cysignals Documentation

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Martin Albrecht, Jeroen Demeyer

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When writing Cython code, special care must be taken to ensure that the code can be interrupted with CTRL-C. Since Cython optimizes for speed, Cython normally does not check for interrupts. For example, code like the following cannot be interrupted in Cython:

```
while True:
    pass
```

While this is running, pressing CTRL-C has no effect. The only way out is to kill the Python process. On certain systems, you can still quit Python by typing CTRL-\ (sending a Quit signal) instead of CTRL-C.

This module provides two related mechanisms to deal with interrupts:

- *Use sig_check()* if you are writing mixed Cython/Python code. Typically this is code with (nested) loops where every individual statement takes little time.
- *Use sig_on() and sig_off()* if you are calling external C libraries or inside pure Cython code (without any Python functions) where even an individual statement, like a library call, can take a long time.

The functions `sig_check()`, `sig_on()` and `sig_off()` can be put in all kinds of Cython functions: `def`, `cdef` or `cpdef`. You cannot put them in pure Python code (files with extension `.py`).

CHAPTER

ONE

BASIC EXAMPLE

The `sig_check()` in the loop below ensures that the loop can be interrupted by `CTRL-C`:

```
include "cysignals/signals.pxi"

from libc.math cimport sin

def sine_sum(double x, long count):
    cdef double s = 0
    for i in range(count):
        sig_check()
        s += sin(i*x)
    return s
```

The line `include "cysignals/signals.pxi"` must be put in every `.pyx` file using cysignals. You must not put this in a `.pxd` file; a `.pxi` file included only in `.pyx` files also works.

Because of cython/cython#483, you should add `include_path=sys.path` to your `cythonize()` call in `setup.py` (otherwise Cython will not find `cysignals/signals.pxi`). See the example directory for this complete working example.

Note: Cython `cdef` or `cpdef` functions with a return type (like `cdef int myfunc():`) need to have an except value to propagate exceptions. Remember this whenever you write `sig_check()` or `sig_on()` inside such a function, otherwise you will see a message like `Exception KeyboardInterrupt: KeyboardInterrupt() in <function name> ignored`.

CHAPTER

TWO

USING `SIG_CHECK()`

`sig_check()` can be used to check for pending interrupts. If an interrupt happens during the execution of C or Cython code, it will be caught by the next `sig_check()`, the next `sig_on()` or possibly the next Python statement. With the latter we mean that certain Python statements also check for interrupts, an example of this is the `print` statement. The following loop *can* be interrupted:

```
>>> while True:
...     print("Hello")
```

The typical use case for `sig_check()` is within tight loops doing complicated stuff (mixed Python and Cython code, potentially raising exceptions). It is reasonably safe to use and gives a lot of control, because in your Cython code, a `KeyboardInterrupt` can *only* be raised during `sig_check()`:

```
def sig_check_example():
    for x in foo:
        # (one loop iteration which does not take a long time)
        sig_check()
```

This `KeyboardInterrupt` is treated like any other Python exception and can be handled as usual:

```
def catch_interrupts():
    try:
        while some_condition():
            sig_check()
            do_something()
    except KeyboardInterrupt:
        # (handle interrupt)
```

Of course, you can also put the `try`/`except` inside the loop in the example above.

The function `sig_check()` is an extremely fast inline function which should have no measurable effect on performance.

CHAPTER

THREE

USING `sig_on()` AND `sig_off()`

Another mechanism for interrupt handling is the pair of functions `sig_on()` and `sig_off()`. It is more powerful than `sig_check()` but also a lot more dangerous. You should put `sig_on()` *before* and `sig_off()` *after* any Cython code which could potentially take a long time. These two *must always* be called in **pairs**, i.e. every `sig_on()` must be matched by a closing `sig_off()`.

In practice your function will probably look like:

```
def sig_example():
    # (some harmless initialization)
    sig_on()
    # (a long computation here, potentially calling a C library)
    sig_off()
    # (some harmless post-processing)
    return something
```

It is possible to put `sig_on()` and `sig_off()` in different functions, provided that `sig_off()` is called before the function which calls `sig_on()` returns. The following code is *invalid*:

```
# INVALID code because we return from function foo()
# without calling sig_off() first.
cdef foo():
    sig_on()

def f1():
    foo()
    sig_off()
```

But the following is valid since you cannot call `foo` interactively:

```
cdef int foo():
    sig_off()
    return 2+2

def f1():
    sig_on()
    return foo()
```

For clarity however, it is best to avoid this.

A common mistake is to put `sig_off()` towards the end of a function (before the `return`) when the function has multiple `return` statements. So make sure there is a `sig_off()` before *every* `return` (and also before every `raise`).

Warning: The code inside `sig_on()` should be pure C or Cython code. If you call any Python code or manipulate any Python object (even something trivial like `x = []`), an interrupt can mess up Python's internal state. When in doubt, try to use *sig_check()* instead.

> Also, when an interrupt occurs inside `sig_on()`, code execution immediately stops without cleaning up. For example, any memory allocated inside `sig_on()` is lost. See *Advanced Functions* for ways to deal with this.

When the user presses `CTRL-C` inside `sig_on()`, execution will jump back to `sig_on()` (the first one if there is a stack) and `sig_on()` will raise `KeyboardInterrupt`. As with `sig_check()`, this exception can be handled in the usual way:

```
def catch_interrupts():
    try:
        sig_on()  # This must be INSIDE the try
        # (some long computation)
        sig_off()
    except KeyboardInterrupt:
        # (handle interrupt)
```

It is possible to stack `sig_on()` and `sig_off()`. If you do this, the effect is exactly the same as if only the outer `sig_on()`/`sig_off()` was there. The inner ones will just change a reference counter and otherwise do nothing. Make sure that the number of `sig_on()` calls equal the number of `sig_off()` calls:

```
def f1():
    sig_on()
    x = f2()
    sig_off()

cdef f2():
    sig_on()
    # ...
    sig_off()
    return ans
```

Extra care must be taken with exceptions raised inside `sig_on()`. The problem is that, if you do not do anything special, the `sig_off()` will never be called if there is an exception. If you need to *raise* an exception yourself, call a `sig_off()` before it:

```
def raising_an_exception():
    sig_on()
    # (some long computation)
    if (something_failed):
        sig_off()
        raise RuntimeError("something failed")
    # (some more computation)
    sig_off()
    return something
```

Alternatively, you can use `try`/`finally` which will also catch exceptions raised by subroutines inside the `try`:

```
def try_finally_example():
    sig_on()  # This must be OUTSIDE the try
    try:
        # (some long computation, potentially raising exceptions)
        return something
    finally:
        sig_off()
```

If you want to also catch this exception, you need a nested `try`:

```
def try_finally_and_catch_example():
    try:
        sig_on()
        try:
            # (some long computation, potentially raising exceptions)
```

```
        finally:
            sig_off()
    except Exception:
        print "Trouble!Trouble!"
```

`sig_on()` is implemented using the C library call `setjmp()` which takes a very small but still measurable amount of time. In very time-critical code, one can conditionally call `sig_on()` and `sig_off()`:

```
def conditional_sig_on_example(long n):
    if n > 100:
        sig_on()
    # (do something depending on n)
    if n > 100:
        sig_off()
```

This should only be needed if both the check (`n > 100` in the example) and the code inside the `sig_on()` block take very little time.

CHAPTER

FOUR

OTHER SIGNALS

Apart from handling interrupts, `sig_on()` provides more general signal handling. For example, it handles `alarm()` time-outs by raising an `AlarmInterrupt` (inherited from `KeyboardInterrupt`) exception.

If the code inside `sig_on()` would generate a segmentation fault or call the C function `abort()` (or more generally, raise any of SIGSEGV, SIGILL, SIGABRT, SIGFPE, SIGBUS), this is caught by the interrupt framework and an exception is raised (`RuntimeError` for SIGABRT, `FloatingPointError` for SIGFPE and the custom exception `SignalError`, based on `BaseException`, otherwise):

```
cdef extern from 'stdlib.h':
    void abort()

def abort_example():
    sig_on()
    abort()
    sig_off()
```

```
>>> abort_example()
Traceback (most recent call last):
...
RuntimeError: Aborted
```

This exception can be handled by a `try`/`except` block as explained above. A segmentation fault or `abort()` unguarded by `sig_on()` would simply terminate the Python Interpreter. This applies only to `sig_on()`, the function `sig_check()` only deals with interrupts and alarms.

Instead of `sig_on()`, there is also a function `sig_str(s)`, which takes a C string `s` as argument. It behaves the same as `sig_on()`, except that the string `s` will be used as a string for the exception. `sig_str(s)` should still be closed by `sig_off()`. Example Cython code:

```
cdef extern from 'stdlib.h':
    void abort()

def abort_example_with_sig_str():
    sig_str("custom error message")
    abort()
    sig_off()
```

Executing this gives:

```
>>> abort_example_with_sig_str()
Traceback (most recent call last):
...
RuntimeError: custom error message
```

With regard to ordinary interrupts (i.e. SIGINT), `sig_str(s)` behaves the same as `sig_on()`: a simple `KeyboardInterrupt` is raised.

CHAPTER

FIVE

ERROR HANDLING IN C LIBRARIES

Some C libraries can produce errors and use some sort of callback mechanism to report errors: an external error handling function needs to be set up which will be called by the C library if an error occurs.

The function `sig_error()` can be used to deal with these errors. This function may only be called within a `sig_on()` block (otherwise the Python interpreter will crash hard) after raising a Python exception. You need to use the Python/C API for this and call `sig_error()` after calling some variant of `PyErr_SetObject()`. Even within Cython, you cannot use the `raise` statement, because then the `sig_error()` will never be executed. The call to `sig_error()` will use the `sig_on()` machinery such that the exception will be seen by `sig_on()`.

A typical error handler implemented in Cython would look as follows:

```
include "cysignals/signals.pxi"
from cpython.exc cimport PyErr_SetString

cdef void error_handler(char *msg):
    PyErr_SetString(RuntimeError, msg)
    sig_error()
```

Exceptions which are raised this way can be handled as usual by putting the `sig_on()` in a `try`/`except` block. For example, in SageMath, the PARI interface can raise a custom `PariError` exception. This can be handled as follows:

```
def handle_pari_error():
    try:
        sig_on()  # This must be INSIDE the try
        # (call to PARI)
        sig_off()
    except PariError:
        # (handle error)
```

SageMath uses this mechanism for libGAP, NTL and PARI.

CHAPTER

SIX

ADVANCED FUNCTIONS

There are several more specialized functions for dealing with interrupts. As mentioned above, `sig_on()` makes no attempt to clean anything up (restore state or freeing memory) when an interrupt occurs. In fact, it would be impossible for `sig_on()` to do that. If you want to add some cleanup code, use `sig_on_no_except()` for this. This function behaves *exactly* like `sig_on()`, except that any exception raised (like `KeyboardInterrupt` or `RuntimeError`) is not yet passed to Python. Essentially, the exception is there, but we prevent Cython from looking for the exception. Then `cython_check_exception()` can be used to make Cython look for the exception.

Normally, `sig_on_no_except()` returns 1. If a signal was caught and an exception raised, `sig_on_no_except()` instead returns 0. The following example shows how to use `sig_on_no_except()`:

```
def no_except_example():
    if not sig_on_no_except():
        # (clean up messed up internal state)

        # Make Cython realize that there is an exception.
        # It will look like the exception was actually raised
        # by cython_check_exception().
        cython_check_exception()
    # (some long computation, messing up internal state of objects)
    sig_off()
```

There is also a function `sig_str_no_except(s)` which is analogous to `sig_str(s)`.

Note: See the file src/cysignals/tests.pyx for more examples of how to use the various `sig_*()` functions.

CHAPTER

SEVEN

TESTING INTERRUPTS

When writing documentation, one sometimes wants to check that certain code can be interrupted in a clean way. The best way to do this is to use `cysignals.alarm()`.

The following is an example of a doctest demonstrating that the SageMath function `factor()` can be interrupted:

```
>>> from cysignals.alarm import alarm, AlarmInterrupt
>>> try:
...     alarm(0.5)
...     factor(10**1000 + 3)
... except AlarmInterrupt:
...     print("alarm!")
alarm!
```

If you use the SageMath doctesting framework, you can instead doctest the exception in the usual way. To avoid race conditions, make sure that the calls to `alarm()` and the function you want to test are in the same doctest:

```
>>> alarm(0.5); factor(10**1000 + 3)
Traceback (most recent call last):
...
AlarmInterrupt
```

CHAPTER

EIGHT

RELEASING THE GLOBAL INTERPRETER LOCK (GIL)

All the functions related to interrupt and signal handling do not require the Python GIL (if you don't know what this means, you can safely ignore this section), they are declared `nogil`. This means that they can be used in Cython code inside `with nogil` blocks. If `sig_on()` needs to raise an exception, the GIL is temporarily acquired internally.

If you use C libraries without the GIL and you want to raise an exception before calling *sig_error()*, remember to acquire the GIL while raising the exception. Within Cython, you can use a with gil context.

Warning: The GIL should never be released or acquired inside a `sig_on()` block. If you want to use a `with nogil` block, put both `sig_on()` and `sig_off()` inside that block. When in doubt, choose to use `sig_check()` instead, which is always safe to use.