Networking without an OS

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PyCon 2016

PYCON 2016

ROSE

CITY

PORTLAND, OREGON

MAY 28TH – JUNE 5TH

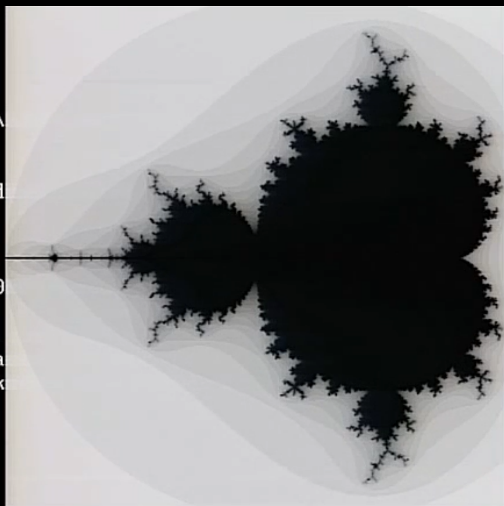
PyCon 2015
Montréal • April 8-16

Porting Python to run without an OS

PyCon 2015

- BIOS Implementation Test Suite (BITS)
- Python in GRUB and EFI, without an OS
- Explore and test hardware and firmware

```
0L
>>> out.OutputString(out, "Hello world!\
Hello world!
0L
>>> fb = (c_uint32 * 800 * 600).from_add
meBufferBase)
>>> for y in range(400):
...     for x in range(400):
...         zx,zy = cx,cy = -2+2.5*x/400
...         for i in range(25):
...             zx,zy = zx*zx-zy*zy+cx,
...             if zx*zx+zy*zy > 4: brea
...         fb[y][x+400] = (250-10*i)*0x
...
>>> _
```



```
Starting the Python interactive interpreter. Press Ctrl-D or Esc to exit.
>>> fb = (c_uint32 * 800 * 600).from_address(bits.present.gop.Mode.contents.Fra
meBufferBase)
>>> import time
>>> def clear():
...   out.ClearScreen(out)
...
>>> def game():
...   k = EFI_KEY_DATA()
...   x = y = 10; xv = 1; yv = 0
...   while True:
...     _ = t.ReadKeyStrokeEx(t, k)
...     if k.scan == 23: break
...     elif k.scan >= 1 and k.scan <= 4:
...       xv = (0,0,1,-1)[k.scan-1]
...       yv = (-1,1,0,0)[k.scan-1]
...     x += xv ; y += yv
...     t1 = time.time()
...     while time.time() - t1 < 0.02: pass
...     if fb[y][x] == 0x0000ff00: break
...     fb[y][x] = 0x0000ff00
...
>>> game()
>>> _
```

BITS Capabilities

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- Direct access to hardware and physical memory
- Python can call EFI firmware protocols via ctypes
- Most of the Python standard library

Most of the Python standard library

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Some modules don't make sense without an OS

os.execve

os.fork

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multiprocessing
popen2
subprocess

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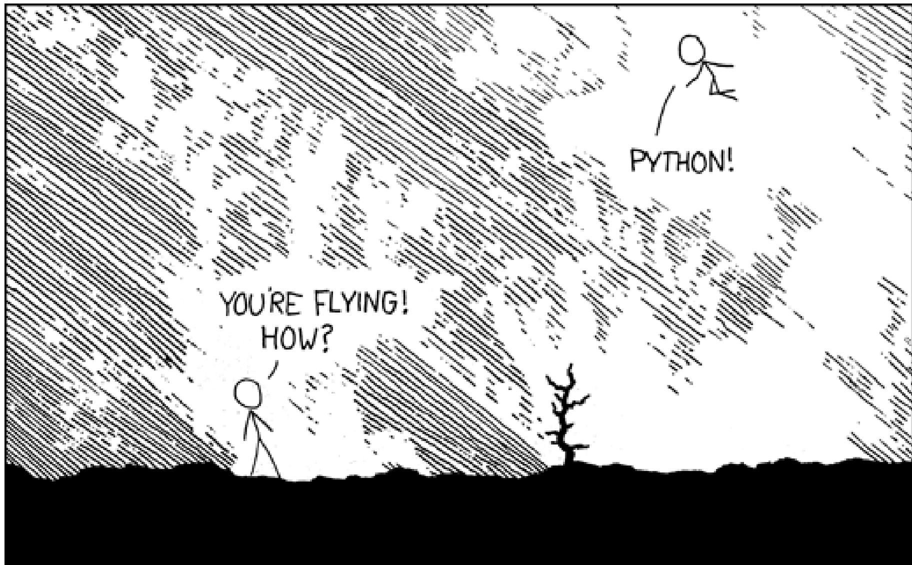
webbrowser



import antigravity

socket
select

socket
select

urllib2
httplib
SocketServer
BaseHTTPServer

EFI networking protocols

- EFI_IP4_CONFIG2_PROTOCOL
- EFI_TCP4_PROTOCOL

Why networking in firmware?

- Send scripts or test data into the machine

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- Send scripts or test data into the machine
- Read test data or logs from the machine
- Avoid relying on a writable filesystem
- Speed up edit/compile/boot/run cycle

Demo

Bridging EFI networking and Python sockets

- Could call EFI network protocols directly
- Want compatibility with existing Python networking code
- Python modules import `socket` and `select`
- `socket` (Python) imports `_socket` (C)

Sockets overview

- “Berkeley” sockets

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- Standard on UNIX/POSIX systems, and on Windows via WinSock
- Focusing exclusively on TCP/IP connections

Creating a socket

- `int s = socket(AF_INET, SOCK_STREAM, 0);`

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Creating a socket

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- `AF_INET` - IP
- `SOCK_STREAM` - TCP
- Can use `s` as either client or server socket

Client socket

- `socket`

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- `socket`
- `connect`

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- `socket`
- `connect`
  - `struct sockaddr`

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- `send/recv`

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- `send/recv`
- `close`

Server socket

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Server socket

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- Many OS-specific replacements for scalability and performance

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Python bindings

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- `s = socket.socket()` - defaults to TCP/IP
- `s.connect`
- `s.bind`, `s.listen`, `s.accept`
- `s.sendall`, `s.recv`
- ```
  rl,wl,xl = select.select([s],[],[])
  if s in rl:
  ```
  ```

CPython implementation

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  - Handle C arguments, addresses, buffer management
- Would have to call EFI protocols from C
  - Or, have many callbacks from C to Python

BITS implementation

- C helper for safe asynchronous event handling
- Otherwise entirely Python
- Python makes all EFI protocol calls

Calling EFI from Python via ctypes

Behind the scenes

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- ctypes returns the error code from EFI

Resource management

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- Python uses garbage collection
- Python GC doesn't know about references from EFI
- Must keep Python object alive as long as EFI references it
- Must explicitly free EFI resources when no longer referenced from Python

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Glossing over quirks, bugs, error handling, workarounds, and compatibility with older versions

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- Similar to the implementation of sockets in an OS kernel

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- Caller expected to call Poll periodically if waiting
  - Improves performance by orders of magnitude
- Solution: call Poll inside helpers for select

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- All EFI socket calls asynchronous
- Calls take a "completion token" with `EFI_EVENT` to signal when done
- For sockets, `EFI_EVENT` must have a callback function
- Need to handle callback safely from Python

Python concurrency model

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- Global Interpreter Lock (GIL)
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- Almost all CPython functions prohibited
- Same problem arises with Ctrl-C and signals

Py_AddPendingCall

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Py_AddPendingCall

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- Can call arbitrary CPython functions from the callback

Handling events

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- dict keeps Python objects live while `EFI_EVENT` references them

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  - Queues data or error when callback called
- `_write_ready` returns true if connected

Implementing select

- Takes read and write lists of sockets
  - Or file descriptors; map to sockets via dict
- Loop over sockets until timeout expires
- Call _read_ready or _write_ready
- _read_ready checks queue, calls Receive or Accept
  - If already running from previous call, call Poll
  - Handle connection closure to provide EOF from recv
  - Queues data or error when callback called
- _write_ready returns true if connected
  - Always calls Poll if connected

class socket

- __init__: Create EFI_TCP4_PROTOCOL from binding protocol

class socket

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- listen: Call Configure for listening socket

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- `accept`: Return queued connection if any
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Socket demo and walkthrough

High-level client demo

High-level server demo

Try it out yourself

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  - Check BIOS settings to enable EFI network stack

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- Or try it on physical hardware
  - Check BIOS settings to enable EFI network stack
  - Use wired Ethernet

BIOS Implementation Test Suite (BITS)
`http://biosbits.org/`

Questions?

Networking without an OS
Demo Backup

Josh Triplett
josh@joshtriplett.org

PyCon 2016

```
$ (cd test ; python -m SimpleHTTPServer 8080)
Serving HTTP on 0.0.0.0 port 8080 ...
```

```
>>> import sys
>>> print sys.platform
BITS-EFI
>>> _
```

```
>>> import sys
>>> print sys.platform
BITS-EFI
>>> import urllib2
>>> print urllib2.urlopen("http://10.0.2.2:8080/hello").read()
IP configuration started
IP configuration complete: 10.0.2.15/255.255.255.0
Hello world!

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>>> print urllib2.urlopen("http://10.0.2.2:8080/hello").read()
Hello world!

>>> _
```

```
>>> import efi
>>> out = efi.system_table.ConOut.contents
>>> out.OutputString(out, "Hello world\r\n")
Hello world
0L
>>> _
```

```
0L
>>> print efi.system_table
EFI_SYSTEM_TABLE(
  ofs=0 Hdr=TableHeader(
    ofs=0 Signature=0x5453595320494249
    ofs=8 Revision=0x20032
    ofs=12 HeaderSize=0x78
    ofs=16 CRC32=0xc57c8b39
    ofs=20 Reserved=0x0)
  ofs=24 FirmwareVendor=EDK II
  ofs=32 FirmwareRevision=0x10000
  ofs=40 ConsoleInHandle=0x7f637f18
  ofs=48 ConIn=<efi.LP_EFI_SIMPLE_TEXT_INPUT_PROTOCOL object at 0x79fa0a70>
  ofs=56 ConsoleOutHandle=0x7f636bd8
  ofs=64 ConOut=<efi.LP_EFI_SIMPLE_TEXT_OUTPUT_PROTOCOL object at
  0x79fa0a70>
  ofs=72 StandardErrorHandle=0x7f636c58
  ofs=80 StdErr=<efi.LP_EFI_SIMPLE_TEXT_OUTPUT_PROTOCOL object at
  0x79fa0a70>
  ofs=88 RuntimeServices=<efi.LP_EFI_RUNTIME_SERVICES object at 0x79fa0a70>
  ofs=96 BootServices=<efi.LP_EFI_BOOT_SERVICES object at 0x79fa0a70>
  ofs=104 NumberOfTableEntries=0x9
  ofs=112 ConfigurationTablePtr=<efi.LP_ConfigurationTable object at
  0x79fa0a70>)
>>> _
```

```
>>> print out
EFI_SIMPLE_TEXT_OUTPUT_PROTOCOL(
  ofs=0 Reset=<CFunctionType object at 0x7a1f51f0>
  ofs=8 OutputString=<CFunctionType object at 0x7a1f51f0>
  ofs=16 TestString=<CFunctionType object at 0x7a1f51f0>
  ofs=24 QueryMode=<CFunctionType object at 0x7a1f51f0>
  ofs=32 SetMode=<CFunctionType object at 0x7a1f51f0>
  ofs=40 SetAttribute=<CFunctionType object at 0x7a1f51f0>
  ofs=48 ClearScreen=<CFunctionType object at 0x7a1f51f0>
  ofs=56 SetCursorPosition=<CFunctionType object at 0x7a1f51f0>
  ofs=64 EnableCursor=<CFunctionType object at 0x7a1f51f0>
  ofs=72 Mode=<efi.LP_SIMPLE_TEXT_OUTPUT_MODE object at 0x79fa0a70>)
>>> _
```

```
>>> import socket, select
>>> s = socket.socket()
>>> s.connect(("10.0.2.2", 8080))
>>> s.sendall("GET /hello\r\n\r\n")
>>> _
```

```
>>> import socket, select
>>> s = socket.socket()
>>> s.connect(("10.0.2.2", 8080))
>>> s.sendall("GET /hello\r\n\r\n")
>>> print s.recv(4096)
Hello world!

>>> _
```

```
>>> s = socket.socket()
>>> s.connect(("10.0.2.2", 8080))
>>> s.sendall("GET /hello\r\n\r\n")
>>> _
```

```
>>> s = socket.socket()
>>> s.connect(("10.0.2.2", 8080))
>>> s.sendall("GET /hello\r\n\r\n")
>>> print s._sock._recv_queue
[]
>>> _
```

```
>>> s = socket.socket()
>>> s.connect(("10.0.2.2", 8080))
>>> s.sendall("GET /hello\r\n\r\n")
>>> print s._sock._recv_queue
[]
>>> print s.recv(1)
H
>>> _
```

```
>>> s = socket.socket()
>>> s.connect(("10.0.2.2", 8080))
>>> s.sendall("GET /hello\r\n\r\n")
>>> print s._sock._recv_queue
[]
>>> print s.recv(1)
H
>>> print s._sock._recv_queue
[<ctypes.c_char_Array_12 object at 0x79fa3170>]
>>> _
```

```
>>> s = socket.socket()
>>> s.connect(("10.0.2.2", 8080))
>>> s.sendall("GET /hello\r\n\r\n")
>>> print s._sock._recv_queue
[]
>>> print s.recv(1)
H
>>> print s._sock._recv_queue
[<ctypes.c_char_Array_12 object at 0x79fa3170>]
>>> print s._sock._recv_queue[0].raw
ello world!

>>> _
```

```
>>> s = socket.socket()
>>> s.connect(("10.0.2.2", 8080))
>>> s.sendall("GET /hello\r\n\r\n")
>>> print s._sock._recv_queue
[]
>>> print s.recv(1)
H
>>> print s._sock._recv_queue
[<ctypes.c_char_Array_12 object at 0x79fa3170>]
>>> print s._sock._recv_queue[0].raw
ello world!

>>> print s.recv(1)
e
>>> print s._sock._recv_queue
[<ctypes.c_char_Array_11 object at 0x79fa0b90>]
>>> _
```

```
>>> s = socket.socket()
>>> s.connect(("10.0.2.2", 8080))
>>> s.sendall("GET /hello\r\n\r\n")
>>> print s._sock._recv_queue
[]
>>> print s.recv(1)
H
>>> print s._sock._recv_queue
[<ctypes.c_char_Array_12 object at 0x79fa3170>]
>>> print s._sock._recv_queue[0].raw
ello world!

>>> print s.recv(1)
e
>>> print s._sock._recv_queue
[<ctypes.c_char_Array_11 object at 0x79fa0b90>]
>>> print s.recv(4096)
llo world!

>>> _
```

```
>>> s = socket.socket()
>>> s.bind(("", 1234))
>>> s.listen(10)
>>> _
```

```
>>> s = socket.socket()
>>> s.bind(("", 1234))
>>> s.listen(10)
>>> print s._sock._accept_queue
[]
>>> _
```

```
>>> s = socket.socket()
>>> s.bind(("", 1234))
>>> s.listen(10)
>>> print s._sock._accept_queue
[]
>>> select.select([s],[],[])

_
```

```
$ telnet localhost 1234
Trying ::1...
Trying 127.0.0.1...
Connected to localhost.
Escape character is '^]'.
```

```
>>> s = socket.socket()
>>> s.bind(("", 1234))
>>> s.listen(10)
>>> print s._sock._accept_queue
[]
>>> select.select([s],[],[])
([<socket._socketobject object at 0x7a1d7e50>], [], [])
>>> _
```

```
>>> s = socket.socket()
>>> s.bind(("", 1234))
>>> s.listen(10)
>>> print s._sock._accept_queue
[]
>>> select.select([s],[],[])
([<socket._socketobject object at 0x7a1d7e50>], [], [])
>>> print s._sock._accept_queue
[(True, 2134465624)]
>>> s2, addr = s.accept()
>>> print addr
('10.0.2.2', 57348)
>>> _
```

```
>>> s = socket.socket()
>>> s.bind(("", 1234))
>>> s.listen(10)
>>> print s._sock._accept_queue
[]
>>> select.select([s],[],[])
([<socket._socketobject object at 0x7a1d7e50>], [], [])
>>> print s._sock._accept_queue
[(True, 2134465624)]
>>> s2, addr = s.accept()
>>> print addr
('10.0.2.2', 57348)
>>> print s._sock._accept_queue
[]
>>> _
```

```
>>> s = socket.socket()
>>> s.bind(("", 1234))
>>> s.listen(10)
>>> print s._sock._accept_queue
[]
>>> select.select([s],[],[])
([<socket._socketobject object at 0x7a1d7e50>], [], [])
>>> print s._sock._accept_queue
[(True, 2134465624)]
>>> s2, addr = s.accept()
>>> print addr
('10.0.2.2', 57348)
>>> print s._sock._accept_queue
[]
>>> data = s2.recv(4096)
_
```

```
$ telnet localhost 1234
Trying ::1...
Trying 127.0.0.1...
Connected to localhost.
Escape character is '^]'.
Hello from the outside world!
```

```
>>> s = socket.socket()
>>> s.bind(("", 1234))
>>> s.listen(10)
>>> print s._sock._accept_queue
[]
>>> select.select([s],[],[])
([<socket._socketobject object at 0x7a1d7e50>], [], [])
>>> print s._sock._accept_queue
[(True, 2134465624)]
>>> s2, addr = s.accept()
>>> print addr
('10.0.2.2', 57348)
>>> print s._sock._accept_queue
[]
>>> data = s2.recv(4096)
>>> s2.sendall(data.upper())
>>> _
```

```
$ telnet localhost 1234
Trying ::1...
Trying 127.0.0.1...
Connected to localhost.
Escape character is '^]'.
Hello from the outside world!
HELLO FROM THE OUTSIDE WORLD!
```

```
>>> print urllib2.urlopen("http://10.0.2.2:8080/hello").read()
Hello world!

>>> _
```

```
>>> print urllib2.urlopen("http://10.0.2.2:8080/hello").read()
Hello world!

>>> post = urllib2.urlopen("http://10.0.2.2:8080/post").read()
>>> _
```

```
>>> print urllib2.urlopen("http://10.0.2.2:8080/hello").read()
Hello world!

>>> post = urllib2.urlopen("http://10.0.2.2:8080/post").read()
>>> print post
#!/usr/bin/python
import BaseHTTPServer

class RequestHandler(BaseHTTPServer.BaseHTTPRequestHandler):
    def do_POST(self):
        l = int(self.headers.get("Content-Length", "-1"))
        data = self.rfile.read(l)
        self.send_response(200)
        print "POST to {}:\n{}".format(self.path, data)

BaseHTTPServer.test(RequestHandler)

>>> _
```

```
$ (cd test ; ./post 8080)
Serving HTTP on 0.0.0.0 port 8080 ...
```

```
>>> print urllib2.urlopen("http://10.0.2.2:8080/hello").read()
Hello world!

>>> post = urllib2.urlopen("http://10.0.2.2:8080/post").read()
>>> print post
#!/usr/bin/python
import BaseHTTPServer

class RequestHandler(BaseHTTPServer.BaseHTTPRequestHandler):
    def do_POST(self):
        l = int(self.headers.get("Content-Length", "-1"))
        data = self.rfile.read(l)
        self.send_response(200)
        print "POST to {}:\n{}".format(self.path, data)

BaseHTTPServer.test(RequestHandler)

>>> print urllib2.urlopen("http://10.0.2.2:8080/post", "Long log data here").re
ad()
>>> _
```

```
$ (cd test ; ./post 8080)
Serving HTTP on 0.0.0.0 port 8080 ...
127.0.0.1 - - [30/May/2016 00:19:52] "POST /post HTTP/1.1" 20
0 -
POST to /post:
Long log data here
```

```
class RequestHandler(BaseHTTPServer.BaseHTTPRequestHandler):
    def do_POST(self):
        l = int(self.headers.get("Content-Length", "-1"))
        data = self.rfile.read(l)
        self.send_response(200)
        print "POST to {}:\n{}".format(self.path, data)

BaseHTTPServer.test(RequestHandler)

>>> print urllib2.urlopen("http://10.0.2.2:8080/post", "Long log data here").re
ad()
>>> import bits
>>> data = "\n".join(["{} {}".format(i, bits.cpuid(0,i)) for i in range(10)])
>>> print data
0 cpuid_result(eax=0x0000000d, ebx=0x756e6547, ecx=0x6c65746e, edx=0x49656e69)
1 cpuid_result(eax=0x00000663, ebx=0x00000800, ecx=0x80202001, edx=0x078bfbfd)
2 cpuid_result(eax=0x00000001, ebx=0x00000000, ecx=0x00000000, edx=0x002c307d)
3 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000, edx=0x00000000)
4 cpuid_result(eax=0x00000121, ebx=0x01c0003f, ecx=0x0000003f, edx=0x00000001)
5 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000003, edx=0x00000000)
6 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000, edx=0x00000000)
7 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000, edx=0x00000000)
8 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000, edx=0x00000000)
9 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000, edx=0x00000000)
>>> _
```

```
        l = int(self.headers.get("Content-Length", "-1"))
        data = self.rfile.read(l)
        self.send_response(200)
        print "POST to {}:\n{}".format(self.path, data)

BaseHTTPServer.test(RequestHandler)

>>> print urllib2.urlopen("http://10.0.2.2:8080/post", "Long log data here").re
ad()
>>> import bits
>>> data = "\n".join(["{} {}".format(i, bits.cpuid(0,i)) for i in range(10)])
>>> print data
0 cpuid_result(eax=0x0000000d, ebx=0x756e6547, ecx=0x6c65746e, edx=0x49656e69)
1 cpuid_result(eax=0x00000663, ebx=0x00000800, ecx=0x80202001, edx=0x078bfbfd)
2 cpuid_result(eax=0x00000001, ebx=0x00000000, ecx=0x00000000, edx=0x002c307d)
3 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000, edx=0x00000000)
4 cpuid_result(eax=0x00000121, ebx=0x01c0003f, ecx=0x0000003f, edx=0x00000001)
5 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000003, edx=0x00000000)
6 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000, edx=0x00000000)
7 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000, edx=0x00000000)
8 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000, edx=0x00000000)
9 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000, edx=0x00000000)
>>> print urllib2.urlopen("http://10.0.2.2:8080/post", data).read()

>>> _
```

```
POST to /post:
0 cpuid_result(eax=0x0000000d, ebx=0x756e6547, ecx=0x6c65746e
, edx=0x49656e69)
1 cpuid_result(eax=0x00000663, ebx=0x00000800, ecx=0x80202001
, edx=0x078bfbfd)
2 cpuid_result(eax=0x00000001, ebx=0x00000000, ecx=0x00000000
, edx=0x002c307d)
3 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000
, edx=0x00000000)
4 cpuid_result(eax=0x00000121, ebx=0x01c0003f, ecx=0x0000003f
, edx=0x00000001)
5 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000003
, edx=0x00000000)
6 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000
, edx=0x00000000)
7 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000
, edx=0x00000000)
8 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000
, edx=0x00000000)
9 cpuid_result(eax=0x00000000, ebx=0x00000000, ecx=0x00000000
, edx=0x00000000)
```

```
>>> print post
#!/usr/bin/python
import BaseHTTPServer

class RequestHandler(BaseHTTPServer.BaseHTTPRequestHandler):
    def do_POST(self):
        l = int(self.headers.get("Content-Length", "-1"))
        data = self.rfile.read(l)
        self.send_response(200)
        print "POST to {}:\n{}".format(self.path, data)

BaseHTTPServer.test(RequestHandler)

>>> exec post
Serving HTTP on 10.0.2.15 port 8000 ...
_
```

```
$ curl http://localhost:8000/path -d 'Test data'
$
```

```
>>> print post
#!/usr/bin/python
import BaseHTTPServer

class RequestHandler(BaseHTTPServer.BaseHTTPRequestHandler):
    def do_POST(self):
        l = int(self.headers.get("Content-Length", "-1"))
        data = self.rfile.read(l)
        self.send_response(200)
        print "POST to {}:\n{}".format(self.path, data)

BaseHTTPServer.test(RequestHandler)

>>> exec post
Serving HTTP on 10.0.2.15 port 8000 ...
10.0.2.2 - - [25/May/1970 02:43:33] "POST /path HTTP/1.1" 200 -
POST to /path:
Test data

_
```