DTrace and SystemTap are monitoring tools, each providing a way to inspect what the processes on a computer system are doing. They both use domain-specific languages allowing a user to write scripts which:

- filter which processes are to be observed
- gather data from the processes of interest
- generate reports on the data

As of Python 3.6, CPython can be built with embedded “markers”, also known as “probes”, that can be observed by a DTrace or SystemTap script, making it easier to monitor what the CPython processes on a system are doing.

**CPython implementation detail:** DTrace markers are implementation details of the CPython interpreter. No guarantees are made about probe compatibility between versions of CPython. DTrace scripts can stop working or work incorrectly without warning when changing CPython versions.


1 Enabling the static markers

macOS comes with built-in support for DTrace. On Linux, in order to build CPython with the embedded markers for SystemTap, the SystemTap development tools must be installed.

On a Linux machine, this can be done via:

```bash
$ yum install systemtap-sdt-devel
```

or:

```bash
$ sudo apt-get install systemtap-sdt-dev
```

CPython must then be configured with the `--with-dtrace` option:

```bash
checking for --with-dtrace... yes
```

On macOS, you can list available DTrace probes by running a Python process in the background and listing all probes made available by the Python provider:

```bash
$ python3.6 -q &
$ sudo dtrace -l -P python
```

```bash
# or: dtrace -l -m python3.6
```

<table>
<thead>
<tr>
<th>ID</th>
<th>PROVIDER</th>
<th>MODULE</th>
<th>FUNCTION</th>
<th>NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>29564</td>
<td>python18035</td>
<td>python3.6</td>
<td>_PyEval_EvalFrameDefault</td>
<td>function-entry</td>
</tr>
<tr>
<td>29565</td>
<td>python18035</td>
<td>python3.6</td>
<td>dtrace_function_entry</td>
<td>function-entry</td>
</tr>
<tr>
<td>29566</td>
<td>python18035</td>
<td>python3.6</td>
<td>_PyEval_EvalFrameDefault</td>
<td>function-&lt;br/&gt;return</td>
</tr>
<tr>
<td>29567</td>
<td>python18035</td>
<td>python3.6</td>
<td>dtrace_function_return</td>
<td>function-&lt;br/&gt;return</td>
</tr>
<tr>
<td>29568</td>
<td>python18035</td>
<td>python3.6</td>
<td></td>
<td>collect gc-done</td>
</tr>
<tr>
<td>29569</td>
<td>python18035</td>
<td>python3.6</td>
<td></td>
<td>collect gc-start</td>
</tr>
<tr>
<td>29570</td>
<td>python18035</td>
<td>python3.6</td>
<td></td>
<td>_PyEval_EvalFrameDefault</td>
</tr>
<tr>
<td>29571</td>
<td>python18035</td>
<td>python3.6</td>
<td></td>
<td>maybe_dtrace_line</td>
</tr>
</tbody>
</table>

On Linux, you can verify if the SystemTap static markers are present in the built binary by seeing if it contains a “.note.stapsdt” section:

```bash
$ readelf -S ./python | grep .note.stapsdt
[30] .note.stapsdt NOTE 0000000000000000 00308d78
```

If you’ve built Python as a shared library (with the `--enable-shared` configure option), you need to look instead within the shared library. For example:

```bash
$ readelf -S libpython3.3dm.so.1.0 | grep .note.stapsdt
[29] .note.stapsdt NOTE 0000000000000000 00365b68
```

Sufficiently modern readelf can print the metadata:

```bash
$ readelf -n ./python
```

Displaying notes found at file offset 0x00000254 with length 0x0000020:

- Owner Data size Description
- GNU 0x00000010 NT_GNU_ABI_TAG (ABI version tag)
  OS: Linux, ABI: 2.6.32

Displaying notes found at file offset 0x00000274 with length 0x0000024:

- Owner Data size Description
- GNU 0x00000014 NT_GNU_BUILD_ID (unique build ID...<br/>-bitstring)
  Build ID: df924a2b08a7e89f6e11251d4602022977af2670
```

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The above metadata contains information for SystemTap describing how it can patch strategically-placed machine code instructions to enable the tracing hooks used by a SystemTap script.

## 2 Static DTrace probes

The following example DTrace script can be used to show the call/return hierarchy of a Python script, only tracing within the invocation of a function called “start”. In other words, import-time function invocations are not going to be listed:

```c
self int indent;

python$target:::function-entry
/copyinstr(arg1) == "start"/
{
    self->trace = 1;
}

python$target:::function-entry
/self->trace/
{
    printf("%d\t%*s:", timestamp, 15, probename);
    printf("%*s", self->indent, "");
    printf("%s:%s:%d\n", basename(copyinstr(arg0)), copyinstr(arg1), arg2);
    self->indent++;
}

python$target:::function-return
```

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It can be invoked like this:

```bash
$ sudo dtrace -q -s call_stack.d -c "python3.6 script.py"
```

The output looks like this:

```
156641360502280 function-entry:call_stack.py:start:23
156641360518804 function-entry: call_stack.py:function_1:1
156641360532797 function-entry: call_stack.py:function_3:9
156641360546807 function-return: call_stack.py:function_3:10
156641360563367 function-return: call_stack.py:function_1:2
156641360578365 function-entry: call_stack.py:function_2:5
156641360591757 function-entry: call_stack.py:function_1:1
156641360605556 function-entry: call_stack.py:function_3:9
156641360617482 function-return: call_stack.py:function_3:10
156641360629814 function-return: call_stack.py:function_1:2
156641360642285 function-return: call_stack.py:function_2:6
156641360656770 function-entry: call_stack.py:function_3:9
156641360669707 function-return: call_stack.py:function_3:10
156641360687853 function-entry: call_stack.py:function_4:13
156641360700719 function-return: call_stack.py:function_4:14
156641360719640 function-return: call_stack.py:function_5:18
156641360732567 function-return: call_stack.py:function_5:21
156641360747370 function-return:call_stack.py:start:28
```

### 3 Static SystemTap markers

The low-level way to use the SystemTap integration is to use the static markers directly. This requires you to explicitly state the binary file containing them.

For example, this SystemTap script can be used to show the call/return hierarchy of a Python script:

```bash
probe process("python").mark("function__entry") {
    filename = user_string($arg1);
    funcname = user_string($arg2);
    lineno = $arg3;

    printf("%s => %s in %s:%d\n",
           thread_indent(1), funcname, filename, lineno);
}
probe process("python").mark("function__return") {
    filename = user_string($arg1);
    funcname = user_string($arg2);
    lineno = $arg3;
}
```
It can be invoked like this:

```
$ stap \
   show-call-hierarchy.stp \n   -c "./python test.py"
```

The output looks like this:

```
11408 python(8274): => __contains__ in Lib/_abcoll.py:362
11414 python(8274): => __getitem__ in Lib/os.py:425
11418 python(8274): => encode in Lib/os.py:490
11424 python(8274): <= encode in Lib/os.py:493
11428 python(8274): <= __getitem__ in Lib/os.py:426
11433 python(8274): <= __contains__ in Lib/_abcoll.py:366
```

where the columns are:

- time in microseconds since start of script
- name of executable
- PID of process

and the remainder indicates the call/return hierarchy as the script executes.

For a `--enable-shared` build of CPython, the markers are contained within the libpython shared library, and the probe’s dotted path needs to reflect this. For example, this line from the above example:

```
probe process("python").mark("function__entry") {
```

should instead read:

```
probe process("python").library("libpython3.6dm.so.1.0").mark("function__entry") {
```

(assuming a debug build of CPython 3.6)

### 4 Available static markers

#### `function__entry(str filename, str funcname, int lineno)`

This marker indicates that execution of a Python function has begun. It is only triggered for pure-Python (bytecode) functions.

The filename, function name, and line number are provided back to the tracing script as positional arguments, which must be accessed using `$arg1`, `$arg2`, `$arg3`:

- `$arg1`: (const char *) `filename`, accessible using `user_string($arg1)`
- `$arg2`: (const char *) `function name`, accessible using `user_string($arg2)`
- `$arg3`: int `line number`

#### `function__return(str filename, str funcname, int lineno)`

This marker is the converse of `function__entry()`, and indicates that execution of a Python function has ended (either via return, or via an exception). It is only triggered for pure-Python (bytecode) functions.

The arguments are the same as for `function__entry()`
line(str filename, str funcname, int lineno)
This marker indicates a Python line is about to be executed. It is the equivalent of line-by-line tracing with a
Python profiler. It is not triggered within C functions.

The arguments are the same as for function__entry().

gc__start(int generation)
Fires when the Python interpreter starts a garbage collection cycle. arg0 is the generation to scan, like gc.
collect().

gc__done(long collected)
Fires when the Python interpreter finishes a garbage collection cycle. arg0 is the number of collected objects.

import__find__load__start(str modulename)
Fires before importlib attempts to find and load the module. arg0 is the module name.
New in version 3.7.

import__find__load__done(str modulename, int found)
Fires after importlib's find_and_load function is called. arg0 is the module name, arg1 indicates if
module was successfully loaded.
New in version 3.7.

audit(str event, void *tuple)
Fires when sys.audit() or PySys_Audit() is called. arg0 is the event name as C string, arg1 is a
PyObject pointer to a tuple object.
New in version 3.8.

5 SystemTap Tapsets

The higher-level way to use the SystemTap integration is to use a “tapset”: SystemTap’s equivalent of a library, which
hides some of the lower-level details of the static markers.

Here is a tapset file, based on a non-shared build of CPython:

```c
/*
   Provide a higher-level wrapping around the function__entry and
   function__return markers:
*/
probe python.function.entry = process("python").mark("function__entry")
{
    filename = user_string($arg1);
    funcname = user_string($arg2);
    lineno = $arg3;
    frameptr = $arg4
}
probe python.function.return = process("python").mark("function__return")
{
    filename = user_string($arg1);
    funcname = user_string($arg2);
    lineno = $arg3;
    frameptr = $arg4
}
```

If this file is installed in SystemTap’s tapset directory (e.g. /usr/share/systemtap/tapset), then these
additional probe points become available:

python.function.entry(str filename, str funcname, int lineno, frameptr)
This probe point indicates that execution of a Python function has begun. It is only triggered for pure-Python
(bytecode) functions.
python.function.return(str filename, str funcname, int lineno, frameptr)

This probe point is the converse of python.function.return, and indicates that execution of a Python function has ended (either via return, or via an exception). It is only triggered for pure-Python (bytecode) functions.

6 Examples

This SystemTap script uses the tapset above to more cleanly implement the example given above of tracing the Python function-call hierarchy, without needing to directly name the static markers:

```sh
probe python.function.entry
{
    printf("%s => %s in %s:%d\n",
            thread_indent(1), funcname, filename, lineno);
}

probe python.function.return
{
    printf("%s <= %s in %s:%d\n",
            thread_indent(-1), funcname, filename, lineno);
}
```

The following script uses the tapset above to provide a top-like view of all running CPython code, showing the top 20 most frequently-entered bytecode frames, each second, across the whole system:

```sh
global fn_calls;

probe python.function.entry
{
    fn_calls[pid(), filename, funcname, lineno] += 1;
}

probe timer.ms(1000) {
    printf("\033[2J\033[1;1H") /* clear screen */
    printf("%6s %80s %6s %30s %6s\n",
            "PID", "FILENAME", "LINE", "FUNCTION", "CALLS")
    foreach ([pid, filename, funcname, lineno] in fn_calls- limit 20) {
        printf("%6d %80s %6d %30s %6d\n",
            pid, filename, lineno, funcname,
            fn_calls[pid, filename, funcname, lineno]);
    }
    delete fn_calls;
}
```