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# Debugging C API extensions and CPython Internals with GDB

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This document explains how the Python GDB extension, `python-gdb.py`, can be used with the GDB debugger to debug CPython extensions and the CPython interpreter itself.

When debugging low-level problems such as crashes or deadlocks, a low-level debugger, such as GDB, is useful to diagnose and correct the issue. By default, GDB (or any of its front-ends) doesn't support high-level information specific to the CPython interpreter.

The `python-gdb.py` extension adds CPython interpreter information to GDB. The extension helps introspect the stack of currently executing Python functions. Given a Python object represented by a `PyObject*` pointer, the extension surfaces the type and value of the object.

Developers who are working on CPython extensions or tinkering with parts of CPython that are written in C can use this document to learn how to use the `python-gdb.py` extension with GDB.

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**Note:** This document assumes that you are familiar with the basics of GDB and the CPython C API. It consolidates guidance from the [devguide](#) and the [Python wiki](#).

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# 1 Prerequisites

You need to have:

- GDB 7 or later. (For earlier versions of GDB, see `Misc/gdbinit` in the CPython sources. Note that this file will be removed in Python 3.12.)
- GDB-compatible debugging information for Python and any extension you are debugging.
- The `python-gdb.py` extension.

The extension is built with Python, but might be distributed separately or not at all. Below, we include tips for a few common systems as examples. Note that even if the instructions match your system, they might be outdated.

## 1.1 Setup with Python built from source

When you build CPython from source, debugging information should be available, and the build should add a `python-gdb.py` file to the root directory of your repository.

To activate support, you must add the directory containing `python-gdb.py` to GDB's "auto-load-safe-path". If you haven't done this, recent versions of GDB will print out a warning with instructions on how to do this.

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**Note:** If you do not see instructions for your version of GDB, put this in your configuration file (`~/.gdbinit` or `~/.config/gdb/gdbinit`):

```
add-auto-load-safe-path /path/to/cpython
```

You can also add multiple paths, separated by `:`.

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## 1.2 Setup for Python from a Linux distro

Most Linux systems provide debug information for the system Python in a package called `python-debuginfo`, `python-dbg` or similar. For example:

- Fedora:

```
sudo dnf install gdb
sudo dnf debuginfo-install python3
```

- Ubuntu:

```
sudo apt install gdb python3-dbg
```

On several recent Linux systems, GDB can download debugging symbols automatically using *debuginfod*. However, this will not install the `python-gdb.py` extension; you generally do need to install the debug info package separately.

## 2 Using the Debug build and Development mode

For easier debugging, you might want to:

- Use a debug build of Python. (When building from source, use `configure --with-pydebug`. On Linux distros, install and run a package like `python-debug` or `python-dbg`, if available.)
- Use the runtime development mode (`-X dev`).

Both enable extra assertions and disable some optimizations. Sometimes this hides the bug you are trying to find, but in most cases they make the process easier.

## 3 Using the `python-gdb` extension

When the extension is loaded, it provides two main features: pretty printers for Python values, and additional commands.

### 3.1 Pretty-printers

This is what a GDB backtrace looks like (truncated) when this extension is enabled:

```
#0  0x000000000041a6b1 in PyObject_Malloc (nbytes=Cannot access memory at address 0x7ffff7fefe8) at Objects/obmalloc.c:748
#1  0x000000000041b7c0 in _PyObject_DebugMallocApi (id=111 'o', nbytes=24) at Objects/obmalloc.c:1445
#2  0x000000000041b717 in _PyObject_DebugMalloc (nbytes=24) at Objects/obmalloc.c:1412
#3  0x000000000044060a in _PyUnicode_New (length=11) at Objects/unicodeobject.c:346
#4  0x00000000004466aa in PyUnicodeUCS2_DecodeUTF8Stateful (s=0x5c2b8d "__lltrace__", size=11, errors=0x0, consumed=0x0) at Objects/unicodeobject.c:2531
#5  0x0000000000446647 in PyUnicodeUCS2_DecodeUTF8 (s=0x5c2b8d "__lltrace__", size=11, errors=0x0) at Objects/unicodeobject.c:2495
#6  0x0000000000440d1b in PyUnicodeUCS2_FromStringAndSize (u=0x5c2b8d "__lltrace__", size=11) at Objects/unicodeobject.c:551
#7  0x0000000000440d94 in PyUnicodeUCS2_FromString (u=0x5c2b8d "__lltrace__") at Objects/unicodeobject.c:569
#8  0x0000000000584abd in PyDict_GetItemString (v={'Yuck': <type at remote 0xad4730>, '__builtins__': <module at remote 0x7ffff7fd5ee8>, '__file__': 'Lib/test/crashers/nasty_eq_vs_dict.py', '__package__': None, 'y': <Yuck(i=0) at remote 0xaaacd80>, 'dict': {0: 0, 1: 1, 2: 2, 3: 3}, '__cached__': None, '__name__': '__main__', 'z': <Yuck(i=0) at remote 0xaace60>, '__doc__': None}, key='0x5c2b8d "__lltrace__") at Objects/dictobject.c:2171
```

Notice how the dictionary argument to `PyDict_GetItemString` is displayed as its `repr()`, rather than an opaque `PyObject *` pointer.

The extension works by supplying a custom printing routine for values of type `PyObject *`. If you need to access lower-level details of an object, then cast the value to a pointer of the appropriate type. For example:

```
(gdb) p globals
$1 = {'__builtins__': <module at remote 0x7ffff7fb1868>, '__name__': '__main__', 'ctypes': <module at remote 0x7ffff7f14360>, '__doc__': None, '__package__': None}
```

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```
(gdb) p *(PyDictObject*)globals
$2 = {ob_refcnt = 3, ob_type = 0x3dbdf85820, ma_fill = 5, ma_used = 5,
ma_mask = 7, ma_table = 0x63d0f8, ma_lookup = 0x3dbdc7ea70
<lookdict_string>, ma_smalltable = {{me_hash = 7065186196740147912,
me_key = '__builtins__', me_value = <module at remote 0x7ffff7fb1868>},
{me_hash = -368181376027291943, me_key = '__name__',
me_value = '__main__'}, {me_hash = 0, me_key = 0x0, me_value = 0x0},
{me_hash = 0, me_key = 0x0, me_value = 0x0},
{me_hash = -9177857982131165996, me_key = 'ctypes',
me_value = <module at remote 0x7ffff7f14360>},
{me_hash = -8518757509529533123, me_key = '__doc__', me_value = None},
{me_hash = 0, me_key = 0x0, me_value = 0x0}, {
me_hash = 6614918939584953775, me_key = '__package__', me_value = None}}}
```

Note that the pretty-printers do not actually call `repr()`. For basic types, they try to match its result closely.

An area that can be confusing is that the custom printer for some types look a lot like GDB's built-in printer for standard types. For example, the pretty-printer for a Python `int` (`PyLongObject*`) gives a representation that is not distinguishable from one of a regular machine-level integer:

```
(gdb) p some_machine_integer
$3 = 42

(gdb) p some_python_integer
$4 = 42
```

The internal structure can be revealed with a cast to `PyLongObject*`:

```
(gdb) p (PyLongObject*)some_python_integer $5 = {ob_base = {ob_base = {ob_refcnt = 8, ob_type =
0x3dad39f5e0}, ob_size = 1}, ob_digit = {42}}
```

A similar confusion can arise with the `str` type, where the output looks a lot like gdb's built-in printer for `char *`:

```
(gdb) p ptr_to_python_str
$6 = '__builtins__'
```

The pretty-printer for `str` instances defaults to using single-quotes (as does Python's `repr` for strings) whereas the standard printer for `char *` values uses double-quotes and contains a hexadecimal address:

```
(gdb) p ptr_to_char_star
$7 = 0x6d72c0 "hello world"
```

Again, the implementation details can be revealed with a cast to `PyUnicodeObject*`:

```
(gdb) p *(PyUnicodeObject*)$6
$8 = {ob_base = {ob_refcnt = 33, ob_type = 0x3dad3a95a0}, length = 12,
str = 0x7fffff2128500, hash = 7065186196740147912, state = 1, defenc = 0x0}
```

## 3.2 py-list

The extension adds a `py-list` command, which lists the Python source code (if any) for the current frame in the selected thread. The current line is marked with a ">":

```
(gdb) py-list
901         if options.profile:
902             options.profile = False
903             profile_me()
904             return
905
>906         u = UI()
```

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```
907         if not u.quit:
908             try:
909                 gtk.main()
910             except KeyboardInterrupt:
911                 # properly quit on a keyboard interrupt...
```

Use `py-list START` to list at a different line number within the Python source, and `py-list START, END` to list a specific range of lines within the Python source.

### 3.3 py-up and py-down

The `py-up` and `py-down` commands are analogous to GDB's regular `up` and `down` commands, but try to move at the level of CPython frames, rather than C frames.

GDB is not always able to read the relevant frame information, depending on the optimization level with which CPython was compiled. Internally, the commands look for C frames that are executing the default frame evaluation function (that is, the core bytecode interpreter loop within CPython) and look up the value of the related `PyFrameObject *`.

They emit the frame number (at the C level) within the thread.

For example:

```
(gdb) py-up
#37 Frame 0x9420b04, for file /usr/lib/python2.6/site-packages/
gnome_sudoku/main.py, line 906, in start_game ()
    u = UI()
(gdb) py-up
#40 Frame 0x948e82c, for file /usr/lib/python2.6/site-packages/
gnome_sudoku/gnome_sudoku.py, line 22, in start_game(main=<module at
↳remote 0xb771b7f4>)
    main.start_game()
(gdb) py-up
Unable to find an older python frame
```

so we're at the top of the Python stack.

The frame numbers correspond to those displayed by GDB's standard `backtrace` command. The command skips C frames which are not executing Python code.

Going back down:

```
(gdb) py-down
#37 Frame 0x9420b04, for file /usr/lib/python2.6/site-packages/gnome_
↳sudoku/main.py, line 906, in start_game ()
    u = UI()
(gdb) py-down
#34 (unable to read python frame information)
(gdb) py-down
#23 (unable to read python frame information)
(gdb) py-down
#19 (unable to read python frame information)
(gdb) py-down
#14 Frame 0x99262ac, for file /usr/lib/python2.6/site-packages/gnome_
↳sudoku/game_selector.py, line 201, in run_swallowed_dialog (self=
↳<NewOrSavedGameSelector(new_game_model=<gtk.ListStore at remote_
↳0x98fab44>, puzzle=None, saved_games=[{'gsd.auto_fills': 0, 'tracking':
↳{'', 'trackers': {}, 'notes': [], 'saved_at': 1270084485, 'game': '7 8 0_
↳0 0 0 0 5 6 0 0 9 0 8 0 1 0 0 0 4 6 0 0 0 0 7 0 6 5 0 0 0 4 7 9 2 0 0 0_
↳9 0 1 0 0 0 3 9 7 6 0 0 0 1 8 0 6 0 0 0 0 2 8 0 0 0 5 0 4 0 6 0 0 2 1 0_
↳0 0 0 0 4 5\n7 8 0 0 0 0 0 0 5 6 0 0 9 0 8 0 1 0 0 0 4 6 0 0 0 0 7 0 6 5_
```

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```
→1 8 3 4 7 9 2 0 0 0 9 0 1 0 0 0 3 9 7 6 0 0 0 1 8 0 6 0 0 0 0 2 8 0 0 0_
→5 0 4 0 6 0 0 2 1 0 0 0 0 0 4 5', 'gsd.impossible_hints': 0, 'timer.__
→absolute_start_time__': <float at remote 0x984b474>, 'gsd.hints': 0,
→'timer.active_time': <float at remote 0x984b494>, 'timer.total_time':
→<float at remote 0x984b464>}], dialog=<gtk.Dialog at remote 0x98faaa4>,
→saved_game_model=<gtk.ListStore at remote 0x98fad24>, sudoku_maker=
→<SudokuMaker(terminated=False, played=[], batch_siz...(truncated)
    swallower.run_dialog(self.dialog)
(gdb) py-down
#11 Frame 0x9aead74, for file /usr/lib/python2.6/site-packages/gnome_
→sudoku/dialog_swallower.py, line 48, in run_dialog (self=
→<SwappableArea(running=<gtk.Dialog at remote 0x98faaa4>, main_page=0)_
→at remote 0x98fa6e4>, d=<gtk.Dialog at remote 0x98faaa4>)
    gtk.main()
(gdb) py-down
#8 (unable to read python frame information)
(gdb) py-down
Unable to find a newer python frame
```

and we're at the bottom of the Python stack.

### 3.4 py-bt

The `py-bt` command attempts to display a Python-level backtrace of the current thread.

For example:

```
(gdb) py-bt
#8 (unable to read python frame information)
#11 Frame 0x9aead74, for file /usr/lib/python2.6/site-packages/gnome_
→sudoku/dialog_swallower.py, line 48, in run_dialog (self=
→<SwappableArea(running=<gtk.Dialog at remote 0x98faaa4>, main_page=0)_
→at remote 0x98fa6e4>, d=<gtk.Dialog at remote 0x98faaa4>)
    gtk.main()
#14 Frame 0x99262ac, for file /usr/lib/python2.6/site-packages/gnome_
→sudoku/game_selector.py, line 201, in run_swallowed_dialog (self=
→<NewOrSavedGameSelector(new_game_model=<gtk.ListStore at remote_
→0x98fab44>, puzzle=None, saved_games=[{'gsd.auto_fills': 0, 'tracking':
→{}}, {'trackers': {}, 'notes': [], 'saved_at': 1270084485, 'game': '7 8 0_
→0 0 0 0 5 6 0 0 9 0 8 0 1 0 0 0 4 6 0 0 0 0 7 0 6 5 0 0 0 4 7 9 2 0 0 0_
→9 0 1 0 0 0 3 9 7 6 0 0 0 1 8 0 6 0 0 0 0 2 8 0 0 0 5 0 4 0 6 0 0 2 1 0_
→0 0 0 0 4 5\n7 8 0 0 0 0 0 0 5 6 0 0 9 0 8 0 1 0 0 0 4 6 0 0 0 0 7 0 6 5_
→1 8 3 4 7 9 2 0 0 0 9 0 1 0 0 0 3 9 7 6 0 0 0 1 8 0 6 0 0 0 0 2 8 0 0 0_
→5 0 4 0 6 0 0 2 1 0 0 0 0 4 5', 'gsd.impossible_hints': 0, 'timer.__
→absolute_start_time__': <float at remote 0x984b474>, 'gsd.hints': 0,
→'timer.active_time': <float at remote 0x984b494>, 'timer.total_time':
→<float at remote 0x984b464>}], dialog=<gtk.Dialog at remote 0x98faaa4>,
→saved_game_model=<gtk.ListStore at remote 0x98fad24>, sudoku_maker=
→<SudokuMaker(terminated=False, played=[], batch_siz...(truncated)
    swallower.run_dialog(self.dialog)
#19 (unable to read python frame information)
#23 (unable to read python frame information)
#34 (unable to read python frame information)
#37 Frame 0x9420b04, for file /usr/lib/python2.6/site-packages/gnome_
→sudoku/main.py, line 906, in start_game ()
    u = UI()
#40 Frame 0x948e82c, for file /usr/lib/python2.6/site-packages/gnome_
→sudoku/gnome_sudoku.py, line 22, in start_game (main=<module at remote_
→0xb771b7f4>)
    main.start_game()
```

The frame numbers correspond to those displayed by GDB's standard `backtrace` command.

### 3.5 py-print

The `py-print` command looks up a Python name and tries to print it. It looks in locals within the current thread, then globals, then finally builtins:

```
(gdb) py-print self
local 'self' = <SwappableArea(running=<gtk.Dialog at remote 0x98faaa4>,
main_page=0) at remote 0x98fa6e4>
(gdb) py-print __name__
global '__name__' = 'gnome_sudoku.dialog_swalloweer'
(gdb) py-print len
builtin 'len' = <built-in function len>
(gdb) py-print scarlet_pimpernel
'scarlet_pimpernel' not found
```

### 3.6 py-locals

The `py-locals` command looks up all Python locals within the current Python frame in the selected thread, and prints their representations:

```
(gdb) py-locals
self = <SwappableArea(running=<gtk.Dialog at remote 0x98faaa4>,
main_page=0) at remote 0x98fa6e4>
d = <gtk.Dialog at remote 0x98faaa4>
```

## 4 Use with GDB commands

The extension commands complement GDB's built-in commands. For example, you can use a frame numbers shown by `py-bt` with the `frame` command to go a specific frame within the selected thread, like this:

```
(gdb) py-bt
(output snipped)
#68 Frame 0xaa4560, for file Lib/test/regrtest.py, line 1548, in <module> ()
    main()
(gdb) frame 68
#68 0x0000000004cd1e6 in PyEval_EvalFrameEx (f=Frame 0xaa4560, for file Lib/test/
→ regrtest.py, line 1548, in <module> (), throwflag=0) at Python/ceval.c:2665
2665                                x = call_function(&sp, oparg);
(gdb) py-list
1543         # Run the tests in a context manager that temporary changes the CWD to
→ a
1544         # temporary and writable directory. If it's not possible to create or
1545         # change the CWD, the original CWD will be used. The original CWD is
1546         # available from test_support.SAVEDCWD.
1547         with test_support.temp_cwd(TESTCWD, quiet=True):
>1548             main()
```

The `info threads` command will give you a list of the threads within the process, and you can use the `thread` command to select a different one:

```
(gdb) info threads
105 Thread 0x7fffeffa18710 (LWP 10260)  sem_wait () at ../nptl/sysdeps/unix/sysv/
→ linux/x86_64/sem_wait.S:86
104 Thread 0x7fffd5fe710 (LWP 10259)  sem_wait () at ../nptl/sysdeps/unix/sysv/
```

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```
↳linux/x86_64/sem_wait.S:86
* 1 Thread 0x7ffff7fe2700 (LWP 10145) 0x00000038e46d73e3 in select () at ../
↳sysdeps/unix/syscall-template.S:82
```

You can use `thread apply all COMMAND` or `(t a a COMMAND` for short) to run a command on all threads. With `py-bt`, this lets you see what every thread is doing at the Python level:

```
(gdb) t a a py-bt

Thread 105 (Thread 0x7ffffefa18710 (LWP 10260)):
#5 Frame 0x7ffffd00019d0, for file /home/david/coding/python-svn/Lib/threading.py,
↳line 155, in _acquire_restore (self=<_RLock(_Verbose__verbose=False, _RLock__
↳owner=140737354016512, _RLock__block=<thread.lock at remote 0x858770>, _RLock__
↳count=1) at remote 0xd7ff40>, count_owner=(1, 140737213728528), count=1,
↳owner=140737213728528)
    self.__block.acquire()
#8 Frame 0x7ffffac001640, for file /home/david/coding/python-svn/Lib/threading.py,
↳line 269, in wait (self=<_Condition(_Condition__lock=<_RLock(_Verbose__
↳verbose=False, _RLock__owner=140737354016512, _RLock__block=<thread.lock at
↳remote 0x858770>, _RLock__count=1) at remote 0xd7ff40>, acquire=<instancemethod
↳at remote 0xd80260>, _is_owned=<instancemethod at remote 0xd80160>, _release
↳save=<instancemethod at remote 0xd803e0>, release=<instancemethod at remote
↳0xd802e0>, _acquire_restore=<instancemethod at remote 0xd7ee60>, _Verbose__
↳verbose=False, _Condition__waiters=[]> at remote 0xd7fd10>, timeout=None, waiter=
↳<thread.lock at remote 0x858a90>, saved_state=(1, 140737213728528))
    self._acquire_restore(saved_state)
#12 Frame 0x7ffffb8001a10, for file /home/david/coding/python-svn/Lib/test/lock_
↳tests.py, line 348, in f ()
    cond.wait()
#16 Frame 0x7ffffb8001c40, for file /home/david/coding/python-svn/Lib/test/lock_
↳tests.py, line 37, in task (tid=140737213728528)
    f()

Thread 104 (Thread 0x7ffffdf5fe710 (LWP 10259)):
#5 Frame 0x7ffffe4001580, for file /home/david/coding/python-svn/Lib/threading.py,
↳line 155, in _acquire_restore (self=<_RLock(_Verbose__verbose=False, _RLock__
↳owner=140737354016512, _RLock__block=<thread.lock at remote 0x858770>, _RLock__
↳count=1) at remote 0xd7ff40>, count_owner=(1, 140736940992272), count=1,
↳owner=140736940992272)
    self.__block.acquire()
#8 Frame 0x7ffffc8002090, for file /home/david/coding/python-svn/Lib/threading.py,
↳line 269, in wait (self=<_Condition(_Condition__lock=<_RLock(_Verbose__
↳verbose=False, _RLock__owner=140737354016512, _RLock__block=<thread.lock at
↳remote 0x858770>, _RLock__count=1) at remote 0xd7ff40>, acquire=<instancemethod
↳at remote 0xd80260>, _is_owned=<instancemethod at remote 0xd80160>, _release
↳save=<instancemethod at remote 0xd803e0>, release=<instancemethod at remote
↳0xd802e0>, _acquire_restore=<instancemethod at remote 0xd7ee60>, _Verbose__
↳verbose=False, _Condition__waiters=[]> at remote 0xd7fd10>, timeout=None, waiter=
↳<thread.lock at remote 0x858860>, saved_state=(1, 140736940992272))
    self._acquire_restore(saved_state)
#12 Frame 0x7ffffac001c90, for file /home/david/coding/python-svn/Lib/test/lock_
↳tests.py, line 348, in f ()
    cond.wait()
#16 Frame 0x7ffffac0011c0, for file /home/david/coding/python-svn/Lib/test/lock_
↳tests.py, line 37, in task (tid=140736940992272)
    f()

Thread 1 (Thread 0x7fffff7fe2700 (LWP 10145)):
#5 Frame 0xcb5380, for file /home/david/coding/python-svn/Lib/test/lock_tests.py,
↳line 16, in _wait ()
    time.sleep(0.01)
```

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```
#8 Frame 0x7ffffd00024a0, for file /home/david/coding/python-svn/Lib/test/lock_
↳ tests.py, line 378, in _check_notify (self=<ConditionTests(_testMethodName='test_
↳ notify', _resultForDoCleanups=<TestResult(_original_stdout=<cStringIO.StringO at
↳ remote 0xc191e0>, skipped=[], _mirrorOutput=False, testsRun=39, buffer=False, _
↳ original_stderr=<file at remote 0x7ffff7fc6340>, _stdout_buffer=<cStringIO.
↳ StringIO at remote 0xc9c7f8>, _stderr_buffer=<cStringIO.StringO at remote
↳ 0xc9c790>, _moduleSetUpFailed=False, expectedFailures=[], errors=[], _
↳ previousTestClass=<type at remote 0x928310>, unexpectedSuccesses=[], failures=[],
↳ shouldStop=False, failfast=False) at remote 0xc185a0>, _threads=(0,), _
↳ cleanups=[], _type_equality_funcs={<type at remote 0x7eba00>: <instancemethod at
↳ remote 0xd750e0>, <type at remote 0x7e7820>: <instancemethod at remote 0xd75160>,
↳ <type at remote 0x7e30e0>: <instancemethod at remote 0xd75060>, <type at remote
↳ 0x7e7d20>: <instancemethod at remote 0xd751e0>, <type at remote 0x7f19e0...
↳ (truncated)
    _wait()
```