteWordVec2| 36
      (QUOTE (2 7 0 0 8 9 2 6 0 10 0 11 2 0 0 0 8 12 1 6 13 0 14 1 0 15 0
        16 2 0 17 18 0 19 2 0 17 18 0 20 2 0 15 18 0 21 1 0 13 0 22 2 7 17
        0 0 23 2 6 15 18 0 24 2 0 15 7 0 25 2 6 17 18 0 26 2 0 17 7 0 27 1
        6 15 0 28 2 6 17 0 15 29 2 0 17 0 0 30 1 7 31 0 32 1 31 0 33 34 1
        31 0 0 35 1 0 31 0 36 1 0 13 0 22 2 0 17 7 0 27 2 0 17 18 0 20 2 0
        0 0 8 12 2 0 15 7 0 25 2 0 15 18 0 21 1 0 31 0 36 2 0 17 18 0 19 2
        0 17 0 0 30 1 0 15 0 16))))))
(QUOTE |lookupComplete|))

```

21.29 INS.lsp BOOTSTRAP

INS depends on itself. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **INS** category which we can write into the **MID** directory. We compile the lisp code and copy the **INS.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

— **INS.lsp BOOTSTRAP** —

```

(/VERSIONCHECK 2)

(SETQ |IntegerNumberSystem;AL| (QUOTE NIL))

(DEFUN |IntegerNumberSystem| NIL
  (LET (#:G1068)
    (COND
      (|IntegerNumberSystem;AL|)
      (T (SETQ |IntegerNumberSystem;AL| (|IntegerNumberSystem;|))))))

(DEFUN |IntegerNumberSystem;| NIL (PROG (#0= #:G1066)
  (RETURN
    (PROG1
      (LETT #0#
        (|sublisV|
          (PAIR
            (QUOTE (#1= #:G1060 #2= #:G1061 #3= #:G1062
              #4= #:G1063 #5= #:G1064 #6= #:G1065))
            (LIST
              (QUOTE (|Integer|))
              (QUOTE (|Integer|))
              (QUOTE (|Integer|))
              (QUOTE (|InputForm|))

```

```

      (QUOTE (|Pattern| (|Integer|)))
      (QUOTE (|Integer|)))
(|Join|
  (|UniqueFactorizationDomain|)
  (|EuclideanDomain|)
  (|OrderedIntegralDomain|)
  (|DifferentialRing|)
  (|ConvertibleTo| (QUOTE #1#))
  (|RetractableTo| (QUOTE #2#))
  (|LinearlyExplicitRingOver| (QUOTE #3#))
  (|ConvertibleTo| (QUOTE #4#))
  (|ConvertibleTo| (QUOTE #5#))
  (|PatternMatchable| (QUOTE #6#))
  (|CombinatorialFunctionCategory|)
  (|RealConstant|)
  (|CharacteristicZero|)
  (|StepThrough|)
  (|mkCategory|
    (QUOTE |domain|)
    (QUOTE (
      ((|odd?| ((|Boolean|) $)) T)
      ((|even?| ((|Boolean|) $)) T)
      ((|base| ($)) T)
      ((|length| ($ $)) T)
      ((|shift| ($ $ $)) T)
      ((|bit?| ((|Boolean|) $ $)) T)
      ((|positiveRemainder| ($ $ $)) T)
      ((|symmetricRemainder| ($ $ $)) T)
      ((|rational?| ((|Boolean|) $)) T)
      ((|rational| ((|Fraction| (|Integer|)) $)) T)
      ((|rationalIfCan|
        ((|Union| (|Fraction| (|Integer|)) "failed") $)) T)
      ((|random| ($)) T)
      ((|random| ($ $)) T)
      ((|hash| ($ $)) T)
      ((|copy| ($ $)) T)
      ((|inc| ($ $)) T)
      ((|dec| ($ $)) T)
      ((|mask| ($ $)) T)
      ((|addmod| ($ $ $ $)) T)
      ((|submod| ($ $ $ $)) T)
      ((|mulmod| ($ $ $ $)) T)
      ((|powmod| ($ $ $ $)) T)
      ((|invmod| ($ $ $)) T)))
    (QUOTE ((|multiplicativeValuation| T) (|canonicalUnitNormal| T)))
    (QUOTE ((|Fraction| (|Integer|)) (|Boolean|))) NIL)))
  |IntegerNumberSystem|)
(SETLT #0# 0 (QUOTE (|IntegerNumberSystem|))))))

(setf (get (QUOTE |IntegerNumberSystem|) (QUOTE NILADIC)) T)

```

21.30 INS-.lsp BOOTSTRAP

INS- depends on **INS**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **INS-** category which we can write into the **MID** directory. We compile the lisp code and copy the **INS-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

— **INS-.lsp BOOTSTRAP** —

```
(/VERSIONCHECK 2)

(PUT
  (QUOTE |INS-;characteristic;Nni;1|)
  (QUOTE |SPADreplace|)
  (QUOTE (XLAM NIL 0)))

(DEFUN |INS-;characteristic;Nni;1| ($ 0)

(DEFUN |INS-;differentiate;2S;2| (|x| $)
  (|spadConstant| $ 9))

(DEFUN |INS-;even?;SB;3| (|x| $)
  (COND
    ((SPADCALL |x| (QREFELT $ 12)) (QUOTE NIL))
    ((QUOTE T) (QUOTE T))))

(DEFUN |INS-;positive?;SB;4| (|x| $)
  (SPADCALL (|spadConstant| $ 9) |x| (QREFELT $ 14)))

(PUT
  (QUOTE |INS-;copy;2S;5|)
  (QUOTE |SPADreplace|)
  (QUOTE (XLAM (|x|) |x|)))

(DEFUN |INS-;copy;2S;5| (|x| $) |x|)

(DEFUN |INS-;bit?;2SB;6| (|x| |i| $)
  (SPADCALL
    (SPADCALL |x|
      (SPADCALL |i| (QREFELT $ 17))
      (QREFELT $ 18))
    (QREFELT $ 12)))

(DEFUN |INS-;mask;2S;7| (|n| $)
```

```

(SPADCALL
  (SPADCALL (|spadConstant| $ 20) |n| (QREFELT $ 18))
  (QREFELT $ 21)))

(PUT
  (QUOTE |INS-;rational?;SB;8|)
  (QUOTE |SPADreplace|)
  (QUOTE (XLAM (|x|) (QUOTE T))))

(DEFUN |INS-;rational?;SB;8| (|x| $)
  (QUOTE T))

(DEFUN |INS-;euclideanSize;SNni;9| (|x| $)
  (PROG (#0=#:G1078 #1=#:G1079)
    (RETURN
      (COND
        ((SPADCALL |x| (|spadConstant| $ 9) (QREFELT $ 24))
          (|error| "euclideanSize called on zero"))
        ((SPADCALL |x| (|spadConstant| $ 9) (QREFELT $ 14))
          (PROG1
            (LETT #0#
              (- (SPADCALL |x| (QREFELT $ 26)))
              |INS-;euclideanSize;SNni;9|)
            (|check-subtype|
              (>= #0# 0)
              (QUOTE (|NonNegativeInteger|))
              #0#)))
          ((QUOTE T)
            (PROG1
              (LETT #1#
                (SPADCALL |x| (QREFELT $ 26))
                |INS-;euclideanSize;SNni;9|)
              (|check-subtype|
                (>= #1# 0)
                (QUOTE (|NonNegativeInteger|))
                #1#))))))))))

(DEFUN |INS-;convert;SF;10| (|x| $)
  (SPADCALL (SPADCALL |x| (QREFELT $ 26)) (QREFELT $ 29)))

(DEFUN |INS-;convert;SDf;11| (|x| $)
  (FLOAT (SPADCALL |x| (QREFELT $ 26)) MOST-POSITIVE-LONG-FLOAT))

(DEFUN |INS-;convert;SIf;12| (|x| $)
  (SPADCALL (SPADCALL |x| (QREFELT $ 26)) (QREFELT $ 34)))

(DEFUN |INS-;retract;SI;13| (|x| $)
  (SPADCALL |x| (QREFELT $ 26)))

(DEFUN |INS-;convert;SP;14| (|x| $)

```



```

(SPADCALL (SPADCALL |x| (QREFELT $ 26)) (QREFELT $ 38)))

(DEFUN |INS-;factor;SF;15| (|x| $)
  (SPADCALL |x| (QREFELT $ 42)))

(DEFUN |INS-;squareFree;SF;16| (|x| $)
  (SPADCALL |x| (QREFELT $ 45)))

(DEFUN |INS-;prime?;SB;17| (|x| $)
  (SPADCALL |x| (QREFELT $ 48)))

(DEFUN |INS-;factorial;2S;18| (|x| $)
  (SPADCALL |x| (QREFELT $ 51)))

(DEFUN |INS-;binomial;3S;19| (|n| |m| $)
  (SPADCALL |n| |m| (QREFELT $ 53)))

(DEFUN |INS-;permutation;3S;20| (|n| |m| $)
  (SPADCALL |n| |m| (QREFELT $ 55)))

(DEFUN |INS-;retractIfCan;SU;21| (|x| $)
  (CONS 0 (SPADCALL |x| (QREFELT $ 26))))

(DEFUN |INS-;init;S;22| ($)
  (|spadConstant| $ 9))

(DEFUN |INS-;nextItem;SU;23| (|n| $)
  (COND
    ((SPADCALL |n| (QREFELT $ 60))
      (CONS 0 (|spadConstant| $ 20)))
    ((SPADCALL (|spadConstant| $ 9) |n| (QREFELT $ 14))
      (CONS 0 (SPADCALL |n| (QREFELT $ 17))))
    ((QUOTE T)
      (CONS 0 (SPADCALL (|spadConstant| $ 20) |n| (QREFELT $ 61))))))

(DEFUN |INS-;patternMatch;SP2Pmr;24| (|x| |p| |l| $)
  (SPADCALL |x| |p| |l| (QREFELT $ 66)))

(DEFUN |INS-;rational;SF;25| (|x| $)
  (SPADCALL (SPADCALL |x| (QREFELT $ 26)) (QREFELT $ 70)))

(DEFUN |INS-;rationalIfCan;SU;26| (|x| $)
  (CONS 0 (SPADCALL (SPADCALL |x| (QREFELT $ 26)) (QREFELT $ 70))))

(DEFUN |INS-;symmetricRemainder;3S;27| (|x| |n| $)
  (PROG (|r|)
    (RETURN
      (SEQ
        (LETT |r|
          (SPADCALL |x| |n| (QREFELT $ 74))

```

```

|INS-;symmetricRemainder;3S;27|)
(EXIT
(COND
  ((SPADCALL |r| (|spadConstant| $ 9) (QREFELT $ 24)) |r|)
  ((QUOTE T)
    (SEQ
      (COND
        ((SPADCALL |n| (|spadConstant| $ 9) (QREFELT $ 14))
          (LETT |n|
            (SPADCALL |n| (QREFELT $ 17))
            |INS-;symmetricRemainder;3S;27|)))
      (EXIT
        (COND
          ((SPADCALL (|spadConstant| $ 9) |r| (QREFELT $ 14))
            (COND
              ((SPADCALL |n|
                (SPADCALL 2 |r| (QREFELT $ 76))
                (QREFELT $ 14))
                (SPADCALL |r| |n| (QREFELT $ 61)))
              ((QUOTE T) |r|)))
            (NULL
              (SPADCALL
                (|spadConstant| $ 9)
                (SPADCALL
                  (SPADCALL 2 |r| (QREFELT $ 76))
                  |n|
                  (QREFELT $ 77))
                (QREFELT $ 14)))
                (SPADCALL |r| |n| (QREFELT $ 77)))
              ((QUOTE T) |r|))))))))))

(DEFUN |INS-;invmod;3S;28| (|a| |b| $)
  (PROG (|q| |r| |r1| |c| |c1| |d| |d1|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |a| (QREFELT $ 79))
            (LETT |a| (SPADCALL |a| |b| (QREFELT $ 80)) |INS-;invmod;3S;28|)))
          (LETT |c| |a| |INS-;invmod;3S;28|)
          (LETT |c1| (|spadConstant| $ 20) |INS-;invmod;3S;28|)
          (LETT |d| |b| |INS-;invmod;3S;28|)
          (LETT |d1| (|spadConstant| $ 9) |INS-;invmod;3S;28|)
          (SEQ G190
            (COND
              ((NULL
                (COND
                  ((SPADCALL |d| (QREFELT $ 60)) (QUOTE NIL))
                  ((QUOTE T) (QUOTE T))))
                (GO G191)))
            (SEQ

```

```

(LETT |q| (SPADCALL |c| |d| (QREFELT $ 81)) |INS-;invmod;3S;28|)
(LETT |r|
  (SPADCALL |c| (SPADCALL |q| |d| (QREFELT $ 82)) (QREFELT $ 61))
  |INS-;invmod;3S;28|)
(LETT |r1|
  (SPADCALL |c1| (SPADCALL |q| |d1| (QREFELT $ 82)) (QREFELT $ 61))
  |INS-;invmod;3S;28|)
(LETT |c| |d| |INS-;invmod;3S;28|)
(LETT |c1| |d1| |INS-;invmod;3S;28|)
(LETT |d| |r| |INS-;invmod;3S;28|)
(EXIT (LETT |d1| |r1| |INS-;invmod;3S;28|)))
NIL
(GO G190)
G191
(EXIT NIL))
(COND
  ((NULL (SPADCALL |c| (QREFELT $ 83)))
    (EXIT (|error| "inverse does not exist"))))
(EXIT
  (COND
    ((SPADCALL |c1| (QREFELT $ 79)) (SPADCALL |c1| |b| (QREFELT $ 77)))
    ((QUOTE T) |c1|))))))

(DEFUN |INS-;powmod;4S;29| (|x| |n| |p| $)
  (PROG (|y| #0=#:G1137 |z|)
    (RETURN
      (SEQ
        (EXIT
          (SEQ
            (COND
              ((SPADCALL |x| (QREFELT $ 79))
                (LETT |x|
                  (SPADCALL |x| |p| (QREFELT $ 80))
                  |INS-;powmod;4S;29|)))
            (EXIT
              (COND
                ((SPADCALL |x| (QREFELT $ 60)) (|spadConstant| $ 9))
                ((SPADCALL |n| (QREFELT $ 60)) (|spadConstant| $ 20))
                ((QUOTE T)
                  (SEQ
                    (LETT |y| (|spadConstant| $ 20) |INS-;powmod;4S;29|)
                    (LETT |z| |x| |INS-;powmod;4S;29|)
                    (EXIT
                      (SEQ G190
                        NIL
                        (SEQ
                          (COND
                            ((SPADCALL |n| (QREFELT $ 12))
                              (LETT |y|
                                (SPADCALL |y| |z| |p| (QREFELT $ 85))

```

```

|INS-;powmod;4S;29|)))
(EXIT
(COND
  ((SPADCALL
    (LETT |n|
      (SPADCALL |n|
        (SPADCALL
          (|spadConstant| $ 20)
          (QREFELT $ 17))
          (QREFELT $ 18))
          |INS-;powmod;4S;29|)
        (QREFELT $ 60))
    (PROGN
      (LETT #0# |y| |INS-;powmod;4S;29|)
      (GO #0#)))
    ((QUOTE T)
      (LETT |z|
        (SPADCALL |z| |z| |p| (QREFELT $ 85))
        |INS-;powmod;4S;29|))))))
NIL
(GO G190)
G191
(EXIT NIL)))))))))
#0#
(EXIT #0#))))))

(DEFUN |IntegerNumberSystem&| (|#1|)
  (PROG (DV$1 |dv$| $ |pv$|)
    (RETURN
      (PROGN
        (LETT DV$1 (|devaluate| |#1|) . #0=(|IntegerNumberSystem&|))
        (LETT |dv$| (LIST (QUOTE |IntegerNumberSystem&|) DV$1) . #0#)
        (LETT $ (make-array 87) . #0#)
        (QSETREFV $ 0 |dv$|)
        (QSETREFV $ 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #0#))
        (|stuffDomainSlots| $)
        (QSETREFV $ 6 |#1|)
        $))))))

(setf (get
  (QUOTE |IntegerNumberSystem&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (|NonNegativeInteger|
          |INS-;characteristic;Nni;1|
          (0 . |Zero|)
          |INS-;differentiate;2S;2|

```

```

(|Boolean|)
(4 . |odd?|)
|INS-;even?;SB;3|
(9 . <)
|INS-;positive?;SB;4|
|INS-;copy;2S;5|
(15 . -)
(20 . |shift|)
|INS-;bit?;2SB;6|
(26 . |One|)
(30 . |dec|)
|INS-;mask;2S;7|
|INS-;rational?;SB;8|
(35 . =)
(|Integer|)
(41 . |convert|)
|INS-;euclideanSize;SNni;9|
(|Float|)
(46 . |coerce|)
|INS-;convert;SF;10|
(|DoubleFloat|)
|INS-;convert;SDf;11|
(|InputForm|)
(51 . |convert|)
|INS-;convert;SIf;12|
|INS-;retract;SI;13|
(|Pattern| 25)
(56 . |coerce|)
|INS-;convert;SP;14|
(|Factored| 6)
(|IntegerFactorizationPackage| 6)
(61 . |factor|)
(|Factored| $)
|INS-;factor;SF;15|
(66 . |squareFree|)
|INS-;squareFree;SF;16|
(|IntegerPrimesPackage| 6)
(71 . |prime?|)
|INS-;prime?;SB;17|
(|IntegerCombinatoricFunctions| 6)
(76 . |factorial|)
|INS-;factorial;2S;18|
(81 . |binomial|)
|INS-;binomial;3S;19|
(87 . |permutation|)
|INS-;permutation;3S;20|
(|Union| 25 (QUOTE "failed"))
|INS-;retractIfCan;SU;21|
|INS-;init;S;22|
(93 . |zero?|)

```

```

(98 . -)
(|Union| $ (QUOTE "failed"))
|INS-;nextItem;SU;23|
(|PatternMatchResult| 25 6)
(|PatternMatchIntegerNumberSystem| 6)
(104 . |patternMatch|)
(|PatternMatchResult| 25 $)
|INS-;patternMatch;SP2Pmr;24|
(|Fraction| 25)
(111 . |coerce|)
|INS-;rational;SF;25|
(|Union| 69 (QUOTE "failed"))
|INS-;rationalIfCan;SU;26|
(116 . |rem|)
(|PositiveInteger|)
(122 . *)
(128 . +)
|INS-;symmetricRemainder;3S;27|
(134 . |negative?|)
(139 . |positiveRemainder|)
(145 . |quo|)
(151 . *)
(157 . |one?|)
|INS-;invmod;3S;28|
(162 . |mulmod|)
|INS-;powmod;4S;29|))
(QUOTE
#(|symmetricRemainder| 169 |squareFree| 175 |retractIfCan| 180
|retract| 185 |rationalIfCan| 190 |rational?| 195 |rational| 200
|prime?| 205 |powmod| 210 |positive?| 217 |permutation| 222
|patternMatch| 228 |nextItem| 235 |mask| 240 |invmod| 245 |init| 251
|factorial| 255 |factor| 260 |even?| 265 |euclideanSize| 270
|differentiate| 275 |copy| 280 |convert| 285 |characteristic| 305
|bit?| 309 |binomial| 315))
(QUOTE NIL)
(CONS
(|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
(QUOTE #())
(CONS
(QUOTE #())
(|makeByteWordVec2| 86
(QUOTE
(0 6 0 9 1 6 11 0 12 2 6 11 0 0 14 1 6 0 0 17 2 6 0 0 0 18 0 6
0 20 1 6 0 0 21 2 6 11 0 0 24 1 6 25 0 26 1 28 0 25 29 1 33 0
25 34 1 37 0 25 38 1 41 40 6 42 1 41 40 6 45 1 47 11 6 48 1 50
6 6 51 2 50 6 6 6 53 2 50 6 6 6 55 1 6 11 0 60 2 6 0 0 0 61 3
65 64 6 37 64 66 1 69 0 25 70 2 6 0 0 0 74 2 6 0 75 0 76 2 6 0
0 0 77 1 6 11 0 79 2 6 0 0 0 80 2 6 0 0 0 81 2 6 0 0 0 82 1 6
11 0 83 3 6 0 0 0 85 2 0 0 0 0 78 1 0 43 0 46 1 0 57 0 58 1

```

```

0 25 0 36 1 0 72 0 73 1 0 11 0 23 1 0 69 0 71 1 0 11 0 49 3 0
0 0 0 0 86 1 0 11 0 15 2 0 0 0 0 56 3 0 67 0 37 67 68 1 0 62
0 63 1 0 0 0 22 2 0 0 0 0 84 0 0 0 59 1 0 0 0 52 1 0 43 0 44
1 0 11 0 13 1 0 7 0 27 1 0 0 0 10 1 0 0 0 16 1 0 31 0 32 1 0
28 0 30 1 0 37 0 39 1 0 33 0 35 0 0 7 8 2 0 11 0 0 19 2 0 0
0 0 54))))))
(QUOTE |lookupComplete|))

```

21.31 INTDOM.lsp BOOTSTRAP

INTDOM depends on itself. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **INTDOM** category which we can write into the **MID** directory. We compile the lisp code and copy the **INTDOM.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— INTDOM.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |IntegralDomain;AL| (QUOTE NIL))

(DEFUN |IntegralDomain| NIL
  (LET (#:G83060)
    (COND
      (|IntegralDomain;AL|)
      (T (SETQ |IntegralDomain;AL| (|IntegralDomain;|))))))

(DEFUN |IntegralDomain;| NIL
  (PROG (#1= #:G83058)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|CommutativeRing|)
            (|Algebra| (QUOTE |$|))
            (|EntireRing|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE (
                ((|exquo| ((|Union| |$| "failed") |$| |$|)) T)
                ((|unitNormal|
                  ((|Record|

```

```

(|:| |unit| |$|)
(|:| |canonical| |$|)
(|:| |associate| |$|)) |$|)) T)
((|unitCanonical| (|$| |$|)) T)
((|associates?| ((|Boolean|) |$| |$|)) T)
((|unit?| ((|Boolean|) |$|)) T)))
NIL
(QUOTE ((|Boolean|)))
NIL))
|IntegralDomain|)
(SETLT #1# 0 (QUOTE (|IntegralDomain|))))))

(setf (get (QUOTE |IntegralDomain|) (QUOTE NILADIC)) T)

```

21.32 INTDOM-.lsp BOOTSTRAP

INTDOM- depends on **INTDOM**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **INTDOM-** category which we can write into the **MID** directory. We compile the lisp code and copy the **INTDOM-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— INTDOM-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |INTDOM-;unitNormal;SR;1| (|x| |$|)
  (VECTOR (|spadConstant| |$| 7) |x| (|spadConstant| |$| 7)))

(DEFUN |INTDOM-;unitCanonical;2S;2| (|x| |$|)
  (QVELT (SPADCALL |x| (QREFELT |$| 10)) 1))

(DEFUN |INTDOM-;recip;SU;3| (|x| |$|)
  (COND
    ((SPADCALL |x| (QREFELT |$| 13)) (CONS 1 "failed"))
    ((QUOTE T) (SPADCALL (|spadConstant| |$| 7) |x| (QREFELT |$| 15)))))

(DEFUN |INTDOM-;unit?;SB;4| (|x| |$|)
  (COND
    ((QEQCAR (SPADCALL |x| (QREFELT |$| 17)) 1) (QUOTE NIL))
    ((QUOTE T) (QUOTE T))))

(DEFUN |INTDOM-;associates?;2SB;5| (|x| |y| |$|)

```



```

(SPADCALL
  (QVELT (SPADCALL |x| (QREFELT |$| 10)) 1)
  (QVELT (SPADCALL |y| (QREFELT |$| 10)) 1)
  (QREFELT |$| 19)))

(DEFUN |INTDOM-;associates?;2SB;6| (|x| |y| |$|)
  (COND
    ((SPADCALL |x| (QREFELT |$| 13)) (SPADCALL |y| (QREFELT |$| 13)))
    ((OR
      (SPADCALL |y| (QREFELT |$| 13))
      (OR
        (QEQCAR (SPADCALL |x| |y| (QREFELT |$| 15)) 1)
        (QEQCAR (SPADCALL |y| |x| (QREFELT |$| 15)) 1)))
      (QUOTE NIL))
    ((QUOTE T) (QUOTE T))))

(DEFUN |IntegralDomain&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|IntegralDomain&|))
        (LETT |dv$| (LIST (QUOTE |IntegralDomain&|) |DV$1|) . #1#)
        (LETT |$| (make-array 21) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        (COND
          ((|HasCategory| |#1| (QUOTE (|Field|))))
          ((QUOTE T)
            (QSETREFV |$| 9
              (CONS (|dispatchFunction| |INTDOM-;unitNormal;SR;1|) |$|))))
        (COND
          ((|HasAttribute| |#1| (QUOTE |canonicalUnitNormal|))
            (QSETREFV |$| 20
              (CONS (|dispatchFunction| |INTDOM-;associates?;2SB;5|) |$|)))
          ((QUOTE T)
            (QSETREFV |$| 20
              (CONS (|dispatchFunction| |INTDOM-;associates?;2SB;6|) |$|))))
        |$|))))

(setf (get
  (QUOTE |IntegralDomain&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (0 . |One|)
        (|Record|

```

```

(|:| |unit| |$|)
(|:| |canonical| |$|)
(|:| |associate| |$|))
(4 . |unitNormal|)
(9 . |unitNormal|)
|INTDOM-;unitCanonical;2S;2|
(|Boolean|)
(14 . |zero?|)
(|Union| |$| (QUOTE "failed"))
(19 . |exquo|)
|INTDOM-;recip;SU;3|
(25 . |recip|)
|INTDOM-;unit?;SB;4|
(30 . |=|)
(36 . |associates?|)))
(QUOTE
  #(|unitNormal| 42 |unitCanonical| 47 |unit?| 52 |recip| 57
    |associates?| 62))
(QUOTE NIL)
(CONS
  (|makeByteWordVec2| 1 (QUOTE NIL))
  (CONS
    (QUOTE #())
    (CONS
      (QUOTE #())
      (|makeByteWordVec2| 20
        (QUOTE
          (0 6 0 7 1 0 8 0 9 1 6 8 0 10 1 6 12 0 13 2 6 14 0 0 15 1 6 14
            0 17 2 6 12 0 0 19 2 0 12 0 0 20 1 0 8 0 9 1 0 0 0 11 1 0 12 0
            18 1 0 14 0 16 2 0 12 0 0 20)))))))
(QUOTE |lookupComplete|)))

```

21.33 LNAGG.lsp BOOTSTRAP

LNAGG depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **LNAGG** category which we can write into the **MID** directory. We compile the lisp code and copy the **LNAGG.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— LNAGG.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)
```

```

(SETQ |LinearAggregate;CAT| (QUOTE NIL))

(SETQ |LinearAggregate;AL| (QUOTE NIL))

(DEFUN |LinearAggregate| (#1=:G85818)
  (LET (#2=:G85819)
    (COND
      ((SETQ #2# (|assoc| (|devaluate| #1#) |LinearAggregate;AL|)) (CDR #2#))
      (T
        (SETQ |LinearAggregate;AL|
          (|cons5|
            (CONS (|devaluate| #1#) (SETQ #2# (|LinearAggregate;| #1#)))
            |LinearAggregate;AL|))
          #2#))))))

(DEFUN |LinearAggregate;| (|t#1|)
  (PROG (#1=:G85817)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR (QUOTE (|t#1|)) (LIST (|devaluate| |t#1|))))
          (|sublisV|
            (PAIR (QUOTE (#2=:G85816)) (LIST (QUOTE (|Integer|))))
            (COND
              (|LinearAggregate;CAT|)
              ((QUOTE T)
                (LETT |LinearAggregate;CAT|
                  (|Join|
                    (|IndexedAggregate| (QUOTE #2#) (QUOTE |t#1|))
                    (|Collection| (QUOTE |t#1|))
                    (|mkCategory|
                      (QUOTE |domain|)
                      (QUOTE (
                        ((|new| (|$$| (|NonNegativeInteger|) |t#1|)) T)
                        ((|concat| (|$$| |$$| |t#1|)) T)
                        ((|concat| (|$$| |t#1| |$$|)) T)
                        ((|concat| (|$$| |$$| |$$|)) T)
                        ((|concat| (|$$| (|List| |$$|)) T)
                        ((|map| (|$$| (|Mapping| |t#1| |t#1| |t#1|) |$$| |$$|)) T)
                        ((|elt| (|$$| |$$| (|UniversalSegment| (|Integer|))) T)
                        ((|delete| (|$$| |$$| (|Integer|))) T)
                        ((|delete| (|$$| |$$| (|UniversalSegment| (|Integer|)))) T)
                        ((|insert| (|$$| |t#1| |$$| (|Integer|))) T)
                        ((|insert| (|$$| |$$| |$$| (|Integer|))) T)
                        ((|setelt| (|t#1| |$$| (|UniversalSegment| (|Integer|)) |t#1|))
                          (|has| |$$| (ATTRIBUTE |shallowlyMutable|))))))
                  NIL
                  (QUOTE (

```

```

(|UniversalSegment| (|Integer|))
(|Integer|)
(|List| |$|)
(|NonNegativeInteger|)))
NIL))
. #3=(|LinearAggregate|))))))
. #3#)
(SETELT #1# 0 (LIST (QUOTE |LinearAggregate|) (|devaluate| |t#1|))))))

```

21.34 LNAGG-.lsp BOOTSTRAP

LNAGG- depends on **LNAGG**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **LNAGG-** category which we can write into the **MID** directory. We compile the lisp code and copy the **LNAGG-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— LNAGG-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |LNAGG-;indices;AL;1| (|a| |$|)
  (PROG (#1#:#:G85833 |i| #2#:#:G85834)
    (RETURN
      (SEQ
        (PROGN
          (LETT #1# NIL |LNAGG-;indices;AL;1|)
          (SEQ
            (LETT |i| (SPADCALL |a| (QREFELT |$| 9)) |LNAGG-;indices;AL;1|)
            (LETT #2# (SPADCALL |a| (QREFELT |$| 10)) |LNAGG-;indices;AL;1|)
            G190
            (COND ((|>| |i| #2#) (GO G191)))
            (SEQ (EXIT (LETT #1# (CONS |i| #1#) |LNAGG-;indices;AL;1|)))
            (LETT |i| (|+| |i| 1) |LNAGG-;indices;AL;1|)
            (GO G190)
            G191
            (EXIT (NREVERSEO #1#))))))))))

(DEFUN |LNAGG-;index?;IAB;2| (|i| |a| |$|)
  (COND
    ((OR
      (|<| |i| (SPADCALL |a| (QREFELT |$| 9)))
      (|<| (SPADCALL |a| (QREFELT |$| 10)) |i|))
      (QUOTE NIL))

```

```

((QUOTE T) (QUOTE T)))

(DEFUN |LNAGG-;concat;ASA;3| (|a| |x| |$|)
  (SPADCALL |a| (SPADCALL 1 |x| (QREFELT |$| 16)) (QREFELT |$| 17)))

(DEFUN |LNAGG-;concat;S2A;4| (|x| |y| |$|)
  (SPADCALL (SPADCALL 1 |x| (QREFELT |$| 16)) |y| (QREFELT |$| 17)))

(DEFUN |LNAGG-;insert;SAIA;5| (|x| |a| |i| |$|)
  (SPADCALL (SPADCALL 1 |x| (QREFELT |$| 16)) |a| |i| (QREFELT |$| 20)))

(DEFUN |LNAGG-;maxIndex;AI;6| (|l| |$|)
  (|+| (|-| (SPADCALL |l| (QREFELT |$| 22)) 1) (SPADCALL |l| (QREFELT |$| 9))))

(DEFUN |LinearAggregate&| (|#1| |#2|)
  (PROG (|DV$1| |DV$2| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|LinearAggregate&|))
        (LETT |DV$2| (|devaluate| |#2|) . #1#)
        (LETT |dv$| (LIST (QUOTE |LinearAggregate&|) |DV$1| |DV$2|) . #1#)
        (LETT |$| (make-array 25) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3
          (LETT |pv$|
            (|buildPredVector| 0 0
              (LIST (|HasAttribute| |#1| (QUOTE |shallowlyMutable|))))
            . #1#))
          (|stuffDomainSlots| |$|)
          (QSETREFV |$| 6 |#1|)
          (QSETREFV |$| 7 |#2|)
          (COND
            ((|HasAttribute| |#1| (QUOTE |finiteAggregate|))
              (QSETREFV |$| 23
                (CONS (|dispatchFunction| |LNAGG-;maxIndex;AI;6|) |$|))))
            |$|))))
    (setf (get
      (QUOTE |LinearAggregate&|)
      (QUOTE |infovec|))
      (LIST
        (QUOTE #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|) (|Integer|)
          (0 . |minIndex|) (5 . |maxIndex|) (|List| 8) |LNAGG-;indices;AL;1|
          (|Boolean|) |LNAGG-;index?;IAB;2| (|NonNegativeInteger|) (10 . |new|)
          (16 . |concat|) |LNAGG-;concat;ASA;3| |LNAGG-;concat;S2A;4|
          (22 . |insert|) |LNAGG-;insert;SAIA;5| (29 . |#|) (34 . |maxIndex|)
          (|List| |$|)))
        (QUOTE #(|maxIndex| 39 |insert| 44 |indices| 51 |index?| 56 |concat| 62))
        (QUOTE NIL)
        (CONS

```

```
(|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
 (QUOTE #())
 (CONS
  (QUOTE #())
  (|makeByteWordVec2| 23 (QUOTE (1 6 8 0 9 1 6 8 0 10 2 6 0 15 7
    16 2 6 0 0 0 17 3 6 0 0 0 8 20 1 6 15 0 22 1 0 8 0 23 1 0 8 0 23 3 0
    0 7 0 8 21 1 0 11 0 12 2 0 13 8 0 14 2 0 0 0 7 18 2 0 0 7 0 19))))))
(QUOTE |lookupComplete|)))
```

21.35 LSAGG.lsp BOOTSTRAP

LSAGG depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **LSAGG** category which we can write into the **MID** directory. We compile the lisp code and copy the **LSAGG.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— LSAGG.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |ListAggregate;CAT| (QUOTE NIL))

(SETQ |ListAggregate;AL| (QUOTE NIL))

(DEFUN |ListAggregate| (#1#:#:G87500)
 (LET (#2#:#:G87501)
  (COND
   ((SETQ #2# (|assoc| (|devalueate| #1#) |ListAggregate;AL|)) (CDR #2#))
   (T
    (SETQ |ListAggregate;AL|
     (|cons5|
      (CONS (|devalueate| #1#) (SETQ #2# (|ListAggregate;| #1#)))
      |ListAggregate;AL|))
     #2#))))

(DEFUN |ListAggregate;| (|t#1|)
 (PROG (#1#:#:G87499)
  (RETURN
   (PROG1
    (LETT #1#
     (|sublisV|
      (PAIR (QUOTE (|t#1|)) (LIST (|devalueate| |t#1|))))
```

```

(COND
  (|ListAggregate;CAT|)
  ((QUOTE T)
    (LETT |ListAggregate;CAT|
      (|Join|
        (|StreamAggregate| (QUOTE |t#1|))
        (|FiniteLinearAggregate| (QUOTE |t#1|))
        (|ExtensibleLinearAggregate| (QUOTE |t#1|))
        (|mkCategory|
          (QUOTE |domain|)
          (QUOTE (((|list| (|$| |t#1|)) T)))
          NIL
          (QUOTE NIL)
          NIL))
        . #2=(|ListAggregate|))))
    . #2#)
  (SETELT #1# 0 (LIST (QUOTE |ListAggregate|) (|devaluate| |t#1|))))))

```

21.36 LSAGG-.lsp BOOTSTRAP

LSAGG- depends on **LSAGG**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **LSAGG-** category which we can write into the **MID** directory. We compile the lisp code and copy the **LSAGG-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— LSAGG-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |LSAGG-;sort!;M2A;1| (|f| |l| |$|)
  (|LSAGG-;mergeSort| |f| |l| (SPADCALL |l| (QREFELT |$| 9)) |$|))

(DEFUN |LSAGG-;list;SA;2| (|x| |$|)
  (SPADCALL |x| (SPADCALL (QREFELT |$| 12)) (QREFELT |$| 13)))

(DEFUN |LSAGG-;reduce;MAS;3| (|f| |x| |$|)
  (COND
    ((SPADCALL |x| (QREFELT |$| 16))
      (|error| "reducing over an empty list needs the 3 argument form"))
    ((QUOTE T)
      (SPADCALL |f|
        (SPADCALL |x| (QREFELT |$| 17))
        (SPADCALL |x| (QREFELT |$| 18))

```

```

(QREFELT |$| 20))))))

(DEFUN |LSAGG-;merge;M3A;4| (|f| |p| |q| |$|)
  (SPADCALL |f|
    (SPADCALL |p| (QREFELT |$| 22))
    (SPADCALL |q| (QREFELT |$| 22))
    (QREFELT |$| 23)))

(DEFUN |LSAGG-;select!;M2A;5| (|f| |x| |$|)
  (PROG (|y| |z|)
    (RETURN
      (SEQ
        (SEQ G190
          (COND
            ((NULL
              (COND
                ((OR
                  (SPADCALL |x| (QREFELT |$| 16))
                  (SPADCALL (SPADCALL |x| (QREFELT |$| 18)) |f|))
                  (QUOTE NIL))
                ((QUOTE T) (QUOTE T))))
              (GO G191)))
          (SEQ
            (EXIT
              (LETT |x| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;select!;M2A;5|)))
            NIL
            (GO G190)
            G191
            (EXIT NIL))
          (EXIT
            (COND
              ((SPADCALL |x| (QREFELT |$| 16)) |x|)
              ((QUOTE T)
                (SEQ
                  (LETT |y| |x| |LSAGG-;select!;M2A;5|)
                  (LETT |z| (SPADCALL |y| (QREFELT |$| 17)) |LSAGG-;select!;M2A;5|)
                  (SEQ
                    G190
                    (COND
                      ((NULL
                        (COND
                          ((SPADCALL |z| (QREFELT |$| 16)) (QUOTE NIL))
                          ((QUOTE T) (QUOTE T))))
                        (GO G191)))
                    (SEQ
                      (EXIT
                        (COND
                          ((SPADCALL (SPADCALL |z| (QREFELT |$| 18)) |f|)
                            (SEQ
                              (LETT |y| |z| |LSAGG-;select!;M2A;5|)

```



```

        (EXIT
          (LETT |z|
            (SPADCALL |z| (QREFELT |$| 17))
            |LSAGG-;select!;M2A;5|))))
      ((QUOTE T)
        (SEQ
          (LETT |z| (SPADCALL |z| (QREFELT |$| 17)) |LSAGG-;select!;M2A;5|)
          (EXIT (SPADCALL |y| |z| (QREFELT |$| 25)))))))
    NIL
    (GO G190)
  G191
  (EXIT NIL))
(EXIT |x|)))))))))

(DEFUN |LSAGG-;merge!;M3A;6| (|f| |p| |q| |$|)
  (PROG (|r| |t|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |p| (QREFELT |$| 16)) |q|)
          ((SPADCALL |q| (QREFELT |$| 16)) |p|)
          ((SPADCALL |p| |q| (QREFELT |$| 28))
            (|error| "cannot merge a list into itself"))
          ((QUOTE T)
            (SEQ
              (COND
                ((SPADCALL
                  (SPADCALL |p| (QREFELT |$| 18))
                  (SPADCALL |q| (QREFELT |$| 18))
                  |f|)
                  (SEQ
                    (LETT |r| (LETT |t| |p| |LSAGG-;merge!;M3A;6|) |LSAGG-;merge!;M3A;6|)
                    (EXIT
                      (LETT |p| (SPADCALL |p| (QREFELT |$| 17)) |LSAGG-;merge!;M3A;6|))))
                  ((QUOTE T)
                    (SEQ
                      (LETT |r| (LETT |t| |q| |LSAGG-;merge!;M3A;6|) |LSAGG-;merge!;M3A;6|)
                      (EXIT
                        (LETT |q| (SPADCALL |q| (QREFELT |$| 17)) |LSAGG-;merge!;M3A;6|))))
                    (SEQ
                      G190
                      (COND
                        ((NULL
                          (COND
                            ((OR
                              (SPADCALL |p| (QREFELT |$| 16))
                              (SPADCALL |q| (QREFELT |$| 16))
                              (QUOTE NIL))
                              ((QUOTE T) (QUOTE T))))
                          (GO G191)))

```

```

(SEQ
  (EXIT
    (COND
      ((SPADCALL
        (SPADCALL |p| (QREFELT |$| 18))
        (SPADCALL |q| (QREFELT |$| 18))
        |f|)
      (SEQ
        (SPADCALL |t| |p| (QREFELT |$| 25))
        (LETT |t| |p| |LSAGG-;merge!;M3A;6|)
        (EXIT
          (LETT |p|
            (SPADCALL |p| (QREFELT |$| 17))
            |LSAGG-;merge!;M3A;6|))))
      ((QUOTE T)
        (SEQ
          (SPADCALL |t| |q| (QREFELT |$| 25))
          (LETT |t| |q| |LSAGG-;merge!;M3A;6|)
          (EXIT
            (LETT |q|
              (SPADCALL |q| (QREFELT |$| 17))
              |LSAGG-;merge!;M3A;6|)))))))
    NIL
    (GO G190)
    G191
    (EXIT NIL))
  (SPADCALL |t|
    (COND
      ((SPADCALL |p| (QREFELT |$| 16)) |q|)
      ((QUOTE T) |p|))
    (QREFELT |$| 25))
  (EXIT |r|))))))

(DEFUN |LSAGG-;insert!;SAIA;7| (|s| |x| |i| |$|)
  (PROG (|m| #1=#:G87547 |y| |z|)
    (RETURN
      (SEQ
        (LETT |m| (SPADCALL |x| (QREFELT |$| 31)) |LSAGG-;insert!;SAIA;7|)
        (EXIT
          (COND
            ((|<| |i| |m|) (|error| "index out of range"))
            ((EQL |i| |m|) (SPADCALL |s| |x| (QREFELT |$| 13)))
            ((QUOTE T)
              (SEQ
                (LETT |y|
                  (SPADCALL |x|
                    (PROG1
                      (LETT #1# (|<| (|<| |i| 1) |m|) |LSAGG-;insert!;SAIA;7|)
                      (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                    (QREFELT |$| 32))

```

```

      |LSAGG-;insert!;SAIA;7|)
    (LETT |z| (SPADCALL |y| (QREFELT |$| 17)) |LSAGG-;insert!;SAIA;7|)
    (SPADCALL |y| (SPADCALL |s| |z| (QREFELT |$| 13)) (QREFELT |$| 25))
    (EXIT |x|)))))))))

(DEFUN |LSAGG-;insert!;2AIA;8| (|w| |x| |i| |$|)
  (PROG (|m| #1=#:G87551 |y| |z|)
    (RETURN
      (SEQ
        (LETT |m| (SPADCALL |x| (QREFELT |$| 31)) |LSAGG-;insert!;2AIA;8|)
        (EXIT
          (COND
            ((|<| |i| |m|) (|error| "index out of range"))
            ((EQL |i| |m|) (SPADCALL |w| |x| (QREFELT |$| 34)))
            ((QUOTE T)
              (SEQ
                (LETT |y|
                  (SPADCALL |x|
                    (PROG1
                      (LETT #1# (|-| (|-| |i| 1) |m|) |LSAGG-;insert!;2AIA;8|)
                      (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                    (QREFELT |$| 32))
                  |LSAGG-;insert!;2AIA;8|)
                (LETT |z| (SPADCALL |y| (QREFELT |$| 17)) |LSAGG-;insert!;2AIA;8|)
                (SPADCALL |y| |w| (QREFELT |$| 25))
                (SPADCALL |y| |z| (QREFELT |$| 34))
                (EXIT |x|)))))))))

(DEFUN |LSAGG-;remove!;M2A;9| (|f| |x| |$|)
  (PROG (|p| |q|)
    (RETURN
      (SEQ
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((SPADCALL |x| (QREFELT |$| 16)) (QUOTE NIL))
                ((QUOTE T) (SPADCALL (SPADCALL |x| (QREFELT |$| 18)) |f|))))
            (GO G191)))
          (SEQ
            (EXIT
              (LETT |x| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;remove!;M2A;9|)))
            NIL
            (GO G190)
            G191
            (EXIT NIL)))
        (EXIT
          (COND
            ((SPADCALL |x| (QREFELT |$| 16)) |x|)

```

```

((QUOTE T)
 (SEQ
  (LETT |p| |x| |LSAGG-;remove!;M2A;9|)
  (LETT |q| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;remove!;M2A;9|)
  (SEQ
   G190
   (COND
    (NULL
     (COND
      ((SPADCALL |q| (QREFELT |$| 16)) (QUOTE NIL))
      ((QUOTE T) (QUOTE T))))
     (GO G191)))
  (SEQ
   (EXIT
    (COND
     ((SPADCALL (SPADCALL |q| (QREFELT |$| 18)) |f|)
      (LETT |q|
       (SPADCALL |p| (SPADCALL |q| (QREFELT |$| 17)) (QREFELT |$| 25))
       |LSAGG-;remove!;M2A;9|))
     ((QUOTE T)
      (SEQ
       (LETT |p| |q| |LSAGG-;remove!;M2A;9|)
       (EXIT
        (LETT |q|
         (SPADCALL |q| (QREFELT |$| 17))
         |LSAGG-;remove!;M2A;9|)))))))
  NIL
  (GO G190)
  G191
  (EXIT NIL))
 (EXIT |x|)))))))))

(DEFUN |LSAGG-;delete!;AIA;10| (|x| |i| |$|)
 (PROG (|m| #1=#:G87564 |y|)
 (RETURN
  (SEQ
   (LETT |m| (SPADCALL |x| (QREFELT |$| 31)) |LSAGG-;delete!;AIA;10|)
   (EXIT
    (COND
     ((|<| |i| |m|) (|error| "index out of range"))
     ((EQL |i| |m|) (SPADCALL |x| (QREFELT |$| 17)))
     ((QUOTE T)
      (SEQ
       (LETT |y|
        (SPADCALL |x|
         (PROG1
          (LETT #1# (|_| (|_| |i| 1) |m|) |LSAGG-;delete!;AIA;10|)
          (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
         (QREFELT |$| 32))
        |LSAGG-;delete!;AIA;10|)

```

```

      (SPADCALL |y| (SPADCALL |y| 2 (QREFELT |$| 32)) (QREFELT |$| 25))
      (EXIT |x|)))))))))

(DEFUN |LSAGG-;delete!;AUsA;11| (|x| |i| |$|)
  (PROG (|l| |m| |h| #1=#:G87569 #2=#:G87570 |t| #3=#:G87571)
    (RETURN
      (SEQ
        (LETT |l| (SPADCALL |i| (QREFELT |$| 39)) |LSAGG-;delete!;AUsA;11|)
        (LETT |m| (SPADCALL |x| (QREFELT |$| 31)) |LSAGG-;delete!;AUsA;11|)
        (EXIT
          (COND
            ((|<| |l| |m|) (|error| "index out of range"))
            ((QUOTE T)
              (SEQ
                (LETT |h|
                  (COND
                    ((SPADCALL |i| (QREFELT |$| 40)) (SPADCALL |i| (QREFELT |$| 41)))
                    ((QUOTE T) (SPADCALL |x| (QREFELT |$| 42))))
                  |LSAGG-;delete!;AUsA;11|)
                (EXIT
                  (COND
                    ((|<| |h| |l|) |x|)
                    ((EQL |l| |m|)
                     (SPADCALL |x|
                       (PROG1
                         (LETT #1# (|-| (|-| |h| 1) |m|) |LSAGG-;delete!;AUsA;11|)
                         (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                         (QREFELT |$| 32)))
                       ((QUOTE T)
                         (SEQ
                           (LETT |t|
                             (SPADCALL |x|
                               (PROG1
                                 (LETT #2# (|-| (|-| |l| 1) |m|) |LSAGG-;delete!;AUsA;11|)
                                 (|check-subtype| (|>=| #2# 0)
                                   (QUOTE (|NonNegativeInteger|)) #2#))
                                 (QREFELT |$| 32))
                                 |LSAGG-;delete!;AUsA;11|)
                               (SPADCALL |t|
                                 (SPADCALL |t|
                                   (PROG1
                                     (LETT #3# (|+| (|-| |h| |l|) 2) |LSAGG-;delete!;AUsA;11|)
                                     (|check-subtype| (|>=| #3# 0)
                                       (QUOTE (|NonNegativeInteger|)) #3#))
                                     (QREFELT |$| 32))
                                     (QREFELT |$| 25))
                                     (EXIT |x|)))))))))
                               (EXIT |x|)))))))))

(DEFUN |LSAGG-;find;MAU;12| (|f| |x| |$|)
  (SEQ

```

```

(SEQ
  G190
  (COND
    ((NULL
      (COND
        ((OR
          (SPADCALL |x| (QREFELT |$| 16))
          (SPADCALL (SPADCALL |x| (QREFELT |$| 18)) |f|))
          (QUOTE NIL))
        ((QUOTE T) (QUOTE T))))
    (GO G191)))
  (SEQ (EXIT (LETT |x| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;find;MAU;12|)))
  NIL
  (GO G190)
  G191
  (EXIT NIL))
(EXIT
  (COND
    ((SPADCALL |x| (QREFELT |$| 16)) (CONS 1 "failed"))
    ((QUOTE T) (CONS 0 (SPADCALL |x| (QREFELT |$| 18)))))))

(DEFUN |LSAGG-;position;MAI;13| (|f| |x| |$|)
  (PROG (|k|)
    (RETURN
      (SEQ
        (SEQ
          (LETT |k| (SPADCALL |x| (QREFELT |$| 31)) |LSAGG-;position;MAI;13|)
          G190
          (COND
            ((NULL
              (COND
                ((OR
                  (SPADCALL |x| (QREFELT |$| 16))
                  (SPADCALL (SPADCALL |x| (QREFELT |$| 18)) |f|))
                  (QUOTE NIL))
                ((QUOTE T) (QUOTE T))))
              (GO G191)))
            (SEQ
              (EXIT
                (LETT |x| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;position;MAI;13|)))
              (LETT |k| (|+| |k| 1) |LSAGG-;position;MAI;13|)
              (GO G190)
              G191
              (EXIT NIL))
            (EXIT
              (COND
                ((SPADCALL |x| (QREFELT |$| 16)) (|-| (SPADCALL |x| (QREFELT |$| 31)) 1))
                ((QUOTE T) |k|)))))))

(DEFUN |LSAGG-;mergeSort| (|f| |p| |n| |$|)

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```

(PROG (#1=:G87593 |l| |q|)
  (RETURN
    (SEQ
      (COND
        ((EQL |n| 2)
          (COND
            ((SPADCALL
              (SPADCALL (SPADCALL |p| (QREFELT |$| 17)) (QREFELT |$| 18))
              (SPADCALL |p| (QREFELT |$| 18)) |f|)
              (LETT |p| (SPADCALL |p| (QREFELT |$| 47)) |LSAGG-;mergeSort|))))))
      (EXIT
        (COND
          ((|<| |n| 3) |p|)
          ((QUOTE T)
            (SEQ
              (LETT |l|
                (PROG1
                  (LETT #1# (QUOTIENT2 |n| 2) |LSAGG-;mergeSort|)
                  (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                  |LSAGG-;mergeSort|)
                (LETT |q| (SPADCALL |p| |l| (QREFELT |$| 48)) |LSAGG-;mergeSort|)
                (LETT |p| (|LSAGG-;mergeSort| |f| |p| |l| |$|) |LSAGG-;mergeSort|)
                (LETT |q|
                  (|LSAGG-;mergeSort| |f| |q| (|-| |n| |l|) |$|)
                  |LSAGG-;mergeSort|)
                (EXIT (SPADCALL |f| |p| |q| (QREFELT |$| 23))))))))))

(DEFUN |LSAGG-;sorted?;MAB;15| (|f| |l| |$|)
  (PROG (#1=:G87603 |p|)
    (RETURN
      (SEQ
        (EXIT
          (COND
            ((SPADCALL |l| (QREFELT |$| 16)) (QUOTE T))
            ((QUOTE T)
              (SEQ
                (LETT |p| (SPADCALL |l| (QREFELT |$| 17)) |LSAGG-;sorted?;MAB;15|)
                (SEQ
                  G190
                  (COND
                    ((NULL
                      (COND
                        ((SPADCALL |p| (QREFELT |$| 16)) (QUOTE NIL))
                        ((QUOTE T) (QUOTE T))))
                    (GO G191)))
                  (SEQ
                    (EXIT
                      (COND
                        ((NULL
                          (SPADCALL

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        (SPADCALL |l| (QREFELT |$| 18))
        (SPADCALL |p| (QREFELT |$| 18))
        |f|))
    (PROGN (LETT #1# (QUOTE NIL) |LSAGG-;sorted?;MAB;15|) (GO #1#)))
((QUOTE T)
 (LETT |p|
  (SPADCALL
   (LETT |l| |p| |LSAGG-;sorted?;MAB;15|)
   (QREFELT |$| 17))
  |LSAGG-;sorted?;MAB;15|))))))
NIL
(GO G190)
G191
(EXIT NIL))
(EXIT (QUOTE T))))))
#1#
(EXIT #1#))))))

(DEFUN |LSAGG-;reduce;MA2S;16| (|f| |x| |i| |$|)
 (PROG (|r|)
  (RETURN
   (SEQ
    (LETT |r| |i| |LSAGG-;reduce;MA2S;16|)
    (SEQ
     G190
     (COND
      ((NULL
       (COND
        ((SPADCALL |x| (QREFELT |$| 16)) (QUOTE NIL))
        ((QUOTE T) (QUOTE T))))
       (GO G191)))
     (SEQ
      (LETT |r|
       (SPADCALL |r| (SPADCALL |x| (QREFELT |$| 18)) |f|)
       |LSAGG-;reduce;MA2S;16|)
      (EXIT
       (LETT |x| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;reduce;MA2S;16|)))
      NIL
      (GO G190)
      G191
      (EXIT NIL))
      (EXIT |r|))))))

(DEFUN |LSAGG-;reduce;MA3S;17| (|f| |x| |i| |a| |$|)
 (PROG (|r|)
  (RETURN
   (SEQ
    (LETT |r| |i| |LSAGG-;reduce;MA3S;17|)
    (SEQ
     G190
```



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(COND
  ((NULL
    (COND
      ((OR
        (SPADCALL |x| (QREFELT |$| 16))
        (SPADCALL |r| |a| (QREFELT |$| 51)))
      (QUOTE NIL))
    ((QUOTE T) (QUOTE T)))) (GO G191)))
(SEQ
  (LETT |r|
    (SPADCALL |r| (SPADCALL |x| (QREFELT |$| 18)) |f|)
    |LSAGG-;reduce;MA3S;17|)
  (EXIT
    (LETT |x| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;reduce;MA3S;17|)))
NIL
(GO G190)
G191
(EXIT NIL))
(EXIT |r|))))))

(DEFUN |LSAGG-;new;NniSA;18| (|n| |s| |$|)
  (PROG (|k| |l|)
    (RETURN
      (SEQ
        (LETT |l| (SPADCALL (QREFELT |$| 12)) |LSAGG-;new;NniSA;18|)
        (SEQ
          (LETT |k| 1 |LSAGG-;new;NniSA;18|)
          G190
          (COND ((QSGREATERP |k| |n|) (GO G191)))
          (SEQ
            (EXIT
              (LETT |l| (SPADCALL |s| |l| (QREFELT |$| 13)) |LSAGG-;new;NniSA;18|)))
            (LETT |k| (QSADD1 |k|) |LSAGG-;new;NniSA;18|)
            (GO G190)
            G191
            (EXIT NIL))
            (EXIT |l|))))))

(DEFUN |LSAGG-;map;M3A;19| (|f| |x| |y| |$|)
  (PROG (|z|)
    (RETURN
      (SEQ
        (LETT |z| (SPADCALL (QREFELT |$| 12)) |LSAGG-;map;M3A;19|)
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((OR (SPADCALL |x| (QREFELT |$| 16)) (SPADCALL |y| (QREFELT |$| 16)))
                (QUOTE NIL))

```

```

      ((QUOTE T) (QUOTE T)))
    (GO G191))
  (SEQ
    (LETT |z|
      (SPADCALL
        (SPADCALL
          (SPADCALL |x| (QREFELT |$| 18))
          (SPADCALL |y| (QREFELT |$| 18))
          |f|)
        |z|
        (QREFELT |$| 13))
      |LSAGG-;map;M3A;19|)
    (LETT |x| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;map;M3A;19|)
    (EXIT (LETT |y| (SPADCALL |y| (QREFELT |$| 17)) |LSAGG-;map;M3A;19|)))
  NIL
  (GO G190)
  G191
  (EXIT NIL))
(EXIT (SPADCALL |z| (QREFELT |$| 47)))))

(DEFUN |LSAGG-;reverse!;2A;20| (|x| |$|)
  (PROG (|z| |y|)
    (RETURN
      (SEQ
        (COND
          ((OR
            (SPADCALL |x| (QREFELT |$| 16))
            (SPADCALL
              (LETT |y| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;reverse!;2A;20|)
              (QREFELT |$| 16)))
            |x|)
          ((QUOTE T)
            (SEQ
              (SPADCALL |x| (SPADCALL (QREFELT |$| 12)) (QREFELT |$| 25))
              (SEQ
                G190
                (COND
                  ((NULL
                    (COND
                      ((SPADCALL |y| (QREFELT |$| 16)) (QUOTE NIL))
                      ((QUOTE T) (QUOTE T)))))
                  (GO G191)))
              (SEQ
                (LETT |z| (SPADCALL |y| (QREFELT |$| 17)) |LSAGG-;reverse!;2A;20|)
                (SPADCALL |y| |x| (QREFELT |$| 25))
                (LETT |x| |y| |LSAGG-;reverse!;2A;20|)
                (EXIT (LETT |y| |z| |LSAGG-;reverse!;2A;20|)))
                NIL
                (GO G190)
                G191

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        (EXIT NIL))
      (EXIT |x|)))))))))

(DEFUN |LSAGG-;copy;2A;21| (|x| |$|)
  (PROG (|k| |y|)
    (RETURN
      (SEQ
        (LETT |y| (SPADCALL (QREFELT |$| 12)) |LSAGG-;copy;2A;21|)
        (SEQ
          (LETT |k| 0 |LSAGG-;copy;2A;21|)
          G190
          (COND
            ((NULL
              (COND
                ((SPADCALL |x| (QREFELT |$| 16)) (QUOTE NIL))
                ((QUOTE T) (QUOTE T))))
              (GO G191)))
          (SEQ
            (COND
              ((EQL |k| 1000)
                (COND
                  ((SPADCALL |x| (QREFELT |$| 56)) (EXIT (|error| "cyclic list"))))))
            (LETT |y|
              (SPADCALL (SPADCALL |x| (QREFELT |$| 18)) |y| (QREFELT |$| 13))
              |LSAGG-;copy;2A;21|)
            (EXIT (LETT |x| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;copy;2A;21|)))
            (LETT |k| (QSADD1 |k|) |LSAGG-;copy;2A;21|)
            (GO G190)
            G191
            (EXIT NIL))
            (EXIT (SPADCALL |y| (QREFELT |$| 47)))))))))

(DEFUN |LSAGG-;copyInto!;2AIA;22| (|y| |x| |s| |$|)
  (PROG (|m| #1=#:G87636 |z|)
    (RETURN
      (SEQ
        (LETT |m| (SPADCALL |y| (QREFELT |$| 31)) |LSAGG-;copyInto!;2AIA;22|)
        (EXIT
          (COND
            ((|<| |s| |m|) (|error| "index out of range"))
            ((QUOTE T)
              (SEQ
                (LETT |z|
                  (SPADCALL |y|
                    (PROG1
                      (LETT #1# (| - | |s| |m|) |LSAGG-;copyInto!;2AIA;22|)
                      (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                      (QREFELT |$| 32))
                  |LSAGG-;copyInto!;2AIA;22|)
                (SEQ

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G190
(COND
  (NULL
    (COND
      ((OR
        (SPADCALL |z| (QREFELT |$| 16))
        (SPADCALL |x| (QREFELT |$| 16)))
      (QUOTE NIL))
    ((QUOTE T) (QUOTE T))))
  (GO G191)))
(SEQ
  (SPADCALL |z| (SPADCALL |x| (QREFELT |$| 18)) (QREFELT |$| 58))
  (LETT |x| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;copyInto!;2AIA;22|)
  (EXIT
    (LETT |z|
      (SPADCALL |z| (QREFELT |$| 17))
      |LSAGG-;copyInto!;2AIA;22|)))
  NIL
  (GO G190)
  G191
  (EXIT NIL))
(EXIT |y|)))))))))

(DEFUN |LSAGG-;position;SA2I;23| (|w| |x| |s| |$|)
  (PROG (|m| #1=#:G87644 |k|)
    (RETURN
      (SEQ
        (LETT |m| (SPADCALL |x| (QREFELT |$| 31)) |LSAGG-;position;SA2I;23|)
        (EXIT
          (COND
            ((|<| |s| |m|) (|error| "index out of range"))
            ((QUOTE T)
              (SEQ
                (LETT |x|
                  (SPADCALL |x|
                    (PROG1
                      (LETT #1# (|<| |s| |m|) |LSAGG-;position;SA2I;23|)
                      (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                    (QREFELT |$| 32))
                  |LSAGG-;position;SA2I;23|)
                (SEQ
                  (LETT |k| |s| |LSAGG-;position;SA2I;23|)
                  G190
                  (COND
                    (NULL
                      (COND
                        ((OR
                          (SPADCALL |x| (QREFELT |$| 16))
                          (SPADCALL |w| (SPADCALL |x| (QREFELT |$| 18)) (QREFELT |$| 51)))
                        (QUOTE NIL))

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```

      ((QUOTE T) (QUOTE T)))
      (GO G191)))
    (SEQ
      (EXIT
        (LETT |x|
          (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;position;SA2I;23|)))
      (LETT |k| (|+| |k| 1) |LSAGG-;position;SA2I;23|)
      (GO G190)
      G191
      (EXIT NIL))
    (EXIT
      (COND
        ((SPADCALL |x| (QREFELT |$| 16))
          (|-| (SPADCALL |x| (QREFELT |$| 31)) 1))
        ((QUOTE T) |k|)))))))))

(DEFUN |LSAGG-;removeDuplicates!;2A;24| (|l| |$|)
  (PROG (|p|)
    (RETURN
      (SEQ
        (LETT |p| |l| |LSAGG-;removeDuplicates!;2A;24|)
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((SPADCALL |p| (QREFELT |$| 16)) (QUOTE NIL))
                ((QUOTE T) (QUOTE T))))
              (GO G191)))
            (SEQ
              (EXIT
                (LETT |p|
                  (SPADCALL |p|
                    (SPADCALL
                      (CONS
                        (FUNCTION |LSAGG-;removeDuplicates!;2A;24!0|)
                        (VECTOR |$| |p|))
                        (SPADCALL |p| (QREFELT |$| 17))
                        (QREFELT |$| 61))
                        (QREFELT |$| 25))
                      |LSAGG-;removeDuplicates!;2A;24|)))
                  NIL
                  (GO G190)
                  G191
                  (EXIT NIL))
                (EXIT |l|))))))
          (EXIT |l|))))))

(DEFUN |LSAGG-;removeDuplicates!;2A;24!0| (|#1| |$$|)
  (PROG (|$$|)
    (LETT |$| (QREFELT |$$| 0) |LSAGG-;removeDuplicates!;2A;24|)

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```

(RETURN
 (PROGN
  (SPADCALL |#1|
   (SPADCALL (QREFELT |$$| 1) (QREFELT |$| 18))
   (QREFELT |$| 51))))))

(DEFUN |LSAGG-;<;2AB;25| (|x| |y| |$|)
 (PROG (#1=#:G87662)
  (RETURN
   (SEQ
    (EXIT
     (SEQ
      (SEQ
       G190
       (COND
        ((NULL
         (COND
          ((OR
           (SPADCALL |x| (QREFELT |$| 16))
           (SPADCALL |y| (QREFELT |$| 16)))
          (QUOTE NIL)))
         ((QUOTE T) (QUOTE T))))
       (GO G191)))
    (SEQ
     (EXIT
      (COND
       ((NULL
        (SPADCALL
         (SPADCALL |x| (QREFELT |$| 18))
         (SPADCALL |y| (QREFELT |$| 18))
         (QREFELT |$| 51)))
        (PROGN
         (LETT #1#
          (SPADCALL
           (SPADCALL |x| (QREFELT |$| 18))
           (SPADCALL |y| (QREFELT |$| 18))
           (QREFELT |$| 63))
          |LSAGG-;<;2AB;25|)
          (GO #1#)))
         ((QUOTE T)
          (SEQ
           (LETT |x| (SPADCALL |x| (QREFELT |$| 17)) |LSAGG-;<;2AB;25|)
           (EXIT
            (LETT |y| (SPADCALL |y| (QREFELT |$| 17)) |LSAGG-;<;2AB;25|))))))
        NIL
        (GO G190)
        G191
        (EXIT NIL))
     (EXIT
      (COND

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      ((SPADCALL |x| (QREFELT |$| 16))
       (COND
        ((SPADCALL |y| (QREFELT |$| 16)) (QUOTE NIL))
        ((QUOTE T) (QUOTE T))))
      ((QUOTE T) (QUOTE NIL))))))
#1#
(EXIT #1#))))

(DEFUN |ListAggregate&| (|#1| |#2|)
  (PROG (|DV$1| |DV$2| |dv$| |$| |pv$|)
    (RETURN
     (PROGN
      (LETT |DV$1| (|devaluate| |#1|) . #1=(|ListAggregate&|))
      (LETT |DV$2| (|devaluate| |#2|) . #1#)
      (LETT |dv$| (LIST (QUOTE |ListAggregate&|) |DV$1| |DV$2|) . #1#)
      (LETT |$| (make-array 66) . #1#)
      (QSETREFV |$| 0 |dv$|)
      (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
      (|stuffDomainSlots| |$|)
      (QSETREFV |$| 6 |#1|)
      (QSETREFV |$| 7 |#2|)
      (COND
       ((|HasCategory| |#2| (QUOTE (|SetCategory|)))
        (QSETREFV |$| 52
         (CONS (|dispatchFunction| |LSAGG-;reduce;MA3S;17|) |$|))))
      (COND
       ((|HasCategory| |#2| (QUOTE (|SetCategory|)))
        (PROGN
         (QSETREFV |$| 60
          (CONS (|dispatchFunction| |LSAGG-;position;SA2I;23|) |$|))
         (QSETREFV |$| 62
          (CONS (|dispatchFunction| |LSAGG-;removeDuplicates!;2A;24|) |$|))))))
      (COND
       ((|HasCategory| |#2| (QUOTE (|OrderedSet|)))
        (QSETREFV |$| 64 (CONS (|dispatchFunction| |LSAGG-;<;2AB;25|) |$|))))
      |$|))))

(setf (get
  (QUOTE |ListAggregate&|)
  (QUOTE |infovec|))
  (LIST
   (QUOTE #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|)
    (|NonNegativeInteger|) (0 . |#|) (|Mapping| 15 7 7) |LSAGG-;sort!;M2A;1|
    (5 . |empty|) (9 . |concat|) |LSAGG-;list;SA;2| (|Boolean|)
    (15 . |empty?|) (20 . |rest|) (25 . |first|) (|Mapping| 7 7 7)
    (30 . |reduce|) |LSAGG-;reduce;MAS;3| (37 . |copy|) (42 . |merge!|)
    |LSAGG-;merge;M3A;4| (49 . |setrest!|) (|Mapping| 15 7)
    |LSAGG-;select!;M2A;5| (55 . |eq?|) |LSAGG-;merge!;M3A;6|
    (|Integer|) (61 . |minIndex|) (66 . |rest|) |LSAGG-;insert!;SAIA;7|
    (72 . |concat!|) |LSAGG-;insert!;2AIA;8| |LSAGG-;remove!;M2A;9|

```

```

|LSAGG-;delete!;AIA;10| (|UniversalSegment| 30) (78 . |lo|)
(83 . |hasHi|) (88 . |hi|) (93 . |maxIndex|) |LSAGG-;delete!;AUsA;11|
(|Union| 7 (QUOTE "failed")) |LSAGG-;find;MAU;12|
|LSAGG-;position;MAI;13| (98 . |reverse!|) (103 . |split!|)
|LSAGG-;sorted?;MAB;15| |LSAGG-;reduce;MA2S;16| (109 . |=|)
(115 . |reduce|) |LSAGG-;new;NniSA;18| |LSAGG-;map;M3A;19|
|LSAGG-;reverse!;2A;20| (123 . |cyclic?|) |LSAGG-;copy;2A;21|
(128 . |setfirst!|) |LSAGG-;copyInto!;2AIA;22| (134 . |position|)
(141 . |remove!|) (147 . |removeDuplicates!|) (152 . |<|) (158 . |<|)
(|Mapping| 7 7)))
(QUOTE #(|sorted?| 164 |sort!| 170 |select!| 176 |reverse!| 182
|removeDuplicates!| 187 |remove!| 192 |reduce| 198 |position| 219
|new| 232 |merge!| 238 |merge| 245 |map| 252 |list| 259 |insert!|
264 |find| 278 |delete!| 284 |copyInto!| 296 |copy| 303 |<| 308))
(QUOTE NIL)
(CONS
(|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
(QUOTE #())
(CONS
(QUOTE #())
(|makeByteWordVec2| 64 (QUOTE (1 6 8 0 9 0 6 0 12 2 6 0 7 0 13 1 6
15 0 16 1 6 0 0 17 1 6 7 0 18 3 6 7 19 0 7 20 1 6 0 0 22 3 6 0 10
0 0 23 2 6 0 0 0 25 2 6 15 0 0 28 1 6 30 0 31 2 6 0 0 8 32 2 6 0 0
0 34 1 38 30 0 39 1 38 15 0 40 1 38 30 0 41 1 6 30 0 42 1 6 0 0 47
2 6 0 0 30 48 2 7 15 0 0 51 4 0 7 19 0 7 7 52 1 6 15 0 56 2 6 7 0
7 58 3 0 30 7 0 30 60 2 6 0 26 0 61 1 0 0 0 62 2 7 15 0 0 63 2 0 15
0 0 64 2 0 15 10 0 49 2 0 0 10 0 11 2 0 0 26 0 27 1 0 0 0 55 1 0 0
0 62 2 0 0 26 0 36 3 0 7 19 0 7 50 4 0 7 19 0 7 7 52 2 0 7 19 0 21
2 0 30 26 0 46 3 0 30 7 0 30 60 2 0 0 8 7 53 3 0 0 10 0 0 29 3 0 0
10 0 0 24 3 0 0 19 0 0 54 1 0 0 7 14 3 0 0 7 0 30 33 3 0 0 0 0 30
35 2 0 44 26 0 45 2 0 0 0 38 43 2 0 0 0 30 37 3 0 0 0 0 30 59 1 0
0 0 57 2 0 15 0 0 64))))))
(QUOTE |lookupComplete|)))

```

21.37 MONOID.lsp BOOTSTRAP

MONOID depends on itself. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **MONOID** category which we can write into the **MID** directory. We compile the lisp code and copy the **MONOID.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.


```

(|/VERSIONCHECK| 2)

(SETQ |Monoid;AL| (QUOTE NIL))

(DEFUN |Monoid| NIL
  (LET (#:G82434)
    (COND
      (|Monoid;AL|)
      (T (SETQ |Monoid;AL| (|Monoid;|))))))

(DEFUN |Monoid;| NIL
  (PROG (#1= #:G82432)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|SemiGroup|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE (
                ((|One| (|$|) |constant|) T)
                ((|sample| (|$|) |constant|) T)
                ((|one?| ((|Boolean|) |$|)) T)
                ((|**| (|$| |$| (|NonNegativeInteger|))) T)
                ((|^| (|$| |$| (|NonNegativeInteger|))) T)
                ((|recip| ((|Union| |$| "failed") |$|)) T)))
              NIL
              (QUOTE ((|NonNegativeInteger|) (|Boolean|)))
              NIL))
          |Monoid|)
        (SETELT #1# 0 (QUOTE (|Monoid|)))))))

(setf (get (QUOTE |Monoid|) (QUOTE NILADIC)) T)

```

21.38 MONOID-.lsp BOOTSTRAP

MONOID- depends on **MONOID**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **MONOID-** category which we can write into the **MID** directory. We compile the lisp code and copy the **MONOID-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— MONOID-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |MONOID-;^;SNniS;1| (|x| |n| |$|)
  (SPADCALL |x| |n| (QREFELT |$| 8)))

(DEFUN |MONOID-;one?;SB;2| (|x| |$|)
  (SPADCALL |x| (|spadConstant| |$| 10) (QREFELT |$| 12)))

(DEFUN |MONOID-;sample;S;3| (|x|)
  (|spadConstant| |$| 10))

(DEFUN |MONOID-;recip;SU;4| (|x| |$|)
  (COND
    ((SPADCALL |x| (QREFELT |$| 15)) (CONS 0 |x|))
    ((QUOTE T) (CONS 1 "failed"))))

(DEFUN |MONOID-;**;SNniS;5| (|x| |n| |$|)
  (COND
    ((ZEROP |n|) (|spadConstant| |$| 10))
    ((QUOTE T) (SPADCALL |x| |n| (QREFELT |$| 20)))))

(DEFUN |Monoid&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|Monoid&|))
        (LETT |dv$| (LIST (QUOTE |Monoid&|) |DV$1|) . #1#)
        (LETT |$| (make-array 22) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        |$|))))

(setf (get
  (QUOTE |Monoid&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (|NonNegativeInteger|)
        (0 . |**|)
        |MONOID-;^;SNniS;1|
        (6 . |One|)
        (|Boolean|)
        (10 . |=|)
        |MONOID-;one?;SB;2|
        |MONOID-;sample;S;3|

```

```

(16 . |one?|)
(|Union| |$| (QUOTE "failed"))
|MONOID-; recip; SU; 4|
(|PositiveInteger|)
(|RepeatedSquaring| 6)
(21 . |expt|)
|MONOID-; **; SNniS; 5|))
(QUOTE #(|sample| 27 |recip| 31 |one?| 36 |^| 41 |**| 47))
(QUOTE NIL)
(CONS
  (|makeByteWordVec2| 1 (QUOTE NIL))
  (CONS
    (QUOTE #())
    (CONS
      (QUOTE #())
      (|makeByteWordVec2| 21
        (QUOTE
          (2 6 0 0 7 8 0 6 0 10 2 6 11 0 0 12 1 6 11 0 15 2 19 6 6 18 20
            0 0 0 14 1 0 16 0 17 1 0 11 0 13 2 0 0 0 7 9 2 0 0 0 7 21))))))
  (QUOTE |lookupComplete|)))

```

21.39 MTSCAT.lsp BOOTSTRAP

MTSCAT depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **MTSCAT** category which we can write into the **MID** directory. We compile the lisp code and copy the **MTSCAT.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— MTSCAT.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |MultivariateTaylorSeriesCategory;CAT| (QUOTE NIL))

(SETQ |MultivariateTaylorSeriesCategory;AL| (QUOTE NIL))

(DEFUN |MultivariateTaylorSeriesCategory|
  (|&REST| #1=#:G83334 |&AUX| #2=#:G83332)
  (DSETQ #2# #1#)
  (LET (#3=#:G83333)
    (COND
      ((SETQ #3#

```

```

(|assoc| (|devalueList| #2#) |MultivariateTaylorSeriesCategory;AL|))
(CDR #3#))
(T
 (SETQ |MultivariateTaylorSeriesCategory;AL|
  (|cons5|
   (CONS
    (|devalueList| #2#)
    (SETQ #3# (APPLY (FUNCTION |MultivariateTaylorSeriesCategory;|) #2#)))
    |MultivariateTaylorSeriesCategory;AL|))
  #3#)))

(DEFUN |MultivariateTaylorSeriesCategory;| (|t#1| |t#2|)
 (PROG (#1=#:G83331)
  (RETURN
   (PROG1
    (LETT #1#
     (|sublisV|
      (PAIR (QUOTE (|t#1| |t#2|)) (LIST (|devalue| |t#1|) (|devalue| |t#2|)))
      (|sublisV|
       (PAIR (QUOTE (#2=#:G83330)) (LIST (QUOTE (|IndexedExponents| |t#2|)))))
       (COND
        (|MultivariateTaylorSeriesCategory;CAT|)
        ((QUOTE T)
         (LETT |MultivariateTaylorSeriesCategory;CAT|
          (|Join|
           (|PartialDifferentialRing| (QUOTE |t#2|))
           (|PowerSeriesCategory| (QUOTE |t#1|) (QUOTE #2#) (QUOTE |t#2|))
           (|InnerEvalable| (QUOTE |t#2|) (QUOTE |$|))
           (|Evalable| (QUOTE |$|))
           (|mkCategory|
            (QUOTE |domain|)
            (QUOTE (
              ((|coefficient| (|$| |$| |t#2| (|NonNegativeInteger|))) T)
              ((|coefficient|
                (|$| |$| (|List| |t#2|) (|List| (|NonNegativeInteger|)))
                T)
              ((|extend| (|$| |$| (|NonNegativeInteger|))) T)
              ((|monomial| (|$| |$| |t#2| (|NonNegativeInteger|))) T)
              ((|monomial|
                (|$| |$| (|List| |t#2|) (|List| (|NonNegativeInteger|)))
                T)
              ((|order| ((|NonNegativeInteger|) |$| |t#2|)) T)
              ((|order|
                ((|NonNegativeInteger|) |$| |t#2| (|NonNegativeInteger|))
                T)
              ((|polynomial|
                ((|Polynomial| |t#1|) |$| (|NonNegativeInteger|))
                T)
              ((|polynomial|
                ((|Polynomial| |t#1|)

```

```

    |$|
    (|NonNegativeInteger|)
    (|NonNegativeInteger|)))
    T)
    ((|integrate| (|$| |$| |t#2|))
     (|has| |t#1| (|Algebra| (|Fraction| (|Integer|))))))
  (QUOTE (
    (|RadicalCategory|)
    (|has| |t#1| (|Algebra| (|Fraction| (|Integer|))))
    (|TranscendentalFunctionCategory|)
    (|has| |t#1| (|Algebra| (|Fraction| (|Integer|))))))
  (QUOTE
    (|Polynomial| |t#1|)
    (|NonNegativeInteger|)
    (|List| |t#2|)
    (|List| (|NonNegativeInteger|)))
    NIL))
  . #3=(|MultivariateTaylorSeriesCategory|))))
  . #3#)
(SETELT #1# 0
(LIST
  (QUOTE |MultivariateTaylorSeriesCategory|)
  (|devaluate| |t#1|)
  (|devaluate| |t#2|))))))

```

21.40 OINTDOM.lsp BOOTSTRAP

OINTDOM depends on itself. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **OINTDOM** category which we can write into the **MID** directory. We compile the lisp code and copy the **OINTDOM.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— OINTDOM.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |OrderedIntegralDomain;AL| (QUOTE NIL))

(DEFUN |OrderedIntegralDomain| NIL
  (LET (#:G84531)
    (COND
      (|OrderedIntegralDomain;AL|)
      (T (SETQ |OrderedIntegralDomain;AL| (|OrderedIntegralDomain;|))))))

```

```
(DEFUN |OrderedIntegralDomain;| NIL
  (PROG (#1=#:G84529)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join| (|IntegralDomain|) (|OrderedRing|)) |OrderedIntegralDomain|)
          (SETELT #1# 0 (QUOTE (|OrderedIntegralDomain|))))))

(setf (get (QUOTE |OrderedIntegralDomain|) (QUOTE NILADIC)) T)
```

21.41 ORDRING.lsp BOOTSTRAP

ORDRING depends on **INT**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ORDRING** category which we can write into the **MID** directory. We compile the lisp code and copy the **ORDRING.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Technically I can't justify this bootstrap stanza based on the lattice since **INT** is already bootstrapped. However using **INT** naked generates a "value stack overflow" error suggesting an infinite recursive loop. This code is here to experiment with breaking that loop.

Note that this code is not included in the generated catdef.spad file.

— ORDRING.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |OrderedRing;AL| (QUOTE NIL))

(DEFUN |OrderedRing| NIL
  (LET (#:G84457)
    (COND
      (|OrderedRing;AL|)
      (T (SETQ |OrderedRing;AL| (|OrderedRing;|)))))

(DEFUN |OrderedRing;| NIL
  (PROG (#1=#:G84455)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|OrderedAbelianGroup|)
            (|Ring|))
```

```

(|Monoid|)
(|mkCategory|
  (QUOTE |domain|)
  (QUOTE (
    ((|positive?| ((|Boolean|) |$|)) T)
    ((|negative?| ((|Boolean|) |$|)) T)
    ((|sign| ((|Integer|) |$|)) T)
    ((|abs| (|$| |$|)) T)))
  NIL
  (QUOTE ((|Integer|) (|Boolean|)))
  NIL))
|OrderedRing|)
(SETELT #1# 0 (QUOTE (|OrderedRing|))))))

(setf (get (QUOTE |OrderedRing|) (QUOTE NILADIC)) T)

```

21.42 ORDRING-.lsp BOOTSTRAP

ORDRING- depends on **ORDRING**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ORDRING-** category which we can write into the **MID** directory. We compile the lisp code and copy the **ORDRING-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ORDRING-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |ORDRING-;positive?;SB;1| (|x| |$|)
  (SPADCALL (|spadConstant| |$| 7) |x| (QREFELT |$| 9)))

(DEFUN |ORDRING-;negative?;SB;2| (|x| |$|)
  (SPADCALL |x| (|spadConstant| |$| 7) (QREFELT |$| 9)))

(DEFUN |ORDRING-;sign;SI;3| (|x| |$|)
  (COND
    ((SPADCALL |x| (QREFELT |$| 12)) 1)
    ((SPADCALL |x| (QREFELT |$| 13)) -1)
    ((SPADCALL |x| (QREFELT |$| 15)) 0)
    (QUOTE T)
    (|error| "x satisfies neither positive?, negative? or zero?"))))

(DEFUN |ORDRING-;abs;2S;4| (|x| |$|)

```

```

(COND
  ((SPADCALL |x| (QREFELT |$| 12)) |x|)
  ((SPADCALL |x| (QREFELT |$| 13)) (SPADCALL |x| (QREFELT |$| 18)))
  ((SPADCALL |x| (QREFELT |$| 15)) (|spadConstant| |$| 7))
  ((QUOTE T)
    (|error| "x satisfies neither positive?, negative? or zero?"))))

(DEFUN |OrderedRing&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|OrderedRing&|))
        (LETT |dv$| (LIST (QUOTE |OrderedRing&|) |DV$1|) . #1#)
        (LETT |$| (make-array 20) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        |$|))))

(setf (get
  (QUOTE |OrderedRing&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (0 . |Zero|)
        (|Boolean|)
        (4 . |<|)
        |ORDRING-;positive?;SB;1|
        |ORDRING-;negative?;SB;2|
        (10 . |positive?|)
        (15 . |negative?|)
        (20 . |One|)
        (24 . |zero?|)
        (|Integer|)
        |ORDRING-;sign;SI;3|
        (29 . |-|)
        |ORDRING-;abs;2S;4|))
      (QUOTE #(|sign| 34 |positive?| 39 |negative?| 44 |abs| 49))
      (QUOTE NIL)
      (CONS
        (|makeByteWordVec2| 1 (QUOTE NIL))
        (CONS
          (QUOTE #())
          (CONS
            (QUOTE #())
            (|makeByteWordVec2| 19
              (QUOTE

```



```

      (0 6 0 7 2 6 8 0 0 9 1 6 8 0 12 1 6 8 0 13 0 6 0 14 1 6 8 0 15
       1 6 0 0 18 1 0 16 0 17 1 0 8 0 10 1 0 8 0 11 1 0 0 0 19))))))
(QUOTE |lookupComplete|)))

```

21.43 POLYCAT.lsp BOOTSTRAP

POLYCAT depends on itself. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **POLYCAT** category which we can write into the **MID** directory. We compile the lisp code and copy the **POLYCAT.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— POLYCAT.lsp BOOTSTRAP —

```

(/VERSIONCHECK 2)

(SETQ |PolynomialCategory;CAT| (QUOTE NIL))

(SETQ |PolynomialCategory;AL| (QUOTE NIL))

(DEFUN |PolynomialCategory| (&REST #0=#:G1430 &AUX #1=#:G1428)
  (DSETQ #1# #0#)
  (LET (#2=#:G1429)
    (COND
      ((SETQ #2# (|assoc| (|devalueateList| #1#) |PolynomialCategory;AL|))
        (CDR #2#))
      (T
        (SETQ |PolynomialCategory;AL|
          (|cons5|
            (CONS (|devalueateList| #1#)
              (SETQ #2# (APPLY (FUNCTION |PolynomialCategory;|) #1#)))
            |PolynomialCategory;AL|)
          #2#))))))

(DEFUN |PolynomialCategory;| (|t#1| |t#2| |t#3|)
  (PROG (#0=#:G1427)
    (RETURN
      (PROG1
        (LETT #0#
          (|sublisV|
            (PAIR (QUOTE (|t#1| |t#2| |t#3|)) (LIST (|devalueate| |t#1|) (|devalueate| |t#2|) (|devalueate| |t#3|))
            (COND
              (|PolynomialCategory;CAT|)
              ((QUOTE T)

```

```

(LETT |PolynomialCategory;CAT|
  (|Join|
    (|PartialDifferentialRing| (QUOTE |t#3|))
    (|FiniteAbelianMonoidRing| (QUOTE |t#1|) (QUOTE |t#2|))
    (|Evalable| (QUOTE $))
    (|InnerEvalable| (QUOTE |t#3|) (QUOTE |t#1|))
    (|InnerEvalable| (QUOTE |t#3|) (QUOTE $))
    (|RetractableTo| (QUOTE |t#3|))
    (|FullyLinearlyExplicitRingOver| (QUOTE |t#1|))
    (|mkCategory| (QUOTE |domain|)
      (QUOTE
        (((|degree| ((|NonNegativeInteger|) $ |t#3|)) T)
          ((|degree| ((|List| (|NonNegativeInteger|)) $ (|List| |t#3|))) T)
          ((|coefficient| ($ $ |t#3| (|NonNegativeInteger|))) T)
          ((|coefficient| ($ $ (|List| |t#3|)
            (|List| (|NonNegativeInteger|)))) T)
          ((|monomials| ((|List| $) $)) T)
          ((|univariate| ((|SparseUnivariatePolynomial| $) $ |t#3|)) T)
          ((|univariate| ((|SparseUnivariatePolynomial| |t#1|) $)) T)
          ((|mainVariable| ((|Union| |t#3| "failed") $)) T)
          ((|minimumDegree| ((|NonNegativeInteger|) $ |t#3|)) T)
          ((|minimumDegree| ((|List| (|NonNegativeInteger|)) $
            (|List| |t#3|))) T)
          ((|monicDivide|
            ((|Record| (:| |quotient| $) (:| |remainder| $)) $ $ |t#3|))
            T)
          ((|monomial| ($ $ |t#3| (|NonNegativeInteger|))) T)
          ((|monomial| ($ $ (|List| |t#3|) (|List| (|NonNegativeInteger|)))
            T)
          ((|multivariate| ($ (|SparseUnivariatePolynomial| |t#1|) |t#3|))
            T)
          ((|multivariate| ($ (|SparseUnivariatePolynomial| $) |t#3|)) T)
          ((|isPlus| ((|Union| (|List| $) "failed") $)) T)
          ((|isTimes| ((|Union| (|List| $) "failed") $)) T)
          ((|isExpt|
            ((|Union|
              (|Record| (:| |var| |t#3|)
                (:| |exponent| (|NonNegativeInteger|)))
              "failed") $))
            T)
          ((|totalDegree| ((|NonNegativeInteger|) $)) T)
          ((|totalDegree| ((|NonNegativeInteger|) $ (|List| |t#3|))) T)
          ((|variables| ((|List| |t#3|) $)) T)
          ((|primitiveMonomials| ((|List| $) $)) T)
          ((|resultant| ($ $ $ |t#3|)) (|has| |t#1| (|CommutativeRing|)))
          ((|discriminant| ($ $ |t#3|)) (|has| |t#1| (|CommutativeRing|)))
          ((|content| ($ $ |t#3|)) (|has| |t#1| (|GcdDomain|)))
          ((|primitivePart| ($ $) (|has| |t#1| (|GcdDomain|)))
          ((|primitivePart| ($ $ |t#3|)) (|has| |t#1| (|GcdDomain|)))
          ((|squareFree| ((|Factored| $) $)) (|has| |t#1| (|GcdDomain|)))

```

```

(|squareFreePart| ($ $)) (|has| |t#1| (|GcdDomain|))))))
(QUOTE
  (((|OrderedSet|) (|has| |t#1| (|OrderedSet|))))
  (((|ConvertibleTo| (|InputForm|))
    (AND (|has| |t#3| (|ConvertibleTo| (|InputForm|)))
          (|has| |t#1| (|ConvertibleTo| (|InputForm|)))))
    (|ConvertibleTo| (|Pattern| (|Integer|)))
    (AND (|has| |t#3| (|ConvertibleTo| (|Pattern| (|Integer|))))
          (|has| |t#1| (|ConvertibleTo| (|Pattern| (|Integer|)))))
    (|ConvertibleTo| (|Pattern| (|Float|)))
    (AND (|has| |t#3| (|ConvertibleTo| (|Pattern| (|Float|))))
          (|has| |t#1| (|ConvertibleTo| (|Pattern| (|Float|)))))
    (|PatternMatchable| (|Integer|))
    (AND
      (|has| |t#3| (|PatternMatchable| (|Integer|)))
      (|has| |t#1| (|PatternMatchable| (|Integer|)))))
    (|PatternMatchable| (|Float|))
    (AND
      (|has| |t#3| (|PatternMatchable| (|Float|)))
      (|has| |t#1| (|PatternMatchable| (|Float|)))))
    (|GcdDomain|) (|has| |t#1| (|GcdDomain|)))
    (|canonicalUnitNormal|
      (|has| |t#1| (ATTRIBUTE |canonicalUnitNormal|)))
    (|PolynomialFactorizationExplicit|
      (|has| |t#1| (|PolynomialFactorizationExplicit|))))))
(QUOTE
  ((|Factored| $)
  (|List| $)
  (|List| |t#3|)
  (|NonNegativeInteger|)
  (|SparseUnivariatePolynomial| $)
  (|SparseUnivariatePolynomial| |t#1|)
  (|List| (|NonNegativeInteger|)))
  NIL))
. #1=(|PolynomialCategory|))))))
. #1#)
(SETELT #0# 0
  (LIST (QUOTE |PolynomialCategory|)
    (|devaluate| |t#1|) (|devaluate| |t#2|) (|devaluate| |t#3|))))))

```

21.44 POLYCAT-.lsp BOOTSTRAP

POLYCAT- depends on **POLYCAT**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **POLYCAT-** category which we can write into the **MID** directory. We compile the lisp code and copy the **POLYCAT-.o** file to the **OUT**

directory. This is eventually forcibly replaced by a recompiled version.
 Note that this code is not included in the generated catdef.spad file.

— POLYCAT-.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(/VERSIONCHECK 2)

(DEFUN |POLYCAT-;eval;SLS;1| (|p| |l| $)
  (PROG (#0=:G1444 #1=:G1438 #2=:G1445 #3=:G1446 |lvar| #4=:G1447
    |e| #5=:G1448)
    (RETURN
      (SEQ
        (COND
          ((NULL |l|) |p|)
          ((QUOTE T)
            (SEQ
              (SEQ
                (EXIT
                  (SEQ
                    (LETT |e| NIL |POLYCAT-;eval;SLS;1|)
                    (LETT #0# |l| |POLYCAT-;eval;SLS;1|)
                    G190
                    (COND
                      ((OR (ATOM #0#)
                        (PROGN (LETT |e| (CAR #0#) |POLYCAT-;eval;SLS;1|) NIL))
                      (GO G191)))
                  (SEQ
                    (EXIT
                      (COND
                        ((QEQCAR
                          (SPADCALL (SPADCALL |e| (QREFELT $ 11)) (QREFELT $ 13)) 1)
                          (PROGN
                            (LETT #1#
                              (|error| "cannot find a variable to evaluate")
                              |POLYCAT-;eval;SLS;1|)
                              (GO #1#))))))
                        (LETT #0# (CDR #0#) |POLYCAT-;eval;SLS;1|)
                        (GO G190)
                        G191
                        (EXIT NIL)))
                    #1# (EXIT #1#))
                  (LETT |lvar|
                    (PROGN
                      (LETT #2# NIL |POLYCAT-;eval;SLS;1|)
                      (SEQ
```

```

(LETT |e| NIL |POLYCAT-;eval;SLS;1|)
(LETT #3# |l| |POLYCAT-;eval;SLS;1|)
G190
(COND
  ((OR (ATOM #3#)
        (PROGN (LETT |e| (CAR #3#) |POLYCAT-;eval;SLS;1|) NIL))
    (GO G191)))
(SEQ
  (EXIT
    (LETT #2#
      (CONS (SPADCALL (SPADCALL |e| (QREFELT $ 11)) (QREFELT $ 14))
        #2#)
      |POLYCAT-;eval;SLS;1|)))
(LETT #3# (CDR #3#) |POLYCAT-;eval;SLS;1|)
(GO G190)
G191
(EXIT (NREVERSEO #2#)))
|POLYCAT-;eval;SLS;1|)
(EXIT
  (SPADCALL |p| |lvar|
    (PROGN
      (LETT #4# NIL |POLYCAT-;eval;SLS;1|)
      (SEQ
        (LETT |e| NIL |POLYCAT-;eval;SLS;1|)
        (LETT #5# |l| |POLYCAT-;eval;SLS;1|)
        G190
        (COND
          ((OR (ATOM #5#)
                (PROGN (LETT |e| (CAR #5#) |POLYCAT-;eval;SLS;1|) NIL))
            (GO G191)))
        (SEQ
          (EXIT
            (LETT #4# (CONS (SPADCALL |e| (QREFELT $ 15)) #4#)
              |POLYCAT-;eval;SLS;1|)))
          (LETT #5# (CDR #5#) |POLYCAT-;eval;SLS;1|)
          (GO G190)
          G191
          (EXIT (NREVERSEO #4#)))
          (QREFELT $ 18)))))))))
(DEFUN |POLYCAT-;monomials;SL;2| (|p| $)
  (PROG (|m1|)
    (RETURN
      (SEQ
        (LETT |m1| NIL |POLYCAT-;monomials;SL;2|)
        (SEQ G190
          (COND
            ((NULL
              (COND
                ((SPADCALL |p| (|spadConstant| $ 21) (QREFELT $ 24)) (QUOTE NIL))

```

```

((QUOTE T) (QUOTE T)))
(GO G191)))
(SEQ
(LETT |m1|
(CONS (SPADCALL |p| (QREFELT $ 25)) |m1|)
|POLYCAT-;monomials;SL;2|)
(EXIT
(LETT |p| (SPADCALL |p| (QREFELT $ 26)) |POLYCAT-;monomials;SL;2|)))
NIL
(GO G190)
G191
(EXIT NIL))
(EXIT (REVERSE |m1|))))))

(DEFUN |POLYCAT-;isPlus;SU;3| (|p| $)
(PROG (|l|)
(RETURN
(COND
((NULL
(CDR (LETT |l| (SPADCALL |p| (QREFELT $ 28)) |POLYCAT-;isPlus;SU;3|)))
(CONS 1 "failed")))
((QUOTE T) (CONS 0 |l|))))))

(DEFUN |POLYCAT-;isTimes;SU;4| (|p| $)
(PROG (|lv| #0=#:G1470 |v| #1=#:G1471 |l| |r|)
(RETURN
(SEQ
(COND
((OR (NULL
(LETT |lv| (SPADCALL |p| (QREFELT $ 31)) |POLYCAT-;isTimes;SU;4|))
(NULL (SPADCALL |p| (QREFELT $ 32))))
(CONS 1 "failed")))
((QUOTE T)
(SEQ
(LETT |l|
(PROGN
(LETT #0# NIL |POLYCAT-;isTimes;SU;4|)
(SEQ
(LETT |v| NIL |POLYCAT-;isTimes;SU;4|)
(LETT #1# |lv| |POLYCAT-;isTimes;SU;4|)
G190
(COND
((OR (ATOM #1#)
(PROGN (LETT |v| (CAR #1#) |POLYCAT-;isTimes;SU;4|) NIL))
(GO G191)))
(SEQ
(EXIT
(LETT #0#
(CONS
(SPADCALL (|spadConstant| $ 33) |v|

```

```

        (SPADCALL |p| |v| (QREFELT $ 36)) (QREFELT $ 37))
    #0#)
    |POLYCAT-;isTimes;SU;4|)))
    (LETT #1# (CDR #1#) |POLYCAT-;isTimes;SU;4|)
    (GO G190)
    G191
    (EXIT (NVERSEO #0#)))
    |POLYCAT-;isTimes;SU;4|)
    (LETT |r| (SPADCALL |p| (QREFELT $ 38)) |POLYCAT-;isTimes;SU;4|)
    (EXIT
    (COND
        ((SPADCALL |r| (|spadConstant| $ 34) (QREFELT $ 39))
        (COND
            ((NULL (CDR |lv|)) (CONS 1 "failed"))
            ((QUOTE T) (CONS 0 |1|))))
        ((QUOTE T)
        (CONS 0 (CONS (SPADCALL |r| (QREFELT $ 40)) |1|)))))))))

(DEFUN |POLYCAT-;isExpt;SU;5| (|p| $)
    (PROG (|u| |d|)
    (RETURN
    (SEQ
    (LETT |u| (SPADCALL |p| (QREFELT $ 42)) |POLYCAT-;isExpt;SU;5|)
    (EXIT
    (COND
        ((OR (QEQCAR |u| 1)
        (NULL
        (SPADCALL |p|
        (SPADCALL (|spadConstant| $ 33)
        (QCDR |u|)
        (LETT |d| (SPADCALL |p| (QCDR |u|) (QREFELT $ 36))
        |POLYCAT-;isExpt;SU;5|)
        (QREFELT $ 37))
        (QREFELT $ 24))))
        (CONS 1 "failed"))
        ((QUOTE T) (CONS 0 (CONS (QCDR |u|) |d|)))))))))

(DEFUN |POLYCAT-;coefficient;SVarSetNniS;6| (|p| |v| |n| $)
    (SPADCALL (SPADCALL |p| |v| (QREFELT $ 47)) |n| (QREFELT $ 49)))

(DEFUN |POLYCAT-;coefficient;SLLS;7| (|p| |lv| |ln| $)
    (COND
        ((NULL |lv|)
        (COND
            ((NULL |ln|) |p|)
            ((QUOTE T) (|error| "mismatched lists in coefficient"))))
        ((NULL |ln|) (|error| "mismatched lists in coefficient"))
        ((QUOTE T)
        (SPADCALL
        (SPADCALL

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```

      (SPADCALL |p| (|SPADfirst| |lv|) (QREFELT $ 47))
      (|SPADfirst| |ln|)
      (QREFELT $ 49))
    (CDR |lv|)
    (CDR |ln|)
    (QREFELT $ 52))))))

(DEFUN |POLYCAT-;monomial;SLLS;8| (|p| |lv| |ln| $)
  (COND
    ((NULL |lv|)
      (COND
        ((NULL |ln|) |p|)
        ((QUOTE T) (|error| "mismatched lists in monomial"))))
    ((NULL |ln|) (|error| "mismatched lists in monomial"))
    ((QUOTE T)
      (SPADCALL
        (SPADCALL |p| (|SPADfirst| |lv|) (|SPADfirst| |ln|) (QREFELT $ 37))
        (CDR |lv|)
        (CDR |ln|)
        (QREFELT $ 54))))))

(DEFUN |POLYCAT-;retract;SVarSet;9| (|p| $)
  (PROG (#0=#:G1496 |q|)
    (RETURN
      (SEQ
        (LETT |q|
          (PROG2
            (LETT #0# (SPADCALL |p| (QREFELT $ 42)) |POLYCAT-;retract;SVarSet;9|)
            (QCDR #0#)
            (|check-union| (QEQCAR #0# 0) (QREFELT $ 9) #0#))
            |POLYCAT-;retract;SVarSet;9|)
          (EXIT
            (COND
              ((SPADCALL (SPADCALL |q| (QREFELT $ 56)) |p| (QREFELT $ 24)) |q|)
              ((QUOTE T) (|error| "Polynomial is not a single variable"))))))))

(DEFUN |POLYCAT-;retractIfCan;SU;10| (|p| $)
  (PROG (|q| #0=#:G1504)
    (RETURN
      (SEQ
        (EXIT
          (SEQ
            (SEQ
              (LETT |q| (SPADCALL |p| (QREFELT $ 42)) |POLYCAT-;retractIfCan;SU;10|)
              (EXIT
                (COND
                  ((QEQCAR |q| 0)
                    (COND
                      ((SPADCALL (SPADCALL (QCDR |q|) (QREFELT $ 56)) |p| (QREFELT $ 24))
                        (PROGN

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        (LETT #0# |q| |POLYCAT-;retractIfCan;SU;10|)
        (GO #0#))))))
    (EXIT (CONS 1 "failed"))))
#0#
(EXIT #0#))))))

(DEFUN |POLYCAT-;mkPrim| (|p| $)
  (SPADCALL
    (|spadConstant| $ 34)
    (SPADCALL |p| (QREFELT $ 59))
    (QREFELT $ 60)))

(DEFUN |POLYCAT-;primitiveMonomials;SL;12| (|p| $)
  (PROG (#0=#:G1509 |q| #1=#:G1510)
    (RETURN
      (SEQ
        (PROGN
          (LETT #0# NIL |POLYCAT-;primitiveMonomials;SL;12|)
          (SEQ
            (LETT |q| NIL |POLYCAT-;primitiveMonomials;SL;12|)
            (LETT #1# (SPADCALL |p| (QREFELT $ 28)) |POLYCAT-;primitiveMonomials;SL;12|)
            G190
            (COND
              ((OR (ATOM #1#)
                (PROGN
                  (LETT |q| (CAR #1#) |POLYCAT-;primitiveMonomials;SL;12|)
                  NIL))
                (GO G191)))
              (SEQ
                (EXIT
                  (LETT #0# (CONS (|POLYCAT-;mkPrim| |q| $) #0#)
                    |POLYCAT-;primitiveMonomials;SL;12|)))
                (LETT #1# (CDR #1#) |POLYCAT-;primitiveMonomials;SL;12|)
                (GO G190)
                G191
                (EXIT (NREVERSEO #0#)))))))))

(DEFUN |POLYCAT-;totalDegree;SNni;13| (|p| $)
  (PROG (#0=#:G1512 |d| |u|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |p| (QREFELT $ 62)) 0)
          ((QUOTE T)
            (SEQ
              (LETT |u|
                (SPADCALL |p|
                  (PROG2
                    (LETT #0#
                      (SPADCALL |p| (QREFELT $ 42))

```

```

    |POLYCAT-;totalDegree;SNni;13|)
    (QCDR #0#)
    (|check-union| (QEQCAR #0# 0) (QREFELT $ 9) #0#))
    (QREFELT $ 47))
    |POLYCAT-;totalDegree;SNni;13|)
(LETT |d| 0 |POLYCAT-;totalDegree;SNni;13|)
(SEQ G190
  (COND
    ((NULL
      (COND
        ((SPADCALL |u| (|spadConstant| $ 63) (QREFELT $ 64)) (QUOTE NIL))
        ((QUOTE T) (QUOTE T)))) (GO G191)))
  (SEQ
    (LETT |d|
      (MAX |d|
        (+
          (SPADCALL |u| (QREFELT $ 65))
          (SPADCALL (SPADCALL |u| (QREFELT $ 66)) (QREFELT $ 67))))
        |POLYCAT-;totalDegree;SNni;13|)
      (EXIT
        (LETT |u|
          (SPADCALL |u| (QREFELT $ 68)) |POLYCAT-;totalDegree;SNni;13|)))
    NIL
    (GO G190)
    G191
    (EXIT NIL))
  (EXIT |d|))))))

(DEFUN |POLYCAT-;totalDegree;SLNni;14| (|p| |lv| $)
  (PROG (#0=:G1520 |v| |w| |d| |u|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |p| (QREFELT $ 62)) 0)
          ((QUOTE T)
            (SEQ
              (LETT |u|
                (SPADCALL |p|
                  (LETT |v|
                    (PROG2
                      (LETT #0#
                        (SPADCALL |p| (QREFELT $ 42))
                        |POLYCAT-;totalDegree;SLNni;14|)
                        (QCDR #0#)
                        (|check-union| (QEQCAR #0# 0) (QREFELT $ 9) #0#))
                        |POLYCAT-;totalDegree;SLNni;14|)
                        (QREFELT $ 47))
                      |POLYCAT-;totalDegree;SLNni;14|)
                    (LETT |d| 0 |POLYCAT-;totalDegree;SLNni;14|)
                    (LETT |w| 0 |POLYCAT-;totalDegree;SLNni;14|)

```

```

(COND
  ((SPADCALL |v| |lv| (QREFELT $ 70))
   (LETT |w| 1 |POLYCAT-;totalDegree;SLNni;14|)))
(SEQ G190
  (COND
    ((NULL
      (COND
        ((SPADCALL |u| (|spadConstant| $ 63) (QREFELT $ 64)) (QUOTE NIL))
        ((QUOTE T) (QUOTE T)))) (GO G191)))
  (SEQ
    (LETT |d|
      (MAX |d|
        (+
          (* |w| (SPADCALL |u| (QREFELT $ 65)))
          (SPADCALL (SPADCALL |u| (QREFELT $ 66)) |lv| (QREFELT $ 71))))
      |POLYCAT-;totalDegree;SLNni;14|)
    (EXIT
      (LETT |u|
        (SPADCALL |u| (QREFELT $ 68))
        |POLYCAT-;totalDegree;SLNni;14|)))
    NIL
    (GO G190)
    G191
    (EXIT NIL))
  (EXIT |d|))))))

(DEFUN |POLYCAT-;resultant;2SVarSetS;15| (|p1| |p2| |mvar| $)
  (SPADCALL
    (SPADCALL |p1| |mvar| (QREFELT $ 47))
    (SPADCALL |p2| |mvar| (QREFELT $ 47))
    (QREFELT $ 73)))

(DEFUN |POLYCAT-;discriminant;SVarSetS;16| (|p| |var| $)
  (SPADCALL (SPADCALL |p| |var| (QREFELT $ 47)) (QREFELT $ 75)))

(DEFUN |POLYCAT-;allMonoms| (|l| $)
  (PROG (#0=#:G1532 |p| #1=#:G1533)
    (RETURN
      (SEQ
        (SPADCALL
          (SPADCALL
            (PROGN
              (LETT #0# NIL |POLYCAT-;allMonoms|)
              (SEQ
                (LETT |p| NIL |POLYCAT-;allMonoms|)
                (LETT #1# |l| |POLYCAT-;allMonoms|)
                G190
                (COND
                  ((OR (ATOM #1#) (PROGN (LETT |p| (CAR #1#) |POLYCAT-;allMonoms|) NIL))
                   (GO G191)))
              )
            )
          )
        )
      )
    )
  )

```

```

      (SEQ
        (EXIT
          (LETT #0#
            (CONS (SPADCALL |p| (QREFELT $ 77)) #0#)
            |POLYCAT-;allMonoms|)))
        (LETT #1# (CDR #1#) |POLYCAT-;allMonoms|)
        (GO G190)
      G191
      (EXIT (NREVERSEO #0#))))
    (QREFELT $ 79))
  (QREFELT $ 80))))))

(DEFUN |POLYCAT-;P2R| (|p| |b| |n| $)
  (PROG (|w| |bj| #0=#:G1538 |i| #1=#:G1537)
    (RETURN
      (SEQ
        (LETT |w|
          (SPADCALL |n| (|spadConstant| $ 22) (QREFELT $ 82))
          |POLYCAT-;P2R|)
        (SEQ
          (LETT |bj| NIL |POLYCAT-;P2R|)
          (LETT #0# |b| |POLYCAT-;P2R|)
          (LETT |i| (SPADCALL |w| (QREFELT $ 84)) |POLYCAT-;P2R|)
          (LETT #1# (QVSIZE |w|) |POLYCAT-;P2R|)
        G190
        (COND
          ((OR (> |i| #1#)
            (ATOM #0#)
            (PROGN (LETT |bj| (CAR #0#) |POLYCAT-;P2R|) NIL))
          (GO G191)))
        (SEQ
          (EXIT
            (SPADCALL |w| |i| (SPADCALL |p| |bj| (QREFELT $ 85)) (QREFELT $ 86))))
          (LETT |i|
            (PROG1 (+ |i| 1) (LETT #0# (CDR #0#) |POLYCAT-;P2R|)) |POLYCAT-;P2R|)
          (GO G190)
        G191
        (EXIT NIL))
      (EXIT |w|))))))

(DEFUN |POLYCAT-;eq2R| (|l| |b| $)
  (PROG (#0=#:G1542 |bj| #1=#:G1543 #2=#:G1544 |p| #3=#:G1545)
    (RETURN
      (SEQ
        (SPADCALL
          (PROGN
            (LETT #0# NIL |POLYCAT-;eq2R|)
            (SEQ
              (LETT |bj| NIL |POLYCAT-;eq2R|)
              (LETT #1# |b| |POLYCAT-;eq2R|)

```

```

G190
(COND
  ((OR (ATOM #1#)
    (PROGN (LETT |bj| (CAR #1#) |POLYCAT-;eq2R|) NIL)) (GO G191)))
(SEQ
  (EXIT
    (LETT #0#
      (CONS
        (PROGN
          (LETT #2# NIL |POLYCAT-;eq2R|)
          (SEQ
            (LETT |p| NIL |POLYCAT-;eq2R|)
            (LETT #3# |l| |POLYCAT-;eq2R|)
            G190
            (COND
              ((OR (ATOM #3#) (PROGN (LETT |p| (CAR #3#) |POLYCAT-;eq2R|) NIL))
                (GO G191)))
            (SEQ
              (EXIT
                (LETT #2#
                  (CONS (SPADCALL |p| |bj| (QREFELT $ 85)) #2#)
                  |POLYCAT-;eq2R|)))
              (LETT #3# (CDR #3#) |POLYCAT-;eq2R|)
              (GO G190)
              G191
              (EXIT (NREVERSEO #2#))))
            #0#)
            |POLYCAT-;eq2R|)))
          (LETT #1# (CDR #1#) |POLYCAT-;eq2R|)
          (GO G190)
          G191
          (EXIT (NREVERSEO #0#))))
        (QREFELT $ 89))))))
(DEFUN |POLYCAT-;reducedSystem;MM;20| (|m| $)
  (PROG (#0=:G1555 |r| #1=:G1556 |b| #2=:G1557 |bj| #3=:G1558 |d| |mm| |l|)
    (RETURN
      (SEQ
        (LETT |l| (SPADCALL |m| (QREFELT $ 92)) |POLYCAT-;reducedSystem;MM;20|)
        (LETT |b|
          (SPADCALL
            (SPADCALL
              (PROGN
                (LETT #0# NIL |POLYCAT-;reducedSystem;MM;20|)
                (SEQ
                  (LETT |r| NIL |POLYCAT-;reducedSystem;MM;20|)
                  (LETT #1# |l| |POLYCAT-;reducedSystem;MM;20|)
                  G190
                  (COND
                    ((OR (ATOM #1#)

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        (PROGN (LETT |r| (CAR #1#) |POLYCAT-;reducedSystem;MM;20|) NIL))
      (GO G191)))
    (SEQ
      (EXIT
        (LETT #0#
          (CONS (|POLYCAT-;allMonoms| |r| $) #0#)
          |POLYCAT-;reducedSystem;MM;20|)))
      (LETT #1# (CDR #1#) |POLYCAT-;reducedSystem;MM;20|)
      (GO G190)
      G191
      (EXIT (NREVERSEO #0#))))
    (QREFELT $ 79))
  (QREFELT $ 80))
|POLYCAT-;reducedSystem;MM;20|)
(LETT |d|
  (PROGN
    (LETT #2# NIL |POLYCAT-;reducedSystem;MM;20|)
    (SEQ
      (LETT |bj| NIL |POLYCAT-;reducedSystem;MM;20|)
      (LETT #3# |b| |POLYCAT-;reducedSystem;MM;20|)
      G190
      (COND
        ((OR (ATOM #3#)
          (PROGN (LETT |bj| (CAR #3#) |POLYCAT-;reducedSystem;MM;20|) NIL))
          (GO G191)))
      (SEQ
        (EXIT
          (LETT #2#
            (CONS (SPADCALL |bj| (QREFELT $ 59)) #2#)
            |POLYCAT-;reducedSystem;MM;20|)))
        (LETT #3# (CDR #3#) |POLYCAT-;reducedSystem;MM;20|)
        (GO G190)
        G191
        (EXIT (NREVERSEO #2#))))
      |POLYCAT-;reducedSystem;MM;20|)
    (LETT |mm|
      (|POLYCAT-;eq2R| (|SPADfirst| |l|) |d| $) |POLYCAT-;reducedSystem;MM;20|)
      (LETT |l| (CDR |l|) |POLYCAT-;reducedSystem;MM;20|)
      (SEQ G190
        (COND
          ((NULL (COND ((NULL |l|) (QUOTE NIL)) ((QUOTE T) (QUOTE T)))) (GO G191)))
        (SEQ
          (LETT |mm|
            (SPADCALL |mm| (|POLYCAT-;eq2R| (|SPADfirst| |l|) |d| $) (QREFELT $ 93))
            |POLYCAT-;reducedSystem;MM;20|)
            (EXIT (LETT |l| (CDR |l|) |POLYCAT-;reducedSystem;MM;20|)))
          NIL
          (GO G190)
          G191
          (EXIT NIL)))

```

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(EXIT |mm|))))))

(DEFUN |POLYCAT-;reducedSystem;MVR;21| (|m| |v| $)
  (PROG (#0=:G1570 |s| #1=:G1571 |b| #2=:G1572 |bj| #3=:G1573 |d| |n|
    |mm| |w| |l| |r|)
  (RETURN
  (SEQ
    (LETT |l| (SPADCALL |m| (QREFELT $ 92)) |POLYCAT-;reducedSystem;MVR;21|)
    (LETT |r| (SPADCALL |v| (QREFELT $ 97)) |POLYCAT-;reducedSystem;MVR;21|)
    (LETT |b|
      (SPADCALL
        (SPADCALL
          (|POLYCAT-;allMonoms| |r| $)
          (SPADCALL
            (PROGN
              (LETT #0# NIL |POLYCAT-;reducedSystem;MVR;21|)
              (SEQ
                (LETT |s| NIL |POLYCAT-;reducedSystem;MVR;21|)
                (LETT #1# |l| |POLYCAT-;reducedSystem;MVR;21|)
                G190
                (COND
                  ((OR (ATOM #1#)
                    (PROGN
                      (LETT |s| (CAR #1#) |POLYCAT-;reducedSystem;MVR;21|)
                      NIL))
                    (GO G191)))
                (SEQ
                  (EXIT
                    (LETT #0#
                      (CONS (|POLYCAT-;allMonoms| |s| $) #0#)
                      |POLYCAT-;reducedSystem;MVR;21|)))
                    (LETT #1# (CDR #1#) |POLYCAT-;reducedSystem;MVR;21|)
                    (GO G190)
                    G191
                    (EXIT (NREVERSEO #0#))))
                  (QREFELT $ 79))
                  (QREFELT $ 98))
                  (QREFELT $ 80))
                |POLYCAT-;reducedSystem;MVR;21|)
              (LETT |d|
                (PROGN
                  (LETT #2# NIL |POLYCAT-;reducedSystem;MVR;21|)
                  (SEQ
                    (LETT |bj| NIL |POLYCAT-;reducedSystem;MVR;21|)
                    (LETT #3# |b| |POLYCAT-;reducedSystem;MVR;21|)
                    G190
                    (COND
                      ((OR (ATOM #3#)
                        (PROGN (LETT |bj| (CAR #3#) |POLYCAT-;reducedSystem;MVR;21|) NIL))
                        (GO G191)))

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(SEQ
  (EXIT
    (LETT #2#
      (CONS (SPADCALL |b| (QREFELT $ 59)) #2#)
      |POLYCAT-;reducedSystem;MVR;21|)))
  (LETT #3# (CDR #3#) |POLYCAT-;reducedSystem;MVR;21|)
  (GO G190)
  G191
  (EXIT (NREVERSE0 #2#))))
|POLYCAT-;reducedSystem;MVR;21|)
(LETT |n| (LENGTH |d|) |POLYCAT-;reducedSystem;MVR;21|)
(LETT |mm|
  (|POLYCAT-;eq2R| (|SPADfirst| |l|) |d| $)
  |POLYCAT-;reducedSystem;MVR;21|)
(LETT |w|
  (|POLYCAT-;P2R| (|SPADfirst| |r|) |d| |n| $)
  |POLYCAT-;reducedSystem;MVR;21|)
(LETT |l| (CDR |l|) |POLYCAT-;reducedSystem;MVR;21|)
(LETT |r| (CDR |r|) |POLYCAT-;reducedSystem;MVR;21|)
(SEQ G190
  (COND
    ((NULL (COND ((NULL |l|) (QUOTE NIL)) ((QUOTE T) (QUOTE T)))))
    (GO G191)))
  (SEQ
    (LETT |mm|
      (SPADCALL |mm| (|POLYCAT-;eq2R| (|SPADfirst| |l|) |d| $) (QREFELT $ 93))
      |POLYCAT-;reducedSystem;MVR;21|)
    (LETT |w|
      (SPADCALL |w|
        (|POLYCAT-;P2R| (|SPADfirst| |r|) |d| |n| $)
        (QREFELT $ 99))
      |POLYCAT-;reducedSystem;MVR;21|)
    (LETT |l| (CDR |l|) |POLYCAT-;reducedSystem;MVR;21|)
    (EXIT (LETT |r| (CDR |r|) |POLYCAT-;reducedSystem;MVR;21|)))
    NIL
    (GO G190)
    G191
    (EXIT NIL))
  (EXIT (CONS |mm| |w|))))))

(DEFUN |POLYCAT-;gcdPolynomial;3Sup;22| (|pp| |qq| $)
  (SPADCALL |pp| |qq| (QREFELT $ 104)))

(DEFUN |POLYCAT-;solveLinearPolynomialEquation;LSupU;23| (|lpp| |pp| $)
  (SPADCALL |lpp| |pp| (QREFELT $ 109)))

(DEFUN |POLYCAT-;factorPolynomial;SupF;24| (|pp| $)
  (SPADCALL |pp| (QREFELT $ 114)))

(DEFUN |POLYCAT-;factorSquareFreePolynomial;SupF;25| (|pp| $)

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(SPADCALL |pp| (QREFELT $ 117)))

(DEFUN |POLYCAT-;factor;SF;26| (|p| $)
  (PROG (|v| |ansR| #0=#:G1615 |w| #1=#:G1616 |up| |ansSUP| #2=#:G1617
    |ww| #3=#:G1618)
    (RETURN
      (SEQ
        (LETT |v| (SPADCALL |p| (QREFELT $ 42)) |POLYCAT-;factor;SF;26|)
        (EXIT
          (COND
            ((QEQCAR |v| 1)
              (SEQ
                (LETT |ansR|
                  (SPADCALL (SPADCALL |p| (QREFELT $ 38)) (QREFELT $ 120))
                  |POLYCAT-;factor;SF;26|)
                (EXIT
                  (SPADCALL
                    (SPADCALL (SPADCALL |ansR| (QREFELT $ 122)) (QREFELT $ 40))
                    (PROGN
                      (LETT #0# NIL |POLYCAT-;factor;SF;26|)
                      (SEQ
                        (LETT |w| NIL |POLYCAT-;factor;SF;26|)
                        (LETT #1#
                          (SPADCALL |ansR| (QREFELT $ 126))
                          |POLYCAT-;factor;SF;26|)
                        G190
                        (COND
                          ((OR (ATOM #1#)
                            (PROGN (LETT |w| (CAR #1#) |POLYCAT-;factor;SF;26|) NIL))
                            (GO G191)))
                        (SEQ
                          (EXIT
                            (LETT #0#
                              (CONS
                                (VECTOR (QVELT |w| 0)
                                  (SPADCALL (QVELT |w| 1) (QREFELT $ 40)) (QVELT |w| 2))
                                  #0#)
                                |POLYCAT-;factor;SF;26|)))
                            (LETT #1# (CDR #1#) |POLYCAT-;factor;SF;26|)
                            (GO G190)
                            G191
                            (EXIT (NREVERSEO #0#))))
                          (QREFELT $ 130))))))
                      ((QUOTE T)
                        (SEQ
                          (LETT |up|
                            (SPADCALL |p| (QCDR |v|) (QREFELT $ 47)) |POLYCAT-;factor;SF;26|)
                          (LETT |ansSUP| (SPADCALL |up| (QREFELT $ 114)) |POLYCAT-;factor;SF;26|)
                          (EXIT
                            (SPADCALL

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(SPADCALL
  (SPADCALL |ansSUP| (QREFELT $ 131)) (QCDR |v|) (QREFELT $ 132))
(PROGN
  (LETT #2# NIL |POLYCAT-;factor;SF;26|)
  (SEQ
    (LETT |ww| NIL |POLYCAT-;factor;SF;26|)
    (LETT #3#
      (SPADCALL |ansSUP| (QREFELT $ 135))
      |POLYCAT-;factor;SF;26|)
    G190
    (COND
      ((OR (ATOM #3#)
        (PROGN (LETT |ww| (CAR #3#) |POLYCAT-;factor;SF;26|) NIL))
        (GO G191)))
    (SEQ
      (EXIT
        (LETT #2#
          (CONS
            (VECTOR (QVELT |ww| 0) (SPADCALL (QVELT |ww| 1) (QCDR |v|)
              (QREFELT $ 132)) (QVELT |ww| 2))
            #2#)
          |POLYCAT-;factor;SF;26|)))
      (LETT #3# (CDR #3#) |POLYCAT-;factor;SF;26|)
      (GO G190)
      G191
      (EXIT (NREVERSE0 #2#))))
    (QREFELT $ 130)))))))))

(DEFUN |POLYCAT-;conditionP;MU;27| (|mat| $)
  (PROG (|l1| #0=:G1653 |z| #1=:G1654 |ch| |l| #2=:G1655 #3=:G1656
    #4=:G1625 #5=:G1623 #6=:G1624 #7=:G1657 |vars| |degs|
    #8=:G1658 |d| #9=:G1659 |nd| #10=:G1652 #11=:G1632 |deg1|
    |redmons| #12=:G1660 |v| #13=:G1662 |u| #14=:G1661 |l1R|
    |monslist| |ans| #15=:G1663 #16=:G1664 |mons| #17=:G1665 |m|
    #18=:G1666 |i| #19=:G1648 #20=:G1646 #21=:G1647)
  (RETURN
    (SEQ
      (EXIT
        (SEQ
          (LETT |l1|
            (SPADCALL (SPADCALL |mat| (QREFELT $ 137)) (QREFELT $ 92))
            |POLYCAT-;conditionP;MU;27|)
          (LETT |l1R|
            (PROGN
              (LETT #0# NIL |POLYCAT-;conditionP;MU;27|)
              (SEQ
                (LETT |z| NIL |POLYCAT-;conditionP;MU;27|)
                (LETT #1# (|SPADfirst| |l1|) |POLYCAT-;conditionP;MU;27|)
                G190
                (COND

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((OR (ATOM #1#)
      (PROGN (LETT |z| (CAR #1#) |POLYCAT-;conditionP;MU;27|) NIL))
      (GO G191)))
(SEQ (EXIT (LETT #0# (CONS NIL #0#) |POLYCAT-;conditionP;MU;27|)))
(LETT #1# (CDR #1#) |POLYCAT-;conditionP;MU;27|)
(GO G190)
G191
(EXIT (NREVERSEO #0#)))
|POLYCAT-;conditionP;MU;27|)
(LETT |monslst| NIL |POLYCAT-;conditionP;MU;27|)
(LETT |ch| (SPADCALL (QREFELT $ 138)) |POLYCAT-;conditionP;MU;27|)
(SEQ
  (LETT |l| NIL |POLYCAT-;conditionP;MU;27|)
  (LETT #2# |l| |POLYCAT-;conditionP;MU;27|)
  G190
  (COND
    ((OR (ATOM #2#)
          (PROGN (LETT |l| (CAR #2#) |POLYCAT-;conditionP;MU;27|) NIL))
          (GO G191)))
  (SEQ
    (LETT |mons|
      (PROGN
        (LETT #6# NIL |POLYCAT-;conditionP;MU;27|)
        (SEQ
          (LETT |u| NIL |POLYCAT-;conditionP;MU;27|)
          (LETT #3# |l| |POLYCAT-;conditionP;MU;27|)
          G190
          (COND
            ((OR (ATOM #3#)
                  (PROGN (LETT |u| (CAR #3#) |POLYCAT-;conditionP;MU;27|) NIL))
                  (GO G191)))
            (SEQ
              (EXIT
                (PROGN
                  (LETT #4#
                    (SPADCALL |u| (QREFELT $ 77))
                    |POLYCAT-;conditionP;MU;27|)
                  (COND
                    (#6#
                     (LETT #5#
                       (SPADCALL #5# #4# (QREFELT $ 139))
                       |POLYCAT-;conditionP;MU;27|))
                     ((QUOTE T)
                      (PROGN
                        (LETT #5# #4# |POLYCAT-;conditionP;MU;27|)
                        (LETT #6# (QUOTE T) |POLYCAT-;conditionP;MU;27|))))))
              (LETT #3# (CDR #3#) |POLYCAT-;conditionP;MU;27|)
              (GO G190)
              G191
              (EXIT NIL))

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(COND (#6# #5#) ((QUOTE T) (|IdentityError| (QUOTE |setUnion|))))
|POLYCAT-;conditionP;MU;27|)
(LETT |redmons| NIL |POLYCAT-;conditionP;MU;27|)
(SEQ
  (LETT |m| NIL |POLYCAT-;conditionP;MU;27|)
  (LETT #7# |mons| |POLYCAT-;conditionP;MU;27|)
  G190
  (COND
    ((OR (ATOM #7#)
      (PROGN (LETT |m| (CAR #7#) |POLYCAT-;conditionP;MU;27|) NIL))
      (GO G191)))
  (SEQ
    (LETT |vars|
      (SPADCALL |m| (QREFELT $ 31))
      |POLYCAT-;conditionP;MU;27|)
    (LETT |degs|
      (SPADCALL |m| |vars| (QREFELT $ 140))
      |POLYCAT-;conditionP;MU;27|)
    (LETT |deg1|
      (PROGN
        (LETT #8# NIL |POLYCAT-;conditionP;MU;27|)
        (SEQ
          (LETT |d| NIL |POLYCAT-;conditionP;MU;27|)
          (LETT #9# |degs| |POLYCAT-;conditionP;MU;27|)
          G190
          (COND
            ((OR (ATOM #9#)
              (PROGN
                (LETT |d| (CAR #9#) |POLYCAT-;conditionP;MU;27|)
                NIL))
              (GO G191)))
          (SEQ
            (EXIT
              (LETT #8#
                (CONS
                  (SEQ
                    (LETT |nd|
                      (SPADCALL |d| |ch| (QREFELT $ 142))
                      |POLYCAT-;conditionP;MU;27|)
                    (EXIT
                      (COND
                        ((QEQCAR |nd| 1)
                          (PROGN
                            (LETT #10#
                              (CONS 1 "failed") |POLYCAT-;conditionP;MU;27|)
                              (GO #10#)))
                        ((QUOTE T)
                          (PROG1
                            (LETT #11# (QCDR |nd|) |POLYCAT-;conditionP;MU;27|)
                            (|check-subtype|

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(>= #11# 0) (QUOTE (|NonNegativeInteger|) #11#))))))
#8#)
|POLYCAT-;conditionP;MU;27|)))
(LETT #9# (CDR #9#) |POLYCAT-;conditionP;MU;27|)
(GO G190)
G191
(EXIT (NREVERSEO #8#)))
|POLYCAT-;conditionP;MU;27|)
(LETT |redmons|
(CONS
 (SPADCALL (|spadConstant| $ 33) |vars| |deg1| (QREFELT $ 54))
 |redmons|)
|POLYCAT-;conditionP;MU;27|)
(EXIT
(LETT |l1R|
(PROGN
(LETT #12# NIL |POLYCAT-;conditionP;MU;27|)
(SEQ
(LETT |v| NIL |POLYCAT-;conditionP;MU;27|)
(LETT #13# |l1R| |POLYCAT-;conditionP;MU;27|)
(LETT |u| NIL |POLYCAT-;conditionP;MU;27|)
(LETT #14# |l| |POLYCAT-;conditionP;MU;27|)
G190
(COND
((OR (ATOM #14#)
(PROGN
(LETT |u| (CAR #14#) |POLYCAT-;conditionP;MU;27|)
NIL)
(ATOM #13#)
(PROGN (LETT |v| (CAR #13#) |POLYCAT-;conditionP;MU;27|) NIL))
(GO G191)))
(SEQ
(EXIT
(LETT #12#
(CONS
(CONS
(SPADCALL
(SPADCALL |u| |vars| |deg1| (QREFELT $ 52))
(QREFELT $ 143))
|v|)
#12#)
|POLYCAT-;conditionP;MU;27|)))
(LETT #14#
(PROG1
(CDR #14#)
(LETT #13# (CDR #13#) |POLYCAT-;conditionP;MU;27|)
|POLYCAT-;conditionP;MU;27|)
(GO G190)
G191
(EXIT (NREVERSEO #12#))))

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        |POLYCAT-;conditionP;MU;27|)))
(LETT #7# (CDR #7#) |POLYCAT-;conditionP;MU;27|)
(GO G190)
G191
(EXIT NIL))
(EXIT
  (LETT |monslst|
    (CONS |redmons| |monslst|)
    |POLYCAT-;conditionP;MU;27|)))
(LETT #2# (CDR #2#) |POLYCAT-;conditionP;MU;27|)
(GO G190)
G191
(EXIT NIL))
(LETT |ans|
  (SPADCALL (SPADCALL (SPADCALL |11R| (QREFELT $ 89)) (QREFELT $ 144))
    (QREFELT $ 146))
  |POLYCAT-;conditionP;MU;27|)
(EXIT
  (COND
    ((QEQCAR |ans| 1) (CONS 1 "failed")))
    ((QUOTE T)
      (SEQ
        (LETT |i| 0 |POLYCAT-;conditionP;MU;27|)
        (EXIT
          (CONS 0
            (PRIMVEC2ARR
              (PROGN
                (LETT #15# (make-array (SIZE |monslst|))
                  |POLYCAT-;conditionP;MU;27|)
                (SEQ
                  (LETT #16# 0 |POLYCAT-;conditionP;MU;27|)
                  (LETT |mons| NIL |POLYCAT-;conditionP;MU;27|)
                  (LETT #17# |monslst| |POLYCAT-;conditionP;MU;27|)
                  G190
                  (COND
                    ((OR (ATOM #17#)
                      (PROGN
                        (LETT |mons| (CAR #17#) |POLYCAT-;conditionP;MU;27|)
                        NIL))
                      (GO G191))))
                  (SEQ
                    (EXIT
                      (SETELT #15# #16#
                        (PROGN
                          (LETT #21# NIL |POLYCAT-;conditionP;MU;27|)
                          (SEQ
                            (LETT |m| NIL |POLYCAT-;conditionP;MU;27|)
                            (LETT #18# |mons| |POLYCAT-;conditionP;MU;27|)
                            G190
                            (COND

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((OR (ATOM #18#)
  (PROGN
    (LETT |m| (CAR #18#) |POLYCAT-;conditionP;MU;27|)
    NIL))
  (GO G191)))
(SEQ
  (EXIT
    (PROGN
      (LETT #19#
        (SPADCALL |m|
          (SPADCALL
            (SPADCALL
              (QCDR |ans|)
              (LETT |i| (+ |i| 1) |POLYCAT-;conditionP;MU;27|)
              (QREFELT $ 147))
              (QREFELT $ 40))
              (QREFELT $ 148))
              |POLYCAT-;conditionP;MU;27|)
            (COND
              (#21#
                (LETT #20#
                  (SPADCALL #20# #19# (QREFELT $ 149))
                  |POLYCAT-;conditionP;MU;27|))
                ((QUOTE T)
                  (PROGN
                    (LETT #20# #19# |POLYCAT-;conditionP;MU;27|)
                    (LETT #21#
                      (QUOTE T)
                      |POLYCAT-;conditionP;MU;27|))))))
              (LETT #18# (CDR #18#) |POLYCAT-;conditionP;MU;27|)
              (GO G190)
              G191
              (EXIT NIL))
              (COND (#21# #20#) ((QUOTE T) (|spadConstant| $ 21))))))
      (LETT #17#
        (PROG1
          (CDR #17#)
          (LETT #16# (QSADD1 #16#) |POLYCAT-;conditionP;MU;27|)
          |POLYCAT-;conditionP;MU;27|)
          (GO G190)
          G191
          (EXIT NIL))
          #15#))))))
#10#
(EXIT #10#))))

(DEFUN |POLYCAT-;charthRoot;SU;28| (|p| $)
  (PROG (|vars| |ans| |ch|)
    (RETURN
      (SEQ

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```

(LETT |vars| (SPADCALL |p| (QREFELT $ 31)) |POLYCAT-;charthRoot;SU;28|)
(EXIT
(COND
((NULL |vars|)
(SEQ
(LETT |ans|
(SPADCALL (SPADCALL |p| (QREFELT $ 143)) (QREFELT $ 151))
|POLYCAT-;charthRoot;SU;28|)
(EXIT
(COND
((QEQCAR |ans| 1) (CONS 1 "failed"))
((QUOTE T) (CONS 0 (SPADCALL (QCDR |ans|) (QREFELT $ 40)))))))
((QUOTE T)
(SEQ
(LETT |ch| (SPADCALL (QREFELT $ 138)) |POLYCAT-;charthRoot;SU;28|)
(EXIT (|POLYCAT-;charthRootlv| |p| |vars| |ch| $))))))

(DEFUN |POLYCAT-;charthRootlv| (|p| |vars| |ch| $)
(PROG (|v| |dd| |cp| |d| #0=:G1687 |ans| |ansx| #1=:G1694)
(RETURN
(SEQ
(EXIT
(COND
((NULL |vars|)
(SEQ
(LETT |ans|
(SPADCALL (SPADCALL |p| (QREFELT $ 143)) (QREFELT $ 151))
|POLYCAT-;charthRootlv|)
(EXIT
(COND
((QEQCAR |ans| 1) (CONS 1 "failed"))
((QUOTE T) (CONS 0 (SPADCALL (QCDR |ans|) (QREFELT $ 40)))))))
((QUOTE T)
(SEQ
(LETT |v| (|SPADfirst| |vars|) |POLYCAT-;charthRootlv|)
(LETT |vars| (CDR |vars|) |POLYCAT-;charthRootlv|)
(LETT |d| (SPADCALL |p| |v| (QREFELT $ 36)) |POLYCAT-;charthRootlv|)
(LETT |ans| (|spadConstant| $ 21) |POLYCAT-;charthRootlv|)
(SEQ G190
(COND ((NULL (< 0 |d|)) (GO G191)))
(SEQ
(LETT |dd|
(SPADCALL |d| |ch| (QREFELT $ 142))
|POLYCAT-;charthRootlv|)
(EXIT
(COND
((QEQCAR |dd| 1)
(PROGN
(LETT #1# (CONS 1 "failed") |POLYCAT-;charthRootlv|)
(GO #1#)))

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((QUOTE T)
  (SEQ
    (LETT |cp|
      (SPADCALL |p| |v| |d| (QREFELT $ 154))
      |POLYCAT-;charthRootlv|)
    (LETT |p|
      (SPADCALL |p|
        (SPADCALL |cp| |v| |d| (QREFELT $ 37))
        (QREFELT $ 155))
      |POLYCAT-;charthRootlv|)
    (LETT |ansx|
      (|POLYCAT-;charthRootlv| |cp| |vars| |ch| $)
      |POLYCAT-;charthRootlv|)
    (EXIT
      (COND
        ((EQCAR |ansx| 1)
          (PROGN
            (LETT #1# (CONS 1 "failed") |POLYCAT-;charthRootlv|)
            (GO #1#)))
        ((QUOTE T)
          (SEQ
            (LETT |d|
              (SPADCALL |p| |v| (QREFELT $ 36))
              |POLYCAT-;charthRootlv|)
            (EXIT
              (LETT |ans|
                (SPADCALL |ans|
                  (SPADCALL (QCDR |ansx|) |v|
                    (PROG1
                      (LETT #0# (QCDR |dd|) |POLYCAT-;charthRootlv|)
                      (|check-subtype| (>= #0# 0)
                        (QUOTE (|NonNegativeInteger|)) #0#))
                    (QREFELT $ 37))
                    (QREFELT $ 149))
                  |POLYCAT-;charthRootlv|))))))))))
    NIL
    (GO G190)
  G191
  (EXIT NIL))
(LETT |ansx|
  (|POLYCAT-;charthRootlv| |p| |vars| |ch| $)
  |POLYCAT-;charthRootlv|)
(EXIT
  (COND
    ((EQCAR |ansx| 1)
      (PROGN
        (LETT #1# (CONS 1 "failed") |POLYCAT-;charthRootlv|)
        (GO #1#)))
    ((QUOTE T)
      (PROGN

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        (LETT #1#
          (CONS 0 (SPADCALL |ans| (QCDR |ansx|) (QREFELT $ 149)))
          |POLYCAT-;charthRootlv|)
        (GO #1#)))))))))
#1#
(EXIT #1#))))))

(DEFUN |POLYCAT-;monicDivide;2SVarSetR;30| (|p1| |p2| |mvar| $)
  (PROG (|result|)
    (RETURN
      (SEQ
        (LETT |result|
          (SPADCALL
            (SPADCALL |p1| |mvar| (QREFELT $ 47))
            (SPADCALL |p2| |mvar| (QREFELT $ 47))
            (QREFELT $ 157))
          |POLYCAT-;monicDivide;2SVarSetR;30|)
        (EXIT
          (CONS
            (SPADCALL (QCAR |result|) |mvar| (QREFELT $ 132))
            (SPADCALL (QCDR |result|) |mvar| (QREFELT $ 132))))))))))

(DEFUN |POLYCAT-;squareFree;SF;31| (|p| $)
  (SPADCALL |p| (QREFELT $ 160)))

(DEFUN |POLYCAT-;squareFree;SF;32| (|p| $)
  (SPADCALL |p| (QREFELT $ 163)))

(DEFUN |POLYCAT-;squareFree;SF;33| (|p| $)
  (SPADCALL |p| (QREFELT $ 163)))

(DEFUN |POLYCAT-;squareFreePart;2S;34| (|p| $)
  (PROG (|s| |f| #0=#:G1710 #1=#:G1708 #2=#:G1706 #3=#:G1707)
    (RETURN
      (SEQ
        (SPADCALL
          (SPADCALL
            (LETT |s| (SPADCALL |p| (QREFELT $ 164)) |POLYCAT-;squareFreePart;2S;34|)
            (QREFELT $ 165))
          (PROGN
            (LETT #3# NIL |POLYCAT-;squareFreePart;2S;34|)
            (SEQ
              (LETT |f| NIL |POLYCAT-;squareFreePart;2S;34|)
              (LETT #0# (SPADCALL |s| (QREFELT $ 168)) |POLYCAT-;squareFreePart;2S;34|)
              G190
              (COND
                ((OR (ATOM #0#)
                  (PROGN (LETT |f| (CAR #0#) |POLYCAT-;squareFreePart;2S;34|) NIL))
                  (GO G191)))
              (SEQ

```

```

(EXIT
  (PROGN
    (LETT #1# (QCAR |f|) |POLYCAT-;squareFreePart;2S;34|)
    (COND
      (#3#
        (LETT #2#
          (SPADCALL #2# #1# (QREFELT $ 148))
          |POLYCAT-;squareFreePart;2S;34|))
      ((QUOTE T)
        (PROGN
          (LETT #2# #1# |POLYCAT-;squareFreePart;2S;34|)
          (LETT #3# (QUOTE T) |POLYCAT-;squareFreePart;2S;34|))))))
    (LETT #0# (CDR #0#) |POLYCAT-;squareFreePart;2S;34|)
    (GO G190)
  G191
  (EXIT NIL))
  (COND (#3# #2#) ((QUOTE T) (|spadConstant| $ 33))))
(QREFELT $ 148))))))

(DEFUN |POLYCAT-;content;SVarSetS;35| (|p| |v| $)
  (SPADCALL (SPADCALL |p| |v| (QREFELT $ 47)) (QREFELT $ 170)))

(DEFUN |POLYCAT-;primitivePart;2S;36| (|p| $)
  (PROG (#0=:G1713)
    (RETURN
      (COND
        ((SPADCALL |p| (QREFELT $ 172)) |p|)
        ((QUOTE T)
          (QVELT
            (SPADCALL
              (PROG2
                (LETT #0#
                  (SPADCALL |p| (SPADCALL |p| (QREFELT $ 173)) (QREFELT $ 174))
                  |POLYCAT-;primitivePart;2S;36|)
                (QCDR #0#)
                (|check-union| (QEQCAR #0# 0) (QREFELT $ 6) #0#))
                (QREFELT $ 176))
              1))))))

(DEFUN |POLYCAT-;primitivePart;SVarSetS;37| (|p| |v| $)
  (PROG (#0=:G1720)
    (RETURN
      (COND
        ((SPADCALL |p| (QREFELT $ 172)) |p|)
        ((QUOTE T)
          (QVELT
            (SPADCALL
              (PROG2
                (LETT #0#
                  (SPADCALL |p| (SPADCALL |p| |v| (QREFELT $ 178)) (QREFELT $ 179))

```

```

        |POLYCAT-;primitivePart;SVarSetS;37|)
      (QCDR #0#)
      (|check-union| (QEQCAR #0# 0) (QREFELT $ 6) #0#))
    (QREFELT $ 176))
  1))))))

(DEFUN |POLYCAT-;<;2SB;38| (|p| |q| $)
  (PROG (|dp| |dq|)
    (RETURN
      (SEQ
        (LETT |dp| (SPADCALL |p| (QREFELT $ 59)) |POLYCAT-;<;2SB;38|)
        (LETT |dq| (SPADCALL |q| (QREFELT $ 59)) |POLYCAT-;<;2SB;38|)
        (EXIT
          (COND
            ((SPADCALL |dp| |dq| (QREFELT $ 181))
              (SPADCALL
                (|spadConstant| $ 22)
                (SPADCALL |q| (QREFELT $ 38))
                (QREFELT $ 182)))
            ((SPADCALL |dq| |dp| (QREFELT $ 181))
              (SPADCALL
                (SPADCALL |p| (QREFELT $ 38))
                (|spadConstant| $ 22)
                (QREFELT $ 182)))
            ((QUOTE T)
              (SPADCALL
                (SPADCALL (SPADCALL |p| |q| (QREFELT $ 155)) (QREFELT $ 38))
                (|spadConstant| $ 22)
                (QREFELT $ 182))))))))))

(DEFUN |POLYCAT-;patternMatch;SP2Pmr;39| (|p| |pat| |l| $)
  (SPADCALL |p| |pat| |l| (QREFELT $ 187)))

(DEFUN |POLYCAT-;patternMatch;SP2Pmr;40| (|p| |pat| |l| $)
  (SPADCALL |p| |pat| |l| (QREFELT $ 193)))

(DEFUN |POLYCAT-;convert;SP;41| (|x| $)
  (SPADCALL (ELT $ 196) (ELT $ 197) |x| (QREFELT $ 201)))

(DEFUN |POLYCAT-;convert;SP;42| (|x| $)
  (SPADCALL (ELT $ 203) (ELT $ 204) |x| (QREFELT $ 208)))

(DEFUN |POLYCAT-;convert;SIf;43| (|p| $)
  (SPADCALL (ELT $ 211) (ELT $ 212) |p| (QREFELT $ 216)))

(DEFUN |PolynomialCategory&| (|#1| |#2| |#3| |#4|)
  (PROG (DV$1 DV$2 DV$3 DV$4 |dv$| $ |pv$|)
    (RETURN
      (PROGN
        (LETT DV$1 (|devaluate| |#1|) . #0=(|PolynomialCategory&|))

```

```

(LETT DV$2 (|devaluate| |#2|) . #0#)
(LETT DV$3 (|devaluate| |#3|) . #0#)
(LETT DV$4 (|devaluate| |#4|) . #0#)
(LETT |dv$| (LIST (QUOTE |PolynomialCategory&|) DV$1 DV$2 DV$3 DV$4) . #0#)
(LETT $ (make-array 226) . #0#)
(QSETREFV $ 0 |dv$|)
(QSETREFV $ 3
  (LETT |pv$|
    (|buildPredVector| 0 0
      (LIST
        (|HasCategory| |#2| (QUOTE (|PolynomialFactorizationExplicit|)))
        (|HasAttribute| |#2| (QUOTE |canonicalUnitNormal|))
        (|HasCategory| |#2| (QUOTE (|GcdDomain|)))
        (|HasCategory| |#2| (QUOTE (|CommutativeRing|)))
        (|HasCategory| |#4| (QUOTE (|PatternMatchable| (|Float|))))
        (|HasCategory| |#2| (QUOTE (|PatternMatchable| (|Float|))))
        (|HasCategory| |#4| (QUOTE (|PatternMatchable| (|Integer|))))
        (|HasCategory| |#2| (QUOTE (|PatternMatchable| (|Integer|))))
        (|HasCategory| |#4| (QUOTE (|ConvertibleTo| (|Pattern| (|Float|)))))
        (|HasCategory| |#2| (QUOTE (|ConvertibleTo| (|Pattern| (|Float|)))))
        (|HasCategory| |#4| (QUOTE (|ConvertibleTo| (|Pattern| (|Integer|)))))
        (|HasCategory| |#2| (QUOTE (|ConvertibleTo| (|Pattern| (|Integer|)))))
        (|HasCategory| |#4| (QUOTE (|ConvertibleTo| (|InputForm|))))
        (|HasCategory| |#2| (QUOTE (|ConvertibleTo| (|InputForm|))))
        (|HasCategory| |#2| (QUOTE (|OrderedSet|))))
      . #0#))
    (|stuffDomainSlots| $)
    (QSETREFV $ 6 |#1|)
    (QSETREFV $ 7 |#2|)
    (QSETREFV $ 8 |#3|)
    (QSETREFV $ 9 |#4|)
    (COND
      ((|testBitVector| |pv$| 4)
        (PROGN
          (QSETREFV $ 74
            (CONS (|dispatchFunction| |POLYCAT-;resultant;2SVarSetS;15|) $))
          (QSETREFV $ 76
            (CONS (|dispatchFunction| |POLYCAT-;discriminant;SVarSetS;16|) $))))))
      (COND
        ((|HasCategory| |#2| (QUOTE (|IntegralDomain|)))
          (PROGN
            (QSETREFV $ 95
              (CONS (|dispatchFunction| |POLYCAT-;reducedSystem;MM;20|) $))
            (QSETREFV $ 102
              (CONS (|dispatchFunction| |POLYCAT-;reducedSystem;MVR;21|) $))))))
      (COND
        ((|testBitVector| |pv$| 1)
          (PROGN
            (QSETREFV $ 105
              (CONS (|dispatchFunction| |POLYCAT-;gcdPolynomial;3Sup;22|) $))

```

```

(QSETREFV $ 112
  (CONS
    (|dispatchFunction|
      |POLYCAT-;solveLinearPolynomialEquation;LSupU;23|)
    $))
(QSETREFV $ 116
  (CONS (|dispatchFunction| |POLYCAT-;factorPolynomial;SupF;24|) $))
(QSETREFV $ 118
  (CONS
    (|dispatchFunction| |POLYCAT-;factorSquareFreePolynomial;SupF;25|)
    $))
(QSETREFV $ 136 (CONS (|dispatchFunction| |POLYCAT-;factor;SF;26|) $))
(COND
  ((|HasCategory| |#2| (QUOTE (|CharacteristicNonZero|)))
    (PROGN
      (QSETREFV $ 150
        (CONS (|dispatchFunction| |POLYCAT-;conditionP;MU;27|) $))))))
(COND
  ((|HasCategory| |#2| (QUOTE (|CharacteristicNonZero|)))
    (PROGN
      (QSETREFV $ 152
        (CONS (|dispatchFunction| |POLYCAT-;charthRoot;SU;28|) $))))))
(COND
  ((|testBitVector| |pv$| 3)
    (PROGN
      (COND
        ((|HasCategory| |#2| (QUOTE (|EuclideanDomain|)))
          (COND
            ((|HasCategory| |#2| (QUOTE (|CharacteristicZero|)))
              (QSETREFV $ 161
                (CONS (|dispatchFunction| |POLYCAT-;squareFree;SF;31|) $)))
              ((QUOTE T)
                (QSETREFV $ 161
                  (CONS (|dispatchFunction| |POLYCAT-;squareFree;SF;32|) $))))))
            ((QUOTE T)
              (QSETREFV $ 161
                (CONS (|dispatchFunction| |POLYCAT-;squareFree;SF;33|) $))))
          (QSETREFV $ 169
            (CONS (|dispatchFunction| |POLYCAT-;squareFreePart;2S;34|) $))
            (QSETREFV $ 171
              (CONS (|dispatchFunction| |POLYCAT-;content;SVarSetS;35|) $))
              (QSETREFV $ 177
                (CONS (|dispatchFunction| |POLYCAT-;primitivePart;2S;36|) $))
                (QSETREFV $ 180
                  (CONS (|dispatchFunction| |POLYCAT-;primitivePart;SVarSetS;37|) $))))))
        ((|testBitVector| |pv$| 15)
          (PROGN
            (QSETREFV $ 183 (CONS (|dispatchFunction| |POLYCAT-;<;2SB;38|) $))
            (COND

```

```

((|testBitVector| |pv$| 8)
(COND
  ((|testBitVector| |pv$| 7)
  (QSETREFV $ 189
  (CONS
    (|dispatchFunction| |POLYCAT-;patternMatch;SP2Pmr;39|)
    $))))))
(COND
  ((|testBitVector| |pv$| 6)
  (COND
    ((|testBitVector| |pv$| 5)
    (QSETREFV $ 195
    (CONS
      (|dispatchFunction| |POLYCAT-;patternMatch;SP2Pmr;40|)
      $))))))
(COND
  ((|testBitVector| |pv$| 12)
  (COND
    ((|testBitVector| |pv$| 11)
    (QSETREFV $ 202
    (CONS (|dispatchFunction| |POLYCAT-;convert;SP;41|) $))))))
(COND
  ((|testBitVector| |pv$| 10)
  (COND
    ((|testBitVector| |pv$| 9)
    (QSETREFV $ 209
    (CONS (|dispatchFunction| |POLYCAT-;convert;SP;42|) $))))))
(COND
  ((|testBitVector| |pv$| 14)
  (COND
    ((|testBitVector| |pv$| 13)
    (QSETREFV $ 217
    (CONS (|dispatchFunction| |POLYCAT-;convert;SIf;43|) $))))))
$)))

(setf (get
  (QUOTE |PolynomialCategory&|)
  (QUOTE |infovec|))
  (LIST (QUOTE
    #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|) (|local| |#3|)
      (|local| |#4|) (|Equation| 6) (0 . |lhs|) (|Union| 9 (QUOTE "failed"))
      (5 . |retractIfCan|) (10 . |retract|) (15 . |rhs|) (|List| 9) (|List| $)
      (20 . |eval|) (|List| 221) |POLYCAT-;eval;SLS;1| (27 . |Zero|)
      (31 . |Zero|) (|Boolean|) (35 . =) (41 . |leadingMonomial|)
      (46 . |reductum|) |POLYCAT-;monomials;SL;2| (51 . |monomials|)
      (|Union| 17 (QUOTE "failed")) |POLYCAT-;isPlus;SU;3| (56 . |variables|)
      (61 . |monomial?|) (66 . |One|) (70 . |One|) (|NonNegativeInteger|)
      (74 . |degree|) (80 . |monomial|) (87 . |leadingCoefficient|) (92 . =)
      (98 . |coerce|) |POLYCAT-;isTimes;SU;4| (103 . |mainVariable|)
      (|Record| (|:| |var| 9) (|:| |exponent| 35))
  ))

```

```

(|Union| 43 (QUOTE "failed")) |POLYCAT-;isExpt;SU;5|
(|SparseUnivariatePolynomial| $) (108 . |univariate|)
(|SparseUnivariatePolynomial| 6) (114 . |coefficient|)
|POLYCAT-;coefficient;SVarSetNniS;6| (|List| 35) (120 . |coefficient|)
|POLYCAT-;coefficient;SLLS;7| (127 . |monomial|)
|POLYCAT-;monomial;SLLS;8| (134 . |coerce|)
|POLYCAT-;retract;SVarSet;9| |POLYCAT-;retractIfCan;SU;10|
(139 . |degree|) (144 . |monomial|) |POLYCAT-;primitiveMonomials;SL;12|
(150 . |ground?|) (155 . |Zero|) (159 . =) (165 . |degree|)
(170 . |leadingCoefficient|) (175 . |totalDegree|) (180 . |reductum|)
|POLYCAT-;totalDegree;SNni;13| (185 . |member?|) (191 . |totalDegree|)
|POLYCAT-;totalDegree;SLNni;14| (197 . |resultant|) (203 . |resultant|)
(210 . |discriminant|) (215 . |discriminant|) (221 . |primitiveMonomials|)
(|List| 6) (226 . |concat|) (231 . |removeDuplicates!|) (|Vector| 7)
(236 . |new|) (|Integer|) (242 . |minIndex|) (247 . |coefficient|)
(253 . |qsetelt!|) (|List| 220) (|Matrix| 7) (260 . |matrix|)
(|List| 78) (|Matrix| 6) (265 . |listOfLists|) (270 . |vertConcat|)
(|Matrix| $) (276 . |reducedSystem|) (|Vector| 6) (281 . |entries|)
(286 . |concat|) (292 . |concat|)
(|Record| (|:| |mat| 88) (|:| |vec| 81)) (|Vector| $)
(298 . |reducedSystem|) (|GeneralPolynomialGcdPackage| 8 9 7 6)
(304 . |gcdPolynomial|) (310 . |gcdPolynomial|)
(|Union| 107 (QUOTE "failed")) (|List| 48)
(|PolynomialFactorizationByRecursion| 7 8 9 6)
(316 . |solveLinearPolynomialEquationByRecursion|)
(|Union| 111 (QUOTE "failed")) (|List| 46)
(322 . |solveLinearPolynomialEquation|) (|Factored| 48)
(328 . |factorByRecursion|) (|Factored| 46) (333 . |factorPolynomial|)
(338 . |factorSquareFreeByRecursion|)
(343 . |factorSquareFreePolynomial|) (|Factored| $) (348 . |factor|)
(|Factored| 7) (353 . |unit|)
(|Union| (QUOTE "nil") (QUOTE "sqfr") (QUOTE "irred") (QUOTE "prime"))
(|Record| (|:| |flg| 123) (|:| |fctr| 7) (|:| |xpnt| 83))
(|List| 124) (358 . |factorList|)
(|Record| (|:| |flg| 123) (|:| |fctr| 6) (|:| |xpnt| 83))
(|List| 127) (|Factored| 6) (363 . |makeFR|) (369 . |unit|)
(374 . |multivariate|)
(|Record| (|:| |flg| 123) (|:| |fctr| 48) (|:| |xpnt| 83))
(|List| 133) (380 . |factorList|) (385 . |factor|) (390 . |transpose|)
(395 . |characteristic|) (399 . |setUnion|) (405 . |degree|)
(|Union| $ (QUOTE "failed")) (411 . |exquo|) (417 . |ground|)
(422 . |transpose|) (|Union| 101 (QUOTE "failed")) (427 . |conditionP|)
(432 . |elt|) (438 . *) (444 . +) (450 . |conditionP|)
(455 . |charthRoot|) (460 . |charthRoot|) (465 . |Zero|)
(469 . |coefficient|) (476 . -)
(|Record| (|:| |quotient| $) (|:| |remainder| $))
(482 . |monicDivide|) |POLYCAT-;monicDivide;2SVarSetR;30|
(|MultivariateSquareFree| 8 9 7 6) (488 . |squareFree|)
(493 . |squareFree|) (|PolynomialSquareFree| 9 8 7 6)
(498 . |squareFree|) (503 . |squareFree|) (508 . |unit|)

```



```

(|Record| (|:| |factor| 6) (|:| |exponent| 83)) (|List| 166)
(513 . |factors|) (518 . |squareFreePart|) (523 . |content|)
(528 . |content|) (534 . |zero?|) (539 . |content|) (544 . |exquo|)
(|Record| (|:| |unit| $) (|:| |canonical| $) (|:| |associate| $))
(550 . |unitNormal|) (555 . |primitivePart|) (560 . |content|)
(566 . |exquo|) (572 . |primitivePart|) (578 . <) (584 . <) (590 . <)
(|PatternMatchResult| 83 6) (|Pattern| 83)
(|PatternMatchPolynomialCategory| 83 8 9 7 6) (596 . |patternMatch|)
(|PatternMatchResult| 83 $) (603 . |patternMatch|)
(|PatternMatchResult| (|Float|) 6) (|Pattern| (|Float|))
(|PatternMatchPolynomialCategory| (|Float|) 8 9 7 6)
(610 . |patternMatch|) (|PatternMatchResult| (|Float|) $)
(617 . |patternMatch|) (624 . |convert|) (629 . |convert|)
(|Mapping| 185 9) (|Mapping| 185 7)
(|PolynomialCategoryLifting| 8 9 7 6 185) (634 . |map|)
(641 . |convert|) (646 . |convert|) (651 . |convert|) (|Mapping| 191 9)
(|Mapping| 191 7) (|PolynomialCategoryLifting| 8 9 7 6 191)
(656 . |map|) (663 . |convert|) (|InputForm|) (668 . |convert|)
(673 . |convert|) (|Mapping| 210 9) (|Mapping| 210 7)
(|PolynomialCategoryLifting| 8 9 7 6 210) (678 . |map|)
(685 . |convert|) (|Record| (|:| |mat| 219) (|:| |vec| (|Vector| 83)))
(|Matrix| 83) (|List| 7) (|Equation| $) (|Union| 83 (QUOTE "failed"))
(|Union| 224 (QUOTE "failed")) (|Fraction| 83)
(|Union| 7 (QUOTE "failed"))))
(QUOTE #(|totalDegree| 690 |squareFreePart| 701 |squareFree| 706
|solveLinearPolynomialEquation| 711 |retractIfCan| 717 |retract| 722
|resultant| 727 |reducedSystem| 734 |primitivePart| 745
|primitiveMonomials| 756 |patternMatch| 761 |monomials| 775
|monomial| 780 |monicDivide| 787 |isTimes| 794 |isPlus| 799
|isExpt| 804 |gcdPolynomial| 809 |factorSquareFreePolynomial| 815
|factorPolynomial| 820 |factor| 825 |eval| 830 |discriminant| 836
|convert| 842 |content| 857 |conditionP| 863 |coefficient| 868
|charthRoot| 882 < 887))
(QUOTE NIL)
(CONS (|makeByteWordVec2| 1 (QUOTE NIL))
(CONS (QUOTE #())
(CONS (QUOTE #())
(|makeByteWordVec2| 217 (QUOTE
(1 10 6 0 11 1 6 12 0 13 1 6 9 0 14 1 10 6 0 15 3 6 0 0 16 17 18 0 6 0
21 0 7 0 22 2 6 23 0 0 24 1 6 0 0 25 1 6 0 0 26 1 6 17 0 28 1 6 16 0
31 1 6 23 0 32 0 6 0 33 0 7 0 34 2 6 35 0 9 36 3 6 0 0 9 35 37 1 6 7
0 38 2 7 23 0 0 39 1 6 0 7 40 1 6 12 0 42 2 6 46 0 9 47 2 48 6 0 35
49 3 6 0 0 16 51 52 3 6 0 0 16 51 54 1 6 0 9 56 1 6 8 0 59 2 6 0 7 8
60 1 6 23 0 62 0 48 0 63 2 48 23 0 0 64 1 48 35 0 65 1 48 6 0 66 1 6
35 0 67 1 48 0 0 68 2 16 23 9 0 70 2 6 35 0 16 71 2 48 6 0 0 73 3 0
0 0 0 9 74 1 48 6 0 75 2 0 0 0 9 76 1 6 17 0 77 1 78 0 17 79 1 78 0
0 80 2 81 0 35 7 82 1 81 83 0 84 2 6 7 0 8 85 3 81 7 0 83 7 86 1 88
0 87 89 1 91 90 0 92 2 88 0 0 0 93 1 0 88 94 95 1 96 78 0 97 2 78 0
0 0 98 2 81 0 0 0 99 2 0 100 94 101 102 2 103 48 48 104 2 0 46 46
46 105 2 108 106 107 48 109 2 0 110 111 46 112 1 108 113 48 114 1 0

```

```

115 46 116 1 108 113 48 117 1 0 115 46 118 1 7 119 0 120 1 121 7 0
122 1 121 125 0 126 2 129 0 6 128 130 1 113 48 0 131 2 6 0 46 9 132
1 113 134 0 135 1 0 119 0 136 1 91 0 0 137 0 6 35 138 2 78 0 0 0 139
2 6 51 0 16 140 2 83 141 0 0 142 1 6 7 0 143 1 88 0 0 144 1 7 145 94
146 2 81 7 0 83 147 2 6 0 0 0 148 2 6 0 0 0 149 1 0 145 94 150 1 7
141 0 151 1 0 141 0 152 0 8 0 153 3 6 0 0 9 35 154 2 6 0 0 0 155 2
48 156 0 0 157 1 159 129 6 160 1 0 119 0 161 1 162 129 6 163 1 6 119
0 164 1 129 6 0 165 1 129 167 0 168 1 0 0 0 169 1 48 6 0 170 2 0 0 0
9 171 1 6 23 0 172 1 6 7 0 173 2 6 141 0 7 174 1 6 175 0 176 1 0 0 0
177 2 6 0 0 9 178 2 6 141 0 0 179 2 0 0 0 9 180 2 8 23 0 0 181 2 7 23
0 0 182 2 0 23 0 0 183 3 186 184 6 185 184 187 3 0 188 0 185 188 189
3 192 190 6 191 190 193 3 0 194 0 191 194 195 1 9 185 0 196 1 7 185
0 197 3 200 185 198 199 6 201 1 0 185 0 202 1 9 191 0 203 1 7 191 0
204 3 207 191 205 206 6 208 1 0 191 0 209 1 9 210 0 211 1 7 210 0
212 3 215 210 213 214 6 216 1 0 210 0 217 2 0 35 0 16 72 1 0 35 0 69
1 0 0 0 169 1 0 119 0 161 2 0 110 111 46 112 1 0 12 0 58 1 0 9 0 57
3 0 0 0 0 9 74 1 0 88 94 95 2 0 100 94 101 102 2 0 0 0 9 180 1 0 0 0
177 1 0 17 0 61 3 0 188 0 185 188 189 3 0 194 0 191 194 195 1 0 17 0
27 3 0 0 0 16 51 55 3 0 156 0 0 9 158 1 0 29 0 41 1 0 29 0 30 1 0 44
0 45 2 0 46 46 46 105 1 0 115 46 118 1 0 115 46 116 1 0 119 0 136 2
0 0 0 19 20 2 0 0 0 9 76 1 0 210 0 217 1 0 185 0 202 1 0 191 0 209 2
0 0 0 9 171 1 0 145 94 150 3 0 0 0 16 51 53 3 0 0 0 9 35 50 1 0 141
0 152 2 0 23 0 0 183))))))
(QUOTE |lookupComplete|))

```

21.45 PSETCAT.lsp BOOTSTRAP

PSETCAT depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **PSETCAT** category which we can write into the **MID** directory. We compile the lisp code and copy the **PSETCAT.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— PSETCAT.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |PolynomialSetCategory;CAT| (QUOTE NIL))

(SETQ |PolynomialSetCategory;AL| (QUOTE NIL))

(DEFUN |PolynomialSetCategory| (|&REST| #1=#:G82375 |&AUX| #2=#:G82373)
  (DSETQ #2# #1#)

```

```

(LET (#3=:G82374)
  (COND
    ((SETQ #3# (|assoc| (|devalueList| #2#) |PolynomialSetCategory;AL|))
     (CDR #3#))
    (T
     (SETQ |PolynomialSetCategory;AL|
       (|cons5|
        (CONS
         (|devalueList| #2#)
         (SETQ #3# (APPLY (FUNCTION |PolynomialSetCategory;|) #2#)))
        |PolynomialSetCategory;AL|))
      #3#))))

(DEFUN |PolynomialSetCategory;| (|t#1| |t#2| |t#3| |t#4|)
  (PROG (#1=:G82372)
    (RETURN
     (PROG1
      (LETT #1#
        (|sublisV|
         (PAIR
          (QUOTE (|t#1| |t#2| |t#3| |t#4|))
          (LIST
           (|devalue| |t#1|)
           (|devalue| |t#2|)
           (|devalue| |t#3|)
           (|devalue| |t#4|)))
         (|sublisV|
          (PAIR (QUOTE (#2=:G82371)) (LIST (QUOTE (|List| |t#4|)))))
         (COND
          (|PolynomialSetCategory;CAT|)
          ((QUOTE T)
           (LETT |PolynomialSetCategory;CAT|
             (|Join|
              (|SetCategory|)
              (|Collection| (QUOTE |t#4|))
              (|CoercibleTo| (QUOTE #2#))
              (|mkCategory|
               (QUOTE |domain|)
               (QUOTE (
                 ((|retractIfCan| ((|Union| |$| "failed") (|List| |t#4|))) T)
                 ((|retract| (|List| |t#4|))) T)
                 ((|mvar| (|t#3| |$|)) T)
                 ((|variables| ((|List| |t#3|) |$|)) T)
                 ((|mainVariables| ((|List| |t#3|) |$|)) T)
                 ((|mainVariable?| ((|Boolean|) |t#3| |$|)) T)
                 ((|collectUnder| (|List| |t#3|)) T)
                 ((|collect| (|List| |t#3|)) T)
                 ((|collectUpper| (|List| |t#3|)) T)
                 ((|sort|
                  ((|Record|

```

```

(|:| |under| |$|)
(|:| |floor| |$|)
(|:| |upper| |$|)) |$| |t#3|))
T)
((|trivialIdeal?| ((|Boolean|) |$|)) T)
((|roughBase?| ((|Boolean|) |$|))
  (|has| |t#1| (|IntegralDomain|)))
((|roughSubIdeal?| ((|Boolean|) |$| |$|))
  (|has| |t#1| (|IntegralDomain|)))
((|roughEqualIdeals?| ((|Boolean|) |$| |$|))
  (|has| |t#1| (|IntegralDomain|)))
((|roughUnitIdeal?| ((|Boolean|) |$|))
  (|has| |t#1| (|IntegralDomain|)))
((|headRemainder|
  ((|Record|
    (|:| |num| |t#4|)
    (|:| |den| |t#1|)) |t#4| |$|))
    (|has| |t#1| (|IntegralDomain|))))
(|remainder|
  ((|Record|
    (|:| |rnum| |t#1|)
    (|:| |polnum| |t#4|)
    (|:| |den| |t#1|)) |t#4| |$|))
    (|has| |t#1| (|IntegralDomain|))))
(|rewriteIdealWithHeadRemainder|
  ((|List| |t#4|) (|List| |t#4|) |$|))
  (|has| |t#1| (|IntegralDomain|)))
(|rewriteIdealWithRemainder| ((|List| |t#4|) (|List| |t#4|) |$|))
  (|has| |t#1| (|IntegralDomain|)))
(|triangular?| ((|Boolean|) |$|))
  (|has| |t#1| (|IntegralDomain|))))))
(QUOTE ((|finiteAggregate| T)))
(QUOTE ((|Boolean|) (|List| |t#4|) (|List| |t#3|)))
NIL))
. #3=(|PolynomialSetCategory|))))))
. #3#)
(SETELT #1# 0
(LIST
  (QUOTE |PolynomialSetCategory|)
  (|devaluate| |t#1|)
  (|devaluate| |t#2|)
  (|devaluate| |t#3|)
  (|devaluate| |t#4|))))))

```

21.46 PSETCAT-.lsp BOOTSTRAP

PSETCAT- depends on **PSETCAT**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **PSETCAT-** category which we can write into the **MID** directory. We compile the lisp code and copy the **PSETCAT-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— PSETCAT-.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(DEFUN |PSETCAT-;elements| (|ps| |$|)
  (PROG (|lp|)
    (RETURN
      (LETT |lp| (SPADCALL |ps| (QREFELT |$| 12)) |PSETCAT-;elements|))))

(DEFUN |PSETCAT-;variables1| (|lp| |$|)
  (PROG (#1=:G82392 |p| #2=:G82393 |lvars|)
    (RETURN
      (SEQ
        (LETT |lvars|
          (PROGN
            (LETT #1# NIL |PSETCAT-;variables1|)
            (SEQ
              (LETT |p| NIL |PSETCAT-;variables1|)
              (LETT #2# |lp| |PSETCAT-;variables1|)
              G190
              (COND
                ((OR (ATOM #2#) (PROGN (LETT |p| (CAR #2#) |PSETCAT-;variables1|) NIL))
                  (GO G191)))
              (SEQ
                (EXIT
                  (LETT #1#
                    (CONS (SPADCALL |p| (QREFELT |$| 14)) #1#) |PSETCAT-;variables1|)))
                (LETT #2# (CDR #2#) |PSETCAT-;variables1|)
                (GO G190)
                G191
                (EXIT (NREVERSEO #1#))))
            |PSETCAT-;variables1|)
          (EXIT
            (SPADCALL
              (CONS (FUNCTION |PSETCAT-;variables1!0|) |$|)
              (SPADCALL (SPADCALL |lvars| (QREFELT |$| 18)) (QREFELT |$| 19))
              (QREFELT |$| 21)))))))

(DEFUN |PSETCAT-;variables1!0| (|#1| |#2| |$|)
```

```

(SPADCALL |#2| |#1| (QREFELT |$| 16)))

(DEFUN |PSETCAT-;variables2| (|lp| |$|)
  (PROG (#1=#:G82397 |p| #2=#:G82398 |lvars|)
    (RETURN
      (SEQ
        (LETT |lvars|
          (PROGN
            (LETT #1# NIL |PSETCAT-;variables2|)
            (SEQ
              (LETT |p| NIL |PSETCAT-;variables2|)
              (LETT #2# |lp| |PSETCAT-;variables2|)
              G190
              (COND
                ((OR (ATOM #2#) (PROGN (LETT |p| (CAR #2#) |PSETCAT-;variables2|) NIL))
                  (GO G191)))
              (SEQ
                (EXIT
                  (LETT #1#
                    (CONS (SPADCALL |p| (QREFELT |$| 22)) #1#) |PSETCAT-;variables2|)))
                (LETT #2# (CDR #2#) |PSETCAT-;variables2|)
                (GO G190)
                G191
                (EXIT (NREVERSEO #1#))))
              |PSETCAT-;variables2|)
            (EXIT
              (SPADCALL
                (CONS (FUNCTION |PSETCAT-;variables2!0|) |$|)
                (SPADCALL |lvars| (QREFELT |$| 19))
                (QREFELT |$| 21)))))))

(DEFUN |PSETCAT-;variables2!0| (|#1| |#2| |$|)
  (SPADCALL |#2| |#1| (QREFELT |$| 16)))

(DEFUN |PSETCAT-;variables;SL;4| (|ps| |$|)
  (|PSETCAT-;variables1| (|PSETCAT-;elements| |ps| |$|) |$|))

(DEFUN |PSETCAT-;mainVariables;SL;5| (|ps| |$|)
  (|PSETCAT-;variables2|
    (SPADCALL (ELT |$| 24) (|PSETCAT-;elements| |ps| |$|) (QREFELT |$| 26))
    |$|))

(DEFUN |PSETCAT-;mainVariable?;VarSetSB;6| (|v| |ps| |$|)
  (PROG (|lp|)
    (RETURN
      (SEQ
        (LETT |lp|
          (SPADCALL (ELT |$| 24) (|PSETCAT-;elements| |ps| |$|) (QREFELT |$| 26))
          |PSETCAT-;mainVariable?;VarSetSB;6|)
        (SEQ

```

```

G190
(COND
  (NULL
    (COND
      ((OR
        (NULL |lp|)
        (SPADCALL
          (SPADCALL (|SPADfirst| |lp|) (QREFELT |$| 22))
          |v|
          (QREFELT |$| 28)))
        (QUOTE NIL))
      ((QUOTE T) (QUOTE T))))
  (GO G191)))
(SEQ (EXIT (LETT |lp| (CDR |lp|) |PSETCAT-;mainVariable?;VarSetSB;6|)))
NIL
(GO G190)
G191
(EXIT NIL))
(EXIT (COND ((NULL |lp|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))))

(DEFUN |PSETCAT-;collectUnder;SVarSetS;7| (|ps| |v| |$|)
  (PROG (|p| |lp| |lq|)
    (RETURN
      (SEQ
        (LETT |lp|
          (|PSETCAT-;elements| |ps| |$|)
          |PSETCAT-;collectUnder;SVarSetS;7|)
        (LETT |lq| NIL |PSETCAT-;collectUnder;SVarSetS;7|)
        (SEQ
          G190
          (COND
            ((NULL (COND ((NULL |lp|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
            (GO G191)))
          (SEQ
            (LETT |p| (|SPADfirst| |lp|) |PSETCAT-;collectUnder;SVarSetS;7|)
            (LETT |lp| (CDR |lp|) |PSETCAT-;collectUnder;SVarSetS;7|)
            (EXIT
              (COND
                ((OR
                  (SPADCALL |p| (QREFELT |$| 24))
                  (SPADCALL (SPADCALL |p| (QREFELT |$| 22)) |v| (QREFELT |$| 16)))
                (LETT |lq| (CONS |p| |lq|) |PSETCAT-;collectUnder;SVarSetS;7|))))))
          NIL
          (GO G190)
          G191
          (EXIT NIL))
        (EXIT (SPADCALL |lq| (QREFELT |$| 30))))))

(DEFUN |PSETCAT-;collectUpper;SVarSetS;8| (|ps| |v| |$|)
  (PROG (|p| |lp| |lq|)

```

```

(RETURN
  (SEQ
    (LETT |lp|
      (|PSETCAT-;elements| |ps| |$|)
      |PSETCAT-;collectUpper;SVarSetS;8|)
    (LETT |lq| NIL |PSETCAT-;collectUpper;SVarSetS;8|)
    (SEQ
      G190
      (COND
        ((NULL (COND ((NULL |lp|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
        (GO G191)))
    (SEQ
      (LETT |p| (|SPADfirst| |lp|) |PSETCAT-;collectUpper;SVarSetS;8|)
      (LETT |lp| (CDR |lp|) |PSETCAT-;collectUpper;SVarSetS;8|)
      (EXIT
        (COND
          ((NULL (SPADCALL |p| (QREFELT |$| 24)))
            (COND
              ((SPADCALL |v| (SPADCALL |p| (QREFELT |$| 22)) (QREFELT |$| 16))
                (LETT |lq| (CONS |p| |lq|) |PSETCAT-;collectUpper;SVarSetS;8|)))))))
      NIL
      (GO G190)
      G191
      (EXIT NIL))
    (EXIT (SPADCALL |lq| (QREFELT |$| 30))))))

(DEFUN |PSETCAT-;collect;SVarSetS;9| (|ps| |v| |$|)
  (PROG (|p| |lp| |lq|)
    (RETURN
      (SEQ
        (LETT |lp| (|PSETCAT-;elements| |ps| |$|) |PSETCAT-;collect;SVarSetS;9|)
        (LETT |lq| NIL |PSETCAT-;collect;SVarSetS;9|)
        (SEQ
          G190
          (COND
            ((NULL (COND ((NULL |lp|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
            (GO G191)))
        (SEQ
          (LETT |p| (|SPADfirst| |lp|) |PSETCAT-;collect;SVarSetS;9|)
          (LETT |lp| (CDR |lp|) |PSETCAT-;collect;SVarSetS;9|)
          (EXIT
            (COND
              ((NULL (SPADCALL |p| (QREFELT |$| 24)))
                (COND
                  ((SPADCALL (SPADCALL |p| (QREFELT |$| 22)) |v| (QREFELT |$| 28))
                    (LETT |lq| (CONS |p| |lq|) |PSETCAT-;collect;SVarSetS;9|)))))))
          NIL
          (GO G190)
          G191
          (EXIT NIL))
      )
    )
  )

```



```

(EXIT (SPADCALL |lq| (QREFELT |$| 30))))))

(DEFUN |PSETCAT-;sort;SVarSetR;10| (|ps| |v| |$|)
  (PROG (|p| |lp| |us| |vs| |ws|)
    (RETURN
      (SEQ
        (LETT |lp| (|PSETCAT-;elements| |ps| |$|) |PSETCAT-;sort;SVarSetR;10|)
        (LETT |us| NIL |PSETCAT-;sort;SVarSetR;10|)
        (LETT |vs| NIL |PSETCAT-;sort;SVarSetR;10|)
        (LETT |ws| NIL |PSETCAT-;sort;SVarSetR;10|)
        (SEQ
          G190
          (COND
            ((NULL (COND ((NULL |lp|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
            (GO G191)))
          (SEQ
            (LETT |p| (|SPADfirst| |lp|) |PSETCAT-;sort;SVarSetR;10|)
            (LETT |lp| (CDR |lp|) |PSETCAT-;sort;SVarSetR;10|)
            (EXIT
              (COND
                ((OR
                  (SPADCALL |p| (QREFELT |$| 24))
                  (SPADCALL (SPADCALL |p| (QREFELT |$| 22)) |v| (QREFELT |$| 16))
                  (LETT |us| (CONS |p| |us|) |PSETCAT-;sort;SVarSetR;10|)
                  ((SPADCALL (SPADCALL |p| (QREFELT |$| 22)) |v| (QREFELT |$| 28))
                    (LETT |vs| (CONS |p| |vs|) |PSETCAT-;sort;SVarSetR;10|)
                    ((QUOTE T) (LETT |ws| (CONS |p| |ws|) |PSETCAT-;sort;SVarSetR;10|))))))
              NIL
              (GO G190)
              G191
              (EXIT NIL))
            (EXIT
              (VECTOR
                (SPADCALL |us| (QREFELT |$| 30))
                (SPADCALL |vs| (QREFELT |$| 30))
                (SPADCALL |ws| (QREFELT |$| 30)))))))
        NIL
        (GO G190)
        G191
        (EXIT NIL))
      (EXIT
        (VECTOR
          (SPADCALL |us| (QREFELT |$| 30))
          (SPADCALL |vs| (QREFELT |$| 30))
          (SPADCALL |ws| (QREFELT |$| 30))))))

(DEFUN |PSETCAT-;;2SB;11| (|ps1| |ps2| |$|)
  (PROG (#1=:G82439 #2=:G82440 #3=:G82437 |p| #4=:G82438)
    (RETURN
      (SEQ
        (SPADCALL
          (SPADCALL
            (PROGN
              (LETT #1# NIL |PSETCAT-;;2SB;11|)
              (SEQ
                (LETT |p| NIL |PSETCAT-;;2SB;11|)
                (LETT #2# (|PSETCAT-;elements| |ps1| |$|) |PSETCAT-;;2SB;11|)
                G190
                (COND

```

```

      ((OR (ATOM #2#) (PROGN (LETT |p| (CAR #2#) |PSETCAT-;=;2SB;11|) NIL))
        (GO G191)))
    (SEQ (EXIT (LETT #1# (CONS |p| #1#) |PSETCAT-;=;2SB;11|)))
    (LETT #2# (CDR #2#) |PSETCAT-;=;2SB;11|)
    (GO G190)
  G191
  (EXIT (NREVERSEO #1#)))
(QREFELT |$| 37))
(SPADCALL
  (PROGN
    (LETT #3# NIL |PSETCAT-;=;2SB;11|)
    (SEQ
      (LETT |p| NIL |PSETCAT-;=;2SB;11|)
      (LETT #4# (|PSETCAT-;elements| |ps2| |$|) |PSETCAT-;=;2SB;11|)
      G190
      (COND
        ((OR (ATOM #4#) (PROGN (LETT |p| (CAR #4#) |PSETCAT-;=;2SB;11|) NIL))
          (GO G191)))
        (SEQ (EXIT (LETT #3# (CONS |p| #3#) |PSETCAT-;=;2SB;11|)))
        (LETT #4# (CDR #4#) |PSETCAT-;=;2SB;11|)
        (GO G190)
        G191
        (EXIT (NREVERSEO #3#)))
      (QREFELT |$| 37))
    (QREFELT |$| 38))))))

(DEFUN |PSETCAT-;localInf?| (|p| |q| |$|)
  (SPADCALL
    (SPADCALL |p| (QREFELT |$| 40))
    (SPADCALL |q| (QREFELT |$| 40))
    (QREFELT |$| 41)))

(DEFUN |PSETCAT-;localTriangular?| (|lp| |$|)
  (PROG (|q| |p|)
    (RETURN
      (SEQ
        (LETT |lp|
          (SPADCALL (ELT |$| 42) |lp| (QREFELT |$| 26)) |PSETCAT-;localTriangular?|)
        (EXIT
          (COND
            ((NULL |lp|) (QUOTE T))
            ((SPADCALL (ELT |$| 24) |lp| (QREFELT |$| 43)) (QUOTE NIL))
            (QUOTE T)
            (SEQ
              (LETT |lp|
                (SPADCALL
                  (CONS (FUNCTION |PSETCAT-;localTriangular?!0|) |$|)
                  |lp|
                  (QREFELT |$| 45))
                |PSETCAT-;localTriangular?|)

```

```

(LETT |p| (|SPADfirst| |lp|) |PSETCAT-;localTriangular?|)
(LETT |lp| (CDR |lp|) |PSETCAT-;localTriangular?|)
(SEQ
  G190
  (COND
    ((NULL
      (COND
        ((NULL |lp|) (QUOTE NIL))
        ((QUOTE T)
          (SPADCALL
            (SPADCALL
              (LETT |q|
                (|SPADfirst| |lp|)
                |PSETCAT-;localTriangular?|)
                (QREFELT |$| 22))
              (SPADCALL |p| (QREFELT |$| 22)) (QREFELT |$| 16))))))
      (GO G191)))
  (SEQ
    (LETT |p| |q| |PSETCAT-;localTriangular?|)
    (EXIT (LETT |lp| (CDR |lp|) |PSETCAT-;localTriangular?|)))
  NIL
  (GO G190)
  G191
  (EXIT NIL))
(EXIT (NULL |lp|)))))))))

(DEFUN |PSETCAT-;localTriangular?!0| (|#1| |#2| |$|)
  (SPADCALL
    (SPADCALL |#2| (QREFELT |$| 22))
    (SPADCALL |#1| (QREFELT |$| 22))
    (QREFELT |$| 16)))

(DEFUN |PSETCAT-;triangular?;SB;14| (|ps| |$|)
  (|PSETCAT-;localTriangular?| (|PSETCAT-;elements| |ps| |$|) |$|))

(DEFUN |PSETCAT-;trivialIdeal?;SB;15| (|ps| |$|)
  (NULL
    (SPADCALL (ELT |$| 42) (|PSETCAT-;elements| |ps| |$|) (QREFELT |$| 26))))

(DEFUN |PSETCAT-;roughUnitIdeal?;SB;16| (|ps| |$|)
  (SPADCALL
    (ELT |$| 24)
    (SPADCALL (ELT |$| 42) (|PSETCAT-;elements| |ps| |$|) (QREFELT |$| 26))
    (QREFELT |$| 43)))

(DEFUN |PSETCAT-;relativelyPrimeLeadingMonomials?| (|p| |q| |$|)
  (PROG (|dp| |dq|)
    (RETURN
      (SEQ
        (LETT |dp|

```

```

      (SPADCALL |p| (QREFELT |$| 40))
      |PSETCAT-;relativelyPrimeLeadingMonomials?|)
(LETT |dq|
  (SPADCALL |q| (QREFELT |$| 40))
  |PSETCAT-;relativelyPrimeLeadingMonomials?|)
(EXIT
  (SPADCALL
    (SPADCALL |dp| |dq| (QREFELT |$| 49))
    (SPADCALL |dp| |dq| (QREFELT |$| 50))
    (QREFELT |$| 51))))))
(DEFUN |PSETCAT-;roughBase?;SB;18| (|ps| |$|)
  (PROG (|p| |lp| |rB?| |copylp|)
    (RETURN
      (SEQ
        (LETT |lp|
          (SPADCALL (ELT |$| 42) (|PSETCAT-;elements| |ps| |$|) (QREFELT |$| 26))
          |PSETCAT-;roughBase?;SB;18|)
        (EXIT
          (COND
            ((NULL |lp|) (QUOTE T))
            ((QUOTE T)
              (SEQ
                (LETT |rB?| (QUOTE T) |PSETCAT-;roughBase?;SB;18|)
                (SEQ
                  G190
                  (COND
                    ((NULL (COND ((NULL |lp|) (QUOTE NIL)) ((QUOTE T) |rB?|)))
                    (GO G191)))
                (SEQ
                  (LETT |p| (|SPADfirst| |lp|) |PSETCAT-;roughBase?;SB;18|)
                  (LETT |lp| (CDR |lp|) |PSETCAT-;roughBase?;SB;18|)
                  (LETT |copylp| |lp| |PSETCAT-;roughBase?;SB;18|)
                  (EXIT
                    (SEQ
                      G190
                      (COND
                        ((NULL (COND ((NULL |copylp|) (QUOTE NIL)) ((QUOTE T) |rB?|)))
                        (GO G191)))
                    (SEQ
                      (LETT |rB?|
                        (|PSETCAT-;relativelyPrimeLeadingMonomials?| |p|
                          (|SPADfirst| |copylp|) |$|)
                          |PSETCAT-;roughBase?;SB;18|)
                        (EXIT (LETT |copylp| (CDR |copylp|) |PSETCAT-;roughBase?;SB;18|)))
                      NIL
                      (GO G190)
                      G191
                      (EXIT NIL))))))
          NIL
          (GO G190)
          G191
          (EXIT NIL))))))
NIL

```

```

(GO G190)
G191
(EXIT NIL))
(EXIT |rB?|)))))))))

(DEFUN |PSETCAT-;roughSubIdeal?;2SB;19| (|ps1| |ps2| |$|)
  (PROG (|lp|)
    (RETURN
      (SEQ
        (LETT |lp|
          (SPADCALL (|PSETCAT-;elements| |ps1| |$|) |ps2| (QREFELT |$| 53))
          |PSETCAT-;roughSubIdeal?;2SB;19|)
          (EXIT (NULL (SPADCALL (ELT |$| 42) |lp| (QREFELT |$| 26))))))))))

(DEFUN |PSETCAT-;roughEqualIdeals?;2SB;20| (|ps1| |ps2| |$|)
  (COND
    ((SPADCALL |ps1| |ps2| (QREFELT |$| 55)) (QUOTE T))
    ((SPADCALL |ps1| |ps2| (QREFELT |$| 56))
      (SPADCALL |ps2| |ps1| (QREFELT |$| 56)))
    ((QUOTE T) (QUOTE NIL))))

(DEFUN |PSETCAT-;exactQuo| (|r| |s| |$|)
  (SPADCALL |r| |s| (QREFELT |$| 58)))

(DEFUN |PSETCAT-;exactQuo| (|r| |s| |$|)
  (PROG (#1=#:G82473)
    (RETURN
      (PROG2
        (LETT #1# (SPADCALL |r| |s| (QREFELT |$| 60)) |PSETCAT-;exactQuo|)
        (QCDR #1#)
        (|check-union| (QEQCAR #1# 0) (QREFELT |$| 7) #1#))))))

(DEFUN |PSETCAT-;headRemainder;PSR;23| (|a| |ps| |$|)
  (PROG (|lp1| |p| |e| |g| |#G47| |#G48| |lca| |lcp| |r| |lp2|)
    (RETURN
      (SEQ
        (LETT |lp1|
          (SPADCALL (ELT |$| 42) (|PSETCAT-;elements| |ps| |$|) (QREFELT |$| 26))
          |PSETCAT-;headRemainder;PSR;23|)
          (EXIT
            (COND
              ((NULL |lp1|) (CONS |a| (|spadConstant| |$| 61)))
              ((SPADCALL (ELT |$| 24) |lp1| (QREFELT |$| 43))
                (CONS (SPADCALL |a| (QREFELT |$| 62)) (|spadConstant| |$| 61)))
              ((QUOTE T)
                (SEQ
                  (LETT |r| (|spadConstant| |$| 61) |PSETCAT-;headRemainder;PSR;23|)
                  (LETT |lp1|
                    (SPADCALL
                      (CONS (|function| |PSETCAT-;localInf?|) |$|)

```

```

( REVERSE (|PSETCAT-;elements| |ps| |$|))
( QREFELT |$| 45))
|PSETCAT-;headRemainder;PSR;23|)
(LETT |lp2| |lp1| |PSETCAT-;headRemainder;PSR;23|)
(SEQ
G190
(COND
( (NULL
( COND
( (OR (SPADCALL |a| (QREFELT |$| 42)) (NULL |lp2|)) (QUOTE NIL))
( (QUOTE T) (QUOTE T))))
( GO G191)))
(SEQ
(LETT |p| (|SPADfirst| |lp2|) |PSETCAT-;headRemainder;PSR;23|)
(LETT |e|
( SPADCALL
( SPADCALL |a| (QREFELT |$| 40))
( SPADCALL |p| (QREFELT |$| 40))
( QREFELT |$| 63))
|PSETCAT-;headRemainder;PSR;23|)
(EXIT
( COND
( (QEQCAR |e| 0)
( SEQ
(LETT |g|
( SPADCALL
(LETT |lca|
( SPADCALL |a| (QREFELT |$| 64))
|PSETCAT-;headRemainder;PSR;23|)
(LETT |lcp|
( SPADCALL |p| (QREFELT |$| 64))
|PSETCAT-;headRemainder;PSR;23|)
( QREFELT |$| 65))
|PSETCAT-;headRemainder;PSR;23|)
( PROG
(LETT |#G47|
( |PSETCAT-;exactQuo| |lca| |g| |$|)
|PSETCAT-;headRemainder;PSR;23|)
(LETT |#G48|
( |PSETCAT-;exactQuo| |lcp| |g| |$|)
|PSETCAT-;headRemainder;PSR;23|)
(LETT |lca| |#G47| |PSETCAT-;headRemainder;PSR;23|)
(LETT |lcp| |#G48| |PSETCAT-;headRemainder;PSR;23|))
(LETT |a|
( SPADCALL
( SPADCALL |lcp|
( SPADCALL |a| (QREFELT |$| 62))
( QREFELT |$| 66))
( SPADCALL
( SPADCALL |lca| (QCDR |e|) (QREFELT |$| 67))

```

```

        (SPADCALL |p| (QREFELT |$| 62)) (QREFELT |$| 68))
        (QREFELT |$| 69))
        |PSETCAT-;headRemainder;PSR;23|)
    (LETT |r|
      (SPADCALL |r| |lcp| (QREFELT |$| 70))
      |PSETCAT-;headRemainder;PSR;23|)
    (EXIT (LETT |lp2| |lp1| |PSETCAT-;headRemainder;PSR;23|))))
  ((QUOTE T)
    (LETT |lp2| (CDR |lp2|) |PSETCAT-;headRemainder;PSR;23|))))))
  NIL
  (GO G190)
G191
  (EXIT NIL))
(EXIT (CONS |a| |r|)))))))))

(DEFUN |PSETCAT-;makeIrreducible!| (|frac| |$|)
  (PROG (|g|)
    (RETURN
      (SEQ
        (LETT |g|
          (SPADCALL (QCDR |frac|) (QCAR |frac|) (QREFELT |$| 73))
          |PSETCAT-;makeIrreducible!|)
        (EXIT
          (COND
            ((SPADCALL |g| (QREFELT |$| 74)) |frac|)
            ((QUOTE T)
              (SEQ
                (PROGN
                  (RPLACA |frac| (SPADCALL (QCAR |frac|) |g| (QREFELT |$| 75)))
                  (QCAR |frac|))
                (PROGN
                  (RPLACD |frac| (|PSETCAT-;exactQuo| (QCDR |frac|) |g| |$|))
                  (QCDR |frac|))
                (EXIT |frac|))))))))))

(DEFUN |PSETCAT-;remainder;PSR;25| (|a| |ps| |$|)
  (PROG (|hRa| |r| |lca| |g| |b| |c|)
    (RETURN
      (SEQ
        (LETT |hRa|
          (|PSETCAT-;makeIrreducible!| (SPADCALL |a| |ps| (QREFELT |$| 76)) |$|)
          |PSETCAT-;remainder;PSR;25|)
        (LETT |a| (QCAR |hRa|) |PSETCAT-;remainder;PSR;25|)
        (LETT |r| (QCDR |hRa|) |PSETCAT-;remainder;PSR;25|)
        (EXIT
          (COND
            ((SPADCALL |a| (QREFELT |$| 42))
              (VECTOR (|spadConstant| |$| 61) |a| |r|))
            ((QUOTE T)
              (SEQ

```

```

(LETT |b|
  (SPADCALL
    (|spadConstant| |$| 61)
    (SPADCALL |a| (QREFELT |$| 40))
    (QREFELT |$| 67))
  |PSETCAT-;remainder;PSR;25|)
(LETT |c| (SPADCALL |a| (QREFELT |$| 64)) |PSETCAT-;remainder;PSR;25|)
(SEQ
  G190
  (COND
    ((NULL
      (COND
        ((SPADCALL
          (LETT |a|
            (SPADCALL |a| (QREFELT |$| 62))
            |PSETCAT-;remainder;PSR;25|)
            (QREFELT |$| 42))
            (QUOTE NIL))
          ((QUOTE T) (QUOTE T))))
      (GO G191)))
  (SEQ
    (LETT |hRa|
      (|PSETCAT-;makeIrreducible!|
        (SPADCALL |a| |ps| (QREFELT |$| 76))
        |$|)
      |PSETCAT-;remainder;PSR;25|)
    (LETT |a| (QCAR |hRa|) |PSETCAT-;remainder;PSR;25|)
    (LETT |r|
      (SPADCALL |r| (QCDR |hRa|) (QREFELT |$| 70))
      |PSETCAT-;remainder;PSR;25|)
    (LETT |g|
      (SPADCALL |c|
        (LETT |lca|
          (SPADCALL |a| (QREFELT |$| 64))
          |PSETCAT-;remainder;PSR;25|)
          (QREFELT |$| 65))
        |PSETCAT-;remainder;PSR;25|)
      (LETT |b|
        (SPADCALL
          (SPADCALL
            (QCDR |hRa|)
            (|PSETCAT-;exactQuo| |c| |g| |$|)
            (QREFELT |$| 70))
            |b|
            (QREFELT |$| 66))
          (SPADCALL
            (|PSETCAT-;exactQuo| |lca| |g| |$|)
            (SPADCALL |a| (QREFELT |$| 40))
            (QREFELT |$| 67))

```



```

        (QREFELT |$| 77))
        |PSETCAT-;remainder;PSR;25|)
    (EXIT (LETT |c| |g| |PSETCAT-;remainder;PSR;25|)))
    NIL
    (GO G190)
    G191
    (EXIT NIL))
    (EXIT (VECTOR |c| |b| |r|)))))))))

(DEFUN |PSETCAT-;rewriteIdealWithHeadRemainder;LSL;26| (|ps| |cs| |$|)
  (PROG (|p| |rs|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |cs| (QREFELT |$| 80)) |ps|)
          ((SPADCALL |cs| (QREFELT |$| 81)) (LIST (|spadConstant| |$| 82)))
          ((QUOTE T)
            (SEQ
              (LETT |ps|
                (SPADCALL (ELT |$| 42) |ps| (QREFELT |$| 26))
                |PSETCAT-;rewriteIdealWithHeadRemainder;LSL;26|)
              (EXIT
                (COND
                  ((NULL |ps|) |ps|)
                  ((SPADCALL (ELT |$| 24) |ps| (QREFELT |$| 43))
                    (LIST (|spadConstant| |$| 83)))
                  ((QUOTE T)
                    (SEQ
                      (LETT |rs| NIL |PSETCAT-;rewriteIdealWithHeadRemainder;LSL;26|)
                      (SEQ
                        G190
                        (COND
                          ((NULL (COND ((NULL |ps|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
                          (GO G191)))
                      (SEQ
                        (LETT |p|
                          (|SPADfirst| |ps|)
                          |PSETCAT-;rewriteIdealWithHeadRemainder;LSL;26|)
                        (LETT |ps|
                          (CDR |ps|)
                          |PSETCAT-;rewriteIdealWithHeadRemainder;LSL;26|)
                        (LETT |p|
                          (QCAR (SPADCALL |p| |cs| (QREFELT |$| 76)))
                          |PSETCAT-;rewriteIdealWithHeadRemainder;LSL;26|)
                        (EXIT
                          (COND
                            ((NULL (SPADCALL |p| (QREFELT |$| 42)))
                              (COND
                                ((SPADCALL |p| (QREFELT |$| 24))
                                  (SEQ

```

```

        (LETT |ps| NIL
          |PSETCAT-;rewriteIdealWithHeadRemainder;LSL;26|)
        (EXIT
          (LETT |rs|
            (LIST (|spadConstant| |$| 83))
            |PSETCAT-;rewriteIdealWithHeadRemainder;LSL;26|))))
      ((QUOTE T)
        (SEQ
          (SPADCALL |p| (QREFELT |$| 84))
          (EXIT
            (LETT |rs|
              (CONS |p| |rs|)
              |PSETCAT-;rewriteIdealWithHeadRemainder;LSL;26|))))))
    NIL
    (GO G190)
  G191
  (EXIT NIL))
(EXIT (SPADCALL |rs| (QREFELT |$| 85|))))))

(DEFUN |PSETCAT-;rewriteIdealWithRemainder;LSL;27| (|ps| |cs| |$|)
  (PROG (|p| |rs|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |cs| (QREFELT |$| 80)) |ps|)
          ((SPADCALL |cs| (QREFELT |$| 81)) (LIST (|spadConstant| |$| 82)))
          ((QUOTE T)
            (SEQ
              (LETT |ps|
                (SPADCALL (ELT |$| 42) |ps| (QREFELT |$| 26))
                |PSETCAT-;rewriteIdealWithRemainder;LSL;27|)
              (EXIT
                (COND
                  ((NULL |ps|) |ps|)
                  ((SPADCALL (ELT |$| 24) |ps| (QREFELT |$| 43))
                    (LIST (|spadConstant| |$| 83)))
                  ((QUOTE T)
                    (SEQ
                      (LETT |rs| NIL |PSETCAT-;rewriteIdealWithRemainder;LSL;27|)
                      (SEQ
                        G190
                        (COND
                          ((NULL (COND ((NULL |ps|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
                          (GO G191)))
                      (SEQ
                        (LETT |p|
                          (|SPADfirst| |ps|)
                          |PSETCAT-;rewriteIdealWithRemainder;LSL;27|)
                        (LETT |ps| (CDR |ps|) |PSETCAT-;rewriteIdealWithRemainder;LSL;27|)
                        (LETT |p|

```

```

(QVELT (SPADCALL |p| |cs| (QREFELT |$| 87)) 1)
|PSETCAT-;rewriteIdealWithRemainder;LSL;27|)
(EXIT
(COND
((NULL (SPADCALL |p| (QREFELT |$| 42)))
(COND
((SPADCALL |p| (QREFELT |$| 24))
(SEQ
(LETT |ps| NIL |PSETCAT-;rewriteIdealWithRemainder;LSL;27|)
(EXIT
(LETT |rs|
(LIST (|spadConstant| |$| 83))
|PSETCAT-;rewriteIdealWithRemainder;LSL;27|))))))
((QUOTE T)
(LETT |rs|
(CONS (SPADCALL |p| (QREFELT |$| 88)) |rs|)
|PSETCAT-;rewriteIdealWithRemainder;LSL;27|))))))
NIL
(GO G190)
G191
(EXIT NIL))
(EXIT (SPADCALL |rs| (QREFELT |$| 85))))))))))

(DEFUN |PolynomialSetCategory&| (|#1| |#2| |#3| |#4| |#5|)
(PROG (|DV$1| |DV$2| |DV$3| |DV$4| |DV$5| |dv$| |$| |pv$|)
(RETURN
(PROGN
(LETT |DV$1| (|devaluate| |#1|) . #1=(|PolynomialSetCategory&|))
(LETT |DV$2| (|devaluate| |#2|) . #1#)
(LETT |DV$3| (|devaluate| |#3|) . #1#)
(LETT |DV$4| (|devaluate| |#4|) . #1#)
(LETT |DV$5| (|devaluate| |#5|) . #1#)
(LETT |dv$|
(LIST
(QUOTE |PolynomialSetCategory&|)
|DV$1| |DV$2| |DV$3| |DV$4| |DV$5|) . #1#)
(LETT |$| (make-array 90) . #1#)
(QSETREFV |$| 0 |dv$|)
(QSETREFV |$| 3
(LETT |pv$|
(|buildPredVector| 0 0
(LIST (|HasCategory| |#2| (QUOTE (|IntegralDomain|))))) . #1#))
(|stuffDomainSlots| |$|)
(QSETREFV |$| 6 |#1|)
(QSETREFV |$| 7 |#2|)
(QSETREFV |$| 8 |#3|)
(QSETREFV |$| 9 |#4|)
(QSETREFV |$| 10 |#5|)
(COND
((|testBitVector| |pv$| 1)

```

```

(PROGN
  (QSETREFV |$| 48
    (CONS (|dispatchFunction| |PSETCAT-;roughUnitIdeal?;SB;16|) |$|))
  (QSETREFV |$| 52
    (CONS (|dispatchFunction| |PSETCAT-;roughBase?;SB;18|) |$|))
  (QSETREFV |$| 54
    (CONS (|dispatchFunction| |PSETCAT-;roughSubIdeal?;2SB;19|) |$|))
  (QSETREFV |$| 57
    (CONS (|dispatchFunction| |PSETCAT-;roughEqualIdeals?;2SB;20|) |$|))))))
(COND
  ((|HasCategory| |#2| (QUOTE (|GcdDomain|))))
  (COND
    ((|HasCategory| |#4| (QUOTE (|ConvertibleTo| (|Symbol|)))))
    (PROGN
      (QSETREFV |$| 72
        (CONS (|dispatchFunction| |PSETCAT-;headRemainder;PSR;23|) |$|))
      (QSETREFV |$| 79
        (CONS (|dispatchFunction| |PSETCAT-;remainder;PSR;25|) |$|))
      (QSETREFV |$| 86
        (CONS
          (|dispatchFunction| |PSETCAT-;rewriteIdealWithHeadRemainder;LSL;26|)
          |$|))
      (QSETREFV |$| 89
        (CONS
          (|dispatchFunction| |PSETCAT-;rewriteIdealWithRemainder;LSL;27|)
          |$|))))))
  |$|))))

(setf (get
  (QUOTE |PolynomialSetCategory&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|) (|local| |#3|)
        (|local| |#4|) (|local| |#5|) (|List| 10) (0 . |members|) (|List| 9)
        (5 . |variables|) (|Boolean|) (10 . |<|) (|List| |$|) (16 . |concat|)
        (21 . |removeDuplicates|) (|Mapping| 15 9 9) (26 . |sort|)
        (32 . |mvar|) |PSETCAT-;variables;SL;4| (37 . |ground?|)
        (|Mapping| 15 10) (42 . |remove|) |PSETCAT-;mainVariables;SL;5|
        (48 . |=|) |PSETCAT-;mainVariable?;VarSetSB;6| (54 . |construct|)
        |PSETCAT-;collectUnder;SVarSetS;7| |PSETCAT-;collectUpper;SVarSetS;8|
        |PSETCAT-;collect;SVarSetS;9| (|Record| (|:| |under| |$|)
        (|:| |floor| |$|) (|:| |upper| |$|)) |PSETCAT-;sort;SVarSetR;10|
        (|Set| 10) (59 . |brace|) (64 . |=|) |PSETCAT-;=;2SB;11|
        (70 . |degree|) (75 . |<|) (81 . |zero?|) (86 . |any?|)
        (|Mapping| 15 10 10) (92 . |sort|) |PSETCAT-;triangular?;SB;14|
        |PSETCAT-;trivialIdeal?;SB;15| (98 . |roughUnitIdeal?|)
        (103 . |sup|) (109 . |+|) (115 . |=|) (121 . |roughBase?|)
        (126 . |rewriteIdealWithRemainder|) (132 . |roughSubIdeal?|)
        (138 . |=|) (144 . |roughSubIdeal?|) (150 . |roughEqualIdeals?|)

```

```

(156 . |quo|) (|Union| |$| (QUOTE "failed")) (162 . |exquo|)
(168 . |One|) (172 . |reductum|) (177 . |subtractIfCan|)
(183 . |leadingCoefficient|) (188 . |gcd|) (194 . |*|)
(200 . |monomial|) (206 . |*|) (212 . |-|) (218 . |*|)
(|Record| (|:| |num| 10) (|:| |den| 7)) (224 . |headRemainder|)
(230 . |gcd|) (236 . |one?|) (241 . |exactQuotient!|)
(247 . |headRemainder|) (253 . |+|) (|Record| (|:| |rnum| 7)
(|:| |polnum| 10) (|:| |den| 7)) (259 . |remainder|)
(265 . |trivialIdeal?|) (270 . |roughUnitIdeal?|)
(275 . |Zero|) (279 . |One|) (283 . |primitivePart!|)
(288 . |removeDuplicates|) (293 . |rewriteIdealWithHeadRemainder|)
(299 . |remainder|) (305 . |unitCanonical|)
(310 . |rewriteIdealWithRemainder|)))
(QUOTE #(|variables| 316 |trivialIdeal?| 321 |triangular?| 326
|sort| 331 |roughUnitIdeal?| 337 |roughSubIdeal?| 342
|roughEqualIdeals?| 348 |roughBase?| 354 |rewriteIdealWithRemainder|
359 |rewriteIdealWithHeadRemainder| 365 |remainder| 371 |mainVariables|
377 |mainVariable?| 382 |headRemainder| 388 |collectUpper| 394
|collectUnder| 400 |collect| 406 |=| 412))
(QUOTE NIL)
(CONS
(|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
(QUOTE #())
(CONS
(QUOTE #())
(|makeByteWordVec2| 89 (QUOTE (1 6 11 0 12 1 10 13 0 14 2 9 15 0
0 16 1 13 0 17 18 1 13 0 0 19 2 13 0 20 0 21 1 10 9 0 22 1 10 15 0 24
2 11 0 25 0 26 2 9 15 0 0 28 1 6 0 11 30 1 36 0 11 37 2 36 15 0 0 38 1
10 8 0 40 2 8 15 0 0 41 1 10 15 0 42 2 11 15 25 0 43 2 11 0 44 0 45 1
0 15 0 48 2 8 0 0 0 49 2 8 0 0 0 50 2 8 15 0 0 51 1 0 15 0 52 2 6 11 11
0 53 2 0 15 0 0 54 2 6 15 0 0 55 2 6 15 0 0 56 2 0 15 0 0 57 2 7 0 0 0
58 2 7 59 0 0 60 0 7 0 61 1 10 0 0 62 2 8 59 0 0 63 1 10 7 0 64 2 7 0
0 0 65 2 10 0 7 0 66 2 10 0 7 8 67 2 10 0 0 0 68 2 10 0 0 0 69 2 7 0
0 0 70 2 0 71 10 0 72 2 10 7 7 0 73 1 7 15 0 74 2 10 0 0 7 75 2 6 71
10 0 76 2 10 0 0 0 77 2 0 78 10 0 79 1 6 15 0 80 1 6 15 0 81 0 10 0
82 0 10 0 83 1 10 0 0 84 1 11 0 0 85 2 0 11 11 0 86 2 6 78 10 0 87 1
10 0 0 88 2 0 11 11 0 89 1 0 13 0 23 1 0 15 0 47 1 0 15 0 46 2 0 34
0 9 35 1 0 15 0 48 2 0 15 0 0 54 2 0 15 0 0 57 1 0 15 0 52 2 0 11 11
0 89 2 0 11 11 0 86 2 0 78 10 0 79 1 0 13 0 27 2 0 15 9 0 29 2 0 71
10 0 72 2 0 0 0 9 32 2 0 0 0 9 31 2 0 0 0 9 33 2 0 15 0 0 39))))))
(QUOTE |lookupComplete|)))

```

21.47 QFCAT.lsp BOOTSTRAP

QFCAT depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **QFCAT** category which we can write into the **MID** directory. We compile the lisp code and copy the **QFCAT.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— QFCAT.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |QuotientFieldCategory;CAT| (QUOTE NIL))

(SETQ |QuotientFieldCategory;AL| (QUOTE NIL))

(DEFUN |QuotientFieldCategory| (#1=#:G103631)
  (LET (#2=#:G103632)
    (COND
      ((SETQ #2# (|assoc| (|devalueate| #1#) |QuotientFieldCategory;AL|))
        (CDR #2#))
      (T
        (SETQ |QuotientFieldCategory;AL|
          (|cons5|
            (CONS (|devalueate| #1#) (SETQ #2# (|QuotientFieldCategory;| #1#)))
            |QuotientFieldCategory;AL|))
          #2#))))))

(DEFUN |QuotientFieldCategory;| (|t#1|)
  (PROG (#1=#:G103630)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR (QUOTE (|t#1|)) (LIST (|devalueate| |t#1|))))
          (COND
            (|QuotientFieldCategory;CAT|)
            ((QUOTE T)
              (LETT |QuotientFieldCategory;CAT|
                (|Join|
                  (|Field|)
                  (|Algebra| (QUOTE |t#1|))
                  (|RetractableTo| (QUOTE |t#1|))
                  (|FullyEvalableOver| (QUOTE |t#1|))
                  (|DifferentialExtension| (QUOTE |t#1|))
                  (|FullyLinearlyExplicitRingOver| (QUOTE |t#1|))
                  (|Patternable| (QUOTE |t#1|))
```

```

(|FullyPatternMatchable| (QUOTE |t#1|))
(|mkCategory|
  (QUOTE |domain|)
  (QUOTE (
    ((|/| (|$| |t#1| |t#1|)) T)
    ((|numer| (|t#1| |$|)) T)
    ((|denom| (|t#1| |$|)) T)
    ((|numerator| (|$| |$|)) T)
    ((|denominator| (|$| |$|)) T)
    ((|wholePart| (|t#1| |$|)) (|has| |t#1| (|EuclideanDomain|)))
    ((|fractionPart| (|$| |$|)) (|has| |t#1| (|EuclideanDomain|)))
    ((|random| (|$|)) (|has| |t#1| (|IntegerNumberSystem|)))
    ((|ceiling| (|t#1| |$|)) (|has| |t#1| (|IntegerNumberSystem|)))
    ((|floor| (|t#1| |$|)) (|has| |t#1| (|IntegerNumberSystem|))))
  (QUOTE (
    ((|StepThrough|) (|has| |t#1| (|StepThrough|)))
    ((|RetractableTo| (|Integer|))
      (|has| |t#1| (|RetractableTo| (|Integer|))))
    ((|RetractableTo| (|Fraction| (|Integer|))
      (|has| |t#1| (|RetractableTo| (|Integer|))))
    ((|OrderedSet|) (|has| |t#1| (|OrderedSet|)))
    ((|OrderedIntegralDomain|) (|has| |t#1| (|OrderedIntegralDomain|)))
    ((|RealConstant|) (|has| |t#1| (|RealConstant|)))
    ((|ConvertibleTo| (|InputForm|))
      (|has| |t#1| (|ConvertibleTo| (|InputForm|))))
    ((|CharacteristicZero|) (|has| |t#1| (|CharacteristicZero|)))
    ((|CharacteristicNonZero|) (|has| |t#1| (|CharacteristicNonZero|)))
    ((|RetractableTo| (|Symbol|))
      (|has| |t#1| (|RetractableTo| (|Symbol|))))
    ((|PolynomialFactorizationExplicit|)
      (|has| |t#1| (|PolynomialFactorizationExplicit|))))
    (QUOTE NIL) NIL)) . #2=(|QuotientFieldCategory|)))) . #2#)
(SETELT #1# 0
  (LIST (QUOTE |QuotientFieldCategory|) (|devaluate| |t#1|))))))

```

21.48 QFCAT-.lsp BOOTSTRAP

QFCAT- depends on **QFCAT**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **QFCAT-** category which we can write into the **MID** directory. We compile the lisp code and copy the **QFCAT-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— QFCAT-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |QFCAT-;numerator;2A;1| (|x| |$|)
  (SPADCALL (SPADCALL |x| (QREFELT |$| 8)) (QREFELT |$| 9)))

(DEFUN |QFCAT-;denominator;2A;2| (|x| |$|)
  (SPADCALL (SPADCALL |x| (QREFELT |$| 11)) (QREFELT |$| 9)))

(DEFUN |QFCAT-;init;A;3| (|$|)
  (SPADCALL (|spadConstant| |$| 13) (|spadConstant| |$| 14) (QREFELT |$| 15)))

(DEFUN |QFCAT-;nextItem;AU;4| (|n| |$|)
  (PROG (|m|)
    (RETURN
      (SEQ
        (LETT |m|
          (SPADCALL
            (SPADCALL |n| (QREFELT |$| 8))
            (QREFELT |$| 18))
          |QFCAT-;nextItem;AU;4|)
        (EXIT
          (COND
            ((EQCAR |m| 1)
              (|error| "We seem to have a Fraction of a finite object"))
            ((QUOTE T)
              (CONS 0
                (SPADCALL (QCDR |m|) (|spadConstant| |$| 14) (QREFELT |$| 15))))))))))

(DEFUN |QFCAT-;map;M2A;5| (|fn| |x| |$|)
  (SPADCALL
    (SPADCALL (SPADCALL |x| (QREFELT |$| 8)) |fn|)
    (SPADCALL (SPADCALL |x| (QREFELT |$| 11)) |fn|)
    (QREFELT |$| 15)))

(DEFUN |QFCAT-;reducedSystem;MM;6| (|m| |$|)
  (SPADCALL |m| (QREFELT |$| 26)))

(DEFUN |QFCAT-;characteristic;Nni;7| (|$|)
  (SPADCALL (QREFELT |$| 30)))

(DEFUN |QFCAT-;differentiate;AMA;8| (|x| |deriv| |$|)
  (PROG (|n| |d|)
    (RETURN
      (SEQ
        (LETT |n| (SPADCALL |x| (QREFELT |$| 8)) |QFCAT-;differentiate;AMA;8|)
        (LETT |d| (SPADCALL |x| (QREFELT |$| 11)) |QFCAT-;differentiate;AMA;8|)
        (EXIT
          (SPADCALL
            (SPADCALL

```



```

      (SPADCALL (SPADCALL |n| |deriv|) |d| (QREFELT |$| 32))
      (SPADCALL |n| (SPADCALL |d| |deriv|) (QREFELT |$| 32))
      (QREFELT |$| 33))
      (SPADCALL |d| 2 (QREFELT |$| 35)) (QREFELT |$| 15))))))

(DEFUN |QFCAT-;convert;AIf;9| (|x| |$|)
  (SPADCALL
    (SPADCALL (SPADCALL |x| (QREFELT |$| 8)) (QREFELT |$| 38))
    (SPADCALL (SPADCALL |x| (QREFELT |$| 11)) (QREFELT |$| 38))
    (QREFELT |$| 39)))

(DEFUN |QFCAT-;convert;AF;10| (|x| |$|)
  (SPADCALL
    (SPADCALL (SPADCALL |x| (QREFELT |$| 8)) (QREFELT |$| 42))
    (SPADCALL (SPADCALL |x| (QREFELT |$| 11)) (QREFELT |$| 42))
    (QREFELT |$| 43)))

(DEFUN |QFCAT-;convert;ADf;11| (|x| |$|)
  (|/|
    (SPADCALL (SPADCALL |x| (QREFELT |$| 8)) (QREFELT |$| 46))
    (SPADCALL (SPADCALL |x| (QREFELT |$| 11)) (QREFELT |$| 46))))

(DEFUN |QFCAT-;<;2AB;12| (|x| |y| |$|)
  (SPADCALL
    (SPADCALL
      (SPADCALL |x| (QREFELT |$| 8))
      (SPADCALL |y| (QREFELT |$| 11))
      (QREFELT |$| 32))
    (SPADCALL
      (SPADCALL |y| (QREFELT |$| 8))
      (SPADCALL |x| (QREFELT |$| 11))
      (QREFELT |$| 32))
    (QREFELT |$| 49)))

(DEFUN |QFCAT-;<;2AB;13| (|x| |y| |$|)
  (PROG (|#G19| |#G20| |#G21| |#G22|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL
            (SPADCALL |x| (QREFELT |$| 11))
            (|spadConstant| |$| 51)
            (QREFELT |$| 49))
            (PROGN
              (LETT |#G19| |y| |QFCAT-;<;2AB;13|)
              (LETT |#G20| |x| |QFCAT-;<;2AB;13|)
              (LETT |x| |#G19| |QFCAT-;<;2AB;13|)
              (LETT |y| |#G20| |QFCAT-;<;2AB;13|))))
          (COND
            ((SPADCALL

```

```

    (SPADCALL |y| (QREFELT |$| 11))
    (|spadConstant| |$| 51)
    (QREFELT |$| 49))
  (PROGN
    (LETT |#G21| |y| |QFCAT-;<;2AB;13|)
    (LETT |#G22| |x| |QFCAT-;<;2AB;13|)
    (LETT |x| |#G21| |QFCAT-;<;2AB;13|)
    (LETT |y| |#G22| |QFCAT-;<;2AB;13|)))
  (EXIT
    (SPADCALL
      (SPADCALL
        (SPADCALL |x| (QREFELT |$| 8))
        (SPADCALL |y| (QREFELT |$| 11))
        (QREFELT |$| 32))
      (SPADCALL
        (SPADCALL |y| (QREFELT |$| 8))
        (SPADCALL |x| (QREFELT |$| 11))
        (QREFELT |$| 32))
      (QREFELT |$| 49))))))

(DEFUN |QFCAT-;<;2AB;14| (|x| |y| |$|)
  (SPADCALL
    (SPADCALL
      (SPADCALL |x| (QREFELT |$| 8))
      (SPADCALL |y| (QREFELT |$| 11))
      (QREFELT |$| 32))
    (SPADCALL
      (SPADCALL |y| (QREFELT |$| 8))
      (SPADCALL |x| (QREFELT |$| 11))
      (QREFELT |$| 32))
    (QREFELT |$| 49)))

(DEFUN |QFCAT-;fractionPart;2A;15| (|x| |$|)
  (SPADCALL |x|
    (SPADCALL (SPADCALL |x| (QREFELT |$| 52)) (QREFELT |$| 9))
    (QREFELT |$| 53)))

(DEFUN |QFCAT-;coerce;SA;16| (|s| |$|)
  (SPADCALL (SPADCALL |s| (QREFELT |$| 56)) (QREFELT |$| 9)))

(DEFUN |QFCAT-;retract;AS;17| (|x| |$|)
  (SPADCALL (SPADCALL |x| (QREFELT |$| 58)) (QREFELT |$| 59)))

(DEFUN |QFCAT-;retractIfCan;AU;18| (|x| |$|)
  (PROG (|r|)
    (RETURN
      (SEQ
        (LETT |r| (SPADCALL |x| (QREFELT |$| 62)) |QFCAT-;retractIfCan;AU;18|)
        (EXIT
          (COND

```

```

((EQCAR |r| 1) (CONS 1 "failed"))
((QUOTE T) (SPADCALL (QCDR |r|) (QREFELT |$| 64)))))))))

(DEFUN |QFCAT-;convert;AP;19| (|x| |$|)
  (SPADCALL
    (SPADCALL (SPADCALL |x| (QREFELT |$| 8)) (QREFELT |$| 67))
    (SPADCALL (SPADCALL |x| (QREFELT |$| 11)) (QREFELT |$| 67))
    (QREFELT |$| 68)))

(DEFUN |QFCAT-;patternMatch;AP2Pmr;20| (|x| |p| |l| |$|)
  (SPADCALL |x| |p| |l| (QREFELT |$| 72)))

(DEFUN |QFCAT-;convert;AP;21| (|x| |$|)
  (SPADCALL
    (SPADCALL (SPADCALL |x| (QREFELT |$| 8)) (QREFELT |$| 76))
    (SPADCALL (SPADCALL |x| (QREFELT |$| 11)) (QREFELT |$| 76))
    (QREFELT |$| 77)))

(DEFUN |QFCAT-;patternMatch;AP2Pmr;22| (|x| |p| |l| |$|)
  (SPADCALL |x| |p| |l| (QREFELT |$| 81)))

(DEFUN |QFCAT-;coerce;FA;23| (|x| |$|)
  (SPADCALL
    (SPADCALL (SPADCALL |x| (QREFELT |$| 86)) (QREFELT |$| 87))
    (SPADCALL (SPADCALL |x| (QREFELT |$| 88)) (QREFELT |$| 87))
    (QREFELT |$| 89)))

(DEFUN |QFCAT-;retract;AI;24| (|x| |$|)
  (SPADCALL (SPADCALL |x| (QREFELT |$| 58)) (QREFELT |$| 91)))

(DEFUN |QFCAT-;retractIfCan;AU;25| (|x| |$|)
  (PROG (|u|)
    (RETURN
      (SEQ
        (LETT |u| (SPADCALL |x| (QREFELT |$| 62)) |QFCAT-;retractIfCan;AU;25|)
        (EXIT
          (COND
            ((EQCAR |u| 1) (CONS 1 "failed"))
            ((QUOTE T) (SPADCALL (QCDR |u|) (QREFELT |$| 94)))))))))

(DEFUN |QFCAT-;random;A;26| (|$|)
  (PROG (|d|)
    (RETURN
      (SEQ
        (SEQ
          G190
          (COND
            (NULL
              (SPADCALL
                (LETT |d| (SPADCALL (QREFELT |$| 96)) |QFCAT-;random;A;26|)

```

```

        (QREFELT |$| 97)))
      (GO G191)))
    (SEQ (EXIT |d|))
  NIL
  (GO G190)
  G191
  (EXIT NIL))
  (EXIT (SPADCALL (SPADCALL (QREFELT |$| 96)) |d| (QREFELT |$| 15))))))

(DEFUN |QFCAT-;reducedSystem;MVR;27| (|m| |v| |$|)
  (PROG (|n|)
    (RETURN
      (SEQ
        (LETT |n|
          (SPADCALL
            (SPADCALL (SPADCALL |v| (QREFELT |$| 100)) |m| (QREFELT |$| 101))
            (QREFELT |$| 102))
          |QFCAT-;reducedSystem;MVR;27|)
        (EXIT
          (CONS
            (SPADCALL |n|
              (SPADCALL |n| (QREFELT |$| 103))
              (SPADCALL |n| (QREFELT |$| 104))
              (|+| 1 (SPADCALL |n| (QREFELT |$| 105)))
              (SPADCALL |n| (QREFELT |$| 106))
              (QREFELT |$| 107))
            (SPADCALL |n| (SPADCALL |n| (QREFELT |$| 105)) (QREFELT |$| 109)))))))

(DEFUN |QuotientFieldCategory&| (|#1| |#2|)
  (PROG (|DV$1| |DV$2| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|QuotientFieldCategory&|))
        (LETT |DV$2| (|devaluate| |#2|) . #1#)
        (LETT |dv$| (LIST (QUOTE |QuotientFieldCategory&|) |DV$1| |DV$2|) . #1#)
        (LETT |$| (make-array 119) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3
          (LETT |pv$|
            (|buildPredVector| 0 0 (LIST
              (|HasCategory| |#2| (QUOTE (|PolynomialFactorizationExplicit|)))
              (|HasCategory| |#2| (QUOTE (|IntegerNumberSystem|)))
              (|HasCategory| |#2| (QUOTE (|EuclideanDomain|)))
              (|HasCategory| |#2| (QUOTE (|RetractableTo| (|Symbol|))))
              (|HasCategory| |#2| (QUOTE (|CharacteristicNonZero|)))
              (|HasCategory| |#2| (QUOTE (|CharacteristicZero|)))
              (|HasCategory| |#2| (QUOTE (|ConvertibleTo| (|InputForm|))))
              (|HasCategory| |#2| (QUOTE (|RealConstant|)))
              (|HasCategory| |#2| (QUOTE (|OrderedIntegralDomain|)))
              (|HasCategory| |#2| (QUOTE (|OrderedSet|))))
          )
        )
      )
    )
  )

```

```

      (|HasCategory| |#2| (QUOTE (|RetractableTo| (|Integer|))))
      (|HasCategory| |#2| (QUOTE (|StepThrough|)))) . #1#)
(|stuffDomainSlots| |$|)
(QSETREFV |$| 6 |#1|)
(QSETREFV |$| 7 |#2|)
(COND
  ((|testBitVector| |pv$| 12)
    (PROGN
      (QSETREFV |$| 16 (CONS (|dispatchFunction| |QFCAT-;init;A;3|) |$|))
      (QSETREFV |$| 20
        (CONS (|dispatchFunction| |QFCAT-;nextItem;AU;4|) |$|))))))
(COND
  ((|testBitVector| |pv$| 7)
    (QSETREFV |$| 40
      (CONS (|dispatchFunction| |QFCAT-;convert;AIf;9|) |$|))))
(COND
  ((|testBitVector| |pv$| 8)
    (PROGN
      (QSETREFV |$| 44
        (CONS (|dispatchFunction| |QFCAT-;convert;AF;10|) |$|))
      (QSETREFV |$| 47
        (CONS (|dispatchFunction| |QFCAT-;convert;ADf;11|) |$|))))))
(COND
  ((|testBitVector| |pv$| 9)
    (COND
      ((|HasAttribute| |#2| (QUOTE |canonicalUnitNormal|))
        (QSETREFV |$| 50 (CONS (|dispatchFunction| |QFCAT-;<;2AB;12|) |$|)))
      ((QUOTE T)
        (QSETREFV |$| 50 (CONS (|dispatchFunction| |QFCAT-;<;2AB;13|) |$|))))))
  ((|testBitVector| |pv$| 10)
    (QSETREFV |$| 50 (CONS (|dispatchFunction| |QFCAT-;<;2AB;14|) |$|))))
(COND
  ((|testBitVector| |pv$| 3)
    (QSETREFV |$| 54
      (CONS (|dispatchFunction| |QFCAT-;fractionPart;2A;15|) |$|))))
(COND
  ((|testBitVector| |pv$| 4)
    (PROGN
      (QSETREFV |$| 57 (CONS (|dispatchFunction| |QFCAT-;coerce;SA;16|) |$|))
      (QSETREFV |$| 60 (CONS (|dispatchFunction| |QFCAT-;retract;AS;17|) |$|))
      (QSETREFV |$| 65
        (CONS (|dispatchFunction| |QFCAT-;retractIfCan;AU;18|) |$|))))))
(COND
  ((|HasCategory| |#2| (QUOTE (|ConvertibleTo| (|Pattern| (|Integer|)))))
    (PROGN
      (QSETREFV |$| 69 (CONS (|dispatchFunction| |QFCAT-;convert;AP;19|) |$|))
      (COND
        ((|HasCategory| |#2| (QUOTE (|PatternMatchable| (|Integer|)))))
          (QSETREFV |$| 74
            (CONS

```

```

        (|dispatchFunction| |QFCAT-;patternMatch;AP2Pmr;20|) |$|))))))
(COND
  ((|HasCategory| |#2| (QUOTE (|ConvertibleTo| (|Pattern| (|Float|))))))
  (PROGN
    (QSETREFV |$| 78 (CONS (|dispatchFunction| |QFCAT-;convert;AP;21|) |$|))
    (COND
      ((|HasCategory| |#2| (QUOTE (|PatternMatchable| (|Float|))))
        (QSETREFV |$| 83
          (CONS (|dispatchFunction| |QFCAT-;patternMatch;AP2Pmr;22|) |$|))))))
(COND
  ((|testBitVector| |pv$| 11)
    (PROGN
      (QSETREFV |$| 90 (CONS (|dispatchFunction| |QFCAT-;coerce;FA;23|) |$|))
      (COND
        ((|domainEqual| |#2| (|Integer|)))
        ((QUOTE T)
          (PROGN
            (QSETREFV |$| 92
              (CONS (|dispatchFunction| |QFCAT-;retract;AI;24|) |$|))
            (QSETREFV |$| 95
              (CONS (|dispatchFunction| |QFCAT-;retractIfCan;AU;25|) |$|))))))
(COND
  ((|testBitVector| |pv$| 2)
    (QSETREFV |$| 98 (CONS (|dispatchFunction| |QFCAT-;random;A;26|) |$|)))
  |$|)))

(setf (get
  (QUOTE |QuotientFieldCategory&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|)
      (0 . |numer|) (5 . |coerce|) |QFCAT-;numerator;2A;1| (10 . |denom|)
      |QFCAT-;denominator;2A;2| (15 . |init|) (19 . |One|) (23 . |/|)
      (29 . |init|) (|Union| |$| (QUOTE "failed")) (33 . |nextItem|)
      (38 . |One|) (42 . |nextItem|) (|Mapping| 7 7) |QFCAT-;map;M2A;5|
      (|Matrix| 7) (|Matrix| 6) (|MatrixCommonDenominator| 7 6)
      (47 . |clearDenominator|) (|Matrix| |$|) |QFCAT-;reducedSystem;MM;6|
      (|NonNegativeInteger|) (52 . |characteristic|)
      |QFCAT-;characteristic;Nni;7| (56 . |*|) (62 . |-|)
      (|PositiveInteger|) (68 . |**|) |QFCAT-;differentiate;AMA;8|
      (|InputForm|) (74 . |convert|) (79 . |/|) (85 . |convert|)
      (|Float|) (90 . |convert|) (95 . |/|) (101 . |convert|)
      (|DoubleFloat|) (106 . |convert|) (111 . |convert|) (|Boolean|)
      (116 . |<|) (122 . |<|) (128 . |Zero|) (132 . |wholePart|)
      (137 . |-|) (143 . |fractionPart|) (|Symbol|) (148 . |coerce|)
      (153 . |coerce|) (158 . |retract|) (163 . |retract|)
      (168 . |retract|) (|Union| 7 (QUOTE "failed")) (173 . |retractIfCan|)
      (|Union| 55 (QUOTE "failed")) (178 . |retractIfCan|)
      (183 . |retractIfCan|) (|Pattern| 84) (188 . |convert|)
      (193 . |/|) (199 . |convert|) (|PatternMatchResult| 84 6)

```

```

(|PatternMatchQuotientFieldCategory| 84 7 6) (204 . |patternMatch|)
(|PatternMatchResult| 84 |$|) (211 . |patternMatch|) (|Pattern| 41)
(218 . |convert|) (223 . |/|) (229 . |convert|)
(|PatternMatchResult| 41 6)
(|PatternMatchQuotientFieldCategory| 41 7 6) (234 . |patternMatch|)
(|PatternMatchResult| 41 |$|) (241 . |patternMatch|) (|Integer|)
(|Fraction| 84) (248 . |numer|) (253 . |coerce|) (258 . |denom|)
(263 . |/|) (269 . |coerce|) (274 . |retract|) (279 . |retract|)
(|Union| 84 (QUOTE "failed")) (284 . |retractIfCan|)
(289 . |retractIfCan|) (294 . |random|) (298 . |zero?|)
(303 . |random|) (|Vector| 6) (307 . |coerce|) (312 . |horizConcat|)
(318 . |reducedSystem|) (323 . |minRowIndex|) (328 . |maxRowIndex|)
(333 . |minColIndex|) (338 . |maxColIndex|) (343 . |subMatrix|)
(|Vector| 7) (352 . |column|) (|Record| (|:| |mat| 23)
(|:| |vec| 108)) (|Vector| |$|) |QFCAT-;reducedSystem;MVR;27|
(|Union| 85 (QUOTE "failed")) (|Record| (|:| |mat| 115)
(|:| |vec| (|Vector| 84))) (|Matrix| 84) (|List| 55) (|List| 29)
(|OutputForm|)))
(QUOTE #(|retractIfCan| 358 |retract| 368 |reducedSystem| 378
|random| 389 |patternMatch| 393 |numerator| 407 |nextItem| 412
|map| 417 |init| 423 |fractionPart| 427 |differentiate| 432
|denominator| 438 |convert| 443 |coerce| 468 |characteristic| 478
|<| 482))
(QUOTE NIL)
(CONS
(|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
(QUOTE #())
(CONS (QUOTE #())
(|makeByteWordVec2| 112 (QUOTE
(1 6 7 0 8 1 6 0 7 9 1 6 7 0 11 0 7 0 13 0 7 0 14 2 6 0 7 7 15 0
0 0 16 1 7 17 0 18 0 6 0 19 1 0 17 0 20 1 25 23 24 26 0 7 29 30 2
7 0 0 0 32 2 7 0 0 0 33 2 7 0 0 34 35 1 7 37 0 38 2 37 0 0 0 39 1
0 37 0 40 1 7 41 0 42 2 41 0 0 0 43 1 0 41 0 44 1 7 45 0 46 1 0 45
0 47 2 7 48 0 0 49 2 0 48 0 0 50 0 7 0 51 1 6 7 0 52 2 6 0 0 0 53 1
0 0 0 54 1 7 0 55 56 1 0 0 55 57 1 6 7 0 58 1 7 55 0 59 1 0 55 0 60
1 6 61 0 62 1 7 63 0 64 1 0 63 0 65 1 7 66 0 67 2 66 0 0 0 68 1 0
66 0 69 3 71 70 6 66 70 72 3 0 73 0 66 73 74 1 7 75 0 76 2 75 0 0
0 77 1 0 75 0 78 3 80 79 6 75 79 81 3 0 82 0 75 82 83 1 85 84 0 86
1 6 0 84 87 1 85 84 0 88 2 6 0 0 0 89 1 0 0 85 90 1 7 84 0 91 1 0
84 0 92 1 7 93 0 94 1 0 93 0 95 0 7 0 96 1 7 48 0 97 0 0 0 98 1 24
0 99 100 2 24 0 0 0 101 1 6 23 27 102 1 23 84 0 103 1 23 84 0 104
1 23 84 0 105 1 23 84 0 106 5 23 0 0 84 84 84 84 107 2 23 108 0 84
109 1 0 93 0 95 1 0 63 0 65 1 0 84 0 92 1 0 55 0 60 2 0 110 27 111
112 1 0 23 27 28 0 0 0 98 3 0 82 0 75 82 83 3 0 73 0 66 73 74 1 0
0 0 10 1 0 17 0 20 2 0 0 21 0 22 0 0 0 16 1 0 0 0 54 2 0 0 0 21 36
1 0 0 0 12 1 0 45 0 47 1 0 37 0 40 1 0 41 0 44 1 0 66 0 69 1 0 75 0
78 1 0 0 55 57 1 0 0 85 90 0 0 29 31 2 0 48 0 0 50))))))
(QUOTE |lookupComplete|)))

```



```

((|nodes| ((|List| |$|) |$|)) T)
((|leaf?| ((|Boolean|) |$|)) T)
((|value| (|t#1| |$|)) T)
((|elt| (|t#1| |$| "value")) T)
((|cyclic?| ((|Boolean|) |$|)) T)
((|leaves| ((|List| |t#1|) |$|)) T)
((|distance| ((|Integer|) |$| |$|)) T)
((|child?| ((|Boolean|) |$| |$|)) (|has| |t#1| (|SetCategory|)))
((|node?| ((|Boolean|) |$| |$|)) (|has| |t#1| (|SetCategory|)))
((|setchildren!| (|$| |$| (|List| |$|)))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
((|setelt| (|t#1| |$| "value" |t#1|))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
((|setvalue!| (|t#1| |$| |t#1|))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|))))
NIL
(QUOTE ((|List| |$|) (|Boolean|) (|Integer|) (|List| |t#1|)))
NIL))
. #2=(|RecursiveAggregate|))))
. #2#)
(SETELT #1# 0 (LIST (QUOTE |RecursiveAggregate|) (|devalue| |t#1|))))))

```

21.50 RCAGG-.lsp BOOTSTRAP

RCAGG- depends on **RCAGG**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **RCAGG-** category which we can write into the **MID** directory. We compile the lisp code and copy the **RCAGG-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— RCAGG-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |RCAGG-;elt;AvalueS;1| (|x| G84515 |$|)
  (SPADCALL |x| (QREFELT |$| 8)))

(DEFUN |RCAGG-;setelt;Avalue2S;2| (|x| G84517 |y| |$|)
  (SPADCALL |x| |y| (QREFELT |$| 11)))

(DEFUN |RCAGG-;child?;2AB;3| (|x| |l| |$|)
  (SPADCALL |x| (SPADCALL |l| (QREFELT |$| 14)) (QREFELT |$| 17)))

(DEFUN |RecursiveAggregate&| (|#1| |#2|)

```

```

(PROG (|DV$1| |DV$2| |dv$| |$| |pv$|)
  (RETURN
    (PROGN
      (LETT |DV$1| (|devaluate| |#1|) . #1=(|RecursiveAggregate&|))
      (LETT |DV$2| (|devaluate| |#2|) . #1#)
      (LETT |dv$| (LIST (QUOTE |RecursiveAggregate&|) |DV$1| |DV$2|) . #1#)
      (LETT |$| (make-array 19) . #1#)
      (QSETREFV |$| 0 |dv$|)
      (QSETREFV |$| 3
        (LETT |pv$|
          (|buildPredVector| 0 0
            (LIST
              (|HasAttribute| |#1| (QUOTE |shallowlyMutable|))
              (|HasCategory| |#2| (QUOTE (|SetCategory|))))
            . #1#))
          (|stuffDomainSlots| |$|)
          (QSETREFV |$| 6 |#1|)
          (QSETREFV |$| 7 |#2|)
          (COND
            ((|testBitVector| |pv$| 1)
              (QSETREFV |$| 12
                (CONS (|dispatchFunction| |RCAGG-;setelt;Avalue2S;2|) |$|))))
            (COND
              ((|testBitVector| |pv$| 2)
                (QSETREFV |$| 18 (CONS (|dispatchFunction| |RCAGG-;child?;2AB;3|) |$|)))
              |$|))))
      (setf (get
        (QUOTE |RecursiveAggregate&|)
        (QUOTE |infovec|))
        (LIST
          (QUOTE #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|)
            (0 . |value|) (QUOTE "value") |RCAGG-;elt;AvalueS;1| (5 . |setvalue!|)
            (11 . |setelt|) (|List| |$|) (18 . |children|) (|Boolean|) (|List| 6)
            (23 . |member?|) (29 . |child?|))))
          (QUOTE #(|setelt| 35 |elt| 42 |child?| 48))
          (QUOTE NIL)
          (CONS (|makeByteWordVec2| 1 (QUOTE NIL))
            (CONS
              (QUOTE #())
              (CONS
                (QUOTE #())
                (|makeByteWordVec2| 18 (QUOTE (1 6 7 0 8 2 6 7 0 7 11 3 0 7 0 9 7 12
                  1 6 13 0 14 2 16 15 6 0 17 2 0 15 0 0 18 3 0 7 0 9 7 12 2 0 7 0 9
                  10 2 0 15 0 0 18))))))
              (QUOTE |lookupComplete|)))

```

21.51 RING.lsp BOOTSTRAP

RING depends on itself. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **RING** category which we can write into the **MID** directory. We compile the lisp code and copy the **RING.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— RING.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |Ring;AL| (QUOTE NIL))

(DEFUN |Ring| NIL
  (LET (#:G82789)
    (COND
      (|Ring;AL|)
      (T (SETQ |Ring;AL| (|Ring;|))))))

(DEFUN |Ring;| NIL
  (PROG (#1= #:G82787)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|Rng|)
            (|Monoid|)
            (|LeftModule| (QUOTE |$|))
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE (
                (|characteristic| ((|NonNegativeInteger|))) T)
                (|coerce| (|$| (|Integer|))) T)))
              (QUOTE ((|unitsKnown| T)))
              (QUOTE ((|Integer|) (|NonNegativeInteger|)))
              NIL))
          |Ring|)
        (SETELT #1# 0 (QUOTE (|Ring|)))))))

(setf (get (QUOTE |Ring|) (QUOTE NILADIC)) T)
```

21.52 RING-.lsp BOOTSTRAP

RING- depends on **RING**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **RING-** category which we can write into the **MID** directory. We compile the lisp code and copy the **RING-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— RING-.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(DEFUN |RING-;coerce;IS;1| (|n| |$|)
  (SPADCALL |n| (|spadConstant| |$| 7) (QREFELT |$| 9)))

(DEFUN |Ring&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|Ring&|))
        (LETT |dv$| (LIST (QUOTE |Ring&|) |DV$1|) . #1#)
        (LETT |$| (make-array 12) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        |$|))))

(setf (get
  (QUOTE |Ring&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (0 . |One|)
        (|Integer|)
        (4 . |*|)
        |RING-;coerce;IS;1|
        (|OutputForm|)))
    (QUOTE #(|coerce| 10))
    (QUOTE NIL)
    (CONS
      (|makeByteWordVec2| 1 (QUOTE NIL))
      (CONS
        (QUOTE #())
        (CONS
```

```
(QUOTE #())
(|makeByteWordVec2| 10 (QUOTE (0 6 0 7 2 6 0 8 0 9 1 0 0 8 10))))))
(QUOTE |lookupComplete|))
```

21.53 RNG.lsp BOOTSTRAP

RNG depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **RNG** category which we can write into the **MID** directory. We compile the lisp code and copy the **RNG.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— RNG.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |Rng;AL| (QUOTE NIL))

(DEFUN |Rng| NIL
  (LET (#:G82722)
    (COND
      (|Rng;AL|)
      (T (SETQ |Rng;AL| (|Rng;|))))))

(DEFUN |Rng;| NIL
  (PROG (#1= #:G82720)
    (RETURN
      (PROG1
        (LETT #1# (|Join| (|AbelianGroup|) (|SemiGroup|)) |Rng|)
        (SETELT #1# 0 (QUOTE (|Rng|)))))))

(setf (get (QUOTE |Rng|) (QUOTE NILADIC)) T)
```

21.54 RNS.lsp BOOTSTRAP

RNS depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **RNS** category which we can write into the **MID**

directory. We compile the lisp code and copy the **RNS.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— RNS.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |RealNumberSystem;AL| (QUOTE NIL))

(DEFUN |RealNumberSystem| NIL
  (LET (#:G105478)
    (COND
      (|RealNumberSystem;AL|)
      (T (SETQ |RealNumberSystem;AL| (|RealNumberSystem;|))))))

(DEFUN |RealNumberSystem;| NIL
  (PROG (#1= #:G105476)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR
              (QUOTE (#2= #:G105472 #3= #:G105473 #4= #:G105474 #5= #:G105475))
              (LIST
                (QUOTE (|Integer|))
                (QUOTE (|Fraction| (|Integer|)))
                (QUOTE (|Pattern| (|Float|)))
                (QUOTE (|Float|)))
              (|Join|
                (|Field|)
                (|OrderedRing|)
                (|RealConstant|)
                (|RetractableTo| (QUOTE #2#))
                (|RetractableTo| (QUOTE #3#))
                (|RadicalCategory|)
                (|ConvertibleTo| (QUOTE #4#))
                (|PatternMatchable| (QUOTE #5#))
                (|CharacteristicZero|)
                (|mkCategory|
                  (QUOTE |domain|)
                  (QUOTE (
                    ((|norm| (|$| |$|)) T)
                    ((|ceiling| (|$| |$|)) T)
                    ((|floor| (|$| |$|)) T)
                    ((|wholePart| ((|Integer|) |$|)) T)
                    ((|fractionPart| (|$| |$|)) T)
                    ((|truncate| (|$| |$|)) T)

```

```

      ((|round| (|$| |$|)) T)
      ((|abs| (|$| |$|)) T))
    NIL
    (QUOTE ((|Integer|))
    NIL)))
  |RealNumberSystem|)
  (SETELT #1# 0 (QUOTE (|RealNumberSystem|))))))

(setf (get (QUOTE |RealNumberSystem|) (QUOTE NILADIC)) T)

```

21.55 RNS-.lsp BOOTSTRAP

RNS- depends **RNS**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **RNS-** category which we can write into the **MID** directory. We compile the lisp code and copy the **RNS.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— RNS-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(PUT
  (QUOTE |RNS-;characteristic;Nni;1|)
  (QUOTE |SPADreplace|)
  (QUOTE (XLAM NIL 0)))

(DEFUN |RNS-;characteristic;Nni;1| (|$|) 0)

(DEFUN |RNS-;fractionPart;2S;2| (|x| |$|)
  (SPADCALL |x| (SPADCALL |x| (QREFELT |$| 9)) (QREFELT |$| 10)))

(DEFUN |RNS-;truncate;2S;3| (|x| |$|)
  (COND
    ((SPADCALL |x| (QREFELT |$| 13))
    (SPADCALL
      (SPADCALL
        (SPADCALL |x| (QREFELT |$| 14))
        (QREFELT |$| 15))
      (QREFELT |$| 14)))
    ((QUOTE T) (SPADCALL |x| (QREFELT |$| 15)))))

(DEFUN |RNS-;round;2S;4| (|x| |$|)

```

```

(COND
  ((SPADCALL |x| (QREFELT |$| 13))
   (SPADCALL
    (SPADCALL |x|
     (SPADCALL
      (|spadConstant| |$| 17)
      (SPADCALL 2 (QREFELT |$| 19))
      (QREFELT |$| 20))
     (QREFELT |$| 10))
    (QREFELT |$| 9))))
  ((QUOTE T)
   (SPADCALL
    (SPADCALL |x|
     (SPADCALL
      (|spadConstant| |$| 17)
      (SPADCALL 2 (QREFELT |$| 19))
      (QREFELT |$| 20))
     (QREFELT |$| 21))
    (QREFELT |$| 9))))))

(DEFUN |RNS-;norm;2S;5| (|x| |$|)
  (SPADCALL |x| (QREFELT |$| 23)))

(DEFUN |RNS-;coerce;FS;6| (|x| |$|)
  (SPADCALL
   (SPADCALL
    (SPADCALL |x| (QREFELT |$| 26))
    (QREFELT |$| 19))
   (SPADCALL
    (SPADCALL |x| (QREFELT |$| 27))
    (QREFELT |$| 19))
   (QREFELT |$| 20)))

(DEFUN |RNS-;convert;SP;7| (|x| |$|)
  (SPADCALL (SPADCALL |x| (QREFELT |$| 30)) (QREFELT |$| 32)))

(DEFUN |RNS-;floor;2S;8| (|x| |$|)
  (PROG (|x1|)
   (RETURN
    (SEQ
     (LETT |x1|
      (SPADCALL (SPADCALL |x| (QREFELT |$| 34)) (QREFELT |$| 19))
      |RNS-;floor;2S;8|)
     (EXIT
      (COND
       ((SPADCALL |x| |x1| (QREFELT |$| 35)) |x|)
       ((SPADCALL |x| (|spadConstant| |$| 36) (QREFELT |$| 37))
        (SPADCALL |x1| (|spadConstant| |$| 17) (QREFELT |$| 10)))
       ((QUOTE T) |x1|)))))))

```



```

(DEFUN |RNS-;ceiling;2S;9| (|x| |$|)
  (PROG (|x1|)
    (RETURN
      (SEQ
        (LETT |x1|
          (SPADCALL (SPADCALL |x| (QREFELT |$| 34)) (QREFELT |$| 19))
          |RNS-;ceiling;2S;9|)
        (EXIT
          (COND
            ((SPADCALL |x| |x1| (QREFELT |$| 35)) |x|)
            ((SPADCALL |x| (|spadConstant| |$| 36) (QREFELT |$| 37)) |x1|)
            ((QUOTE T)
              (SPADCALL |x1| (|spadConstant| |$| 17) (QREFELT |$| 21))))))))))

(DEFUN |RNS-;patternMatch;SP2Pmr;10| (|x| |p| |l| |$|)
  (PROG (|r|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |p| (QREFELT |$| 40))
            (SPADCALL |p| |x| |l| (QREFELT |$| 42)))
          ((SPADCALL |p| (QREFELT |$| 43))
            (SEQ
              (LETT |r|
                (SPADCALL |p| (QREFELT |$| 45))
                |RNS-;patternMatch;SP2Pmr;10|)
              (EXIT
                (COND
                  ((QEQCAR |r| 0)
                    (COND
                      ((SPADCALL
                        (SPADCALL |x| (QREFELT |$| 30))
                        (QCDR |r|)
                        (QREFELT |$| 46))
                        |l|)
                      ((QUOTE T) (SPADCALL (QREFELT |$| 47))))))
                  ((QUOTE T) (SPADCALL (QREFELT |$| 47))))))
                ((QUOTE T) (SPADCALL (QREFELT |$| 47))))))

(DEFUN |RealNumberSystem&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|RealNumberSystem&|))
        (LETT |dv$| (LIST (QUOTE |RealNumberSystem&|) |DV$1|) . #1#)
        (LETT |$| (make-array 52) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)

```

```

    |$|)))

(setf (get
      (QUOTE |RealNumberSystem&|)
      (QUOTE |infovec|))
      (LIST
        (QUOTE
          #(NIL NIL NIL NIL NIL NIL
            (|local| |#1|)
            (|NonNegativeInteger|)
            |RNS-;characteristic;Nni;1|
            (0 . |truncate|)
            (5 . |-|)
            |RNS-;fractionPart;2S;2|
            (|Boolean|)
            (11 . |negative?|)
            (16 . |-|)
            (21 . |floor|)
            |RNS-;truncate;2S;3|
            (26 . |One|)
            (|Integer|)
            (30 . |coerce|)
            (35 . |/|)
            (41 . |+|)
            |RNS-;round;2S;4|
            (47 . |abs|)
            |RNS-;norm;2S;5|
            (|Fraction| 18)
            (52 . |numer|)
            (57 . |denom|)
            |RNS-;coerce;FS;6|
            (|Float|)
            (62 . |convert|)
            (|Pattern| 29)
            (67 . |coerce|)
            |RNS-;convert;SP;7|
            (72 . |wholePart|)
            (77 . |=|)
            (83 . |Zero|)
            (87 . |<|)
            |RNS-;floor;2S;8|
            |RNS-;ceiling;2S;9|
            (93 . |generic?|)
            (|PatternMatchResult| 29 6)
            (98 . |addMatch|)
            (105 . |constant?|)
            (|Union| 29 (QUOTE "failed"))
            (110 . |retractIfCan|)
            (115 . |=|)
            (121 . |failed|)

```

```

(|PatternMatchResult| 29 |$|)
|RNS-;patternMatch;SP2Pmr;10|
(|DoubleFloat|)
(|OutputForm|)))
(QUOTE
  #(|truncate| 125 |round| 130 |patternMatch| 135 |norm| 142
    |fractionPart| 147 |floor| 152 |convert| 157 |coerce| 162
    |characteristic| 172 |ceiling| 176))
(QUOTE NIL)
(CONS
  (|makeByteWordVec2| 1 (QUOTE NIL))
  (CONS
    (QUOTE #())
    (CONS
      (QUOTE #())
      (|makeByteWordVec2| 49
        (QUOTE
          (1 6 0 0 9 2 6 0 0 0 10 1 6 12 0 13 1 6 0 0 14 1 6 0 0 15 0 6 0
            17 1 6 0 18 19 2 6 0 0 0 20 2 6 0 0 0 21 1 6 0 0 23 1 25 18 0
            26 1 25 18 0 27 1 6 29 0 30 1 31 0 29 32 1 6 18 0 34 2 6 12 0
            0 35 0 6 0 36 2 6 12 0 0 37 1 31 12 0 40 3 41 0 31 6 0 42 1 31
            12 0 43 1 31 44 0 45 2 29 12 0 0 46 0 41 0 47 1 0 0 0 16 1 0 0
            0 22 3 0 48 0 31 48 49 1 0 0 0 24 1 0 0 0 11 1 0 0 0 38 1 0 31
            0 33 1 0 0 25 28 1 0 0 25 28 0 0 7 8 1 0 0 0 39))))))
(QUOTE |lookupComplete|)))

```

21.56 SETAGG.lsp BOOTSTRAP

SETAGG depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **SETAGG** category which we can write into the **MID** directory. We compile the lisp code and copy the **SETAGG.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— SETAGG.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |SetAggregate;CAT| (QUOTE NIL))

(SETQ |SetAggregate;AL| (QUOTE NIL))

(DEFUN |SetAggregate| (#1=#:G83200)

```

```

(LET (#2=#:G83201)
  (COND
    ((SETQ #2# (|assoc| (|devalueate| #1#) |SetAggregate;AL|)) (CDR #2#))
    (T
      (SETQ |SetAggregate;AL|
        (|cons5|
          (CONS (|devalueate| #1#) (SETQ #2# (|SetAggregate;| #1#)))
          |SetAggregate;AL|))
        #2#))))

(DEFUN |SetAggregate;| (|t#1|)
  (PROG (#1=#:G83199)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR (QUOTE (|t#1|)) (LIST (|devalueate| |t#1|))))
          (COND
            (|SetAggregate;CAT|)
            ((QUOTE T)
              (LETT |SetAggregate;CAT|
                (|Join|
                  (|SetCategory|)
                  (|Collection| (QUOTE |t#1|))
                  (|mkCategory|
                    (QUOTE |domain|)
                    (QUOTE (
                      ((|<| ((|Boolean|) |$| |$|)) T)
                      ((|brace| (|$|)) T)
                      ((|brace| (|$| (|List| |t#1|))) T)
                      ((|set| (|$|)) T)
                      ((|set| (|$| (|List| |t#1|))) T)
                      ((|intersect| (|$| |$| |$|)) T)
                      ((|difference| (|$| |$| |$|)) T)
                      ((|difference| (|$| |$| |t#1|)) T)
                      ((|symmetricDifference| (|$| |$| |$|)) T)
                      ((|subset?| ((|Boolean|) |$| |$|)) T)
                      ((|union| (|$| |$| |$|)) T)
                      ((|union| (|$| |$| |t#1|)) T)
                      ((|union| (|$| |t#1| |$|)) T)))
                  (QUOTE ((|partiallyOrderedSet| T)))
                  (QUOTE ((|Boolean|) (|List| |t#1|)))
                  NIL))
                . #2=(|SetAggregate|))))
          . #2#)
        (SETELT #1# 0 (LIST (QUOTE |SetAggregate|) (|devalueate| |t#1|))))))

```

21.57 SETAGG-.lsp BOOTSTRAP

SETAGG- depends on **SETAGG**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **SETAGG-** category which we can write into the **MID** directory. We compile the lisp code and copy the **SETAGG-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— SETAGG-.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(DEFUN |SETAGG-;symmetricDifference;3A;1| (|x| |y| |$|)
  (SPADCALL
    (SPADCALL |x| |y| (QREFELT |$| 8))
    (SPADCALL |y| |x| (QREFELT |$| 8))
    (QREFELT |$| 9)))

(DEFUN |SETAGG-;union;ASA;2| (|s| |x| |$|)
  (SPADCALL |s| (SPADCALL (LIST |x|) (QREFELT |$| 12)) (QREFELT |$| 9)))

(DEFUN |SETAGG-;union;S2A;3| (|x| |s| |$|)
  (SPADCALL |s| (SPADCALL (LIST |x|) (QREFELT |$| 12)) (QREFELT |$| 9)))

(DEFUN |SETAGG-;difference;ASA;4| (|s| |x| |$|)
  (SPADCALL |s| (SPADCALL (LIST |x|) (QREFELT |$| 12)) (QREFELT |$| 8)))

(DEFUN |SetAggregate&| (|#1| |#2|)
  (PROG (|DV$1| |DV$2| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|SetAggregate&|))
        (LETT |DV$2| (|devaluate| |#2|) . #1#)
        (LETT |dv$| (LIST (QUOTE |SetAggregate&|) |DV$1| |DV$2|) . #1#)
        (LETT |$| (make-array 16) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        (QSETREFV |$| 7 |#2|)
        |$|))))

(setf (get
  (QUOTE |SetAggregate&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|))
```

```

(0 . |difference|) (6 . |union|) |SETAGG-;symmetricDifference;3A;1|
(|List| 7) (12 . |brace|) |SETAGG-;union;ASA;2| |SETAGG-;union;S2A;3|
|SETAGG-;difference;ASA;4|))
(QUOTE #(|union| 17 |symmetricDifference| 29 |difference| 35))
(QUOTE NIL)
(CONS
  (|makeByteWordVec2| 1 (QUOTE NIL))
  (CONS
    (QUOTE #())
    (CONS
      (QUOTE #())
      (|makeByteWordVec2| 15 (QUOTE (2 6 0 0 0 8 2 6 0 0 0 9 1 6 0 11 12 2
        0 0 7 0 14 2 0 0 0 7 13 2 0 0 0 0 10 2 0 0 0 7 15))))))
  (QUOTE |lookupComplete|)))

```

21.58 SETCAT.lsp BOOTSTRAP

SETCAT needs **SINT** which needs **UFD** which needs **GCDDOM** which needs **COM-RING** which needs **RING** which needs **RNG** which needs **ABELGRP** which needs **CAB-MON** which needs **ABELMON** which needs **ABELSG** which needs **SETCAT**. We break this chain with **SETCAT.lsp** which we cache here. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **SETCAT** category which we can write into the **MID** directory. We compile the lisp code and copy the **SETCAT.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— SETCAT.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |SetCategory;AL| (QUOTE NIL))

(DEFUN |SetCategory| NIL
  (LET (#:G82359)
    (COND
      (|SetCategory;AL|)
      (T (SETQ |SetCategory;AL| (|SetCategory;|))))))

(DEFUN |SetCategory;| NIL
  (PROG (#1= #:G82357)
    (RETURN
      (PROG1
        (LETT #1#

```

```

(|sublisV|
  (PAIR
    (QUOTE (#2=#:G82356))
    (LIST (QUOTE (|OutputForm|))))
  (|Join|
    (|BasicType|)
    (|CoercibleTo| (QUOTE #2#))
    (|mkCategory|
      (QUOTE |domain|)
      (QUOTE (
        ((|hash| ((|SingleInteger|) |$|)) T)
        ((|latex| ((|String|) |$|)) T)))
      NIL
      (QUOTE ((|String|) (|SingleInteger|)))
      NIL)))
    |SetCategory|)
  (SETELT #1# 0 (QUOTE (|SetCategory|))))))

(setf (get (QUOTE |SetCategory|) (QUOTE NILADIC)) T)

```

21.59 SETCAT-.lsp BOOTSTRAP

SETCAT- is the implementation of the operations exported by **SETCAT**. It comes into existence whenever **SETCAT** gets compiled by Axiom. However this will not happen at the lisp level so we also cache this information here. See the explanation under the **SETCAT.lsp** section for more details.

Note that this code is not included in the generated catdef.spad file.

— SETCAT-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(PUT
  (QUOTE |SETCAT-;hash;SSi;1|)
  (QUOTE |SPADreplace|)
  (QUOTE (XLAM (|s|) 0)))

(DEFUN |SETCAT-;hash;SSi;1| (|s| |$|) 0)

(PUT
  (QUOTE |SETCAT-;latex;SS;2|)
  (QUOTE |SPADreplace|)
  (QUOTE (XLAM (|s|) "\mbox{\bf Unimplemented}")))

```

```

(DEFUN |SETCAT-;latex;SS;2| (|s| |$|)
  "\mbox{\bf Unimplemented}")

(DEFUN |SetCategory&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|SetCategory&|))
        (LETT |dv$| (LIST (QUOTE |SetCategory&|) |DV$1|) . #1#)
        (LETT |$| (make-array 11) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        |$|))))))

(setf (get
  (QUOTE |SetCategory&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (|SingleInteger|)
        |SETCAT-;hash;SSi;1|
        (|String|)
        |SETCAT-;latex;SS;2|))
    (QUOTE
      #(|latex| 0 |hash| 5))
    (QUOTE NIL)
    (CONS
      (|makeByteWordVec2| 1 (QUOTE NIL))
      (CONS
        (QUOTE #())
        (CONS
          (QUOTE #())
          (|makeByteWordVec2|
            10
            (QUOTE (1 0 9 0 10 1 0 7 0 8))))))
    (QUOTE |lookupComplete|)))

```

21.60 STAGG.lsp BOOTSTRAP

STAGG depends on a chain of files. We need to break this cycle to build the algebra. So we

keep a cached copy of the translated **STAGG** category which we can write into the **MID** directory. We compile the lisp code and copy the **STAGG.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— STAGG.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(SETQ |StreamAggregate;CAT| (QUOTE NIL))

(SETQ |StreamAggregate;AL| (QUOTE NIL))

(DEFUN |StreamAggregate| (#1=#:G87035)
  (LET (#2=#:G87036)
    (COND
      ((SETQ #2# (|assoc| (|devalue| #1#) |StreamAggregate;AL|)) (CDR #2#))
      (T
        (SETQ |StreamAggregate;AL|
          (|cons5|
            (CONS (|devalue| #1#) (SETQ #2# (|StreamAggregate;| #1#)))
            |StreamAggregate;AL|))
          #2#))))
  v
(DEFUN |StreamAggregate;| (|t#1|)
  (PROG (#1=#:G87034)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR (QUOTE (|t#1|)) (LIST (|devalue| |t#1|)))
            (COND
              (|StreamAggregate;CAT|)
              ((QUOTE T)
                (LETT |StreamAggregate;CAT|
                  (|Join|
                    (|UnaryRecursiveAggregate| (QUOTE |t#1|))
                    (|LinearAggregate| (QUOTE |t#1|))
                    (|mkCategory|
                      (QUOTE |domain|)
                      (QUOTE (
                        ((|explicitlyFinite?| ((|Boolean|) |$|)) T)
                        ((|possiblyInfinite?| ((|Boolean|) |$|)) T)))
                      NIL
                      (QUOTE ((|Boolean|)))
                      NIL))
                  . #2#(|StreamAggregate|))))
          . #2#)
```

```
(SETELT #1# 0 (LIST (QUOTE |StreamAggregate|) (|devaluate| |t#1|))))))
```

21.61 STAGG-.lsp BOOTSTRAP

STAGG- depends on **STAGG**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **STAGG-** category which we can write into the **MID** directory. We compile the lisp code and copy the **STAGG-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— STAGG-.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)

(DEFUN |STAGG-;explicitlyFinite?;AB;1| (|x| |$|)
  (COND ((SPADCALL |x| (QREFELT |$| 9)) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))

(DEFUN |STAGG-;possiblyInfinite?;AB;2| (|x| |$|)
  (SPADCALL |x| (QREFELT |$| 9)))

(DEFUN |STAGG-;first;ANniA;3| (|x| |n| |$|)
  (PROG (#1#:#G87053 |i|)
    (RETURN
      (SEQ
        (SPADCALL
          (PROGN
            (LETT #1# NIL |STAGG-;first;ANniA;3|)
            (SEQ
              (LETT |i| 1 |STAGG-;first;ANniA;3|)
              G190
              (COND ((QSGREATERP |i| |n|) (GO G191)))
              (SEQ
                (EXIT
                  (LETT #1#
                    (CONS
                      (|STAGG-;c2| |x|
                        (LETT |x| (SPADCALL |x| (QREFELT |$| 12)) |STAGG-;first;ANniA;3|)
                        |$|)
                      #1#)
                    |STAGG-;first;ANniA;3|))))
              (LETT |i| (QSADD1 |i|) |STAGG-;first;ANniA;3|)
              (GO G190)
              G191
              (EXIT (NREVERSE0 #1#))))))
```

```

(QREFELT |$| 14))))))

(DEFUN |STAGG-;c2| (|x| |r| |$|)
  (COND
    ((SPADCALL |x| (QREFELT |$| 17)) (|error| "Index out of range"))
    ((QUOTE T) (SPADCALL |x| (QREFELT |$| 18)))))

(DEFUN |STAGG-;elt;AIS;5| (|x| |i| |$|)
  (PROG (#1=#:G87056)
    (RETURN
      (SEQ
        (LETT |i| (|-| |i| (SPADCALL |x| (QREFELT |$| 20))) |STAGG-;elt;AIS;5|)
        (COND
          ((OR
            (|<| |i| 0)
            (SPADCALL
              (LETT |x|
                (SPADCALL |x|
                  (PROG1
                    (LETT #1# |i| |STAGG-;elt;AIS;5|)
                    (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                    (QREFELT |$| 21))
                    |STAGG-;elt;AIS;5|)
                    (QREFELT |$| 17)))
              (EXIT (|error| "index out of range"))))
            (EXIT (SPADCALL |x| (QREFELT |$| 18)))))))

(DEFUN |STAGG-;elt;AUaA;6| (|x| |i| |$|)
  (PROG (|l| #1=#:G87060 |h| #2=#:G87062 #3=#:G87063)
    (RETURN
      (SEQ
        (LETT |l|
          (|-| (SPADCALL |i| (QREFELT |$| 24)) (SPADCALL |x| (QREFELT |$| 20)))
          |STAGG-;elt;AUaA;6|)
        (EXIT
          (COND
            ((|<| |l| 0) (|error| "index out of range"))
            ((NULL (SPADCALL |i| (QREFELT |$| 25)))
              (SPADCALL
                (SPADCALL |x|
                  (PROG1
                    (LETT #1# |l| |STAGG-;elt;AUaA;6|)
                    (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                    (QREFELT |$| 21))
                    (QREFELT |$| 26)))
                (QUOTE T)
                (SEQ
                  (LETT |h|
                    (|-| (SPADCALL |i| (QREFELT |$| 27)) (SPADCALL |x| (QREFELT |$| 20)))
                    |STAGG-;elt;AUaA;6|)

```

```

(EXIT
(COND
  ((|<| |h| |l|) (SPADCALL (QREFELT |$| 28)))
  ((QUOTE T)
   (SPADCALL
    (SPADCALL |x|
     (PROG1
      (LETT #2# |l| |STAGG-;elt;AUsA;6|)
      (|check-subtype|
       (|>=| #2# 0) (QUOTE (|NonNegativeInteger|)) #2#))
      (QREFELT |$| 21)))
     (PROG1
      (LETT #3# (|+| (|-| |h| |l|) 1) |STAGG-;elt;AUsA;6|)
      (|check-subtype| (|>=| #3# 0) (QUOTE (|NonNegativeInteger|)) #3#))
      (QREFELT |$| 29))))))))))

(DEFUN |STAGG-;concat;3A;7| (|x| |y| |$|)
  (SPADCALL (SPADCALL |x| (QREFELT |$| 26)) |y| (QREFELT |$| 31)))

(DEFUN |STAGG-;concat;LA;8| (|l| |$|)
  (COND
   ((NULL |l|) (SPADCALL (QREFELT |$| 28)))
   ((QUOTE T)
    (SPADCALL
     (SPADCALL (|SPADfirst| |l|) (QREFELT |$| 26))
     (SPADCALL (CDR |l|) (QREFELT |$| 34))
     (QREFELT |$| 31))))))

(DEFUN |STAGG-;map!;M2A;9| (|f| |l| |$|)
  (PROG (|y|)
  (RETURN
   (SEQ
    (LETT |y| |l| |STAGG-;map!;M2A;9|)
    (SEQ
     G190
     (COND
      ((NULL
       (COND
        ((SPADCALL |l| (QREFELT |$| 17)) (QUOTE NIL))
        ((QUOTE T) (QUOTE T))))
       (GO G191)))
     (SEQ
      (SPADCALL |l|
       (SPADCALL (SPADCALL |l| (QREFELT |$| 18)) |f|) (QREFELT |$| 36))
      (EXIT (LETT |l| (SPADCALL |l| (QREFELT |$| 12)) |STAGG-;map!;M2A;9|)))
     NIL
     (GO G190)
     G191
     (EXIT NIL))
    (EXIT |y|))))))

```

```

(DEFUN |STAGG-;fill!;ASA;10| (|x| |s| |$|)
  (PROG (|y|)
    (RETURN
      (SEQ
        (LETT |y| |x| |STAGG-;fill!;ASA;10|)
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((SPADCALL |y| (QREFELT |$| 17)) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
            (GO G191)))
          (SEQ
            (SPADCALL |y| |s| (QREFELT |$| 36))
            (EXIT (LETT |y| (SPADCALL |y| (QREFELT |$| 12)) |STAGG-;fill!;ASA;10|)))
          NIL
          (GO G190)
          G191
          (EXIT NIL))
        (EXIT |x|))))))

(DEFUN |STAGG-;setelt;AI2S;11| (|x| |i| |s| |$|)
  (PROG (#1=:G87081)
    (RETURN
      (SEQ
        (LETT |i|
          (|-| |i| (SPADCALL |x| (QREFELT |$| 20))) |STAGG-;setelt;AI2S;11|)
        (COND
          ((OR
            (|<| |i| 0)
            (SPADCALL
              (LETT |x|
                (SPADCALL |x|
                  (PROG1
                    (LETT #1# |i| |STAGG-;setelt;AI2S;11|)
                    (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                    (QREFELT |$| 21))
                    |STAGG-;setelt;AI2S;11|)
                    (QREFELT |$| 17)))
              (EXIT (|error| "index out of range"))))
            (EXIT (SPADCALL |x| |s| (QREFELT |$| 36)))))))

(DEFUN |STAGG-;setelt;AUs2S;12| (|x| |i| |s| |$|)
  (PROG (|l| |h| #1=:G87086 #2=:G87087 |z| |y|)
    (RETURN
      (SEQ
        (LETT |l|
          (|-| (SPADCALL |i| (QREFELT |$| 24)) (SPADCALL |x| (QREFELT |$| 20)))
          |STAGG-;setelt;AUs2S;12|)

```

```

(EXIT
(COND
  ((|<| |l| 0) (|error| "index out of range"))
  ((QUOTE T)
   (SEQ
    (LETT |h|
      (COND
        ((SPADCALL |i| (QREFELT |$| 25))
         (|-|
          (SPADCALL |i| (QREFELT |$| 27))
          (SPADCALL |x| (QREFELT |$| 20))))
        ((QUOTE T) (SPADCALL |x| (QREFELT |$| 41))))
    |STAGG-;setelt;AUs2S;12|)
   (EXIT
    (COND
      ((|<| |h| |l|) |s|)
      ((QUOTE T)
       (SEQ
        (LETT |y|
          (SPADCALL |x|
            (PROG1
              (LETT #1# |l| |STAGG-;setelt;AUs2S;12|)
              (|check-subtype|
               (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
              (QREFELT |$| 21))
            |STAGG-;setelt;AUs2S;12|)
          (LETT |z|
            (SPADCALL |y|
              (PROG1
                (LETT #2# (|+| (|-| |h| |l|) 1) |STAGG-;setelt;AUs2S;12|)
                (|check-subtype|
                 (|>=| #2# 0) (QUOTE (|NonNegativeInteger|)) #2#))
                (QREFELT |$| 21))
              |STAGG-;setelt;AUs2S;12|)
            (SEQ
              G190
              (COND
                ((NULL
                  (COND
                    ((SPADCALL |y| |z| (QREFELT |$| 42)) (QUOTE NIL))
                    ((QUOTE T) (QUOTE T))))
                 (GO G191)))
              (SEQ
                (SPADCALL |y| |s| (QREFELT |$| 36))
                (EXIT
                 (LETT |y|
                  (SPADCALL |y| (QREFELT |$| 12))
                  |STAGG-;setelt;AUs2S;12|)))
              NIL
              (GO G190))

```

```

G191
(EXIT NIL))
(EXIT |s|))))))))))

(DEFUN |STAGG-;concat!;3A;13| (|x| |y| |$|)
  (SEQ
    (COND
      ((SPADCALL |x| (QREFELT |$| 17)) |y|)
      ((QUOTE T)
        (SEQ
          (SPADCALL (SPADCALL |x| (QREFELT |$| 44)) |y| (QREFELT |$| 45))
          (EXIT |x|))))))

(DEFUN |StreamAggregate&| (|#1| |#2|)
  (PROG (|DV$1| |DV$2| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|StreamAggregate&|))
        (LETT |DV$2| (|devaluate| |#2|) . #1#)
        (LETT |dv$| (LIST (QUOTE |StreamAggregate&|) |DV$1| |DV$2|) . #1#)
        (LETT |$| (make-array 51) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        (QSETREFV |$| 7 |#2|)
        (COND
          ((|HasAttribute| |#1| (QUOTE |shallowlyMutable|))
            (PROGN
              (QSETREFV |$| 32 (CONS (|dispatchFunction| |STAGG-;concat;3A;7|) |$|))
              (QSETREFV |$| 35 (CONS (|dispatchFunction| |STAGG-;concat;LA;8|) |$|))
              (QSETREFV |$| 38 (CONS (|dispatchFunction| |STAGG-;map!;M2A;9|) |$|))
              (QSETREFV |$| 39 (CONS (|dispatchFunction| |STAGG-;fill!;ASA;10|) |$|))
              (QSETREFV |$| 40
                (CONS (|dispatchFunction| |STAGG-;setelt;AI2S;11|) |$|))
              (QSETREFV |$| 43
                (CONS (|dispatchFunction| |STAGG-;setelt;AUs2S;12|) |$|))
              (QSETREFV |$| 46
                (CONS (|dispatchFunction| |STAGG-;concat!;3A;13|) |$|))))
          |$|))))

(setf (get
  (QUOTE |StreamAggregate&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|)
      (|Boolean|) (0 . |cyclic?|) |STAGG-;explicitlyFinite?;AB;1|
      |STAGG-;possiblyInfinite?;AB;2| (5 . |rest|) (|List| 7)
      (10 . |construct|) (|NonNegativeInteger|) |STAGG-;first;ANniA;3|
      (15 . |empty?|) (20 . |first|) (|Integer|) (25 . |minIndex|)

```

```

(30 . |rest|) |STAGG-;elt;AIS;5| (|UniversalSegment| 19) (36 . |lo|)
(41 . |hasHi|) (46 . |copy|) (51 . |hi|) (56 . |empty|) (60 . |first|)
|STAGG-;elt;AUsA;6| (66 . |concat!|) (72 . |concat|) (|List| |$|)
(78 . |concat|) (83 . |concat|) (88 . |setfirst!|) (|Mapping| 7 7)
(94 . |map!|) (100 . |fill!|) (106 . |setelt|) (113 . |maxIndex|)
(118 . |eq?!|) (124 . |setelt|) (131 . |tail|) (136 . |setrest!|)
(142 . |concat!|) (QUOTE "rest") (QUOTE "last") (QUOTE "first")
(QUOTE "value"))))
(QUOTE #(|setelt| 148 |possiblyInfinite?!| 162 |map!| 167 |first| 173
|fill!| 179 |explicitlyFinite?!| 185 |elt| 190 |concat!| 202 |concat| 208))
(QUOTE NIL)
(CONS
(|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
(QUOTE #())
(CONS
(QUOTE #())
(|makeByteWordVec2| 46 (QUOTE (1 6 8 0 9 1 6 0 0 12 1 6 0 13 14 1 6
8 0 17 1 6 7 0 18 1 6 19 0 20 2 6 0 0 15 21 1 23 19 0 24 1 23 8
0 25 1 6 0 0 26 1 23 19 0 27 0 6 0 28 2 6 0 0 15 29 2 6 0 0 0 31
2 0 0 0 32 1 6 0 33 34 1 0 0 33 35 2 6 7 0 7 36 2 0 0 37 0 38 2
0 0 0 7 39 3 0 7 0 19 7 40 1 6 19 0 41 2 6 8 0 0 42 3 0 7 0 23 7 43
1 6 0 0 44 2 6 0 0 0 45 2 0 0 0 0 46 3 0 7 0 19 7 40 3 0 7 0 23 7 43
1 0 8 0 11 2 0 0 37 0 38 2 0 0 0 15 16 2 0 0 0 7 39 1 0 8 0 10 2 0 7
0 19 22 2 0 0 0 23 30 2 0 0 0 0 46 1 0 0 33 35 2 0 0 0 0 32))))))
(QUOTE |lookupComplete|)))

```

21.62 TSETCAT.lsp BOOTSTRAP

TSETCAT depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **TSETCAT** category which we can write into the **MID** directory. We compile the lisp code and copy the **TSETCAT.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— TSETCAT.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |TriangularSetCategory;CAT| (QUOTE NIL))

(SETQ |TriangularSetCategory;AL| (QUOTE NIL))

(DEFUN |TriangularSetCategory| (|&REST| #1=#:G82394 |&AUX| #2=#:G82392)

```



```

(DSETQ #2# #1#)
(LET (#3=#:G82393)
  (COND
    ((SETQ #3# (|assoc| (|devalueList| #2#) |TriangularSetCategory;AL|))
      (CDR #3#))
    (T
      (SETQ |TriangularSetCategory;AL|
        (|cons5|
          (CONS
            (|devalueList| #2#)
            (SETQ #3# (APPLY (FUNCTION |TriangularSetCategory;|) #2#)))
            |TriangularSetCategory;AL|))
          #3#))))))

(DEFUN |TriangularSetCategory;| (|t#1| |t#2| |t#3| |t#4|)
  (PROG (#1=#:G82391)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR
              (QUOTE (|t#1| |t#2| |t#3| |t#4|))
              (LIST
                (|devalue| |t#1|)
                (|devalue| |t#2|)
                (|devalue| |t#3|)
                (|devalue| |t#4|))))
            (COND
              (|TriangularSetCategory;CAT|)
              ((QUOTE T)
                (LETT |TriangularSetCategory;CAT|
                  (|Join|
                    (|PolynomialSetCategory|
                      (QUOTE |t#1|)
                      (QUOTE |t#2|)
                      (QUOTE |t#3|)
                      (QUOTE |t#4|))
                    (|mkCategory|
                      (QUOTE |domain|)
                      (QUOTE (
                        ((|infRittWu?| ((|Boolean|) |$| |$|)) T)
                        ((|basicSet| (
                          (|Union|
                            (|Record| (|:| |bas| |$|) (|:| |top| (|List| |t#4|))) "failed")
                            (|List| |t#4|)
                            (|Mapping| (|Boolean|) |t#4| |t#4|)))
                          T)
                        ((|basicSet| (
                          (|Union|
                            (|Record| (|:| |bas| |$|) (|:| |top| (|List| |t#4|))) "failed")

```

```

(|List| |t#4|)
(|Mapping| (|Boolean|) |t#4|)
(|Mapping| (|Boolean|) |t#4| |t#4|)))
T)
((|initials| ((|List| |t#4|) |$|)) T)
((|degree| ((|NonNegativeInteger|) |$|)) T)
((|quasiComponent| (
  (|Record|
    (|:| |close| (|List| |t#4|))
    (|:| |open| (|List| |t#4|))
    |$|))
  T)
  ((|normalized?| ((|Boolean|) |t#4| |$|)) T)
  ((|normalized?| ((|Boolean|) |$|)) T)
  ((|reduced?| (
    (|Boolean|)
    |t#4|
    |$|
    (|Mapping| (|Boolean|) |t#4| |t#4|)))
    T)
  ((|stronglyReduced?| ((|Boolean|) |t#4| |$|)) T)
  ((|headReduced?| ((|Boolean|) |t#4| |$|)) T)
  ((|initiallyReduced?| ((|Boolean|) |t#4| |$|)) T)
  ((|autoReduced?| (
    (|Boolean|)
    |$|
    (|Mapping| (|Boolean|) |t#4| (|List| |t#4|))))
    T)
  ((|stronglyReduced?| ((|Boolean|) |$|)) T)
  ((|headReduced?| ((|Boolean|) |$|)) T)
  ((|initiallyReduced?| ((|Boolean|) |$|)) T)
  ((|reduce| (
    |t#4|
    |t#4|
    |$|
    (|Mapping| |t#4| |t#4| |t#4|)
    (|Mapping| (|Boolean|) |t#4| |t#4|)))
    T)
  ((|rewriteSetWithReduction| (
    (|List| |t#4|)
    (|List| |t#4|)
    |$|
    (|Mapping| |t#4| |t#4| |t#4|)
    (|Mapping| (|Boolean|) |t#4| |t#4|)))
    T)
  ((|stronglyReduce| (|t#4| |t#4| |$|)) T)
  ((|headReduce| (|t#4| |t#4| |$|)) T)
  ((|initiallyReduce| (|t#4| |t#4| |$|)) T)
  ((|removeZero| (|t#4| |t#4| |$|)) T)
  ((|collectQuasiMonic| (|$| |$|)) T)

```

```

((|reduceByQuasiMonic| (|t#4| |t#4| |$|)) T)
((|zeroSetSplit| ((|List| |$|) (|List| |t#4|))) T)
((|zeroSetSplitIntoTriangularSystems|
  ((|List|
    (|Record| (|:| |close| |$|) (|:| |open| (|List| |t#4|))))
    (|List| |t#4|)))
  T)
((|first| ((|Union| |t#4| "failed") |$|)) T)
((|last| ((|Union| |t#4| "failed") |$|)) T)
((|rest| ((|Union| |$| "failed") |$|)) T)
((|algebraicVariables| ((|List| |t#3|) |$|)) T)
((|algebraic?| ((|Boolean|) |t#3| |$|)) T)
((|select| ((|Union| |t#4| "failed") |$| |t#3|)) T)
((|extendIfCan| ((|Union| |$| "failed") |$| |t#4|)) T)
((|extend| (|$| |$| |t#4|)) T)
((|coHeight| ((|NonNegativeInteger|) |$|))
  (|has| |t#3| (|Finite|))))
(QUOTE (
  (|finiteAggregate| T)
  (|shallowlyMutable| T)))
(QUOTE ((|NonNegativeInteger|)
  (|Boolean|)
  (|List| |t#3|)
  (|List| (|Record| (|:| |close| |$|) (|:| |open| (|List| |t#4|))))
  (|List| |t#4|)
  (|List| |$|)))
NIL))
. #2=(|TriangularSetCategory|))))
. #2#)
(SETELT #1# 0
  (LIST
    (QUOTE |TriangularSetCategory|)
    (|devaluate| |t#1|)
    (|devaluate| |t#2|)
    (|devaluate| |t#3|)
    (|devaluate| |t#4|))))))

```

21.63 TSETCAT-.lsp BOOTSTRAP

TSETCAT depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **TSETCAT** category which we can write into the **MID** directory. We compile the lisp code and copy the **TSETCAT.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— TSETCAT-.lsp BOOTSTRAP —

```

(/VERSIONCHECK 2)

(DEFUN |TSETCAT-;=;2SB;1| (|ts| |us| $)
  (PROG (#0=:G1475 #1=:G1481)
    (RETURN
      (COND
        ((SPADCALL |ts| (QREFELT $ 12)) (SPADCALL |us| (QREFELT $ 12)))
        ((OR
          (SPADCALL |us| (QREFELT $ 12))
          (NULL
            (SPADCALL
              (PROG2
                (LETT #0# (SPADCALL |ts| (QREFELT $ 14)) |TSETCAT-;=;2SB;1|)
                (QCDR #0#)
                (|check-union| (QEQCAR #0# 0) (QREFELT $ 10) #0#))
              (PROG2
                (LETT #0# (SPADCALL |us| (QREFELT $ 14)) |TSETCAT-;=;2SB;1|)
                (QCDR #0#)
                (|check-union| (QEQCAR #0# 0) (QREFELT $ 10) #0#))
              (QREFELT $ 15))))
            (QUOTE NIL))
          ((QUOTE T)
            (SPADCALL
              (PROG2
                (LETT #1# (SPADCALL |ts| (QREFELT $ 17)) |TSETCAT-;=;2SB;1|)
                (QCDR #1#)
                (|check-union| (QEQCAR #1# 0) (QREFELT $ 6) #1#))
              (PROG2
                (LETT #1# (SPADCALL |us| (QREFELT $ 17)) |TSETCAT-;=;2SB;1|)
                (QCDR #1#)
                (|check-union| (QEQCAR #1# 0) (QREFELT $ 6) #1#))
              (QREFELT $ 18)))))))

(DEFUN |TSETCAT-;infRittWu?;2SB;2| (|ts| |us| $)
  (PROG (|p| #0=:G1489 |q| |v|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |us| (QREFELT $ 12))
            (COND
              ((SPADCALL |ts| (QREFELT $ 12)) (QUOTE NIL))
              ((QUOTE T) (QUOTE T))))
          ((SPADCALL |ts| (QREFELT $ 12)) (QUOTE NIL))
          ((QUOTE T)
            (SEQ
              (LETT |p|

```

```

(PROG2
  (LETT #0# (SPADCALL |ts| (QREFELT $ 20)) |TSETCAT-;infRittWu?;2SB;2|)
  (QCDR #0#)
  (|check-union| (QEQCAR #0# 0) (QREFELT $ 10) #0#))
|TSETCAT-;infRittWu?;2SB;2|)
(LETT |q|
  (PROG2
    (LETT #0# (SPADCALL |us| (QREFELT $ 20)) |TSETCAT-;infRittWu?;2SB;2|)
    (QCDR #0#)
    (|check-union| (QEQCAR #0# 0) (QREFELT $ 10) #0#))
    |TSETCAT-;infRittWu?;2SB;2|)
  (EXIT
    (COND
      ((SPADCALL |p| |q| (QREFELT $ 21)) (QUOTE T))
      ((SPADCALL |p| |q| (QREFELT $ 22)) (QUOTE NIL))
      ((QUOTE T)
        (SEQ
          (LETT |v| (SPADCALL |p| (QREFELT $ 23)) |TSETCAT-;infRittWu?;2SB;2|)
          (EXIT
            (SPADCALL
              (SPADCALL |ts| |v| (QREFELT $ 24))
              (SPADCALL |us| |v| (QREFELT $ 24)) (QREFELT $ 25))))))))))

(DEFUN |TSETCAT-;reduced?;PSMB;3| (|p| |ts| |redOp?| $)
  (PROG (|lp|)
    (RETURN
      (SEQ
        (LETT |lp| (SPADCALL |ts| (QREFELT $ 28)) |TSETCAT-;reduced?;PSMB;3|)
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((NULL |lp|) (QUOTE NIL))
                ((QUOTE T) (SPADCALL |p| (|SPADfirst| |lp|) |redOp?|))))
              (GO G191)))
          (SEQ (EXIT (LETT |lp| (CDR |lp|) |TSETCAT-;reduced?;PSMB;3|)))
          NIL
          (GO G190)
          G191
          (EXIT NIL))
        (EXIT (NULL |lp|))))))

(DEFUN |TSETCAT-;basicSet;LMU;4| (|ps| |redOp?| $)
  (PROG (|b| |bs| |p| |ts|)
    (RETURN
      (SEQ
        (LETT |ps|
          (SPADCALL (ELT $ 31) |ps| (QREFELT $ 33))
          |TSETCAT-;basicSet;LMU;4|)

```

```

(EXIT
(COND
  ((SPADCALL (ELT $ 34) |ps| (QREFELT $ 35)) (CONS 1 "failed")))
((QUOTE T)
  (SEQ
    (LETT |ps|
      (SPADCALL (ELT $ 21) |ps| (QREFELT $ 36))
      |TSETCAT-;basicSet;LMU;4|)
    (LETT |bs| (SPADCALL (QREFELT $ 37)) |TSETCAT-;basicSet;LMU;4|)
    (LETT |ts| NIL |TSETCAT-;basicSet;LMU;4|)
    (SEQ
      G190
      (COND
        ((NULL (COND ((NULL |ps|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
        (GO G191)))
    (SEQ
      (LETT |b| (|SPADfirst| |ps|) |TSETCAT-;basicSet;LMU;4|)
      (LETT |bs|
        (SPADCALL |bs| |b| (QREFELT $ 38))
        |TSETCAT-;basicSet;LMU;4|)
      (LETT |ps| (CDR |ps|) |TSETCAT-;basicSet;LMU;4|)
      (EXIT
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((OR
                  (NULL |ps|)
                  (SPADCALL
                    (LETT |p| (|SPADfirst| |ps|) |TSETCAT-;basicSet;LMU;4|)
                    |bs| |redOp?| (QREFELT $ 39)))
                  (QUOTE NIL)))
                ((QUOTE T) (QUOTE T))))
              (GO G191)))
          (SEQ
            (LETT |ts| (CONS |p| |ts|) |TSETCAT-;basicSet;LMU;4|)
            (EXIT (LETT |ps| (CDR |ps|) |TSETCAT-;basicSet;LMU;4|)))
          NIL
          (GO G190)
          G191
          (EXIT NIL))))
      (GO G190)
      G191
      (EXIT NIL))
    (EXIT (CONS 0 (CONS |bs| |ts|))))))))))

(DEFUN |TSETCAT-;basicSet;LMMU;5| (|ps| |pred?| |redOp?| $)
  (PROG (|bps| |b| |bs| |p| |gps| |ts|)

```

```

(RETURN
  (SEQ
    (LETT |ps|
      (SPADCALL (ELT $ 31) |ps| (QREFELT $ 33))
      |TSETCAT-;basicSet;LMMU;5|)
    (EXIT
      (COND
        ((SPADCALL (ELT $ 34) |ps| (QREFELT $ 35)) (CONS 1 "failed"))
        ((QUOTE T)
          (SEQ
            (LETT |gps| NIL |TSETCAT-;basicSet;LMMU;5|)
            (LETT |bps| NIL |TSETCAT-;basicSet;LMMU;5|)
            (SEQ
              G190
              (COND
                ((NULL (COND ((NULL |ps|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
                (GO G191)))
            (SEQ
              (LETT |p| (|SPADfirst| |ps|) |TSETCAT-;basicSet;LMMU;5|)
              (LETT |ps| (CDR |ps|) |TSETCAT-;basicSet;LMMU;5|)
              (EXIT
                (COND
                  ((SPADCALL |p| |pred?|)
                    (LETT |gps| (CONS |p| |gps|) |TSETCAT-;basicSet;LMMU;5|))
                  ((QUOTE T)
                    (LETT |bps| (CONS |p| |bps|) |TSETCAT-;basicSet;LMMU;5|))))))
              NIL
              (GO G190)
              G191
              (EXIT NIL))
            (LETT |gps|
              (SPADCALL (ELT $ 21) |gps| (QREFELT $ 36)) |TSETCAT-;basicSet;LMMU;5|)
              (LETT |bs| (SPADCALL (QREFELT $ 37)) |TSETCAT-;basicSet;LMMU;5|)
              (LETT |ts| NIL |TSETCAT-;basicSet;LMMU;5|)
              (SEQ
                G190
                (COND
                  ((NULL (COND ((NULL |gps|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
                  (GO G191)))
                (SEQ
                  (LETT |b| (|SPADfirst| |gps|) |TSETCAT-;basicSet;LMMU;5|)
                  (LETT |bs|
                    (SPADCALL |bs| |b| (QREFELT $ 38)) |TSETCAT-;basicSet;LMMU;5|)
                    (LETT |gps| (CDR |gps|) |TSETCAT-;basicSet;LMMU;5|)
                    (EXIT
                      (SEQ
                        G190
                        (COND
                          ((NULL
                            (COND

```



```

        |TSETCAT-;initials;SL;6|)
        (QREFELT $ 34)))
    (LETT |lip|
      (CONS (SPADCALL |ip| (QREFELT $ 46)) |lip|)
      |TSETCAT-;initials;SL;6|)))
    (EXIT (LETT |lp| (CDR |lp|) |TSETCAT-;initials;SL;6|)))
  NIL
  (GO G190)
  G191
  (EXIT NIL))
  (EXIT (SPADCALL |lip| (QREFELT $ 47)))))))))

(DEFUN |TSETCAT-;degree;SNni;7| (|ts| $)
  (PROG (|lp| |d|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |ts| (QREFELT $ 12)) 0)
          ((QUOTE T)
            (SEQ
              (LETT |lp| (SPADCALL |ts| (QREFELT $ 28)) |TSETCAT-;degree;SNni;7|)
              (LETT |d|
                (SPADCALL (|SPADfirst| |lp|) (QREFELT $ 50))
                |TSETCAT-;degree;SNni;7|)
              (SEQ
                G190
                (COND
                  ((NULL
                    (COND
                      ((NULL
                        (LETT |lp| (CDR |lp|) |TSETCAT-;degree;SNni;7|)) (QUOTE NIL))
                        ((QUOTE T) (QUOTE T))))
                    (GO G191)))
                (SEQ
                  (EXIT
                    (LETT |d|
                      (* |d| (SPADCALL (|SPADfirst| |lp|) (QREFELT $ 50))
                        |TSETCAT-;degree;SNni;7|)))
                    NIL
                    (GO G190)
                    G191
                    (EXIT NIL))
                  (EXIT |d|)))))))))

(DEFUN |TSETCAT-;quasiComponent;SR;8| (|ts| $)
  (CONS (SPADCALL |ts| (QREFELT $ 28)) (SPADCALL |ts| (QREFELT $ 52))))

(DEFUN |TSETCAT-;normalized?;PSB;9| (|p| |ts| $)
  (SPADCALL |p| (SPADCALL |ts| (QREFELT $ 28)) (QREFELT $ 56)))

```

```

(DEFUN |TSETCAT-;stronglyReduced?;PSB;10| (|p| |ts| $)
  (SPADCALL |p| (SPADCALL |ts| (QREFELT $ 28)) (QREFELT $ 58)))

(DEFUN |TSETCAT-;headReduced?;PSB;11| (|p| |ts| $)
  (SPADCALL (SPADCALL |p| (QREFELT $ 60)) |ts| (QREFELT $ 61)))

(DEFUN |TSETCAT-;initiallyReduced?;PSB;12| (|p| |ts| $)
  (PROG (|lp| |red|)
    (RETURN
      (SEQ
        (LETT |lp|
          (SPADCALL |ts| (QREFELT $ 28)) |TSETCAT-;initiallyReduced?;PSB;12|)
        (LETT |red| (QUOTE T) |TSETCAT-;initiallyReduced?;PSB;12|)
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((OR (NULL |lp|) (SPADCALL |p| (QREFELT $ 34))) (QUOTE NIL))
                ((QUOTE T) |red|)))
              (GO G191)))
          (SEQ
            (SEQ
              G190
              (COND
                ((NULL
                  (COND
                    ((NULL |lp|) (QUOTE NIL))
                    ((QUOTE T)
                     (SPADCALL
                      (SPADCALL |p| (QREFELT $ 23))
                      (SPADCALL (|SPADfirst| |lp|) (QREFELT $ 23))
                      (QREFELT $ 63))))))
                  (GO G191)))
            (SEQ (EXIT (LETT |lp| (CDR |lp|) |TSETCAT-;initiallyReduced?;PSB;12|)))
            NIL
            (GO G190)
            G191
            (EXIT NIL))
          (EXIT
            (COND
              ((NULL (NULL |lp|))
               (COND
                 ((SPADCALL
                  (SPADCALL (|SPADfirst| |lp|) (QREFELT $ 23))
                  (SPADCALL |p| (QREFELT $ 23))
                  (QREFELT $ 64))
                 (COND
                   ((SPADCALL |p| (|SPADfirst| |lp|) (QREFELT $ 65))
                    (SEQ

```

```

        (LETT |lp| (CDR |lp|) |TSETCAT-;initiallyReduced?;PSB;12|)
      (EXIT
        (LETT |p|
          (SPADCALL |p| (QREFELT $ 45))
          |TSETCAT-;initiallyReduced?;PSB;12|))))
    ((QUOTE T)
      (LETT |red| (QUOTE NIL) |TSETCAT-;initiallyReduced?;PSB;12|))))
  ((QUOTE T)
    (LETT |p|
      (SPADCALL |p| (QREFELT $ 45))
      |TSETCAT-;initiallyReduced?;PSB;12|))))))
NIL
(GO G190)
G191
(EXIT NIL))
(EXIT |red|))))))

(DEFUN |TSETCAT-;reduce;PSMMP;13| (|p| |ts| |redOp| |redOp?| $)
  (PROG (|ts0| #0= #:G1572 |reductor| #1= #:G1575)
    (RETURN
      (SEQ
        (COND
          ((OR (SPADCALL |ts| (QREFELT $ 12)) (SPADCALL |p| (QREFELT $ 34))) |p|)
          ((QUOTE T)
            (SEQ
              (LETT |ts0| |ts| |TSETCAT-;reduce;PSMMP;13|)
              (SEQ
                G190
                (COND
                  ((NULL
                    (COND
                      ((OR
                        (SPADCALL |ts| (QREFELT $ 12))
                        (SPADCALL |p| (QREFELT $ 34)))
                      (QUOTE NIL))
                    ((QUOTE T) (QUOTE T))))
                  (GO G191)))
              (SEQ
                (LETT |reductor|
                  (PROG2
                    (LETT #0# (SPADCALL |ts| (QREFELT $ 14)) |TSETCAT-;reduce;PSMMP;13|)
                    (QCDR #0#)
                    (|check-union| (QEQCAR #0# 0) (QREFELT $ 10) #0#))
                    |TSETCAT-;reduce;PSMMP;13|)
                  (LETT |ts|
                    (PROG2
                      (LETT #1# (SPADCALL |ts| (QREFELT $ 17)) |TSETCAT-;reduce;PSMMP;13|)
                      (QCDR #1#)
                      (|check-union| (QEQCAR #1# 0) (QREFELT $ 6) #1#))
                      |TSETCAT-;reduce;PSMMP;13|)

```

```

(EXIT
  (COND
    ((NULL (SPADCALL |p| |reductor| |redOp?|))
      (SEQ
        (LETT |p|
          (SPADCALL |p| |reductor| |redOp|) |TSETCAT-;reduce;PSMMP;13|)
          (EXIT (LETT |ts| |ts0| |TSETCAT-;reduce;PSMMP;13|))))))
    NIL
    (GO G190)
    G191
    (EXIT NIL))
  (EXIT |p|))))))

(DEFUN |TSETCAT-;rewriteSetWithReduction;LSMML;14|
  (|lp| |ts| |redOp| |redOp?| $)
  (PROG (|p| |rs|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |ts| (QREFELT $ 69)) |lp|)
          ((QUOTE T)
            (SEQ
              (LETT |lp|
                (SPADCALL (ELT $ 31) |lp| (QREFELT $ 33))
                |TSETCAT-;rewriteSetWithReduction;LSMML;14|)
              (EXIT
                (COND
                  ((NULL |lp|) |lp|)
                  ((SPADCALL (ELT $ 34) |lp| (QREFELT $ 35))
                    (LIST (|spadConstant| $ 70)))
                  ((QUOTE T)
                    (SEQ
                      (LETT |rs| NIL |TSETCAT-;rewriteSetWithReduction;LSMML;14|)
                      (SEQ
                        G190
                        (COND
                          ((NULL (COND ((NULL |lp|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
                          (GO G191)))
                      (SEQ
                        (LETT |p|
                          (|SPADfirst| |lp|)
                          |TSETCAT-;rewriteSetWithReduction;LSMML;14|)
                        (LETT |lp| (CDR |lp|) |TSETCAT-;rewriteSetWithReduction;LSMML;14|)
                        (LETT |p|
                          (SPADCALL
                            (SPADCALL |p| |ts| |redOp| |redOp?| (QREFELT $ 71))
                            (QREFELT $ 46))
                          |TSETCAT-;rewriteSetWithReduction;LSMML;14|)
                        (EXIT
                          (COND

```



```

(QCDR #0#)
(|check-union| (QEQCAR #0# 0) (QREFELT $ 10) #0#))
(QREFELT $ 73))
|TSETCAT-;removeZero;PSP;18|)
(EXIT
(COND
((SPADCALL |q| (QREFELT $ 31))
(PROGN (LETT #1# |q| |TSETCAT-;removeZero;PSP;18|) (GO #1#)))
((SPADCALL (SPADCALL |q| |tsv-| (QREFELT $ 84)) (QREFELT $ 31))
(PROGN
(LETT #1#
(|spadConstant| $ 85)
|TSETCAT-;removeZero;PSP;18|) (GO #1#)))))))))
(EXIT
(COND
((SPADCALL |tsv-| (QREFELT $ 12)) |p|)
((QUOTE T)
(SEQ
(LETT |q| (|spadConstant| $ 85) |TSETCAT-;removeZero;PSP;18|)
(SEQ
G190
(COND
((NULL
(SPADCALL (SPADCALL |p| |v| (QREFELT $ 86)) (QREFELT $ 88)))
(GO G191)))
(SEQ
(LETT |q|
(SPADCALL
(SPADCALL
(SPADCALL
(SPADCALL |p| (QREFELT $ 45))
|tsv-| (QREFELT $ 84))
(SPADCALL |p| (QREFELT $ 89))
(QREFELT $ 90))
|q|
(QREFELT $ 91))
|TSETCAT-;removeZero;PSP;18|)
(EXIT
(LETT |p|
(SPADCALL |p| (QREFELT $ 92))
|TSETCAT-;removeZero;PSP;18|)))
NIL
(GO G190)
G191
(EXIT NIL))
(EXIT
(SPADCALL |q|
(SPADCALL |p| |tsv-| (QREFELT $ 84))
(QREFELT $ 91)))))))))

```

#1#

```

(EXIT #1#))))))

(DEFUN |TSETCAT-;reduceByQuasiMonic;PSP;19| (|p| |ts| $)
  (COND
    ((OR (SPADCALL |p| (QREFELT $ 34)) (SPADCALL |ts| (QREFELT $ 12))) |p|)
    ((QUOTE T)
      (QVELT (SPADCALL |p| (SPADCALL |ts| (QREFELT $ 94)) (QREFELT $ 96)) 1))))))

(DEFUN |TSETCAT-;autoReduced?;SMB;20| (|ts| |redOp?| $)
  (PROG (|p| |lp|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |ts| (QREFELT $ 12)) (QUOTE T))
          ((QUOTE T)
            (SEQ
              (LETT |lp|
                (SPADCALL |ts| (QREFELT $ 28)) |TSETCAT-;autoReduced?;SMB;20|)
              (LETT |p| (|SPADfirst| |lp|) |TSETCAT-;autoReduced?;SMB;20|)
              (LETT |lp| (CDR |lp|) |TSETCAT-;autoReduced?;SMB;20|)
              (SEQ
                G190
                (COND
                  ((NULL
                    (COND
                      ((NULL |lp|) (QUOTE NIL))
                      ((QUOTE T) (SPADCALL |p| |lp| |redOp?|))))
                  (GO G191)))
              (SEQ
                (LETT |p| (|SPADfirst| |lp|) |TSETCAT-;autoReduced?;SMB;20|)
                (EXIT (LETT |lp| (CDR |lp|) |TSETCAT-;autoReduced?;SMB;20|)))
              NIL
              (GO G190)
              G191
              (EXIT NIL))
              (EXIT (NULL |lp|))))))))))

(DEFUN |TSETCAT-;stronglyReduced?;SB;21| (|ts| $)
  (SPADCALL |ts| (ELT $ 58) (QREFELT $ 100)))

(DEFUN |TSETCAT-;normalized?;SB;22| (|ts| $)
  (SPADCALL |ts| (ELT $ 56) (QREFELT $ 100)))

(DEFUN |TSETCAT-;headReduced?;SB;23| (|ts| $)
  (SPADCALL |ts| (ELT $ 103) (QREFELT $ 100)))

(DEFUN |TSETCAT-;initiallyReduced?;SB;24| (|ts| $)
  (SPADCALL |ts| (ELT $ 105) (QREFELT $ 100)))

(DEFUN |TSETCAT-;mvar;SV;25| (|ts| $)

```

```

(PROG (#0=#:G1627)
  (RETURN
    (COND
      ((SPADCALL |ts| (QREFELT $ 12))
        (|error| "Error from TSETCAT in mvar : #1 is empty"))
      ((QUOTE T)
        (SPADCALL
          (PROG2
            (LETT #0# (SPADCALL |ts| (QREFELT $ 14)) |TSETCAT-;mvar;SV;25|)
            (QCDR #0#)
            (|check-union| (QEQCAR #0# 0) (QREFELT $ 10) #0#))
          (QREFELT $ 23))))))

(DEFUN |TSETCAT-;first;SU;26| (|ts| $)
  (PROG (|lp|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |ts| (QREFELT $ 12)) (CONS 1 "failed"))
          ((QUOTE T)
            (SEQ
              (LETT |lp|
                (SPADCALL (ELT $ 22) (SPADCALL |ts| (QREFELT $ 28)) (QREFELT $ 36))
                |TSETCAT-;first;SU;26|)
              (EXIT (CONS 0 (|SPADfirst| |lp|))))))))))

(DEFUN |TSETCAT-;last;SU;27| (|ts| $)
  (PROG (|lp|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |ts| (QREFELT $ 12)) (CONS 1 "failed"))
          ((QUOTE T)
            (SEQ
              (LETT |lp|
                (SPADCALL (ELT $ 21) (SPADCALL |ts| (QREFELT $ 28)) (QREFELT $ 36))
                |TSETCAT-;last;SU;27|)
              (EXIT (CONS 0 (|SPADfirst| |lp|))))))))))

(DEFUN |TSETCAT-;rest;SU;28| (|ts| $)
  (PROG (|lp|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |ts| (QREFELT $ 12)) (CONS 1 "failed"))
          ((QUOTE T)
            (SEQ
              (LETT |lp|
                (SPADCALL (ELT $ 22) (SPADCALL |ts| (QREFELT $ 28)) (QREFELT $ 36))
                |TSETCAT-;rest;SU;28|)
              (EXIT (CONS 0 (|SPADfirst| |lp|))))))))))

```



```

(EXIT (CONS 0 (SPADCALL (CDR |lp|) (QREFELT $ 110)))))))))

(DEFUN |TSETCAT-;coerce;SL;29| (|ts| $)
  (SPADCALL (ELT $ 22) (SPADCALL |ts| (QREFELT $ 28)) (QREFELT $ 36)))

(DEFUN |TSETCAT-;algebraicVariables;SL;30| (|ts| $)
  (PROG (#0=:G1652 |p| #1=:G1653)
    (RETURN
      (SEQ
        (PROGN
          (LETT #0# NIL |TSETCAT-;algebraicVariables;SL;30|)
          (SEQ
            (LETT |p| NIL |TSETCAT-;algebraicVariables;SL;30|)
            (LETT #1#
              (SPADCALL |ts| (QREFELT $ 28)) |TSETCAT-;algebraicVariables;SL;30|)
            G190
            (COND
              ((OR
                (ATOM #1#)
                (PROGN (LETT |p| (CAR #1#) |TSETCAT-;algebraicVariables;SL;30|) NIL))
                (GO G191)))
            (SEQ
              (EXIT
                (LETT #0#
                  (CONS (SPADCALL |p| (QREFELT $ 23)) #0#)
                  |TSETCAT-;algebraicVariables;SL;30|)))
              (LETT #1# (CDR #1#) |TSETCAT-;algebraicVariables;SL;30|)
              (GO G190)
              G191
              (EXIT (NREVERSEO #0#)))))))))

(DEFUN |TSETCAT-;algebraic?;VSB;31| (|v| |ts| $)
  (SPADCALL |v| (SPADCALL |ts| (QREFELT $ 115)) (QREFELT $ 116)))

(DEFUN |TSETCAT-;select;SVU;32| (|ts| |v| $)
  (PROG (|lp|)
    (RETURN
      (SEQ
        (LETT |lp|
          (SPADCALL (ELT $ 22) (SPADCALL |ts| (QREFELT $ 28)) (QREFELT $ 36))
          |TSETCAT-;select;SVU;32|)
        (SEQ
          G190
          (COND
            (NULL
              (COND
                ((OR
                  (NULL |lp|)
                  (SPADCALL |v|
                    (SPADCALL (|SPADfirst| |lp|) (QREFELT $ 23))

```

```

        (QREFELT $ 64)))
        (QUOTE NIL))
        ((QUOTE T) (QUOTE T))))
        (GO G191)))
        (SEQ (EXIT (LETT |lp| (CDR |lp|) |TSETCAT-;select;SVU;32|)))
        NIL
        (GO G190)
        G191
        (EXIT NIL))
        (EXIT
        (COND
        ((NULL |lp|) (CONS 1 "failed"))
        ((QUOTE T) (CONS 0 (|SPADfirst| |lp|)))))))))

(DEFUN |TSETCAT-;collectQuasiMonic;2S;33| (|ts| $)
  (PROG (|newlp| |lp|)
    (RETURN
      (SEQ
        (LETT |lp|
          (SPADCALL |ts| (QREFELT $ 28))
          |TSETCAT-;collectQuasiMonic;2S;33|)
        (LETT |newlp| NIL |TSETCAT-;collectQuasiMonic;2S;33|)
        (SEQ
          G190
          (COND
            ((NULL (COND ((NULL |lp|) (QUOTE NIL)) ((QUOTE T) (QUOTE T))))
            (GO G191)))
          (SEQ
            (COND
              ((SPADCALL (SPADCALL (|SPADfirst| |lp|) (QREFELT $ 45)) (QREFELT $ 34))
                (LETT |newlp|
                  (CONS (|SPADfirst| |lp|) |newlp|)
                  |TSETCAT-;collectQuasiMonic;2S;33|)))
              (EXIT (LETT |lp| (CDR |lp|) |TSETCAT-;collectQuasiMonic;2S;33|)))
            NIL
            (GO G190)
            G191
            (EXIT NIL))
            (EXIT (SPADCALL |newlp| (QREFELT $ 110)))))))))

(DEFUN |TSETCAT-;collectUnder;SVS;34| (|ts| |v| $)
  (PROG (|lp|)
    (RETURN
      (SEQ
        (LETT |lp|
          (SPADCALL (ELT $ 22) (SPADCALL |ts| (QREFELT $ 28)) (QREFELT $ 36))
          |TSETCAT-;collectUnder;SVS;34|)
        (SEQ
          G190
          (COND

```

```

      (NULL
      (COND
      ((OR
      (NULL |lp|)
      (SPADCALL
      (SPADCALL (|SPADfirst| |lp|) (QREFELT $ 23))
      |v|
      (QREFELT $ 63)))
      (QUOTE NIL))
      ((QUOTE T) (QUOTE T))))
      (GO G191)))
      (SEQ (EXIT (LETT |lp| (CDR |lp|) |TSETCAT-;collectUnder;SVS;34|)))
      NIL
      (GO G190)
      G191
      (EXIT NIL))
      (EXIT (SPADCALL |lp| (QREFELT $ 110))))))

(DEFUN |TSETCAT-;collectUpper;SVS;35| (|ts| |v| $)
  (PROG (|lp2| |lp1|)
    (RETURN
    (SEQ
    (LETT |lp1|
      (SPADCALL (ELT $ 22) (SPADCALL |ts| (QREFELT $ 28)) (QREFELT $ 36))
      |TSETCAT-;collectUpper;SVS;35|)
    (LETT |lp2| NIL |TSETCAT-;collectUpper;SVS;35|)
    (SEQ
    G190
    (COND
    ((NULL
    (COND
    ((NULL |lp1|) (QUOTE NIL))
    ((QUOTE T)
    (SPADCALL |v|
    (SPADCALL (|SPADfirst| |lp1|) (QREFELT $ 23))
    (QREFELT $ 63))))
    (GO G191)))
    (SEQ
    (LETT |lp2|
      (CONS (|SPADfirst| |lp1|) |lp2|)
      |TSETCAT-;collectUpper;SVS;35|)
    (EXIT (LETT |lp1| (CDR |lp1|) |TSETCAT-;collectUpper;SVS;35|)))
    NIL
    (GO G190)
    G191
    (EXIT NIL))
    (EXIT (SPADCALL (REVERSE |lp2|) (QREFELT $ 110))))))

(DEFUN |TSETCAT-;construct;LS;36| (|lp| $)
  (PROG (|rif|)

```

```

(RETURN
  (SEQ
    (LETT |rif| (SPADCALL |lp| (QREFELT $ 122)) |TSETCAT-;construct;LS;36|)
    (EXIT
      (COND
        ((QEQCAR |rif| 0) (QCDR |rif|))
        ((QUOTE T)
          (|error| "in construct : LP -> $ from TSETCAT : bad arg"))))))))

(DEFUN |TSETCAT-;retractIfCan;LU;37| (|lp| $)
  (PROG (|rif|)
    (RETURN
      (SEQ
        (COND
          ((NULL |lp|) (CONS 0 (SPADCALL (QREFELT $ 37))))
          ((QUOTE T)
            (SEQ
              (LETT |lp|
                (SPADCALL (ELT $ 22) |lp| (QREFELT $ 36))
                |TSETCAT-;retractIfCan;LU;37|)
              (LETT |rif|
                (SPADCALL (CDR |lp|) (QREFELT $ 122))
                |TSETCAT-;retractIfCan;LU;37|)
              (EXIT
                (COND
                  ((QEQCAR |rif| 0)
                    (SPADCALL (QCDR |rif|) (|SPADfirst| |lp|) (QREFELT $ 124)))
                  ((QUOTE T)
                    (|error| "in retractIfCan : LP -> ... from TSETCAT : bad arg"))
                ))))))))

(DEFUN |TSETCAT-;extend;SPS;38| (|ts| |p| $)
  (PROG (|eif|)
    (RETURN
      (SEQ
        (LETT |eif| (SPADCALL |ts| |p| (QREFELT $ 124)) |TSETCAT-;extend;SPS;38|)
        (EXIT
          (COND
            ((QEQCAR |eif| 0) (QCDR |eif|))
            ((QUOTE T)
              (|error| "in extend : ($,P) -> $ from TSETCAT : bad ars"))))))))

(DEFUN |TSETCAT-;coHeight;SNni;39| (|ts| $)
  (PROG (|n| |m| #0=#:G1696)
    (RETURN
      (SEQ
        (LETT |n| (SPADCALL (QREFELT $ 127)) |TSETCAT-;coHeight;SNni;39|)
        (LETT |m|
          (LENGTH (SPADCALL |ts| (QREFELT $ 28)))
          |TSETCAT-;coHeight;SNni;39|)

```

```

(EXIT
 (PROG2
  (LETT #0# (SPADCALL |n| |m| (QREFELT $ 128)) |TSETCAT-;coHeight;SNni;39|)
  (QCDR #0#)
  (|check-union| (QEQCAR #0# 0) (|NonNegativeInteger|) #0#))))))

(DEFUN |TriangularSetCategory&| (|#1| |#2| |#3| |#4| |#5|)
 (PROG (DV$1 DV$2 DV$3 DV$4 DV$5 |dv$| $ |pv$|)
 (RETURN
  (PROGN
   (LETT DV$1 (|devaluate| |#1|) . #0=(|TriangularSetCategory&|))
   (LETT DV$2 (|devaluate| |#2|) . #0#)
   (LETT DV$3 (|devaluate| |#3|) . #0#)
   (LETT DV$4 (|devaluate| |#4|) . #0#)
   (LETT DV$5 (|devaluate| |#5|) . #0#)
   (LETT |dv$|
    (LIST (QUOTE |TriangularSetCategory&|) DV$1 DV$2 DV$3 DV$4 DV$5) . #0#)
    (LETT $ (make-array 131) . #0#)
    (QSETREFV $ 0 |dv$|)
    (QSETREFV $ 3
     (LETT |pv$|
      (|buildPredVector| 0 0 (LIST (|HasCategory| |#4| (QUOTE (|Finite|)))))
      . #0#))
     (|stuffDomainSlots| $)
     (QSETREFV $ 6 |#1|)
     (QSETREFV $ 7 |#2|)
     (QSETREFV $ 8 |#3|)
     (QSETREFV $ 9 |#4|)
     (QSETREFV $ 10 |#5|)
     (COND
      ((|testBitVector| |pv$| 1)
       (QSETREFV $ 129
        (CONS (|dispatchFunction| |TSETCAT-;coHeight;SNni;39|) $))))
      $))))

(setf (get
 (QUOTE |TriangularSetCategory&|)
 (QUOTE |infovec|))
 (LIST (QUOTE
 # (NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|) (|local| |#3|)
 (|local| |#4|) (|local| |#5|) (|Boolean|) (0 . |empty?|)
 (|Union| 10 (QUOTE "failed")) (5 . |first|) (10 . =)
 (|Union| $ (QUOTE "failed")) (16 . |rest|) (21 . =) |TSETCAT-;=;2SB;1|
 (27 . |last|) (32 . |infRittWu?|) (38 . |supRittWu?|) (44 . |mvar|)
 (49 . |collectUpper|) (55 . |infRittWu?|) |TSETCAT-;infRittWu?;2SB;2|
 (|List| 10) (61 . |members|) (|Mapping| 11 10 10)
 |TSETCAT-;reduced?;PSMB;3| (66 . |zero?|) (|Mapping| 11 10)
 (71 . |remove|) (77 . |ground?|) (82 . |any?|) (88 . |sort|)
 (94 . |empty|) (98 . |extend|) (104 . |reduced?|)
 (|Record| (|:| |bas| $) (|:| |top| 27))

```

```

(|Union| 40 (QUOTE "failed")) |TSETCAT-;basicSet;LMU;4|
(111 . |concat|) |TSETCAT-;basicSet;LMMU;5| (117 . |init|)
(122 . |primPartElseUnitCanonical|) (127 . |removeDuplicates|)
|TSETCAT-;initials;SL;6| (|NonNegativeInteger|) (132 . |mdeg|)
|TSETCAT-;degree;SNni;7| (137 . |initials|)
(|Record| (|:| |close| 27) (|:| |open| 27))
|TSETCAT-;quasiComponent;SR;8| (|List| $) (142 . |normalized?|)
|TSETCAT-;normalized?;PSB;9| (148 . |reduced?|)
|TSETCAT-;stronglyReduced?;PSB;10| (154 . |head|)
(159 . |stronglyReduced?|) |TSETCAT-;headReduced?;PSB;11|
(165 . <) (171 . =) (177 . |reduced?|)
|TSETCAT-;initiallyReduced?;PSB;12| (|Mapping| 10 10 10)
|TSETCAT-;reduce;PSMMP;13| (183 . |trivialIdeal?|) (188 . |One|)
(192 . |reduce|) |TSETCAT-;rewriteSetWithReduction;LSMML;14|
(200 . |lazyPrem|) |TSETCAT-;stronglyReduce;PSP;15|
(206 . |headReduce|) (212 . |headReduced?|)
|TSETCAT-;headReduce;PSP;16| (218 . |initiallyReduce|)
(224 . |initiallyReduced?|) |TSETCAT-;initiallyReduce;PSP;17|
(230 . |collectUnder|) (236 . |algebraic?|) (242 . |select|)
(248 . |removeZero|) (254 . |Zero|) (258 . |degree|) (|Integer|)
(264 . |positive?|) (269 . |mainMonomial|) (274 . *) (280 . +)
(286 . |tail|) |TSETCAT-;removeZero;PSP;18| (291 . |collectQuasiMonic|)
(|Record| (|:| |rnum| 7) (|:| |polnum| 10) (|:| |den| 7))
(296 . |remainder|) |TSETCAT-;reduceByQuasiMonic;PSP;19|
(|Mapping| 11 10 27) |TSETCAT-;autoReduced?;SMB;20|
(302 . |autoReduced?|) |TSETCAT-;stronglyReduced?;SB;21|
|TSETCAT-;normalized?;SB;22| (308 . |headReduced?|)
|TSETCAT-;headReduced?;SB;23| (314 . |initiallyReduced?|)
|TSETCAT-;initiallyReduced?;SB;24| |TSETCAT-;mvar;SV;25|
|TSETCAT-;first;SU;26| |TSETCAT-;last;SU;27| (320 . |construct|)
|TSETCAT-;rest;SU;28| |TSETCAT-;coerce;SL;29| (|List| 9)
|TSETCAT-;algebraicVariables;SL;30| (325 . |algebraicVariables|)
(330 . |member?|) |TSETCAT-;algebraic?;VSB;31|
|TSETCAT-;select;SVU;32| |TSETCAT-;collectQuasiMonic;2S;33|
|TSETCAT-;collectUnder;SVS;34| |TSETCAT-;collectUpper;SVS;35|
(336 . |retractIfCan|) |TSETCAT-;construct;LS;36|
(341 . |extendIfCan|) |TSETCAT-;retractIfCan;LU;37|
|TSETCAT-;extend;SPS;38| (347 . |size|) (351 . |subtractIfCan|)
(357 . |coHeight|) (|OutputForm|)))
(QUOTE #(|stronglyReduced?| 362 |stronglyReduce| 373 |select| 379
|rewriteSetWithReduction| 385 |retractIfCan| 393 |rest| 398 |removeZero|
403 |reduced?| 409 |reduceByQuasiMonic| 416 |reduce| 422
|quasiComponent| 430 |normalized?| 435 |mvar| 446 |last| 451
|initials| 456 |initiallyReduced?| 461 |initiallyReduce| 472
|infRittWu?| 478 |headReduced?| 484 |headReduce| 495 |first| 501
|extend| 506 |degree| 512 |construct| 517 |collectUpper| 522
|collectUnder| 528 |collectQuasiMonic| 534 |coerce| 539 |coHeight|
544 |basicSet| 549 |autoReduced?| 562 |algebraicVariables| 568
|algebraic?| 573 = 579))
(QUOTE NIL)

```

```

(CONS
  (|makeByteWordVec2| 1 (QUOTE NIL))
  (CONS (QUOTE #()) (CONS (QUOTE #())
    (|makeByteWordVec2| 129 (QUOTE (1 6 11 0 12 1 6 13 0 14 2 10 11 0 0 15
      1 6 16 0 17 2 6 11 0 0 18 1 6 13 0 20 2 10 11 0 0 21 2 10 11 0 0 22
      1 10 9 0 23 2 6 0 0 9 24 2 6 11 0 0 25 1 6 27 0 28 1 10 11 0 31 2 27
      0 32 0 33 1 10 11 0 34 2 27 11 32 0 35 2 27 0 29 0 36 0 6 0 37 2 6 0
      0 10 38 3 6 11 10 0 29 39 2 27 0 0 0 43 1 10 0 0 45 1 10 0 0 46 1 27
      0 0 47 1 10 49 0 50 1 6 27 0 52 2 10 11 0 55 56 2 10 11 0 55 58 1 10
      0 0 60 2 6 11 10 0 61 2 9 11 0 0 63 2 9 11 0 0 64 2 10 11 0 0 65 1 6
      11 0 69 0 10 0 70 4 6 10 10 0 67 29 71 2 10 0 0 0 73 2 10 0 0 0 75 2
      10 11 0 0 76 2 10 0 0 0 78 2 10 11 0 0 79 2 6 0 0 9 81 2 6 11 9 0 82
      2 6 13 0 9 83 2 6 10 10 0 84 0 10 0 85 2 10 49 0 9 86 1 87 11 0 88 1
      10 0 0 89 2 10 0 0 0 90 2 10 0 0 0 91 1 10 0 0 92 1 6 0 0 94 2 6 95
      10 0 96 2 6 11 0 98 100 2 10 11 0 55 103 2 10 11 0 55 105 1 6 0 27
      110 1 6 113 0 115 2 113 11 9 0 116 1 6 16 27 122 2 6 16 0 10 124 0
      9 49 127 2 49 16 0 0 128 1 0 49 0 129 1 0 11 0 101 2 0 11 10 0 59 2
      0 10 10 0 74 2 0 13 0 9 118 4 0 27 27 0 67 29 72 1 0 16 27 125 1 0
      16 0 111 2 0 10 10 0 93 3 0 11 10 0 29 30 2 0 10 10 0 97 4 0 10 10 0
      67 29 68 1 0 53 0 54 1 0 11 0 102 2 0 11 10 0 57 1 0 9 0 107 1 0 13
      0 109 1 0 27 0 48 1 0 11 0 106 2 0 11 10 0 66 2 0 10 10 0 80 2 0 11
      0 0 26 1 0 11 0 104 2 0 11 10 0 62 2 0 10 10 0 77 1 0 13 0 108 2 0 0
      0 10 126 1 0 49 0 51 1 0 0 27 123 2 0 0 0 9 121 2 0 0 0 9 120 1 0 0
      0 119 1 0 27 0 112 1 0 49 0 129 3 0 41 27 32 29 44 2 0 41 27 29 42 2
      0 11 0 98 99 1 0 113 0 114 2 0 11 9 0 117 2 0 11 0 0 19))))))
  (QUOTE |lookupComplete|)))

```

21.64 UFD.lsp BOOTSTRAP

UFD needs **GCDDOM** which needs **COMRING** which needs **RING** which needs **RNG** which needs **ABELGRP** which needs **CABMON** which needs **ABELMON** which needs **ABELSG** which needs **SETCAT** which needs **SINT** which needs **UFD**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **UFD** category which we can write into the **MID** directory. We compile the lisp code and copy the **UFD.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— UFD.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |UniqueFactorizationDomain;AL| (QUOTE NIL))

```

```

(DEFUN |UniqueFactorizationDomain| NIL
  (LET (#:G83334)
    (COND
      (|UniqueFactorizationDomain;AL|)
      (T
        (SETQ
          |UniqueFactorizationDomain;AL|
          (|UniqueFactorizationDomain;|))))))

(DEFUN |UniqueFactorizationDomain;| NIL
  (PROG (#1= #:G83332)
    (RETURN
      (PROG1
        (LETT #1#
          (|Join|
            (|GcdDomain|)
            (|mkCategory|
              (QUOTE |domain|)
              (QUOTE (
                ((|prime?| ((|Boolean|) |$|)) T)
                ((|squareFree| ((|Factored| |$|) |$|)) T)
                ((|squareFreePart| (|$| |$|)) T)
                ((|factor| ((|Factored| |$|) |$|)) T)))
                NIL
                (QUOTE ((|Factored| |$|) (|Boolean|)))
                NIL))
          |UniqueFactorizationDomain|)
        (SETELT #1# 0 (QUOTE (|UniqueFactorizationDomain|))))))

(setf (get (QUOTE |UniqueFactorizationDomain|) (QUOTE NILADIC)) T)

```

21.65 UFD-.lsp BOOTSTRAP

UFD- needs **UFD**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **UFD-** category which we can write into the **MID** directory. We compile the lisp code and copy the **UFD-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— UFD-.lsp BOOTSTRAP —

```
(|/VERSIONCHECK| 2)
```



```

(DEFUN |UFD-;squareFreePart;2S;1| (|x| |$|)
  (PROG (|s| |f| #1=#:G83349 #2=#:G83347 #3=#:G83345 #4=#:G83346)
    (RETURN
      (SEQ
        (SPADCALL
          (SPADCALL
            (LETT |s|
              (SPADCALL |x| (QREFELT |$| 8))
              |UFD-;squareFreePart;2S;1|)
            (QREFELT |$| 10))
          (PROGN
            (LETT #4# NIL |UFD-;squareFreePart;2S;1|)
            (SEQ
              (LETT |f| NIL |UFD-;squareFreePart;2S;1|)
              (LETT #1#
                (SPADCALL |s| (QREFELT |$| 13))
                |UFD-;squareFreePart;2S;1|)
              G190
              (COND
                ((OR
                  (ATOM #1#)
                  (PROGN
                    (LETT |f| (CAR #1#) |UFD-;squareFreePart;2S;1|)
                    NIL))
                  (GO G191)))
              (SEQ
                (EXIT
                  (PROGN
                    (LETT #2# (QCAR |f|) |UFD-;squareFreePart;2S;1|)
                    (COND
                      (#4#
                        (LETT #3#
                          (SPADCALL #3# #2# (QREFELT |$| 14))
                          |UFD-;squareFreePart;2S;1|)
                        ((QUOTE T)
                          (PROGN
                            (LETT #3# #2# |UFD-;squareFreePart;2S;1|)
                            (LETT #4# (QUOTE T)
                              |UFD-;squareFreePart;2S;1|))))))
                    (LETT #1# (CDR #1#) |UFD-;squareFreePart;2S;1|)
                    (GO G190)
                    G191
                    (EXIT NIL))
                  (COND
                    (#4# #3#)
                    ((QUOTE T) (|spadConstant| |$| 15))))
                (QREFELT |$| 14))))))
      )
    )
  )
(DEFUN |UFD-;prime?;SB;2| (|x| |$|)

```

```

(EQL
  (LENGTH (SPADCALL (SPADCALL |x| (QREFELT |$| 17)) (QREFELT |$| 21))) 1))

(DEFUN |UniqueFactorizationDomain&| (|#1|)
  (PROG (|DV$1| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|UniqueFactorizationDomain&|))
        (LETT |dv$| (LIST (QUOTE |UniqueFactorizationDomain&|) |DV$1|) . #1#)
        (LETT |$| (make-array 24) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3 (LETT |pv$| (|buildPredVector| 0 0 NIL) . #1#))
        (|stuffDomainSlots| |$|)
        (QSETREFV |$| 6 |#1|)
        |$|))))))

(setf (get
  (QUOTE |UniqueFactorizationDomain&|)
  (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL
        (|local| |#1|)
        (|Factored| |$|)
        (0 . |squareFree|)
        (|Factored| 6)
        (5 . |unit|)
        (|Record| (|:| |factor| 6) (|:| |exponent| (|Integer|)))
        (|List| 11)
        (10 . |factors|)
        (15 . |*|)
        (21 . |One|)
        |UFD-;squareFreePart;2S;1|
        (25 . |factor|)
        (|Union|
          (QUOTE "nil") (QUOTE "sqfr") (QUOTE "irred") (QUOTE "prime"))
          (|Record| (|:| |flg| 18) (|:| |fctr| 6) (|:| |xpnt| (|Integer|)))
          (|List| 19)
          (30 . |factorList|)
          (|Boolean|)
          |UFD-;prime?;SB;2|))
        (QUOTE #(|squareFreePart| 35 |prime?| 40))
        (QUOTE NIL)
      (CONS
        (|makeByteWordVec2| 1 (QUOTE NIL))
        (CONS
          (QUOTE #())
          (CONS
            (QUOTE #())
            (|makeByteWordVec2| 23

```

```

(QUOTE
  (1 6 7 0 8 1 9 6 0 10 1 9 12 0 13 2 6 0 0 0 14 0 6 0 15 1 6 7
    0 17 1 9 20 0 21 1 0 0 0 16 1 0 22 0 23))))))
(QUOTE |lookupComplete|)))

```

21.66 ULSCAT.lsp BOOTSTRAP

ULSCAT depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **ULSCAT** category which we can write into the **MID** directory. We compile the lisp code and copy the **ULSCAT.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— ULSCAT.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |UnivariateLaurentSeriesCategory;CAT| (QUOTE NIL))

(SETQ |UnivariateLaurentSeriesCategory;AL| (QUOTE NIL))

(DEFUN |UnivariateLaurentSeriesCategory| (#1= #:G83278)
  (LET (#2= #:G83279)
    (COND
      ((SETQ #2# (|assoc| (|devalue| #1#) |UnivariateLaurentSeriesCategory;AL|))
        (CDR #2#))
      (T
        (SETQ |UnivariateLaurentSeriesCategory;AL|
          (|cons5|
            (CONS
              (|devalue| #1#)
              (SETQ #2# (|UnivariateLaurentSeriesCategory;| #1#)))
              |UnivariateLaurentSeriesCategory;AL|))
            #2#))))))

(DEFUN |UnivariateLaurentSeriesCategory;| (|t#1|)
  (PROG (#1= #:G83277)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR (QUOTE (|t#1|)) (LIST (|devalue| |t#1|)))
            (|sublisV|

```

```

(PAIR (QUOTE (#2=:G83276)) (LIST (QUOTE (|Integer|))))
(COND
  (|UnivariateLaurentSeriesCategory;CAT|)
  ((QUOTE T)
    (LETT |UnivariateLaurentSeriesCategory;CAT|
      (|Join|
        (|UnivariatePowerSeriesCategory| (QUOTE |t#1|) (QUOTE #2#))
        (|mkCategory| (QUOTE |domain|)
          (QUOTE (
            (|series|
              (|$|
                (|Stream| (|Record| (|:| |k| (|Integer|)) (|:| |c| |t#1|))))))
              T)
            ((|multiplyCoefficients| (|$| (|Mapping| |t#1| (|Integer|)) |$|))
              T)
            ((|rationalFunction|
              ((|Fraction| (|Polynomial| |t#1|)) |$| (|Integer|)))
              (|has| |t#1| (|IntegralDomain|)))
            ((|rationalFunction|
              ((|Fraction| (|Polynomial| |t#1|)) |$| (|Integer|) (|Integer|))
              (|has| |t#1| (|IntegralDomain|)))
            ((|integrate| (|$| |$|))
              (|has| |t#1| (|Algebra| (|Fraction| (|Integer|))))
            ((|integrate| (|$| |$| (|Symbol|)))
              (AND
                (|has| |t#1|
                  (SIGNATURE |variables| ((|List| (|Symbol|)) |t#1|)))
                (|has| |t#1| (SIGNATURE |integrate| (|t#1| |t#1| (|Symbol|))))
                (|has| |t#1| (|Algebra| (|Fraction| (|Integer|)))))
              ((|integrate| (|$| |$| (|Symbol|)))
                (AND
                  (|has| |t#1| (|AlgebraicallyClosedFunctionSpace| (|Integer|)))
                  (|has| |t#1| (|PrimitiveFunctionCategory|))
                  (|has| |t#1| (|TranscendentalFunctionCategory|))
                  (|has| |t#1| (|Algebra| (|Fraction| (|Integer|)))))
                (QUOTE (
                  ((|RadicalCategory|)
                    (|has| |t#1| (|Algebra| (|Fraction| (|Integer|)))))
                  ((|TranscendentalFunctionCategory|)
                    (|has| |t#1| (|Algebra| (|Fraction| (|Integer|)))))
                  ((|Field|) (|has| |t#1| (|Field|))))
                (QUOTE (
                  (|Symbol|)
                  (|Fraction| (|Polynomial| |t#1|))
                  (|Integer|)
                  (|Stream| (|Record| (|:| |k| (|Integer|)) (|:| |c| |t#1|))))
                  NIL))
                . #3=(|UnivariateLaurentSeriesCategory|))))))
    . #3#)
  (SETELT #1# 0

```

```
(LIST (QUOTE |UnivariateLaurentSeriesCategory|) (|devaluate| |t#1|))))))
```

21.67 UPOLYC.lsp BOOTSTRAP

UPOLYC depends on itself. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **UPOLYC** category which we can write into the **MID** directory. We compile the lisp code and copy the **UPOLYC.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— UPOLYC.lsp BOOTSTRAP —

```
(/VERSIONCHECK 2)

(SETQ |UnivariatePolynomialCategory;CAT| (QUOTE NIL))

(SETQ |UnivariatePolynomialCategory;AL| (QUOTE NIL))

(DEFUN |UnivariatePolynomialCategory| (#0=#:G1438)
  (LET (#1=#:G1439)
    (COND
      ((SETQ #1# (|assoc| (|devaluate| #0#) |UnivariatePolynomialCategory;AL|))
        (CDR #1#))
      (T
        (SETQ |UnivariatePolynomialCategory;AL|
          (|cons5|
            (CONS (|devaluate| #0#) (SETQ #1# (|UnivariatePolynomialCategory;| #0#)))
            |UnivariatePolynomialCategory;AL|))
          #1#))))))

(DEFUN |UnivariatePolynomialCategory;| (|t#1|)
  (PROG (#0=#:G1437)
    (RETURN
      (PROG1
        (LETT #0#
          (|sublisV|
            (PAIR (QUOTE (|t#1|)) (LIST (|devaluate| |t#1|))))
            (|sublisV|
              (PAIR
                (QUOTE (#1=#:G1435 #2=#:G1436))
                (LIST
                  (QUOTE (|NonNegativeInteger|))
                  (QUOTE (|SingletonAsOrderedSet|))))
              (COND
```

```

(|UnivariatePolynomialCategory;CAT|)
((QUOTE T)
  (LETT |UnivariatePolynomialCategory;CAT|
    (|Join|
      (|PolynomialCategory| (QUOTE |t#1|) (QUOTE #1#) (QUOTE #2#))
      (|Eltable| (QUOTE |t#1|) (QUOTE |t#1|))
      (|Eltable| (QUOTE $) (QUOTE $))
      (|DifferentialRing|)
      (|DifferentialExtension| (QUOTE |t#1|))
      (|mkCategory|
        (QUOTE |domain|)
        (QUOTE
          (((|vectorise| ((|Vector| |t#1|) $ (|NonNegativeInteger|))) T)
            ((|unvectorise| ($ (|Vector| |t#1|))) T)
            ((|makeSUP| ((|SparseUnivariatePolynomial| |t#1|) $)) T)
            ((|unmakeSUP| ($ (|SparseUnivariatePolynomial| |t#1|))) T)
            ((|multiplyExponents| ($ $ (|NonNegativeInteger|))) T)
            ((|divideExponents|
              ((|Union| $ "failed") $ (|NonNegativeInteger|))) T)
            ((|monicDivide|
              ((|Record| (:| |quotient| $) (:| |remainder| $)) $ $)) T)
            ((|karatsubaDivide|
              ((|Record| (:| |quotient| $) (:| |remainder| $)) $
                (|NonNegativeInteger|))) T)
            ((|shiftRight| ($ $ (|NonNegativeInteger|))) T)
            ((|shiftLeft| ($ $ (|NonNegativeInteger|))) T)
            ((|pseudoRemainder| ($ $ $)) T)
            ((|differentiate| ($ $ (|Mapping| |t#1| |t#1|) $)) T)
            ((|discriminant| (|t#1| $)) (|has| |t#1| (|CommutativeRing|)))
            ((|resultant| (|t#1| $ $)) (|has| |t#1| (|CommutativeRing|)))
            ((|elt| ((|Fraction| $) (|Fraction| $) (|Fraction| $)))
              (|has| |t#1| (|IntegralDomain|)))
            ((|order| ((|NonNegativeInteger|) $ $))
              (|has| |t#1| (|IntegralDomain|)))
            ((|subResultantGcd| ($ $ $))
              (|has| |t#1| (|IntegralDomain|)))
            ((|composite| ((|Union| $ "failed") $ $))
              (|has| |t#1| (|IntegralDomain|)))
            ((|composite|
              ((|Union| (|Fraction| $) "failed") (|Fraction| $) $))
              (|has| |t#1| (|IntegralDomain|)))
            ((|pseudoQuotient| ($ $ $)) (|has| |t#1| (|IntegralDomain|)))
            ((|pseudoDivide|
              ((|Record| (:| |coef| |t#1|) (:| |quotient| $)
                (:| |remainder| $)) $ $))
              (|has| |t#1| (|IntegralDomain|)))
            ((|separate|
              ((|Record| (:| |primePart| $) (:| |commonPart| $)) $ $))
              (|has| |t#1| (|GcdDomain|)))
            ((|elt| (|t#1| (|Fraction| $) |t#1|)) (|has| |t#1| (|Field|)))
          )
        )
      )
    )
  )

```

```

      ((|integrate| ($ $))
       (|has| |t#1| (|Algebra| (|Fraction| (|Integer|))))))
    (QUOTE (
      ((|StepThrough|) (|has| |t#1| (|StepThrough|)))
      ((|Eltable| (|Fraction| $) (|Fraction| $))
       (|has| |t#1| (|IntegralDomain|)))
      ((|EuclideanDomain|) (|has| |t#1| (|Field|)))
      (|additiveValuation| (|has| |t#1| (|Field|))))
    (QUOTE (
      (|Fraction| $)
      (|NonNegativeInteger|)
      (|SparseUnivariatePolynomial| |t#1|)
      (|Vector| |t#1|)))
    NIL))
  . #3=(|UnivariatePolynomialCategory|))))))
. #3#)
(SETELT #0# 0
 (LIST (QUOTE |UnivariatePolynomialCategory|) (|devaluate| |t#1|))))))

```

21.68 UPOLYC-.lsp BOOTSTRAP

UPOLYC- depends on **UPOLYC**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **UPOLYC-** category which we can write into the **MID** directory. We compile the lisp code and copy the **UPOLYC-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— UPOLYC-.lsp BOOTSTRAP —

```

(/VERSIONCHECK 2)

(DEFUN |UPOLYC-;variables;SL;1| (|p| $)
  (COND
    ((OR (SPADCALL |p| (QREFELT $ 9)) (ZEROP (SPADCALL |p| (QREFELT $ 11))))
     NIL)
    ((QUOTE T) (LIST (SPADCALL (QREFELT $ 13))))))

(DEFUN |UPOLYC-;degree;SSaosNni;2| (|p| |v| $) (SPADCALL |p| (QREFELT $ 11)))

(DEFUN |UPOLYC-;totalDegree;SLNni;3| (|p| |lv| $)
  (COND ((NULL |lv|) 0) ((QUOTE T) (SPADCALL |p| (QREFELT $ 17)))))

(DEFUN |UPOLYC-;degree;SLL;4| (|p| |lv| $)

```

```

(COND ((NULL |lv|) NIL) ((QUOTE T) (LIST (SPADCALL |p| (QREFELT $ 11))))))

(DEFUN |UPOLYC-;eval;SLLS;5| (|p| |lv| |lq| $)
  (COND
    ((NULL |lv|) |p|)
    ((NULL (NULL (CDR |lv|)))
      (|error| "can only eval a univariate polynomial once"))
    ((QUOTE T)
      (SPADCALL |p| (|SPADfirst| |lv|) (|SPADfirst| |lq|) (QREFELT $ 21))))))

(DEFUN |UPOLYC-;eval;SSaos2S;6| (|p| |v| |q| $)
  (SPADCALL |p| |q| (QREFELT $ 24)))

(DEFUN |UPOLYC-;eval;SLLS;7| (|p| |lv| |lr| $)
  (COND
    ((NULL |lv|) |p|)
    ((NULL (NULL (CDR |lv|)))
      (|error| "can only eval a univariate polynomial once"))
    ((QUOTE T)
      (SPADCALL |p| (|SPADfirst| |lv|) (|SPADfirst| |lr|) (QREFELT $ 26))))))

(DEFUN |UPOLYC-;eval;SSaosRS;8| (|p| |v| |r| $)
  (SPADCALL (SPADCALL |p| |r| (QREFELT $ 29)) (QREFELT $ 30)))

(DEFUN |UPOLYC-;eval;SLS;9| (|p| |le| $)
  (COND
    ((NULL |le|) |p|)
    ((NULL (NULL (CDR |le|)))
      (|error| "can only eval a univariate polynomial once"))
    ((QUOTE T)
      (COND
        ((QEQCAR
          (SPADCALL
            (SPADCALL (|SPADfirst| |le|) (QREFELT $ 33))
            (QREFELT $ 35)) 1) |p|)
          ((QUOTE T)
            (SPADCALL |p|
              (SPADCALL (|SPADfirst| |le|) (QREFELT $ 36)) (QREFELT $ 24)))))))

(DEFUN |UPOLYC-;mainVariable;SU;10| (|p| $)
  (COND
    ((ZEROP (SPADCALL |p| (QREFELT $ 11))) (CONS 1 "failed"))
    ((QUOTE T) (CONS 0 (SPADCALL (QREFELT $ 13))))))

(DEFUN |UPOLYC-;minimumDegree;SSaosNni;11| (|p| |v| $)
  (SPADCALL |p| (QREFELT $ 40)))

(DEFUN |UPOLYC-;minimumDegree;SLL;12| (|p| |lv| $)
  (COND ((NULL |lv|) NIL) ((QUOTE T) (LIST (SPADCALL |p| (QREFELT $ 40))))))

```



```

(DEFUN |UPOLYC-;monomial;SSaosNniS;13| (|p| |v| |n| $)
  (PROG NIL
    (RETURN
      (SPADCALL
        (CONS (FUNCTION |UPOLYC-;monomial;SSaosNniS;13!0|) (VECTOR $ |n|))
          |p| (QREFELT $ 45))))))

(DEFUN |UPOLYC-;monomial;SSaosNniS;13!0| (|x1| $$)
  (PROG (|n| $)
    (LETT |n| (QREFELT $$ 1) . #0=(|UPOLYC-;monomial;SSaosNniS;13|))
    (LETT $ (QREFELT $$ 0) . #0#)
    (RETURN (PROGN (SPADCALL |x1| |n| (QREFELT $ 43))))))

(DEFUN |UPOLYC-;coerce;SaosS;14| (|v| $)
  (SPADCALL (|spadConstant| $ 48) 1 (QREFELT $ 49)))

(DEFUN |UPOLYC-;makeSUP;SSup;15| (|p| $)
  (COND
    ((SPADCALL |p| (QREFELT $ 9)) (|spadConstant| $ 52))
    ((QUOTE T)
      (SPADCALL
        (SPADCALL
          (SPADCALL |p| (QREFELT $ 53))
          (SPADCALL |p| (QREFELT $ 11))
          (QREFELT $ 54))
        (SPADCALL
          (SPADCALL |p| (QREFELT $ 55))
          (QREFELT $ 56))
          (QREFELT $ 57))))))

(DEFUN |UPOLYC-;unmakeSUP;SupS;16| (|sp| $)
  (COND
    ((SPADCALL |sp| (QREFELT $ 59)) (|spadConstant| $ 60))
    ((QUOTE T)
      (SPADCALL
        (SPADCALL
          (SPADCALL |sp| (QREFELT $ 61))
          (SPADCALL |sp| (QREFELT $ 62))
          (QREFELT $ 49))
        (SPADCALL (SPADCALL |sp| (QREFELT $ 63)) (QREFELT $ 64))
          (QREFELT $ 65))))))

(DEFUN |UPOLYC-;karatsubaDivide;SNniR;17| (|p| |n| $)
  (SPADCALL |p|
    (SPADCALL (|spadConstant| $ 48) |n| (QREFELT $ 49))
    (QREFELT $ 68)))

(DEFUN |UPOLYC-;shiftRight;SNniS;18| (|p| |n| $)
  (QCAR
    (SPADCALL |p|

```

```

(SPADCALL (|spadConstant| $ 48) |n| (QREFELT $ 49))
(QREFELT $ 68)))

(DEFUN |UPOLYC-;shiftLeft;SNniS;19| (|p| |n| $)
(SPADCALL |p|
(SPADCALL (|spadConstant| $ 48) |n| (QREFELT $ 49))
(QREFELT $ 71)))

(DEFUN |UPOLYC-;solveLinearPolynomialEquation;LSupU;20| (|lpp| |pp| $)
(SPADCALL |lpp| |pp| (QREFELT $ 77)))

(DEFUN |UPOLYC-;factorPolynomial;SupF;21| (|pp| $)
(SPADCALL |pp| (QREFELT $ 83)))

(DEFUN |UPOLYC-;factorSquareFreePolynomial;SupF;22| (|pp| $)
(SPADCALL |pp| (QREFELT $ 86)))

(DEFUN |UPOLYC-;factor;SF;23| (|p| $)
(PROG (|ansR| #0#:#:G1523 |w| #1#:#:G1524)
(RETURN
(SEQ
(COND
((ZEROP (SPADCALL |p| (QREFELT $ 11)))
(SEQ
(LETT |ansR|
(SPADCALL (SPADCALL |p| (QREFELT $ 53)) (QREFELT $ 89))
|UPOLYC-;factor;SF;23|)
(EXIT
(SPADCALL
(SPADCALL (SPADCALL |ansR| (QREFELT $ 91)) (QREFELT $ 30))
(PROGN
(LETT #0# NIL |UPOLYC-;factor;SF;23|)
(SEQ
(LETT |w| NIL |UPOLYC-;factor;SF;23|)
(LETT #1# (SPADCALL |ansR| (QREFELT $ 95)) |UPOLYC-;factor;SF;23|)
G190
(COND
((OR (ATOM #1#)
(PROGN (LETT |w| (CAR #1#) |UPOLYC-;factor;SF;23|) NIL))
(GO G191)))
(SEQ
(EXIT
(LETT #0#
(CONS
(VECTOR
(QVELT |w| 0)
(SPADCALL (QVELT |w| 1) (QREFELT $ 30))
(QVELT |w| 2))
#0#)
|UPOLYC-;factor;SF;23|)))

```

```

        (LETT #1# (CDR #1#) |UPOLYC-;factor;SF;23|)
        (GO G190)
      G191
        (EXIT (NREVERSEO #0#))))
      (QREFELT $ 99))))))
    ((QUOTE T)
      (SPADCALL (ELT $ 64)
        (SPADCALL (SPADCALL |p| (QREFELT $ 56)) (QREFELT $ 100))
        (QREFELT $ 104)))))))))

(DEFUN |UPOLYC-;vectorise;SNniV;24| (|p| |n| $)
  (PROG (|v| |m| |i| #0#:#:G1529 #1#:#:G1525)
    (RETURN
      (SEQ
        (LETT |m|
          (SPADCALL
            (LETT |v|
              (SPADCALL |n| (|spadConstant| $ 106) (QREFELT $ 108))
              |UPOLYC-;vectorise;SNniV;24|)
              (QREFELT $ 110))
              |UPOLYC-;vectorise;SNniV;24|)
            (SEQ (LETT |i| (SPADCALL |v| (QREFELT $ 110)) |UPOLYC-;vectorise;SNniV;24|) (LETT #0#
              (QVSIZE |v|)
              |UPOLYC-;vectorise;SNniV;24|)
              G190
              (COND ((> |i| #0#) (GO G191)))
              (SEQ
                (EXIT
                  (SPADCALL |v| |i|
                    (SPADCALL |p|
                      (PROG1
                        (LETT #1# (- |i| |m|) |UPOLYC-;vectorise;SNniV;24|)
                        (|check-subtype| (>= #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                        (QREFELT $ 111))
                        (QREFELT $ 112))))))
                (LETT |i| (+ |i| 1) |UPOLYC-;vectorise;SNniV;24|) (GO G190) G191 (EXIT NIL))
                (EXIT |v|))))))
          (DEFUN |UPOLYC-;unvectorise;VS;25| (|v| $)
            (PROG (|i| #0#:#:G1534 #1#:#:G1530 |p|)
              (RETURN
                (SEQ
                  (LETT |p| (|spadConstant| $ 60) |UPOLYC-;unvectorise;VS;25|)
                  (SEQ
                    (LETT |i| 1 |UPOLYC-;unvectorise;VS;25|)
                    (LETT #0# (QVSIZE |v|) |UPOLYC-;unvectorise;VS;25|)
                    G190
                    (COND ((QSGREATERP |i| #0#) (GO G191)))
                    (SEQ
                      (EXIT

```

```

(LETT |p|
  (SPADCALL |p|
    (SPADCALL
      (SPADCALL |v| |i| (QREFELT $ 114))
      (PROG1
        (LETT #1# (- |i| 1) |UPOLYC-;unvectorise;VS;25|)
        (|check-subtype| (>= #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
        (QREFELT $ 49))
        (QREFELT $ 65))
      |UPOLYC-;unvectorise;VS;25|)))
  (LETT |i| (QSADD1 |i|) |UPOLYC-;unvectorise;VS;25|)
  (GO G190)
  G191
  (EXIT NIL))
(EXIT |p|))))))

(DEFUN |UPOLYC-;retract;SR;26| (|p| $)
  (COND
    ((SPADCALL |p| (QREFELT $ 9)) (|spadConstant| $ 106))
    ((ZEROP (SPADCALL |p| (QREFELT $ 11))) (SPADCALL |p| (QREFELT $ 53)))
    ((QUOTE T) (|error| "Polynomial is not of degree 0"))))

(DEFUN |UPOLYC-;retractIfCan;SU;27| (|p| $)
  (COND
    ((SPADCALL |p| (QREFELT $ 9)) (CONS 0 (|spadConstant| $ 106)))
    ((ZEROP (SPADCALL |p| (QREFELT $ 11)))
      (CONS 0 (SPADCALL |p| (QREFELT $ 53))))
    ((QUOTE T) (CONS 1 "failed"))))

(DEFUN |UPOLYC-;init;S;28| ($)
  (SPADCALL (|spadConstant| $ 119) (QREFELT $ 30)))

(DEFUN |UPOLYC-;nextItemInner| (|n| $)
  (PROG (|nn| |n1| |n2| #0=#:G1555 |n3|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |n| (QREFELT $ 9))
            (CONS 0
              (SPADCALL
                (PROG2
                  (LETT #0#
                    (SPADCALL (|spadConstant| $ 106) (QREFELT $ 122))
                    |UPOLYC-;nextItemInner|)
                  (QCDR #0#)
                  (|check-union| (QECCAR #0# 0) (QREFELT $ 7) #0#))
                    (QREFELT $ 30))))
            ((ZEROP (SPADCALL |n| (QREFELT $ 11)))
              (SEQ
                (LETT |nn|

```

```

(SPADCALL (SPADCALL |n| (QREFELT $ 53)) (QREFELT $ 122))
|UPOLYC-;nextItemInner|)
(EXIT
(COND
  ((QEQCAR |nn| 1) (CONS 1 "failed")))
  ((QUOTE T) (CONS 0 (SPADCALL (QCDR |nn|) (QREFELT $ 30))))))
((QUOTE T)
(SEQ
  (LETT |n1| (SPADCALL |n| (QREFELT $ 55)) |UPOLYC-;nextItemInner|)
  (LETT |n2| (|UPOLYC-;nextItemInner| |n1| $) |UPOLYC-;nextItemInner|)
  (EXIT
  (COND
    ((QEQCAR |n2| 0)
    (CONS 0
    (SPADCALL
    (SPADCALL
    (SPADCALL |n| (QREFELT $ 53))
    (SPADCALL |n| (QREFELT $ 11))
    (QREFELT $ 49))
    (QCDR |n2|)
    (QREFELT $ 65))))
    ((< (+ 1 (SPADCALL |n1| (QREFELT $ 11)))
    (SPADCALL |n| (QREFELT $ 11)))
    (CONS 0
    (SPADCALL
    (SPADCALL
    (SPADCALL |n| (QREFELT $ 53))
    (SPADCALL |n| (QREFELT $ 11))
    (QREFELT $ 49))
    (SPADCALL
    (PROG2
    (LETT #0#
    (SPADCALL (|spadConstant| $ 119) (QREFELT $ 122))
    |UPOLYC-;nextItemInner|)
    (QCDR #0#)
    (|check-union| (QEQCAR #0# 0) (QREFELT $ 7) #0#))
    (+ 1 (SPADCALL |n1| (QREFELT $ 11)))
    (QREFELT $ 49))
    (QREFELT $ 65))))
    ((QUOTE T)
    (SEQ
    (LETT |n3|
    (SPADCALL (SPADCALL |n| (QREFELT $ 53)) (QREFELT $ 122))
    |UPOLYC-;nextItemInner|)
    (EXIT
    (COND
      ((QEQCAR |n3| 1) (CONS 1 "failed")))
      ((QUOTE T)
      (CONS 0
      (SPADCALL (QCDR |n3|)

```

```

(SPADCALL |n| (QREFELT $ 11)) (QREFELT $ 49)))))))))))))

(DEFUN |UPOLYC-;nextItem;SU;30| (|n| $)
  (PROG (|n1| #0=:G1568)
    (RETURN
      (SEQ
        (LETT |n1| (|UPOLYC-;nextItemInner| |n| $) |UPOLYC-;nextItem;SU;30|)
        (EXIT
          (COND
            ((QEQCAR |n1| 1)
              (CONS 0
                (SPADCALL
                  (PROG2
                    (LETT #0#
                      (SPADCALL (|spadConstant| $ 119) (QREFELT $ 122))
                      |UPOLYC-;nextItem;SU;30|)
                    (QCDR #0#)
                    (|check-union| (QEQCAR #0# 0) (QREFELT $ 7) #0#))
                  (+ 1 (SPADCALL |n| (QREFELT $ 11)) (QREFELT $ 49))))
                ((QUOTE T) |n1|)))))))

(DEFUN |UPOLYC-;content;SSaosS;31| (|p| |v| $)
  (SPADCALL (SPADCALL |p| (QREFELT $ 125)) (QREFELT $ 30)))

(DEFUN |UPOLYC-;primeFactor| (|p| |q| $)
  (PROG (#0=:G1574 |p1|)
    (RETURN
      (SEQ
        (LETT |p1|
          (PROG2
            (LETT #0# (SPADCALL |p| (SPADCALL |p| |q| (QREFELT $ 127)) (QREFELT $ 128)) |UPOLYC-;primeFactor|)
            (QCDR #0#)
            (|check-union| (QEQCAR #0# 0) (QREFELT $ 6) #0#))
            |UPOLYC-;primeFactor|)
          (EXIT
            (COND
              ((SPADCALL |p1| |p| (QREFELT $ 129)) |p|)
              ((QUOTE T) (|UPOLYC-;primeFactor| |p1| |q| $)))))))

(DEFUN |UPOLYC-;separate;2SR;33| (|p| |q| $)
  (PROG (|a| #0=:G1580)
    (RETURN
      (SEQ
        (LETT |a| (|UPOLYC-;primeFactor| |p| |q| $) |UPOLYC-;separate;2SR;33|)
        (EXIT
          (CONS |a|
            (PROG2
              (LETT #0# (SPADCALL |p| |a| (QREFELT $ 128)) |UPOLYC-;separate;2SR;33|)
              (QCDR #0#)
              (|check-union| (QEQCAR #0# 0) (QREFELT $ 6) #0#)))))))

```

```

(DEFUN |UPOLYC-;differentiate;SM2S;34| (|x| |deriv| |x'| $)
  (PROG (|dg| |lc| #0=#:G1585 |d|)
    (RETURN
      (SEQ
        (LETT |d| (|spadConstant| $ 60) |UPOLYC-;differentiate;SM2S;34|)
        (SEQ G190
          (COND
            ((NULL (< 0
              (LETT |dg|
                (SPADCALL |x| (QREFELT $ 11)) |UPOLYC-;differentiate;SM2S;34|)))
              (GO G191)))
          (SEQ
            (LETT |lc| (SPADCALL |x| (QREFELT $ 53)) |UPOLYC-;differentiate;SM2S;34|)
            (LETT |d|
              (SPADCALL
                (SPADCALL |d|
                  (SPADCALL |x'|
                    (SPADCALL
                      (SPADCALL |dg| |lc| (QREFELT $ 133))
                      (PROG1
                        (LETT #0# (- |dg| 1) |UPOLYC-;differentiate;SM2S;34|)
                        (|check-subtype| (>= #0# 0) (QUOTE (|NonNegativeInteger|)) #0#))
                        (QREFELT $ 49))
                        (QREFELT $ 71))
                        (QREFELT $ 65))
                      (SPADCALL (SPADCALL |lc| |deriv|) |dg| (QREFELT $ 49)) (QREFELT $ 65))
                      |UPOLYC-;differentiate;SM2S;34|)
                    (EXIT
                      (LETT |x|
                        (SPADCALL |x| (QREFELT $ 55)) |UPOLYC-;differentiate;SM2S;34|)))
                      NIL
                      (GO G190)
                      G191
                      (EXIT NIL)))
            (EXIT
              (SPADCALL |d|
                (SPADCALL
                  (SPADCALL (SPADCALL |x| (QREFELT $ 53)) |deriv|)
                  (QREFELT $ 30))
                  (QREFELT $ 65)))))))

(DEFUN |UPOLYC-;ncdiff| (|n| |x'| $)
  (PROG (#0=#:G1603 |n1|)
    (RETURN
      (COND
        ((ZEROP |n|) (|spadConstant| $ 60))
        ((ZEROP
          (LETT |n1|
            (PROG1

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    (LETT #0# (- |n| 1) |UPOLYC-;ncdiff|)
    (|check-subtype| (>= #0# 0) (QUOTE (|NonNegativeInteger|)) #0#))
    |UPOLYC-;ncdiff|))
  |x'|)
((QUOTE T)
 (SPADCALL
  (SPADCALL |x'|
   (SPADCALL (|spadConstant| $ 48) |n1| (QREFELT $ 49)) (QREFELT $ 71))
  (SPADCALL
   (SPADCALL (|spadConstant| $ 48) 1 (QREFELT $ 49))
   (|UPOLYC-;ncdiff| |n1| |x'| $)
   (QREFELT $ 71))
  (QREFELT $ 65))))))

(DEFUN |UPOLYC-;differentiate;SM2S;36| (|x| |deriv| |x'| $)
 (PROG (|dg| |lc| |d|)
 (RETURN
 (SEQ
 (LETT |d| (|spadConstant| $ 60) |UPOLYC-;differentiate;SM2S;36|)
 (SEQ
 G190
 (COND
 ((NULL (< 0
 (LETT |dg|
 (SPADCALL |x| (QREFELT $ 11)) |UPOLYC-;differentiate;SM2S;36|)))
 (GO G191)))
 (SEQ
 (LETT |lc|
 (SPADCALL |x| (QREFELT $ 53)) |UPOLYC-;differentiate;SM2S;36|)
 (LETT |d|
 (SPADCALL
 (SPADCALL |d|
 (SPADCALL (SPADCALL |lc| |deriv|) |dg| (QREFELT $ 49))
 (QREFELT $ 65))
 (SPADCALL |lc| (|UPOLYC-;ncdiff| |dg| |x'| $) (QREFELT $ 136))
 (QREFELT $ 65))
 |UPOLYC-;differentiate;SM2S;36|)
 (EXIT
 (LETT |x|
 (SPADCALL |x| (QREFELT $ 55)) |UPOLYC-;differentiate;SM2S;36|)))
 NIL
 (GO G190)
 G191
 (EXIT NIL)))
 (EXIT
 (SPADCALL |d|
 (SPADCALL
 (SPADCALL (SPADCALL |x| (QREFELT $ 53)) |deriv|) (QREFELT $ 30))
 (QREFELT $ 65))))))

```



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(DEFUN |UPOLYC-;differentiate;SMS;37| (|x| |deriv| $)
  (SPADCALL |x| |deriv| (|spadConstant| $ 47) (QREFELT $ 137)))

(DEFUN |UPOLYC-;differentiate;2S;38| (|x| $)
  (PROG (|dg| #0=#:G1612 |d|)
    (RETURN
      (SEQ
        (LETT |d| (|spadConstant| $ 60) |UPOLYC-;differentiate;2S;38|)
        (SEQ
          G190
          (COND
            ((NULL (< 0
              (LETT |dg|
                (SPADCALL |x| (QREFELT $ 11)) |UPOLYC-;differentiate;2S;38|)))
              (GO G191)))
          (SEQ
            (LETT |d|
              (SPADCALL |d|
                (SPADCALL
                  (SPADCALL |dg| (SPADCALL |x| (QREFELT $ 53)) (QREFELT $ 133))
                  (PROG1
                    (LETT #0# (- |dg| 1) |UPOLYC-;differentiate;2S;38|)
                    (|check-subtype| (>= #0# 0) (QUOTE (|NonNegativeInteger|)) #0#))
                    (QREFELT $ 49))
                    (QREFELT $ 65))
                    |UPOLYC-;differentiate;2S;38|)
                (EXIT
                  (LETT |x| (SPADCALL |x| (QREFELT $ 55)) |UPOLYC-;differentiate;2S;38|)))
              NIL
              (GO G190)
              G191
              (EXIT NIL))
            (EXIT |d|))))))

(DEFUN |UPOLYC-;differentiate;SSaosS;39| (|x| |v| $)
  (SPADCALL |x| (QREFELT $ 140)))

(DEFUN |UPOLYC-;elt;3F;40| (|g| |f| $)
  (SPADCALL
    (SPADCALL (SPADCALL |g| (QREFELT $ 143)) |f| (QREFELT $ 145))
    (SPADCALL (SPADCALL |g| (QREFELT $ 146)) |f| (QREFELT $ 145))
    (QREFELT $ 147)))

(DEFUN |UPOLYC-;pseudoQuotient;3S;41| (|p| |q| $)
  (PROG (|n| #0=#:G1658 #1=#:G1660)
    (RETURN
      (SEQ
        (LETT |n|
          (+ (- (SPADCALL |p| (QREFELT $ 11)) (SPADCALL |q| (QREFELT $ 11))) 1)
          |UPOLYC-;pseudoQuotient;3S;41|)

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(EXIT
(COND
  ((< |n| 1) (|spadConstant| $ 60))
  ((QUOTE T)
  (PROG2
    (LETT #1#
      (SPADCALL
        (SPADCALL
          (SPADCALL
            (SPADCALL
              (SPADCALL |q| (QREFELT $ 53))
              (PROG1
                (LETT #0# |n| |UPOLYC-;pseudoQuotient;3S;41|)
                (|check-subtype| (>= #0# 0) (QUOTE (|NonNegativeInteger|)) #0#))
                (QREFELT $ 149))
                |p| (QREFELT $ 136))
              (SPADCALL |p| |q| (QREFELT $ 150)) (QREFELT $ 151))
              |q| (QREFELT $ 128))
              |UPOLYC-;pseudoQuotient;3S;41|)
              (QCDR #1#)
              (|check-union| (QEQCAR #1# 0) (QREFELT $ 6) #1#))))))))))

(DEFUN |UPOLYC-;pseudoDivide;2SR;42| (|p| |q| $)
  (PROG (|n| |preml| #0#:#:G1666 |lc| #1#:#:G1668)
  (RETURN
    (SEQ
      (LETT |n|
        (+ (- (SPADCALL |p| (QREFELT $ 11)) (SPADCALL |q| (QREFELT $ 11))) 1)
        |UPOLYC-;pseudoDivide;2SR;42|)
      (EXIT
        (COND
          ((< |n| 1) (VECTOR (|spadConstant| $ 48) (|spadConstant| $ 60) |p|))
          ((QUOTE T)
            (SEQ
              (LETT |preml|
                (SPADCALL |p| |q| (QREFELT $ 150)) |UPOLYC-;pseudoDivide;2SR;42|)
              (LETT |lc|
                (SPADCALL
                  (SPADCALL |q| (QREFELT $ 53))
                  (PROG1
                    (LETT #0# |n| |UPOLYC-;pseudoDivide;2SR;42|)
                    (|check-subtype| (>= #0# 0) (QUOTE (|NonNegativeInteger|)) #0#))
                    (QREFELT $ 149))
                    |UPOLYC-;pseudoDivide;2SR;42|)
                  (EXIT
                    (VECTOR |lc|
                      (PROG2
                        (LETT #1#
                          (SPADCALL
                            (SPADCALL

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        (SPADCALL |lc| |p| (QREFELT $ 136)) |prem| (QREFELT $ 151))
        |q| (QREFELT $ 128))
        |UPOLYC-;pseudoDivide;2SR;42|)
        (QCDR #1#)
        (|check-union| (QEQCAR #1# 0) (QREFELT $ 6) #1#))
        |prem|)))))))))

(DEFUN |UPOLYC-;composite;FSU;43| (|f| |q| $)
  (PROG (|n| |d|)
    (RETURN
      (SEQ
        (LETT |n|
          (SPADCALL (SPADCALL |f| (QREFELT $ 143)) |q| (QREFELT $ 155))
          |UPOLYC-;composite;FSU;43|)
        (EXIT
          (COND
            ((QEQCAR |n| 1) (CONS 1 "failed"))
            ((QUOTE T)
              (SEQ
                (LETT |d|
                  (SPADCALL (SPADCALL |f| (QREFELT $ 146)) |q| (QREFELT $ 155))
                  |UPOLYC-;composite;FSU;43|)
                (EXIT
                  (COND
                    ((QEQCAR |d| 1) (CONS 1 "failed"))
                    ((QUOTE T)
                      (CONS 0
                        (SPADCALL (QCDR |n|) (QCDR |d|) (QREFELT $ 156)))))))))))))

(DEFUN |UPOLYC-;composite;2SU;44| (|p| |q| $)
  (PROG (|cqr| |v| |u| |w| #0=#:G1694)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |p| (QREFELT $ 159)) (CONS 0 |p|))
          ((QUOTE T)
            (SEQ
              (EXIT
                (SEQ
                  (LETT |cqr|
                    (SPADCALL |p| |q| (QREFELT $ 160)) |UPOLYC-;composite;2SU;44|)
                  (COND
                    ((SPADCALL (QVELT |cqr| 2) (QREFELT $ 159))
                      (SEQ
                        (LETT |v|
                          (SPADCALL (QVELT |cqr| 2) (QVELT |cqr| 0) (QREFELT $ 161))
                          |UPOLYC-;composite;2SU;44|)
                        (EXIT
                          (COND
                            ((QEQCAR |v| 0)

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      (SEQ
        (LETT |u|
          (SPADCALL (QVELT |cqr| 1) |q| (QREFELT $ 155))
          |UPOLYC-;composite;2SU;44|)
        (EXIT
          (COND
            ((QEQCAR |u| 0)
              (SEQ
                (LETT |w|
                  (SPADCALL (QCDR |u|) (QVELT |cqr| 0) (QREFELT $ 161))
                  |UPOLYC-;composite;2SU;44|)
                (EXIT
                  (COND
                    ((QEQCAR |w| 0)
                      (PROGN
                        (LETT #0#
                          (CONS 0
                            (SPADCALL (QCDR |v|)
                              (SPADCALL
                                (SPADCALL (|spadConstant| $ 48) 1 (QREFELT $ 49))
                                (QCDR |w|)
                                (QREFELT $ 71))
                                (QREFELT $ 65)))
                              |UPOLYC-;composite;2SU;44|)
                                (GO #0#))))))))))))))
                        (EXIT (CONS 1 "failed")))) #0# (EXIT #0#)))))))))
      (DEFUN |UPOLYC-;elt;S2F;45| (|p| |f| $)
        (PROG (|n| #0=#:G1701 |ans|)
          (RETURN
            (SEQ
              (COND
                ((SPADCALL |p| (QREFELT $ 9)) (|spadConstant| $ 163))
                ((QUOTE T)
                  (SEQ
                    (LETT |ans|
                      (SPADCALL
                        (SPADCALL (SPADCALL |p| (QREFELT $ 53)) (QREFELT $ 30))
                        (QREFELT $ 164))
                      |UPOLYC-;elt;S2F;45|)
                    (LETT |n| (SPADCALL |p| (QREFELT $ 11)) |UPOLYC-;elt;S2F;45|)
                    (SEQ
                      G190
                      (COND
                        ((NULL
                          (COND
                            ((SPADCALL
                              (LETT |p|
                                (SPADCALL |p| (QREFELT $ 55)) |UPOLYC-;elt;S2F;45|) (QREFELT $ 9))
                              (QUOTE NIL))

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      ((QUOTE T) (QUOTE T)))
      (GO G191)))
    (SEQ
      (EXIT
        (LETT |ans|
          (SPADCALL
            (SPADCALL |ans|
              (SPADCALL |f|
                (PROG1
                  (LETT #0#
                    (- |n|
                      (LETT |n|
                        (SPADCALL |p| (QREFELT $ 11))
                        |UPOLYC-;elt;S2F;45|))
                        |UPOLYC-;elt;S2F;45|)
                        (|check-subtype| (>= #0# 0) (QUOTE (|NonNegativeInteger|)) #0#))
                        (QREFELT $ 165))
                        (QREFELT $ 166))
                        (SPADCALL
                          (SPADCALL (SPADCALL |p| (QREFELT $ 53)) (QREFELT $ 30))
                          (QREFELT $ 164))
                          (QREFELT $ 167))
                          |UPOLYC-;elt;S2F;45|)))
          NIL
          (GO G190)
          G191
          (EXIT NIL))
        (EXIT
          (COND
            ((ZEROP |n|) |ans|)
            ((QUOTE T)
              (SPADCALL |ans|
                (SPADCALL |f| |n| (QREFELT $ 168)) (QREFELT $ 166))))))))))
  (DEFUN |UPOLYC-;order;2SNni;46| (|p| |q| $)
    (PROG (|u| #0#:#:G1715 |ans|)
      (RETURN
        (SEQ
          (EXIT
            (COND
              ((SPADCALL |p| (QREFELT $ 9))
                (|error| "order: arguments must be nonzero"))
              ((< (SPADCALL |q| (QREFELT $ 11)) 1)
                (|error| "order: place must be non-trivial"))
              ((QUOTE T)
                (SEQ
                  (LETT |ans| 0 |UPOLYC-;order;2SNni;46|)
                  (EXIT
                    (SEQ
                      G190

```

```

NIL
(SEQ
  (LETT |u|
    (SPADCALL |p| |q| (QREFELT $ 128)) |UPOLYC-;order;2SNni;46|)
  (EXIT
    (COND
      ((QEQCAR |u| 1)
        (PROGN (LETT #0# |ans| |UPOLYC-;order;2SNni;46|) (GO #0#)))
      ((QUOTE T)
        (SEQ
          (LETT |p| (QCDR |u|) |UPOLYC-;order;2SNni;46|)
          (EXIT (LETT |ans| (+ |ans| 1) |UPOLYC-;order;2SNni;46|)))))))
NIL
(GO G190)
G191
(EXIT NIL))))))
#0# (EXIT #0#))))

(DEFUN |UPOLYC-;squareFree;SF;47| (|p| $) (SPADCALL |p| (QREFELT $ 172)))

(DEFUN |UPOLYC-;squareFreePart;2S;48| (|p| $) (SPADCALL |p| (QREFELT $ 174)))

(DEFUN |UPOLYC-;gcdPolynomial;3Sup;49| (|pp| |qq| $)
  (COND
    ((SPADCALL |pp| (QREFELT $ 176)) (SPADCALL |qq| (QREFELT $ 177)))
    ((SPADCALL |qq| (QREFELT $ 176)) (SPADCALL |pp| (QREFELT $ 177)))
    ((QUOTE T)
      (SPADCALL
        (SPADCALL
          (SPADCALL
            (SPADCALL |pp| (QREFELT $ 178))
            (SPADCALL |qq| (QREFELT $ 178))
            (QREFELT $ 127))
          (SPADCALL
            (SPADCALL |pp| (QREFELT $ 179))
            (SPADCALL |qq| (QREFELT $ 179))
            (QREFELT $ 180))
            (QREFELT $ 179))
          (QREFELT $ 181))
        (QREFELT $ 177))))))

(DEFUN |UPOLYC-;squareFreePolynomial;SupF;50| (|pp| $)
  (SPADCALL |pp| (QREFELT $ 184)))

(DEFUN |UPOLYC-;elt;F2R;51| (|f| |r| $)
  (SPADCALL
    (SPADCALL (SPADCALL |f| (QREFELT $ 143)) |r| (QREFELT $ 29))
    (SPADCALL (SPADCALL |f| (QREFELT $ 146)) |r| (QREFELT $ 29))
    (QREFELT $ 186)))

```

```

(DEFUN |UPOLYC-;euclideanSize;SNni;52| (|x| $)
  (COND
    ((SPADCALL |x| (QREFELT $ 9))
      (|error| "euclideanSize called on 0 in Univariate Polynomial"))
    ((QUOTE T)
      (SPADCALL |x| (QREFELT $ 11))))))

(DEFUN |UPOLYC-;divide;2SR;53| (|x| |y| $)
  (PROG (|lc| |f| #0#:#:G1728 |n| |quot|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |y| (QREFELT $ 9))
            (|error| "division by 0 in Univariate Polynomials"))
          ((QUOTE T)
            (SEQ
              (LETT |quot| (|spadConstant| $ 60) |UPOLYC-;divide;2SR;53|)
              (LETT |lc|
                (SPADCALL (SPADCALL |y| (QREFELT $ 53)) (QREFELT $ 189))
                |UPOLYC-;divide;2SR;53|)
              (SEQ
                G190
                (COND
                  ((NULL
                    (COND
                      ((OR (SPADCALL |x| (QREFELT $ 9))
                        (< (SPADCALL |x| (QREFELT $ 11))
                          (SPADCALL |y| (QREFELT $ 11))))
                      (QUOTE NIL))
                    ((QUOTE T) (QUOTE T))))
                  (GO G191)))
                (SEQ
                  (LETT |f|
                    (SPADCALL |lc| (SPADCALL |x| (QREFELT $ 53)) (QREFELT $ 190))
                    |UPOLYC-;divide;2SR;53|)
                  (LETT |n|
                    (PROG1
                      (LETT #0#
                        (- (SPADCALL |x| (QREFELT $ 11)) (SPADCALL |y| (QREFELT $ 11)))
                        |UPOLYC-;divide;2SR;53|)
                      (|check-subtype| (>= #0# 0) (QUOTE (|NonNegativeInteger|)) #0#))
                      |UPOLYC-;divide;2SR;53|)
                  (LETT |quot|
                    (SPADCALL |quot| (SPADCALL |f| |n| (QREFELT $ 49)) (QREFELT $ 65))
                    |UPOLYC-;divide;2SR;53|)
                  (EXIT
                    (LETT |x|
                      (SPADCALL |x|
                        (SPADCALL (SPADCALL |f| |n| (QREFELT $ 49)) |y| (QREFELT $ 71))

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        (QREFELT $ 151))
        |UPOLYC-;divide;2SR;53|)))
    NIL
    (GO G190)
    G191
    (EXIT NIL))
    (EXIT (CONS |quot| |x|)))))))))

(DEFUN |UPOLYC-;integrate;2S;54| (|p| $)
  (PROG (|l| |d| |ans|)
    (RETURN
      (SEQ
        (LETT |ans| (|spadConstant| $ 60) |UPOLYC-;integrate;2S;54|)
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((SPADCALL |p| (|spadConstant| $ 60) (QREFELT $ 129)) (QUOTE NIL))
                ((QUOTE T) (QUOTE T))))
              (GO G191)))
          (SEQ
            (LETT |l| (SPADCALL |p| (QREFELT $ 53)) |UPOLYC-;integrate;2S;54|)
            (LETT |d| (+ 1 (SPADCALL |p| (QREFELT $ 11))) |UPOLYC-;integrate;2S;54|)
            (LETT |ans|
              (SPADCALL |ans|
                (SPADCALL
                  (SPADCALL (SPADCALL |d| (QREFELT $ 193)) (QREFELT $ 194))
                  (SPADCALL |l| |d| (QREFELT $ 49))
                  (QREFELT $ 195))
                  (QREFELT $ 65))
                |UPOLYC-;integrate;2S;54|)
              (EXIT
                (LETT |p| (SPADCALL |p| (QREFELT $ 55)) |UPOLYC-;integrate;2S;54|)))
            NIL
            (GO G190)
            G191
            (EXIT NIL))
            (EXIT |ans|))))))

(DEFUN |UnivariatePolynomialCategory&| (|#1| |#2|)
  (PROG (DV$1 DV$2 |dv$| $ |pv$|)
    (RETURN
      (PROGN
        (LETT DV$1 (|devaluate| |#1|) . #0=(|UnivariatePolynomialCategory&|))
        (LETT DV$2 (|devaluate| |#2|) . #0#)
        (LETT |dv$| (LIST (QUOTE |UnivariatePolynomialCategory&|) DV$1 DV$2) . #0#)
        (LETT $ (MAKE-ARRAY 203) . #0#)
        (QSETREFV $ 0 |dv$|)
        (QSETREFV $ 3

```



```

(LETT |pv$|
  (|buildPredVector| 0 0
    (LIST
      (|HasCategory| |#2| (QUOTE (|Algebra| (|Fraction| (|Integer|))))))
      (|HasCategory| |#2| (QUOTE (|Field|))))
      (|HasCategory| |#2| (QUOTE (|GcdDomain|))))
      (|HasCategory| |#2| (QUOTE (|IntegralDomain|))))
      (|HasCategory| |#2| (QUOTE (|CommutativeRing|))))
      (|HasCategory| |#2| (QUOTE (|StepThrough|))))
      . #0#))
(|stuffDomainSlots| $)
(QSETREFV $ 6 |#1|)
(QSETREFV $ 7 |#2|)
(COND
  ((|HasCategory| |#2| (QUOTE (|PolynomialFactorizationExplicit|))))
  (PROGN
    (QSETREFV $ 81
      (CONS
        (|dispatchFunction| |UPOLYC-;solveLinearPolynomialEquation;LSupU;20|)
        $))
      (QSETREFV $ 85
        (CONS (|dispatchFunction| |UPOLYC-;factorPolynomial;SupF;21|) $))
        (QSETREFV $ 87
          (CONS
            (|dispatchFunction| |UPOLYC-;factorSquareFreePolynomial;SupF;22|)
            $))
          (QSETREFV $ 105 (CONS (|dispatchFunction| |UPOLYC-;factor;SF;23|) $))))))
  (COND
    (|testBitVector| |pv$| 6)
    (PROGN
      (QSETREFV $ 120 (CONS (|dispatchFunction| |UPOLYC-;init;S;28|) $))
      NIL
      (QSETREFV $ 124
        (CONS (|dispatchFunction| |UPOLYC-;nextItem;SU;30|) $))))))
  (COND
    (|testBitVector| |pv$| 3)
    (PROGN
      (QSETREFV $ 126
        (CONS (|dispatchFunction| |UPOLYC-;content;SSaOS;31|) $))
        NIL
        (QSETREFV $ 131
          (CONS (|dispatchFunction| |UPOLYC-;separate;2SR;33|) $))))))
  (COND
    (|testBitVector| |pv$| 5)
    (QSETREFV $ 135
      (CONS (|dispatchFunction| |UPOLYC-;differentiate;SM2S;34|) $)))
    (QUOTE T)
    (PROGN
      (QSETREFV $ 135
        (CONS (|dispatchFunction| |UPOLYC-;differentiate;SM2S;36|) $))))))

```

```

(COND
  ((|testBitVector| |pv$| 4)
   (PROGN
    (QSETREFV $ 148 (CONS (|dispatchFunction| |UPOLYC-;elt;3F;40|) $))
    (QSETREFV $ 152
      (CONS (|dispatchFunction| |UPOLYC-;pseudoQuotient;3S;41|) $))
    (QSETREFV $ 154
      (CONS (|dispatchFunction| |UPOLYC-;pseudoDivide;2SR;42|) $))
    (QSETREFV $ 158
      (CONS (|dispatchFunction| |UPOLYC-;composite;FSU;43|) $))
    (QSETREFV $ 162
      (CONS (|dispatchFunction| |UPOLYC-;composite;2SU;44|) $))
    (QSETREFV $ 169 (CONS (|dispatchFunction| |UPOLYC-;elt;S2F;45|) $))
    (QSETREFV $ 170
      (CONS (|dispatchFunction| |UPOLYC-;order;2SNni;46|) $))))))
(COND
  ((|testBitVector| |pv$| 3)
   (PROGN
    (QSETREFV $ 173
      (CONS (|dispatchFunction| |UPOLYC-;squareFree;SF;47|) $))
    (QSETREFV $ 175
      (CONS (|dispatchFunction| |UPOLYC-;squareFreePart;2S;48|) $))))))
(COND
  ((|HasCategory| |#2| (QUOTE (|PolynomialFactorizationExplicit|)))
   (PROGN
    (QSETREFV $ 182
      (CONS (|dispatchFunction| |UPOLYC-;gcdPolynomial;3Sup;49|) $))
    (QSETREFV $ 185
      (CONS
        (|dispatchFunction| |UPOLYC-;squareFreePolynomial;SupF;50|)
        $))))))
(COND
  ((|testBitVector| |pv$| 2)
   (PROGN
    (QSETREFV $ 187 (CONS (|dispatchFunction| |UPOLYC-;elt;F2R;51|) $))
    (QSETREFV $ 188
      (CONS (|dispatchFunction| |UPOLYC-;euclideanSize;SNni;52|) $))
    (QSETREFV $ 191
      (CONS (|dispatchFunction| |UPOLYC-;divide;2SR;53|) $))))))
(COND
  ((|testBitVector| |pv$| 1)
   (QSETREFV $ 196
     (CONS (|dispatchFunction| |UPOLYC-;integrate;2S;54|) $))))
  $))))

(SETF
  (GET (QUOTE |UnivariatePolynomialCategory&|) (QUOTE |infovec|))
  (LIST
    (QUOTE
      #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|) (|Boolean|)

```

```

(0 . |zero?|) (|NonNegativeInteger|) (5 . |degree|)
(|SingletonAsOrderedSet|) (10 . |create|) (|List| 12)
|UPOLYC-;variables;SL;1| |UPOLYC-;degree;SSaonsNni;2|
(14 . |totalDegree|) |UPOLYC-;totalDegree;SLNni;3| (|List| 10)
|UPOLYC-;degree;SLL;4| (19 . |eval|) (|List| $) |UPOLYC-;eval;SLLS;5|
(26 . |elt|) |UPOLYC-;eval;SSaons2S;6| (32 . |eval|) (|List| 7)
|UPOLYC-;eval;SLLS;7| (39 . |elt|) (45 . |coerce|)
|UPOLYC-;eval;SSaonsRS;8| (|Equation| 6) (50 . |lhs|)
(|Union| 12 (QUOTE "failed")) (55 . |mainVariable|) (60 . |rhs|)
(|List| 199) |UPOLYC-;eval;SLS;9| |UPOLYC-;mainVariable;SU;10|
(65 . |minimumDegree|) |UPOLYC-;minimumDegree;SSaonsNni;11|
|UPOLYC-;minimumDegree;SLL;12| (70 . +) (|Mapping| 10 10)
(76 . |mapExponents|) |UPOLYC-;monomial;SSaonsNniS;13| (82 . |One|)
(86 . |One|) (90 . |monomial|) |UPOLYC-;coerce;SaonsS;14|
(|SparseUnivariatePolynomial| 7) (96 . |Zero|)
(100 . |leadingCoefficient|) (105 . |monomial|) (111 . |reductum|)
(116 . |makeSUP|) (121 . +) |UPOLYC-;makeSUP;SSup;15| (127 . |zero?|)
(132 . |Zero|) (136 . |leadingCoefficient|) (141 . |degree|)
(146 . |reductum|) (151 . |unmakeSUP|) (156 . +)
|UPOLYC-;unmakeSUP;SupS;16| (|Record| (|:| |quotient| $)
(|:| |remainder| $)) (162 . |monicDivide|)
|UPOLYC-;karatsubaDivide;SNniR;17| |UPOLYC-;shiftRight;SNniS;18|
(168 . *) |UPOLYC-;shiftLeft;SNniS;19| (|Union| 74 (QUOTE "failed"))
(|List| 75) (|SparseUnivariatePolynomial| 6)
(|PolynomialFactorizationByRecursionUnivariate| 7 6)
(174 . |solveLinearPolynomialEquationByRecursion|)
(|Union| 79 (QUOTE "failed")) (|List| 80)
(|SparseUnivariatePolynomial| $)
(180 . |solveLinearPolynomialEquation|) (|Factored| 75)
(186 . |factorByRecursion|) (|Factored| 80) (191 . |factorPolynomial|)
(196 . |factorSquareFreeByRecursion|)
(201 . |factorSquareFreePolynomial|) (|Factored| $) (206 . |factor|)
(|Factored| 7) (211 . |unit|) (|Union| (QUOTE "nil") (QUOTE "sqfr")
(QUOTE "irred") (QUOTE "prime")) (|Record| (|:| |flg| 92)
(|:| |fctr| 7) (|:| |xpnt| 109)) (|List| 93) (216 . |factorList|)
(|Record| (|:| |flg| 92) (|:| |fctr| 6) (|:| |xpnt| 109)) (|List| 96)
(|Factored| 6) (221 . |makeFR|) (227 . |factorPolynomial|)
(|Mapping| 6 51) (|Factored| 51) (|FactoredFunctions2| 51 6)
(232 . |map|) (238 . |factor|) (243 . |Zero|) (|Vector| 7)
(247 . |new|) (|Integer|) (253 . |minIndex|) (258 . |coefficient|)
(264 . |qsetelt!|) |UPOLYC-;vectorise;SNniV;24| (271 . |elt|)
|UPOLYC-;unvectorise;VS;25| |UPOLYC-;retract;SR;26|
(|Union| 7 (QUOTE "failed")) |UPOLYC-;retractIfCan;SU;27|
(277 . |init|) (281 . |init|) (|Union| $ (QUOTE "failed"))
(285 . |nextItem|) (290 . |One|) (294 . |nextItem|) (299 . |content|)
(304 . |content|) (310 . |gcd|) (316 . |exquo|) (322 . =)
(|Record| (|:| |primePart| $) (|:| |commonPart| $)) (328 . |separate|)
(334 . |Zero|) (338 . *) (|Mapping| 7 7) (344 . |differentiate|)
(351 . *) (357 . |differentiate|) |UPOLYC-;differentiate;SMS;37|
|UPOLYC-;differentiate;2S;38| (364 . |differentiate|)

```

```

|UPOLYC-;differentiate;SSaOS;39| (|Fraction| 6) (369 . |numer|)
(|Fraction| $) (374 . |elt|) (380 . |denom|) (385 . /) (391 . |elt|)
(397 . **) (403 . |pseudoRemainder|) (409 . -) (415 . |pseudoQuotient|)
(|Record| (|:| |coef| 7) (|:| |quotient| $) (|:| |remainder| $))
(421 . |pseudoDivide|) (427 . |composite|) (433 . /)
(|Union| 144 (QUOTE "failed")) (439 . |composite|) (445 . |ground?|)
(450 . |pseudoDivide|) (456 . |exquo|) (462 . |composite|)
(468 . |Zero|) (472 . |coerce|) (477 . **) (483 . *) (489 . +)
(495 . **) (501 . |elt|) (507 . |order|)
(|UnivariatePolynomialSquareFree| 7 6) (513 . |squareFree|)
(518 . |squareFree|) (523 . |squareFreePart|) (528 . |squareFreePart|)
(533 . |zero?|) (538 . |unitCanonical|) (543 . |content|)
(548 . |primitivePart|) (553 . |subResultantGcd|) (559 . *)
(565 . |gcdPolynomial|) (|UnivariatePolynomialSquareFree| 6 75)
(571 . |squareFree|) (576 . |squareFreePolynomial|) (581 . /)
(587 . |elt|) (593 . |euclideanSize|) (598 . |inv|) (603 . *)
(609 . |divide|) (|Fraction| 109) (615 . |coerce|) (620 . |inv|)
(625 . *) (631 . |integrate|) (|List| 198) (|Symbol|) (|Equation| $)
(|Union| 109 (QUOTE "failed")) (|Union| 192 (QUOTE "failed"))
(|OutputForm|)))
(QUOTE #(|vectorise| 636 |variables| 642 |unvectorise| 647
|unmakeSUP| 652 |totalDegree| 657 |squareFreePolynomial| 663
|squareFreePart| 668 |squareFree| 673
|solveLinearPolynomialEquation| 678 |shiftRight| 684
|shiftLeft| 690 |separate| 696 |retractIfCan| 702
|retract| 707 |pseudoQuotient| 712 |pseudoDivide| 718
|order| 724 |nextItem| 730 |monomial| 735 |minimumDegree| 742
|makeSUP| 754 |mainVariable| 759 |karatsubaDivide| 764
|integrate| 770 |init| 775 |gcdPolynomial| 779
|factorSquareFreePolynomial| 785 |factorPolynomial| 790
|factor| 795 |eval| 800 |euclideanSize| 834 |elt| 839
|divide| 857 |differentiate| 863 |degree| 887 |content| 899
|composite| 905 |coerce| 917))
(QUOTE NIL)
(CONS (|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
(QUOTE #())
(CONS
(QUOTE #())
(|makeByteWordVec2| 196 (QUOTE (1 6 8 0 9 1 6 10 0 11 0 12 0 13 1 6
10 0 17 3 6 0 0 12 0 21 2 6 0 0 0 24 3 6 0 0 12 7 26 2 6 7 0 7 29
1 6 0 7 30 1 32 6 0 33 1 6 34 0 35 1 32 6 0 36 1 6 10 0 40 2 10 0
0 0 43 2 6 0 44 0 45 0 6 0 47 0 7 0 48 2 6 0 7 10 49 0 51 0 52 1
6 7 0 53 2 51 0 7 10 54 1 6 0 0 55 1 6 51 0 56 2 51 0 0 0 57 1 51
8 0 59 0 6 0 60 1 51 7 0 61 1 51 10 0 62 1 51 0 0 63 1 6 0 51 64
2 6 0 0 0 65 2 6 67 0 0 68 2 6 0 0 0 71 2 76 73 74 75 77 2 0 78
79 80 81 1 76 82 75 83 1 0 84 80 85 1 76 82 75 86 1 0 84 80 87
1 7 88 0 89 1 90 7 0 91 1 90 94 0 95 2 98 0 6 97 99 1 7 84 80
100 2 103 98 101 102 104 1 0 88 0 105 0 7 0 106 2 107 0 10 7 108
1 107 109 0 110 2 6 7 0 10 111 3 107 7 0 109 7 112 2 107 7 0 109

```

```

114 0 7 0 119 0 0 0 120 1 7 121 0 122 0 75 0 123 1 0 121 0 124 1
6 7 0 125 2 0 0 0 12 126 2 6 0 0 0 127 2 6 121 0 0 128 2 6 8 0 0
129 2 0 130 0 0 131 0 75 0 132 2 7 0 10 0 133 3 0 0 0 134 0 135
2 6 0 7 0 136 3 6 0 0 134 0 137 1 6 0 0 140 1 142 6 0 143 2 6 144
0 144 145 1 142 6 0 146 2 142 0 0 0 147 2 0 144 144 148 2 7 0
0 10 149 2 6 0 0 0 150 2 6 0 0 0 151 2 0 0 0 0 152 2 0 153 0 0 154
2 6 121 0 0 155 2 142 0 6 6 156 2 0 157 144 0 158 1 6 8 0 159 2 6
153 0 0 160 2 6 121 0 7 161 2 0 121 0 0 162 0 142 0 163 1 142 0 6
164 2 142 0 0 109 165 2 142 0 0 0 166 2 142 0 0 0 167 2 142 0 0 10
168 2 0 144 0 144 169 2 0 10 0 0 170 1 171 98 6 172 1 0 88 0 173 1
171 6 6 174 1 0 0 0 175 1 75 8 0 176 1 75 0 0 177 1 75 6 0 178 1
75 0 0 179 2 75 0 0 0 180 2 75 0 6 0 181 2 0 80 80 80 182 1 183 82
75 184 1 0 84 80 185 2 7 0 0 0 186 2 0 7 144 7 187 1 0 10 0 188 1
7 0 0 189 2 7 0 0 0 190 2 0 67 0 0 191 1 192 0 109 193 1 192 0 0
194 2 6 0 192 0 195 1 0 0 0 196 2 0 107 0 10 113 1 0 14 0 15 1 0
0 107 115 1 0 0 51 66 2 0 10 0 14 18 1 0 84 80 185 1 0 0 0 175 1
0 88 0 173 2 0 78 79 80 81 2 0 0 0 10 70 2 0 0 0 10 72 2 0 130 0
0 131 1 0 117 0 118 1 0 7 0 116 2 0 0 0 0 152 2 0 153 0 0 154 2
0 10 0 0 170 1 0 121 0 124 3 0 0 0 12 10 46 2 0 10 0 12 41 2 0
19 0 14 42 1 0 51 0 58 1 0 34 0 39 2 0 67 0 10 69 1 0 0 0 196
0 0 0 120 2 0 80 80 80 182 1 0 84 80 87 1 0 84 80 85 1 0 88 0
105 3 0 0 0 14 22 23 3 0 0 0 12 0 25 3 0 0 0 12 7 31 3 0 0 0 14
27 28 2 0 0 0 37 38 1 0 10 0 188 2 0 144 0 144 169 2 0 7 144 7
187 2 0 144 144 144 148 2 0 67 0 0 191 3 0 0 0 134 0 135 2 0 0
0 134 138 1 0 0 0 139 2 0 0 0 12 141 2 0 19 0 14 20 2 0 10 0 12
16 2 0 0 0 12 126 2 0 121 0 0 162 2 0 157 144 0 158 1 0 0 12 50))))))
(QUOTE |lookupComplete|)))

```

21.69 URAGG.lsp BOOTSTRAP

URAGG depends on a chain of files. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **URAGG** category which we can write into the **MID** directory. We compile the lisp code and copy the **URAGG.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— URAGG.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(SETQ |UnaryRecursiveAggregate;CAT| (QUOTE NIL))

(SETQ |UnaryRecursiveAggregate;AL| (QUOTE NIL))

```

```

(DEFUN |UnaryRecursiveAggregate| (#1=#:G84596)
  (LET (#2=#:G84597)
    (COND
      ((SETQ #2# (|assoc| (|devalueate| #1#) |UnaryRecursiveAggregate;AL|))
        (CDR #2#))
      (T
        (SETQ |UnaryRecursiveAggregate;AL|
          (|cons5|
            (CONS (|devalueate| #1#) (SETQ #2# (|UnaryRecursiveAggregate;| #1#))
              |UnaryRecursiveAggregate;AL|))
            #2#))))))

(DEFUN |UnaryRecursiveAggregate;| (|t#1|)
  (PROG (#1=#:G84595)
    (RETURN
      (PROG1
        (LETT #1#
          (|sublisV|
            (PAIR (QUOTE (|t#1|)) (LIST (|devalueate| |t#1|))))
          (COND
            (|UnaryRecursiveAggregate;CAT|)
            ((QUOTE T)
              (LETT |UnaryRecursiveAggregate;CAT|
                (|Join|
                  (|RecursiveAggregate| (QUOTE |t#1|))
                  (|mkCategory|
                    (QUOTE |domain|)
                    (QUOTE (
                      ((|concat| (|$| |$| |$|)) T)
                      ((|concat| (|$| |t#1| |$|)) T)
                      ((|first| (|t#1| |$|)) T)
                      ((|elt| (|t#1| |$| "first")) T)
                      ((|first| (|$| |$| (|NonNegativeInteger|))) T)
                      ((|rest| (|$| |$|)) T)
                      ((|elt| (|$| |$| "rest")) T)
                      ((|rest| (|$| |$| (|NonNegativeInteger|))) T)
                      ((|last| (|t#1| |$|)) T)
                      ((|elt| (|t#1| |$| "last")) T)
                      ((|last| (|$| |$| (|NonNegativeInteger|))) T)
                      ((|tail| (|$| |$|)) T)
                      ((|second| (|t#1| |$|)) T)
                      ((|third| (|t#1| |$|)) T)
                      ((|cycleEntry| (|$| |$|)) T)
                      ((|cycleLength| ((|NonNegativeInteger|) |$|)) T)
                      ((|cycleTail| (|$| |$|)) T)
                      ((|concat!| (|$| |$| |$|))
                        (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
                      ((|concat!| (|$| |$| |t#1|))
                        (|has| |$| (ATTRIBUTE |shallowlyMutable|))))
                    ))
                  ))
                ))
              ))
            ))
          ))

```

```

((|cycleSplit!| (|$| |$|))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
((|setfirst!| (|t#1| |$| |t#1|))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
((|setelt| (|t#1| |$| "first" |t#1|))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
((|setrest!| (|$| |$| |$|))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
((|setelt| (|$| |$| "rest" |$|))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
((|setlast!| (|t#1| |$| |t#1|))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
((|setelt| (|t#1| |$| "last" |t#1|))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|)))
((|split!| (|$| |$| (|Integer|))
  (|has| |$| (ATTRIBUTE |shallowlyMutable|))))
NIL
(QUOTE ((|Integer|) (|NonNegativeInteger|))
  NIL))
. #2=(|UnaryRecursiveAggregate|)))))
. #2#)
(SETELT #1# 0
  (LIST (QUOTE |UnaryRecursiveAggregate|) (|devaluate| |t#1|))))))

```

21.70 URAGG-.lsp BOOTSTRAP

URAGG- depends on **URAGG**. We need to break this cycle to build the algebra. So we keep a cached copy of the translated **URAGG-** category which we can write into the **MID** directory. We compile the lisp code and copy the **URAGG-.o** file to the **OUT** directory. This is eventually forcibly replaced by a recompiled version.

Note that this code is not included in the generated catdef.spad file.

— URAGG-.lsp BOOTSTRAP —

```

(|/VERSIONCHECK| 2)

(DEFUN |URAGG-;elt;AfirstS;1| (|x| G84610 |$|)
  (SPADCALL |x| (QREFELT |$| 8)))

(DEFUN |URAGG-;elt;AlastS;2| (|x| G84612 |$|)
  (SPADCALL |x| (QREFELT |$| 11)))

(DEFUN |URAGG-;elt;ArestA;3| (|x| G84614 |$|)
  (SPADCALL |x| (QREFELT |$| 14)))

```

```

(DEFUN |URAGG-;second;AS;4| (|x| |$|)
  (SPADCALL (SPADCALL |x| (QREFELT |$| 14)) (QREFELT |$| 8)))

(DEFUN |URAGG-;third;AS;5| (|x| |$|)
  (SPADCALL
    (SPADCALL (SPADCALL |x| (QREFELT |$| 14)) (QREFELT |$| 14))
    (QREFELT |$| 8)))

(DEFUN |URAGG-;cyclic?;AB;6| (|x| |$|)
  (COND
    ((OR
      (SPADCALL |x| (QREFELT |$| 20))
      (SPADCALL (|URAGG-;findCycle| |x| |$|) (QREFELT |$| 20)))
      (QUOTE NIL))
    ((QUOTE T) (QUOTE T))))

(DEFUN |URAGG-;last;AS;7| (|x| |$|)
  (SPADCALL (SPADCALL |x| (QREFELT |$| 22)) (QREFELT |$| 8)))

(DEFUN |URAGG-;nodes;AL;8| (|x| |$|)
  (PROG (|l|)
    (RETURN
      (SEQ
        (LETT |l| NIL |URAGG-;nodes;AL;8|)
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((SPADCALL |x| (QREFELT |$| 20)) (QUOTE NIL))
                ((QUOTE T) (QUOTE T))))
              (GO G191)))
          (SEQ
            (LETT |l| (CONS |x| |l|) |URAGG-;nodes;AL;8|)
            (EXIT (LETT |x| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;nodes;AL;8|)))
          NIL
          (GO G190)
          G191
          (EXIT NIL))
        (EXIT (NREVERSE |l|))))))

(DEFUN |URAGG-;children;AL;9| (|x| |$|)
  (PROG (|l|)
    (RETURN
      (SEQ
        (LETT |l| NIL |URAGG-;children;AL;9|)
        (EXIT
          (COND
            ((SPADCALL |x| (QREFELT |$| 20)) |l|)

```



```

((QUOTE T) (CONS (SPADCALL |x| (QREFELT |$| 14)) |1|))))))

(DEFUN |URAGG-;leaf?;AB;10| (|x| |$|)
  (SPADCALL |x| (QREFELT |$| 20)))

(DEFUN |URAGG-;value;AS;11| (|x| |$|)
  (COND
    ((SPADCALL |x| (QREFELT |$| 20)) (|error| "value of empty object"))
    ((QUOTE T) (SPADCALL |x| (QREFELT |$| 8)))))

(DEFUN |URAGG-;less?;ANniB;12| (|l| |n| |$|)
  (PROG (|i|)
    (RETURN
      (SEQ
        (LETT |i| |n| |URAGG-;less?;ANniB;12|)
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((|<| 0 |i|)
                (COND
                  ((SPADCALL |l| (QREFELT |$| 20)) (QUOTE NIL))
                  ((QUOTE T) (QUOTE T))))
                ((QUOTE T) (QUOTE NIL))))
            (GO G191)))
          (SEQ
            (LETT |l| (SPADCALL |l| (QREFELT |$| 14)) |URAGG-;less?;ANniB;12|)
            (EXIT (LETT |i| (|-| |i| 1) |URAGG-;less?;ANniB;12|)))
          NIL
          (GO G190)
          G191
          (EXIT NIL))
        (EXIT (|<| 0 |i|))))))

(DEFUN |URAGG-;more?;ANniB;13| (|l| |n| |$|)
  (PROG (|i|)
    (RETURN
      (SEQ
        (LETT |i| |n| |URAGG-;more?;ANniB;13|)
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((|<| 0 |i|)
                (COND
                  ((SPADCALL |l| (QREFELT |$| 20)) (QUOTE NIL))
                  ((QUOTE T) (QUOTE T))))
                ((QUOTE T) (QUOTE NIL))))
            (GO G191)))
          (SEQ
            (LETT |l| (SPADCALL |l| (QREFELT |$| 14)) |URAGG-;more?;ANniB;13|)
            (EXIT (LETT |i| (|-| |i| 1) |URAGG-;more?;ANniB;13|)))
          NIL
          (GO G190)
          G191
          (EXIT NIL))
        (EXIT (|<| 0 |i|))))))

```

```

      (GO G191)))
    (SEQ
      (LETT |l| (SPADCALL |l| (QREFELT |$| 14)) |URAGG-;more?;ANniB;13|)
      (EXIT (LETT |i| (|-| |i| 1) |URAGG-;more?;ANniB;13|)))
    NIL
    (GO G190)
  G191
  (EXIT NIL))
(EXIT
  (COND
    ((ZEROP |i|)
      (COND
        ((SPADCALL |l| (QREFELT |$| 20)) (QUOTE NIL))
        ((QUOTE T) (QUOTE T))))
    ((QUOTE T) (QUOTE NIL))))))

(DEFUN |URAGG-;size?;ANniB;14| (|l| |n| |$|)
  (PROG (|i|)
    (RETURN
      (SEQ
        (LETT |i| |n| |URAGG-;size?;ANniB;14|)
        (SEQ
          G190
          (COND
            ((NULL
              (COND
                ((SPADCALL |l| (QREFELT |$| 20)) (QUOTE NIL))
                ((QUOTE T) (|<| 0 |i|))))
              (GO G191)))
          (SEQ
            (LETT |l| (SPADCALL |l| (QREFELT |$| 14)) |URAGG-;size?;ANniB;14|)
            (EXIT (LETT |i| (|-| |i| 1) |URAGG-;size?;ANniB;14|)))
            NIL
            (GO G190)
          G191
          (EXIT NIL))
        (EXIT
          (COND
            ((SPADCALL |l| (QREFELT |$| 20)) (ZEROP |i|))
            ((QUOTE T) (QUOTE NIL))))))

(DEFUN |URAGG-;#;ANni;15| (|x| |$|)
  (PROG (|k|)
    (RETURN
      (SEQ
        (SEQ
          (LETT |k| 0 |URAGG-;#;ANni;15|)
          G190
          (COND
            ((NULL

```

```

(COND
  ((SPADCALL |x| (QREFELT |$| 20)) (QUOTE NIL))
  ((QUOTE T) (QUOTE T))))
(GO G191)))
(SEQ
  (COND
    ((EQL |k| 1000)
      (COND
        ((SPADCALL |x| (QREFELT |$| 33)) (EXIT (|error| "cyclic list")))))
    (EXIT (LETT |x| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;#;ANni;15|)))
  (LETT |k| (QSADD1 |k|) |URAGG-;#;ANni;15|)
  (GO G190)
  G191
  (EXIT NIL))
(EXIT |k|))))))

(DEFUN |URAGG-;tail;2A;16| (|x| |$|)
  (PROG (|k| |y|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |x| (QREFELT |$| 20)) (|error| "empty list"))
          ((QUOTE T)
            (SEQ
              (LETT |y| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;tail;2A;16|)
              (SEQ
                (LETT |k| 0 |URAGG-;tail;2A;16|)
                G190
                (COND
                  ((NULL
                    (COND
                      ((SPADCALL |y| (QREFELT |$| 20)) (QUOTE NIL))
                      ((QUOTE T) (QUOTE T))))
                  (GO G191)))
                (SEQ
                  (COND
                    ((EQL |k| 1000)
                      (COND
                        ((SPADCALL |x| (QREFELT |$| 33))
                          (EXIT (|error| "cyclic list"))))))
                    (EXIT
                      (LETT |y|
                        (SPADCALL (LETT |x| |y| |URAGG-;tail;2A;16|) (QREFELT |$| 14))
                        |URAGG-;tail;2A;16|)))
                      (LETT |k| (QSADD1 |k|) |URAGG-;tail;2A;16|)
                      (GO G190)
                      G191
                      (EXIT NIL))
                      (EXIT |x|))))))))))

```

```

(DEFUN |URAGG-;findCycle| (|x| |$|)
  (PROG (#1=#:G84667 |y|)
    (RETURN
      (SEQ
        (EXIT
          (SEQ
            (LETT |y| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;findCycle|)
            (SEQ
              G190
              (COND
                ((NULL
                  (COND
                    ((SPADCALL |y| (QREFELT |$| 20)) (QUOTE NIL))
                    ((QUOTE T) (QUOTE T))))
                (GO G191)))
              (SEQ
                (COND
                  ((SPADCALL |x| |y| (QREFELT |$| 36))
                    (PROGN (LETT #1# |x| |URAGG-;findCycle|) (GO #1#))))
                  (LETT |x| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;findCycle|)
                  (LETT |y| (SPADCALL |y| (QREFELT |$| 14)) |URAGG-;findCycle|)
                  (COND
                    ((SPADCALL |y| (QREFELT |$| 20))
                      (PROGN (LETT #1# |y| |URAGG-;findCycle|) (GO #1#))))
                    (COND
                      ((SPADCALL |x| |y| (QREFELT |$| 36))
                        (PROGN (LETT #1# |y| |URAGG-;findCycle|) (GO #1#))))
                    (EXIT (LETT |y| (SPADCALL |y| (QREFELT |$| 14)) |URAGG-;findCycle|)))
                  NIL
                  (GO G190)
                  G191
                  (EXIT NIL))
                  (EXIT |y|)))
                #1#
                (EXIT #1#))))))

(DEFUN |URAGG-;cycleTail;2A;18| (|x| |$|)
  (PROG (|y| |z|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL
            (LETT |y|
              (LETT |x| (SPADCALL |x| (QREFELT |$| 37)) |URAGG-;cycleTail;2A;18|)
              |URAGG-;cycleTail;2A;18|)
            (QREFELT |$| 20))
            |x|)
          ((QUOTE T)
            (SEQ
              (LETT |z| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;cycleTail;2A;18|)

```

```

(SEQ
  G190
  (COND
    ((NULL
      (COND
        ((SPADCALL |x| |z| (QREFELT |$| 36)) (QUOTE NIL))
        ((QUOTE T) (QUOTE T))))
      (GO G191)))
  (SEQ
    (LETT |y| |z| |URAGG-;cycleTail;2A;18|)
    (EXIT
      (LETT |z|
        (SPADCALL |z| (QREFELT |$| 14)) |URAGG-;cycleTail;2A;18|)))
  NIL
  (GO G190)
  G191
  (EXIT NIL))
(EXIT |y|))))))

(DEFUN |URAGG-;cycleEntry;2A;19| (|x| |$|)
  (PROG (|l| |z| |k| |y|)
    (RETURN
      (SEQ
        (COND
          ((SPADCALL |x| (QREFELT |$| 20)) |x|)
          ((SPADCALL
            (LETT |y| (|URAGG-;findCycle| |x| |$|) |URAGG-;cycleEntry;2A;19|)
            (QREFELT |$| 20))
            |y|)
            ((QUOTE T)
              (SEQ
                (LETT |z| (SPADCALL |y| (QREFELT |$| 14)) |URAGG-;cycleEntry;2A;19|)
                (SEQ
                  (LETT |l| 1 |URAGG-;cycleEntry;2A;19|)
                  G190
                  (COND
                    ((NULL
                      (COND
                        ((SPADCALL |y| |z| (QREFELT |$| 36)) (QUOTE NIL))
                        ((QUOTE T) (QUOTE T))))
                      (GO G191)))
                    (SEQ
                      (EXIT
                        (LETT |z|
                          (SPADCALL |z| (QREFELT |$| 14)) |URAGG-;cycleEntry;2A;19|)))
                      (LETT |l|
                        (QSADD1 |l|) |URAGG-;cycleEntry;2A;19|) (GO G190) G191 (EXIT NIL))
                      (LETT |y| |x| |URAGG-;cycleEntry;2A;19|)
                      (SEQ
                        (LETT |k| 1 |URAGG-;cycleEntry;2A;19|)

```

```

G190
(COND ((QSGREATERP |k| |l|) (GO G191)))
(SEQ
  (EXIT
    (LETT |y|
      (SPADCALL |y| (QREFELT |$| 14)) |URAGG-;cycleEntry;2A;19|)))
  (LETT |k| (QSADD1 |k|) |URAGG-;cycleEntry;2A;19|)
  (GO G190)
G191
(EXIT NIL))
(SEQ
  G190
  (COND
    (NULL
      (COND
        ((SPADCALL |x| |y| (QREFELT |$| 36)) (QUOTE NIL))
        ((QUOTE T) (QUOTE T))))
      (GO G191)))
  (SEQ
    (LETT |x| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;cycleEntry;2A;19|)
    (EXIT
      (LETT |y|
        (SPADCALL |y| (QREFELT |$| 14)) |URAGG-;cycleEntry;2A;19|)))
  NIL
  (GO G190)
  G191
  (EXIT NIL))
(EXIT |x|))))))

(DEFUN |URAGG-;cycleLength;ANni;20| (|x| |$|)
  (PROG (|k| |y|)
    (RETURN
      (SEQ
        (COND
          ((OR
            (SPADCALL |x| (QREFELT |$| 20))
            (SPADCALL
              (LETT |x| (|URAGG-;findCycle| |x| |$|) |URAGG-;cycleLength;ANni;20|)
              (QREFELT |$| 20)))
            0)
          ((QUOTE T)
            (SEQ
              (LETT |y| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;cycleLength;ANni;20|)
              (SEQ
                (LETT |k| 1 |URAGG-;cycleLength;ANni;20|)
                G190
                (COND
                  (NULL
                    (COND
                      ((SPADCALL |x| |y| (QREFELT |$| 36)) (QUOTE NIL))

```

```

        ((QUOTE T) (QUOTE T)))
      (GO G191)))
    (SEQ
      (EXIT
        (LETT |y|
          (SPADCALL |y| (QREFELT |$| 14)) |URAGG-;cycleLength;ANni;20|)))
      (LETT |k| (QSADD1 |k|) |URAGG-;cycleLength;ANni;20|)
      (GO G190)
      G191
      (EXIT NIL))
    (EXIT |k|)))))))))

(DEFUN |URAGG-;rest;ANniA;21| (|x| |n| |$|)
  (PROG (|i|)
    (RETURN
      (SEQ
        (SEQ
          (LETT |i| 1 |URAGG-;rest;ANniA;21|)
          G190
          (COND ((QSGREATERP |i| |n|) (GO G191)))
          (SEQ
            (EXIT
              (COND
                ((SPADCALL |x| (QREFELT |$| 20)) (|error| "Index out of range"))
                ((QUOTE T)
                  (LETT |x| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;rest;ANniA;21|))))))
          (LETT |i| (QSADD1 |i|) |URAGG-;rest;ANniA;21|)
          (GO G190)
          G191
          (EXIT NIL))
          (EXIT |x|))))))

(DEFUN |URAGG-;last;ANniA;22| (|x| |n| |$|)
  (PROG (|m| #1=#:G84694)
    (RETURN
      (SEQ
        (LETT |m| (SPADCALL |x| (QREFELT |$| 42)) |URAGG-;last;ANniA;22|)
        (EXIT
          (COND
            ((|<| |m| |n|) (|error| "index out of range"))
            ((QUOTE T)
              (SPADCALL
                (SPADCALL |x|
                  (PROG1
                    (LETT #1# (|-| |m| |n|) |URAGG-;last;ANniA;22|)
                    (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                    (QREFELT |$| 43))
                  (QREFELT |$| 44))))))))))

(DEFUN |URAGG-;=;2AB;23| (|x| |y| |$|)

```

```

(PROG (|k| #1=#:G84705)
  (RETURN
    (SEQ
      (EXIT
        (COND
          ((SPADCALL |x| |y| (QREFELT |$| 36)) (QUOTE T))
          ((QUOTE T)
            (SEQ
              (SEQ
                (LETT |k| 0 |URAGG-;=;2AB;23|)
                G190
              (COND
                ((NULL
                  (COND
                    ((OR
                      (SPADCALL |x| (QREFELT |$| 20))
                      (SPADCALL |y| (QREFELT |$| 20)))
                    (QUOTE NIL))
                  ((QUOTE T) (QUOTE T))))
                (GO G191)))
              (SEQ
                (COND
                  ((EQL |k| 1000)
                    (COND
                      ((SPADCALL |x| (QREFELT |$| 33))
                        (EXIT (|error| "cyclic list")))))
                  (COND
                    ((NULL
                      (SPADCALL
                        (SPADCALL |x| (QREFELT |$| 8))
                        (SPADCALL |y| (QREFELT |$| 8))
                        (QREFELT |$| 46)))
                      (EXIT (PROGN (LETT #1# (QUOTE NIL) |URAGG-;=;2AB;23|) (GO #1#))))
                    (LETT |x| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;=;2AB;23|)
                    (EXIT (LETT |y| (SPADCALL |y| (QREFELT |$| 14)) |URAGG-;=;2AB;23|)))
                  (LETT |k| (QSADD1 |k|) |URAGG-;=;2AB;23|)
                  (GO G190)
                  G191
                  (EXIT NIL))
                (EXIT
                  (COND
                    ((SPADCALL |x| (QREFELT |$| 20)) (SPADCALL |y| (QREFELT |$| 20)))
                    ((QUOTE T) (QUOTE NIL)))))))
          #1#
          (EXIT #1#))))))

(DEFUN |URAGG-;node?;2AB;24| (|u| |v| |$|)
  (PROG (|k| #1=#:G84711)
    (RETURN
      (SEQ

```



```

(EXIT
  (SEQ
    (SEQ
      (LETT |k| 0 |URAGG-;node?;2AB;24|)
      G190
      (COND
        ((NULL
          (COND
            ((SPADCALL |v| (QREFELT |$| 20)) (QUOTE NIL))
            ((QUOTE T) (QUOTE T))))
          (GO G191)))
      (SEQ
        (EXIT
          (COND
            ((SPADCALL |u| |v| (QREFELT |$| 48))
              (PROGN (LETT #1# (QUOTE T) |URAGG-;node?;2AB;24|) (GO #1#)))
            ((QUOTE T)
              (SEQ
                (COND
                  ((EQL |k| 1000)
                    (COND
                      ((SPADCALL |v| (QREFELT |$| 33))
                        (EXIT (|error| "cyclic list")))))
                  (EXIT
                    (LETT |v|
                      (SPADCALL |v| (QREFELT |$| 14))
                      |URAGG-;node?;2AB;24|))))))
              (LETT |k| (QSADD1 |k|) |URAGG-;node?;2AB;24|) (GO G190) G191 (EXIT NIL))
              (EXIT (SPADCALL |u| |v| (QREFELT |$| 48))))
              #1# (EXIT #1#))))))

(DEFUN |URAGG-;setelt;Afirst2S;25| (|x| G84713 |a| |$|)
  (SPADCALL |x| |a| (QREFELT |$| 50)))

(DEFUN |URAGG-;setelt;Alast2S;26| (|x| G84715 |a| |$|)
  (SPADCALL |x| |a| (QREFELT |$| 52)))

(DEFUN |URAGG-;setelt;Arest2A;27| (|x| G84717 |a| |$|)
  (SPADCALL |x| |a| (QREFELT |$| 54)))

(DEFUN |URAGG-;concat;3A;28| (|x| |y| |$|)
  (SPADCALL (SPADCALL |x| (QREFELT |$| 44)) |y| (QREFELT |$| 56)))

(DEFUN |URAGG-;setlast!;A2S;29| (|x| |s| |$|)
  (SEQ
    (COND
      ((SPADCALL |x| (QREFELT |$| 20)) (|error| "setlast: empty list"))
      ((QUOTE T)
        (SEQ
          (SPADCALL (SPADCALL |x| (QREFELT |$| 22)) |s| (QREFELT |$| 50))

```

```

(EXIT |s|))))))

(DEFUN |URAGG-;setchildren!;ALA;30| (|u| |lv| |$|)
  (COND
    ((EQL (LENGTH |lv|) 1) (SPADCALL |u| (|SPADfirst| |lv|) (QREFELT |$| 54)))
    ((QUOTE T) (|error| "wrong number of children specified"))))

(DEFUN |URAGG-;setvalue!;A2S;31| (|u| |s| |$|)
  (SPADCALL |u| |s| (QREFELT |$| 50)))

(DEFUN |URAGG-;split!;AIA;32| (|p| |n| |$|)
  (PROG (#1=#:G84725 |q|)
    (RETURN
      (SEQ
        (COND
          ((|<| |n| 1) (|error| "index out of range"))
          ((QUOTE T)
            (SEQ
              (LETT |p|
                (SPADCALL |p|
                  (PROG1
                    (LETT #1# (|<| |n| 1) |URAGG-;split!;AIA;32|)
                    (|check-subtype| (|>=| #1# 0) (QUOTE (|NonNegativeInteger|)) #1#))
                    (QREFELT |$| 43))
                  |URAGG-;split!;AIA;32|)
                (LETT |q| (SPADCALL |p| (QREFELT |$| 14)) |URAGG-;split!;AIA;32|)
                (SPADCALL |p| (SPADCALL (QREFELT |$| 61)) (QREFELT |$| 54))
                (EXIT |q|))))))))))

(DEFUN |URAGG-;cycleSplit!;2A;33| (|x| |$|)
  (PROG (|y| |z|)
    (RETURN
      (SEQ
        (COND
          ((OR
            (SPADCALL
              (LETT |y| (SPADCALL |x| (QREFELT |$| 37)) |URAGG-;cycleSplit!;2A;33|)
              (QREFELT |$| 20))
            (SPADCALL |x| |y| (QREFELT |$| 36))) |y|)
          ((QUOTE T)
            (SEQ
              (LETT |z| (SPADCALL |x| (QREFELT |$| 14)) |URAGG-;cycleSplit!;2A;33|)
              (SEQ G190
                (COND
                  ((NULL
                    (COND
                      ((SPADCALL |z| |y| (QREFELT |$| 36)) (QUOTE NIL))
                      ((QUOTE T) (QUOTE T))))
                  (GO G191)))
                (SEQ

```

```

(LETT |x| |z| |URAGG-;cycleSplit!;2A;33|)
(EXIT
  (LETT |z|
    (SPADCALL |z| (QREFELT |$| 14)) |URAGG-;cycleSplit!;2A;33|)))
NIL
(GO G190)
G191
(EXIT NIL))
(SPADCALL |x|
  (SPADCALL (QREFELT |$| 61)) (QREFELT |$| 54)) (EXIT |y|))))))

(DEFUN |UnaryRecursiveAggregate&| (|#1| |#2|)
  (PROG (|DV$1| |DV$2| |dv$| |$| |pv$|)
    (RETURN
      (PROGN
        (LETT |DV$1| (|devaluate| |#1|) . #1=(|UnaryRecursiveAggregate&|))
        (LETT |DV$2| (|devaluate| |#2|) . #1#)
        (LETT |dv$| (LIST (QUOTE |UnaryRecursiveAggregate&|) |DV$1| |DV$2|) . #1#)
        (LETT |$| (make-array 66) . #1#)
        (QSETREFV |$| 0 |dv$|)
        (QSETREFV |$| 3
          (LETT |pv$|
            (|buildPredVector| 0 0
              (LIST (|HasAttribute| |#1| (QUOTE |shallowlyMutable|)))
                . #1#))
            (|stuffDomainSlots| |$|)
            (QSETREFV |$| 6 |#1|)
            (QSETREFV |$| 7 |#2|)
            (COND
              ((|HasAttribute| |#1| (QUOTE |finiteAggregate|))
                (QSETREFV |$| 45
                  (CONS (|dispatchFunction| |URAGG-;last;ANniA;22|) |$|))))
              (COND
                ((|HasCategory| |#2| (QUOTE (|SetCategory|)))
                  (PROGN
                    (QSETREFV |$| 47 (CONS (|dispatchFunction| |URAGG-;=;2AB;23|) |$|))
                    (QSETREFV |$| 49
                      (CONS (|dispatchFunction| |URAGG-;node?;2AB;24|) |$|))))
                  (COND
                    ((|testBitVector| |pv$| 1)
                      (PROGN
                        (QSETREFV |$| 51
                          (CONS (|dispatchFunction| |URAGG-;setelt;Afirst2S;25|) |$|))
                        (QSETREFV |$| 53
                          (CONS (|dispatchFunction| |URAGG-;setelt;Alast2S;26|) |$|))
                        (QSETREFV |$| 55
                          (CONS (|dispatchFunction| |URAGG-;setelt;Arest2A;27|) |$|))
                        (QSETREFV |$| 57
                          (CONS (|dispatchFunction| |URAGG-;concat;3A;28|) |$|))
                        (QSETREFV |$| 58
```

```

(CONS (|dispatchFunction| |URAGG-;setlast!;A2S;29|) |$|))
(QSETREFV |$| 59
(CONS (|dispatchFunction| |URAGG-;setchildren!;ALA;30|) |$|))
(QSETREFV |$| 60
(CONS (|dispatchFunction| |URAGG-;setvalue!;A2S;31|) |$|))
(QSETREFV |$| 63
(CONS (|dispatchFunction| |URAGG-;split!;AIA;32|) |$|))
(QSETREFV |$| 64
(CONS (|dispatchFunction| |URAGG-;cycleSplit!;2A;33|) |$|))))))
|$|))))

(setf (get
(QUOTE |UnaryRecursiveAggregate&|)
(QUOTE |infovec|))
(LIST
(QUOTE #(NIL NIL NIL NIL NIL NIL (|local| |#1|) (|local| |#2|)
(0 . |first|) (QUOTE "first") |URAGG-;elt;AfirstS;1| (5 . |last|)
(QUOTE "last") |URAGG-;elt;AlastS;2| (10 . |rest|) (QUOTE "rest")
|URAGG-;elt;ArestA;3| |URAGG-;second;AS;4| |URAGG-;third;AS;5|
(|Boolean|) (15 . |empty?|) |URAGG-;cyclic?;AB;6| (20 . |tail|)
|URAGG-;last;AS;7| (|List| |$|) |URAGG-;nodes;AL;8|
|URAGG-;children;AL;9| |URAGG-;leaf?;AB;10| |URAGG-;value;AS;11|
(|NonNegativeInteger|) |URAGG-;less?;ANniB;12| |URAGG-;more?;ANniB;13|
|URAGG-;size?;ANniB;14| (25 . |cyclic?|) |URAGG-;#;ANni;15|
|URAGG-;tail;2A;16| (30 . |eq?|) (36 . |cycleEntry|)
|URAGG-;cycleTail;2A;18| |URAGG-;cycleEntry;2A;19|
|URAGG-;cycleLength;ANni;20| |URAGG-;rest;ANniA;21| (41 . |#|)
(46 . |rest|) (52 . |copy|) (57 . |last|) (63 . |=|) (69 . |=|)
(75 . |=|) (81 . |node?|) (87 . |setfirst!|) (93 . |setelt|)
(100 . |setlast!|) (106 . |setelt|) (113 . |setrest!|)
(119 . |setelt|) (126 . |concat!|) (132 . |concat|) (138 . |setlast!|)
(144 . |setchildren!|) (150 . |setvalue!|) (156 . |empty|) (|Integer|)
(160 . |split!|) (166 . |cycleSplit!|) (QUOTE "value"))))
(QUOTE #( |value| 171 |third| 176 |tail| 181 |split!| 186 |size?| 192
|setvalue!| 198 |setlast!| 204 |setelt| 210 |setchildren!| 231 |second|
237 |rest| 242 |nodes| 248 |node?| 253 |more?| 259 |less?| 265 |leaf?|
271 |last| 276 |elt| 287 |cyclic?| 305 |cycleTail| 310 |cycleSplit!|
315 |cycleLength| 320 |cycleEntry| 325 |concat| 330 |children| 336 |=|
341 |#| 347)))
(QUOTE NIL)
(CONS
(|makeByteWordVec2| 1 (QUOTE NIL))
(CONS
(QUOTE #())
(CONS
(QUOTE #())
(|makeByteWordVec2| 64 (QUOTE (1 6 7 0 8 1 6 7 0 11 1 6 0 0 14 1 6
19 0 20 1 6 0 0 22 1 6 19 0 33 2 6 19 0 0 36 1 6 0 0 37 1 6 29 0
42 2 6 0 0 29 43 1 6 0 0 44 2 0 0 0 29 45 2 7 19 0 0 46 2 0 19 0
0 47 2 6 19 0 0 48 2 0 19 0 0 49 2 6 7 0 7 50 3 0 7 0 9 7 51 2 6

```

```

7 0 7 52 3 0 7 0 12 7 53 2 6 0 0 0 54 3 0 0 0 15 0 55 2 6 0 0 0 56
2 0 0 0 0 57 2 0 7 0 7 58 2 0 0 0 24 59 2 0 7 0 7 60 0 6 0 61 2 0
0 0 62 63 1 0 0 0 64 1 0 7 0 28 1 0 7 0 18 1 0 0 0 35 2 0 0 0 62 63
2 0 19 0 29 32 2 0 7 0 7 60 2 0 7 0 7 58 3 0 7 0 12 7 53 3 0 0 0 15
0 55 3 0 7 0 9 7 51 2 0 0 0 24 59 1 0 7 0 17 2 0 0 0 29 41 1 0 24 0
25 2 0 19 0 0 49 2 0 19 0 29 31 2 0 19 0 29 30 1 0 19 0 27 2 0 0 0
29 45 1 0 7 0 23 2 0 7 0 12 13 2 0 0 0 15 16 2 0 7 0 9 10 1 0 19 0
21 1 0 0 0 38 1 0 0 0 64 1 0 29 0 40 1 0 0 0 39 2 0 0 0 0 57 1 0 24
0 26 2 0 19 0 0 47 1 0 29 0 34))))))
(QUOTE |lookupComplete|))

```

Chapter 22

Chunk collections

— algebra —

```
\getchunk{category ABELGRP AbelianGroup}  
\getchunk{category ABELMON AbelianMonoid}  
\getchunk{category AMR AbelianMonoidRing}  
\getchunk{category ABELSG AbelianSemiGroup}  
\getchunk{category AGG Aggregate}  
\getchunk{category ALGEBRA Algebra}  
\getchunk{category ACF AlgebraicallyClosedField}  
\getchunk{category ACFS AlgebraicallyClosedFunctionSpace}  
\getchunk{category ATADDVA AdditiveValuationAttribute}  
\getchunk{category ATAPPRO ApproximateAttribute}  
\getchunk{category ATARBEX ArbitraryExponentAttribute}  
\getchunk{category ATARBPR ArbitraryPrecisionAttribute}  
\getchunk{category AHYP ArcHyperbolicFunctionCategory}  
\getchunk{category ATRIG ArcTrigonometricFunctionCategory}  
\getchunk{category ALAGG AssociationListAggregate}  
\getchunk{category ATTREG AttributeRegistry}  
  
\getchunk{category BGAGG BagAggregate}  
\getchunk{category BATYPE BasicType}  
\getchunk{category BLMETCT BlowUpMethodCategory}  
\getchunk{category BMODULE BiModule}  
\getchunk{category BRAGG BinaryRecursiveAggregate}  
\getchunk{category BTCAT BinaryTreeCategory}  
\getchunk{category BTAGG BitAggregate}  
  
\getchunk{category CACHSET CachableView}  
\getchunk{category CABMON CancellationAbelianMonoid}  
\getchunk{category ATCANON CanonicalAttribute}  
\getchunk{category ATCANCL CanonicalClosedAttribute}
```

```

\getchunk{category ATCUNOR CanonicalUnitNormalAttribute}
\getchunk{category ATCENRL CentralAttribute}
\getchunk{category CHARNZ CharacteristicNonZero}
\getchunk{category CHARZ CharacteristicZero}
\getchunk{category KOERCE CoercibleTo}
\getchunk{category CLAGG Collection}
\getchunk{category CFCAT CombinatorialFunctionCategory}
\getchunk{category COMBOPC CombinatorialOpsCategory}
\getchunk{category ATCS CommutativeStarAttribute}
\getchunk{category COMPAR Comparable}
\getchunk{category COMRING CommutativeRing}
\getchunk{category COMPCAT ComplexCategory}
\getchunk{category KONVERT ConvertibleTo}

\getchunk{category DQAGG DequeueAggregate}
\getchunk{category DSTRCAT DesingTreeCategory}
\getchunk{category DIAGG Dictionary}
\getchunk{category DIOPS DictionaryOperations}
\getchunk{category DIFEXT DifferentialExtension}
\getchunk{category DPOLCAT DifferentialPolynomialCategory}
\getchunk{category DIFRING DifferentialRing}
\getchunk{category DIVCAT DivisorCategory}
\getchunk{category DVARCAT DifferentialVariableCategory}
\getchunk{category DIRPCAT DirectProductCategory}
\getchunk{category DIVRING DivisionRing}
\getchunk{category DLAGG DoublyLinkedAggregate}

\getchunk{category ELEMFUN ElementaryFunctionCategory}
\getchunk{category ELTAB Eltable}
\getchunk{category ELTAGG EltableAggregate}
\getchunk{category ENTIRER EntireRing}
\getchunk{category EUCDOM EuclideanDomain}
\getchunk{category EVALAB Evalable}
\getchunk{category ES ExpressionSpace}
\getchunk{category ELAGG ExtensibleLinearAggregate}
\getchunk{category XF ExtensionField}

\getchunk{category FIELD Field}
\getchunk{category FPC FieldOfPrimeCharacteristic}
\getchunk{category FILECAT FileCategory}
\getchunk{category FNCAT FileNameCategory}
\getchunk{category FINITE Finite}
\getchunk{category FAMR FiniteAbelianMonoidRing}
\getchunk{category ATFINAG FiniteAggregateAttribute}
\getchunk{category FAXF FiniteAlgebraicExtensionField}
\getchunk{category FDIVCAT FiniteDivisorCategory}
\getchunk{category FFIELD FiniteFieldCategory}
\getchunk{category FLAGG FiniteLinearAggregate}
\getchunk{category FINRANG FiniteRankAlgebra}
\getchunk{category FINAALG FiniteRankNonAssociativeAlgebra}

```

```

\getchunk{category FSAGG FiniteSetAggregate}
\getchunk{category FPS FloatingPointSystem}
\getchunk{category FORTFN FortranFunctionCategory}
\getchunk{category FMTC FortranMachineTypeCategory}
\getchunk{category FMC FortranMatrixCategory}
\getchunk{category FMFUN FortranMatrixFunctionCategory}
\getchunk{category FORTCAT FortranProgramCategory}
\getchunk{category FVC FortranVectorCategory}
\getchunk{category FVFUN FortranVectorFunctionCategory}
\getchunk{category FRAMALG FramedAlgebra}
\getchunk{category FRNAALG FramedNonAssociativeAlgebra}
\getchunk{category FAMONC FreeAbelianMonoidCategory}
\getchunk{category FLALG FreeLieAlgebra}
\getchunk{category FMCAT FreeModuleCat}
\getchunk{category FEVALAB FullyEvaluableOver}
\getchunk{category FLINEXP FullyLinearlyExplicitRingOver}
\getchunk{category FPATMAB FullyPatternMatchable}
\getchunk{category FRETRCT FullyRetractableTo}
\getchunk{category FFCAT FunctionFieldCategory}
\getchunk{category FS FunctionSpace}

\getchunk{category GCDDOM GcdDomain}
\getchunk{category GRALG GradedAlgebra}
\getchunk{category GRMOD GradedModule}
\getchunk{category GROUP Group}

\getchunk{category HOAGG HomogeneousAggregate}
\getchunk{category HYPCAT HyperbolicFunctionCategory}

\getchunk{category IXAGG IndexedAggregate}
\getchunk{category IDPC IndexedDirectProductCategory}
\getchunk{category INFCLCT InfinitelyClosePointCategory}
\getchunk{category IEVALAB InnerEvaluable}
\getchunk{category INS IntegerNumberSystem}
\getchunk{category INTDOM IntegralDomain}
\getchunk{category INTCAT IntervalCategory}

\getchunk{category ATJACID JacobiIdentityAttribute}

\getchunk{category KDAGG KeyedDictionary}

\getchunk{category ATLR LazyRepresentationAttribute}
\getchunk{category LZSTAGG LazyStreamAggregate}
\getchunk{category LALG LeftAlgebra}
\getchunk{category LMODULE LeftModule}
\getchunk{category ATLUNIT LeftUnitaryAttribute}
\getchunk{category LIECAT LieAlgebra}
\getchunk{category LNAGG LinearAggregate}
\getchunk{category LINEXP LinearlyExplicitRingOver}
\getchunk{category LODOCAT LinearOrdinaryDifferentialOperatorCategory}

```



```

\getchunk{category LFCAT LiouvillianFunctionCategory}
\getchunk{category LSAGG ListAggregate}
\getchunk{category LOCPOWC LocalPowerSeriesCategory}
\getchunk{category LOGIC Logic}

\getchunk{category MATCAT MatrixCategory}
\getchunk{category MODULE Module}
\getchunk{category MONAD Monad}
\getchunk{category MONADWU MonadWithUnit}
\getchunk{category MONOGEN MonogenicAlgebra}
\getchunk{category MLO MonogenicLinearOperator}
\getchunk{category MONOID Monoid}
\getchunk{category MDAGG MultiDictionary}
\getchunk{category ATMULVA MultiplicativeValuationAttribute}
\getchunk{category MSETAGG MultisetAggregate}
\getchunk{category MTSCAT MultivariateTaylorSeriesCategory}

\getchunk{category NAALG NonAssociativeAlgebra}
\getchunk{category NASRING NonAssociativeRing}
\getchunk{category NARNG NonAssociativeRng}
\getchunk{category NTSCAT NormalizedTriangularSetCategory}
\getchunk{category ATNOTHR NotherianAttribute}
\getchunk{category ATNZDIV NoZeroDivisorsAttribute}
\getchunk{category ATNULSQ NullSquareAttribute}
\getchunk{category NUMINT NumericalIntegrationCategory}
\getchunk{category OPTCAT NumericalOptimizationCategory}

\getchunk{category OC OctonionCategory}
\getchunk{category A1AGG OneDimensionalArrayAggregate}
\getchunk{category OM OpenMath}
\getchunk{category OAGROUP OrderedAbelianGroup}
\getchunk{category OAMON OrderedAbelianMonoid}
\getchunk{category OAMONS OrderedAbelianMonoidSup}
\getchunk{category OASGP OrderedAbelianSemiGroup}
\getchunk{category OCAMON OrderedCancellationAbelianMonoid}
\getchunk{category ORDFIN OrderedFinite}
\getchunk{category OINTDOM OrderedIntegralDomain}
\getchunk{category ORDMON OrderedMonoid}
\getchunk{category OMSAGG OrderedMultisetAggregate}
\getchunk{category ORDRING OrderedRing}
\getchunk{category ORDSET OrderedSet}
\getchunk{category ODECAT OrdinaryDifferentialEquationsSolverCategory}

\getchunk{category PADICCT PAdicIntegerCategory}
\getchunk{category PDECAT PartialDifferentialEquationsSolverCategory}
\getchunk{category PDRING PartialDifferentialRing}
\getchunk{category ATPOSET PartiallyOrderedSetAttribute}
\getchunk{category PTRANFN PartialTranscendentalFunctions}
\getchunk{category PATAB Patternable}
\getchunk{category PATMAB PatternMatchable}

```

```

\getchunk{category PERMCAT PermutationCategory}
\getchunk{category PLACESC PlacesCategory}
\getchunk{category PPCURVE PlottablePlaneCurveCategory}
\getchunk{category PSCURVE PlottableSpaceCurveCategory}
\getchunk{category PTCAT PointCategory}
\getchunk{category POLYCAT PolynomialCategory}
\getchunk{category PFECAT PolynomialFactorizationExplicit}
\getchunk{category PSETCAT PolynomialSetCategory}
\getchunk{category PSCAT PowerSeriesCategory}
\getchunk{category PRIMCAT PrimitiveFunctionCategory}
\getchunk{category PID PrincipalIdealDomain}
\getchunk{category PRQAGG PriorityQueueAggregate}
\getchunk{category PRSPCAT ProjectiveSpaceCategory}
\getchunk{category PACEXTC PseudoAlgebraicClosureOfAlgExtOfRationalNumberCategory}
\getchunk{category PACFFC PseudoAlgebraicClosureOfFiniteFieldCategory}
\getchunk{category PACPERC PseudoAlgebraicClosureOfPerfectFieldCategory}
\getchunk{category PACRATC PseudoAlgebraicClosureOfRationalNumberCategory}

\getchunk{category QUATCAT QuaternionCategory}
\getchunk{category QUAGG QueueAggregate}
\getchunk{category QFCAT QuotientFieldCategory}

\getchunk{category RADCAT RadicalCategory}
\getchunk{category RCFIELD RealClosedField}
\getchunk{category REAL RealConstant}
\getchunk{category RNS RealNumberSystem}
\getchunk{category RRCC RealRootCharacterizationCategory}
\getchunk{category RMATCAT RectangularMatrixCategory}
\getchunk{category RCAGG RecursiveAggregate}
\getchunk{category RPOLCAT RecursivePolynomialCategory}
\getchunk{category RSETCAT RegularTriangularSetCategory}
\getchunk{category RETRACT RetractableTo}
\getchunk{category ATRUNIT RightUnitaryAttribute}
\getchunk{category RMODULE RightModule}
\getchunk{category RING Ring}
\getchunk{category RNG Rng}

\getchunk{category SEGCAT SegmentCategory}
\getchunk{category SEGXCAT SegmentExpansionCategory}
\getchunk{category SGROUP SemiGroup}
\getchunk{category SETAGG SetAggregate}
\getchunk{category SETCAT SetCategory}
\getchunk{category SETCATD SetCategoryWithDegree}
\getchunk{category SEXCAT SExpressionCategory}
\getchunk{category ATSHMUT ShallowlyMutableAttribute}
\getchunk{category SPFCAT SpecialFunctionCategory}
\getchunk{category SNTSCAT SquareFreeNormalizedTriangularSetCategory}
\getchunk{category SFRTCAT SquareFreeRegularTriangularSetCategory}
\getchunk{category SMATCAT SquareMatrixCategory}
\getchunk{category SKAGG StackAggregate}

```

```

\getchunk{category STEP StepThrough}
\getchunk{category STAGG StreamAggregate}
\getchunk{category SRAGG StringAggregate}
\getchunk{category STRICAT StringCategory}

\getchunk{category TBAGG TableAggregate}
\getchunk{category SPACEC ThreeSpaceCategory}
\getchunk{category TSETCAT TriangularSetCategory}
\getchunk{category TRIGCAT TrigonometricFunctionCategory}
\getchunk{category TRANFUN TranscendentalFunctionCategory}
\getchunk{category ARR2CAT TwoDimensionalArrayCategory}
\getchunk{category TYPE Type}

\getchunk{category URAGG UnaryRecursiveAggregate}
\getchunk{category UFD UniqueFactorizationDomain}
\getchunk{category ATUNIKN UnitsKnownAttribute}
\getchunk{category ULSCAT UnivariateLaurentSeriesCategory}
\getchunk{category ULSCCAT UnivariateLaurentSeriesConstructorCategory}
\getchunk{category UPOLYC UnivariatePolynomialCategory}
\getchunk{category UPSCAT UnivariatePowerSeriesCategory}
\getchunk{category UPXSCAT UnivariatePuisseuxSeriesCategory}
\getchunk{category UPXSCCA UnivariatePuisseuxSeriesConstructorCategory}
\getchunk{category OREPCAT UnivariateSkewPolynomialCategory}
\getchunk{category UTSCAT UnivariateTaylorSeriesCategory}

\getchunk{category VECTCAT VectorCategory}
\getchunk{category VSPACE VectorSpace}

\getchunk{category XALG XAlgebra}
\getchunk{category XFALG XFreeAlgebra}
\getchunk{category XPOLYC XPolynomialsCat}

```

— dotabb —

```

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  bgcolor="#ECEA81";
  node [shape=box, color=white, style=filled];

\getchunk{CATEGORY.dotabb}
\getchunk{A1AGG.dotabb}
\getchunk{ABELGRP.dotabb}
\getchunk{ABELMON.dotabb}
\getchunk{ABELSG.dotabb}
\getchunk{ACF.dotabb}
\getchunk{ACFS.dotabb}
\getchunk{AGG.dotabb}

```

\getchunk{AHYP.dotabb}
\getchunk{ALAGG.dotabb}
\getchunk{ALGEBRA.dotabb}
\getchunk{AMR.dotabb}
\getchunk{ARR2CAT.dotabb}
\getchunk{ATADDVA.dotabb}
\getchunk{ATAPPRO.dotabb}
\getchunk{ATARBEX.dotabb}
\getchunk{ATARBPR.dotabb}
\getchunk{ATCANCL.dotabb}
\getchunk{ATCANON.dotabb}
\getchunk{ATCENRL.dotabb}
\getchunk{ATCS.dotabb}
\getchunk{ATCUNOR.dotabb}
\getchunk{ATFINAG.dotabb}
\getchunk{ATJACID.dotabb}
\getchunk{ATLUNIT.dotabb}
\getchunk{ATLR.dotabb}
\getchunk{ATMULVA.dotabb}
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\getchunk{ATNULSQ.dotabb}
\getchunk{ATNZDIV.dotabb}
\getchunk{ATPOSET.dotabb}
\getchunk{ATRIG.dotabb}
\getchunk{ATRUNIT.dotabb}
\getchunk{ATSHMUT.dotabb}
\getchunk{ATTREG.dotabb}
\getchunk{ATUNIKN.dotabb}
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\getchunk{BLMETCT.dotabb}
\getchunk{BMODULE.dotabb}
\getchunk{BRAGG.dotabb}
\getchunk{BTAGG.dotabb}
\getchunk{BTCAT.dotabb}
\getchunk{CABMON.dotabb}
\getchunk{CACHSET.dotabb}
\getchunk{CFCAT.dotabb}
\getchunk{CHARNZ.dotabb}
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\getchunk{CLAGG.dotabb}
\getchunk{COMBOPC.dotabb}
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\getchunk{COMPCAT.dotabb}
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\getchunk{DIAGG.dotabb}
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\getchunk{DIFRING.dotabb}
\getchunk{DIOPS.dotabb}
\getchunk{DIRPCAT.dotabb}

```
\getchunk{DIVCAT.dotabb}  
\getchunk{DIVRING.dotabb}  
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\getchunk{DPOLCAT.dotabb}  
\getchunk{DQAGG.dotabb}  
\getchunk{DSTRCAT.dotabb}  
\getchunk{DVARCAT.dotabb}  
\getchunk{ELAGG.dotabb}  
\getchunk{ELEMFUN.dotabb}  
\getchunk{ELTAB.dotabb}  
\getchunk{ELTAGG.dotabb}  
\getchunk{ENTIRER.dotabb}  
\getchunk{ES.dotabb}  
\getchunk{EUCDOM.dotabb}  
\getchunk{EVALAB.dotabb}  
\getchunk{FAMONC.dotabb}  
\getchunk{FAMR.dotabb}  
\getchunk{FAXF.dotabb}  
\getchunk{FDIVCAT.dotabb}  
\getchunk{FEVALAB.dotabb}  
\getchunk{FFCAT.dotabb}  
\getchunk{FFIELDC.dotabb}  
\getchunk{FIELD.dotabb}  
\getchunk{FILECAT.dotabb}  
\getchunk{FINAALG.dotabb}  
\getchunk{FINITE.dotabb}  
\getchunk{FINRALG.dotabb}  
\getchunk{FLAGG.dotabb}  
\getchunk{FLALG.dotabb}  
\getchunk{FLINEXP.dotabb}  
\getchunk{FMC.dotabb}  
\getchunk{FMCAT.dotabb}  
\getchunk{FMFUN.dotabb}  
\getchunk{FMTC.dotabb}  
\getchunk{FNCAT.dotabb}  
\getchunk{FORTCAT.dotabb}  
\getchunk{FORTFN.dotabb}  
\getchunk{FPATMAB.dotabb}  
\getchunk{FPC.dotabb}  
\getchunk{FPS.dotabb}  
\getchunk{FRAMALG.dotabb}  
\getchunk{FRETRCT.dotabb}  
\getchunk{FRNAALG.dotabb}  
\getchunk{FS.dotabb}  
\getchunk{FSAGG.dotabb}  
\getchunk{FVC.dotabb}  
\getchunk{FVFUN.dotabb}  
\getchunk{GCDDOM.dotabb}  
\getchunk{GRALG.dotabb}  
\getchunk{GRMOD.dotabb}
```

```
\getchunk{GROUP.dotabb}  
\getchunk{HOAGG.dotabb}  
\getchunk{HYPCAT.dotabb}  
\getchunk{IDPC.dotabb}  
\getchunk{INFCLCT.dotabb}  
\getchunk{IEVALAB.dotabb}  
\getchunk{INS.dotabb}  
\getchunk{INTCAT.dotabb}  
\getchunk{INTDOM.dotabb}  
\getchunk{IXAGG.dotabb}  
\getchunk{KDAGG.dotabb}  
\getchunk{KOERCE.dotabb}  
\getchunk{KONVERT.dotabb}  
\getchunk{LALG.dotabb}  
\getchunk{LFCAT.dotabb}  
\getchunk{LIECAT.dotabb}  
\getchunk{LINEXP.dotabb}  
\getchunk{LMODULE.dotabb}  
\getchunk{LNAGG.dotabb}  
\getchunk{LODOCAT.dotabb}  
\getchunk{LOGIC.dotabb}  
\getchunk{LSAGG.dotabb}  
\getchunk{LZSTAGG.dotabb}  
\getchunk{MAGCDOC.dotabb}  
\getchunk{MATCAT.dotabb}  
\getchunk{MDAGG.dotabb}  
\getchunk{MLO.dotabb}  
\getchunk{MODULE.dotabb}  
\getchunk{MONAD.dotabb}  
\getchunk{MONADWU.dotabb}  
\getchunk{MONOGEN.dotabb}  
\getchunk{MONOID.dotabb}  
\getchunk{MSETAGG.dotabb}  
\getchunk{MTSCAT.dotabb}  
\getchunk{NAALG.dotabb}  
\getchunk{NARNG.dotabb}  
\getchunk{NASRING.dotabb}  
\getchunk{NTSCAT.dotabb}  
\getchunk{NUMINT.dotabb}  
\getchunk{OAGROUP.dotabb}  
\getchunk{OAMON.dotabb}  
\getchunk{OAMONS.dotabb}  
\getchunk{OASGP.dotabb}  
\getchunk{OC.dotabb}  
\getchunk{OCAMON.dotabb}  
\getchunk{ODECAT.dotabb}  
\getchunk{OINTDOM.dotabb}  
\getchunk{OM.dotabb}  
\getchunk{OMSAGG.dotabb}  
\getchunk{OPTCAT.dotabb}
```

```
\getchunk{ORDFIN.dotabb}  
\getchunk{ORDMON.dotabb}  
\getchunk{ORDRING.dotabb}  
\getchunk{ORDSET.dotabb}  
\getchunk{OREPCAT.dotabb}  
\getchunk{PACFFC.dotabb}  
\getchunk{PACPERC.dotabb}  
\getchunk{PACRATC.dotabb}  
\getchunk{PADICCT.dotabb}  
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\getchunk{PATMAB.dotabb}  
\getchunk{PDECAT.dotabb}  
\getchunk{PDRING.dotabb}  
\getchunk{PERMCAT.dotabb}  
\getchunk{PFECAT.dotabb}  
\getchunk{PID.dotabb}  
\getchunk{PLACESC.dotabb}  
\getchunk{POLYCAT.dotabb}  
\getchunk{PPCURVE.dotabb}  
\getchunk{PRIMCAT.dotabb}  
\getchunk{PRQAGG.dotabb}  
\getchunk{PRSPCAT.dotabb}  
\getchunk{PSCAT.dotabb}  
\getchunk{PSCURVE.dotabb}  
\getchunk{PSETCAT.dotabb}  
\getchunk{PTCAT.dotabb}  
\getchunk{PTRANFN.dotabb}  
\getchunk{QFCAT.dotabb}  
\getchunk{QUAGG.dotabb}  
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\getchunk{RADCAT.dotabb}  
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\getchunk{RMODULE.dotabb}  
\getchunk{RNG.dotabb}  
\getchunk{RNS.dotabb}  
\getchunk{RPOLCAT.dotabb}  
\getchunk{RRCC.dotabb}  
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\getchunk{SEGCAT.dotabb}  
\getchunk{SEGXCAT.dotabb}  
\getchunk{SETAGG.dotabb}  
\getchunk{SETCAT.dotabb}  
\getchunk{SETCATD.dotabb}  
\getchunk{SEXCAT.dotabb}  
\getchunk{SFRTCAT.dotabb}
```

```

\getchunk{SGROUP.dotabb}
\getchunk{SKAGG.dotabb}
\getchunk{SMATCAT.dotabb}
\getchunk{SNTSCAT.dotabb}
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\getchunk{SRAGG.dotabb}
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\getchunk{STRICAT.dotabb}
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\getchunk{TSETCAT.dotabb}
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\getchunk{UPXSCCA.dotabb}
\getchunk{URAGG.dotabb}
\getchunk{UTSCAT.dotabb}
\getchunk{VECTCAT.dotabb}
\getchunk{VSPACE.dotabb}
\getchunk{XALG.dotabb}
\getchunk{XF.dotabb}
\getchunk{XFALG.dotabb}
\getchunk{XPOLYC.dotabb}
}

```

— dotfull —

```

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  node [shape=box, color=white, style=filled];

\getchunk{CATEGORY.dotfull}
\getchunk{A1AGG.dotfull}
\getchunk{ABELGRP.dotfull}
\getchunk{ABELMON.dotfull}
\getchunk{ABELSG.dotfull}
\getchunk{ACF.dotfull}

```



```
\getchunk{ACFS.dotfull}  
\getchunk{AGG.dotfull}  
\getchunk{AHYP.dotfull}  
\getchunk{ALAGG.dotfull}  
\getchunk{ALGEBRA.dotfull}  
\getchunk{AMR.dotfull}  
\getchunk{ARR2CAT.dotfull}  
\getchunk{ATADDVA.dotfull}  
\getchunk{ATAPPRO.dotfull}  
\getchunk{ATARBEX.dotfull}  
\getchunk{ATARBPR.dotfull}  
\getchunk{ATCANCL.dotfull}  
\getchunk{ATCANON.dotfull}  
\getchunk{ATCENRL.dotfull}  
\getchunk{ATCS.dotfull}  
\getchunk{ATCUNOR.dotfull}  
\getchunk{ATFINAG.dotfull}  
\getchunk{ATJACID.dotfull}  
\getchunk{ATLUNIT.dotfull}  
\getchunk{ATLR.dotfull}  
\getchunk{ATMULVA.dotfull}  
\getchunk{ATNOTHR.dotfull}  
\getchunk{ATNULSQ.dotfull}  
\getchunk{ATNZDIV.dotfull}  
\getchunk{ATPOSET.dotfull}  
\getchunk{ATRIG.dotfull}  
\getchunk{ATRUNIT.dotfull}  
\getchunk{ATSHMUT.dotfull}  
\getchunk{ATTREG.dotfull}  
\getchunk{ATUNIKN.dotfull}  
\getchunk{BASTYPE.dotfull}  
\getchunk{BGAGG.dotfull}  
\getchunk{BLMETCT.dotfull}  
\getchunk{BMODULE.dotfull}  
\getchunk{BRAGG.dotfull}  
\getchunk{BTAGG.dotfull}  
\getchunk{BTCAT.dotfull}  
\getchunk{CABMON.dotfull}  
\getchunk{CACHSET.dotfull}  
\getchunk{CFCAT.dotfull}  
\getchunk{CHARNZ.dotfull}  
\getchunk{CHARZ.dotfull}  
\getchunk{CLAGG.dotfull}  
\getchunk{COMBOPC.dotfull}  
\getchunk{COMPAR.dotfull}  
\getchunk{COMPCAT.dotfull}  
\getchunk{COMRING.dotfull}  
\getchunk{DIAGG.dotfull}  
\getchunk{DIFEXT.dotfull}  
\getchunk{DIFRING.dotfull}
```

```
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\getchunk{DIRPCAT.dotfull}  
\getchunk{DIVCAT.dotfull}  
\getchunk{DIVRING.dotfull}  
\getchunk{DLAGG.dotfull}  
\getchunk{DPOLCAT.dotfull}  
\getchunk{DQAGG.dotfull}  
\getchunk{DSTRCAT.dotfull}  
\getchunk{DVARCAT.dotfull}  
\getchunk{ELAGG.dotfull}  
\getchunk{ELEMFUN.dotfull}  
\getchunk{ELTAB.dotfull}  
\getchunk{ELTAGG.dotfull}  
\getchunk{ENTIRER.dotfull}  
\getchunk{ES.dotfull}  
\getchunk{EUCDOM.dotfull}  
\getchunk{EVALAB.dotfull}  
\getchunk{FAMONC.dotfull}  
\getchunk{FAMR.dotfull}  
\getchunk{FAXF.dotfull}  
\getchunk{FDIVCAT.dotfull}  
\getchunk{FEVALAB.dotfull}  
\getchunk{FFCAT.dotfull}  
\getchunk{FFIELDC.dotfull}  
\getchunk{FIELD.dotfull}  
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