Parents and Elements

Release 9.6

The Sage Development Team

May 16, 2022
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1.1 Abstract base class for Sage objects

class sage.structure.sage_object.SageObject
    Bases: object
    Base class for all (user-visible) objects in Sage
    Every object that can end up being returned to the user should inherit from SageObject.
    _ascii_art_()
        Return an ASCII art representation.
        To implement multi-line ASCII art output in a derived class you must override this method. Unlike _repr_(), which is sometimes used for the hash key, the output of _ascii_art_() may depend on settings and is allowed to change during runtime.
        OUTPUT:
        An AsciiArt object, see sage.typeset.ascii_art for details.
    EXAMPLES:
    You can use the ascii_art() function to get the ASCII art representation of any object in Sage:

    sage: result = ascii_art(integral(exp(x+x^2)/(x+1), x))
    ...  
    sage: result
    / 
    | 2  
    |  x + x  
    | e  
    | ----- dx  
    | x + 1  
    /  

    Alternatively, you can use the %display ascii_art/simple magic to switch all output to ASCII art and back:

        sage: from sage.repl.interpreter import get_test_shell
        sage: shell = get_test_shell()
        sage: shell.run_cell('tab = StandardTableaux(3)[2]; tab')
        [[1, 2], [3]]
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```python
sage: shell.run_cell('%display ascii_art')
sage: shell.run_cell('tab')
1 2
3
sage: shell.run_cell('Tableaux.options(ascii_art="table", convention="French")')
sage: shell.run_cell('tab')
+---+
| 3 |
+----+
| 1 2 |
+----+

sage: shell.run_cell('%display plain')
sage: shell.run_cell('Tableaux.options._reset()')
sage: shell.quit()
```

_`cache_key`_

Return a hashable key which identifies this objects for caching. The output must be hashable itself, or a
tuple of objects which are hashable or define a `_cache_key`.

This method will only be called if the object itself is not hashable.

Some immutable objects (such as $p$-adic numbers) cannot implement a reasonable hash function because
their `==` operator has been modified to return `True` for objects which might behave differently in some
computations:

```python
sage: K.<a> = Qq(9)  # optional - α
    → sage.rings.padics
sage: b = a + O(3)  # optional - α
    → sage.rings.padics
sage: c = a + 3  # optional - α
    → sage.rings.padics
sage: b  # optional - α
    → sage.rings.padics
a + O(3)
sage: c  # optional - α
    → sage.rings.padics
a + 3 + O(3^20)
sage: b == c  # optional - α
    → sage.rings.padics
True
sage: b == a  # optional - α
    → sage.rings.padics
True
sage: c == a  # optional - α
    → sage.rings.padics
False
```

If such objects defined a non-trivial hash function, this would break caching in many places. However, such
objects should still be usable in caches. This can be achieved by defining an appropriate `_cache_key`:

```python
sage: hash(b)  # optional - α
    → sage.rings.padics
Traceback (most recent call last):
```

(continues on next page)
...  
TypeError: unhashable type: 'sage.rings.padics.qadic_flint_CR.
˓→qAdicCappedRelativeElement'

sage: @cached_method
    ....: def f(x): return x==a
sage: f(b)                      # optional -
       ←sage.rings.padics
True
sage: f(c)                      # if b and c were hashable, this would return True  # optional -
       ←sage.rings.padics
False
sage: b._cache_key()            # optional -
       ←sage.rings.padics
(..., ((0, 1),), 0, 1)
sage: c._cache_key()            # optional -
       ←sage.rings.padics
(..., ((0, 1), (1,)), 0, 20)

An implementation must make sure that for elements a and b, if a != b, then also a._cache_key() != b._cache_key(). In practice this means that the _cache_key should always include the parent as its first argument:

sage: S.<a> = Qq(4)            # optional -
       ←sage.rings.padics
sage: d = a + O(2)            # optional -
       ←sage.rings.padics
sage: b._cache_key() == d._cache_key()  # this would be True if the parents were...
       ←not included  # optional - sage.rings.padics
False

category()

dump(filename, compress=True)
    Same as self.save(filename, compress)
dumps(compress=True)
    Dump self to a string s, which can later be reconstituted as self using loads(s).

There is an optional boolean argument compress which defaults to True.

EXAMPLES:

sage: from sage.misc.persist import comp
sage: O = SageObject()
sage: p_comp = O.dumps()  # optional -
       ←sage.rings.padics
sage: p_uncomp = O.dumps(compress=False)  # optional -
       ←sage.rings.padics
sage: comp.decompress(p_comp) == p_uncomp
True
sage: import pickletools
sage: pickletools.dis(p_uncomp)
0: \x80 PROTO 2
2: c GLOBAL 'sage.structure.sage_object SageObject'
41: q BINPUT ...

(continues on next page)
43: )   EMPTY_TUPLE
44: \x81  NEWOBJ
45: q    BINPUT   ...   47: .   STOP
highest protocol among opcodes = 2

parent()
Return the type of self to support the coercion framework.

EXAMPLES:

sage: t = log(sqrt(2) - 1) + log(sqrt(2) + 1); t  # optional - sage.
       → symbolic
log(sqrt(2) + 1) + log(sqrt(2) - 1)
sage: u = t.maxima_methods()  # optional - sage.
       → symbolic
sage: u.parent()  # optional - sage.
       → symbolic
<class 'sage.symbolic.maxima_wrapper.MaximaWrapper'>

rename(x=None)
Change self so it prints as x, where x is a string.

Note:  This is only supported for Python classes that derive from SageObject.

EXAMPLES:

sage: x = PolynomialRing(QQ, 'x', sparse=True).gen()
sage: g = x^3 + x - 5
sage: g
x^3 + x - 5
sage: g.rename('a polynomial')
sage: g
a polynomial
sage: g + x
x^3 + 2*x - 5
sage: h = g^100
sage: str(h)[:20]
'x^300 + 100*x^298 - '
sage: h.rename('x^300 + ...')
sage: h
x^300 + ...

Real numbers are not Python classes, so rename is not supported:

sage: a = 3.14
sage: type(a)
<... 'sage.rings.real_mpfr.RealLiteral'>
sage: a.rename('pi')
Traceback (most recent call last):
  ... NotImplementedError: object does not support renaming: 3.14000000000000
Note: The reason C-extension types are not supported by default is if they were then every single one would have to carry around an extra attribute, which would be slower and waste a lot of memory.

To support them for a specific class, add a cdef public __custom_name attribute.

reset_name()

Remove the custom name of an object.

EXAMPLES:

```
sage: P.<x> = QQ[]
sage: P
Univariate Polynomial Ring in x over Rational Field
sage: P.rename('A polynomial ring')
sage: P
A polynomial ring
sage: P.reset_name()
sage: P
Univariate Polynomial Ring in x over Rational Field
```

save(filename=None, compress=True)

Save self to the given filename.

EXAMPLES:

```
sage: f = x^3 + 5
    # optional - x
    → sage.symbolic
sage: f.save(os.path.join(SAGE_TMP, 'file'))
    # optional - x
    → sage.symbolic
sage: load(os.path.join(SAGE_TMP, 'file.sobj'))
    # optional - x
    → sage.symbolic
x^3 + 5
```

1.2 Base class for objects of a category

CLASS HIERARCHY:

- SageObject
  - CategoryObject
    * Parent

Many category objects in Sage are equipped with generators, which are usually special elements of the object. For example, the polynomial ring \( \mathbb{Z}[x, y, z] \) is generated by \( x, y, \) and \( z \). In Sage the i th generator of an object \( X \) is obtained using the notation \( X \text{.gen}(i) \). From the Sage interactive prompt, the shorthand notation \( X.i \) is also allowed.

The following examples illustrate these functions in the context of multivariate polynomial rings and free modules.

EXAMPLES:

```
sage: R = PolynomialRing(ZZ, 3, 'x')
sage: R.ngens()
3
sage: R.gen(0)
```

(continues on next page)
This example illustrates generators for a free module over $\mathbb{Z}$.

```python
sage: M = FreeModule(ZZ, 4)
sage: M
Ambient free module of rank 4 over the principal ideal domain Integer Ring
sage: M.ngens()
4
sage: M.gen(0)
(1, 0, 0, 0)
sage: M.gens()
((1, 0, 0, 0), (0, 1, 0, 0), (0, 0, 1, 0), (0, 0, 0, 1))
```

The example illustrates the optional third argument:

```python
sage: QQ.Hom(ZZ, Sets())
Set of Morphisms from Rational Field to Integer Ring in Category of sets
```

Homspaces are defined for very general Sage objects, even elements of familiar rings.

```python
sage: n = 5; Hom(n,7)
Set of Morphisms from 5 to 7 in Category of elements of Integer Ring
sage: z=(2/3); Hom(z,8/1)
Set of Morphisms from 2/3 to 8 in Category of elements of Rational Field
```

This example illustrates the optional third argument:

```python
sage: QQ.Hom(ZZ, Sets())
Set of Morphisms from Rational Field to Integer Ring in Category of sets
```

```python
sage: base()
sage: base_ring()
```

Return the base ring of `self`.

INPUT:

- `self` – an object over a base ring; typically a module

EXAMPLES:
Note that the coordinates of the elements of a module can lie in a bigger ring, the \texttt{coordinate\_ring}:

\begin{verbatim}
sage: M = (ZZ^2) * (1/2)
sage: v = M([1/2, 0])
sage: v.base_ring()
Integer Ring
sage: parent(v[0])
Rational Field
sage: v.coordinate_ring()
Rational Field
\end{verbatim}

More examples:

\begin{verbatim}
sage: F = FreeAlgebra(QQ, 'x')
sage: F.base_ring()
Rational Field
sage: F.__class__.base_ring
<method 'base\_ring' of 'sage.structure.category_object.CategoryObject' objects>
sage: E = CombinatorialFreeModule(ZZ, [1,2,3])
sage: F = CombinatorialFreeModule(ZZ, [2,3,4])
sage: H = Hom(E, F)
sage: H.base_ring()
Integer Ring
sage: H.__class__.base_ring
<method 'base\_ring' of 'sage.structure.category_object.CategoryObject' objects>
\end{verbatim}

\textbf{Todo:} Move this method elsewhere (typically in the Modules category) so as not to pollute the namespace of all category objects.

\texttt{categories()} 
Return the categories of \texttt{self}.

\texttt{EXAMPLES:}

\begin{verbatim}
sage: ZZ.categories()
[Join of Category of euclidean domains
 and Category of infinite enumerated sets
 and Category of metric spaces,
 Category of euclidean domains,
 Category of principal ideal domains,
 Category of unique factorization domains,
\end{verbatim}

(continues on next page)
category()

gens_dict(copy=True)
Return a dictionary whose entries are {name:variable,...}, where name stands for the variable names of this object (as strings) and variable stands for the corresponding defining generators (as elements of this object).

EXAMPLES:

sage: B.<a,b,c,d> = BooleanPolynomialRing()
sage: B.gens_dict()
{'a': a, 'b': b, 'c': c, 'd': d}

gens_dict_recursive()
Return the dictionary of generators of self and its base rings.

OUTPUT:
• a dictionary with string names of generators as keys and generators of self and its base rings as values.

EXAMPLES:

sage: R = QQ['x,y']['z,w']
sage: sorted(R.gens_dict_recursive().items())
[('w', w), ('x', x), ('y', y), ('z', z)]

inject_variables(scope=None, verbose=True)
Inject the generators of self with their names into the namespace of the Python code from which this function is called.

Thus, e.g., if the generators of self are labeled ‘a’, ‘b’, and ‘c’, then after calling this method the variables a, b, and c in the current scope will be set equal to the generators of self.

NOTE: If Foo is a constructor for a Sage object with generators, and Foo is defined in Cython, then it would typically call inject_variables() on the object it creates. E.g., PolynomialRing(QQ, 'y') does this so that the variable y is the generator of the polynomial ring.

latex_name()
latex_variable_names()
Returns the list of variable names suitable for latex output.

All _SOMETHING substrings are replaced by _{SOMETHING} recursively so that subscripts of subscripts work.

EXAMPLES:

sage: R, x = PolynomialRing(QQ, 'x', 12).objgens()
sage: x
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(objgen)

Return the tuple (self, self.gen()).

EXAMPLES:

sage: R, x = PolynomialRing(QQ, 'x').objgen()
sage: R
Univariate Polynomial Ring in x over Rational Field
sage: x
x

(objgens)

Return the tuple (self, self.gens()).

EXAMPLES:

sage: R = PolynomialRing(QQ, 3, 'x'); R
Multivariate Polynomial Ring in x0, x1, x2 over Rational Field
sage: R.objgens()
(Multivariate Polynomial Ring in x0, x1, x2 over Rational Field, (x0, x1, x2))

(variable_name)

Return the first variable name.

OUTPUT: a string

EXAMPLES:

sage: R.<z,y,a42> = ZZ[]
sage: R.variable_name()
'z'
sage: R.<x> = InfinitePolynomialRing(ZZ)
sage: R.variable_name()
'x'

(variable_names)

Return the list of variable names corresponding to the generators.

OUTPUT: a tuple of strings

EXAMPLES:

sage: R.<z,y,a42> = QQ[]
sage: R.variable_names()
('z', 'y', 'a42')
sage: S = R.quotient_ring(z+y)
sage: S.variable_names()
('zbar', 'ybar', 'a42bar')

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```
sage: T.<x> = InfinitePolynomialRing(ZZ)
sage: T.variable_names()
('x',)
```

`sage.structure.category_object.certify_names(names)`
Check that names are valid variable names.

**INPUT:**

- names – an iterable with strings representing variable names

**OUTPUT:** True (for efficiency of the Cython call)

**EXAMPLES:**

```
sage: from sage.structure.category_object import certify_names as cn
sage: cn(["a", "b", "c"])
1
sage: cn("abc")
1
sage: cn([])
1
sage: cn([" "])
Traceback (most recent call last):
... ValueError: variable name must be nonempty
sage: cn(["_foo"])
Traceback (most recent call last):
... ValueError: variable name '_foo' does not start with a letter
sage: cn(["x'"])
Traceback (most recent call last):
... ValueError: variable name "x'" is not alphanumeric
sage: cn(["a", "b", "b"])
Traceback (most recent call last):
... ValueError: variable name 'b' appears more than once
```

`sage.structure.category_object.check_default_category(default_category, category)`

`sage.structure.category_object.normalize_names(ngens, names)`
Return a tuple of strings of variable names of length ngens given the input names.

**INPUT:**

- ngens – integer: number of generators. The value ngens=-1 means that the number of generators is unknown a priori.
- names – any of the following:
  - a tuple or list of strings, such as ('x', 'y')
  - a comma-separated string, such as x,y
  - a string prefix, such as 'alpha'
  - a string of single character names, such as 'xyz'
OUTPUT: a tuple of \texttt{ngens} strings to be used as variable names.

EXAMPLES:

\begin{verbatim}
from sage.structure.category_object import normalize_names as nn

sage: nn(0, "")
()

sage: nn(0, [])
()

sage: nn(0, None)
()

sage: nn(1, 'a')
('a',)

sage: nn(2, 'z_z')
('z_z0', 'z_z1')

sage: nn(3, 'x, y, z')
('x', 'y', 'z')

sage: nn(2, 'ab')
('a', 'b')

sage: nn(2, 'x0')
('x00', 'x01')

sage: nn(3, (' a ', ' bb ', ' ccc '))
('a', 'bb', 'ccc')

sage: nn(4, ['a1', 'a2', 'b1', 'b11'])
('a1', 'a2', 'b1', 'b11')
\end{verbatim}

Arguments are converted to strings:

\begin{verbatim}
sage: nn(1, u'a')
('a',)

sage: var('alpha')
alpha

sage: nn(2, alpha)
('alpha0', 'alpha1')

sage: nn(1, [alpha])
('alpha',)
\end{verbatim}

With an unknown number of generators:

\begin{verbatim}
sage: nn(-1, 'a')
('a',)

sage: nn(-1, 'x, y, z')
('x', 'y', 'z')
\end{verbatim}

Test errors:

\begin{verbatim}
sage: nn(3, ['x', "y"])
Traceback (most recent call last):
...
IndexError: the number of names must equal the number of generators

sage: nn(None, "a")
Traceback (most recent call last):
...
TypeError: 'NoneType' object cannot be interpreted as an integer
\end{verbatim}

(continues on next page)
Traceback (most recent call last):
...
ValueError: variable name must be nonempty
`sage: nn(1, "foo@")`
Traceback (most recent call last):
...
ValueError: variable name 'foo@' is not alphanumeric
`sage: nn(2, "_foo")`
Traceback (most recent call last):
...
ValueError: variable name '_foo0' does not start with a letter
`sage: nn(1, 3/2)`
Traceback (most recent call last):
...
ValueError: variable name '3/2' is not alphanumeric
2.1 Parents

2.1.1 Base class for parent objects

CLASS HIERARCHY:

SageObject
    CategoryObject
    Parent

A simple example of registering coercions:

```
sage: class A_class(Parent):
    ....:     def __init__(self, name):
    ....:         Parent.__init__(self)
    ....:         self._populate_coercion_lists_()
    ....:         self.rename(name)
    ....:
    ....:         def category(self):
    ....:             return Sets()

    ....:         def _element_constructor_(self, i):
    ....:             assert (isinstance(i, (int, Integer)))
    ....:             return ElementWrapper(self, i)

sage: A = A_class("A")
sage: B = A_class("B")
sage: C = A_class("C")

sage: def f(a):
    ....:     return B(a.value+1)

sage: class MyMorphism(Morphism):
    ....:     def __init__(self, domain, codomain):
    ....:         Morphism.__init__(self, Hom(domain, codomain))

    ....:         def _call_(self, x):
    ....:             return self.codomain()(x.value)

sage: f = MyMorphism(A,B)
sage: f
```

Generic morphism:

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When implementing an element of a ring, one would typically provide the element class with \_rmul\_ and/or \_lmul\_ methods for the action of a base ring, and with \_mul\_ for the ring multiplication. However, prior to trac ticket \#14249, it would have been necessary to additionally define a method \_an_element\_() for the parent. But now, the following example works:

```python
sage: from sage.structure.element import RingElement
sage: class MyElement(RingElement):
    ....:
    def \_init\_(self, parent, x, y):
        ...
        RingElement.\_init\_(self, parent)
    ....:
    def \_mul\_(self, other):
        ...
        return self
    ....:
    def \_rmul\_(self, other):
        ...
        return self
    ....:
    def \_lmul\_(self, other):
        ...
        return self
sage: class MyParent(Parent):
    ....:
    Element = MyElement
```

Now, we define

```python
sage: P = MyParent(base=ZZ, category=Rings())
sage: a = P(1,2)
sage: a*a is a
True
sage: a*2 is a
True
sage: 2*a is a
True
```

```
class sage.structure.parent.EltPair
    Bases: object
    short_repr()

class sage.structure.parent.Parent
    Bases: sage.structure.category_object.CategoryObject
    Base class for all parents.
```
Parents are the Sage/mathematical analogues of container objects in computer science.

INPUT:

- **base** – An algebraic structure considered to be the “base” of this parent (e.g. the base field for a vector space).

- **category** – a category or list/tuple of categories. The category in which this parent lies (or list or tuple thereof). Since categories support more general super-categories, this should be the most specific category possible. If category is a list or tuple, a JoinCategory is created out of them. If category is not specified, the category will be guessed (see `CategoryObject`), but will not be used to inherit parent’s or element’s code from this category.

- **names** – Names of generators.

- **normalize** – Whether to standardize the names (remove punctuation, etc)

- **facade** – a parent, or tuple thereof, or True

If facade is specified, then `Sets().Facade()` is added to the categories of the parent. Furthermore, if facade is not True, the internal attribute `_facade_for` is set accordingly for use by `SetsFacade.ParenMethods.facade_for()`.

Internal invariants:

- `self._element_init_pass_parent == guess_pass_parent(self, self._element_constructor)` Ensures that `__call__()` passes down the parent properly to `_element_constructor()` (See trac ticket #5979).

**Todo:** Eventually, category should be `Sets` by default.

`__call__(x=0, *args, **kwds)`

This is the generic call method for all parents.

When called, it will find a map based on the Parent (or type) of x. If a coercion exists, it will always be chosen. This map will then be called (with the arguments and keywords if any).

By default this will dispatch as quickly as possible to `_element_constructor()` though faster pathways are possible if so desired.

`_populate_coercion_lists_(coerce_list=[], action_list=[], convert_list=[], embedding=None, convert_method_name=None, element_constructor=None, init_no_parent=None, unpickling=False)`

This function allows one to specify coercions, actions, conversions and embeddings involving this parent.

IT SHOULD ONLY BE CALLED DURING THE `__INIT__` method, often at the end.

INPUT:

- **coerce_list** – a list of coercion Morphisms to self and parents with canonical coercions to self

- **action_list** – a list of actions on and by self

- **convert_list** – a list of conversion Maps to self and parents with conversions to self

- **embedding** – a single Morphism from self

- **convert_method_name** – a name to look for that other elements can implement to create elements of self (e.g. `_integer_`)

- **init_no_parent** – if True omit passing self in as the first argument of element_constructor for conversion. This is useful if parents are unique, or element_constructor is a bound method (this latter case can be detected automatically).
__mul__(x)
This is a multiplication method that more or less directly calls another attribute _mul_ (single underscore). This is because __mul__ cannot be implemented via inheritance from the parent methods of the category, but _mul_ can be inherited. This is, e.g., used when creating twosided ideals of matrix algebras. See trac ticket #7797.

EXAMPLES:

```sage
sage: MS = MatrixSpace(QQ,2,2)
```
This matrix space is in fact an algebra, and in particular it is a ring, from the point of view of categories:

```sage
sage: MS.category()
Category of infinite finite dimensional algebras with basis
over (number fields and quotient fields and metric spaces)
sage: MS in Rings()
True
```
However, its class does not inherit from the base class Ring:

```sage
sage: isinstance(MS,Ring)
False
```
Its _mul_ method is inherited from the category, and can be used to create a left or right ideal:

```sage
sage: MS._mul_.__module__
'sage.categories.rings'
sage: MS*MS.1 # indirect doctest
Left Ideal
(
  [0 1]
  [0 0]
)
of Full MatrixSpace of 2 by 2 dense matrices over Rational Field
sage: MS*[MS.1,2]
Left Ideal
(
  [0 1]
  [0 0],
  [2 0]
  [0 2]
)
of Full MatrixSpace of 2 by 2 dense matrices over Rational Field
sage: MS.1*MS
Right Ideal
(
  [0 1]
  [0 0]
)
of Full MatrixSpace of 2 by 2 dense matrices over Rational Field
sage: [MS.1,2]*MS
Right Ideal
(
  [0 1]
)
```
(continues on next page)
[0 0],
[2 0]
[0 2]
) of Full MatrixSpace of 2 by 2 dense matrices over Rational Field

**__contains__(x)**

True if there is an element of self that is equal to x under ==, or if x is already an element of self. Also, True in other cases involving the Symbolic Ring, which is handled specially.

For many structures we test this by using **__call__()** and then testing equality between x and the result.

The Symbolic Ring is treated differently because it is ultra-permissive about letting other rings coerce in, but ultra-strict about doing comparisons.

**EXAMPLES:**

```sage
sage: 2 in Integers(7)
True
sage: 2 in ZZ
True
sage: Integers(7)(3) in ZZ
True
sage: 3/1 in ZZ
True
sage: 5 in QQ
True
sage: I in RR
False
sage: SR(2) in ZZ
True
sage: RIF(1, 2) in RIF
True
sage: pi in RIF # there is no element of RIF equal to pi
False
sage: sqrt(2) in CC
True
sage: pi in RR
True
sage: pi in CC
True
sage: pi in RDF
True
sage: pi in CDF
True
```

Note that we have

```sage
sage: 3/2 in RIF
True
```

because 3/2 has an exact representation in RIF (i.e. can be represented as an interval that contains exactly one value):
On the other hand, we have

```python
sage: RIF(2/3).is_exact()
False

sage: RIF(2/3).is_exact()
False
sage: RIF(2/3).endpoints()
(0.666666666666666, 0.666666666666667)
sage: RIF(2/3) == RIF(2/3)
False
```

because $2/3$ has no exact representation in `RIF`. Since `RIF(2/3)` is a nontrivial interval, it cannot be equal to anything (not even itself):

```python
sage: RIF(2/3).is_exact()
False
```

>_coerce_map_from_(S)_

Override this method to specify coercions beyond those specified in `coerce_list`.

If no such coercion exists, return None or False. Otherwise, it may return either an actual Map to use for the coercion, a callable (in which case it will be wrapped in a Map), or True (in which case a generic map will be provided).

>_convert_map_from_(S)_

Override this method to provide additional conversions beyond those given in `convert_list`.

This function is called after coercions are attempted. If there is a coercion morphism in the opposite direction, one should consider adding a section method to that.

This MUST return a Map from $S$ to self, or None. If None is returned then a generic map will be provided.

>_get_action_(S, op, self_on_left)_

Override this method to provide an action of self on $S$ or $S$ on self beyond what was specified in `action_list`.

This must return an action which accepts an element of self and an element of $S$ (in the order specified by `self_on_left`).

>_an_element_()_

Return an element of self.

Want it in sufficient generality that poorly-written functions will not work when they are not supposed to. This is cached so does not have to be super fast.

EXAMPLES:

```python
sage: QQ._an_element_()
1/2
sage: ZZ['x,y,z']._an_element_()
x
```

>_repr_option_(key)_

Metadata about the `_repr_()` output.

INPUT:

• key – string. A key for different metadata informations that can be inquired about.

Valid key arguments are:
• 'ascii_art': The _repr_() output is multi-line ascii art and each line must be printed starting at the same column, or the meaning is lost.

• 'element_ascii_art': same but for the output of the elements. Used in sage.repl.display.formatter.

• 'element_is_atomic': the elements print atomically, that is, parenthesis are not required when printing out any of $x - y$, $x + y$, $x^y$ and $x/y$.

**OUTPUT:**
Boolean.

**EXAMPLES:**

```
sage: ZZ._repr_option('ascii_art')
False
sage: MatrixSpace(ZZ, 2)._repr_option('element_ascii_art')
True
```

**_init_category_(category)**
Initialize the category framework.

Most parents initialize their category upon construction, and this is the recommended behavior. For example, this happens when the constructor calls Parent._init__() directly or indirectly. However, some parents defer this for performance reasons. For example, sage.matrix.matrix_space.MatrixSpace does not.

**EXAMPLES:**
```
sage: P = Parent()
sage: P.category()
Category of sets
sage: class MyParent(Parent):
    ....:     def __init__(self):
    ....:         self._init_category_(Groups())
sage: MyParent().category()
Category of groups
```

**_is_coercion_cached_(domain)**
Test whether the coercion from domain is already cached.

**EXAMPLES:**
```
sage: R.<XX> = QQ
sage: R._remove_from_coerce_cache(QQ)
sage: R._is_coercion_cached(QQ)
False
sage: _ = R.coerce_map_from(QQ)
sage: R._is_coercion_cached(QQ)
True
```

**_is_conversion_cached_(domain)**
Test whether the conversion from domain is already set.

**EXAMPLES:**
```
sage: P = Parent()
sage: P._is_conversion_cached(P)
False
sage: P.convert_map_from(P)
Identity endomorphism of <sage.structure.parent.Parent object at ...>
sage: P._is_conversion_cached(P)
True
```

**Hom** *(codomain, category=None)*

Return the homspace \(\text{Hom}(\text{self}, \text{codomain}, \text{category})\).

**INPUT:**

- codomain – a parent
- category – a category or None (default: None) If None, the meet of the category of self and codomain is used.

**OUTPUT:**

The homspace of all homomorphisms from self to codomain in the category category.

**See also:**

Hom()

**EXAMPLES:**

```
sage: R.<x,y> = PolynomialRing(QQ, 2)
sage: R.Hom(QQ)
Set of Homomorphisms from Multivariate Polynomial Ring in x, y over Rational Field to Rational Field
```

Homspaces are defined for very general Sage objects, even elements of familiar rings:

```
sage: n = 5; Hom(n,7)
Set of Morphisms from 5 to 7 in Category of elements of Integer Ring
sage: z=(2/3); Hom(z,8/1)
Set of Morphisms from 2/3 to 8 in Category of elements of Rational Field
```

This example illustrates the optional third argument:

```
sage: QQ.Hom(ZZ, Sets())
Set of Morphisms from Rational Field to Integer Ring in Category of sets
```

A parent may specify how to construct certain homsets by implementing a method `_Hom_(codomain, category)`. See :func:`~sage.categories.homset.Hom()` for details.

**an_element()**

Returns a (preferably typical) element of this parent.

This is used both for illustration and testing purposes. If the set self is empty, an_element() raises the exception EmptySetError.

This calls `_an_element_()` (which see), and caches the result. Parent are thus encouraged to override `_an_element_()`.

**EXAMPLES:**
In case the set is empty, an `EmptySetError` is raised:

```python
sage: Set([]).an_element()
Traceback (most recent call last):
  ...  
EmptySetError
```

### category()

**EXAMPLES:**

```python
sage: P = Parent()

sage: P.category()
Category of sets
```

```python
sage: class MyParent(Parent):
    ....:     def __init__(self):
    ....:

sage: MyParent().category()
Category of sets
```

### coerce(x)

Return `x` as an element of `self`, if and only if there is a canonical coercion from the parent of `x` to `self`.

**EXAMPLES:**

```python
sage: QQ.coerce(ZZ(2))
2

sage: ZZ.coerce(QQ(2))
Traceback (most recent call last):
  ...  
TypeError: no canonical coercion from Rational Field to Integer Ring
```

We make an exception for zero:

```python
sage: V = GF(7)^7
sage: V.coerce(0)
(0, 0, 0, 0, 0, 0, 0)
```

### coerce_embedding()

Return the embedding of `self` into some other parent, if such a parent exists.

This does not mean that there are no coercion maps from `self` into other fields, this is simply a specific morphism specified out of `self` and usually denotes a special relationship (e.g. sub-objects, choice of completion, etc.)

**EXAMPLES:**

```python
sage: K.<a>=NumberField(x^3+x^2+1,embedding=1)

sage: K.coerce_embedding()
Generic morphism:
  From: Number Field in a with defining polynomial x^3 + x^2 + 1 with a = -1.
  To:   465571231876768?
```

(continues on next page)
To: Real Lazy Field
Defn: a \rightarrow -1.4655712318767687

```python
sage: K.<a>=NumberField(x^3+x^2+1,embedding=CC.gen())
sage: K.coerce_embedding()
Generic morphism:
  From: Number Field in a with defining polynomial x^3 + x^2 + 1 with a = 0.
  → 2327856159383841? + 0.7925519925154479?*I
To:  Complex Lazy Field
Defn: a \rightarrow 0.2327856159383841? + 0.7925519925154479?*I
```

**coerce_map_from**($S$)

Return a Map object to coerce from $S$ to $self$ if one exists, or **None** if no such coercion exists.

**EXAMPLES:**

By [trac ticket #12313](https://trac.sagemath.org/ticket/12313), a special kind of weak key dictionary is used to store coercion and conversion maps, namely **MonoDict**. In that way, a memory leak was fixed that would occur in the following test:

```python
sage: import gc
sage: K = GF(1<<55,'t')
sage: for i in range(50):
    a = K.random_element()
    E = EllipticCurve(j=a)
    b = K.has_coerce_map_from(E)

sage: _ = gc.collect()
```

**convert_map_from**($S$)

This function returns a Map from $S$ to $self$, which may or may not succeed on all inputs. If a coercion map from $S$ to $self$ exists, then the it will be returned. If a coercion from $self$ to $S$ exists, then it will attempt to return a section of that map.

Under the new coercion model, this is the fastest way to convert elements of $S$ to elements of $self$ (short of manually constructing the elements) and is used by **__call__**.

**EXAMPLES:**

```python
sage: m = ZZ.convert_map_from(QQ)
```

**element_class**()

The (default) class for the elements of this parent

**FIXME**'s and design issues:

- If $self$.Element is “trivial enough”, should we optimize it away with: $self$.element_class
  = dynamic_class(“%s.element_class”%self.__class__.__name__, (category.element_class,),
self.Element)

• This should lookup for Element classes in all super classes

get_action(S, op=None, self_on_left=True, self_el=None, S_el=None)
Returns an action of self on S or S on self.

To provide additional actions, override _get_action_.

Warning: This is not the method that you typically want to call. Instead, call coercion_model.
get_action(...) which caches results (this Parent.get_action method does not).

has_coerce_map_from(S)
Return True if there is a natural map from S to self. Otherwise, return False.

EXAMPLES:

```python
sage: RDF.has_coerce_map_from(QQ)
True
sage: RDF.has_coerce_map_from(QQ['x'])
False
sage: RDF['x'].has_coerce_map_from(QQ['x'])
True
sage: RDF['x,y'].has_coerce_map_from(QQ['x'])
True
```

hom(im_gens, codomain=None, check=None, base_map=None, category=None, **kwds)
Return the unique homomorphism from self to codomain that sends self.gens() to the entries of
im_gens. Raises a TypeError if there is no such homomorphism.

INPUT:

• im_gens – the images in the codomain of the generators of this object under the homomorphism
• codomain – the codomain of the homomorphism
• base_map – a map from the base ring to the codomain. If not given, coercion is used.
• check – whether to verify that the images of generators extend to define a map (using only canonical
cooercions).

OUTPUT:
A homomorphism self –> codomain

Note: As a shortcut, one can also give an object X instead of im_gens, in which case return the (if it
exists) natural map to X.

EXAMPLES:
Polynomial Ring: We first illustrate construction of a few homomorphisms involving a polynomial ring:

```python
sage: R.<x> = PolynomialRing(ZZ)
sage: f = R.hom([5], QQ)
sage: f(x^2 - 19)
6
```
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```
sage: R.<x> = PolynomialRing(QQ)
sage: f = R.hom([5], GF(7))
Traceback (most recent call last):
...
ValueError: relations do not all (canonically) map to 0 under map determined by
→ images of generators

sage: R.<x> = PolynomialRing(GF(7))
sage: f = R.hom([3], GF(49, 'a'))
sage: f
Ring morphism:
    From: Univariate Polynomial Ring in x over Finite Field of size 7
    To:   Finite Field in a of size 7^2
    Defn: x |--> 3
sage: f(x+6)
2
sage: f(x^2+1)
3

Natural morphism:

sage: f = ZZ.hom(GF(5))
sage: f(7)
2
sage: f
Natural morphism:
    From: Integer Ring
    To:   Finite Field of size 5

There might not be a natural morphism, in which case a TypeError is raised:

sage: QQ.hom(ZZ)
Traceback (most recent call last):
...
TypeError: natural coercion morphism from Rational Field to Integer Ring not
→ defined
```

```
is_exact()
Test whether the ring is exact.

Note: This defaults to true, so even if it does return True you have no guarantee (unless the ring has properly overloaded this).

OUTPUT:
Return True if elements of this ring are represented exactly, i.e., there is no precision loss when doing arithmetic.

EXAMPLES:

sage: QQ.is_exact()
True
sage: ZZ.is_exact()
```

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True
\[
\text{\texttt{sage: Qp(7).is_exact()}} \\
\text{False}
\]
\[
\text{\texttt{sage: Zp(7, type='capped-abs').is_exact()}} \\
\text{False}
\]

**register_action**(*action*)

Update the coercion model to use *action* to act on *self*.

*action* should be of type `sage.categories.action.Action`.

**EXAMPLES:**

\[
\text{\texttt{sage: import sage.categories.action}} \\
\text{\texttt{sage: import operator}} \\
\text{\texttt{sage: class SymmetricGroupAction(sage.categories.action.Action):}} \\
\text{\texttt{...: \quad "Act on a multivariate polynomial ring by permuting the generators."}} \\
\text{\texttt{...: \quad def \_init\_(self, G, M, is_left=True):}} \\
\text{\texttt{...: \quad \quad sage.categories.action.Action\._init\_(self, G, M, is_left, \_}} \\
\text{\texttt{\_operator.mul)}} \\
\text{\texttt{...: \quad def \_act\_(self, g, a):}} \\
\text{\texttt{...: \quad \quad D = \{\}}} \\
\text{\texttt{...: \quad \quad for k, v in a.dict().items():}} \\
\text{\texttt{...: \quad \quad \quad nk = [0]*\text{len}(k)}} \\
\text{\texttt{...: \quad \quad \quad for i in range(\text{len}(k)):}} \\
\text{\texttt{...: \quad \quad \quad \quad nk[g[i+1]-1] = k[i]}}} \\
\text{\texttt{...: \quad \quad D[tuple(nk)] = v}}} \\
\text{\texttt{...: \quad return a.parent()\(\{\)D\)}} \\
\text{\texttt{sage: R.<x, y, z> = QQ['x, y, z']}} \\
\text{\texttt{sage: G = SymmetricGroup(3)}} \\
\text{\texttt{sage: act = SymmetricGroupAction(G, R)}} \\
\text{\texttt{sage: t = x + 2*y + 3*z}} \\
\text{\texttt{sage: act(G((1, 2)), t)}} \\
2*x + y + 3*z \\
\text{\texttt{sage: act(G((2, 3)), t)}} \\
x + 3*y + 2*z \\
\text{\texttt{sage: act(G((1, 2, 3)), t)}} \\
3*x + y + 2*z \\
\]

This should fail, since we have not registered the left action:

\[
\text{\texttt{sage: G((1,2)) \* t}} \\
\text{Traceback (most recent call last):} \\
\text{...} \\
\text{TypeError: ...}
\]

Now let’s make it work:

\[
\text{\texttt{sage: R\._unset_coercions_used()}} \\
\text{\texttt{sage: R.register_action(act)}}
\]
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sage: G((1, 2)) * t
2*x + y + 3*z

**register_coercion(mor)**

Update the coercion model to use \( \text{mor} : P \to \text{self} \) to coerce from a parent \( P \) into \( \text{self} \).

For safety, an error is raised if another coercion has already been registered or discovered between \( P \) and \( \text{self} \).

**EXAMPLES:**

sage: K.<a> = ZZ['a']
sage: L.<b> = ZZ['b']
sage: L_into_K = L.hom([-a]) # non-trivial automorphism
sage: K.register_coercion(L_into_K)
sage: K(0) + b
-a
sage: a + b
0
sage: K(b) # check that convert calls coerce first; normally this is just a
-a
sage: L(0) + a in K # this goes through the coercion mechanism of K
True
sage: L(a) in L # this still goes through the convert mechanism of L
True
sage: K.register_coercion(L_into_K)
Traceback (most recent call last):
  ...  
AssertionError: coercion from Univariate Polynomial Ring in b over Integer Ring → to Univariate Polynomial Ring in a over Integer Ring already registered or discovered

**register_conversion(mor)**

Update the coercion model to use mor : \( P \to \text{self} \) to convert from \( P \) into \( \text{self} \).

**EXAMPLES:**

sage: K.<a> = ZZ['a']
sage: M.<c> = ZZ['c']
sage: M_into_K = M.hom([a]) # trivial automorphism
sage: K._unset_coercions_used()
sage: K.register_conversion(M_into_K)
sage: K(c)
a
sage: K(0) + c
Traceback (most recent call last):
  ...
  TypeError: ...

**register_embedding(embedding)**

Add embedding to coercion model.

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This method updates the coercion model to use embedding \( \texttt{self} \to P \) to embed \texttt{self} into the parent \( P \).

There can only be one embedding registered; it can only be registered once; and it must be registered before using this parent in the coercion model.

**EXAMPLES:**

```python
sage: S3 = AlternatingGroup(3)
sage: G = SL(3, QQ)
sage: p = S3[2]; p.matrix()
[0 0 1]
[1 0 0]
[0 1 0]
```

In general one cannot mix matrices and permutations:

```python
sage: G(p)
Traceback (most recent call last):
...  
TypeError: unable to convert (1,3,2) to a rational
sage: phi = S3.hom(lambda p: G(p.matrix()), codomain = G)
sage: phi(p)
[0 0 1]
[1 0 0]
[0 1 0]
sage: S3._unset_coercions_used()
sage: S3.register_embedding(phi)
```

By trac ticket #14711, coerce maps should be copied when using outside of the coercion system:

```python
sage: phi = copy(S3.coerce_embedding()); phi
Generic morphism:
    From: Alternating group of order 3!/2 as a permutation group
    To:   Special Linear Group of degree 3 over Rational Field
sage: phi(p)
[0 0 1]
[1 0 0]
[0 1 0]
```

This does not work since matrix groups are still old-style parents (see trac ticket #14014):

```python
sage: G(p)  # todo: not implemented
```

Though one can have a permutation act on the rows of a matrix:

```python
sage: G(1) * p
[0 0 1]
[1 0 0]
[0 1 0]
```

Some more advanced examples:

```python
sage: x = QQ['x'].0
sage: t = abs(ZZ.random_element(10^6))
sage: K = NumberField(x^2 + 2*3*7*11, "a"+str(t))
```

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```python
sage: a = K.gen()
sage: K_into_MS = K.hom([a.matrix()])
sage: K._unset_coercions_used()
sage: K.register_embedding(K_into_MS)

sage: L = NumberField(x^2 + 2*3*7*11*19*31, "b"+str(abs(ZZ.random_element(10^→6))))
sage: b = L.gen()
sage: L_into_MS = L.hom([b.matrix()])
sage: L._unset_coercions_used()
sage: L.register_embedding(L_into_MS)

sage: K.coerce_embedding()(a)
[ 0 1]
[462 0]
sage: L.coerce_embedding()(b)
[ 0 1]
[272118 0]

sage: a.matrix() * b.matrix()
[272118 0]
[0 -462]
```

class sage.structure.parent.Set_generic

Bases: sage.structure.parent.Parent

Abstract base class for sets.

object()

Return the underlying object of self.

EXAMPLES:

```python
sage: Set(QQ).object()
Rational Field
```

sage.structure.parent.is_Parent(x)

Return True if x is a parent object, i.e., derives from sage.structure.parent.Parent and False otherwise.

EXAMPLES:

```python
sage: from sage.structure.parent import is_Parent
sage: is_Parent(2/3)
False
sage: is_Parent(ZZ)
True
sage: is_Parent(Primes())
True
```
2.1.2 Indexed Generators

class sage.structure.indexed_generators.IndexedGenerators(indices, prefix='x', **kwds)
Bases: object

Abstract base class for parents whose elements consist of generators indexed by an arbitrary set.

Options controlling the printing of elements:

- **prefix** – string, prefix used for printing elements of this module (optional, default 'x'). With the default, a monomial indexed by 'a' would be printed as \texttt{x['a']}.
- **latex_prefix** – string or \texttt{None}, prefix used in the \LaTeX representation of elements (optional, default \texttt{None}). If this is anything except the empty string, it prints the index as a subscript. If this is \texttt{None}, it uses the setting for \texttt{prefix}, so if \texttt{prefix} is set to "B", then a monomial indexed by 'a' would be printed as \texttt{B_{a}}. If this is the empty string, then don't print monomials as subscripts: the monomial indexed by 'a' would be printed as a, or as \texttt{[a]} if \texttt{latex_bracket} is \texttt{True}.
- **names** – dict with strings as values or list of strings (optional): a mapping from the indices of the generators to strings giving the generators explicit names. This is used instead of the print options \texttt{prefix} and \texttt{bracket} when \texttt{names} is specified.
- **latex_names** – dict with strings as values or list of strings (optional): same as \texttt{names} except using the \LaTeX representation.
- **bracket** – \texttt{None}, \texttt{bool}, string, or list or tuple of strings (optional, default \texttt{None}): if \texttt{None}, use the value of the attribute \texttt{self._repr_option_bracket}, which has default value \texttt{True}. (\texttt{self._repr_option_bracket} is available for backwards compatibility. Users should set \texttt{bracket} instead. If \texttt{bracket} is set to anything except \texttt{None}, it overrides the value of \texttt{self._repr_option_bracket}.) If \texttt{False}, do not include brackets when printing elements: a monomial indexed by 'a' would be printed as \texttt{B'a'}, and a monomial indexed by (1,2,3) would be printed as \texttt{B(1,2,3)}. If \texttt{True}, use "[" and "]" as brackets. If it is one of ["", ",", or "]", use it and its partner as brackets. If it is any other string, use it as both brackets. If it is a list or tuple of strings, use the first entry as the left bracket and the second entry as the right bracket.
- **latex_bracket** – \texttt{bool}, \texttt{string}, or \texttt{list} or \texttt{tuple} of \texttt{strings} (optional, default \texttt{False}): if \texttt{False}, do not include brackets in the \LaTeX representation of elements. This option is only relevant if \texttt{latex_prefix} is the empty string; otherwise, brackets are not used regardless. If \texttt{True}, use "left[" and "]right]" as brackets. If this is one of ["", ",", or "]", use it and its partner, prepended with "left" and "right", as brackets. If this is any other string, use it as both brackets. If this is a list or tuple of strings, use the first entry as the left bracket and the second entry as the right bracket.
- **scalar_mult** – string to use for scalar multiplication in the print representation (optional, default "*")
- **latex_scalar_mult** – string or \texttt{None} (default: \texttt{None}), string to use for scalar multiplication in the latex representation. If \texttt{None}, use the empty string if \texttt{scalar_mult} is set to "*", otherwise use the value of \texttt{scalar_mult}.
- **tensor_symbol** – string or \texttt{None} (default: \texttt{None}), string to use for tensor product in the print representation. If \texttt{None}, use \texttt{sage.categories.tensor.symbol} and \texttt{sage.categories.tensor.unicode_symbol}.
- **sorting_key** – a key function (default: \texttt{lambda x: x}), to use for sorting elements in the output of elements
- **sorting_reverse** – \texttt{bool} (default: \texttt{False}), if \texttt{True} sort elements in reverse order in the output of elements
- **string_quotes** – \texttt{bool} (default: \texttt{True}), if \texttt{True} then display string indices with quotes
- **iterate_key** – \texttt{bool} (default: \texttt{False}) iterate through the elements of the key and print the result as comma separated objects for string output
Note: These print options may also be accessed and modified using the `print_options()` method, after the parent has been defined.

EXAMPLES:
We demonstrate a variety of the input options:

```python
sage: from sage.structureindexed_generators import IndexedGenerators
sage: I = IndexedGenerators(ZZ, prefix='A')
  'A[2]'
sage: I._repr_generator(2)
  'A_{2}'
sage: I._latex_generator(2)
  '\text{\text{A}}_{2}''
sage: I = IndexedGenerators(ZZ, prefix='', latex_bracket='()')
  'x(2)'
sage: I._repr_generator(2)
  'x_{2}''
sage: I = IndexedGenerators(ZZ, prefix='', latex_bracket='[|]')
  'x|2>'
```

`indices()`  
Return the indices of self.

EXAMPLES:

```python
sage: F = CombinatorialFreeModule(QQ, ['a', 'b', 'c'])
  
sage: F.indices()
  {'a', 'b', 'c'}
```

`prefix()`  
Return the prefix used when displaying elements of self.

EXAMPLES:

```python
sage: F = CombinatorialFreeModule(QQ, ['a', 'b', 'c'])
  
sage: F.prefix()
  'B'
```

`print_options(**kwds)`  
Return the current print options, or set an option.
INPUT: all of the input is optional; if present, it should be in the form of keyword pairs, such as latex_bracket='('. The allowable keywords are:

- prefix
- latex_prefix
- names
- latex_names
- bracket
- latex_bracket
- scalar_mult
- latex_scalar_mult
- tensor_symbol
- string_quotes
- sorting_key
- sorting_reverse
- iterate_key

See the documentation for IndexedGenerators for descriptions of the effects of setting each of these options.

OUTPUT: if the user provides any input, set the appropriate option(s) and return nothing. Otherwise, return the dictionary of settings for print and LaTeX representations.

EXAMPLES:

```sage
sage: F = CombinatorialFreeModule(ZZ, [1,2,3], prefix='x')
sage: F.print_options()
{...'prefix': 'x'...}
sage: F.print_options(bracket='(')
sage: F.print_options()
{...'bracket': '('...}
```

sage.structure.indexed_generators.parse_indices_names(names, index_set, prefix, kwds=None)

Parse the names, index set, and prefix input, along with setting default values for keyword arguments kwds.

OUTPUT:

The triple (N, I, p):

- N is the tuple of variable names,
- I is the index set, and
- p is the prefix.

This modifies the dictionary kwds.

**Note:** When the indices, names, or prefix have not been given, it should be passed to this function as None.

**Note:** For handling default prefixes, if the result will be None if it is not processed in this function.
EXAMPLES:

```python
sage: from sage.structure.indexed_generators import parse_indices_names
sage: d = {}
```

```python
sage: parse_indices_names('x,y,z', ZZ, None, d)
((('x', 'y', 'z'), Integer Ring, None)
```

```python
sage: d
{}```

```python
sage: parse_indices_names('x,y,z', None, None, d)
((('x', 'y', 'z'), {'x': 'y', 'z'}), '')
```

```python
sage: d
{'string_quotes': False}
```

```python
sage: parse_indices_names(None, ZZ, None, d)
(None, Integer Ring, None)
```

```python
sage: d
{}```

```python
sage: parse_indices_names(['a','b','c'], ZZ, 'x', d)
((('a', 'b', 'c'), Integer Ring, 'x')
```

```python
sage: d
{'string_quotes': True, 'bracket': '[]'}
```

```python
sage: parse_indices_names('x,y,z', None, 'A', d)
((('x', 'y', 'z'), {'x': 'y', 'z'}), 'A')
```

```python
sage: d
{'bracket': '[]', 'string_quotes': True}
```

```python
sage: from sage.structure.indexed_generators import split_index_keywords
sage: d = {'string_quotes': False, 'bracket': None, 'base': QQ}
```

```python
sage: split_index_keywords(d)
{'bracket': None, 'string_quotes': False}
```

```python
sage: d
{'base': Rational Field}
```

```python
sage: from sage.structure.indexed_generators import standardize_names_index_set
```

```python
sage: standardize_names_index_set(names=None, index_set=None, ngens=None)
```

```
Standardize the names and index_set inputs.
```

**INPUT:**

- names – (optional) the variable names
• `index_set` – (optional) the index set
• `ngens` – (optional) the number of generators

If `ngens` is a negative number, then this does not check that the number of variable names matches the size of the index set.

OUTPUT:

A pair `(names_std, index_set_std)`, where `names_std` is either `None` or a tuple of strings, and where `index_set_std` is a finite enumerated set. The purpose of `index_set_std` is to index the generators of some object (e.g., the basis of a module); the strings in `names_std`, when they exist, are used for printing these indices. The `ngens`

If `names` contains exactly one name `X` and `ngens` is greater than 1, then `names_std` are `Xi` for `i` in `range(ngens)`.

### 2.1.3 Precision management for non-exact objects

Manage the default precision for non-exact objects such as power series rings or laurent series rings.

EXAMPLES:

```
sage: R.<x> = PowerSeriesRing(QQ)
sage: R.default_prec()
20
sage: cos(x)
1 - 1/2*x^2 + 1/24*x^4 - 1/720*x^6 + 1/40320*x^8 - 1/3628800*x^10 +
1/479001600*x^12 - 1/87178291200*x^14 + 1/20922789888000*x^16 -
1/64023737057280000*x^18 + O(x^20)
```

```
sage: R.<x> = PowerSeriesRing(QQ, default_prec=10)
sage: R.default_prec()
10
sage: cos(x)
1 - 1/2*x^2 + 1/24*x^4 - 1/720*x^6 + 1/40320*x^8 + O(x^10)
```

Note: Subclasses of `Nonexact` which require to change the default precision should implement a method `set_default_prec`.

```python
class sage.structure.nonexact.Nonexact(prec=20):
    Bases: object
    A non-exact object with default precision.

    INPUT:

    • `prec` – a non-negative integer representing the default precision of `self` (default: 20)

    `default_prec()`
    Return the default precision for `self`.

    EXAMPLES:

    sage: R = QQ[[x]]
sage: R.default_prec()
    20
```
sage: R.<x> = PowerSeriesRing(QQ, default_prec=10)
sage: R.default_prec()
10

set_default_prec(prec)
Set the default precision for self

Warning: This method is outdated. If a subclass of class:None:exact requires this method, please overload it instead.

2.1.4 Global options

The GlobalOptions class provides a generic mechanism for setting and accessing global options for parents in one or several related classes, typically for customizing the representation of their elements. This class will eventually also support setting options on a parent by parent basis.

These options should be “attached” to one or more classes as an options method.

See also:

For good examples of GlobalOptions in action see sage.combinat.partition.Partitions.options and sage.combinat.tableau.Tableaux.options.

Construction of options classes

The general setup for creating a set of global options is:

```python
sage: from sage.structure.global_options import GlobalOptions
sage: class MyOptions(GlobalOptions):
    ...:     '''
    ...:     Nice options
    ...:     '''
    ...:     @OPTIONS
    ...:     '''
    ...:     NAME = 'option name'
    ...:     module = 'sage.some_module.some_file'
    ...:     option_class = 'name_of_class_controlled_by_options'
    ...:     first_option = dict(default='with_bells',
    ...:                         description='Changes the functionality of _repr_',
    ...:                         values=dict(with_bells='causes _repr_ to print with bells',
    ...:                                   with_whistles='causes _repr_ to print with␣
    ...:                                   _whistles'),
    ...:                         alias=dict(bells='option1', whistles='option2'))
    ...:     # second_option = dict(...)
    ...:     # third_option = dict(...)
```

Note the syntax using the class keyword. However, because of some metaclass magic, the resulting MyOptions object becomes an instance of GlobalOptions instead of a subclass. So, despite the class syntax, MyOptions is not a class.

The options constructed by GlobalOptions have to be explicitly associated to the class that they control using the following arguments:

- **NAME** – A descriptive name for the options class. This is optional; the default is the name of the constructed class.
• module – The sage module containing the options class (optional)

• option_class – The name of the options class. This is optional and defaults to NAME if not explicitly set.

It is only possible to pickle a GlobalOptions class if the corresponding module is specified and if the options are explicitly attached to the corresponding class as a options method.

Each option is specified as a dictionary which describes the possible values for the option and its documentation. The possible entries in this dictionary are:

• alias – Allows for several option values to do the same thing.

• alt_name – An alternative name for this option.

• checker – A validation function which returns whether a user supplied value is valid or not. This is typically useful for large lists of legal values such as NN.

• default – Gives the default value for the option.

• description – A one line description of the option.

• link_to – Links this option to another one in another set of global options. This is used for example to allow Partitions and Tableaux to share the same convention option.

• setter – A function which is called after the value of the option is changed.

• values – A dictionary assigning each valid value for the option to a short description of what it does.

• case_sensitive – (Default: True) True or False depending on whether the values of the option are case sensitive.

For each option, either a complete list of possible values, via values, or a validation function, via checker, must be given. The values can be quite arbitrary, including user-defined functions which customize the default behaviour of the classes such as the output of _repr_ or latex(). See Dispatchers below, and _dispatcher(), for more information.

The documentation for the options is automatically constructed from the docstring of the class by replacing the magic word @OPTIONS@ with a description of each option.

The basic structure for defining a GlobalOptions class is best illustrated by an example:

```python
sage: from sage.structure.global_options import GlobalOptions
sage: class Menu(object):
....:     class options(GlobalOptions):
....:         '''
....:         Fancy documentation
....:         -------------------
....:         @OPTIONS@
....:         
....:         The END!
....:         '''
....:         NAME = 'menu'
....:         entree = dict(default='soup',
....:                         description='The first course of a meal',
....:                         values=dict(soup='soup of the day', bread='oven baked'),
....:                         alias=dict(rye='bread'))
....:         appetizer = dict(alt_name='entree')
....:         main = dict(default='pizza', description='Main meal',
....:                      values=dict(pizza='thick crust', pasta='penne arrabiata'),
....:                      case_sensitive=False)
....:         dessert = dict(default='espresso', description='Dessert',
```

(continues on next page)
In the examples above, the options are constructed when the options object is created. However, it is also possible to construct the options dynamically using the GlobalOptions._add_to_options() methods.

For more details see GlobalOptions.

Accessing and setting option values

All options and their values, when they are strings, are forced to be lower case. The values of an options class can be set and accessed by calling the class or by treating the class as an array.

Continuing the example from Construction of options classes:

Note that, provided there is no ambiguity, options and their values can be abbreviated:

(sage) Menu.options('d')
'cake'
(sage) Menu.options('m', 't', des='esp', ent='sou') # get and set several values at once
['pizza', 10]
(sage) Menu.options(t=15)
(sage) Menu.options('tip')
15
(sage) Menu.options.tip
15
(sage) Menu.options(e='s', m='Pi'); Menu.options()
Current options for menu
- dessert: cake
- entree: soup
- main: pizza
- tip: 15
Setter functions

Each option of a `GlobalOptions` can be equipped with an optional setter function which is called after the value of the option is changed. In the following example, setting the option ‘add’ changes the state of the class by setting an attribute in this class using a `classmethod()`. Note that the options object is inserted after the creation of the class in order to access the `classmethod()` as `A.setter`:

```python
sage: from sage.structure.global_options import GlobalOptions
global
sage: class A(SageObject):
    ....:    state = 0
    ....:    @classmethod
    ....:    def setter(cls, option, val):
    ....:        cls.state += int(val)
sage: class options(GlobalOptions):
    ....:        NAME = "A"
    ....:        add = dict(default=1,
    ....:             checker=lambda v: int(v)>0,
    ....:             description='An option with a setter',
    ....:             setter=A.setter)
sage: A.options = options
sage: A.options
Current options for A
  - add: 1
sage: a = A(); a.state
1
sage: a.options()
Current options for A
  - add: 1
sage: a.options(add=4)
sage: a.state
5
sage: a.options()
Current options for A
  - add: 4
```

Documentation for options

The documentation for a `GlobalOptions` is automatically generated from the supplied options. For example, the generated documentation for the options menu defined in `Construction of options classes` is the following:

```
Fancy documentation
-------------------

OPTIONS:
```

(continues on next page)
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- ``appetizer`` -- alternative name for ``entree``
- ``dessert`` -- (default: ``espresso``)

  Dessert
  - ``cake`` -- waist begins again
  - ``cream`` -- fluffy, white stuff
  - ``espresso`` -- life begins again

- ``entree`` -- (default: ``soup``)

  The first course of a meal
  - ``bread`` -- oven baked
  - ``rye`` -- alias for ``bread``
  - ``soup`` -- soup of the day

- ``main`` -- (default: ``pizza``)

  Main meal
  - ``pasta`` -- penne arrabiata
  - ``pizza`` -- thick crust

- ``tip`` -- (default: ``10``)

  Reward for good service

The END!

See :class:`sage.structure.global_options.GlobalOptions` for more features of these options.

In addition, help on each option, and its list of possible values, can be obtained by (trying to) set the option equal to `?`:

```
sage: Menu.options.dessert?                  # not tested
  - ``dessert`` -- (default: ``espresso``)

  Dessert
  - ``cake`` -- waist begins again
  - ``cream`` -- fluffy, white stuff
  - ``espresso`` -- life begins again
```
Dispatchers

The whole idea of a GlobalOptions class is that the options change the default behaviour of the associated classes. This can be done either by simply checking what the current value of the relevant option is. Another possibility is to use the options class as a dispatcher to associated methods. To use the dispatcher feature of a GlobalOptions class it is necessary to implement separate methods for each value of the option where the naming convention for these methods is that they start with a common prefix and finish with the value of the option.

If the value of a dispatchable option is set equal to a (user defined) function then this function is called instead of a class method.

For example, the options MyOptions can be used to dispatch the _repr_ method of the associated class MyClass as follows:

```python
class MyClass(...):
    def _repr_(self):
        return self.options._dispatch(self, '_repr_', 'first_option')
    def _repr_with_bells(self):
        print('Bell!')
    def _repr_with_whistles(self):
        print('Whistles!')
class MyOptions(GlobalOptions):
    ...
```

In this example, first_option is an option of MyOptions which takes values bells, whistles, and so on. Note that it is necessary to make self, which is an instance of MyClass, an argument of the dispatcher because _dispatch() is a method of GlobalOptions and not a method of MyClass. Apart from MyOptions, as it is a method of this class, the arguments are the attached class (here MyClass), the prefix of the method of MyClass being dispatched, the option of MyOptions which controls the dispatching. All other arguments are passed through to the corresponding methods of MyClass. In general, a dispatcher is invoked as:

```python
self.options._dispatch(self, dispatch_to, option, *args, **kargs)
```

Usually this will result in the method dispatch_to + '_' + MyOptions(options) of self being called with arguments *args and **kargs (if dispatch_to[-1] == '_' then the method dispatch_to + MyOptions(options) is called).

If MyOptions(options) is itself a function then the dispatcher will call this function instead. In this way, it is possible to allow the user to customise the default behaviour of this method. See _dispatch() for an example of how this can be achieved.

The dispatching capabilities of GlobalOptions allows options to be applied automatically without needing to parse different values of the option (the cost is that there must be a method for each value). The dispatching capabilities can also be used to make one option control several methods:

```python
def __le__(self, other):
    return self.options._dispatch(self, '_le_', 'cmp', other)
def __ge__(self, other):
    return self.options._dispatch(self, '_ge_', 'cmp', other)
def _le_option_a(self, other):
    return ...
def _ge_option_a(self, other):
    return ...
def _le_option_b(self, other):
    return ...
```

(continues on next page)
def _ge_option_b(self, other):
    return ...

See _dispatch() for more details.

**Doc testing**

All of the options and their effects should be doc-tested. However, in order not to break other tests, all options should be returned to their default state at the end of each test. To make this easier, every GlobalOptions class has a _reset() method for doing exactly this.

**Pickling**

Options classes can only be pickled if they are the options for some standard sage class. In this case the class is specified using the arguments to GlobalOptions. For example options() is defined as:

```python
class Partitions(UniqueRepresentation, Parent):
    ...
    class options(GlobalOptions):
        NAME = 'Partitions'
        module = 'sage.combinat.partition'
        ...
```

Here is an example to test the pickling of a GlobalOptions instance:

```python
sage: TestSuite(Partitions.options).run()
```

**AUTHORS:**

- Andrew Mathas (2013): initial version
- Andrew Mathas (2016): overhaul making the options attributes, enabling pickling and attaching the options to a class.
- Jeroen Demeyer (2017): use subclassing to create instances

```python
class sage.structure.global_options.GlobalOptions(NAME=None, module='', option_class='', doc='', end_doc='', **options)
```

Bases: object

The GlobalOptions class is a generic class for setting and accessing global options for Sage objects.

While it is possible to create instances of GlobalOptions the usual way, the recommended syntax is to subclass from GlobalOptions. Thanks to some metaclass magic, this actually creates an instance of GlobalOptions instead of a subclass.

**INPUT** (as “attributes” of the class):

- **NAME** – specifies a name for the options class (optional; default: class name)
- **module** – gives the module that contains the associated options class
- **option_class** – gives the name of the associated module class (default: NAME)
- **option = dict(...)** – dictionary specifying an option

The options are specified by keyword arguments with their values being a dictionary which describes the option. The allowed/expected keys in the dictionary are:
• alias – defines alias/synonym for option values
• alt_name – alternative name for an option
• checker – a function for checking whether a particular value for the option is valid
• default – the default value of the option
• description – documentation string
• link_to – links to an option for this set of options to an option in another GlobalOptions
• setter – a function (class method) which is called whenever this option changes
• values – a dictionary of the legal values for this option (this automatically defines the corresponding checker); this dictionary gives the possible options, as keys, together with a brief description of them
• case_sensitive – (default: True) True or False depending on whether the values of the option are case sensitive

Options and their values can be abbreviated provided that this abbreviation is a prefix of a unique option.

EXAMPLES:

```python
sage: from sage.structure.global_options import GlobalOptions
sage: class Menu(object):
    ....:     class options(GlobalOptions):
        ....:         '''
        ....:         Fancy documentation
        ....:         -------------------
        ....:         @OPTIONS
        ....:         '''
        ....:         NAME = 'menu'
        ....:         entree = dict(default='soup',
        ....:                         description='The first course of a meal',
        ....:                         values=dict(soup='soup of the day',
          ....:                                bread='oven baked'),
        ....:                         alias=dict(rye='bread'))
        ....:         appetizer = dict(alt_name='entree')
        ....:         main = dict(default='pizza',
        ....:                         description='Main meal',
        ....:                         values=dict(pizza='thick crust',
          ....:                                pasta='penne arrabiata'),
        ....:                         case_sensitive=False)
        ....:         dessert = dict(default='espresso',
        ....:                         description='Dessert',
        ....:                         values=dict(espresso='life begins again',
          ....:                                cake='waist begins again',
          ....:                                cream='fluffy white stuff'))
        ....:         tip = dict(default=10,
        ....:                         description='Reward for good service',
        ....:                         checker=lambda tip: tip in range(0,20))

sage: Menu.options
Current options for menu
- dessert: espresso
- entree: soup
- main: pizza
- tip: 10
sage: Menu.options(entree='s')  # unambiguous abbreviations are allowed
sage: Menu.options(t=15)
```

(continues on next page)
sage: (Menu.options['tip'], Menu.options('t'))
(15, 15)
sage: Menu.options()
Current options for menu
- dessert: espresso
- entree: soup
- main:  pizza
- tip:  15
sage: Menu.options._reset(); Menu.options()
Current options for menu
- dessert: espresso
- entree: soup
- main:  pizza
- tip:  10
sage: Menu.options.tip=40
Traceback (most recent call last):
...  ValueError: 40 is not a valid value for tip in the options for menu
sage: Menu.options(m='p')  # ambiguous abbreviations are not allowed
Traceback (most recent call last):
...  ValueError: p is not a valid value for main in the options for menu

The documentation for the options class is automatically generated from the information which specifies the options:

Fancy documentation
-------------------

OPTIONS:

- dessert: (default: espresso)
  Dessert
  - `cake`  -- waist begins again
  - `cream` -- fluffy white stuff
  - `espresso` -- life begins again

- entree: (default: soup)
  The first course of a meal
  - `bread` -- oven baked
  - `rye`   -- alias for bread
  - `soup`  -- soup of the day

- main: (default: pizza)
  Main meal
  - `pasta` -- penne arrabiata
  - `pizza` -- thick crust

- tip: (default: 10)
Reward for good service

End of Fancy documentation

See :class:`sage.structure.global_options.GlobalOptions` for more features of these options.

The possible values for an individual option can be obtained by (trying to) set it equal to `?`:

```sage
sage: Menu.options(des='?')
- `dessert` -- (default: `espresso`)
  Dessert

- `cake` -- waist begins again
- `cream` -- fluffy white stuff
- `espresso` -- life begins again
```

Current value: espresso

```
class sage.structure.global_options.GlobalOptionsMeta
    Bases: type
    Metaclass for GlobalOptions

    This class is itself an instance of GlobalOptionsMetaMeta, which implements the subclass magic.

class sage.structure.global_options.GlobalOptionsMetaMeta
    Bases: type

class sage.structure.global_options.Option(options, name)
    Bases: object
    An option.

    Each option for an options class is an instance of this class which implements the magic that allows the options to the attributes of the options class that can be looked up, set and called.

    By way of example, this class implements the following functionality.

    EXAMPLES:

    ```sage
    sage: Partitions.options.display = 'compact'
    sage: Partitions.options.display('list')
    sage: Partitions.options._reset()
    ```
```

2.1. Parents 43
2.2 Old-Style Parents ( Deprecated)

2.2.1 Base class for old-style parent objects

CLASS HIERARCHY:

SageObject
  Parent
    ParentWithBase  ParentWithGens

class sage.structure.parent_old.Parent
  Bases: sage.structure.parent.Parent

Parents are the Sage / mathematical analogues of container objects in computer science.

2.2.2 Base class for old-style parent objects with a base ring

class sage.structure.parent_base.ParentWithBase
  Bases: sage.structure.parent_old.Parent

This class is being deprecated, see parent.Parent for the new model.

   base_extend(X)

2.2.3 Base class for old-style parent objects with generators

   Note: This class is being deprecated, see sage.structure.parent.Parent and sage.structure.
   category_object.CategoryObject for the new model.

Many parent objects in Sage are equipped with generators, which are special elements of the object. For example, the
polynomial ring $\mathbb{Z}[x, y, z]$ is generated by $x, y,$ and $z$. In Sage the $i^{th}$ generator of an object $X$ is obtained using
the notation $X.gen(i)$. From the Sage interactive prompt, the shorthand notation $X.i$ is also allowed.

REQUIRED: A class that derives from ParentWithGens must define the ngens() and gen(i) methods.

OPTIONAL: It is also good if they define gens() to return all gens, but this is not necessary.

The gens function returns a tuple of all generators, the ngens function returns the number of generators.

The _assign_names functions is for internal use only, and is called when objects are created to set the generator
names. It can only be called once.

The following examples illustrate these functions in the context of multivariate polynomial rings and free modules.

EXAMPLES:

```
sage: R = PolynomialRing(ZZ, 3, 'x')
sage: R.ngens()
3
sage: R.gen(0)
x0
sage: R.gens()
(x0, x1, x2)
```
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(continued from previous page)

```python
sage: R.variable_names()
('x0', 'x1', 'x2')
```

This example illustrates generators for a free module over \( \mathbb{Z} \).

```python
sage: M = FreeModule(ZZ, 4)
sage: M
Ambient free module of rank 4 over the principal ideal domain Integer Ring
sage: M.ngens()
4
sage: M.gen(0)
(1, 0, 0, 0)
sage: M.gens()
((1, 0, 0, 0), (0, 1, 0, 0), (0, 0, 1, 0), (0, 0, 0, 1))
```

```python
class sage.structure.parent_gens.ParentWithGens
    Bases: sage.structure.parent_base.ParentWithBase

    EXAMPLES:

    sage: from sage.structure.parent_gens import ParentWithGens
    sage: class MyParent(ParentWithGens):
    ....:     def ngens(self):
    ....:         return 3
    ....:
    ....:     P = MyParent(base=QQ, names='a,b,c', normalize=True, category=Groups())
    ....:     P
    Category of groups
    sage: P._names
    ('a', 'b', 'c')

gen(i=0)
gens()
    Return a tuple whose entries are the generators for this object, in order.

hom(im_gens, codomain=None, base_map=None, category=None, check=True)
    Return the unique homomorphism from self to codomain that sends self.gens() to the entries of im_gens and induces the map base_map on the base ring. Raises a TypeError if there is no such homomorphism.

    INPUT:

    - im_gens – the images in the codomain of the generators of this object under the homomorphism
    - codomain – the codomain of the homomorphism
    - base_map – a map from the base ring of the domain into something that coerces into the codomain
    - category – the category of the resulting morphism
    - check – whether to verify that the images of generators extend to define a map (using only canonical coercions)

    OUTPUT:

    - a homomorphism self \rightarrow \text{codomain}

    Note: As a shortcut, one can also give an object X instead of im_gens, in which case return the (if it
exists) natural map to X.

EXAMPLES: Polynomial Ring We first illustrate construction of a few homomorphisms involving a polynomial ring.

```python
sage: R.<x> = PolynomialRing(ZZ)

sage: f = R.hom([5], QQ)

sage: f(x^2 - 19)
6

sage: R.<x> = PolynomialRing(QQ)

sage: f = R.hom([5], GF(7))
Traceback (most recent call last):
  ...
ValueError: relations do not all (canonically) map to 0 under map determined by
   images of generators

sage: R.<x> = PolynomialRing(GF(7))

sage: f = R.hom([3], GF(49, 'a'))

sage: f
Ring morphism:
  From: Univariate Polynomial Ring in x over Finite Field of size 7
  To:   Finite Field in a of size 7^2
  Defn: x |--> 3

sage: f(x+6)
2

sage: f(x^2+1)
3
```

EXAMPLES: Natural morphism

```python
sage: f = ZZ.hom(GF(5))

sage: f(7)
2

sage: f
Natural morphism:
  From: Integer Ring
  To:   Finite Field of size 5
```

There might not be a natural morphism, in which case a TypeError exception is raised.

```python
sage: QQ.hom(ZZ)
Traceback (most recent call last):
  ...
TypeError: natural coercion morphism from Rational Field to Integer Ring not
  defined
```

You can specify a map on the base ring:

```python
sage: k = GF(2)

sage: R.<a> = k[]

sage: l.<a> = k.extension(a^3 + a^2 + 1)

sage: R.<b> = l[]

sage: m.<b> = l.extension(b^2 + b + a)
```

(continues on next page)
\begin{verbatim}
sage: n.<z> = GF(2^6)
sage: m.hom([z^4 + z^3 + 1], base_map=l.hom([z^5 + z^4 + z^2]))
Ring morphism:
    From: Univariate Quotient Polynomial Ring in b over Finite Field in a of size 2^3 with modulus b^2 + b + a
    To:   Finite Field in z of size 2^6
    Defn: b |--> z^4 + z^3 + 1
    with map of base ring

gens()
class sage.structure.parent_gens.localvars
Bases: object

Context manager for safely temporarily changing the variables names of an object with generators.

Objects with named generators are globally unique in Sage. Sometimes, though, it is very useful to be able to temporarily display the generators differently. The new Python with statement and the localvars context manager make this easy and safe (and fun!)

Suppose X is any object with generators. Write

\begin{verbatim}
with localvars(X, names[, latex_names] [,normalize=False]):
    some code
...
\end{verbatim}

and the indented code will be run as if the names in X are changed to the new names. If you give normalize=True, then the names are assumed to be a tuple of the correct number of strings.

EXAMPLES:

\begin{verbatim}
sage: R.<x,y> = PolynomialRing(QQ,2)
sage: with localvars(R, 'z,w'):
    ....:    print(x^3 + y^3 - x*y)
    z^3 + w^3 - z*w
\end{verbatim}

\begin{Verbatim}
Note: I wrote this because it was needed to print elements of the quotient of a ring R by an ideal I using the print function for elements of R. See the code in quotient_ring_element.pyx.
\end{Verbatim}

AUTHOR:
• William Stein (2006-10-31)

2.2.4 Pure python code for abstract base class for objects with generators

sage.structure.gens_py.abelian_iterator(M)
sage.structure.gens_py.multiplicative_iterator(M)
\end{verbatim}
3.1 Elements

AUTHORS:

- David Harvey (2006-10-16): changed CommutativeAlgebraElement to derive from CommutativeRingElement instead of AlgebraElement
- David Harvey (2006-10-29): implementation and documentation of new arithmetic architecture
- Gonzalo Tornaria (2007-06): recursive base extend for coercion – lots of tests
- Robert Bradshaw (2007-2010): arithmetic operators and coercion
- Maarten Derickx (2010-07): added architecture for is_square and sqrt
- Jeroen Demeyer (2016-08): moved all coercion to the base class Element, see trac ticket #20767

3.1.1 The Abstract Element Class Hierarchy

This is the abstract class hierarchy, i.e., these are all abstract base classes.

```
SageObject
  Element
    ModuleElement
      RingElement
        CommutativeRingElement
          IntegralDomainElement
            DedekindDomainElement
              PrincipalIdealDomainElement
                EuclideanDomainElement
        FieldElement
        CommutativeAlgebraElement
          Expression
        AlgebraElement
          Matrix
            InfinityElement
        AdditiveGroupElement
          Vector
    MonoidElement
```
3.1.2 How to Define a New Element Class

Elements typically define a method \_new\_c, e.g.,

```python
cdef \_new\_c(self, defining data):
    cdef FreeModuleElement\_generic\_dense x
    x = FreeModuleElement\_generic\_dense.__new__(FreeModuleElement\_generic\_dense)
    x._parent = self._parent
    x._entries = v
```

that creates a new sibling very quickly from defining data with assumed properties.

**Arithmetic for Elements**

Sage has a special system for handling arithmetic operations on Sage elements (that is instances of `Element`), in particular to manage uniformly mixed arithmetic operations using the *coercion model*. We describe here the rules that must be followed by both arithmetic implementers and callers.

**A quick summary for the impatient**

To implement addition for any `Element` subclass, override the `def \_add\_(self, other)` method instead of the usual Python `\_add\_` special method. Within `\_add\_(self, other)`, you may assume that `self` and `other` have the same parent.

If the implementation is generic across all elements in a given category \( C \), then this method can be put in \( C \). `ElementMethods`.

When writing Cython code, `\_add\_` should be a cpdef method: `cpdef \_add\_(self, other)`.

When doing arithmetic with two elements having different parents, the *coercion model* is responsible for “coercing” them to a common parent and performing arithmetic on the coerced elements.

**Arithmetic in more detail**

The aims of this system are to provide (1) an efficient calling protocol from both Python and Cython, (2) uniform coercion semantics across Sage, (3) ease of use, (4) readability of code.

We will take addition as an example; all other operators are similar. There are two relevant functions, with differing names (single vs. double underscores).

- `def Element.__add__(left, right)`

  This function is called by Python or Cython when the binary `+` operator is encountered. It assumes that at least one of its arguments is an `Element`.

  It has a fast pathway to deal with the most common case where both arguments have the same parent. Otherwise, it uses the coercion model to work out how to make them have the same parent. The coercion model then adds the coerced elements (technically, it calls `operator.add`). Note that the result of coercion is not required to be a Sage `Element`; it could be a plain Python type.
Note that, although this function is declared as `def`, it doesn’t have the usual overheads associated with Python functions (either for the caller or for `__add__` itself). This is because Python has optimised calling protocols for such special functions.

- **def Element._add_(self, other)**

  This is the function that you should override to implement addition in a subclass of `Element`.

  The two arguments to this function are guaranteed to have the **same parent**, but not necessarily the same Python type.

  When implementing `_add_` in a Cython extension type, use `cpdef _add_` instead of `def _add_`.

  In Cython code, if you want to add two elements and you know that their parents are identical, you are encouraged to call this function directly, instead of using `x + y`. This only works if Cython knows that the left argument is an `Element`. You can always cast explicitly: `(<Element>x)._add_(y)` to force this. In plain Python, `x + y` is always the fastest way to add two elements because the special method `__add__` is optimized unlike the normal method `_add_`.

  The difference in the names of the arguments (`left, right` versus `self, other`) is intentional: `self` is guaranteed to be an instance of the class in which the method is defined. In Cython, we know that at least one of `left` or `right` is an instance of the class but we do not know a priori which one.

  Powering is a special case: first of all, the 3-argument version of `pow()` is not supported. Second, the coercion model checks whether the exponent looks like an integer. If so, the function `_pow_int` is called. If the exponent is not an integer, the arguments are coerced to a common parent and `_pow_` is called. So, if your type only supports powering to an integer exponent, you should implement only `_pow_int`. If you want to support arbitrary powering, implement both `_pow_` and `_pow_int`.

  For addition, multiplication and powering (not for other operators), there is a fast path for operations with a C `long`. For example, implement `cdef _add_long(self, long n)` with optimized code for `self + n`. The addition and multiplication are assumed to be commutative, so they are also called for `n + self` or `n * self`. From Cython code, you can also call `_add_long` or `_mul_long` directly. This is strictly an optimization: there is a default implementation falling back to the generic arithmetic function.

**Examples**

We need some `Parent` to work with:

```
sage: from sage.structure.parent import Parent
sage: class ExampleParent(Parent):
    ....:     def __init__(self, name, **kwds):
    ....:         Parent.__init__(self, **kwds)
    ....:         self.rename(name)
```

We start with a very basic example of a Python class implementing `_add_`:

```
sage: from sage.structure.element import Element
sage: class MyElement(Element):
    ....:     def _add_(self, other):
    ....:         return 42
sage: p = ExampleParent("Some parent")
sage: x = MyElement(p)
sage: x + x
42
```

When two different parents are involved, this no longer works since there is no coercion:
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```python
sage: q = ExampleParent("Other parent")
sage: y = MyElement(q)
sage: x + y
Traceback (most recent call last):
  ... TypeError: unsupported operand parent(s) for +: 'Some parent' and 'Other parent'
```

If `_add_` is not defined, an error message is raised, referring to the parents:

```python
sage: x = Element(p)
sage: x._add_(x)
Traceback (most recent call last):
  ... AttributeError: 'sage.structure.element.Element' object has no attribute '_add_
```

We can also implement arithmetic generically in categories:

```python
sage: class MyCategory(Category):
    ....:     def super_categories(self):
    ....:         return [Sets()]
    ....:     class ElementMethods:
    ....:         def _add_(self, other):
    ....:             return 42
sage: p = ExampleParent("Parent in my category", category=MyCategory())
sage: x = Element(p)
sage: x + x
42
```

**Implementation details**

Implementing the above features actually takes a bit of magic. Casual callers and implementers can safely ignore it, but here are the details for the curious.

To achieve fast arithmetic, it is critical to have a fast path in Cython to call the `_add_` method of a Cython object. So we would like to declare `_add_` as a `cpdef` method of class `Element`. Remember however that the abstract classes coming from categories come after `Element` in the method resolution order (or fake method resolution order in case of a Cython class). Hence any generic implementation of `_add_` in such an abstract class would in principle be shadowed by `Element._add_`. This is worked around by defining `Element._add_` as a `cdef` instead of a `cpdef` method. Concrete implementations in subclasses should be `cpdef` or `def` methods.

Let us now see what happens upon evaluating `x + y` when `x` and `y` are instances of a class that does not implement `_add_` but where `_add_` is implemented in the category. First, `x._add__(y)` is called, where `_add__` is implemented in `Element`. Assuming that `x` and `y` have the same parent, a Cython call to `x._add__(y)` will be done. The latter is implemented to trigger a Python level call to `x._add__(y)` which will succeed as desired.
In case that Python code calls \texttt{x\_add\_y} directly, \texttt{Element\_add\_} will be invisible, and the method lookup will continue down the MRO and find the \texttt{\_add\_} method in the category.

\textbf{class} sage.structure.element.AdditiveGroupElement
\texttt{\Bases: sage.structure.element.ModuleElement}

Generic element of an additive group.

\texttt{order()}
Return additive order of element

\textbf{class} sage.structure.element.AlgebraElement
\texttt{\Bases: sage.structure.element.RingElement}

\textbf{class} sage.structure.element.CommutativeAlgebraElement
\texttt{\Bases: sage.structure.element.CommutativeRingElement}

\textbf{class} sage.structure.element.CommutativeRingElement
\texttt{\Bases: sage.structure.element.RingElement}

Base class for elements of commutative rings.

\texttt{divides(x)}
Return \texttt{True} if \texttt{self} divides \texttt{x}.

\textbf{EXAMPLES:}

\begin{verbatim}
sage: P.<x> = PolynomialRing(QQ)
sage: x.divides(x^2)
 True
sage: x.divides(x^2+2)
False
sage: (x^2+2).divides(x)
False
sage: P.<x> = PolynomialRing(ZZ)
sage: x.divides(x^2)
 True
sage: x.divides(x^2+2)
False
sage: (x^2+2).divides(x)
False
\end{verbatim}

\texttt{trac ticket \#5347} has been fixed:

\begin{verbatim}
sage: K = GF(7)
sage: K(3).divides(1)
 True
sage: K(3).divides(K(1))
 True
\end{verbatim}

\begin{verbatim}
sage: R = Integers(128)
sage: R(0).divides(1)
False
sage: R(0).divides(0)
 True
sage: R(0).divides(R(0))
 True
sage: R(1).divides(0)
 False
\end{verbatim}

(continues on next page)
If $x$ has different parent than `self`, they are first coerced to a common parent if possible. If this coercion fails, it returns a `TypeError`. This fixes [trac ticket #5759](https://trac.sagemath.org/ticket/5759).

```
sage: Zmod(2)(0).divides(Zmod(2)(0))
True
sage: Zmod(2)(0).divides(Zmod(2)(1))
False
sage: Zmod(5)(1).divides(Zmod(2)(1))
Traceback (most recent call last):
  ... TypeError: no common canonical parent for objects with parents: 'Ring of \(\mathbb{Z}\) modulo 5' and 'Ring of integers modulo 2'
sage: Zmod(35)(4).divides(Zmod(7)(1))
True
sage: Zmod(35)(7).divides(Zmod(7)(1))
False
```

`inverse_mod(I)`

Return an inverse of `self` modulo the ideal $I$, if defined, i.e., if $I$ and `self` together generate the unit ideal.

**EXAMPLES:**

```
sage: F = GF(25)
sage: x = F.gen()
sage: z = F.zero()
sage: x.inverse_mod(F.ideal(z))
2*z2 + 3
sage: x.inverse_mod(F.ideal(1))
1
sage: z.inverse_mod(F.ideal(1))
1
sage: z.inverse_mod(F.ideal(z))
Traceback (most recent call last):
  ... ValueError: an element of a proper ideal does not have an inverse modulo that
˓→ideal
```

`is_square(root=False)`

Return whether or not the ring element `self` is a square.

If the optional argument `root` is `True`, then also return the square root (or `None`, if it is not a square).

**INPUT:**

- `root` - whether or not to also return a square root (default: `False`)

**OUTPUT:**

- `bool` – whether or not a square
- `object` – (optional) an actual square root if found, and `None` otherwise.
EXAMPLES:

```
sage: R.<x> = PolynomialRing(QQ)
sage: f = 12*(x+1)^2 * (x+3)^2
sage: f.is_square()
False
sage: f.is_square(root=True)
(False, None)
sage: h = f/3
sage: h.is_square()
True
sage: h.is_square(root=True)
(True, 2*x^2 + 8*x + 6)
```

Note: This is the is_square implementation for general commutative ring elements. It’s implementation is to raise a NotImplementedError. The function definition is here to show what functionality is expected and provide a general framework.

```
mod(I)
```

Return a representative for self modulo the ideal I (or the ideal generated by the elements of I if I is not an ideal.)

EXAMPLES: Integers Reduction of 5 modulo an ideal:

```
sage: n = 5
sage: n.mod(3*ZZ)
2
```

Reduction of 5 modulo the ideal generated by 3:

```
sage: n.mod(3)
2
```

Reduction of 5 modulo the ideal generated by 15 and 6, which is (3).

```
sage: n.mod([15,6])
2
```

EXAMPLES: Univariate polynomials

```
sage: R.<x> = PolynomialRing(QQ)
sage: f = x^3 + x + 1
sage: f.mod(x + 1)
-1
```

Reduction for \(\mathbb{Z}[x]\):

```
sage: R.<x> = PolynomialRing(ZZ)
sage: f = x^3 + x + 1
sage: f.mod(x + 1)
-1
```

When little is implemented about a given ring, then mod may simply return \(f\).
EXAMPLES: Multivariate polynomials
We reduce a polynomial in two variables modulo a polynomial and an ideal:

```
sage: R.<x,y,z> = PolynomialRing(QQ, 3)
sage: (x^2 + y^2 + z^2).mod(x+y+z)
sage: 2*y^2 + 2*y*z + 2*z^2
```

Notice above that \(x\) is eliminated. In the next example, both \(y\) and \(z\) are eliminated:

```
sage: (x^2 + y^2 + z^2).mod((x - y, y - z))
sage: 3*z^2
```

```
sage: f = (x^2 + y^2 + z^2)^2; f
sage: x^4 + 2*x^2*y^2 + y^4 + 2*x^2*z^2 + 2*y^2*z^2 + z^4
```
```
sage: f.mod((x - y, y - z))
sage: 9*z^4
```

In this example \(y\) is eliminated:

```
sage: (x^2 + y^2 + z^2).mod((x^3, y - z))
sage: x^2 + 2*z^2
```

\sqrt{\text{extend=True, all=False, name=None}}

It computes the square root.

**INPUT:**

- `extend` - Whether to make a ring extension containing a square root if \(\text{self}\) is not a square (default: True)
- `all` - Whether to return a list of all square roots or just a square root (default: False)
- `name` - Required when `extend=True` and \(\text{self}\) is not a square. This will be the name of the generator extension.

**OUTPUT:**

- If all=False it returns a square root. (throws an error if extend=False and self is not a square)
- If all=True it returns a list of all the square roots (could be empty if extend=False and self is not a square)

**ALGORITHM:**

It uses is_square(root=true) for the hard part of the work, the rest is just wrapper code.

**EXAMPLES:**

```
sage: R.<x> = ZZ[]
sage: (x^2).sqrt()
x
sage: f=x^2-4*x+4; f.sqrt(all=True)
[x - 2, -x + 2]
sage: sqtx=x.sqrt(name="y"); sqtx
y
sage: sqtx^2
x
sage: x.sqrt(all=true,name="y")
[y, -y]
sage: x.sqrt(extend=False,all=True)
```
[]
sage: x.sqrt()
Traceback (most recent call last):
...
TypeError: Polynomial is not a square. You must specify the name of the square\n→ root when using the default extend = True
sage: x.sqrt(extend=False)
Traceback (most recent call last):
...
ValueError: trying to take square root of non-square x with extend = False

class sage.structure.element.DedekindDomainElement
    Bases: sage.structure.element.IntegralDomainElement

class sage.structure.element.Element
    Bases: sage.structure.sage_object.SageObject

Generic element of a structure. All other types of elements (RingElement, ModuleElement, etc) derive from
this type.

Subtypes must either call __init__() to set _parent, or may set _parent themselves if that would be more
efficient.

__richcmp__(left, right, op)
Basic default implementation of rich comparisons for elements with equal parents.
It does a comparison by id for == and !=. Calling this default method with <, <=, > or >= will return
NotImplemented.

EXAMPLES:
sage: from sage.structure.parent import Parent
sage: from sage.structure.element import Element
sage: P = Parent()
...

We now create an Element class where we define __richcmp__ and check that comparison works:

sage: cython(''
    ....: from sage.structure.richcmp cimport rich_to_bool
    ....: from sage.structure.element cimport Element
    ....: cdef class FloatCmp(Element):
    ....:     cdef float x
    ....:     def __init__(self, float v):
    ....:         self.x = v
    ....:     cpdef __richcmp__(self, other, int op):

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(continued from previous page)

```python
...:   cdef float x1 = (<FloatCmp>self).x
...:   cdef float x2 = (<FloatCmp>other).x
...:   return rich_to_bool(op, (x1 > x2) - (x1 < x2))
...:  

sage: a = FloatCmp(1)
sage: b = FloatCmp(2)
sage: a <= b, b <= a
(True, False)
```

**__add__(left, right)**
Top-level addition operator for Element invoking the coercion model.

See *Arithmetic for Elements*.

EXAMPLES:

```python
sage: from sage.structure.element import Element
sage: class MyElement(Element):
    ....:   def __add__(self, other):
    ....:       return 42
sage: e = MyElement(Parent())
sage: e + e
42
```

**__sub__(left, right)**
Top-level subtraction operator for Element invoking the coercion model.

See *Arithmetic for Elements*.

EXAMPLES:

```python
sage: from sage.structure.element import Element
sage: class MyElement(Element):
    ....:   def __sub__(self, other):
    ....:       return 42
sage: e = MyElement(Parent())
sage: e - e
42
```

**__neg__()**
Top-level negation operator for Element.

EXAMPLES:

```python
sage: from sage.structure.element import Element
sage: class MyElement(Element):
    ....:   def __neg__(self):
    ....:       return 42
sage: e = MyElement(Parent())
sage: -e
42
```

**__mul__(left, right)**
Top-level multiplication operator for Element invoking the coercion model.

See *Arithmetic for Elements*.
EXAMPLES:

```
sage: from sage.structure.element import Element
sage: class MyElement(Element):
    ....:    def _mul_(self, other):
    ....:        return 42
sage: e = MyElement(Parent())
sage: e * e
42
```

__truediv__(left, right)
Top-level true division operator for Element invoking the coercion model.

See Arithmetic for Elements.

EXAMPLES:

```
sage: operator.truediv(2, 3)
2/3
sage: operator.truediv(pi, 3)
1/3*pi
sage: x = polygen(QQ, 'x')
sage: K.<i> = NumberField(x^2 + 1)
sage: operator.truediv(2, K.ideal(i+1))
Fractional ideal (-i + 1)
```

__floordiv__(left, right)
Top-level floor division operator for Element invoking the coercion model.

See Arithmetic for Elements.

EXAMPLES:

```
sage: 7 // 3
2
sage: 7 // int(3)
2
sage: int(7) // 3
2
```

```
sage: from sage.structure.element import Element
sage: class MyElement(Element):
    ....:    def _div_(self, other):
    ....:        return 42
sage: e = MyElement(Parent())
sage: e // e
42
```
__mod__(left, right)
Top-level modulo operator for Element invoking the coercion model.

See Arithmetic for Elements.

EXAMPLES:

```python
sage: 7 % 3
1
sage: 7 % int(3)
1
sage: int(7) % 3
1
```

```python
sage: from sage.structure.element import Element
sage: class MyElement(Element):
....:     def _mod_(self, other):
....:         return 42
sage: e = MyElement(Parent())
```

```python
sage: e % e
42
```

base_extend(R)
base_ring()
Returns the base ring of this element’s parent (if that makes sense).

category()
is_zero()
Returns True if self equals self.parent()(0).

The default implementation is to fall back to not self.__bool__.

**Warning:** Do not re-implement this method in your subclass but implement __bool__ instead.

n(prec=None, digits=None, algorithm=None)
Alias for numerical_approx().

EXAMPLES:

```python
sage: (2/3).n()
```

```python
0.6666666666666667
```

element_numerical_approx(prec=None, digits=None, algorithm=None)
Returns a numerical approximation of self with prec bits (or decimal digits) of precision.

No guarantee is made about the accuracy of the result.

INPUT:

- prec – precision in bits
- digits – precision in decimal digits (only used if prec is not given)
- algorithm – which algorithm to use to compute this approximation (the accepted algorithms depend on the object)
If neither \texttt{prec} nor \texttt{digits} is given, the default precision is 53 bits (roughly 16 digits).

**EXAMPLES:**

\begin{verbatim}
sage: (2/3).numerical_approx()
0.666666666666667
sage: pi.n(digits=10)
3.141592654
sage: pi.n(prec=20)
3.1416
\end{verbatim}

\textbf{parent}(x=None)

Return the parent of this element; or, if the optional argument \texttt{x} is supplied, the result of coercing \texttt{x} into the parent of this element.

\textbf{subs}(inDict=None,**kwds)

Substitutes given generators with given values while not touching other generators. This is a generic wrapper around \texttt{__call__}. The syntax is meant to be compatible with the corresponding method for symbolic expressions.

**INPUT:**

- \texttt{inDict} - (optional) dictionary of inputs
- **\texttt{kwds}** - named parameters

**OUTPUT:**

- new object if substitution is possible, otherwise self.

**EXAMPLES:**

\begin{verbatim}
sage: x, y = PolynomialRing(ZZ,2,'xy').gens()
sage: f = x^2 + y + x^2*y^2 + 5
sage: f((5,y))
25*y^2 + y + 30
sage: f.subs({x:5})
25*y^2 + y + 30
sage: (1/f).subs(x=5)
1/(25*y^2 + y + 30)
sage: Integer(5).subs(x=4)
5
\end{verbatim}

\textbf{substitute}(inDict=None,**kwds)

This is an alias for self.subs().

**INPUT:**

- \texttt{inDict} - (optional) dictionary of inputs
- **\texttt{kwds}** - named parameters

**OUTPUT:**

- new object if substitution is possible, otherwise self.

**EXAMPLES:**
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```python
sage: x, y = PolynomialRing(ZZ, 2, 'xy').gens()
sage: f = x^2 + y + x^2*y^2 + 5
sage: f((5, y))
25*y^2 + y + 30
sage: f.substitute({x: 5})
25*y^2 + y + 30
sage: f.substitute(x=5)
25*y^2 + y + 30
sage: (1/f).substitute(x=5)
1/(25*y^2 + y + 30)
sage: Integer(5).substitute(x=4)
5
```

```python
class sage.structure.element.ElementWithCachedMethod
Bases: sage.structure.element.Element

An element class that fully supports cached methods.

**NOTE:**

The `cached_method` decorator provides a convenient way to automatically cache the result of a computation. Since trac ticket #11115, the cached method decorator applied to a method without optional arguments is faster than a hand-written cache in Python, and a cached method without any arguments (except `self`) is actually faster than a Python method that does nothing more but to return 1. A cached method can also be inherited from the parent or element class of a category.

However, this holds true only if attribute assignment is supported. If you write an extension class in Cython that does not accept attribute assignment then a cached method inherited from the category will be slower (for `Parent`) or the cache would even break (for `Element`).

This class should be used if you write an element class, cannot provide it with attribute assignment, but want that it inherits a cached method from the category. Under these conditions, your class should inherit from this class rather than `Element`. Then, the cache will work, but certainly slower than with attribute assignment. Lazy attributes work as well.

**EXAMPLES:**

We define three element extension classes. The first inherits from `Element`, the second from this class, and the third simply is a Python class. We also define a parent class and, in Python, a category whose element and parent classes define cached methods.

```python
sage: cython_code = ["from sage.structure.element cimport Element," + "ElementWithCachedMethod", + "from sage.structure.richcmp cimport richcmp", + "cdef class MyBrokenElement(Element):", + " cdef public object x", + " def __init__(self, P, x):", + " self.x = x", + " Element.__init__(self, P), -self.x)", + " def __repr__(self):", + " return MyBrokenElement(self.parent(), -self.x)", + " def _richcmp_(left, right, int op):", + " return '<%s>' % self.x", + " def __hash__(self):", + " return hash(self.x)", + " cpdef _richcmp_(left, right, int op):", + " (continues on next page)"
```

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....:    "    return richcmp(left.x, right.x, op)",
....:    "    def raw_test(self):
....:        "    return -self",
....:    "cdef class MyElement(ElementWithCachedMethod):",
....:    "    cdef public object x",
....:    "    def __init__(self, P, x):
....:        "    self.x = x",
....:    "    Element.__init__(self, P)",
....:    "    def __neg__(self):
....:        "    return MyElement(self.parent(), -self.x)",
....:    "    def __repr__(self):
....:        "    return '%<%>
....:    "    def __hash__(self):
....:        "    return hash(self.x)",
....:    "    cpdef _richcmp_(left, right, int op):
....:        "    return richcmp(left.x, right.x, op)",
....:    "    def raw_test(self):
....:        "    return -self",
....:    "class MyPythonElement(MyBrokenElement): pass",
....:    "from sage.structure.parent cimport Parent",
....:    "cdef class MyParent(Parent):",
....:    "    Element = MyElement"
]sage: cython('\n'.join(cython_code))
sage: cython_code = ['"from sage.all import cached_method, cached_in_parent_method,
Category, Objects",
....:    "class MyCategory(Category):
....:        "    @cached_method",
....:    "    def super_categories(self):
....:        "    return [Objects()]
....:    "    class ElementMethods",
....:    "        "    @cached_method",
....:    "        "    def element_cache_test(self):
....:        "    return -self",
....:    "        "    @cached_in_parent_method",
....:    "        "    def element_via_parent_test(self):
....:        "    return -self",
....:    "    class ParentMethods",
....:    "        "    @cached_method",
....:    "        "    def one(self):
....:        "    return self.element_class(self,1)
....:    "    @cached_method",
....:    "    def invert(self, x):
....:        "    return -x]
sage: cython('\n'.join(cython_code))
sage: C = MyCategory()
sage: P = MyParent(category=C)
sage: ebroken = MyBrokenElement(P,5)
sage: e = MyElement(P,5)

The cached methods inherited by MyElement works:

```
sage: e.element_cache_test()
```

(continues on next page)
The other element class can only inherit a cached_in_parent_method, since the cache is stored in the parent. In fact, equal elements share the cache, even if they are of different types:

```
sage: e == ebroken
True
sage: type(e) == type(ebroken)
False
sage: ebroken.element_via_parent_test() is e.element_via_parent_test()
True
```

However, the cache of the other inherited method breaks, although the method as such works:

```
sage: ebroken.element_cache_test()
<-5>
sage: ebroken.element_cache_test() is ebroken.element_cache_test()
False
```

Since e and ebroken share the cache, when we empty it for one element it is empty for the other as well:

```
sage: b = ebroken.element_via_parent_test()
sage: e.element_via_parent_test.clear_cache()
sage: b is ebroken.element_via_parent_test()
False
```

Note that the cache only breaks for elements that do not allow attribute assignment. A Python version of MyBrokenElement therefore allows for cached methods:

```
sage: epython = MyPythonElement(P, 5)
sage: epython.element_cache_test()
<-5>
sage: epython.element_cache_test() is epython.element_cache_test()
True
```

```python
class sage.structure.element.EuclideanDomainElement
    Bases: sage.structure.element.PrincipalIdealDomainElement

degree()
    leading_coefficient()
    quo_rem(other)
```

```python
class sage.structure.element.Expression
    Bases: sage.structure.element.CommutativeRingElement

Abstract base class for Expression.
```

```python
class sage.structure.element.FieldElement
    Bases: sage.structure.element.CommutativeRingElement
```
The divides method checks whether self divides other for field elements.

Since this is a field, all values divide all other values, except that zero does not divide any non-zero values.

Examples:

```python
sage: K.<rt3> = QQ[sqrt(3)]
sage: K(0).divides(rt3)
False
sage: rt3.divides(K(17))
True
sage: K(0).divides(K(0))
True
sage: rt3.divides(K(0))
True
```

The is_unit method returns True if self is a unit in its parent ring.

Examples:

```python
sage: a = 2/3; a.is_unit()
True
```

On the other hand, 2 is not a unit, since its parent is $\mathbb{Z}$.

```python
sage: a = 2; a.is_unit()
False
sage: parent(a)
Integer Ring
```

However, a is a unit when viewed as an element of $\mathbb{Q}$:

```python
sage: a = QQ(2); a.is_unit()
True
```

The quo_rem method returns the quotient and remainder obtained by dividing self by right. Since this element lives in a field, the remainder is always zero and the quotient is self/right.
order()  
Return the additive order of self.

class sage.structure.element.ModuleElementWithMutability  
Bases: sage.structure.element.ModuleElement  
Generic element of a module with mutability.

is Immutable()  
Return True if this vector is immutable, i.e., the entries cannot be changed.

EXAMPLES:

```python  
sage: v = vector(QQ['x,y'], [1..5]); v.is_immutable()  
False  
sage: v.set_immutable()  
sage: v.is_immutable()  
True  
```

isMutable()  
Return True if this vector is mutable, i.e., the entries can be changed.

EXAMPLES:

```python  
sage: v = vector(QQ['x,y'], [1..5]); v.is_mutable()  
True  
sage: v.set_immutable()  
sage: v.is_mutable()  
False  
```

setImmutable()  
Make this vector immutable. This operation can't be undone.

EXAMPLES:

```python  
sage: v = vector([1..5]); v  
(1, 2, 3, 4, 5)  
sage: v[1] = 10  
sage: v.set Immutable()  
sage: v[1] = 10  
Traceback (most recent call last):  
...  
ValueError: vector is immutable; please change a copy instead (use copy())  
```

class sage.structure.element.MonoidElement  
Bases: sage.structure.element.Element  
Generic element of a monoid.

multiplicative_order()  
Return the multiplicative order of self.

order()  
Return the multiplicative order of self.

powers(n)  
Return the list \([x^0, x^1, \ldots, x^{n-1}]\).

EXAMPLES:
class sage.structure.element.MultiplicativeGroupElement
    Bases: sage.structure.element.MonoidElement

    Generic element of a multiplicative group.

    order()
    Return the multiplicative order of self.

class sage.structure.element.PrincipalIdealDomainElement
    Bases: sage.structure.element.DedekindDomainElement

gcd(right)
    Return the greatest common divisor of self and other.

lcm(right)
    Return the least common multiple of self and right.

class sage.structure.element.RingElement
    Bases: sage.structure.element.ModuleElement

abs()
    Return the absolute value of self. (This just calls the __abs__ method, so it is equivalent to the abs() built-in function.)

    EXAMPLES:

    sage: RR(-1).abs()
    1.00000000000000
    sage: ZZ(-1).abs()
    1
    sage: CC(I).abs()
    1.00000000000000
    sage: Mod(-15, 37).abs()
    Traceback (most recent call last):
    ... ArithmeticError: absolute value not defined on integers modulo n.

additive_order()
    Return the additive order of self.

is_nilpotent()
    Return True if self is nilpotent, i.e., some power of self is 0.

is_one()

is_prime()
    Is self a prime element?

    A prime element is a non-zero, non-unit element \( p \) such that, whenever \( p \) divides \( ab \) for some \( a \) and \( b \), then \( p \) divides \( a \) or \( p \) divides \( b \).

    EXAMPLES:
For polynomial rings, prime is the same as irreducible:

```python
sage: R.<x,y> = QQ[]
sage: x.is_prime()
True
sage: (x^2 + y^3).is_prime()
True
sage: (x^2 - y^2).is_prime()
False
sage: R(0).is_prime()
False
sage: R(2).is_prime()
False
```

For the Gaussian integers:

```python
sage: K.<i> = QuadraticField(-1)
sage: ZI = K.ring_of_integers()
sage: ZI(3).is_prime()
True
sage: ZI(5).is_prime()
False
sage: ZI(2+i).is_prime()
True
sage: ZI(0).is_prime()
False
sage: ZI(1).is_prime()
False
```

In fields, an element is never prime:

```python
sage: RR(0).is_prime()
False
sage: RR(2).is_prime()
False
```

For integers, prime numbers are redefined to be positive:

```python
sage: RingElement.is_prime(-2)
True
sage: Integer.is_prime(-2)
False
```

**multiplicative_order()**

Return the multiplicative order of self, if self is a unit, or raise `ArithmeticError` otherwise.

**powers(n)**

Return the list \([x^0, x^1, \ldots, x^{n-1}]\).

```python
EXAMPLES:

sage: 5.powers(3)
[1, 5, 25]
```

**class** `sage.structure.element.Vector`

Bases: `sage.structure.element.ModuleElementWithMutability`
sage.structure.element.bin_op(x, y, op)

sage.structure.element.canonical_coercion(x, y)

canonical_coercion(x, y) is what is called before doing an arithmetic operation between x and y. It returns a pair (z, w) such that z is got from x and w from y via canonical coercion and the parents of z and w are identical.

EXAMPLES:

```
sage: A = Matrix([[0, 1], [1, 0]])
sage: canonical_coercion(A, 1)
([0 1] [1 0], [0 1], [1 0])
```

sage.structure.element.coerce_binop(method)

Decorator for a binary operator method for applying coercion to the arguments before calling the method.

Consider a parent class in the category framework, $S$, whose element class expose a method $\text{binop}$. If $a$ and $b$ are elements of $S$, then $a.\text{binop}(b)$ behaves as expected. If $a$ and $b$ are not elements of $S$, but rather have a common parent $T$ whose element class also exposes $\text{binop}$, we would rather expect $a.\text{binop}(b)$ to compute $aa.\text{binop}(bb)$, where $aa = T(a)$ and $bb = T(b)$. This decorator ensures that behaviour without having to otherwise modify the implementation of $\text{binop}$ on the element class of $A$.

Since coercion will be attempted on the arguments of the decorated method, a $\text{TypeError}$ will be thrown if there is no common parent between the elements. An $\text{AttributeError}$ or $\text{NotImplementedError}$ or similar will be thrown if there is a common parent of the arguments, but its element class does not implement a method of the same name as the decorated method.

EXAMPLES:

Sparse polynomial rings uses `@coerce_binop` on $\gcd$:

```
sage: S.<x> = PolynomialRing(ZZ, sparse=True)
sage: f = x^2
sage: g = x
sage: f.gcd(g)  # indirect doctest
x
sage: T = PolynomialRing(QQ, name='x', sparse=True)
sage: h = 1/2*T(x)
sage: u = f.gcd(h); u  # indirect doctest
x
sage: u.parent() == T
True
```

Another real example:

```
sage: R1=QQ['x,y']
sage: R2=QQ['x,y,z']
sage: f=R1(1)
sage: g=R1(2)
sage: h=R2(1)
sage: f.gcd(g)
1
sage: f.gcd(g,algorithm='modular')
1
sage: f.gcd(h)
```

(continues on next page)
We demonstrate a small class using \texttt{@coerce\_binop} on a method:

```python
sage: from sage.structure.element import coerce_binop
sage: class MyRational(Rational):
    ....: def __init__(self, value):
    ....:     self.v = value
    ....: @coerce_binop
    ....: def test_add(self, other, keyword='z'):
    ....:     return (self.v, other, keyword)
```

Calls \texttt{func} directly if the two arguments have the same parent:

```python
sage: x = MyRational(1)
sage: x.test_add(1/2)
(1, 1/2, 'z')
sage: x.test_add(1/2, keyword=3)
(1, 1/2, 3)
```

Passes through coercion and does a method lookup if the left operand is not the same. If the common parent's element class does not have a method of the same name, an exception is raised:

```python
sage: x.test_add(2)
(1, 2, 'z')
sage: x.test_add(2, keyword=3)
(1, 2, 3)
sage: x.test_add(CC(2))
Traceback (most recent call last):
... AttributeError: 'sage.rings.complex_mpfr.ComplexNumber' object has no attribute 'test_add'
```

\texttt{sage.structure.element.coercion\_traceback(\texttt{dump=True})}

This function is very helpful in debugging coercion errors. It prints the tracebacks of all the errors caught in the coercion detection. Note that failure is cached, so some errors may be omitted the second time around (as it remembers not to retry failed paths for speed reasons).

For performance and caching reasons, exception recording must be explicitly enabled before using this function.

\textbf{EXAMPLES:}

```python
sage: cm = sage.structure.element.get_coercion_model()
sage: cm.record_exceptions()
sage: 1 + 1/5
6/5
sage: coercion_traceback()  # Should be empty, as all went well.
sage: 1/5 + GF(5).gen()
```
sage.structure.element.get_coercion_model()

Return the global coercion model.

EXAMPLES:

```python
sage: import sage.structure.element as e
sage: cm = e.get_coercion_model()
sage: cm
<sage.structure.coerce.CoercionModel object at ...>
sage: cm is coercion_model
True
```

sage.structure.element.have_same_parent(left, right)

Return True if and only if left and right have the same parent.

**Warning:** This function assumes that at least one of the arguments is a Sage Element. When in doubt, use the slower `parent(left)` is `parent(right)` instead.

EXAMPLES:

```python
sage: from sage.structure.element import have_same_parent
sage: have_same_parent(1, 3)
True
sage: have_same_parent(1, 1/2)
False
sage: have_same_parent(gap(1), gap(1/2))
True
```

These have different types but the same parent:

```python
sage: a = RLF(2)
sage: b = exp(a)
sage: type(a)
<... 'sage.rings.real_lazy.LazyWrapper'>
sage: type(b)
<... 'sage.rings.real_lazy.LazyNamedUnop'>
sage: have_same_parent(a, b)
True
```

sage.structure.element.is_AdditiveGroupElement(x)

Return True if x is of type AdditiveGroupElement.
sage.structure.element.is_AlgebraElement(x)
    Return True if x is of type AlgebraElement.

sage.structure.element.is_CommutativeAlgebraElement(x)
    Return True if x is of type CommutativeAlgebraElement.

sage.structure.element.is_CommutativeRingElement(x)
    Return True if x is of type CommutativeRingElement.

sage.structure.element.is_DedekindDomainElement(x)
    Return True if x is of type DedekindDomainElement.

sage.structure.element.is_Element(x)
    Return True if x is of type Element.

    EXAMPLES:

    sage: from sage.structure.element import is_Element
    sage: is_Element(2/3)
    True
    sage: is_Element(QQ^3)
    False

sage.structure.element.is_EuclideanDomainElement(x)
    Return True if x is of type EuclideanDomainElement.

sage.structure.element.is_FieldElement(x)
    Return True if x is of type FieldElement.

sage.structure.element.is_InfinityElement(x)
    Return True if x is of type InfinityElement.

sage.structure.element.is_IntegralDomainElement(x)
    Return True if x is of type IntegralDomainElement.

sage.structure.element.is_MonoidElement(x)
    Return True if x is of type MonoidElement.

sage.structure.element.is_MultiplicativeGroupElement(x)
    Return True if x is of type MultiplicativeGroupElement.

sage.structure.element.is_PrincipalIdealDomainElement(x)
    Return True if x is of type PrincipalIdealDomainElement.
sage.structure.element.is_RingElement(x)
    Return True if x is of type RingElement.

sage.structure.element.is_Vector(x)

sage.structure.element.make_element(_class, _dict, parent)
    This function is only here to support old pickles.
    Pickling functionality is moved to Element.__getstate__, __setstate__ functions.

sage.structure.element.parent(x)
    Return the parent of the element x.

        Usually, this means the mathematical object of which x is an element.

        INPUT:
          * x – an element

        OUTPUT:
          * If x is a Sage Element, return x.parent().
          * Otherwise, return type(x).

See also:

Parents, Conversion and Coercion Section in the Sage Tutorial

EXAMPLES:

```
sage: a = 42
sage: parent(a)
Integer Ring
sage: b = 42/1
sage: parent(b)
Rational Field
sage: c = 42.0
sage: parent(c)
Real Field with 53 bits of precision
```

Some more complicated examples:

```
sage: x = Partition([3,2,1,1,1])
sage: parent(x)
Partitions
sage: v = vector(RDF, [1,2,3])
sage: parent(v)
Vector space of dimension 3 over Real Double Field
```

The following are not considered to be elements, so the type is returned:

```
sage: d = int(42)  # Python int
sage: parent(d)
<... 'int'>
sage: L = list(range(10))
sage: parent(L)
<... 'list'>
```

3.1. Elements
3.2 Element Wrapper

Wrapping Sage or Python objects as Sage elements.

AUTHORS:

• Nicolas Thiery (2008-2010): Initial version
• Travis Scrimshaw (2013-05-04): Cythonized version

class sage.structure.element_wrapper.DummyParent(name)
Bases: sage.structure.unique_representation.UniqueRepresentation, sage.structure.parent.Parent

A class for creating dummy parents for testing ElementWrapper

class sage.structure.element_wrapper.ElementWrapper
Bases: sage.structure.element.Element

A class for wrapping Sage or Python objects as Sage elements.

EXAMPLES:

```python
sage: from sage.structure.element_wrapper import DummyParent
sage: parent = DummyParent("A parent")
```
```
sage: o = ElementWrapper(parent, "bla"); o
'bla'
```
```
sage: isinstance(o, sage.structure.element.Element)
True
```
```
sage: o.parent()
A parent
```
```
sage: o.value
'bla'
```

Note that o is not an instance of str, but rather contains a str. Therefore, o does not inherit the string methods. On the other hand, it is provided with reasonable default implementations for equality testing, hashing, etc.

The typical use case of ElementWrapper is for trivially constructing new element classes from pre-existing Sage or Python classes, with a containment relation. Here we construct the tropical monoid of integers endowed with min as multiplication.

```python
sage: class MinMonoid(Parent):
....:     def __repr__(self):
....:         return "The min monoid"
....:
sage: M = MinMonoid()
```
```
sage: class MinMonoidElement(ElementWrapper):
....:     wrapped_class = Integer
....:     ....:     def __mul__(self, other):
....:         return MinMonoidElement(self.parent(), min(self.value, other.value))
```
```
sage: x = MinMonoidElement(M, 5); x
```
```
sage: x.parent()
The min monoid
```
```
sage: x.value
```
```
(continues on next page)```
This example was voluntarily kept to a bare minimum. See the examples in the categories (e.g. `Semigroups()` . `example()` ) for several full featured applications.

```
sage: y = MinMonoidElement(M, 3)
sage: x * y
3
```

Warning: Versions before trac ticket #14519 had parent as the second argument and the value as the first.

value

```python
class sage.structure.element_wrapper.ElementWrapperCheckWrappedClass
    Bases: sage.structure.element_wrapper.ElementWrapper

    An element wrapper such that comparison operations are done against subclasses of wrapped_class.

    wrapped_class
    alias of builtins.object

class sage.structure.element_wrapper.ElementWrapperTester
    Bases: sage.structure.element_wrapper.ElementWrapper

    Test class for the default __copy() method of subclasses of ElementWrapper.

    append(x)
```

3.3 Elements, Array and Lists With Clone Protocol

This module defines several classes which are subclasses of `Element` and which roughly implement the “prototype” design pattern (see [Prototype_pattern], [GHJV1994]). Those classes are intended to be used to model mathematical objects, which are by essence immutable. However, in many occasions, one wants to construct the data-structure encoding of a new mathematical object by small modifications of the data structure encoding some already built object. For the resulting data-structure to correctly encode the mathematical object, some structural invariants must hold. One problem is that, in many cases, during the modification process, there is no possibility but to break the invariants.

For example, in a list modeling a permutation of \(\{1, \ldots, n\}\), the integers must be distinct. A very common operation is to take a permutation to make a copy with some small modifications, like exchanging two consecutive values in the list or cycling some values. Though the result is clearly a permutations there’s no way to avoid breaking the permutations invariants at some point during the modifications.

The main purpose of this module is to define the class

- `ClonableElement` as an abstract super class,

and its subclasses:

- `ClonableArray` for arrays (lists of fixed length) of objects;
- `ClonableList` for (resizeable) lists of objects;
- `NormalizedClonableList` for lists of objects with a normalization method;
- `ClonableIntArray` for arrays of int.

See also:

The following parents from `sage.structure.list_clone_demo` demonstrate how to use them:
• IncreasingArrays() (see IncreasingArray and the parent class IncreasingArrays)
• IncreasingLists() (see IncreasingList and the parent class IncreasingLists)
• SortedLists() (see SortedList and the parent class SortedLists)
• IncreasingIntArrays() (see IncreasingIntArray and the parent class IncreasingIntArrays)

EXAMPLES:
We now demonstrate how IncreasingArray works, creating an instance el through its parent IncreasingArrays():

```
sage: from sage.structure.list_clone_demo import IncreasingArrays
sage: P = IncreasingArrays()
sage: P([1, 4, 8])
[1, 4, 8]
```

If one tries to create this way a list which in not increasing, an error is raised:

```
sage: IncreasingArrays()([5, 4, 8])
Traceback (most recent call last):
... ValueError: array is not increasing
```

Once created modifying el is forbidden:

```
sage: el = P([1, 4, 8])
sage: el[1] = 3
Traceback (most recent call last):
... ValueError: object is immutable; please change a copy instead.
```

However, you can modify a temporarily mutable clone:

```
sage: with el.clone() as elc:
....:     elc[1] = 3
sage: [el, elc]
[[1, 4, 8], [1, 3, 8]]
```

We check that the original and the modified copy now are in a proper immutable state:

```
sage: el.is_immutable(), elc.is_immutable()
(True, True)
sage: elc[1] = 5
Traceback (most recent call last):
... ValueError: object is immutable; please change a copy instead.
```

You can break the property that the list is increasing during the modification:

```
sage: with el.clone() as elc2:
....:     elc2[1] = 12
....:     print(elc2)
....:     elc2[2] = 25
[1, 12, 8]
```

(continues on next page)
But this property must be restored at the end of the `with` block; otherwise an error is raised:

```
sage: with elc2.clone() as el3:
    ...:
    el3[1] = 100
Traceback (most recent call last):
...
ValueError: array is not increasing
```

Finally, as an alternative to the `with` syntax one can use:

```
sage: el4 = copy(elc2)
sage: el4[1] = 10
sage: el4.set_immutable()
sage: el4.check()
```

REFERENCES:

- [Prototype_pattern]
- [GHJV1994]

AUTHORS:

- Florent Hivert (2010-03): initial revision

```python
class sage.structure.list_clone.ClonableArray
    Bases: sage.structure.list_clone.ClonableElement

    Array with clone protocol

    The class of objects which are `Element` behave as arrays (i.e. lists of fixed length) and implement the clone protocol. See `ClonableElement` for details about clone protocol.

    INPUT:

    - `parent` – a `Parent`
    - `lst` – a list
    - `check` – a boolean specifying if the invariant must be checked using method `check()`.
    - `immutable` – a boolean telling whether the created element is immutable (defaults to True)

    See also:

    `IncreasingArray` for an example of usage.
```

EXAMPLES:

```
sage: from sage.structure.list_clone_demo import IncreasingArrays
sage: IA = IncreasingArrays()
sage: iai = IA([1, 4, 6]); iai
[1, 4, 6]
sage: with iai.clone() as iai2:
    ...:
    iai2[1] = 5
sage: iai2
[1, 5, 6]
```
sage: with ia1.clone() as ia2:
    
    ia2[1] = 7

Traceback (most recent call last):
...

ValueError: array is not increasing

**check()**

Check that self fulfill the invariants

This is an abstract method. Subclasses are supposed to overload check.

**EXAMPLES:**

```python
sage: from sage.structure.list_clone import ClonableArray
def check_example():
    ClonableArray(Parent(), [1,2,3])
```

```python
sage: ClonableArray(Parent(), [1,2,3])
Traceback (most recent call last):
...

NotImplementedError: this should never be called, please overload the check␣
˓→method
```

```python
sage: from sage.structure.list_clone_demo import IncreasingArrays
def check_example():
    e = IncreasingArrays()([1,2,4])
```

```python
sage: e.count(1)
1
sage: e.count(2)
2
sage: e.count(3)
0
```

**index(x, start=None, stop=None)**

Return the smallest k such that s[k] == x and i <= k < j

**EXAMPLES:**

```python
sage: from sage.structure.list_clone_demo import IncreasingArrays
def index_example():
    e = IncreasingArrays()([1,2,2,4])
```

```python
sage: e.index(1)
0
sage: e.index(4)
2
sage: e.index(5)
Traceback (most recent call last):
...

ValueError: 5 is not in list
```

**class sage.structure.list_clone.ClonableElement**

Bases: `sage.structure.element.Element`

Abstract class for elements with clone protocol
This class is a subclass of `Element` and implements the “prototype” design pattern (see [Prototype_pattern], [GHJV1994]). The role of this class is:

- to manage copy and mutability and hashing of elements
- to ensure that at the end of a piece of code an object is restored in a meaningful mathematical state.

A class \( C \) inheriting from `ClonableElement` must implement the following two methods

- `obj.__copy__()` – returns a fresh copy of `obj`
- `obj.check()` – returns nothing, raise an exception if `obj` doesn’t satisfy the data structure invariants and ensure to call `obj._require_mutable()` at the beginning of any modifying method.

Additionally, one can also implement

- `obj._hash_()` – return the hash value of `obj`.

Then, given an instance `obj` of `C`, the following sequences of instructions ensures that the invariants of `new_obj` are properly restored at the end:

```python
with obj.clone() as new_obj:
    ...
    # lot of invariant breaking modifications on new_obj
    ...
# invariants are ensured to be fulfilled
```

The following equivalent sequence of instructions can be used if speed is needed, in particular in Cython code:

```python
new_obj = obj.__copy__()  
...
# lot of invariant breaking modifications on new_obj
...
new_obj.set_immutable()
new_obj.check()
# invariants are ensured to be fulfilled
```

Finally, if the class implements the `_hash_` method, then `ClonableElement` ensures that the hash value can only be computed on an immutable object. It furthermore caches it so that it is only computed once.

**Warning:** for the hash caching mechanism to work correctly, the hash value cannot be 0.

**EXAMPLES:**

The following code shows a minimal example of usage of `ClonableElement`. We implement a class or pairs \((x, y)\) such that \(x < y\):

```python
sage: from sage.structure.list_clone import ClonableElement
sage: class IntPair(ClonableElement):
.....:    def __init__(self, parent, x, y):
.....:        ClonableElement.__init__(self, parent=parent)
.....:        self._x = x
.....:        self._y = y
.....:        self.set_immutable()
.....:        self.check()
.....:    def _repr_(self):
.....:        return f'\((\{self._x}\), \{self._y}\)'
```

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```python
......: def check(self):
......:     if self._x >= self._y:
......:         raise ValueError("Incorrectly ordered pair")
......: def get_x(self): return self._x
......: def get_y(self): return self._y
......: def set_x(self, v): self._require_mutable(); self._x = v
......: def set_y(self, v): self._require_mutable(); self._y = v
```

**Note:** we don’t need to define `__copy__` since it is properly inherited from `Element`.

We now demonstrate the behavior. Let’s create an `IntPair`:

```
sage: myParent = Parent()
sage: el = IntPair(myParent, 1, 3); el
(x=1, y=3)
sage: el.get_x()
1
```

Modifying it is forbidden:

```
sage: el.set_x(4)
Traceback (most recent call last):
... ValueError: object is immutable; please change a copy instead.
```

However, you can modify a mutable copy:

```
sage: with el.clone() as el1:
......:     el1.set_x(2)
sage: [el, el1]
[(x=1, y=3), (x=2, y=3)]
```

We check that the original and the modified copy are in a proper immutable state:

```
sage: el.isImmutable(), el1.isImmutable()
(True, True)
sage: el1.set_x(4)
Traceback (most recent call last):
... ValueError: object is immutable; please change a copy instead.
```

A modification which doesn’t restore the invariant $x < y$ at the end is illegal and raise an exception:

```
sage: with el.clone() as elc2:
......:     elc2.set_x(5)
Traceback (most recent call last):
... ValueError: Incorrectly ordered pair
```

```
copy(check=True)
Return a clone that is mutable copy of self.
```
INPUT:

- check – a boolean indicating if self.check() must be called after modifications.

EXAMPLES:

```python
sage: from sage.structure.list_clone_demo import IncreasingArrays
sage: el = IncreasingArrays([1,2,3])
sage: with el.clone() as ell:
    ....:   ell[2] = 5
sage: ell
[1, 2, 5]
```

isImmutable()

Return True if self is immutable (cannot be changed) and False if it is not.

To make self immutable use self.setImmutable().

EXAMPLES:

```python
sage: from sage.structure.list_clone_demo import IncreasingArrays
sage: el = IncreasingArrays([1,2,3])
```

isMutable()

Return True if self is mutable (can be changed) and False if it is not.

To make this object immutable use self.setImmutable().

EXAMPLES:

```python
sage: from sage.structure.list_clone_demo import IncreasingArrays
sage: el = IncreasingArrays([1,2,3])
```

setImmutable()

Makes self immutable, so it can never again be changed.

EXAMPLES:

```python
sage: from sage.structure.list_clone_demo import IncreasingArrays
sage: el = IncreasingArrays([1,2,3])
```
False

```sage```
el1[2] = 4
Traceback (most recent call last):
...
ValueError: object is immutable; please change a copy instead.
```

```class```
sage.structure.list_clone.ClonableIntArray
Bases: sage.structure.list_clone.ClonableElement

Array of int with clone protocol

The class of objects which are `Element` behave as list of int and implement the clone protocol. See `ClonableElement` for details about clone protocol.

**INPUT:**

- `parent` – a `Parent`
- `lst` – a list
- `check` – a boolean specifying if the invariant must be checked using method `check()`
- `immutable` – a boolean telling whether the created element is immutable (defaults to `True`)

**See also:**

`IncreasingIntArray` for an example of usage.

```check()```
Check that `self` fulfill the invariants

This is an abstract method. Subclasses are supposed to overload `check()`.

**EXAMPLES:**

```sage```
from sage.structure.list_clone import ClonableArray
sage: ClonableArray(Parent(), [1,2,3]) # indirect doctest
Traceback (most recent call last):
...
NotImplementedError: this should never be called, please overload the check...
```

```sage```
from sage.structure.list_clone_demo import IncreasingIntArrays
sage: el = IncreasingIntArrays([1,2,4]) # indirect doctest
```

```index(item)```

**EXAMPLES:**

```sage```
from sage.structure.list_clone_demo import IncreasingIntArrays
sage: c = IncreasingIntArrays([1,2,4])
sage: c.index(1)
0
sage: c.index(4)
2
sage: c.index(5)
Traceback (most recent call last):
...
ValueError: list.index(x): x not in list
```
list()
Convert self into a Python list.

EXAMPLES:

```python
sage: from sage.structure.list_clone_demo import IncreasingIntArrays
sage: I = IncreasingIntArrays()(range(5))
False
sage: I.list() == list(range(5))
True
sage: I = IncreasingIntArrays()(range(1000))
True
```

class sage.structure.list_clone.ClonableList
Bases: sage.structure.list_clone.ClonableArray

List with clone protocol

The class of objects which are \textit{Element} behave as lists and implement the clone protocol. See \textit{ClonableElement} for details about clone protocol.

See also:

\textit{IncreasingList} for an example of usage.

append\( (el) \)
Appends \(el\) to self

INPUT: \(el\) – any object

EXAMPLES:

```python
sage: from sage.structure.list_clone_demo import IncreasingLists
sage: el = IncreasingLists()([1])
sage: el.append(3)
Traceback (most recent call last):
  ... ValueError: object is immutable; please change a copy instead.
sage: with el.clone() as elc:
  ....:  elc.append(4)
  ....:  elc.append(6)
sage: elc[1, 4, 6]
sage: with el.clone() as elc:
  ....:  elc.append(4)
  ....:  elc.append(2)
Traceback (most recent call last):
  ...
ValueError: array is not increasing
```

extend\( (it) \)
Extends self by the content of the iterable \(it\)

INPUT: \(it\) – any iterable

EXAMPLES:
```
sage: from sage.structure.list_clone_demo import IncreasingLists
sage: el = IncreasingLists([1, 4, 5, 8, 9])
sage: el.extend((10,11))
Traceback (most recent call last):
  ... ValueError: object is immutable; please change a copy instead.

sage: with el.clone() as elc:
  ....:   elc.extend((10,11))
sage: elc
[1, 4, 5, 8, 9, 10, 11]

sage: el2 = IncreasingLists([15, 16])
sage: with el.clone() as elc:
  ....:   elc.extend(el2)
sage: elc
[1, 4, 5, 8, 9, 15, 16]

sage: with el.clone() as elc:
  ....:   elc.insert(2, 6)
Traceback (most recent call last):
  ... ValueError: array is not increasing

```

**insert**(index, el)

Inserts el in self at position index

**INPUT:**

- el – any object
- index – any int

**EXAMPLES:**

```
sage: from sage.structure.list_clone_demo import IncreasingLists
sage: el = IncreasingLists([1, 4, 5, 8, 9])
sage: el.insert(3, 6)
Traceback (most recent call last):
  ... ValueError: object is immutable; please change a copy instead.

sage: with el.clone() as elc:
  ....:   elc.insert(3, 6)
sage: elc
[1, 4, 5, 6, 8, 9]

sage: with el.clone() as elc:
  ....:   elc.insert(2, 6)
Traceback (most recent call last):
  ... ValueError: array is not increasing

```

**pop**(index=- 1)

Remove self[index] from self and returns it

**INPUT:** index - any int, default to -1

**EXAMPLES:**
sage: from sage.structure.list_clone_demo import IncreasingLists
sage: el = IncreasingLists([1, 4, 5, 8, 9])

Traceback (most recent call last):
  ...  
ValueError: object is immutable; please change a copy instead.

sage: with el.clone() as elc:
    print(elc.pop())
9
sage: elc  
[1, 4, 5, 8]

sage: with el.clone() as elc:
    print(elc.pop(2))
5
sage: elc  
[1, 4, 8, 9]

remove(el)

Remove the first occurrence of el from self.

INPUT: el - any object

EXAMPLES:

sage: from sage.structure.list_clone_demo import IncreasingLists
sage: el = IncreasingLists([1, 4, 5, 8, 9])

Traceback (most recent call last):
  ...  
ValueError: object is immutable; please change a copy instead.

sage: with el.clone() as elc:
    elc.remove(4)

sage: elc  
[1, 5, 8, 9]

sage: with el.clone() as elc:
    elc.remove(10)

Traceback (most recent call last):
  ...  
ValueError: list.remove(x): x not in list

class sage.structure.list_clone.NormalizedClonableList

Bases: sage.structure.list_clone.ClonableList

List with clone protocol and normal form

This is a subclass of ClonableList which call a method normalize() at creation and after any modification of its instance.

See also:

SortedList for an example of usage.

EXAMPLES:

We construct a sorted list through its parent:
Normalization is also performed after modification:

```python
sage: with sl1.clone() as sl2:
....:   sl2[1] = 12
sage: sl2
[1, 4, 6, 12]
```

**normalize()**

Normalize self

This is an abstract method. Subclasses are supposed to overload `normalize()`. The call `self.normalize()` is supposed to

- call `self._require_mutable()` to check that `self` is in a proper mutable state
- modify `self` to put it in a normal form

**EXAMPLES:**

```python
sage: from sage.structure.list_clone_demo import SortedList, SortedLists
class IncreasingArray

sage: IncreasingArrays()([1,2,3]) # indirect doctest
[1, 2, 3]
```

### 3.4 Elements, Array and Lists With Clone Protocol, demonstration classes

This module demonstrate the usage of the various classes defined in `list_clone`

**class** `sage.structure.list_clone_demo.IncreasingArray`

**Bases**: `sage.structure.list_clone.ClonableArray`

A small extension class for testing `ClonableArray`.

**check()**

Check that `self` is increasing.

**EXAMPLES:**

```python
sage: IncreasingArrays()([1,2,3]) # indirect doctest
[1, 2, 3]
```

Traceback (most recent call last):
...
ValueError: array is not increasing
class sage.structure.list_clone_demo.IncreasingArrays
    Bases: sage.structure.unique_representation.UniqueRepresentation, sage.structure.parent.Parent

    A small (incomplete) parent for testing ClonableArray

    Element
        alias of IncreasingArray

class sage.structure.list_clone_demo.IncreasingIntArray
    Bases: sage.structure.list_clone.ClonableIntArray

    A small extension class for testing ClonableIntArray.

    check()
        Check that self is increasing.

        EXAMPLES:

        sage: from sage.structure.list_clone_demo import IncreasingIntArrays
        sage: IncreasingIntArrays()([1,2,3]) # indirect doctest
        [1, 2, 3]
        sage: IncreasingIntArrays()([3,2,1]) # indirect doctest
        Traceback (most recent call last):
        ... ValueError: array is not increasing

class sage.structure.list_clone_demo.IncreasingIntArrays
    Bases: sage.structure.list_clone_demo.IncreasingArrays

    A small (incomplete) parent for testing ClonableIntArray

    Element
        alias of IncreasingIntArray

class sage.structure.list_clone_demo.IncreasingList
    Bases: sage.structure.list_clone_demo.IncreasingArrays

    A small extension class for testing ClonableList

    check()
        Check that self is increasing

        EXAMPLES:

        sage: from sage.structure.list_clone_demo import IncreasingLists
        sage: IncreasingLists()([1,2,3]) # indirect doctest
        [1, 2, 3]
        sage: IncreasingLists()([3,2,1]) # indirect doctest
        Traceback (most recent call last):
        ... ValueError: array is not increasing

class sage.structure.list_clone_demo.IncreasingLists
    Bases: sage.structure.list_clone_demo.IncreasingArrays

    A small (incomplete) parent for testing ClonableList

    Element
        alias of IncreasingList
class sage.structure.list_clone_demo.SortedList
    Bases: sage.structure.list_clone.NormalizedClonableList

    A small extension class for testing NormalizedClonableList.

    check()
    Check that self is strictly increasing

    EXAMPLES:

    sage: from sage.structure.list_clone_demo import SortedList, SortedLists
    sage: SortedLists()([1,2,3]) # indirect doctest
    [1, 2, 3]
    sage: SortedLists()([3,2,2]) # indirect doctest
    Traceback (most recent call last):
    ...  
    ValueError: list is not strictly increasing

normalize()
    Normalize self

    Sort the list stored in self.

    EXAMPLES:

    sage: from sage.structure.list_clone_demo import SortedList, SortedLists
    sage: l = SortedList(SortedLists(), [3,1,2], False, False)
    sage: l
    # indirect doctest
    [1, 2, 3]
    sage: l[1] = 5; l
    [1, 5, 3]
    sage: l.normalize(); l
    [1, 3, 5]

class sage.structure.list_clone_demo.SortedLists
    Bases: sage.structure.list_clone_demo.IncreasingLists

    A small (incomplete) parent for testing NormalizedClonableList

    Element
        alias of SortedList
4.1 Formal sums

AUTHORS:

- David Harvey (2006-09-20): changed FormalSum not to derive from “list” anymore, because that breaks new Element interface
- Nick Alexander (2006-12-06): added test cases.

FUNCTIONS:

- `FormalSums(ring)` – create the module of formal finite sums with coefficients in the given ring.
- `FormalSum(list of pairs (coeff, number))` – create a formal sum

EXAMPLES:

```python
sage: A = FormalSum([(1, 2/3)]); A
2/3
sage: B = FormalSum([(3, 1/5)]); B
3*1/5
sage: -B
-3*1/5
sage: A + B
2/3 + 3*1/5
sage: A - B
2/3 - 3*1/5
sage: 3*A
9*1/5
sage: 2*A
2*2/3
sage: list(2*A + A)
[(3, 2/3)]
```

```python
class sage.structure.formal_sum.FormalSum(x, parent=None, check=True, reduce=True)
    Bases: sage.structure.element.ModuleElement

A formal sum over a ring.
```
reduce()

EXAMPLES:

```python
sage: a = FormalSum([(-2,3), (2,3)], reduce=False); a
-2*3 + 2*3
sage: a.reduce()
sage: a
0
```

class sage.structure.formal_sum.FormalSums

Bases: `sage.structure.unique_representation.UniqueRepresentation`, `sage.modules.module.Module`

The R-module of finite formal sums with coefficients in some ring R.

EXAMPLES:

```python
sage: FormalSums()
Abelian Group of all Formal Finite Sums over Integer Ring
sage: FormalSums(ZZ)
Abelian Group of all Formal Finite Sums over Integer Ring
sage: FormalSums(GF(7))
Abelian Group of all Formal Finite Sums over Finite Field of size 7
sage: FormalSums(ZZ[sqrt(2)])
Abelian Group of all Formal Finite Sums over Order in Number Field in sqrt2 with defining polynomial x^2 - 2 with sqrt2 = 1.414213562373095?
```

Element

alias of FormalSum

base_extend(R)

EXAMPLES:

```python
sage: F7 = FormalSums(ZZ).base_extend(GF(7)); F7
Abelian Group of all Formal Finite Sums over Finite Field of size 7
```

The following tests against a bug that was fixed at trac ticket #18795:

```python
sage: isinstance(F7, F7.category().parent_class)
True
```

sage.structure.formal_sum.formal_sums = Abelian Group of all Formal Finite Sums over Integer Ring
4.2 Factorizations

The **Factorization** class provides a structure for holding quite general lists of objects with integer multiplicities. These may hold the results of an arithmetic or algebraic factorization, where the objects may be primes or irreducible polynomials and the multiplicities are the (non-zero) exponents in the factorization. For other types of examples, see below.

**Factorization** class objects contain a list, so can be printed nicely and be manipulated like a list of prime-exponent pairs, or easily turned into a plain list. For example, we factor the integer \(-45\):

```
sage: F = factor(-45)
```

This returns an object of type **Factorization**:  

```
sage: type(F)
<class 'sage.structure.factorization_integer.IntegerFactorization'>
```

It prints in a nice factored form:

```
sage: F
-1 * 3^2 * 5
```

There is an underlying list representation, which ignores the unit part:

```
sage: list(F)
[(3, 2), (5, 1)]
```

A **Factorization** is not actually a list:

```
sage: isinstance(F, list)
False
```

However, we can access the **Factorization** \(F\) itself as if it were a list:

```
sage: F[0]
(3, 2)
sage: F[1]
(5, 1)
```

To get at the unit part, use the **Factorization.unit()** function:

```
sage: F.unit()
-1
```

All factorizations are immutable, up to ordering with **sort()** and simplifying with **simplify()**. Thus if you write a function that returns a cached version of a factorization, you do not have to return a copy.

```
sage: F = factor(-12); F
-1 * 2^2 * 3
sage: F[0] = (5,4)
Traceback (most recent call last):
  ...
TypeError: 'Factorization' object does not support item assignment
```

**EXAMPLES:**

---

**4.2. Factorizations**
This more complicated example involving polynomials also illustrates that the unit part is not discarded from factorizations:

```
sage: x = QQ['x'].0
sage: f = -5*(x-2)*(x-3)
sage: f
-5*x^2 + 25*x - 30
sage: F = f.factor(); F
(-5) * (x - 3) * (x - 2)
sage: F.unit()
-5
sage: F.value()
-5*x^2 + 25*x - 30
```

The underlying list is the list of pairs \((p_i, e_i)\), where each \(p_i\) is a ‘prime’ and each \(e_i\) is an integer. The unit part is discarded by the list:

```
sage: list(F)
[(x - 3, 1), (x - 2, 1)]
sage: len(F)
2
sage: F[1]
(x - 2, 1)
```

In the ring \(\mathbb{Z}[x]\), the integer \(-5\) is not a unit, so the factorization has three factors:

```
sage: x = ZZ['x'].0
sage: f = -5*(x-2)*(x-3)
sage: f
-5*x^2 + 25*x - 30
sage: F = f.factor(); F
(-1) * 5 * (x - 3) * (x - 2)
sage: F.universe()
Univariate Polynomial Ring in x over Integer Ring
sage: F.unit()
-1
sage: list(F)
[(5, 1), (x - 3, 1), (x - 2, 1)]
sage: F.value()
-5*x^2 + 25*x - 30
sage: len(F)
3
```

On the other hand, \(-1\) is a unit in \(\mathbb{Z}\), so it is included in the unit:

```
sage: x = ZZ['x'].0
sage: f = -1*(x-2)*(x-3)
sage: f
-1*(x - 3) * (x - 2)
sage: F = f.factor(); F
(-1) * (x - 3) * (x - 2)
sage: F.unit()
-1
sage: list(F)
[(x - 3, 1), (x - 2, 1)]
```

Factorizations can involve fairly abstract mathematical objects:
```sage
sage: F = ModularSymbols(11,4).factorization()
sage: F
(Modular Symbols subspace of dimension 2 of Modular Symbols space of dimension 6 for\n...Gamma_0(11) of weight 4 with sign 0 over Rational Field) *
(Modular Symbols subspace of dimension 2 of Modular Symbols space of dimension 6 for\n...Gamma_0(11) of weight 4 with sign 0 over Rational Field) *
(Modular Symbols subspace of dimension 2 of Modular Symbols space of dimension 6 for\n...Gamma_0(11) of weight 4 with sign 0 over Rational Field)
sage: type(F)
<class 'sage.structure.factorization.Factorization'>
```

```sage
sage: K.<a> = NumberField(x^2 + 3); K
Number Field in a with defining polynomial x^2 + 3
sage: f = K.factor(15); f
(Fractional ideal (1/2*a + 3/2))^2 * (Fractional ideal (5))
sage: f.universe()
Monoid of ideals of Number Field in a with defining polynomial x^2 + 3
sage: f.unit()
Fractional ideal (1)
sage: g = K.factor(9); g
(Fractional ideal (1/2*a + 3/2))^4
sage: f.lcm(g)
(Fractional ideal (1/2*a + 3/2))^4 * (Fractional ideal (5))
sage: f.gcd(g)
(Fractional ideal (1/2*a + 3/2))^2
sage: f.is_integral()
True
```

AUTHORS:

- John Cremona (2008-08-22): added division, lcm, gcd, is_integral and universe functions

```sage
class sage.structure.factorization.Factorization(x, unit=None, cr=False, sort=True, simplify=True)
Bases: sage.structure.sage_object.SageObject
A formal factorization of an object.

EXAMPLES:
```
```sage
sage: N = 2006
sage: F = N.factor(); F
2 * 17 * 59
sage: F.unit()
1
sage: F = factor(-2006); F
-1 * 2 * 17 * 59
sage: F.unit()
-1
sage: loads(F.dumps()) == F
(continues on next page)
```
Parents and Elements, Release 9.6

(continued from previous page)

\[
\text{True}
\]

\begin{verbatim}
sage: F = \text{Factorization}([[x,1/3]])
Traceback (most recent call last):
...  
TypeError: no conversion of this rational to integer
\end{verbatim}

**base_change**\((U)\)

Return the factorization self, with its factors (including the unit part) coerced into the universe \(U\).

**EXAMPLES:**

\begin{verbatim}
sage: F = \text{factor}(2006)
sage: F\text{.universe()}
Integer Ring
sage: P.<x> = \text{ZZ}[x]
sage: F\text{.base_change(P).universe()}
Univariate Polynomial Ring in x over Integer Ring
\end{verbatim}

This method will return a TypeError if the coercion is not possible:

\begin{verbatim}
sage: g = x^2 - 1
sage: F = \text{factor}(g); F
(x - 1) \cdot (x + 1)
sage: F\text{.universe()}
Univariate Polynomial Ring in x over Integer Ring
sage: F\text{.base_change(\text{ZZ})}
Traceback (most recent call last):
...  
TypeError: Impossible to coerce the factors of (x - 1) \cdot (x + 1) into Integer Ring
\end{verbatim}

**expand()**

Return the product of the factors in the factorization, multiplied out.

**EXAMPLES:**

\begin{verbatim}
sage: F = \text{factor}(-2006); F
-1 \cdot 2 \cdot 17 \cdot 59
sage: F\text{.value()}
-2006
sage: R.<x,y> = \text{FreeAlgebra(\text{ZZ}, 2)}
sage: F = \text{Factorization}([[x,3], (y,2), (x,1)]); F
x^3 \cdot y^2 \cdot x
sage: F\text{.value()}
x^3 \cdot y^2 \cdot x
\end{verbatim}

**gcd**(other)

Return the gcd of two factorizations.

If the two factorizations have different universes, this method will attempt to find a common universe for
the gcd. A TypeError is raised if this is impossible.

**EXAMPLES:**

\[94\text{ Chapter 4. Mathematical Data Structures}\]
```sage
sage: factor(-30).gcd(factor(-160))
2 * 5
sage: factor(gcd(-30,160))
2 * 5
sage: R.<x> = ZZ[]
sage: (factor(-20).gcd(factor(5*x+10))).universe()
Univariate Polynomial Ring in x over Integer Ring
```

**is_commutative()**

Return True if my factors commute.

**EXAMPLES:**

```sage
sage: F = factor(2006)
sage: F.is_commutative()
True
sage: K = QuadraticField(23, 'a')
sage: F = K.factor(13)
sage: F.is_commutative()
True
sage: R.<x,y,z> = FreeAlgebra(QQ, 3)
sage: F = Factorization([(z, 2)], 3)
sage: F.is_commutative()
False
sage: (F*F^-1).is_commutative()
False
```

**is_integral()**

Return True iff all exponents of this Factorization are non-negative.

**EXAMPLES:**

```sage
sage: F = factor(-10); F
-1 * 2 * 5
sage: F.is_integral()
True
sage: F = factor(-10) / factor(16); F
-1 * 2^-3 * 5
sage: F.is_integral()
False
```

**lcm(other)**

Return the lcm of two factorizations.

If the two factorizations have different universes, this method will attempt to find a common universe for the lcm. A TypeError is raised if this is impossible.

**EXAMPLES:**

```sage
sage: factor(-10).lcm(factor(-16))
2^4 * 5
sage: factor(lcm(-10,16))
2^4 * 5
```

(continues on next page)
prod()  
Return the product of the factors in the factorization, multiplied out.

EXAMPLES:

```sage
sage: F = factor(-2006); F
-1 * 2 * 17 * 59
sage: F.value()
-2006
```

radical()  
Return the factorization of the radical of the value of self.

First, check that all exponents in the factorization are positive, raise ValueError otherwise. If all exponents are positive, return self with all exponents set to 1 and with the unit set to 1.

EXAMPLES:

```sage
sage: F = factor(-100); F
-1 * 2^2 * 5^2
sage: F.radical()
2 * 5
```

radical_value()  
Return the product of the prime factors in self.

First, check that all exponents in the factorization are positive, raise ValueError otherwise. If all exponents are positive, return the product of the prime factors in self. This should be functionally equivalent to self.radical().value()

EXAMPLES:

```sage
sage: F = factor(-100); F
-1 * 2^2 * 5^2
sage: F.radical_value()
10
```
**simplify()**
Combine adjacent products as much as possible.

**sort(key=None)**
Sort the factors in this factorization.

**INPUT:**
- **key** - (default: *None*) comparison key

**OUTPUT:**
- changes this factorization to be sorted (inplace)

If **key** is *None*, we determine the comparison key as follows:

If the prime in the first factor has a dimension method, then we sort based first on *dimension* then on the exponent.

If there is no dimension method, we next attempt to sort based on a degree method, in which case, we sort based first on *degree*, then exponent to break ties when two factors have the same degree, and if those match break ties based on the actual prime itself.

Otherwise, we sort according to the prime itself.

**EXAMPLES:**

We create a factored polynomial:

```sage
x = polygen(QQ,'x')
F = factor(x^3 + 1); F
(x + 1) * (x^2 - x + 1)
```

We sort it by decreasing degree:

```sage
F.sort(key=lambda x: (-x[0].degree(), x))
F
(x^2 - x + 1) * (x + 1)
```

**unit()**
Return the unit part of this factorization.

**EXAMPLES:**

We create a polynomial over the real double field and factor it:

```sage
x = polygen(RDF,'x')
F = factor(-2*x^2 - 1); F
(-2.0) * (x^2 + 0.5000000000000001)
```

Note that the unit part of the factorization is **−2.0**:

```sage
F.unit()
-2.0
```

```sage
F = factor(-2006); F
-1 * 2 * 17 * 59
```

```sage
F.unit()
-1
```

### 4.2. Factorizations
universe()

Return the parent structure of my factors.

Note: This used to be called base_ring, but the universe of a factorization need not be a ring.

EXAMPLES:

```python
sage: F = factor(2006)
sage: F.universe()
Integer Ring
```

```python
sage: R.<x,y,z> = FreeAlgebra(QQ, 3)
sage: F = Factorization([(z, 2)], 3)
sage: (F*F^-1).universe()
Free Algebra on 3 generators (x, y, z) over Rational Field
```

```python
sage: F = ModularSymbols(11,4).factorization()
sage: F.universe()
```

value()

Return the product of the factors in the factorization, multiplied out.

EXAMPLES:

```python
sage: F = factor(-2006); F
-1 * 2 * 17 * 59
sage: F.value()
-2006
```

```python
sage: R.<x,y> = FreeAlgebra(ZZ, 2)
sage: F = Factorization([(x,3), (y, 2), (x,1)]); F
x^3 * y^2 * x
sage: F.value()
x^3*y^2*x
```

## 4.3 IntegerFactorization objects

```python
class sage.structure.factorization_integer.IntegerFactorization(x, unit=None, cr=False, sort=True, simplify=True, unsafe=False)
```

Bases: `sage.structure.factorization.Factorization`

A lightweight class for an IntegerFactorization object, inheriting from the more general Factorization class.

In the Factorization class the user has to create a list containing the factorization data, which is then passed to the actual Factorization object upon initialization.

However, for the typical use of integer factorization via the Integer.factor() method in sage.rings.integer this is noticeably too much overhead, slowing down the factorization of integers of up to about 40 bits by a factor of around 10. Moreover, the initialization done in the Factorization class is typically unnecessary: the caller can guarantee that the list contains pairs of an Integer and an int, as well as that the list is sorted.
4.4 Finite Homogeneous Sequences

A mutable sequence of elements with a common guaranteed category, which can be set immutable.

Sequence derives from list, so has all the functionality of lists and can be used wherever lists are used. When a sequence is created without explicitly given the common universe of the elements, the constructor coerces the first and second element to some canonical common parent, if possible, then the second and third, etc. If this is possible, it then coerces everything into the canonical parent at the end. (Note that canonical coercion is very restrictive.) The sequence then has a function `universe()` which returns either the common canonical parent (if the coercion succeeded), or the category of all objects (`Objects()`). So if you have a list \( v \) and type:

\[
\begin{align*}
\text{sage: } v &= \begin{bmatrix} 1, \frac{2}{3}, 5 \end{bmatrix} \\
\text{sage: } w &= \text{Sequence}(v) \\
\text{sage: } w.\text{universe}() \\
\text{Rational Field}
\end{align*}
\]

then since \( w.\text{universe}() \) is \( \mathbb{Q} \), you’re guaranteed that all elements of \( w \) are rationals:

\[
\begin{align*}
\text{sage: } v[0].\text{parent}() \\
\text{Integer Ring} \\
\text{sage: } w[0].\text{parent}() \\
\text{Rational Field}
\end{align*}
\]

If you do assignment to \( w \) this property of being rationals is guaranteed to be preserved:

\[
\begin{align*}
\text{sage: } w[0] &= 2 \\
\text{sage: } w[0].\text{parent}() \\
\text{Rational Field} \\
\text{sage: } w[0] &= 'hi' \\
\text{Traceback (most recent call last):} \\
\text{...} \\
\text{TypeError: unable to convert 'hi' to a rational}
\end{align*}
\]

However, if you do \( w = \text{Sequence}(v) \) and the resulting universe is \( \text{Objects}() \), the elements are not guaranteed to have any special parent. This is what should happen, e.g., with finite field elements of different characteristics:

\[
\begin{align*}
\text{sage: } v &= \text{Sequence([\text{GF}(3)(1), \text{GF}(7)(1)])} \\
\text{sage: } v.\text{universe}() \\
\text{Category of objects}
\end{align*}
\]

You can make a list immutable with \( v.\text{freeze}() \). Assignment is never again allowed on an immutable list.

Creation of a sequence involves making a copy of the input list, and substantial coercions. It can be greatly sped up by explicitly specifying the universe of the sequence:

\[
\begin{align*}
\text{sage: } v &= \text{Sequence(range(10000), universe=ZZ)} \\
\end{align*}
\]

A mutable list of elements with a common guaranteed universe, which can be set immutable.
A universe is either an object that supports coercion (e.g., a parent), or a category.

INPUT:
- **x** - a list or tuple instance
- **universe** - (default: None) the universe of elements; if None determined using canonical coercions and the entire list of elements. If list is empty, is category Objects() of all objects.
- **check** – (default: True) whether to coerce the elements of x into the universe
- **immutable** - (default: True) whether or not this sequence is immutable
- **cr** - (default: False) if True, then print a carriage return after each comma when printing this sequence.
- **cr_str** - (default: False) if True, then print a carriage return after each comma when calling str() on this sequence.
- **use_sage_types** – (default: False) if True, coerce the built-in Python numerical types int, float, complex to the corresponding Sage types (this makes functions like vector() more flexible)

OUTPUT:
- a sequence

EXAMPLES:

```
sage: v = Sequence(range(10))
sage: v.universe()
<class 'int'>
sage: v
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
```

We can request that the built-in Python numerical types be coerced to Sage objects:

```
sage: v = Sequence(range(10), use_sage_types=True)
sage: v.universe()
Integer Ring
sage: v
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
```

You can also use seq for “Sequence”, which is identical to using Sequence:

```
sage: v = seq([1,2,1/1]); v
[1, 2, 1]
sage: v.universe()
Rational Field
```

Note that assignment coerces if possible:

```
sage: v = Sequence(range(10), ZZ)
sage: a = QQ(5)
sage: v[3] = a
sage: parent(v[3])
Integer Ring
sage: parent(a)
Rational Field
sage: v[3] = 2/3
```

(continues on next page)
...TypeError: no conversion of this rational to integer

Sequences can be used absolutely anywhere lists or tuples can be used:

```
sage: isinstance(v, list)
True
```

Sequence can be immutable, so entries can't be changed:

```
sage: v = Sequence([1,2,3], immutable=True)
sage: v.is_immutable()
True
sage: v[0] = 5
Traceback (most recent call last):
...
ValueError: object is immutable; please change a copy instead.
```

Only immutable sequences are hashable (unlike Python lists), though the hashing is potentially slow, since it first involves conversion of the sequence to a tuple, and returning the hash of that.:

```
sage: v = Sequence(range(10), ZZ, immutable=True)
sage: hash(v) == hash(tuple(range(10)))
True
```

If you really know what you are doing, you can circumvent the type checking (for an efficiency gain):

```
sage: list.__setitem__(v, int(1), 2/3)     # bad circumvention
sage: v
[0, 2/3, 2, 3, 4, 5, 6, 7, 8, 9]
sage: list.__setitem__(v, int(1), int(2))     # not so bad circumvention
```

You can make a sequence with a new universe from an old sequence.:

```
sage: w = Sequence(v, QQ)
sage: w
[0, 2, 2, 3, 4, 5, 6, 7, 8, 9]
sage: w.universe()
Rational Field
sage: w[1] = 2/3
sage: w
[0, 2/3, 2, 3, 4, 5, 6, 7, 8, 9]
```

The default universe for any sequence, if no compatible parent structure can be found, is the universe of all Sage objects.

This example illustrates how every element of a list is taken into account when constructing a sequence.:

```
sage: v = Sequence([1,7,6,GF(5)(3)]); v
[1, 2, 1, 3]
sage: v.universe()
Finite Field of size 5
```
class sage.structure.sequence.Sequence_generic(x, universe=None, check=True, immutable=False, cr=False, cr_str=None, use_sage_types=False)

Bases: sage.structure.sage_object.SageObject, list

A mutable list of elements with a common guaranteed universe, which can be set immutable.

A universe is either an object that supports coercion (e.g., a parent), or a category.

INPUT:

- `x` - a list or tuple instance
- `universe` - (default: None) the universe of elements; if None determined using canonical coercions and the entire list of elements. If list is empty, is category Objects() of all objects.
- `check` - (default: True) whether to coerce the elements of x into the universe
- `immutable` - (default: True) whether or not this sequence is immutable
- `cr` - (default: False) if True, then print a carriage return after each comma when printing this sequence.
- `use_sage_types` – (default: False) if True, coerce the built-in Python numerical types int, float, complex to the corresponding Sage types (this makes functions like vector() more flexible)

OUTPUT:

- a sequence

EXAMPLES:

```python
sage: v = Sequence(range(10))
sage: v.universe()
<class 'int'>
sage: v
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
```

We can request that the built-in Python numerical types be coerced to Sage objects:

```python
sage: v = Sequence(range(10), use_sage_types=True)
sage: v.universe()
Integer Ring
sage: v
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
```

You can also use seq for “Sequence”, which is identical to using Sequence:

```python
sage: v = seq([1,2,1/1]); v
[1, 2, 1]
sage: v.universe()
Rational Field
```

Note that assignment coerces if possible,

```python
sage: v = Sequence(range(10), ZZ)
sage: a = QQ(5)
sage: v[3] = a
sage: parent(v[3])
Integer Ring
sage: parent(a)
Rational Field
```
sage: v[3] = 2/3
Traceback (most recent call last):
...  
TypeError: no conversion of this rational to integer

Sequences can be used absolutely anywhere lists or tuples can be used:

```
sage: isinstance(v, list)
True
```

Sequence can be immutable, so entries can’t be changed:

```
sage: v = Sequence([1,2,3], immutable=True)
sage: v.is Immutable()
True
sage: v[0] = 5
Traceback (most recent call last):
...  
ValueError: object is immutable; please change a copy instead.
```

Only immutable sequences are hashable (unlike Python lists), though the hashing is potentially slow, since it first involves conversion of the sequence to a tuple, and returning the hash of that.

```
sage: v = Sequence(range(10), ZZ, immutable=True)
sage: hash(v) == hash(tuple(range(10)))
True
```

If you really know what you are doing, you can circumvent the type checking (for an efficiency gain):

```
sage: list.__setitem__(v, int(1), 2/3)  # bad circumvention
sage: v
[0, 2/3, 2, 3, 4, 5, 6, 7, 8, 9]
sage: list.__setitem__(v, int(1), int(2))  # not so bad circumvention
```

You can make a sequence with a new universe from an old sequence.

```
sage: w = Sequence(v, QQ)
sage: w
[0, 2, 2, 3, 4, 5, 6, 7, 8, 9]
sage: w.Universe()
Rational Field
sage: w[1] = 2/3
sage: w
[0, 2/3, 2, 3, 4, 5, 6, 7, 8, 9]
```

The default universe for any sequence, if no compatible parent structure can be found, is the universe of all Sage objects.

This example illustrates how every element of a list is taken into account when constructing a sequence.

```
sage: v = Sequence([[1,7,6,GF(5)(3)]]; v
[1, 2, 1, 3]
sage: v.Universe()
Finite Field of size 5
```

4.4. Finite Homogeneous Sequences
append(x)
EXAMPLES:

```python
sage: v = Sequence([1,2,3,4], immutable=True)
sage: v.append(34)
Traceback (most recent call last):
...:
ValueError: object is immutable; please change a copy instead.
sage: v = Sequence([1/3,2,3,4])
sage: v.append(4)
sage: type(v[4])
<class 'sage.rings.rational.Rational'>
```

extend(iterable)
Extend list by appending elements from the iterable.

EXAMPLES:

```python
sage: B = Sequence([1,2,3])
sage: B.extend(range(4))
sage: B
[1, 2, 3, 0, 1, 2, 3]
```

insert(index, object)
Insert object before index.

EXAMPLES:

```python
sage: B = Sequence([1,2,3])
sage: B.insert(10, 5)
sage: B
[1, 2, 3, 5]
```

is_immutable()
Return True if this object is immutable (can not be changed) and False if it is not.

To make this object immutable use set_immutable().

EXAMPLES:

```python
sage: v = Sequence([1,2,3,4/5])
sage: v[0] = 5
sage: v
[5, 2, 3, 4/5]
sage: v.is_immutable()
False
sage: v.set_immutable()

sage: v.is_immutable()
True
```

is_mutable()
EXAMPLES:

```python
sage: a = Sequence([1,2/3,-2/5])
sage: a.is_mutable()
True
```
sage: a[0] = 100
sage: type(a[0])
<class 'sage.rings.rational.Rational'>
sage: a.set_immutable()
sage: a[0] = 50
Traceback (most recent call last):
  ...
ValueError: object is immutable; please change a copy instead.
sage: a.is_mutable()
False

pop(index=-1)
Remove and return item at index (default last)

EXAMPLES:

sage: B = Sequence([1,2,3])
sage: B.pop(1)
2
sage: B
[1, 3]

remove(value)
Remove first occurrence of value

EXAMPLES:

sage: B = Sequence([1,2,3])
sage: B.remove(2)
sage: B
[1, 3]

reverse()
Reverse the elements of self, in place.

EXAMPLES:

sage: B = Sequence([1,2,3])
sage: B.reverse(); B
[3, 2, 1]

set_immutable()
Make this object immutable, so it can never again be changed.

EXAMPLES:

sage: v = Sequence([1,2,3,4/5])
sage: v[0] = 5
sage: v
[5, 2, 3, 4/5]
sage: v.set_immutable()
Traceback (most recent call last):
  ...
ValueError: object is immutable; please change a copy instead.
**sort**(*key=None, reverse=False*)

Sort this list *IN PLACE*.

**INPUT:**

- *key* - see Python list *sort*
- *reverse* - see Python list *sort*

**EXAMPLES:**

```
sage: B = Sequence([3,2,1/5])
sage: B.sort()
sage: B
[1/5, 2, 3]
sage: B.sort(reverse=True); B
[3, 2, 1/5]
```

**universe()**

Return the universe of the sequence.

**EXAMPLES:**

```
sage: Sequence([1,2/3,-2/5]).universe()
Rational Field
sage: Sequence([1,2/3,'-2/5']).universe()
Category of objects
```

`sage.structure.sequence.seq(x, universe=None, check=True, immutable=False, cr=False, cr_str=None, use_sage_types=False)`

A mutable list of elements with a common guaranteed universe, which can be set immutable.

A universe is either an object that supports coercion (e.g., a parent), or a category.

**INPUT:**

- *x* - a list or tuple instance
- *universe* - (default: None) the universe of elements; if None determined using canonical coercions and the entire list of elements. If list is empty, is category Objects() of all objects.
- *check* – (default: True) whether to coerce the elements of *x* into the universe
- *immutable* - (default: True) whether or not this sequence is immutable
- *cr* - (default: False) if True, then print a carriage return after each comma when printing this sequence.
- *cr_str* - (default: False) if True, then print a carriage return after each comma when calling *str()* on this sequence.
- *use_sage_types* – (default: False) if True, *coerce* the built-in Python numerical types int, float, complex to the corresponding Sage types (this makes functions like *vector()* more flexible)

**OUTPUT:**

- a sequence

**EXAMPLES:**

```
sage: v = Sequence(range(10))
sage: v.universe()
<class 'int'>
```
We can request that the built-in Python numerical types be coerced to Sage objects:

```
sage: v = Sequence(range(10), use_sage_types=True)
sage: v.universe()
Integer Ring
sage: v
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
```

You can also use `seq` for “Sequence”, which is identical to using `Sequence`:

```
sage: v = seq([1,2,1/1]); v
[1, 2, 1]
sage: v.universe()
Rational Field
```

Note that assignment coerces if possible:

```
sage: v = Sequence(range(10), ZZ)
sage: a = QQ(5)
sage: v[3] = a
sage: parent(v[3])
Integer Ring
sage: parent(a)
Rational Field
sage: v[3] = 2/3
Traceback (most recent call last):
  ...TypeError: no conversion of this rational to integer
```

Sequences can be used absolutely anywhere lists or tuples can be used:

```
sage: isinstance(v, list)
True
```

Sequence can be immutable, so entries can’t be changed:

```
sage: v = Sequence([1,2,3], immutable=True)
sage: v.is_immutable()
True
sage: v[0] = 5
Traceback (most recent call last):
  ...ValueError: object is immutable; please change a copy instead.
```

Only immutable sequences are hashable (unlike Python lists), though the hashing is potentially slow, since it first involves conversion of the sequence to a tuple, and returning the hash of that:

```
sage: v = Sequence(range(10), ZZ, immutable=True)
sage: hash(v) == hash(tuple(range(10)))
True
```

4.4. Finite Homogeneous Sequences
If you really know what you are doing, you can circumvent the type checking (for an efficiency gain):

```python
sage: list.__setitem__(v, int(1), 2/3)  # bad circumvention
sage: v
[0, 2/3, 2, 3, 4, 5, 6, 7, 8, 9]
sage: list.__setitem__(v, int(1), int(2))  # not so bad circumvention
```

You can make a sequence with a new universe from an old sequence:

```python
sage: w = Sequence(v, QQ)
sage: w
[0, 2, 3, 4, 5, 6, 7, 8, 9]
sage: w.universe()
Rational Field
sage: w[1] = 2/3
sage: w
[0, 2/3, 2, 3, 4, 5, 6, 7, 8, 9]
```

The default universe for any sequence, if no compatible parent structure can be found, is the universe of all Sage objects.

This example illustrates how every element of a list is taken into account when constructing a sequence:

```python
sage: v = Sequence([1,7,6,GF(5)(3)]); v
[1, 2, 1, 3]
sage: v.universe()
Finite Field of size 5
```

### 4.5 Set factories

A set factory $F$ is a device for constructing some Parent $P$ that models subsets of a big set $S$. Typically, each such parent is constructed as the subset of $S$ of all elements satisfying a certain collection of constraints $cons$. In such a hierarchy of subsets, one needs an easy and flexible control on how elements are constructed. For example, one may want to construct the elements of $P$ in some subclass of the class of the elements of $S$. On other occasions, one also often needs $P$ to be a facade parent, whose elements are represented as elements of $S$ (see FacadeSets).

The role of a set factory is twofold:

- *Manage a database* of constructors for the different parents $P = F(cons)$ depending on the various kinds of constraints $cons$. Note: currently there is no real support for that. We are gathering use cases before fixing the interface.

- Ensure that the elements $e = P(...)$ created by the different parents follows a consistent policy concerning their class and parent.
Basic usage: constructing parents through a factory

The file `sage.structure.set_factories_example` shows an example of a `SetFactory` together with typical implementation. Note that the written code is intentionally kept minimal, many things and in particular several iterators could be written in a more efficient way.

Consider the set $S$ of couples $(x, y)$ with $x$ and $y$ in $I := \{0, 1, 2, 3, 4\}$. We represent an element of $S$ as a 2-elements tuple, wrapped in a class `XPair` deriving from `ElementWrapper`. You can create a `XPair` with any `Parent`:

```python
sage: from sage.structure.set_factories import *
sage: from sage.structure.set_factories_example import *
sage: p = XPair(Parent(), (0,1)); p
(0, 1)
```

Now, given $(a, b) \in S$ we want to consider the following subsets of $S$

$$
S_a := \{(x, y) \in S \mid x = a\},
$$

$$
S_b := \{(x, y) \in S \mid y = b\},
$$

$$
S_{a b} := \{(x, y) \in S \mid x = a, y = b\}.
$$

The constraints considered here are admittedly trivial. In a realistic example, there would be much more of them. And for some sets of constraints no good enumeration algorithms would be known.

In Sage, those sets are constructed by passing the constraints to the factory. We first create the set with no constraints at all:

```python
sage: XYPairs
Factory for XY pairs
sage: S = XYPairs(); S.list()
[(0, 0), (1, 0), ..., (4, 0), (0, 1), (1, 1), ..., (3, 4), (4, 4)]
sage: S.cardinality()
25
```

Let us construct $S_2$, $S_3$ and $S_{23}$:

```python
sage: Sx2 = XYPairs(x=2); Sx2.list()
[(2, 0), (2, 1), (2, 2), (2, 3), (2, 4)]
sage: Sy3 = XYPairs(y=3); Sy3.list()
[(0, 3), (1, 3), (2, 3), (3, 3), (4, 3)]
sage: S23 = XYPairs(x=2, y=3); S23.list()
[(2, 3)]
```

Set factories provide an alternative way to build subsets of an already constructed set: each set constructed by a factory has a method `subset()` which accept new constraints. Sets constructed by the factory or the `subset()` methods are identical:

```python
sage: Sx2s = S.subset(x=2); Sx2 is Sx2s
True
sage: Sx2.subset(y=3) is S23
True
```

It is not possible to change an already given constraint:

```python
sage: S23.subset(y=5)
Traceback (most recent call last):
```

(continues on next page)
... ValueError: Duplicate value for constraints 'y': was 3 now 5

Constructing custom elements: policies

We now come to the point of factories: constructing custom elements. The writer of \texttt{XYPairs()} decided that, by default, the parents \texttt{Sx2}, \texttt{Sy3} and \texttt{S23} are facade for parent \texttt{S}. This means that each element constructed by those subsets behaves as if they where directly constructed by \texttt{S} itself:

\begin{verbatim}
sage: Sx2.an_element().parent()
AllPairs
sage: el = Sx2.an_element()
sage: el.parent() is S
True
sage: type(el) is S.element_class
True
\end{verbatim}

This is not always desirable. The device which decides how to construct an element is called a \textit{policy} (see \texttt{SetFactoryPolicy}). Each factory should have a default policy. Here is the policy of \texttt{XYPairs()}:

\begin{verbatim}
sage: XYPairs._default_policy
Set factory policy for <class 'sage.structure.set_factories_example.XYPair'> with parent
   → AllPairs[=Factory for XY pairs()]
\end{verbatim}

This means that with the current policy, the parent builds elements with class \texttt{XYPair} and parent \texttt{AllPairs} which is itself constructed by calling the factory \texttt{XYPairs()} with constraints (). There is a lot of flexibility to change that. We now illustrate how to make a few different choices.

1 - In a first use case, we want to add some methods to the constructed elements. As illustration, we add here a new method \texttt{sum} which returns \(x + y\). We therefore create a new class for the elements which inherits from \texttt{XYPair}:

\begin{verbatim}
sage: class NewXYPair(XYPair):
    ...:     def sum(self):
    ...:         return sum(self.value)
\end{verbatim}

Here is an instance of this class (with a dummy parent):

\begin{verbatim}
sage: el = NewXYPair(Parent(), (2,3))
sage: el.sum()
5
\end{verbatim}

We now want to have subsets generating those new elements while still having a single real parent (the one with no constraint) for each element. The corresponding policy is called \textit{TopMostParentPolicy}. It takes three parameters:

- the factory;
- the parameters for void constraint;
- the class used for elements.

Calling the factory with this policy returns a new set which builds its elements with the new policy:

\begin{verbatim}
sage: new_policy = TopMostParentPolicy(XYPairs, (), NewXYPair)
sage: NewS = XYPairs(policy=new_policy)
\end{verbatim}
sage: el = NewS.an_element(); el
(0, 0)
sage: el.sum()
0
sage: el.parent()  # NewS
True
sage: isinstance(el, NewXYPair)
True

Newly constructed subsets inherit the policy:

sage: NewS2 = NewS.subset(x=2)
sage: el2 = NewS2.an_element(); el2
(2, 0)
sage: el2.sum()
2
sage: el2.parent()  # NewS
True

2 - In a second use case, we want the elements to remember which parent created them. The corresponding policy is called *SelfParentPolicy*. It takes only two parameters:

- the factory;
- the class used for elements.

Here is an example:

sage: selfpolicy = SelfParentPolicy(XYPairs, NewXYPair)
sage: SelfS = XYPairs(policy=selfpolicy)
sage: el = SelfS.an_element()
sage: el.parent()  # SelfS
True

Now all subsets are the parent of the elements that they create:

sage: SelfS2 = SelfS.subset(x=2)
sage: el2 = SelfS2.an_element()
sage: el2.parent()  # SelfS2
False
sage: el2.parent()  # SelfS2
True

3 - Finally, a common use case is to construct simple python object which are not Sage sage.structure.Element. As an example, we show how to build a parent TupleS which construct pairs as tuple. The corresponding policy is called *BareFunctionPolicy*. It takes two parameters:

- the factory;
- the function called to construct the elements.

Here is how to do it:

sage: cons = lambda t, check: tuple(t)  # ignore the check parameter
sage: tuplepolicy = BareFunctionPolicy(XYPairs, cons)
sage: P = XYPairs(x=2, policy=tuplepolicy)
Here are the currently implemented policies:

- **FacadeParentPolicy**: reuse an existing parent together with its element_class
- **TopMostParentPolicy**: use a parent created by the factory itself and provide a class \texttt{Element} for it. In this case, we need to specify the set of constraints which build this parent taking the ownership of all elements and the class which will be used for the \texttt{Element}.
- **SelfParentPolicy**: provide systematically \texttt{Element} and element_class and ensure that the parent is \texttt{self}.
- **BareFunctionPolicy**: instead of calling a class constructor element are passed to a function provided to the policy.

\textbf{Todo}: Generalize \texttt{TopMostParentPolicy} to be able to have several topmost parents.

\section*{Technicalities: how policies inform parents}

Parents built from factories should inherit from \texttt{ParentWithSetFactory}. This class provide a few methods related to factories and policies. The \underline{\texttt{__init__}} method of \texttt{ParentWithSetFactory} must be provided with the set of constraints and the policy. A parent built from a factory must create elements through a call to the method \underline{\texttt{_element_constructor_}}. The current way in which policies inform parents how to builds their elements is set by a few attributes. So the class must accept attribute adding. The precise details of which attributes are set may be subject to change in the future.

\section*{How to write a set factory}

\textbf{See also:}

\texttt{set_factories_example} for an example of a factory.

Here are the specifications:

A parent built from a factory should

- \textit{inherit} from \texttt{ParentWithSetFactory}. It should accept a policy argument and pass it verbatim to the \underline{\texttt{__init__}} method of \texttt{ParentWithSetFactory} together with the set of constraints;
- \textit{create its elements} through calls to the method \underline{\texttt{_element_constructor_}};
- \textit{define a method \texttt{ParentWithSetFactory.check_element}} which checks if a built element indeed belongs to it. The method should accept an extra keyword parameter called check specifying which level of check should be performed. It will only be called when \texttt{bool(check)} evaluates to \texttt{True}.

The constructor of the elements of a parent from a factory should:

- receive the parent as first mandatory argument;
- accept an extra optional keyword parameter called \texttt{check} which is meant to tell if the input must be checked or not. The precise meaning of \texttt{check} is intentionally left vague. The only intent is that if \texttt{bool(check)} evaluates to \texttt{False}, no check is performed at all.
A factory should

- *define a method* `__call__` *which is responsible for calling the appropriate parent constructor given the constraints;*
- *define a method* overloading `SetFactory.add_constraints()` *which is responsible of computing the union of two sets of constraints;*
- *optionally* define a method or an attribute `__default_policy__` passed to the `ParentWithSetFactory` if no policy is given to the factory.

**Todo:** There is currently no support for dealing with sets of constraints. The set factory and the parents must cooperate to consistently handle them. More support, together with a generic mechanism to select the appropriate parent class from the constraints, will be added as soon as we have gathered sufficiently enough use-cases.

**AUTHORS:**

- Florent Hivert (2011-2012): initial revision

```python
class sage.structure.set_factories.BareFunctionPolicy(factory, constructor):
    Bases: sage.structure.set_factories.SetFactoryPolicy
    Policy where element are constructed using a bare function.
    INPUT:
    • factory – an instance of `SetFactory`
    • constructor – a function
    Given a factory F and a function c, returns a policy for parent P creating element using the function f.

    EXAMPLES:
    sage: from sage.structure.set_factories import BareFunctionPolicy
    sage: from sage.structure.set_factories_example import XYPairs
    sage: cons = lambda t, check: tuple(t)  # ignore the check parameter
    sage: tuplepolicy = BareFunctionPolicy(XYPairs, cons)
    sage: P = XYPairs(x=2, policy=tuplepolicy)
    sage: el = P.an_element()
    sage: type(el)
    <...
```

```python
... 'tuple'>
```

```python
def element_constructor_attributes(constraints):
    return the element constructor attributes as per `SetFactoryPolicy`.  

    INPUT:
    • constraints – a bunch of constraints

class sage.structure.set_factories.FacadeParentPolicy(factory, parent):
    Bases: sage.structure.set_factories.SetFactoryPolicy
    Policy for facade parent.
    INPUT:
    • factory – an instance of `SetFactory`
    • parent – an instance of `Parent`
```
Given a factory $F$ and a class $E$, returns a policy for parent $P$ creating elements as if they were created by parent.

**EXAMPLES:**

```python
sage: from sage.structure.set_factories import SelfParentPolicy, FacadeParentPolicy
sage: from sage.structure.set_factories_example import XYPairs, XYPair

We create a custom standard parent $P$:

```python
sage: selfpolicy = SelfParentPolicy(XYPairs, XYPair)
sage: P = XYPairs(x=2, policy=selfpolicy)
sage: pol = FacadeParentPolicy(XYPairs, P)
sage: P2 = XYPairs(x=2, y=3, policy=pol)
sage: el = P2.an_element()
sage: el.parent() is P
True
sage: type(el) is P.element_class
True
```

If parent is itself a facade parent, then transitivity is correctly applied:

```python
sage: P = XYPairs()
sage: P2 = XYPairs(x=2)
sage: P2.category()
Category of facade finite enumerated sets
sage: pol = FacadeParentPolicy(XYPairs, P)
sage: P23 = XYPairs(x=2, y=3, policy=pol)
sage: el = P2.an_element()
sage: el.parent() is P
True
sage: type(el) is P.element_class
True
```

**element_constructor_attributes(constraints)**

Return the element constructor attributes as per `SetFactoryPolicy.element_constructor_attributes()`.

**INPUT:**

- `constraints` – a bunch of constraints

**class** `sage.structure.set_factories.ParenWithSetFactory(constraints, policy, category=None)`

**Bases:** `sage.structure.parent.Parent`

Abstract class for parent belonging to a set factory.

**INPUT:**

- `constraints` – a set of constraints
- `policy` – the policy for element construction
- `category` – the category of the parent (default to `None`)

Depending on the constraints and the policy, initialize the parent in a proper category to set up element construction.

**EXAMPLES:**
```python
sage: from sage.structure.set_factories_example import XYPairs, PairsX_
sage: P = PairsX_(3, XYPairs._default_policy)
sage: P
is XYPairs(3)
True
sage: P.category()
Category of facade finite enumerated sets
```

**check_element**(x, check)

Check that x verifies the constraints of self.

**INPUT:**

- x – an instance of self.element_class.
- check – the level of checking to be performed (usually a boolean).

This method may assume that x was properly constructed by self or a possible super-set of self for which self is a facade. It should return nothing if x verifies the constraints and raise a `ValueError` explaining which constraints x fails otherwise.

The method should accept an extra parameter check specifying which level of check should be performed. It will only be called when `bool(check)` evaluates to True.

**Todo:** Should we always call check element and let it decide which check has to be performed ?

**EXAMPLES:**

```python
sage: from sage.structure.set_factories_example import XYPairs
sage: S = XYPairs()
sage: el = S((2,3))
sage: S.check_element(el, True)
sage: XYPairs(x=2).check_element(el, True)
sage: XYPairs(x=3).check_element(el, True)
Traceback (most recent call last):
  ...
ValueError: Wrong first coordinate
sage: XYPairs(y=4).check_element(el, True)
Traceback (most recent call last):
  ...
ValueError: Wrong second coordinate
```

**constraints()**

Return the constraints defining self.

**Note:** Currently there is no specification on how constraints are passed as arguments.

**EXAMPLES:**

```python
sage: from sage.structure.set_factories_example import XYPairs
sage: XYPairs().constraints()
()
sage: XYPairs(x=3).constraints()
(3, None)
```

(continues on next page)
sage: XYPairs(y=2).constraints()
(\text{None}, 2)

\textbf{facade\_policy()}
Return the policy for parent facade for \texttt{self}.

\textbf{EXAMPLES:}

sage: from sage.structure.set_factories import SelfParentPolicy
sage: from sage.structure.set_factories_example import XYPairs, XYPair

We create a custom standard parent \texttt{P}:

sage: selfpolicy = SelfParentPolicy(XYPairs, XYPair)
sage: P = XYPairs(x=2, policy=selfpolicy)
sage: P.facade_policy()
Set factory policy for facade parent \{(2, b) \mid b \text{ in range}(5)\}

Now passing \texttt{P.facade\_policy()} creates parent which are facade for \texttt{P}:

sage: P3 = XYPairs(x=2, y=3, policy=P.facade_policy())
sage: P3.facade_for() == (P,)
True
sage: el = P3.an_element()
(sage: el.parent() == P)
True

\textbf{factory()}
Return the factory which built \texttt{self}.

\textbf{EXAMPLES:}

sage: from sage.structure.set_factories_example import XYPairs
sage: XYPairs().factory() is XYPairs
True
sage: XYPairs(x=3).factory() is XYPairs
True

\textbf{policy()}
Return the policy used when \texttt{self} was created.

\textbf{EXAMPLES:}

sage: from sage.structure.set_factories_example import XYPairs
sage: XYPairs().policy()
Set factory policy for \texttt{<class 'sage.structure.set_factories_example.XYPair'>} with parent \texttt{AllPairs[=Factory for XY pairs()]}\n
sage: XYPairs(x=3).policy()
Set factory policy for \texttt{<class 'sage.structure.set_factories_example.XYPair'>} with parent \texttt{AllPairs[=Factory for XY pairs()]}\n
\textbf{subset(*args, **options)}
Return a subset of \texttt{self} by adding more constraints.
Note: Currently there is no specification on how constraints are passed as arguments.

EXAMPLES:

```python
sage: from sage.structure.set_factories_example import XYPairs
sage: S = XYPairs()
sage: S3 = S.subset(x=3)
sage: S3.list()
[(3, 0), (3, 1), (3, 2), (3, 3), (3, 4)]
```

```python
class sage.structure.set_factories(SelfParentPolicy(factory, Element))
    Bases: sage.structure.set_factories.SetFactoryPolicy

Policy where each parent is a standard parent.

INPUT:

- **factory** – an instance of SetFactory
- **Element** – a subclass of Element

Given a factory F and a class E, returns a policy for parent P creating elements in class E and parent P itself.

EXAMPLES:

```python
sage: from sage.structure.set_factories import SelfParentPolicy
sage: from sage.structure.set_factories_example import XYPairs, XYPair, Pairs_Y
sage: pol = SelfParentPolicy(XYPairs, XYPair)
sage: S = Pairs_Y(3, pol)
sage: el = S.an_element()
sage: el.parent() is S
True
	sage: class Foo(XYPair): pass
sage: pol = SelfParentPolicy(XYPairs, Foo)
sage: S = Pairs_Y(3, pol)
sage: el = S.an_element()
sage: isinstance(el, Foo)
True
```

```python
def element_constructor_attributes(constraints)
    Return the element constructor attributes as per SetFactoryPolicy.

    INPUT:

    - **constraints** – a bunch of constraints
```

```python
class sage.structure.set_factories.SetFactory
    Bases: sage.structure.unique_representation.UniqueRepresentation, sage.structure.sage_object.SageObject

This class is currently just a stub that we will be using to add more structures on factories.

```python
add_constraints(cons, *args, **opts)
    Add constraints to the set of constraints cons.

    Should return a set of constraints.
```

4.5. Set factories
Note: Currently there is no specification on how constraints are passed as arguments.

EXAMPLES:

```python
sage: from sage.structure.set_factories_example import XYPairs
sage: XYPairs.add_constraints((3,),((None, 2), {}))
(3, 2)
sage: XYPairs.add_constraints((3,),((None, None), {'y': 2}))
(3, 2)
```

class sage.structure.set_factories.SetFactoryPolicy(factory)
Bases: sage.structure.unique_representation.UniqueRepresentation, sage.structure.sage_object.SageObject

Abstract base class for policies.

A policy is a device which is passed to a parent inheriting from ParentWithSetFactory in order to set-up the element construction framework.

INPUT:

• factory – a SetFactory

**Warning:** This class is a base class for policies, one should not try to create instances.

element_constructor_attributes(constraints)
Element constructor attributes.

INPUT:

• constraints – a bunch of constraints

Should return the attributes that are prerequisite for element construction. This is co-ordinated with ParentWithSetFactory.element_constructor_(). Currently two standard attributes are provided in facade_element_constructor_attributes() and self_element_constructor_attributes(). You should return the one needed depending on the given constraints.

EXAMPLES:

```python
sage: from sage.structure.set_factories_example import XYPairs, XYPair
sage: pol = XYPairs._default_policy
sage: pol.element_constructor_attributes(())
{'Element': <class 'sage.structure.set_factories_example.XYPair'>,
 '_parent_for': 'self'}
sage: pol.element_constructor_attributes((1))
{'_facade_for': AllPairs,
 '_parent_for': AllPairs,
 'element_class': <class 'sage.structure.set_factories_example.AllPairs_with_
 →category.element_class'>}
```

facade_element_constructor_attributes(parent)
Element Constructor Attributes for facade parent.

The list of attributes which must be set during the init of a facade parent with factory.
INPUT:

- parent – the actual parent for the elements

EXAMPLES:

```python
sage: from sage.structure.set_factories_example import XYPairs, XYPair
sage: pol = XYPairs._default_policy
sage: pol.facade_element_constructor_attributes(XYPairs())
{'_facade_for': AllPairs, '_parent_for': AllPairs, 'element_class': <class 'sage.structure.set_factories_example.AllPairs_with_category.element_class'>}
```

```python
factory()

Return the factory for self.

EXAMPLES:

```python
sage: from sage.structure.set_factories import SetFactoryPolicy, SelfParentPolicy
sage: from sage.structure.set_factories_example import XYPairs, XYPair
sage: XYPairs._default_policy.factory()  
Factory for XY pairs
sage: XYPairs._default_policy.factory() is XYPairs
True
```

```python
self_element_constructor_attributes(Element)

Element Constructor Attributes for non facade parent.

The list of attributes which must be set during the init of a non facade parent with factory.

INPUT:

- Element – the class used for the elements

EXAMPLES:

```python
sage: from sage.structure.set_factories_example import XYPairs, XYPair
sage: pol = XYPairs._default_policy
sage: pol.self_element_constructor_attributes(XYPair)
{'Element': <class 'sage.structure.set_factories_example.XYPair'>, '_parent_for': 'self'}
```

class sage.structure.set_factories.TopMostParentPolicy(factory, top_constraints, Element)

Policy where the parent of the elements is the topmost parent.

INPUT:

- factory – an instance of SetFactory
- top_constraints – the empty set of constraints.
- Element – a subclass of Element

Given a factory $F$ and a class $E$, returns a policy for parent $P$ creating element in class $E$ and parent $F(*top\_constraints, policy)$.

EXAMPLES:
The goal of this module is to exemplify the use of set factories. Note that the code is intentionally kept minimal; many things and in particular several iterators could be written in a more efficient way.

See also:

*set_factories* for an introduction to set factories, their specifications, and examples of their use and implementation based on this module.

We describe here a factory used to construct the set $S$ of couples $(x, y)$ with $x$ and $y$ in $I := \{0, 1, 2, 3, 4\}$, together with the following subsets, where $(a, b) \in S$

$S_a := \{(x, y) \in S \mid x = a\}$,

$S^b := \{(x, y) \in S \mid y = b\}$,

$S^a_b := \{(x, y) \in S \mid x = a, y = b\}$.

### 4.6 An example of set factory

```python
def check_element(el, check):
    pass

def pairs_y(letter):
    pass
```

```
class sage.structure.set_factories_example.ParentWithSetFactory:
    pass

class sage.sets.disjoint_unionEnumerated_sets.DisjointUnionEnumeratedSets:
    pass

class sage.structure set_factories_example.AllPairs(policy):
    Bases: sage.structure.set_factories_example.ParentWithSetFactory, sage.sets.disjoint_unionEnumerated_sets.DisjointUnionEnumeratedSets
    
    This parent shows how one can use set factories together with DisjointUnionEnumeratedSets.
    
    It is constructed as the disjoint union (DisjointUnionEnumeratedSets) of Pairs_Y parents:
    
    $S := \bigcup_{i=0,1,...,4} S^y$
    ```

**Warning:** When writing a parent $P$ as a disjoint union of a family of parents $P_i$, the parents $P_i$ must be constructed as facade parents for $P$. As a consequence, it should be passed $P.facade_policy()$ as policy argument. See the source code of *pairs_y()* for an example.
This is an internal function which should be hidden from the user (typically under the name `_pairs_y`). We put it here for documentation.

```python
class sage.structure.set_factories_example.PairsX_(x, policy):
    Bases: sage.structure.set_factories.ParentWithSetFactory, sage.structure.unique_representation.UniqueRepresentation
    The set of pairs \((x, 0), (x, 1), ..., (x, 4)\).
    an_element()
    check_element(el, check)
```

```python
class sage.structure.set_factories_example.Pairs_Y(y, policy):
    Bases: sage.structure.set_factories.ParentWithSetFactory, sage.sets.disjoint_union_enumerated_sets.DisjointUnionEnumeratedSets
    The set of pairs \((0, y), (1, y), ..., (4, y)\).
    It is constructed as the disjoint union (DisjointUnionEnumeratedSets) of SingletonPair parents:
    \[ S^y := \bigcup_{i=0,1,...,4} S^y_i \]
    See also:
    AllPairs for how to properly construct DisjointUnionEnumeratedSets using ParentWithSetFactory.
    an_element()
    check_element(el, check)
    single_pair(letter)
    Construct the singleton pair parent
    Construct a singleton pair for (self.y, letter) as a facade parent for self.
    See also:
    AllPairs for how to properly construct DisjointUnionEnumeratedSets using ParentWithSetFactory.
```

```python
class sage.structure.set_factories_example.SingletonPair(x, y, policy):
    Bases: sage.structure.set_factories.ParentWithSetFactory, sage.structure.unique_representation.UniqueRepresentation
    check_element(el, check)
```

```python
class sage.structure.set_factories_example.XYPair(parent, value, check=True):
    Bases: sage.structure.element_wrapper.ElementWrapper
    A class for Elements \((x, y)\) with \(x\) and \(y\) in \(\{0, 1, 2, 3, 4\}\).
    EXAMPLES:
    ```python
    sage: from sage.structure.set_factories_example import XYPair
    sage: p = XYPair(Parent(), (0,1)); p
    (0, 1)
    sage: p = XYPair(Parent(), (0,8))
    Traceback (most recent call last):
    ...ValueError: numbers must be in range(5)
    ```
    sage.structure.set_factories_example.XYPairs = Factory for XY pairs
```

4.6. An example of set factory
class sage.structure.set_factories_example.XYPairsFactory
    Bases: sage.structure.set_factories.SetFactory

    An example of set factory, for sets of pairs of integers.

    See also:
    set_factories for an introduction to set factories.

    add_constraints(cons, args_opts)
        Add constraints to the set cons as per SetFactory.add_constraints.

        This is a crude implementation for the sake of the demonstration which should not be taken as an example.

        EXAMPLES:
        sage: from sage.structure.set_factories_example import XYPairs
        sage: XYPairs.add_constraints((3,None), ((2,), {}))
        Traceback (most recent call last):
        ...  
        ValueError: Duplicate value for constraints 'x': was 3 now 2 
        sage: XYPairs.add_constraints((), ((2,), {}))
        (2, None)
        sage: XYPairs.add_constraints((), ((2,), {'y':3}))
        (2, 3)
CHAPTER
FIVE

USE OF HEURISTIC AND PROBABILISTIC ALGORITHMS

5.1 Global proof preferences

```python
class sage.structure.proof.proof.WithProof(subsystem, t):
    Bases: object

    Use WithProof to temporarily set the value of one of the proof systems for a block of code, with a guarantee that it will be set back to how it was before after the block is done, even if there is an error.

    EXAMPLES:

    sage: proof.arithmetic(True)
    sage: with proof.WithProof('arithmetic',False):  # this would hang "forever" if...
    ....:    print((10^1000 + 453).is_prime())
    ....:    print(1/0)
    Traceback (most recent call last):
    ...:
    ZeroDivisionError: rational division by zero
    sage: proof.arithmetic()
    True
```

```python
sage.structure.proof.proof.get_flag(t=None, subsystem=None)
```

Used for easily determining the correct proof flag to use.

EXAMPLES:

```python
sage: from sage.structure.proof.proof import get_flag
sage: get_flag(False)
False
sage: get_flag(True)
True
sage: get_flag()
True
sage: proof.all(False)
sage: get_flag()
False
```
5.2 Whether or not computations are provably correct by default
6.1 Cython-like rich comparisons in Python

With “rich comparisons”, we mean the Python 3 comparisons which are usually implemented in Python using methods like \_eq\_ and \_lt\_. Internally in Python, there is only one rich comparison slot \texttt{tp\_richcompare}. The actual operator is passed as an integer constant (defined in this module as \texttt{op\_LT}, \texttt{op\_LE}, \texttt{op\_EQ}, \texttt{op\_NE}, \texttt{op\_GT}, \texttt{op\_GE}).

Cython exposes rich comparisons in \texttt{cdef} classes as the \texttt{\_richcmp\_} special method. The Sage coercion model also supports rich comparisons this way: for two instances \texttt{x} and \texttt{y} of \texttt{Element}, \texttt{x\_richcmp\_\(y\), \texttt{op}} is called when the user does something like \texttt{x <\= y} (possibly after coercion if \texttt{x} and \texttt{y} have different parents).

Various helper functions exist to make it easier to implement rich comparison: the most important one is the \texttt{richcmp()} function. This is analogous to the Python 2 function \texttt{cmp()} but implements rich comparison, with the comparison operator (e.g. \texttt{op\_GE}) as third argument. There is also \texttt{richcmp\_not\_equal()} which is like \texttt{richcmp()} but it is optimized assuming that the compared objects are not equal.

The functions \texttt{rich\_to\_bool()} and \texttt{rich\_to\_bool\_sgn()} can be used to convert results of \texttt{cmp()} (i.e. -1, 0 or 1) to a boolean True/False for rich comparisons.

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\texttt{sage\_structure\_richcmp.revop(op)}

Return the reverse operation of \texttt{op}.

For example, \texttt{<=} becomes \texttt{>=}, etc.

EXAMPLES:

```
sage: from sage\_structure\_richcmp import revop
sage: [revop(i) for i in range(6)]
[4, 5, 2, 3, 0, 1]
```

\texttt{sage\_structure\_richcmp.rich\_to\_bool(op, c)}

Return the corresponding True or False value for a rich comparison, given the result of an old-style comparison.

INPUT:

• \texttt{op} – a rich comparison operation (e.g. \texttt{Py\_EQ})

• \texttt{c} – the result of an old-style comparison: -1, 0 or 1.

OUTPUT: 1 or 0 (corresponding to True and False)

See also:

\texttt{rich\_to\_bool\_sgn()} if \texttt{c} could be outside the [-1, 0, 1] range.
EXAMPLES:

```python
sage: from sage.structure.richcmp import (rich_to_bool,
...:     op_EQ, op_NE, op_LT, op_LE, op_GT, op_GE)
sage: for op in (op_LT, op_LE, op_EQ, op_NE, op_GT, op_GE):
...:     for c in (-1, 0, 1):
...:         print(rich_to_bool(op, c))
True False False
True True False
False True False
False True True
```

Indirect tests using integers:

```python
sage: 0 < 5, 5 < 5, 5 < -8
(True, False, False)
sage: 0 <= 5, 5 <= 5, 5 <= -8
(True, True, False)
sage: 0 >= 5, 5 >= 5, 5 >= -8
(False, True, True)
sage: 0 > 5, 5 > 5, 5 > -8
(False, False, True)
sage: 0 == 5, 5 == 5, 5 == -8
(False, True, False)
sage: 0 != 5, 5 != 5, 5 != -8
(True, False, True)
```

```
sage.structure.richcmp.rich_to_bool_sgn(op, c)
Same as rich_to_bool, but allow any c < 0 and c > 0 instead of only −1 and 1.
```

Note: This is in particular needed for mpz_cmp().

```
sage.structure.richcmp.richcmp(x, y, op)
Return the result of the rich comparison of x and y with operator op.
```

INPUT:

- x, y – arbitrary Python objects
- op – comparison operator (one of op_LT, `op_LE, op_EQ, op_NE, op_GT, op_GE).

EXAMPLES:

```python
sage: from sage.structure.richcmp import *
sage: richcmp(3, 4, op_LT)
True
sage: richcmp(x, x^2, op_EQ)  # optional - sage.symbolic
x == x^2
```

The two examples above are completely equivalent to 3 < 4 and x == x^2. For this reason, it only makes sense in practice to call richcmp with a non-constant value for op.

We can write a custom `Element` class which shows a more realistic example of how to use this:
```python
sage: from sage.structure.element import Element
sage: class MyElement(Element):
    ....: def __init__(self, parent, value):
    ....:
    ....:     Element.__init__(self, parent)
    ....:     self.v = value
    ....: def __richcmp__(self, other, op):
    ....:     return richcmp(self.v, other.v, op)

sage: P = Parent()
sage: x = MyElement(P, 3)
sage: y = MyElement(P, 3)
sage: x < y
False
sage: x == y
True
sage: x > y
False
```

`sage.structure.richcmp.richcmp_by_eq_and_lt(eq_attr, lt_attr)`
Create a rich comparison method for a partial order, where the order is specified by methods called `eq_attr` and `lt_attr`.

INPUT when creating the method:
- `eq_attr` – attribute name for equality comparison
- `lt_attr` – attribute name for less-than comparison

INPUT when calling the method:
- `self` – objects having methods `eq_attr` and `lt_attr`
- `other` – arbitrary object. If it does have `eq_attr` and `lt_attr` methods, these are used for the comparison. Otherwise, the comparison is undefined.
- `op` – a rich comparison operation (e.g. `op_EQ`)

**Note:** For efficiency, identical objects (when `self` is `other`) always compare equal.

**Note:** The order is partial, so `x <= y` is implemented as `x == y` or `x < y`. It is not required that this is the negation of `y < x`.

**Note:** This function is intended to be used as a method `__richcmp__` in a class derived from `sage.structure.element.Element` or a method `__richcmp__` in a class using `richcmp_method()`.

**EXAMPLES:**

```python
sage: from sage.structure.richcmp import richcmp_by_eq_and_lt
sage: from sage.structure.element import Element

sage: class C(Element):
    ....: def __init__(self, a, b):
    ....:
    ....:     super(C, self).__init__(ZZ)
```

(continues on next page)

---

**6.1. Cython-like rich comparisons in Python**
Parents and Elements, Release 9.6

(continued from previous page)

```python
....:     self.a = a
....:     self.b = b
....:     __richcmp__ = richcmp_by_eq_and_lt("eq", "lt")
....:     def eq(self, other):
....:         return self.a == other.a and self.b == other.b
....:     def lt(self, other):
....:         return self.a < other.a and self.b < other.b

sage: x = C(1,2); y = C(2,1); z = C(3,3)

sage: x == x, x <= x, x == C(1,2), x <= C(1,2)  # indirect doctest
(True, True, True, True)

sage: y == z, y != z
(False, True)

sage: x < y, y < x, x > y, y > x, x <= y, x >= y
(False, False, False, False, False, False)

sage: y < z, z < y, y > z, z > y, y <= z, z <= y
(True, False, False, True, True, False)

sage: z < x, x < z, z > x, x > z, z <= x, x <= z
(False, True, True, False, False, True)
```

A simple example using `richcmp_method`:

```python
sage: from sage.structure.richcmp import richcmp_method, richcmp_by_eq_and_lt
sage: @richcmp_method
class C(object):
....:     __richcmp__ = richcmp_by_eq_and_lt("_eq", "_lt")
....:     def _eq(self, other):
....:         return True
....:     def _lt(self, other):
....:         return True

sage: a = C(); b = C()
sage: a == b
True
sage: a > b  # Calls b._lt(a)
True
sage: class X(object): pass
sage: x = X()
sage: a == x  # Does not call a._eq(x) because x does not have _eq
False
```

`sage.structure.richcmp.richcmp_item(x, y, op)`
This function is meant to implement lexicographic rich comparison of sequences (lists, vectors, polynomials, ...). The inputs `x` and `y` are corresponding items of such lists which should compared.

**INPUT:**

- `x, y` – arbitrary Python objects. Typically, these are `X[i]` and `Y[i]` for sequences `X` and `Y`.
- `op` – comparison operator (one of `op_LT`, `op_LE`, `op_EQ`, `op_NE`, `op_GT`, `op_GE`)

**OUTPUT:**

Assuming that `x = X[i]` and `y = Y[i]`:
• if the comparison $X \{\text{op}\} Y$ (where $\text{op}$ is the given operation) could not be decided yet (i.e. we should compare the next items in the list): return 

```
NotImplemented
```

• otherwise, if the comparison $X \{\text{op}\} Y$ could be decided: return $x \{\text{op}\} y$, which should then also be the result for $X \{\text{op}\} Y$.

**Note:** Since $x \{\text{op}\} y$ cannot return 

```
NotImplemented
```

the two cases above are mutually exclusive.

The semantics of the comparison is different from Python lists or tuples in the case that the order is not total. Assume that $A$ and $B$ are lists whose rich comparison is implemented using `richcmp_item` (as in EXAMPLES below). Then

- $A <= B$ iff $A < B$ or $A[i] <= B[i]$ for all $i$.
- $A >= B$ iff $A > B$ or $A[i] >= B[i]$ for all $i$.

See below for a detailed description of the exact semantics of `richcmp_item` in general.

**EXAMPLES:**

```
sage: from sage.structure.richcmp import *
sage: @richcmp_method
class Listcmp(list):
    def __richcmp__(self, other, op):
        for i in range(len(self)):
            res = richcmp_item(self[i], other[i], op)
        if res is not NotImplemented:
            return res
        return rich_to_bool(op, 0)  # Consider the lists to be equal

sage: a = Listcmp([0, 1, 3])
sage: b = Listcmp([0, 2, 1])
sage: a == a
True
sage: a != a
False
sage: a < a
False
sage: a <= a
True
sage: a > a
False
sage: a >= a
True
sage: a == b, b == a
(False, False)
sage: a != b, b != a
(True, True)
sage: a < b, b > a
(True, True)
```

(continues on next page)
sage: a <= b, b >= a
(True, True)
sage: a > b, b < a
(False, False)
sage: a >= b, b <= a
(False, False)

The above tests used a list of integers, where the result of comparisons are the same as for Python lists.

If we want to see the difference, we need more general entries in the list. The comparison rules are made to be consistent with setwise operations. If \(A\) and \(B\) are sets, we define \(A \{\text{op}\} B\) to be true if \(a \{\text{op}\} b\) is true for every \(a \in A\) and \(b \in B\). Interval comparisons are a special case of this. For lists of non-empty(!) sets, we want that \([A_1, A_2] \{\text{op}\} [B_1, B_2]\) is true if and only if \([a_1, a_2] \{\text{op}\} [b_1, b_2]\) is true for all elements. We verify this:

```python
sage: @richcmp_method
class Setcmp(tuple):
    def __richcmp__(self, other, op):
        return all(richcmp(x, y, op)
                   for x in self for y in other)
sage: sym = {op_EQ: "==", op_NE: "!="}
sage: for A1 in Set(range(4)).subsets():
    if not A1: continue
    for B1 in Set(range(4)).subsets():
        if not B1: continue
        for A2 in Set(range(4)).subsets():
            if not A2: continue
            for B2 in Set(range(3)).subsets():
                if not B2: continue
                L1 = Listcmp([Setcmp(A1), Setcmp(A2)])
                L2 = Listcmp([Setcmp(B1), Setcmp(B2)])
                for op in range(6):
                    reslist = richcmp(L1, L2, op)
                    reselt = all(richcmp([a1, a2], [b1, b2], op)
                                 for a1 in A1_
                                 --for a2 in A2 for b1 in B1 for b2 in B2)
                    assert reslist is reselt
```

EXACT SEMANTICS:

Above, we only described how \texttt{richcmp\_item} behaves when it is used to compare sequences. Here, we specify the exact semantics. First of all, recall that the result of \texttt{richcmp\_item(x, y, op)} is either \texttt{NotImplemented} or \(x \{\text{op}\} y\).

- if \texttt{op} is \texttt{==}: return \texttt{NotImplemented} if \(x == y\). If \(x == y\) is false, then return \(x == y\).
- if \texttt{op} is \texttt{!=}: return \texttt{NotImplemented} if not \(x != y\). If \(x != y\) is true, then return \(x != y\).
- if \texttt{op} is \texttt{<}: return \texttt{NotImplemented} if \(x == y\). If \(x < y\) or not \(x <= y\), return \(x < y\). Otherwise (if both \(x == y\) and \(x < y\) are false but \(x <= y\) is true), return \texttt{NotImplemented}.
- if \texttt{op} is \texttt{<=}: return \texttt{NotImplemented} if \(x == y\). If \(x < y\) or not \(x <= y\), return \(x <= y\). Otherwise (if both \(x == y\) and \(x < y\) are false but \(x <= y\) is true), return \texttt{NotImplemented}.
- the \texttt{>} and \texttt{>=} operators are analogous to \texttt{<} and \texttt{<=}.

\texttt{sage.structure.richcmp.richcmp\_method(cls)}

Class decorator to implement rich comparison using the special method \texttt{__richcmp\__} (analogous to Cython)
instead of the 6 methods __eq__ and friends.

This changes the class in-place and returns the given class.

EXAMPLES:

```python
sage: from sage.structure.richcmp import *
sage: sym = {op_EQ: "==", op_NE: "!="}, op_LT: "<", op_GT: ",", op_LE: ",", op_GE:
˓→"}  
sage: @richcmp_method
....: class A(str):
....:     def __richcmp__(self, other, op):
....:         print("%s %s %s" % (self, sym[op], other))

sage: A("left") < A("right")
left < right
sage: object() <= A("right")
right >= <object object at ...>
```

We can call this comparison with the usual Python special methods:

```python
sage: x = A("left"); y = A("right")
sage: x.__eq__(y)
left == right
```

Everything still works in subclasses:

```python
sage: class B(A):
....:     pass
sage: x = B("left"); y = B("right")
sage: x != y
left != right
```

We can override __richcmp__ with standard Python rich comparison methods and conversely:

```python
sage: class C(A):
....:     def __ne__(self, other):
....:         return False

sage: C("left") != C("right")
False
sage: C("left") == C("right")  # Calls __eq__ from class A
left == right
```

(continues on next page)
```python
sage: Derived() == Derived()
True
```

`sage.structure.richcmp.richcmp_not_equal(x, y, op)`
Like `richcmp(x, y, op)` but assuming that `x` is not equal to `y`.

**INPUT:**
- `op` – a rich comparison operation (e.g. `Py_EQ`)

**OUTPUT:**
If `op` is not `op_EQ` or `op_NE`, the result of `richcmp(x, y, op)`. If `op` is `op_EQ`, return `False`. If `op` is `op_NE`, return `True`.

This is useful to compare lazily two objects `A` and `B` according to 2 (or more) different parameters, say width and height for example. One could use:

```python
return richcmp((A.width(), A.height()), (B.width(), B.height()), op)
```

but this will compute both width and height in all cases, even if `A.width()` and `B.width()` are enough to decide the comparison.

Instead one can do:

```python
wA = A.width()
wB = B.width()
if wA != wB:
    return richcmp_not_equal(wA, wB, op)
return richcmp(A.height(), B.height(), op)
```

The difference with `richcmp` is that `richcmp_not_equal` assumes that its arguments are not equal, which is excluding the case where the comparison cannot be decided so far, without knowing the rest of the parameters.

**EXAMPLES:**

```python
sage: from sage.structure.richcmp import (richcmp_not_equal, ...
....:     op_EQ, op_NE, op_LT, op_LE, op_GT, op_GE)
sage: for op in (op_LT, op_LE, op_EQ, op_NE, op_GT, op_GE):
....:     print(richcmp_not_equal(3, 4, op))
True
True
False
True
False
False
```

```python
sage: for op in (op_LT, op_LE, op_EQ, op_NE, op_GT, op_GE):
....:     print(richcmp_not_equal(5, 4, op))
False
False
False
True
```

Chapter 6. Utilities
6.2 Unique Representation

Abstract classes for cached and unique representation behavior.

See also:

`sage.structure.factory.UniqueFactory`

AUTHORS:


6.2.1 What is a cached representation?

Instances of a class have a *cached representation behavior* when several instances constructed with the same arguments share the same memory representation. For example, calling twice:

```
sage: G = SymmetricGroup(6)
sage: H = SymmetricGroup(6)
```

to create the symmetric group on six elements gives back the same object:

```
sage: G is H
True
```

This is a standard design pattern. Besides saving memory, it allows for sharing cached data (say representation theoretical information about a group). And of course a look-up in the cache is faster than the creation of a new object.

Implementing a cached representation

Sage provides two standard ways to create a cached representation: `CachedRepresentation` and `UniqueFactory`. Note that, in spite of its name, `UniqueFactory` does not ensure unique representation behaviour, which will be explained below.

Using `CachedRepresentation`

It is often very easy to use `CachedRepresentation`: One simply writes a Python class and adds `CachedRepresentation` to the list of base classes. If one does so, then the arguments used to create an instance of this class will by default also be used as keys for the cache:

```
sage: from sage.structure.unique_representation import CachedRepresentation
sage: class C(CachedRepresentation):
....:    def __init__(self, a, b=0):
....:        self.a = a
....:        self.b = b
....:    def __repr__(self):
....:        return "C(%s, %s)"%(self.a, self.b)
sage: a = C(1)
sage: a is C(1)
True
```
In addition, pickling just works, provided that Python is able to look up the class. Hence, in the following two lines, we explicitly put the class into the \_main\_ module. This is needed in doctests, but not in an interactive session:

```python
sage: import \_main\_

sage: \_main\_.C = C

sage: loads(dumps(a)) is a
True
```

Often, this very easy approach is sufficient for applications. However, there are some pitfalls. Since the arguments are used for caching, all arguments must be hashable, i.e., must be valid as dictionary keys:

```python
sage: C((1,2))
C((1, 2), 0)

sage: C([1,2])

sage: Traceback (most recent call last):
... TypeError: unhashable type: 'list'
```

In addition, equivalent ways of providing the arguments are not automatically normalised when forming the cache key, and hence different but equivalent arguments may yield distinct instances:

```python
sage: C(1) is C(1,0)
False

sage: C(1) is C(a=1)
False

sage: repr(C(1)) == repr(C(a=1))
True
```

It should also be noted that the arguments are compared by equality, not by identity. This is often desired, but can imply subtle problems. For example, since C(1) already is in the cache, and since the unit elements in different finite fields are all equal to the integer one, we find:

```python
sage: GF(5)(1) == 1 == GF(3)(1)
True

sage: C(1) is C(GF(3)(1)) is C(GF(5)(1))
True
```

But C(2) is not in the cache, and the number two is not equal in different finite fields (i.e., GF(5)(2) == GF(3)(2) returns as False), even though it is equal to the number two in the ring of integers (GF(5)(2) == 2 == GF(3)(2) returns as True; equality is not transitive when comparing elements of distinct algebraic structures!!). Hence, we have:

```python
sage: GF(5)(2) == GF(3)(2)
False

sage: C(GF(3)(2)) is C(GF(5)(2))
False
```
Normalising the arguments

CachedRepresentation uses the metaclass ClasscallMetaclass. Its __classcall__ method is a WeakCachedFunction. This function creates an instance of the given class using the given arguments, unless it finds the result in the cache. This has the following implications:

- The arguments must be valid dictionary keys (i.e., they must be hashable; see above).
- It is a weak cache, hence, if the user does not keep a reference to the resulting instance, then it may be removed from the cache during garbage collection.
- It is possible to preprocess the input arguments by implementing a __classcall__ or a __classcall_private__ method, but in order to benefit from caching, CachedRepresentation.__classcall__() should at some point be called.

Note: For technical reasons, it is needed that __classcall__ respectively __classcall_private__ are “static methods”, i.e., they are callable objects that do not bind to an instance or class. For example, a cached function can be used here, because it is callable, but does not bind to an instance or class, because it has no __get__() method. A usual Python function, however, has a __get__() method and would thus under normal circumstances bind to an instance or class, and thus the instance or class would be passed to the function as the first argument. To prevent a callable object from being bound to the instance or class, one can prepend the @staticmethod decorator to the definition; see staticmethod.

For more on Python's __get__() method, see: https://docs.python.org/2/howto/descriptor.html

Warning: If there is preprocessing, then the preprocessed arguments passed to CachedRepresentation.__classcall__() must be invariant under the preprocessing. That is to say, preprocessing the input arguments twice must have the same effect as preprocessing the input arguments only once. That is to say, the preprocessing must be idempotent.

The reason for this warning lies in the way pickling is implemented. If the preprocessed arguments are passed to CachedRepresentation.__classcall__(), then the resulting instance will store the preprocessed arguments in some attribute, and will use them for pickling. If the pickle is unpickled, then preprocessing is applied to the preprocessed arguments—and this second round of preprocessing must not change the arguments further, since otherwise a different instance would be created.

We illustrate the warning by an example. Imagine that one has instances that are created with an integer-valued argument, but only depend on the square of the argument. It would be a mistake to square the given argument during preprocessing:

```python
sage: class WrongUsage(CachedRepresentation):
    ....:     @staticmethod
    ....:     def __classcall__(cls, n):
    ....:         return super(WrongUsage,cls).__classcall__(cls, n^2)
    ....:     def __init__(self, n):
    ....:         self.n = n
    ....:     def __repr__(self):
    ....:         return "Something(%d)"%self.n
sage: import __main__
sage: __main__.WrongUsage = WrongUsage # This is only needed in doctests
sage: w = WrongUsage(3); w
Something(9)
```

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Indeed, the reduction data are obtained from the preprocessed argument. By consequence, if the resulting instance is pickled and unpickled, the argument gets squared again:

```python
sage: loads(dumps(w))
Something(81)
```

Instead, the preprocessing should only take the absolute value of the given argument, while the squaring should happen inside of the `__init__` method, where it won’t mess with the cache:

```python
sage: class BetterUsage(CachedRepresentation):
    ....:     @staticmethod
    ....:     def __classcall__(cls, n):
    ....:         return super(BetterUsage, cls).__classcall__(cls, abs(n))
    ....:     def __init__(self, n):
    ....:         self.n = n^2
    ....:     def __repr__(self):
    ....:         return "SomethingElse(%d)"%self.n
sage: __main__.BetterUsage = BetterUsage  # This is only needed in doctests
sage: b = BetterUsage(3); b
SomethingElse(9)
sage: loads(dumps(b)) is b
True
sage: b is BetterUsage(-3)
True
```

In our next example, we create a cached representation class `C` that returns an instance of a sub-class `C1` or `C2` depending on the given arguments. This is implemented in a static `__classcall_private__` method of `C`, letting it choose the sub-class according to the given arguments. Since a `__classcall_private__` method will be ignored on sub-classes, the caching of `CachedRepresentation` is available to both `C1` and `C2`. But for illustration, we overload the static `__classcall__` method on `C2`, doing some argument preprocessing. We also create a sub-class `C2b` of `C2`, demonstrating that the `__classcall__` method is used on the sub-class (in contrast to a `__classcall_private__` method!)

```python
sage: class C(CachedRepresentation):
    ....:     @staticmethod
    ....:     def __classcall_private__(cls, n, implementation=0):
    ....:         if not implementation:
    ....:             return C.__classcall__(cls, n)
    ....:         if implementation==1:
    ....:             return C1(n)
    ....:         if implementation>1:
    ....:             return C2(n, implementation)
    ....:     def __init__(self, n):
    ....:         self.n = n
    ....:     def __repr__(self):
    ....:         return "C(%d, 0)"%self.n
sage: class C1(C):
    ....:     def __repr__(self):
    ....:         return "C1(%d)"%self.n
sage: class C2(C):
```

(continued on next page)
In the above example, C drops the argument implementation if it evaluates to False, and since the cached __classcall__ is called in this case, we have:

```
sage: C(1) is C(1,0)  # not needed in an interactive session
True
```

(Note that we were able to bypass the issue of arguments having to be hashable by catching the empty list [] during preprocessing in the __classcall_private__ method. Similarly, unhashable arguments can be made hashable – e. g., lists normalized to tuples – in the __classcall_private__ method before they are further delegated to __classcall__. See TCrystal for an example.)

If we call C1 directly or if we provide implementation=1 to C, we obtain an instance of C1. Since it uses the __classcall__ method inherited from CachedRepresentation, the resulting instances are cached:

```
sage: C1(2) is C2(2)
True
```

The class C2 preprocesses the input arguments. Instances can, again, be obtained directly or by calling C:

```
sage: C(1, implementation=3) is C2(1,3)
True
```

The argument preprocessing of C2 is inherited by C2b, since __classcall__ and not __classcall_private__ is used. Pickling works, since the preprocessing of arguments is idempotent:

```
sage: c2b = C2b(2,3); c2b
C2b((2, 2, 2))
sage: loads(dumps(c2b)) is c2b
True
```
Using UniqueFactory

For creating a cached representation using a factory, one has to

- create a class separately from the factory. This class must inherit from object. Its instances must allow attribute assignment.
- write a method create_key (or create_key_and_extra_args) that creates the cache key from the given arguments.
- write a method create_object that creates an instance of the class from a given cache key.
- create an instance of the factory with a name that allows to conclude where it is defined.

An example:

```python
sage: class C(object):
....:     def __init__(self, t):
....:         self.t = t
....:     def __repr__(self):
....:         return "C%s"%repr(self.t)

sage: from sage.structure.factory import UniqueFactory
sage: class MyFactory(UniqueFactory):
....:     def create_key(self, n, m=None):
....:         if isinstance(n, (tuple, list)) and m is None:
....:             return tuple(n)
....:         return (n,)*m
....:     def create_object(self, version, key, **extra_args):
....:         # We ignore version and extra_args
....:         return C(key)
```

Now, we define an instance of the factory, stating that it can be found under the name "F" in the __main__ module. By consequence, pickling works:

```python
sage: F = MyFactory("__main__.F")
sage: __main__.F = F           # not needed in an interactive session
sage: loads(dumps(F)) is F
True
```

We can now create cached instances of C by calling the factory. The cache only takes into account the key computed with the method create_key that we provided. Hence, different given arguments may result in the same instance. Note that, again, the cache is weak, hence, the instance might be removed from the cache during garbage collection, unless an external reference is preserved.

```python
sage: a = F(1, 2); a
C(1, 1)
sage: a is F((1,1))
True
```

If the class of the returned instances is a sub-class of object, and if the resulting instance allows attribute assignment, then pickling of the resulting instances is automatically provided for, and respects the cache.

```python
sage: loads(dumps(a)) is a
True
```

This is because an attribute is stored that explains how the instance was created:
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sage: a._factory_data
(<__main__.MyFactory object at ...>, (...), (1, 1), {})

Note: If a class is used that does not inherit from object then unique pickling is not provided.

Caching is only available if the factory is called. If an instance of the class is directly created, then the cache is not used:

sage: C((1,1))  
C(1, 1)  
sage: C((1,1)) is a  
False

Comparing the two ways of implementing a cached representation

In this sub-section, we discuss advantages and disadvantages of the two ways of implementing a cached representation, depending on the type of application.

Simplicity and transparency

In many cases, turning a class into a cached representation requires nothing more than adding CachedRepresentation to the list of base classes of this class. This is, of course, a very easy and convenient way. Writing a factory would involve a lot more work.

If preprocessing of the arguments is needed, then we have seen how to do this by a __classcall_private__ or __classcall__ method. But these are double underscore methods and hence, for example, invisible in the automatically created reference manual. Moreover, preprocessing and caching are implemented in the same method, which might be confusing. In a unique factory, these two tasks are cleanly implemented in two separate methods. With a factory, it is possible to create the resulting instance by arguments that are different from the key used for caching. This is significantly restricted with CachedRepresentation due to the requirement that argument preprocessing be idempotent.

Hence, if advanced preprocessing is needed, then UniqueFactory might be easier and more transparent to use than CachedRepresentation.

Class inheritance

Using CachedRepresentation has the advantage that one has a class and creates cached instances of this class by the usual Python syntax:

sage: G = SymmetricGroup(6)  
sage: isinstance(G, SymmetricGroup)  
True

In contrast, a factory is just a callable object that returns something that has absolutely nothing to do with the factory, and may in fact return instances of quite different classes:

6.2. Unique Representation
This can be confusing to the user. Namely, the user might determine the class of an instance and try to create further instances by calling the class rather than the factory—which is a mistake since it works around the cache (and also since the class might be more restrictive than the factory – i.e., the type of K5 in the above doctest cannot be called on a prime power which is not a prime). This mistake can more easily be avoided by using `CachedRepresentation`.

We have seen above that one can easily create new cached-representation classes by subclassing an existing cached-representation class, even making use of an existing argument preprocess. This would be much more complicated with a factory. Namely, one would need to rewrite old factories making them aware of the new classes, and/or write new factories for the new classes.

### Python versus extension classes

`CachedRepresentation` uses a metaclass, namely `ClasscallMetaclasse`. Hence, it can currently not be a Cython extension class. Moreover, it is supposed to be used by providing it as a base class. But in typical applications, one also has another base class, say, `Parent`. Hence, one would like to create a class with at least two base classes, which is currently impossible in Cython extension classes.

In other words, when using `CachedRepresentation`, one must work with Python classes. These can be defined in Cython code (.pyx files) and can thus benefit from Cython’s speed inside of their methods, but they must not be `cdef` class and can thus not use `cdef` attributes or methods.

Such restrictions do not exist when using a factory. However, if attribute assignment does not work, then the automatic pickling provided by `UniqueFactory` will not be available.

### 6.2.2 What is a unique representation?

Instances of a class have a *unique instance behavior* when instances of this class evaluate equal if and only if they are identical. Sage provides the base class `WithEqualityById`, which provides comparison by identity and a hash that is determined by the memory address of the instance. Both the equality test and the hash are implemented in Cython and are very fast, even when one has a Python class inheriting from `WithEqualityById`.

In many applications, one wants to combine unique instance and cached representation behaviour. This is called *unique representation* behaviour. We have seen above that symmetric groups have a cached representation behaviour. However, they do not show the *unique* representation behaviour, since they are equal to groups created in a totally different way, namely to subgroups:

```
sage: G = SymmetricGroup(6)
sage: G3 = G.subgroup([G((1,2,3,4,5,6)),G((1,2))])
sage: G is G3
(continues on next page)
```
False
sage: type(G) == type(G3)
False
sage: G == G3
True

The unique representation behaviour can conveniently be implemented with a class that inherits from `UniqueRepresentation`: By adding `UniqueRepresentation` to the base classes, the class will simultaneously inherit from `CachedRepresentation` and from `WithEqualityById`.

For example, a symmetric function algebra is uniquely determined by the base ring. Thus, it is reasonable to use `UniqueRepresentation` in this case:

```python
sage: isinstance(SymmetricFunctions(CC), SymmetricFunctions)
True
sage: issubclass(SymmetricFunctions, UniqueRepresentation)
True
```

`UniqueRepresentation` differs from `CachedRepresentation` only by adding `WithEqualityById` as a base class. Hence, the above examples of argument preprocessing work for `UniqueRepresentation` as well.

Note that a cached representation created with `UniqueFactory` does not automatically provide unique representation behaviour, in spite of its name! Hence, for unique representation behaviour, one has to implement hash and equality test accordingly, for example by inheriting from `WithEqualityById`.

```python
class sage.structure.unique_representation.CachedRepresentation
    Bases: object
    
    Classes derived from CachedRepresentation inherit a weak cache for their instances.

    Note: If this class is used as a base class, then instances are (weakly) cached, according to the arguments used to create the instance. Pickling is provided, of course by using the cache.

    Note: Using this class, one can have arbitrary hash and comparison. Hence, unique representation behaviour is not provided.

See also:

`UniqueRepresentation`, `unique_representation`

EXAMPLES:

Providing a class with a weak cache for the instances is easy: Just inherit from `CachedRepresentation`:

```python
sage: from sage.structure.unique_representation import CachedRepresentation
sage: class MyClass(CachedRepresentation):
....:     # all the rest as usual
....:     pass
```

We start with a simple class whose constructor takes a single value as argument (TODO: find a more meaningful example):
Two coexisting instances of `MyClass` created with the same argument data are guaranteed to share the same identity. Since trac ticket #12215, this is only the case if there is some strong reference to the returned instance, since otherwise it may be garbage collected:

```
sage: x = MyClass(1)
sage: y = MyClass(1)
sage: x is y  # There is a strong reference
True
sage: z = MyClass(2)
sage: x is z  
False
```

In particular, modifying any one of them modifies the other (reference effect):

```
sage: x.value = 3
sage: x.value, y.value
(3, 3)
sage: y.value = 1
sage: x.value, y.value
(1, 1)
```

The arguments can consist of any combination of positional or keyword arguments, as taken by a usual `__init__` function. However, all values passed in should be hashable:

```
sage: MyClass(value = [1,2,3])
Traceback (most recent call last):
...
TypeError: unhashable type: 'list'
```

### Argument preprocessing

Sometimes, one wants to do some preprocessing on the arguments, to put them in some canonical form. The following example illustrates how to achieve this; it takes as argument any iterable, and canonicalizes it into a tuple (which is hashable!):

```
sage: class MyClass2(CachedRepresentation):
    ....:     @staticmethod
    ....:     def __classcall__(cls, iterable):
    ....:         t = tuple(iterable)
    ....:         return super(MyClass2, cls).__classcall__(cls, t)
    ....:    ....:     def __init__(self, value):
    ....:         self.value = value

sage: x = MyClass2([1,2,3])
```

(continues on next page)
A similar situation arises when the constructor accepts default values for some of its parameters. Alas, the obvious implementation does not work:

```
sage: class MyClass3(CachedRepresentation):
    ....:     def __init__(self, value = 3):
    ....:         self.value = value
sage: MyClass3(3)
False
```

Instead, one should do:

```
sage: class MyClass3(UniqueRepresentation):
    ....:     @staticmethod
    ....:     def __classcall__(cls, value = 3):
    ....:         return super(MyClass3, cls).__classcall__(cls, value)
    ....:     def __init__(self, value):
    ....:         self.value = value
sage: MyClass3(3)
True
```

A bit of explanation is in order. First, the call `MyClass2([1,2,3])` triggers a call to `MyClass2.__classcall__(MyClass2, [1,2,3])`. This is an extension of the standard Python behavior, needed by `CachedRepresentation`, and implemented by the `ClasscallMetaclass`. Then, `MyClass2.__classcall__` does the desired transformations on the arguments. Finally, it uses `super` to call the default implementation of `__classcall__` provided by `CachedRepresentation`. This one in turn handles the caching and, if needed, constructs and initializes a new object in the class using `__new__` and `__init__` as usual.

Constraints:

- `__classcall__()` is a staticmethod (like, implicitly, `__new__`)
- the preprocessing on the arguments should be idempotent. That is, if `MyClass2.__classcall__(<arguments>)` calls `CachedRepresentation.__classcall__(<preprocessed_arguments>)`, then `MyClass2.__classcall__(<preprocessed_arguments>)` should also result in a call to `CachedRepresentation.__classcall__(<preprocessed_arguments>)`.
- `MyClass2.__classcall__` should return the result of `CachedRepresentation.__classcall__()` without modifying it.

Other than that `MyClass2.__classcall__` may play any tricks, like acting as a factory and returning objects from other classes.

**Warning:** It is possible, but strongly discouraged, to let the `__classcall__` method of a class C return objects that are not instances of C. Of course, instances of a `subclass` of C are fine. Compare the examples in `unique_representation`.

---

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We illustrate what is meant by an “idempotent” preprocessing. Imagine that one has instances that are created with an integer-valued argument, but only depend on the square of the argument. It would be a mistake to square the given argument during preprocessing:

```
sage: class WrongUsage(CachedRepresentation):
    ....:     @staticmethod
    ....:     def __classcall__(cls, n):
    ....:         return super(WrongUsage, cls).__classcall__(cls, n^2)
    ....:     def __init__(self, n):
    ....:         self.n = n
    ....:     def __repr__(self):
    ....:         return "Something(%d)"%self.n

sage: import __main__
```

```
sage: __main__.WrongUsage = WrongUsage  # This is only needed in doctests
sage: w = WrongUsage(3); w
Something(9)
```

Indeed, the reduction data are obtained from the preprocessed arguments. By consequence, if the resulting instance is pickled and unpickled, the argument gets squared again:

```
sage: loads(dumps(w))
Something(81)
```

Instead, the preprocessing should only take the absolute value of the given argument, while the squaring should happen inside of the __init__ method, where it won’t mess with the cache:

```
sage: class BetterUsage(CachedRepresentation):
    ....:     @staticmethod
    ....:     def __classcall__(cls, n):
    ....:         return super(BetterUsage, cls).__classcall__(cls, abs(n))
    ....:     def __init__(self, n):
    ....:         self.n = n^2
    ....:     def __repr__(self):
    ....:         return "SomethingElse(%d)"%self.n
```

```
sage: __main__.BetterUsage = BetterUsage  # This is only needed in doctests
sage: b = BetterUsage(3); b
SomethingElse(9)
```

```
sage: loads(dumps(b)) is b
True
```

```
sage: b is BetterUsage(-3)
True
```
Cached representation and mutability

`CachedRepresentation` is primarily intended for implementing objects which are (at least semantically) immutable. This is in particular assumed by the default implementations of `copy` and `deepcopy`:

```python
sage: copy(x) is x
True
sage: from copy import deepcopy
sage: deepcopy(x) is x
True
```

However, in contrast to `UniqueRepresentation`, using `CachedRepresentation` allows for a comparison that is not by identity:

```python
sage: t = MyClass(3)
sage: z = MyClass(2)
sage: t.value = 2
sage: t.value == z.value
True
sage: t == z
True
sage: t is z
False
```

More on cached representation and identity

`CachedRepresentation` is implemented by means of a cache. This cache uses weak references in general, but strong references to the most recently created objects. Hence, when all other references to, say, `MyClass(1)` have been deleted, the instance is eventually deleted from memory (after enough other objects have been created to remove the strong reference to `MyClass(1)`). A later call to `MyClass(1)` reconstructs the instance from scratch:

```python
sage: class SomeClass(UniqueRepresentation):
    ...:     def __init__(self, i):
    ...:         print("creating new instance for argument %s" % i)
    ...:         self.i = i
    ...:     def __del__(self):
    ...:         print("deleting instance for argument %s" % self.i)

sage: class OtherClass(UniqueRepresentation):
    ...:     def __init__(self, i):
    ...:         pass

sage: O = SomeClass(1)
creating new instance for argument 1
sage: O is SomeClass(1)
True
sage: O is SomeClass(2)
creating new instance for argument 2
False
sage: L = [OtherClass(i) for i in range(200)]
deleting instance for argument 2
```

(continues on next page)
Cached representation and pickling

The default Python pickling implementation (by reconstructing an object from its class and dictionary, see “The pickle protocol” in the Python Library Reference) does not preserve cached representation, as Python has no chance to know whether and where the same object already exists.

CachedRepresentation tries to ensure appropriate pickling by implementing a `__reduce__` method returning the arguments passed to the constructor:

```
sage: import __main__  # Fake MyClass being defined in a python module
sage: __main__.MyClass = MyClass
sage: x = MyClass(1)
sage: loads(dumps(x)) is x
True
```

CachedRepresentation uses the `__reduce__` pickle protocol rather than `__getnewargs__` because the latter does not handle keyword arguments:

```
sage: x = MyClass(value = 1)
sage: x.__reduce__()
(<function unreduce at ...>, (<class '__main__.MyClass'>, (), {'value': 1}))
sage: x is loads(dumps(x))
True
```

**Note:** The default implementation of `__reduce__` in CachedRepresentation requires to store the constructor’s arguments in the instance dictionary upon construction:

```
sage: x.__dict__
{'_reduction': (<class '__main__.MyClass'>, (), {'value': 1}), 'value': 1}
```

It is often easy in a derived subclass to reconstruct the constructor’s arguments from the instance data structure. When this is the case, `__reduce__` should be overridden; automatically the arguments won’t be stored anymore:

```
sage: class MyClass3(UniqueRepresentation):
    ....:    def __init__(self, value):
    ....:        self.value = value
    ....:
    ....:    def __reduce__(self):
    ....:        return (MyClass3, (self.value,))
sage: import __main__; __main__.MyClass3 = MyClass3  # Fake MyClass3 being defined in a python module
sage: x = MyClass3(1)
sage: loads(dumps(x)) is x
```

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Migrating classes to CachedRepresentation and unpickling

We check that, when migrating a class to `CachedRepresentation`, older pickles can still be reasonably unpickled. Let us create a (new style) class, and pickle one of its instances:

```python
sage: class MyClass4(object):
  ....:     def __init__(self, value):
  ....:         self.value = value
sage: import __main__; __main__.MyClass4 = MyClass4  # Fake MyClass4 being defined, in a python module
sage: pickle = dumps(MyClass4(1))
```

It can be unpickled:

```python
sage: y = loads(pickle)
sage: y.value
1
```

Now, we upgrade the class to derive from `UniqueRepresentation`, which inherits from `CachedRepresentation`:

```python
sage: class MyClass4(UniqueRepresentation, object):
  ....:     def __init__(self, value):
  ....:         self.value = value
sage: import __main__; __main__.MyClass4 = MyClass4  # Fake MyClass4 being defined, in a python module
sage: __main__.MyClass4 = MyClass4
```

The pickle can still be unpickled:

```python
sage: y = loads(pickle)
sage: y.value
1
```

Note however that, for the reasons explained above, unique representation is not guaranteed in this case:

```python
sage: y is MyClass4(1)
False
```

**Todo:** Illustrate how this can be fixed on a case by case basis.

Now, we redo the same test for a class deriving from `SageObject`:

```python
sage: class MyClass4(SageObject):
  ....:     def __init__(self, value):
```

(continues on next page)
Caveat: unpickling instances of a formerly old-style class is not supported yet by default:

```
sage: class MyClass4:
    ....:   def __init__(self, value):
    ....:       self.value = value
sage: import __main__; __main__.MyClass4 = MyClass4  # Fake MyClass4 being defined.
˓→in a python module
sage: pickle = dumps(MyClass4(1))

sage: class MyClass4(UniqueRepresentation, SageObject):
    ....:   def __init__(self, value):
    ....:       self.value = value
sage: __main__.MyClass4 = MyClass4  # Fake MyClass4 being defined.
˓→in a python module
sage: pickle = dumps(MyClass4(1))

sage: class MyClass4(UniqueRepresentation, SageObject):
    ....:   def __init__(self, value):
    ....:       self.value = value
sage: __main__.MyClass4 = MyClass4  # todo: not implemented
sage: y = loads(pickle)  # todo: not implemented
sage: y.value
```

Rationale for the current implementation

`CachedRepresentation` and derived classes use the `ClasscallMetaclass` of the standard Python type. The following example explains why.

We define a variant of `MyClass` where the calls to `__init__` are traced:

```
sage: class MyClass(CachedRepresentation):
    ....:       def __init__(self, value):
    ....:           print("initializing object")
    ....:           self.value = value

Let us create an object twice:

```
sage: x = MyClass(1)
initializing object
sage: z = MyClass(1)
```

As desired the `__init__` method was only called the first time, which is an important feature.

As far as we can tell, this is not achievable while just using `__new__` and `__init__` (as defined by type; see Section Basic Customization in the Python Reference Manual). Indeed, `__init__` is called systematically on the result of `__new__` whenever the result is an instance of the class.
Another difficulty is that argument preprocessing (as in the example above) cannot be handled by \texttt{\_\_new\_\_}, since the unprocessed arguments will be passed down to \texttt{\_\_init\_\_}.

\begin{verbatim}
class sage.structure.unique_representation.UniqueRepresentation
Bases: sage.structure.unique_representation.CachedRepresentation, sage.misc.fast_methods.WithEqualityById

Classes derived from UniqueRepresentation inherit a unique representation behavior for their instances.

See also:

unique_representation

EXAMPLES:
The short story: to construct a class whose instances have a unique representation behavior one just has to do:

\begin{verbatim}
sage: class MyClass(UniqueRepresentation):
....:    # all the rest as usual
....:    pass
\end{verbatim}

Everything below is for the curious or for advanced usage.

\textbf{What is unique representation?}

Instances of a class have a \textit{unique representation behavior} when instances evaluate equal if and only if they are identical (i.e., share the same memory representation), if and only if they were created using equal arguments. For example, calling twice:

\begin{verbatim}
sage: f = SymmetricFunctions(QQ)
sage: g = SymmetricFunctions(QQ)
\end{verbatim}

to create the symmetric function algebra over \(\mathbb{Q}\) actually gives back the same object:

\begin{verbatim}
sage: f == g
True
sage: f is g
True
\end{verbatim}

This is a standard design pattern. It allows for sharing cached data (say representation theoretical information about a group) as well as for very fast hashing and equality testing. This behaviour is typically desirable for parents and categories. It can also be useful for intensive computations where one wants to cache all the operations on a small set of elements (say the multiplication table of a small group), and access this cache as quickly as possible.

\texttt{UniqueRepresentation} is very easy to use: a class just needs to derive from it, or make sure some of its super classes does. Also, it groups together the class and the factory in a single gadget:

\begin{verbatim}
sage: isinstance(SymmetricFunctions(CC), SymmetricFunctions)
True
sage: issubclass(SymmetricFunctions, UniqueRepresentation)
True
\end{verbatim}

This nice behaviour is not available when one just uses a factory:
In addition, `UniqueFactory` only provides the `cached` representation behaviour, but not the `unique` representation behaviour—the examples in `unique_representation` explain this difference.

On the other hand, the `UniqueRepresentation` class is more intrusive, as it imposes a behavior (and a metaclass) on all the subclasses. In particular, the unique representation behaviour is imposed on all subclasses (unless the `__classcall__` method is overloaded and not called in the subclass, which is not recommended). Its implementation is also more technical, which leads to some subtleties.

**EXAMPLES:**

We start with a simple class whose constructor takes a single value as argument. This pattern is similar to what is done in `sage.combinat.sf.sf.SymmetricFunctions`:

```python
sage: class MyClass(UniqueRepresentation):
    ....:     def __init__(self, value):
    ....:         self.value = value
```

Two coexisting instances of `MyClass` created with the same argument data are guaranteed to share the same identity. Since trac ticket #12215, this is only the case if there is some strong reference to the returned instance, since otherwise it may be garbage collected:

```python
sage: x = MyClass(1)
sage: y = MyClass(1)
sage: x is y  # There is a strong reference
True
sage: z = MyClass(2)
sage: x is z
False
```

In particular, modifying any one of them modifies the other (reference effect):

```python
sage: x.value = 3
sage: x.value, y.value
(3, 3)
sage: y.value = 1
sage: x.value, y.value
(1, 1)
```

When comparing two instances of a unique representation with `==` or `!=` comparison by identity is used:

```python
sage: x == y
True
sage: x is y
True
sage: z = MyClass(2)
sage: x == z
False
```
A hash function equivalent to `object.__hash__() ` is used, which is compatible with comparison by identity. However this means that the hash function may change in between Sage sessions, or even within the same Sage session.

```
sage: hash(x) == object.__hash__(x)
True
```

**Warning:** It is possible to inherit from `UniqueRepresentation` and then overload comparison in a way that destroys the unique representation property. We strongly recommend against it! You should use `CachedRepresentation` instead.

---

### Mixing super types and super classes

```
sage.structure.unique_representation.unreduce(cls, args, keywords)
```

Calls a class on the given arguments:

```
sage: sage.structure.unique_representation.unreduce(Integer, (1,), {})
1
```

---

**Todo:** should reuse something preexisting …

---

### 6.3 Factory for cached representations

See also: 

`sage.structure.unique_representation`

Using a `UniqueFactory` is one way of implementing a *cached representation behaviour*. In spite of its name, using a `UniqueFactory` is not enough to ensure the *unique representation behaviour*. See `unique_representation` for a detailed explanation.

With a `UniqueFactory`, one can preprocess the given arguments. There is special support for specifying a subset of the arguments that serve as the unique key, so that still *all* given arguments are used to create a new instance, but only the specified subset is used to look up in the cache. Typically, this is used to construct objects that accept an optional `check=[True|False]` argument, but whose result should be unique regardless of said optional argument. (This use case should be handled with care, though: Any checking which isn’t done in the `create_key` or `create_key_and_extra_args` method will be done only when a new object is generated, but not when a cached object is retrieved from cache. Consequently, if the factory is once called with `check=False`, a subsequent call with `check=True` cannot be expected to perform all checks unless these checks are all in the `create_key` or `create_key_and_extra_args` method.)
For a class derived from `CachedRepresentation`, argument preprocessing can be obtained by providing a custom static `__classcall__` or `__classcall_private__` method, but this seems less transparent. When argument preprocessing is not needed or the preprocessor is not very sophisticated, then generally `CachedRepresentation` is much easier to use than a factory.

**AUTHORS:**

- Simon King (2013): extended documentation.
- Julian Rueth (2014-05-09): use `_cache_key` if parameters are unhashable

```python
class sage.structure.factory.UniqueFactory
    Bases: sage.structure.sage_object.SageObject

This class is intended to make it easy to cache objects.

It is based on the idea that the object is uniquely defined by a set of defining data (the key). There is also the possibility of some non-defining data (extra args) which will be used in initial creation, but not affect the caching.

**Warning:** This class only provides cached representation behaviour. Hence, using `UniqueFactory`, it is still possible to create distinct objects that evaluate equal. Unique representation behaviour can be added, for example, by additionally inheriting from `sage.misc.fast_methods.WithEqualityById`.

The objects created are cached (using weakrefs) based on their key and returned directly rather than re-created if requested again. Pickling is taken care of by the factory, and will return the same object for the same version of Sage, and distinct (but hopefully equal) objects for different versions of Sage.

**Warning:** The objects returned by a `UniqueFactory` must be instances of new style classes (hence, they must be instances of `object`) that must not only allow a weak reference, but must accept general attribute assignment. Otherwise, pickling won’t work.

**USAGE:**

A *unique factory* provides a way to create objects from parameters (the type of these objects can depend on the parameters, and is often determined only at runtime) and to cache them by a certain key derived from these parameters, so that when the factory is being called again with the same parameters (or just with parameters which yield the same key), the object is being returned from cache rather than constructed anew.

An implementation of a unique factory consists of a factory class and an instance of this factory class.

The factory class has to be a class inheriting from `UniqueFactory`. Typically it only needs to implement `create_key()` (a method that creates a key from the given parameters, under which key the object will be stored in the cache) and `create_object()` (a method that returns the actual object from the key). Sometimes, one would also implement `create_key_and_extra_args()` (this differs from `create_key()` in allowing to also create some additional arguments from the given parameters, which arguments then get passed to `create_object()` and thus can have an effect on the initial creation of the object, but do not affect the key) or `other_keys()`. Other methods are not supposed to be overloaded.

The factory class itself cannot be called to create objects. Instead, an instance of the factory class has to be created first. For technical reasons, this instance has to be provided with a name that allows Sage to find its definition. Specifically, the name of the factory instance (or the full path to it, if it is not in the global namespace) has to be passed to the factory class as a string variable. So, if our factory class has been called `A` and is located in `sage/spam/battletoads.py`, then we need to define an instance (say, `B`) of `A` by writing `B = A("sage.spam.battletoads.B")` (or `B = A("B")` if this `B` will be imported into global namespace). This instance can then be used to create objects (by calling `B(*parameters)`).
Notice that the objects created by the factory don’t inherit from the factory class. They do know about the factory that created them (this information, along with the keys under which this factory caches them, is stored in the _factory_data attributes of the objects), but not via inheritance.

EXAMPLES:
The below examples are rather artificial and illustrate particular aspects. For a “real-life” usage case of UniqueFactory, see the finite field factory in sage.rings.finite_rings.finite_field_constructor.

In many cases, a factory class is implemented by providing the two methods create_key() and create_object(). In our example, we want to demonstrate how to use “extra arguments” to choose a specific implementation, with preference given to an instance found in the cache, even if its implementation is different. Hence, we implement create_key_and_extra_args() rather than create_key(), putting the chosen implementation into the extra arguments. Then, in the create_object() method, we create and return instances of the specified implementation.

```python
sage: from sage.structure.factory import UniqueFactory
sage: class MyFactory(UniqueFactory):
    ....: def create_key_and_extra_args(self, *args, **kwds):
    ....:     return args, {'impl': kwds.get('impl', None)}
    ....: def create_object(self, version, key, **extra_args):
    ....:     impl = extra_args['impl']
    ....:     if impl == 'C':
    ....:         return C(*key)
    ....:     if impl == 'D':
    ....:         return D(*key)
    ....:     return E(*key)
```

Now we can create a factory instance. It is supposed to be found under the name “F” in the "__main__" module. Note that in an interactive session, F would automatically be in the __main__ module. Hence, the second and third of the following four lines are only needed in doctests.

```python
sage: F = MyFactory("__main__.F")
sage: import __main__
sage: __main__.F = F
sage: loads(dumps(F)) is F
True
```

Now we create three classes C, D and E. The first is a Cython extension-type class that does not allow weak references nor attribute assignment. The second is a Python class that is not derived from object. The third allows attribute assignment and is derived from object.

```python
sage: cython("cdef class C: pass")
sage: class D:
    ....:     def __init__(self, *args):
    ....:         self.t = args
    ....:     def __repr__(self):
    ....:         return "D%s"%repr(self.t)

sage: class E(D, object): pass
```

Again, being in a doctest, we need to put the class D into the __main__ module, so that Python can find it:

```python
sage: import __main__
sage: __main__.D = D
```

6.3. Factory for cached representations
It is impossible to create an instance of C with our factory, since it does not allow weak references:

```
sage: F(1, impl='C')
Traceback (most recent call last):
...
TypeError: cannot create weak reference to '....C' object
```

Let us try again, with a Cython class that does allow weak references. Now, creation of an instance using the factory works:

```
sage: cython(''cdef class C:
....:   cdef __weakref__
....: ''
....:
sage: c = F(1, impl='C')
sage: isinstance(c, C)
True
```

The cache is used when calling the factory again—even if it is suggested to use a different implementation. This is because the implementation is only considered an "extra argument" that does not count for the key.

```
sage: c is F(1, impl='C') is F(1, impl='D') is F(1)
True
```

However, pickling and unpickling does not use the cache. This is because the factory has tried to assign an attribute to the instance that provides information on the key used to create the instance, but failed:

```
sage: loads(dumps(c)) is c
False
sage: hasattr(c, '_factory_data')
False
```

We have already seen that our factory will only take the requested implementation into account if the arguments used as key have not been used yet. So, we use other arguments to create an instance of class D:

```
sage: d = F(2, impl='D')
sage: isinstance(d, D)
True
```

The factory only knows about the pickling protocol used by new style classes. Hence, again, pickling and unpickling fails to use the cache, even though the “factory data” are now available (this is not the case on Python 3 which only has new style classes):

```
sage: loads(dumps(d)) is d
True
sage: d._factory_data
(<__main__.MyFactory object at ...>,
(2,),
{"impl": 'D'})
```

Only when we have a new style class that can be weak referenced and allows for attribute assignment, everything works:
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```python
sage: e = F(3)
sage: isinstance(e, E)
True
sage: loads(dumps(e)) is e
True
sage: e._factory_data
(...),
(3,),
{'impl': None})
```

```python
create_key(*args, **kwds)
```
Given the parameters (arguments and keywords), create a key that uniquely determines this object.

```
sage: from sage.structure.test_factory import test_factory
sage: test_factory.create_key(1, 2, key=5)
(1, 2)
```

```python
create_key_and_extra_args(*args, **kwds)
```
Return a tuple containing the key (uniquely defining data) and any extra arguments (empty by default).

Defaults to `create_key()`.

```
sage: from sage.structure.test_factory import test_factory
sage: test_factory.create_key_and_extra_args(1, 2, key=5)
((1, 2), {})
sage: GF.create_key_and_extra_args(3)
((3, ('x',), None, 'modn', 3, 1, True, None, None, None), {})
```

```python
create_object(version, key, **extra_args)
```
Create the object from the key and extra arguments. This is only called if the object was not found in the cache.

```
sage: from sage.structure.test_factory import test_factory
sage: test_factory.create_object(0, (1,2,3))
Making object (1, 2, 3)
<sage.structure.test_factory.A object at ...>
sage: test_factory('a')
Making object ('a',)
<sage.structure.test_factory.A object at ...>
sage: test_factory('a') # NOT called again
<sage.structure.test_factory.A object at ...>
```

```python
get_object(version, key, extra_args)
```
Returns the object corresponding to key, creating it with `extra_args` if necessary (for example, it isn’t in the cache or it is unpickling from an older version of Sage).

```
sage: get_object(0, (1,2,3))
Making object (1, 2, 3)
<sage.structure.test_factory.A object at ...>
sage: get_object('a')
Making object ('a',)
<sage.structure.test_factory.A object at ...>
```

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```python
sage: from sage.structure.test_factory import test_factory
sage: a = test_factory.get_object(3.0, 'a', {}); a
Making object a
<a.sage.structure.test_factory.A object at ...>
sage: test_factory.get_object(3.0, 'a', {}) is test_factory.get_object(3.0, 'a', {})
True
sage: test_factory.get_object(3.0, 'a', {}) is test_factory.get_object(3.1, 'a', {})
False
sage: test_factory.get_object(3.0, 'a', {}) is test_factory.get_object(3.0, 'b', {})
False
```

**get_version(sage_version)**

This is provided to allow more or less granular control over pickle versioning. Objects pickled in the same version of Sage will unpickle to the same rather than simply equal objects. This can provide significant gains as arithmetic must be performed on objects with identical parents. However, if there has been an incompatible change (e.g. in element representation) we want the version number to change so coercion is forced between the two parents.

Defaults to the Sage version that is passed in, but coarser granularity can be provided.

**EXAMPLES:**

```python
sage: from sage.structure.test_factory import test_factory
sage: test_factory.get_version((3,1,0))
(3, 1, 0)
```

**other_keys(key, obj)**

Sometimes during object creation, certain defaults are chosen which may result in a new (more specific) key. This allows the more specific key to be regarded as equivalent to the original key returned by `create_key()` for the purpose of lookup in the cache, and is used for pickling.

**EXAMPLES:**

The GF factory used to have a custom `other_keys()` method, but this was removed in trac ticket #16934:

```python
sage: key, _ = GF.create_key_and_extra_args(27, 'k'); key
(27, ('k'), x^3 + 2*x + 1, 'givaro', 3, 3, True, None, 'poly', True)
sage: K = GF.create_object(0, key); K
Finite Field in k of size 3^3
sage: GF.other_keys(key, K)
[]
sage: K = GF(7^49, 'a')
sage: loads(dumps(K)) is K
True
```

**reduce_data(obj)**

The results of this function can be returned from `__reduce__()`. This is here so the factory internals can change without having to re-write `__reduce__()` methods that use it.

**EXAMPLES:**
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```python
sage: from sage.modules.free_module import FreeModuleFactory_with_standard_basis as F
sage: V = F(ZZ, 5)
sage: factory, data = F.reduce_data(V)
sage: factory(*data)
Ambient free module of rank 5 over the principal ideal domain Integer Ring
True
sage: from sage.structure.test_factory import test_factory
sage: a = test_factory(1, 2)
Making object (1, 2)
sage: test_factory.reduce_data(a)
(<built-in function generic_factory_unpickle>,
 (<sage.structure.test_factory.UniqueFactoryTester object at ...>,
 (...),
 (1, 2),
 { }))
```

Note that the ellipsis (...) here stands for the Sage version.

```python
sage.structure.factory.generic_factory_reduce(self, proto)
    Used to provide a __reduce__ method if one does not already exist.

    EXAMPLES:

    ```python
    sage: V = QQ^6
    sage: sage.structure.factory.generic_factory_reduce(V, 1) == V.__reduce_ex__(1)
    True
    ```

sage.structure.factory.generic_factory_unpickle(factory, *args)
    Method used for unpickling the object.

    The unpickling mechanism needs a plain Python function to call. It takes a factory as the first argument, passes the rest of the arguments onto the factory's `UniqueFactory.get_object()` method.

    EXAMPLES:

    ```python
    sage: from sage.modules.free_module import FreeModuleFactory_with_standard_basis as F
    sage: V = F(ZZ, 5)
sage: func, data = F.reduce_data(V)
sage: func is sage.structure.factory.generic_factory_unpickle
    True
    sage: sage.structure.factory.generic_factory_unpickle(*data)
    is V
    True
    ```

sage.structure.factory.lookup_global(name)
    Used in unpickling the factory itself.

    EXAMPLES:

    ```python
    sage: from sage.structure.factory import lookup_global
    sage: lookup_global('ZZ')
    Integer Ring
    ```
```

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sage: lookup_global('sage.rings.all.ZZ')
Integer Ring

sage.structure.factory.register_factory_unpickle(name, callable)
Register a callable to handle the unpickling from an old UniqueFactory object.

UniqueFactory pickles use a global name through generic_factory_unpickle(), so the usual register_unpickle_override() cannot be used here.

See also:
generic_factory_unpickle()

6.4 Dynamic classes

Why dynamic classes?

The short answer:

• Multiple inheritance is a powerful tool for constructing new classes by combining preexisting building blocks.
• There is a combinatorial explosion in the number of potentially useful classes that can be produced this way.
• The implementation of standard mathematical constructions calls for producing such combinations automatically.
• Dynamic classes, i.e. classes created on the fly by the Python interpreter, are a natural mean to achieve this.

The long answer:

Say we want to construct a new class MyPermutation for permutations in a given set $S$ (in Sage, $S$ will be modelled by a parent, but we won’t discuss this point here). First, we have to choose a data structure for the permutations, typically among the following:

• Stored by cycle type
• Stored by code
• Stored in list notation - C arrays of short ints (for small permutations) - python lists of ints (for huge permutations)
• Stored by reduced word
• Stored as a function
• ... 

Luckily, the Sage library provides (or will provide) classes implementing each of those data structures. Those classes all share a common interface (or possibly a common abstract base class). So we can just derive our class from the chosen one:

```python
class MyPermutation(PermutationCycleType):
    ...
```

Then we may want to further choose a specific memory behavior (unique representation, copy-on-write) which (hopefully) can again be achieved by inheritance:

```python
class MyPermutation(UniqueRepresentation, PermutationCycleType):
    ...
```
Finally, we may want to endow the permutations in $S$ with further operations coming from the (algebraic) structure of $S$:

- group operations
- or just monoid operations (for a subset of permutations not stable by inverse)
- poset operations (for left/right/Bruhat order)
- word operations (searching for substrings, patterns, ...)

Or any combination thereof. Now, our class typically looks like:

```python
class MyPermutation(UniqueRepresentation, PermutationCycleType, PosetElement, ...
    GroupElement):
    ...
```

Note the combinatorial explosion in the potential number of classes which can be created this way.

In practice, such classes will be used in mathematical constructions like:

```python
SymmetricGroup(5).subset(... TODO: find a good example in the context above ...)
```

In such a construction, the structure of the result, and therefore the operations on its elements can only be determined at execution time. Let us take another standard construction:

```python
A = cartesian_product( B, C )
```

Depending on the structure of $B$ and $C$, and possibly on further options passed down by the user, $A$ may be:

- an enumerated set
- a group
- an algebra
- a poset
- ...

Or any combination thereof.

Hardcoding classes for all potential combinations would be at best tedious. Furthermore, this would require a cumbersome mechanism to lookup the appropriate class depending on the desired combination.

Instead, one may use the ability of Python to create new classes dynamically:

```python
type("class name", tuple of base classes, dictionary of methods)
```

This paradigm is powerful, but there are some technicalities to address. The purpose of this library is to standardize its use within Sage, and in particular to ensure that the constructed classes are reused whenever possible (unique representation), and can be pickled.
Combining dynamic classes and Cython classes

Cython classes cannot inherit from a dynamic class (there might be some partial support for this in the future). On the other hand, such an inheritance can be partially emulated using \_\_getattr\_\_(). See sage.categories.examples.semigroups_cython for an example.

```python
class sage.structure.dynamic_class.DynamicClasscallMetaclass
    Bases: sage.structure.dynamic_class.DynamicMetaclas, sage.misc.classcall_metaclas.
    ClasscallMetaclas

class sage.structure.dynamic_class.DynamicInheritComparisonClasscallMetaclas
    Bases: sage.structure.dynamic_class.DynamicMetaclas, sage.misc.inherit_comparison.
    InheritComparisonClasscallMetaclas

class sage.structure.dynamic_class.DynamicInheritComparisonMetaclas
    Bases: sage.structure.dynamic_class.DynamicMetaclas, sage.misc.inherit_comparison.
    InheritComparisonMetaclas

class sage.structure.dynamic_class.DynamicMetaclas
    Bases: type
    A metaclass implementing an appropriate reduce-by-construction method

sage.structure.dynamic_class.M
    alias of sage.structure.dynamic_class.DynamicInheritComparisonClasscallMetaclas

class sage.structure.dynamic_class.TestClass
    Bases: object
    A class used for checking that introspection works

bla()
    bla ...

sage.structure.dynamic_class.dynamic_class(name, bases, cls=None, reduction=None, doccls=None, prepend_cls_bases=True, cache=True)
```

**INPUT:**

- `name` - a string
- `bases` - a tuple of classes
- `cls` - a class or None
- `reduction` - a tuple or None
- `doccls` - a class or None
- `prepend_cls_bases` - a boolean (default: True)
- `cache` - a boolean or "ignore_reduction" (default: True)

Constructs dynamically a new class `C` with name `name`, and bases `bases`. If `cls` is provided, then its methods will be inserted into `C`, and its bases will be prepended to `bases` (unless `prepend_cls_bases` is False).

The module, documentation and source introspection is taken from `doccls`, or `cls` if `doccls` is None, or `bases[0]` if both are None (therefore `bases` should be non empty if `cls` is `None`).

The constructed class can safely be pickled (assuming the arguments themselves can).

Unless `cache` is False, the result is cached, ensuring unique representation of dynamic classes.

See `sage.structure.dynamic_class` for a discussion of the dynamic classes paradigm, and its relevance to Sage.
EXAMPLES:

To setup the stage, we create a class Foo with some methods, cached methods, and lazy attributes, and a class Bar:

```python
sage: from sage.misc.lazy_attribute import lazy_attribute
sage: from sage.misc.cachefunc import cached_function
sage: from sage.structure.dynamic_class import dynamic_class
sage: class Foo(object):
    ....:    "The Foo class"
    ....:    def __init__(self, x):
    ....:        self._x = x
    ....:        @cached_method
    ....:        def f(self):
    ....:            return self._x^2
    ....:        def g(self):
    ....:            return self._x^2
    ....:        @lazy_attribute
    ....:        def x(self):
    ....:            return self._x
sage: class Bar:
    ....:    def bar(self):
    ....:        return self._x^2
```

We now create a class FooBar which is a copy of Foo, except that it also inherits from Bar:

```python
sage: FooBar = dynamic_class("FooBar", (Bar,), Foo)
sage: x = FooBar(3)
sage: x.f()
9
sage: x.f() is x.f()
True
sage: x.x
3
sage: x.bar()
9
sage: FooBar.__name__
'FooBar'
sage: FooBar.__module__
'__main__'
sage: Foo.__bases__
(<class 'object'>,)
sage: FooBar.__bases__
(<class '__main__.Bar'>,)
sage: Foo.mro()
[<class '__main__.Foo'>, <class 'object'>]
sage: FooBar.mro()
[<class '__main__.FooBar'>, <class '__main__.Bar'>, <class 'object'>]
```

If all the base classes have a zero __dictoffset__, the dynamic class also has a zero __dictoffset__. This means that the instances of the class don’t have a __dict__ (see trac ticket #23435):

```python
sage: dyn = dynamic_class("dyn", (Integer,))
```

(continues on next page)
Pickling

Dynamic classes are pickled by construction. Namely, upon unpickling, the class will be reconstructed by recalling dynamic_class with the same arguments:

```
sage: type(FooBar).__reduce__(FooBar)
(<function dynamic_class at ...>, ('FooBar', (<class '__main__.Bar'>,), <class '__main__.Foo'>, None, None))
```

Technically, this is achieved by using a metaclass, since the Python pickling protocol for classes is to pickle by name:

```
sage: type(FooBar)
<class 'sage.structure.dynamic_class.DynamicMetaclass'>
```

The following (meaningless) example illustrates how to customize the result of the reduction:

```
sage: BarFoo = dynamic_class("BarFoo", (Foo,), Bar, reduction = (str, (3,)))
sage: type(BarFoo).__reduce__(BarFoo)
(<class 'str'>, (3,))
sage: loads(dumps(BarFoo))
'3'
```

Caching

By default, the built class is cached:

```
sage: dynamic_class("FooBar", (Bar,), Foo) is FooBar
True
sage: dynamic_class("FooBar", (Bar,), Foo, cache=True) is FooBar
True
```

and the result depends on the reduction:

```
sage: dynamic_class("BarFoo", (Foo,), Bar, reduction = (str, (3,))) is BarFoo
True
sage: dynamic_class("BarFoo", (Foo,), Bar, reduction = (str, (2,))) is BarFoo
False
```

With cache=False, a new class is created each time:

```
sage: FooBar1 = dynamic_class("FooBar", (Bar,), Foo, cache=False); FooBar1
<class '__main__.FooBar'>
sage: FooBar2 = dynamic_class("FooBar", (Bar,), Foo, cache=False); FooBar2
<class '__main__.FooBar'>
sage: FooBar1 is FooBar
False
(continues on next page)
With cache="ignore_reduction", the class does not depend on the reduction:

```
sage: BarFoo = dynamic_class("BarFoo", (Foo,), Bar, reduction = (str, (3,)), cache="ignore_reduction")
sage: dynamic_class("BarFoo", (Foo,), Bar, reduction = (str, (2,)), cache="ignore_reduction") is BarFoo
True
```

In particular, the reduction used is that provided upon creating the first class:

```
sage: dynamic_class("BarFoo", (Foo,), Bar, reduction = (str, (2,)), cache="ignore_reduction")._reduction
(<class 'str'>, (3,))
```

**Warning:** The behaviour upon creating several dynamic classes from the same data but with different values for cache option is currently left unspecified. In other words, for a given application, it is recommended to consistently use the same value for that option.

```
sage.structure.dynamic_class.dynamic_class_internal(name, bases, cls=None, reduction=None, doccls=None, prepend_cls_bases=True)
```

See `sage.structure.dynamic_class.dynamic_class?` for indirect doctests.

### 6.5 Mutability Cython Implementation

**class** `sage.structure.mutability.Mutability`

Bases: `object`

Class to mix in mutability feature.

**EXAMPLES:**

```
sage: class A(SageObject, Mutability):
....:     def __init__(self, val):
....:         self._val = val
....:     def change(self, val):
....:         self._require_mutable()
....:         self._val = val
....:     def __hash__(self):
....:         self._require_immutable()
....:         return hash(self._val)
sage: a = A(4)
sage: a._val
4
sage: a.change(6); a._val
6
sage: hash(a)
```

Traceback (most recent call last):
...  
ValueError: object is mutable; please make it immutable first  
sage: a.set_immutable()  
sage: a.change(4)  
Traceback (most recent call last):  
...  
ValueError: object is immutable; please change a copy instead  
sage: hash(a)
6

**is_immutable()**
Return True if this object is immutable (cannot be changed) and False if it is not.

To make this object immutable use `self.set_immutable()`.

**EXAMPLES:**

```
sage: v = Sequence([1,2,3,4/5])  
sage: v[0] = 5  
sage: v  
[5, 2, 3, 4/5]  
sage: v.is_immutable()  
False  
sage: v.set_immutable()  
sage: v.is_immutable()  
True
```

**is_mutable()**
Return True if this object is mutable (can be changed) and False if it is not.

To make this object immutable use `self.set_immutable()`.

**EXAMPLES:**

```
sage: v = Sequence([1,2,3,4/5])  
sage: v[0] = 5  
sage: v  
[5, 2, 3, 4/5]  
sage: v.is_mutable()  
True  
sage: v.set_immutable()  
sage: v.is_mutable()  
False
```

**set_immutable()**
Make this object immutable, so it can never again be changed.

**EXAMPLES:**

```
sage: v = Sequence([1,2,3,4/5])  
sage: v[0] = 5  
sage: v  
[5, 2, 3, 4/5]  
sage: v.set_immutable()  
```
sage.structure.mutability.require_immutable(f)

A decorator that requires immutability for a method to be called.

**Note:** Objects whose methods use this decorator should have an attribute `_is_immutable`. Otherwise, the object is assumed to be mutable.

**EXAMPLES:**

```python
sage: from sage.structure.mutability import require_mutable, require_immutable
sage: class A(object):
    ....: def __init__(self, val):
    ....:     self._m = val
    ....: @require_mutable
    ....: def change(self, new_val):
    ....:     'change self'
    ....:     self._m = new_val
    ....: @require_immutable
    ....: def __hash__(self):
    ....:     'implement hash'
    ....:     return hash(self._m)

sage: a = A(5)
sage: a.change(6)
Traceback (most recent call last):
  ...: ValueError: <class '__main__.A'> instance is mutable, <function ...__hash__ at ...> must not be called
sage: a._is_immutable = True
sage: hash(a)
6
sage: a.change(7)
Traceback (most recent call last):
  ...: ValueError: <class '__main__.A'> instance is immutable, <function ...change at ...> must not be called

sage: from sage.misc.sageinspect import sage_getdoc
sage: print(sage_getdoc(a.__hash__));
implement hash
```

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object is assumed to be mutable.

EXAMPLES:

```python
sage: from sage.structure.mutability import require_mutable, require_immutable
sage: class A(object):
....:     def __init__(self, val):
....:         self._m = val
....:     @require_mutable
....:     def change(self, new_val):
....:         'change self'
....:         self._m = new_val
....:     @require_immutable
....:     def __hash__(self):
....:         'implement hash'
....:         return hash(self._m)

sage: a = A(5)
sage: a.change(6)
sage: hash(a)
Traceback (most recent call last):
  ... ValueError: <class '__main__.A'> instance is mutable, <function ...__hash__ at ...>
  → must not be called
sage: a._is_immutable = True
sage: hash(a)
6
sage: a.change(7)  # indirect doctest
Traceback (most recent call last):
  ... ValueError: <class '__main__.A'> instance is immutable, <function ...change at ...>
  → must not be called
sage: from sage.misc.sageinspect import sage_getdoc
sage: print(sage_getdoc(a.change))
change self
```

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7.1 Debug options for the `sage.structure` modules

EXAMPLES:

```python
code
sage: from sage.structure.debug_options import debug
sage: debug.unique_parent_warnings
False
sage: debug.refine_category_hash_check
True
```

```python
class sage.structure.debug_options.DebugOptions_class
    Bases: object
    refine_category_hash_check
    unique_parent_warnings
```

7.2 Performance Test for Clone Protocol

see `sage.structure.list_clone.ClonableArray`

EXAMPLES:

```python
code
sage: from sage.structure.list_clone_timings import *
sage: cmd =['
.....:   "e.__copy__()",
.....:   "copy(e)",
.....:   "e.clone()",&
.....:   "e.__class__(e.parent(), e._get_list())",
.....:   "e.__class__(e.parent(), e[:])",
.....:   "e.check()",&
.....:   "",
.....:   "add1_internal(e)",&
.....:   "add1_immutable(e)",&
.....:   "add1_mutable(e)",&
.....:   "add1_with(e)",&
.....:   "",
.....:   "cy_add1_internal(e)",&
.....:   "cy_add1_immutable(e)"
```
Various timings using a Cython class:

```python
class sage.structure.list_clone_timings.IncreasingArrays:
    Bases: sage.structure.list_clone_demo.IncreasingArrays
```

Various timings using a Python class:

```python
class sage.structure.list_clone_timings.IncreasingArraysPy
    Bases: sage.structure.list_clone_demo.IncreasingArrays
```
class Element
    Bases: sage.structure.list_clone.ClonableArray

    A small class for testing ClonableArray: Increasing Lists

    check()
        Check that self is increasing.

    EXAMPLES:

    sage: from sage.structure.list_clone_timings import IncreasingArraysPy
    sage: IncreasingArraysPy([[1,2,3]]) # indirect doctest
    [1, 2, 3]
    sage: IncreasingArraysPy([[3,2,1]]) # indirect doctest
    Traceback (most recent call last):
    ... ValueError: Lists is not increasing

sage.structure.list_clone_timings.add1Immutable(bla)
sage.structure.list_clone_timings.add1Internal(bla)
sage.structure.list_clone_timings.add1Mutable(bla)
sage.structure.list_clone_timings.add1With(bla)

7.3 Cython Functions for Timing Clone Protocol

sage.structure.list_clone_timings_cy.add1Immutable(bla)
sage.structure.list_clone_timings_cy.add1Internal(bla)
sage.structure.list_clone_timings_cy.add1Mutable(bla)
sage.structure.list_clone_timings_cy.add1With(bla)

7.4 Test of the factory module

class sage.structure.test_factory.A
    Bases: object

class sage.structure.test_factory.UniqueFactoryTester
    Bases: sage.structure.factory.UniqueFactory

    create_key(*args, **kwds)
        EXAMPLES:

        sage: from sage.structure.test_factory import UniqueFactoryTester
        sage: test_factory = UniqueFactoryTester('foo')
        sage: test_factory.create_key(1, 2, 3)
        (1, 2, 3)

    create_object(version, key, **extra_args)
        EXAMPLES:
```python
sage: from sage.structure.test_factory import UniqueFactoryTester
sage: test_factory = UniqueFactoryTester('foo')
```
```python
sage: test_factory.create_object('version', key=(1, 2, 4))
Making object (1, 2, 4)
<sage.structure.test_factory.A object at ...>
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