Sage 9.1 Reference Manual: Python technicalities

Release 9.1

The Sage Development Team

May 21, 2020

CONTENTS

1 Utilities for interfacing with the standard library's atexit module. 3

2 String <-> bytes encoding/decoding 5

3 Various functions to debug Python internals 7

4 Variants of getattr() 11

5 Metaclasses for Cython extension types 17
- 5.1 How to use . . . 17
- 5.2 Implementation . . . 18

6 Slot wrappers 19

7 Delete item from PyDict by exact value and hash 21

8 Indices and Tables 23

Python Module Index 25

Index 27

SageMath has various modules to provide access to low-level Python internals.

CHAPTER

ONE

UTILITIES FOR INTERFACING WITH THE STANDARD LIBRARY'S ATEXIT MODULE.

class sage.cpython.atexit.**restore_atexit**

Bases: object

Context manager that restores the state of the atexit module to its previous state when exiting the context.

INPUT:

- run (bool, default: False) – if True, when exiting the context (but before restoring the old exit functions), run all atexit functions which were added inside the context.
- clear (bool, default: equal to run) – if True, clear already registered atexit handlers upon entering the context.

Warning: The combination run=True and clear=False will cause already-registered exit functions to be run twice: once when exiting the context and again when exiting Python.

EXAMPLES:

For this example we will wrap the entire example with restore_atexit(clear=True) so as to start with a fresh atexit module state for the sake of the example.

Note that the function atexit._run_exitfuncs() runs all registered handlers, and then clears the list of handlers, so we can use it to test manipulation of the atexit state:

```
sage: import atexit
sage: from sage.cpython.atexit import restore_atexit
sage: def handler(*args, **kwargs):
....:     import sys # see https://trac.sagemath.org/ticket/25270#comment:56
....:     sys.stdout.write(str((args, kwargs)))
....:     sys.stdout.write('\n')
sage: atexit.register(handler, 1, 2, c=3)
<function handler at 0x...>
sage: atexit.register(handler, 4, 5, d=6)
<function handler at 0x...>
sage: with restore_atexit(clear=True):
....:     atexit._run_exitfuncs()  # Should be none registered
....:     atexit.register(handler, 1, 2, c=3)
....:     with restore_atexit():
....:         atexit._run_exitfuncs()  # Run just registered handler
....:     atexit._run_exitfuncs()  # Handler should be run again
<function handler at 0x...>
```

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```
((1, 2), {'c': 3})
((1, 2), {'c': 3})
```

We test the `run` option:

```
sage: with restore_atexit(run=True):
....:     # this handler is run when exiting the context
....:     _ = atexit.register(handler, 7, 8, e=9)
((7, 8), {'e': 9})
sage: with restore_atexit(clear=False, run=True):
....:     # original handlers are run when exiting the context
....:     pass
((4, 5), {'d': 6})
((1, 2), {'c': 3})
```

The original handlers are still in place:

```
sage: atexit._run_exitfuncs()
((4, 5), {'d': 6})
((1, 2), {'c': 3})
```

CHAPTER

TWO

STRING <-> BYTES ENCODING/DECODING

sage.cpython.string.**bytes_to_str**(*b*, *encoding=None*, *errors=None*)

Convert bytes to str.

On Python 2 this is a no-op since bytes is str. On Python 3 this decodes the given bytes to a Python 3 unicode str using the specified encoding.

EXAMPLES:

```
sage: import six
sage: from sage.cpython.string import bytes_to_str
sage: s = bytes_to_str(b'\xcf\x80')
sage: if six.PY2:
....:     s == b'\xcf\x80'
....: else:
....:     s == u'π'
True
sage: bytes_to_str([])
Traceback (most recent call last):
...
TypeError: expected bytes, list found
```

sage.cpython.string.**str_to_bytes**(*s*, *encoding=None*, *errors=None*)

Convert str or unicode to bytes.

On Python 3 this encodes the given str to a Python 3 bytes using the specified encoding.

On Python 2 this is a no-op on str input since str is bytes. However, this function also accepts Python 2 unicode objects and treats them the same as Python 3 unicode str objects.

EXAMPLES:

```
sage: import six
sage: from sage.cpython.string import str_to_bytes
sage: if six.PY2:
....:     bs = [str_to_bytes('\xcf\x80'), str_to_bytes(u'π')]
....: else:
....:     bs = [str_to_bytes(u'π')]
sage: all(b == b'\xcf\x80' for b in bs)
True
sage: str_to_bytes([])
Traceback (most recent call last):
...
TypeError: expected str... list found
```

CHAPTER

THREE

VARIOUS FUNCTIONS TO DEBUG PYTHON INTERNALS

sage.cpython.debug.**getattr_debug**(*obj*, *name*, *default='_no_default'*)

A re-implementation of `getattr()` with lots of debugging info.

This will correctly use `__getattr__` if needed. On the other hand, it assumes a generic (not overridden) implementation of `__getattribute__`. Note that Cython implements `__getattr__` for a cdef class using `__getattribute__`, so this will not detect a `__getattr__` in that case.

INPUT:

- `obj` – the object whose attribute is requested
- `name` – (string) the name of the attribute
- `default` – default value to return if attribute was not found

EXAMPLES:

```
sage: _ = getattr_debug(list, "reverse")
getattr_debug(obj=<type 'list'>, name='reverse'):
  type(obj) = <type 'type'>
  object has __dict__ slot (<type 'dict'>)
  did not find 'reverse' in MRO classes
  found 'reverse' in object __dict__
  returning <method 'reverse' of 'list' objects> (<type 'method_descriptor'>)
sage: _ = getattr_debug([], "reverse")
getattr_debug(obj=[], name='reverse'):
  type(obj) = <type 'list'>
  object does not have __dict__ slot
  found 'reverse' in dict of <type 'list'>
  got <method 'reverse' of 'list' objects> (<type 'method_descriptor'>)
  attribute is ordinary descriptor (has __get__)
  calling __get__()
  returning <built-in method reverse of list object at 0x... (<type 'builtin_
↪function_or_method'>)
sage: _ = getattr_debug([], "__doc__")
getattr_debug(obj=[], name='__doc__'):
  type(obj) = <type 'list'>
  object does not have __dict__ slot
  found '__doc__' in dict of <type 'list'>
  got ... 'str'>)
  returning ... 'str'>)
sage: _ = getattr_debug(gp(1), "log")
getattr_debug(obj=1, name='log'):
  type(obj) = <class 'sage.interfaces.gp.GpElement'>
  object has __dict__ slot (<type 'dict'>)
  did not find 'log' in MRO classes
```

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```
  object __dict__ does not have 'log'
  calling __getattr__()
  returning log (<class 'sage.interfaces.expect.FunctionElement'>)
sage: from ipywidgets import IntSlider
sage: _ = getattr_debug(IntSlider(), "value")
getattr_debug(obj=IntSlider(value=0), name='value'):
  type(obj) = <class 'ipywidgets.widgets.widget_int.IntSlider'>
  object has __dict__ slot (<type 'dict'>)
  found 'value' in dict of <class 'ipywidgets.widgets.widget_int._Int'>
  got <traitlets.traitlets.CInt object at ... (<class 'traitlets.traitlets.CInt'>)
  attribute is data descriptor (has __get__ and __set__)
  ignoring __dict__ because we have a data descriptor
  calling __get__()
  returning 0 (<type 'int'>)
sage: _ = getattr_debug(1, "foo")
Traceback (most recent call last):
...
AttributeError: 'sage.rings.integer.Integer' object has no attribute 'foo'
sage: _ = getattr_debug(1, "foo", "xyz")
getattr_debug(obj=1, name='foo'):
  type(obj) = <type 'sage.rings.integer.Integer'>
  object does not have __dict__ slot
  did not find 'foo' in MRO classes
  class does not have __getattr__
  attribute not found
  returning default 'xyz'
```

sage.cpython.debug.**shortrepr**(*obj*, *max=50*)

Return `repr(obj)` bounded to `max` characters. If the string is too long, it is truncated and `~~~` is added to the end.

EXAMPLES:

```
sage: from sage.cpython.debug import shortrepr
sage: print(shortrepr("Hello world!"))
'Hello world!'
sage: print(shortrepr("Hello world!" * 4))
'Hello world!Hello world!Hello world!Hello world!'
sage: print(shortrepr("Hello world!" * 5))
'Hello world!Hello world!Hello world!Hello worl~~~
```

sage.cpython.debug.**type_debug**(*cls*)

Print all internals of the type `cls`

EXAMPLES:

```
sage: type_debug(object)  # random
<type 'object'> (0x7fc57da7f040)
  ob_refcnt: 9739
  ob_type: <type 'type'>
  tp_name: object
  tp_basicsize: 16
  tp_itemsize: 0
  tp_dictoffset: 0
  tp_weaklistoffset: 0
  tp_base (__base__): NULL
  tp_bases (__bases__): tuple:
```

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```
tp_mro (__mro__): tuple:
  <type 'object'>
tp_dict (__dict__): dict:
  '__setattr__': <slot wrapper '__setattr__' of 'object' objects>
  '__reduce_ex__': <method '__reduce_ex__' of 'object' objects>
  '__new__': <built-in method __new__ of type object at 0x7fc57da7f040>
  '__reduce__': <method '__reduce__' of 'object' objects>
  '__str__': <slot wrapper '__str__' of 'object' objects>
  '__format__': <method '__format__' of 'object' objects>
  '__getattribute__': <slot wrapper '__getattribute__' of 'object' objects>
  '__class__': <attribute '__class__' of 'object' objects>
  '__delattr__': <slot wrapper '__delattr__' of 'object' objects>
  '__subclasshook__': <method '__subclasshook__' of 'object' objects>
  '__repr__': <slot wrapper '__repr__' of 'object' objects>
  '__hash__': <slot wrapper '__hash__' of 'object' objects>
  '__sizeof__': <method '__sizeof__' of 'object' objects>
  '__doc__': 'The most base type'
  '__init__': <slot wrapper '__init__' of 'object' objects>
tp_alloc: PyType_GenericAlloc
tp_new (__new__): 0x7fc57d7594f0
tp_init (__init__): 0x7fc57d758ee0
tp_dealloc (__dealloc__): 0x7fc57d757010
tp_free: PyObject_Del
tp_repr (__repr__): 0x7fc57d75b990
tp_print: NULL
tp_hash (__hash__): _Py_HashPointer
tp_call (__call__): NULL
tp_str (__str__): 0x7fc57d757020
tp_compare (__cmp__): NULL
tp_richcompare (__richcmp__): NULL
tp_getattr (__getattribute__): NULL
tp_setattr (__setattribute__): NULL
tp_getattro (__getattribute__): PyObject_GenericGetAttr
tp_setattro (__setattribute__): PyObject_GenericSetAttr
tp_iter (__iter__): NULL
tp_iternext (__next__): NULL
tp_descr_get (__get__): NULL
tp_descr_set (__set__): NULL
tp_cache: NULL
tp_weaklist: NULL
tp_traverse: NULL
tp_clear: NULL
tp_is_gc: NULL
tp_as_number: NULL
tp_as_sequence: NULL
tp_as_mapping: NULL
tp_as_buffer: NULL
tp_flags:
  HAVE_GETCHARBUFFER
  HAVE_SEQUENCE_IN
  HAVE_INPLACEOPS
  HAVE_RICHCOMPARE
  HAVE_WEAKREFS
  HAVE_ITER
  HAVE_CLASS
  BASETYPE
  READY
```

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```
    HAVE_INDEX
    HAVE_VERSION_TAG
    VALID_VERSION_TAG
  tp_version_tag: 2
sage: type_debug(None)
Traceback (most recent call last):
...
TypeError: None is not a type
```

CHAPTER

FOUR

VARIANTS OF GETATTR()

class sage.cpython.getattr.**AttributeErrorMessage**

Bases: object

Tries to emulate the standard Python `AttributeError` message.

Note: The typical fate of an attribute error is being caught. Hence, under normal circumstances, nobody will ever see the error message. The idea for this class is to provide an object that is fast to create and whose string representation is an attribute error's message. That string representation is only created if someone wants to see it.

EXAMPLES:

```
sage: 1.bla  #indirect doctest
Traceback (most recent call last):
...
AttributeError: 'sage.rings.integer.Integer' object has no attribute 'bla'
sage: QQ[x].gen().bla
Traceback (most recent call last):
...
AttributeError: 'sage.rings.polynomial.polynomial_rational_flint.Polynomial_
↪rational_flint' object has no attribute 'bla'
```

```
sage: from sage.cpython.getattr import AttributeErrorMessage
sage: AttributeErrorMessage(int(1), 'bla')
'int' object has no attribute 'bla'
```

AUTHOR:

- Simon King (2011-05-21)

cls

name

sage.cpython.getattr.**dir_with_other_class**(*self*, *cls*)

Emulates `dir(self)`, as if self was also an instance `cls`, right after `caller_class` in the method resolution order (`self.__class__.mro()`)

EXAMPLES:

```
sage: class A(object):
....:     a = 1
....:     b = 2
....:     c = 3
```

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```
sage: class B(object):
....:     b = 2
....:     c = 3
....:     d = 4
sage: x = A()
sage: x.c = 1; x.e = 1
sage: from sage.cpython.getattr import dir_with_other_class
sage: dir_with_other_class(x, B)
[..., 'a', 'b', 'c', 'd', 'e']
```

Check that objects without dicts are well handled:

```
sage: cython("cdef class A:\n    cdef public int a")
sage: cython("cdef class B:\n    cdef public int b")
sage: x = A()
sage: x.a = 1
sage: hasattr(x,'__dict__')
False
sage: dir_with_other_class(x, B)
[..., 'a', 'b']
```

sage.cpython.getattr.**getattr_from_other_class**(*self*, *cls*, *name*)

Emulate `getattr(self, name)`, as if `self` was an instance of `cls`.

INPUT:

- `self` – some object
- `cls` – a new-style class
- `name` – a string

If self is an instance of cls, raises an `AttributeError`, to avoid a double lookup. This function is intended to be called from __getattr__, and so should not be called if name is an attribute of self.

EXAMPLES:

```
sage: from sage.cpython.getattr import getattr_from_other_class
sage: class A(object):
....:     def inc(self):
....:         return self + 1
....:
....:     @staticmethod
....:     def greeting():
....:         print("Hello World!")
....:
....:     @lazy_attribute
....:     def lazy_attribute(self):
....:         return repr(self)
sage: getattr_from_other_class(1, A, "inc")
<bound method A.inc of 1>
sage: getattr_from_other_class(1, A, "inc")()
2
```

Static methods work:

```
sage: getattr_from_other_class(1, A, "greeting")()
Hello World!
```

Caveat: lazy attributes work with extension types only if they allow attribute assignment or have a public attribute `__cached_methods` of type `<dict>`. This condition is satisfied, e.g., by any class that is derived from `Parent`:

```
sage: getattr_from_other_class(1, A, "lazy_attribute")
Traceback (most recent call last):
...
AttributeError: 'sage.rings.integer.Integer' object has no attribute 'lazy_
↪attribute'
```

The integer ring is a parent, so, lazy attributes work:

```
sage: getattr_from_other_class(ZZ, A, "lazy_attribute")
'Integer Ring'
sage: getattr_from_other_class(PolynomialRing(QQ, name='x', sparse=True).one(), A,
↪ "lazy_attribute")
'1'
sage: getattr_from_other_class(17, A, "lazy_attribute")
Traceback (most recent call last):
...
AttributeError: 'sage.rings.integer.Integer' object has no attribute 'lazy_
↪attribute'
```

In general, descriptors are not yet well supported, because they often do not accept to be cheated with the type of their instance:

```
sage: A.__weakref__.__get__(1)
Traceback (most recent call last):
...
TypeError: descriptor '__weakref__' for 'A' objects doesn't apply
to 'sage.rings.integer.Integer' object
```

When this occurs, an `AttributeError` is raised:

```
sage: getattr_from_other_class(1, A, "__weakref__")
Traceback (most recent call last):
...
AttributeError: 'sage.rings.integer.Integer' object has no attribute '__weakref__'
```

This was caught by trac ticket #8296 for which we do a couple more tests:

```
sage: "__weakref__" in dir(A)
True
sage: "__weakref__" in dir(1)  # py2
False
sage: 1.__weakref__
Traceback (most recent call last):
...
AttributeError: 'sage.rings.integer.Integer' object has no attribute '__weakref__'

sage: n = 1
sage: ip = get_ipython()                # not tested: only works in interactive␣
↪shell
sage: ip.magic_psearch('n.N')           # not tested: only works in interactive␣
↪shell
n.N
sage: ip.magic_psearch('n.__weakref__')  # not tested: only works in interactive␣
↪shell
```

Caveat: When __call__ is not defined for instances, using `A.__call__` yields the method `__call__` of the class. We use a workaround but there is no guarantee for robustness.

sage: getattr_from_other_class(1, A, "__call__") Traceback (most recent call last): ... AttributeError: 'sage.rings.integer.Integer' object has no attribute '__call__'

`sage.cpython.getattr.`**`raw_getattr`**(*obj*, *name*)

Like `getattr(obj, name)` but without invoking the binding behavior of descriptors under normal attribute access. This can be used to easily get unbound methods or other descriptors.

This ignores `__getattribute__` hooks but it does support `__getattr__`.

Note: For Cython classes, `__getattr__` is actually implemented as `__getattribute__`, which means that it is not supported by `raw_getattr`.

EXAMPLES:

```
sage: class X:
....:     @property
....:     def prop(self):
....:         return 42
....:     def method(self):
....:         pass
....:     def __getattr__(self, name):
....:         return "magic " + name
sage: raw_getattr(X, "prop")
<property object at ...>
sage: raw_getattr(X, "method")
<function ...method at ...>
sage: raw_getattr(X, "attr")
Traceback (most recent call last):
...
AttributeError: '...' object has no attribute 'attr'
sage: x = X()
sage: raw_getattr(x, "prop")
<property object at ...>
sage: raw_getattr(x, "method")
<function ...method at ...>
sage: raw_getattr(x, "attr")
'magic attr'
sage: x.__dict__["prop"] = 'no'
sage: x.__dict__["method"] = 'yes'
sage: x.__dict__["attr"] = 'ok'
sage: raw_getattr(x, "prop")
<property object at ...>
sage: raw_getattr(x, "method")
'yes'
sage: raw_getattr(x, "attr")
'ok'
```

The same tests with an inherited new-style class:

```
sage: class Y(X, object):
....:     pass
sage: raw_getattr(Y, "prop")
<property object at ...>
sage: raw_getattr(Y, "method")
```

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```
<function ...method at ...>
sage: raw_getattr(Y, "attr")
Traceback (most recent call last):
...
AttributeError: '...' object has no attribute 'attr'
sage: y = Y()
sage: raw_getattr(y, "prop")
<property object at ...>
sage: raw_getattr(y, "method")
<function ...method at ...>
sage: raw_getattr(y, "attr")
'magic attr'
sage: y.__dict__["prop"] = 'no'
sage: y.__dict__["method"] = 'yes'
sage: y.__dict__["attr"] = 'ok'
sage: raw_getattr(y, "prop")
<property object at ...>
sage: raw_getattr(y, "method")
'yes'
sage: raw_getattr(y, "attr")
'ok'
```

CHAPTER

FIVE

METACLASSES FOR CYTHON EXTENSION TYPES

Cython does not support metaclasses, but this module can be used to implement metaclasses for extension types.

Warning: This module has many caveats and you can easily get segfaults if you make a mistake. It relies on undocumented Python and Cython behaviour, so things might break in future versions.

5.1 How to use

To enable this metaclass mechanism, you need to put `cimport sage.cpython.cython_metaclass` in your module (in the `.pxd` file if you are using one).

In the extension type (a.k.a. `cdef class`) for which you want to define a metaclass, define a method `__getmetaclass__` with a single unused argument. This method should return a type to be used as metaclass:

```
cimport sage.cpython.cython_metaclass
cdef class MyCustomType(object):
    def __getmetaclass__(_):
        from foo import MyMetaclass
        return MyMetaclass
```

The above `__getmetaclass__` method is analogous to `__metaclass__ = MyMetaclass` in Python 2.

Warning: `__getmetaclass__` must be defined as an ordinary method taking a single argument, but this argument should not be used in the method (it will be `None`).

When a type `cls` is being constructed with metaclass `meta`, then `meta.__init__(cls, None, None, None)` is called from Cython. In Python, this would be `meta.__init__(cls, name, bases, dict)`.

Warning: The `__getmetaclass__` method is called while the type is being created during the import of the module. Therefore, `__getmetaclass__` should not refer to any global objects, including the type being created or other types defined or imported in the module (unless you are very careful). Note that non-imported `cdef` functions are not Python objects, so those are safe to call.

The same warning applies to the `__init__` method of the metaclass.

Warning: The `__new__` method of the metaclass (including the `__cinit__` method for Cython extension types) is never called if you're using this from Cython. In particular, the metaclass cannot have any attributes or virtual methods.

EXAMPLES:

```
sage: cython('''
....: cimport sage.cpython.cython_metaclass
....: cdef class MyCustomType(object):
....:     def __getmetaclass__(_):
....:         class MyMetaclass(type):
....:             def __init__(*args):
....:                 print("Calling MyMetaclass.__init__{}".format(args))
....:         return MyMetaclass
....:
....: cdef class MyDerivedType(MyCustomType):
....:     pass
....: ''')
Calling MyMetaclass.__init__(<type '...MyCustomType'>, None, None, None)
Calling MyMetaclass.__init__(<type '...MyDerivedType'>, None, None, None)
sage: MyCustomType.__class__
<class '...MyMetaclass'>
sage: class MyPythonType(MyDerivedType):
....:     pass
Calling MyMetaclass.__init__(<class '...MyPythonType'>, 'MyPythonType', (<type '...
↪MyDerivedType'>,), {...})
```

5.2 Implementation

All this is implemented by defining

```
#define PyTypeReady(t)  Sage_PyType_Ready(t)
```

and then implementing the function `Sage_PyType_Ready(t)` which first calls `PyType_Ready(t)` and then handles the metaclass stuff.

CHAPTER

SIX

SLOT WRAPPERS

A slot wrapper is installed in the dict of an extension type to access a special method implemented in C. For example, `object.__init__` or `Integer.__lt__`. Note that slot wrappers are always unbound (there is a bound variant called method-wrapper).

EXAMPLES:

```
sage: int.__add__
<slot wrapper '__add__' of 'int' objects>
```

Pure Python classes have normal methods, not slot wrappers:

```
sage: class X(object):
....:     def __add__(self, other):
....:         return NotImplemented
sage: X.__add__     # py2
<unbound method X.__add__>
sage: X.__add__     # py3
<function X.__add__ at ...>
```

`sage.cpython.wrapperdescr.`**`wrapperdescr_call`**(*slotwrapper*, *self*, **args*, ***kwds*)

Call a slot wrapper without any type checks.

The main reason to use this is to call arithmetic slots like `__mul__` without having to worry about whether to call `T.__mul__(a, b)` or `T.__rmul__(b, a)`.

INPUT:

- `slotwrapper` – a slot wrapper (for example `int.__add__`).
- `self` – the first positional argument. Normally, this should be of the correct type (an `int` when calling `int.__add__`). However, this check is skipped: you can pass an arbitrary object.
- `*args`, `**kwds` – further arguments.

Warning: Since this skips type checks, it can easily crash Python if used incorrectly.

EXAMPLES:

```
sage: from sage.cpython.wrapperdescr import wrapperdescr_call
sage: wrapperdescr_call(Integer.__mul__, 6, 9)
54
sage: wrapperdescr_call(Integer.__mul__, 7/5, 9)
63/5
sage: from sage.structure.element import Element
```

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```
sage: wrapperdescr_call(Element.__mul__, 6, 9)
54
sage: wrapperdescr_call(Element.__mul__, 7/5, 9)
63/5
sage: from sage.numerical.mip import MixedIntegerLinearProgram
sage: wrapperdescr_call(type.__call__, MixedIntegerLinearProgram,␣
↪maximization=False)
Mixed Integer Program (no objective, 0 variables, 0 constraints)
```

CHAPTER

SEVEN

DELETE ITEM FROM PYDICT BY EXACT VALUE AND HASH

Beware that the implementation of the routine here relies on implementation details of CPython's dict that go beyond the published API. This file depends on python version when cythonized. It expects PY_VERSION_HEX to be available in the cythonization and the result depends on it (and needs to match the python version the C-compiler compiles it against). Usage should do something along the lines of

cythonize("dict_del_by_value.pyx", compile_time_env({"PY_VERSION_HEX": sys.hexversion}))

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sage.cpython.dict_del_by_value.**init_lookdict**()

sage.cpython.dict_del_by_value.**test_del_dictitem_by_exact_value**(*D*, *value*, *h*)

This function helps testing some cdef function used to delete dictionary items.

INPUT:

- `D` – a Python `<dict>`.
- `value` – an object that is value `D`.
- `h` – the hash of the key under which to find `value` in `D`.

The underlying cdef function deletes an item from `D` that is in the hash bucket determined by `h` and whose value is identic with `value`. Of course, this only makes sense if the pairs `(h, value)` corresponding to items in `D` are pair-wise distinct.

If a matching item can not be found, the function does nothing and silently returns.

CHAPTER

EIGHT

INDICES AND TABLES

- Index
- Module Index
- Search Page

PYTHON MODULE INDEX

C

sage.cpython.atexit, 3
sage.cpython.cython_metaclass, 17
sage.cpython.debug, 7
sage.cpython.dict_del_by_value, 21
sage.cpython.getattr, 11
sage.cpython.string, 5
sage.cpython.wrapperdescr, 19

INDEX

A

AttributeErrorMessage (*class in sage.cpython.getattr*), 11

B

bytes_to_str() (*in module sage.cpython.string*), 5

C

cls (*sage.cpython.getattr.AttributeErrorMessage attribute*), 11

D

dir_with_other_class() (*in module sage.cpython.getattr*), 11

G

getattr_debug() (*in module sage.cpython.debug*), 7
getattr_from_other_class() (*in module sage.cpython.getattr*), 12

I

init_lookdict() (*in module sage.cpython.dict_del_by_value*), 21

N

name (*sage.cpython.getattr.AttributeErrorMessage attribute*), 11

R

raw_getattr() (*in module sage.cpython.getattr*), 14
restore_atexit (*class in sage.cpython.atexit*), 3

S

sage.cpython.atexit (*module*), 3
sage.cpython.cython_metaclass (*module*), 17
sage.cpython.debug (*module*), 7
sage.cpython.dict_del_by_value (*module*), 21
sage.cpython.getattr (*module*), 11
sage.cpython.string (*module*), 5
sage.cpython.wrapperdescr (*module*), 19
shortrepr() (*in module sage.cpython.debug*), 8
str_to_bytes() (*in module sage.cpython.string*), 5

T

test_del_dictitem_by_exact_value() (*in module sage.cpython.dict_del_by_value*), 21
type_debug() (*in module sage.cpython.debug*), 8

W

wrapperdescr_call() (*in module sage.cpython.wrapperdescr*), 19