Memory Forensics

Part I

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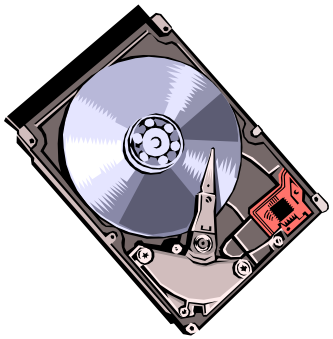
“Prerequisites”

- For memory forensics, strong skills in all of these areas
- "Learn on the job" as necessary

Traditional Digital Forensics	**OS Internals**	**Data Structures**
C	**Assembler**	**Python** 😐

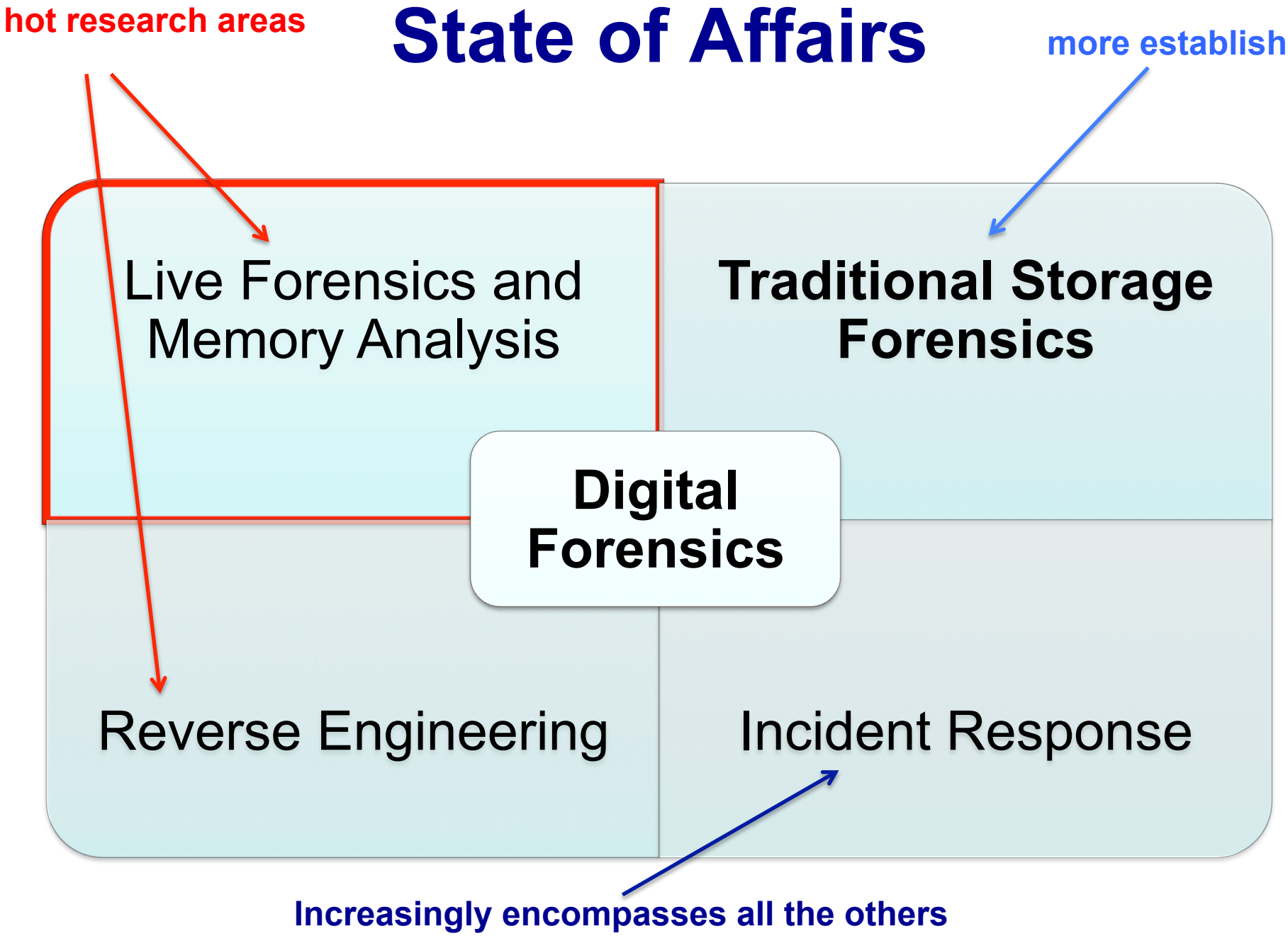
Digital Forensics



Definition: "Tools and techniques to recover, preserve, and examine digital evidence stored on or transmitted by digital devices."

Computers, PDAs, cell phones, videogame consoles, digital cameras, copy machines, printers, digital voice recorders…

State of Affairs



Where's the Evidence?

Files and Deleted Files	Filesystem metadata	Application metadata	Windows registry
Print spool files	Hibernation files	Temp files	Log files
Slack space	Swap files	Browser caches	Network traces

RAM: OS and app data structures

Some Data is Only in RAM

Clipboard data

Volatile registry branches

Network connections

Running processes

Open files

Encryption keys

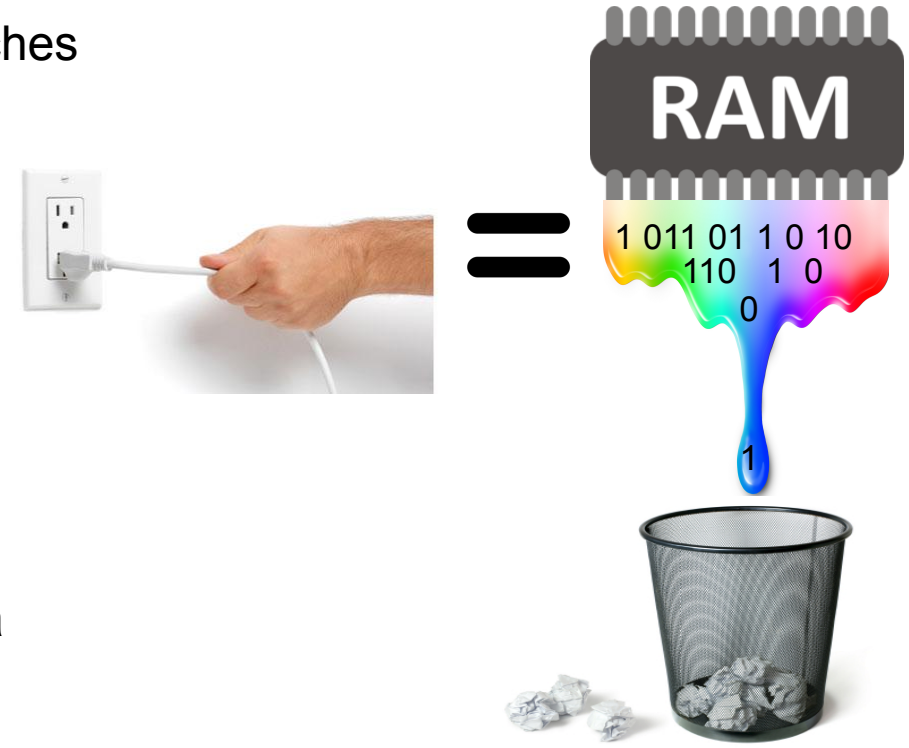
Private browsing data

Kernel structures

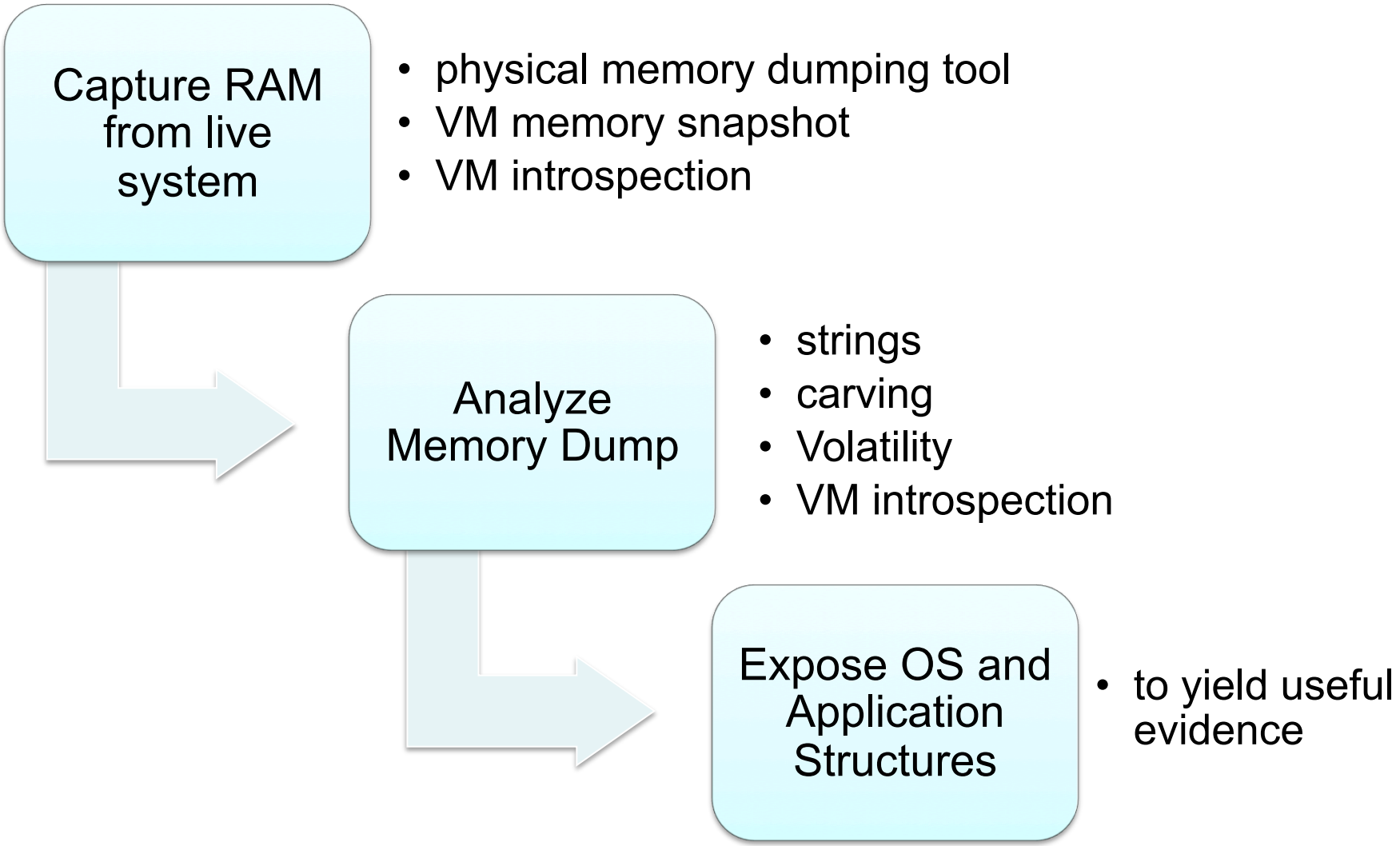
Application structures

…

…



Memory Analysis



Physical Memory Dumps

- Essentially, a complete copy of RAM
- A collection of pages (4K on Intel)
- Must impose order—otherwise, essentially a random set of 4K chunks

Memory Analysis / Live Forensics

- Live forensics
  - Analysis on the box (while live)
  - Run commands (e.g., ps)
  - Record results
- Memory Analysis aka Memory Forensics
  - Capture memory dump
  - Analyze using:
    - List following techniques
    - Carving techniques
    - Hybrid approaches
- Sometimes both

Memory Analysis: Then

- `strings` (since dinosaurs roamed)
  - seriously—essentially no tools, circa 2004
- `pt_finder` (~2006)
  - Windows process enumeration
- FACE (~2008)
  - Memory analysis framework created at UNO
- …

Memory Analysis: 2004

```
$ grep -i murder /dev/mem
```

```
I loved Sally, but I murdered her in
the park on…
Murder
murder
Murderous
You murdered my hamster!
Murdered
```

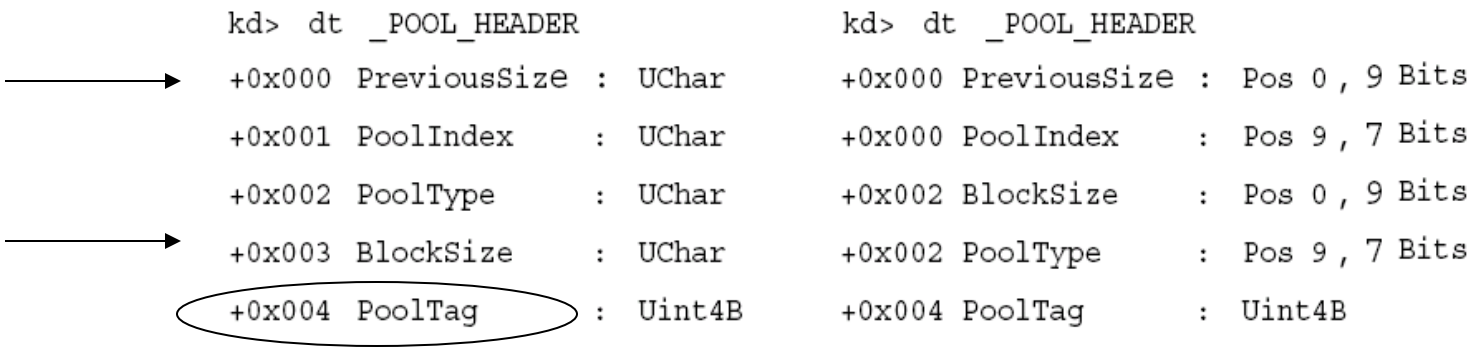
`pt_finder`: Andreas Schuster's Approach

- Scan memory to find kernel structures describing processes and threads
  - Normal
  - Hidden
  - **Terminated**
- Don't rely on kernel lists/tables
- Instead, search memory dump for objects that **look like** processes/threads

Schuster (2)

- Important ideas:
  - Memory is needed to store kernel objects
    - Use info about how kernel performs allocation to find blocks of allocated memory
  - Kernel objects have an OBJECT_HEADER structure
  - Further, processes and threads have a DISPATCH_HEADER, used for scheduling/ synchronization
- Use these ideas to develop templates for discovering interesting structures in a Windows memory dump
- Walk memory dump in 4K steps

Schuster: POOL_TAG



```
kd> dt _POOL_HEADER                          kd> dt _POOL_HEADER
+0x000 PreviousSize : UChar                  +0x000 PreviousSize : Pos 0, 9 Bits
+0x001 PoolIndex    : UChar                  +0x000 PoolIndex    : Pos 9, 7 Bits
+0x002 PoolType     : UChar                  +0x002 BlockSize    : Pos 0, 9 Bits
+0x003 BlockSize    : UChar                  +0x002 PoolType     : Pos 9, 7 Bits
+0x004 PoolTag      : Uint4B                 +0x004 PoolTag      : Uint4B
```

Fig. 1 – Definitions of the POOL_HEADER structure in Windows 2000 (left) and later versions (right).

PoolTag == 0xe36f7250 for processes
PoolTag == 0xe5726854 for threads

Schuster: OBJECT_HEADER

Known values for live/dead processes and threads!


```
kd> dt_OBJECT_HEADER
+0x000 PointerCount        : Int4B
+0x004 HandleCount         : Int4B
+0x004 SEntry              : Ptr32
+0x008 Type                : Ptr32
+0x00c NameInfoOffset      : UChar
+0x00d HandleInfoOffset    : UChar
+0x00e QuotaInfoOffset     : UChar
+0x00f Flags               : UChar
+0x010 ObjectCreateInfo    : Ptr32
+0x010 QuotaBlockCharged   : Ptr32
+0x014 SecurityDescriptor  : Ptr32
```

Fig. 2 – The OBJECT_HEADER structure provides information about an object's instance.

Also know information about lengths associated with name.

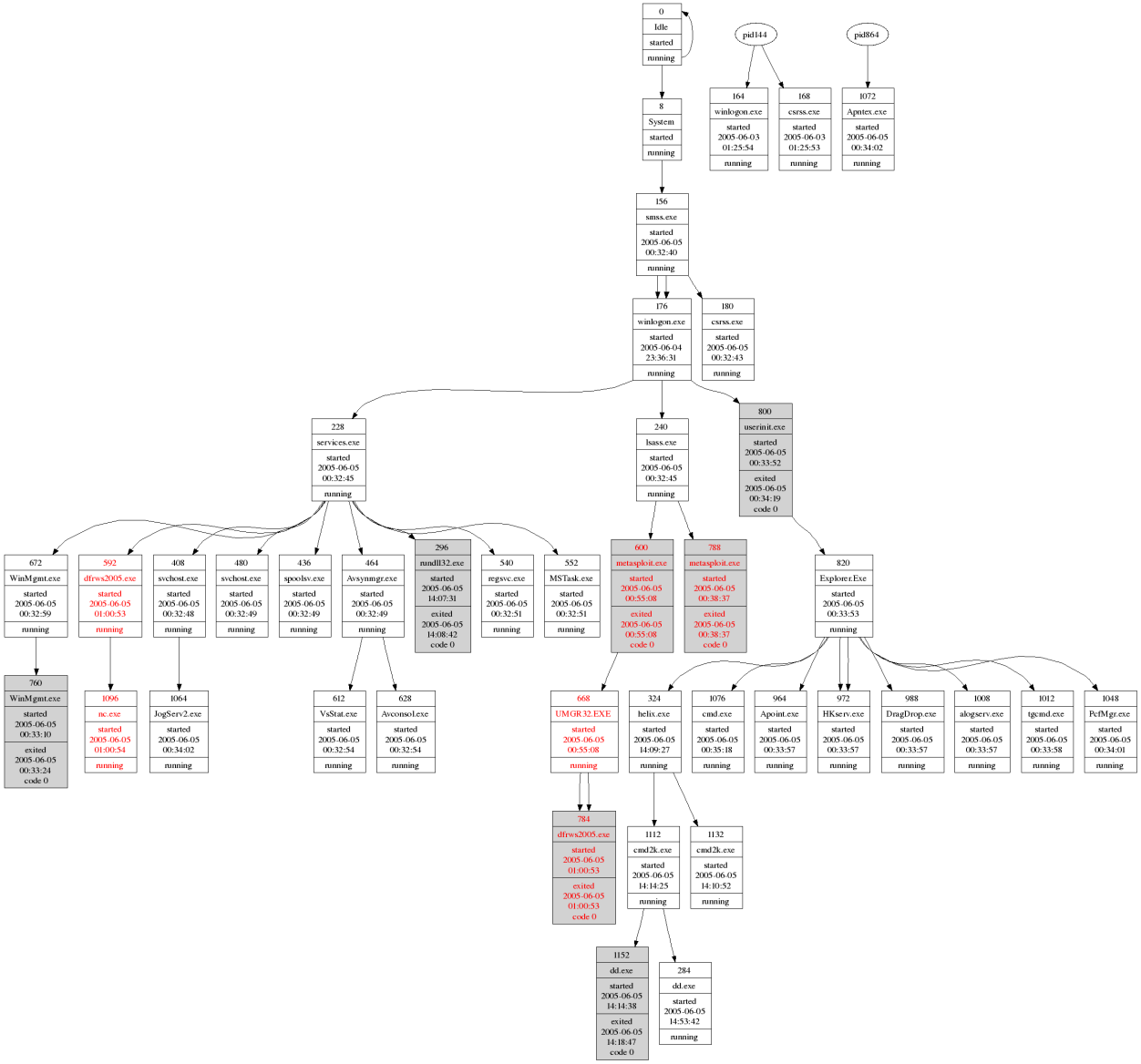
Schuster: Additional Tests

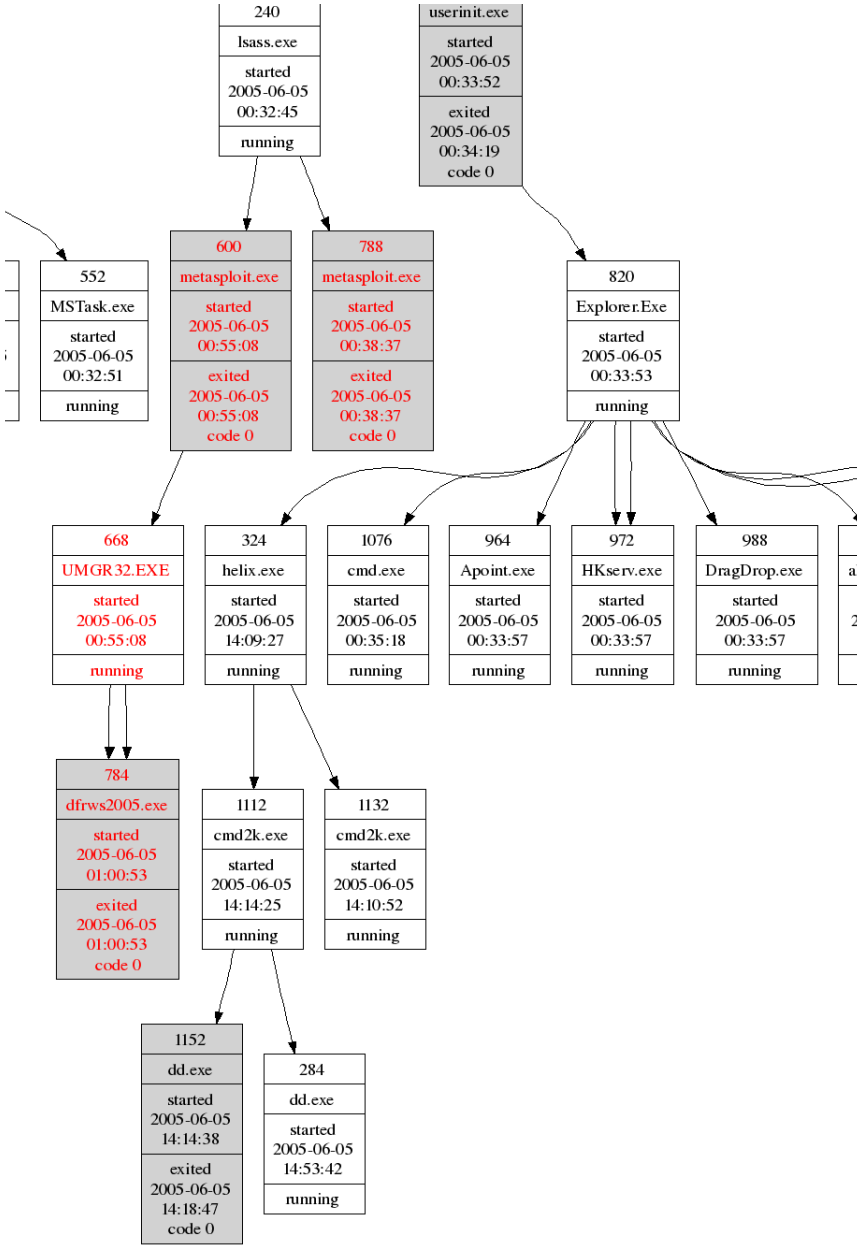
- Know some characteristics of DISPATCH_HEADER
- Know some characteristics of ETHREAD structures (e.g., pointers to owning process, DISPATCH_HEADER w/ type thread, …)

For a certain Windows version, size field is constant for a particular object type.

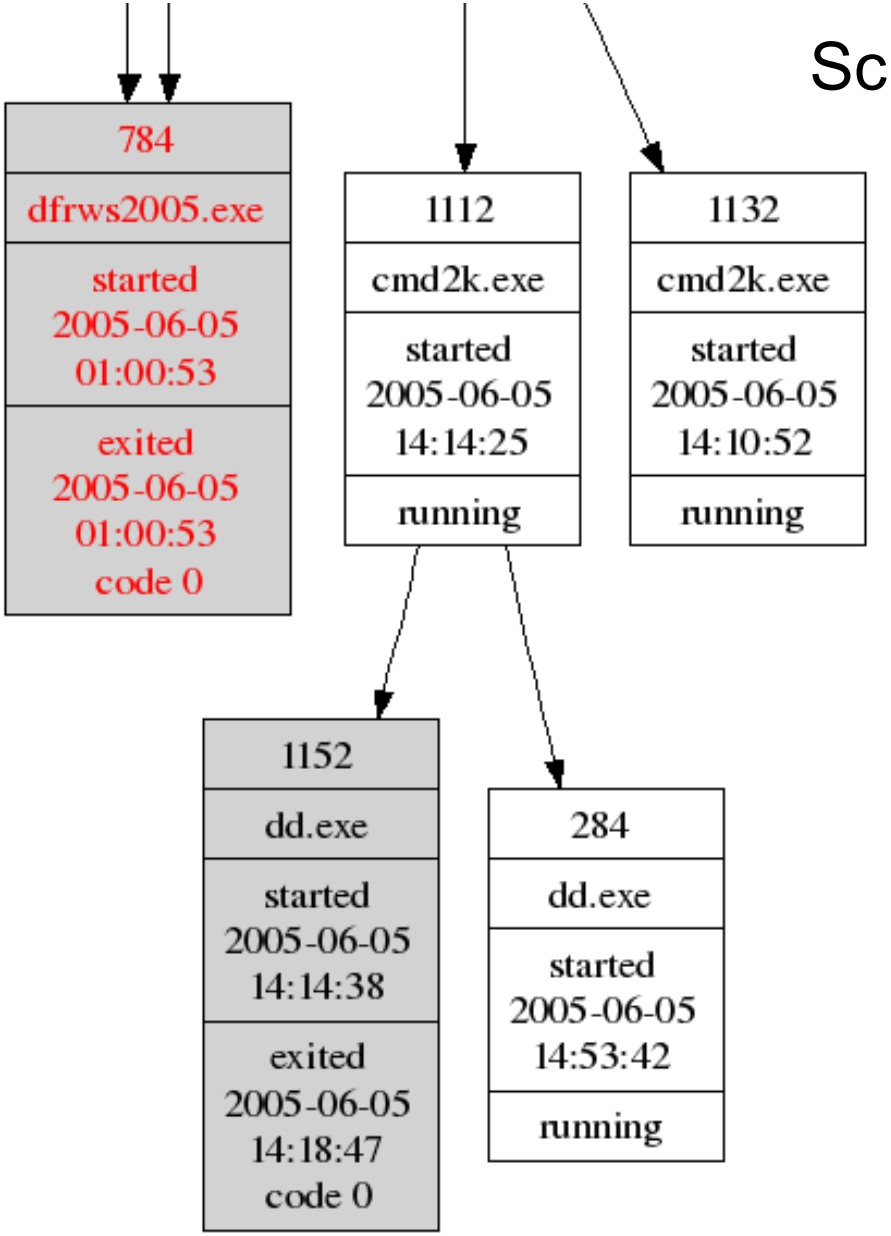
Schuster: Results

- Perl-based PTFinder
- Visualization using Graphviz

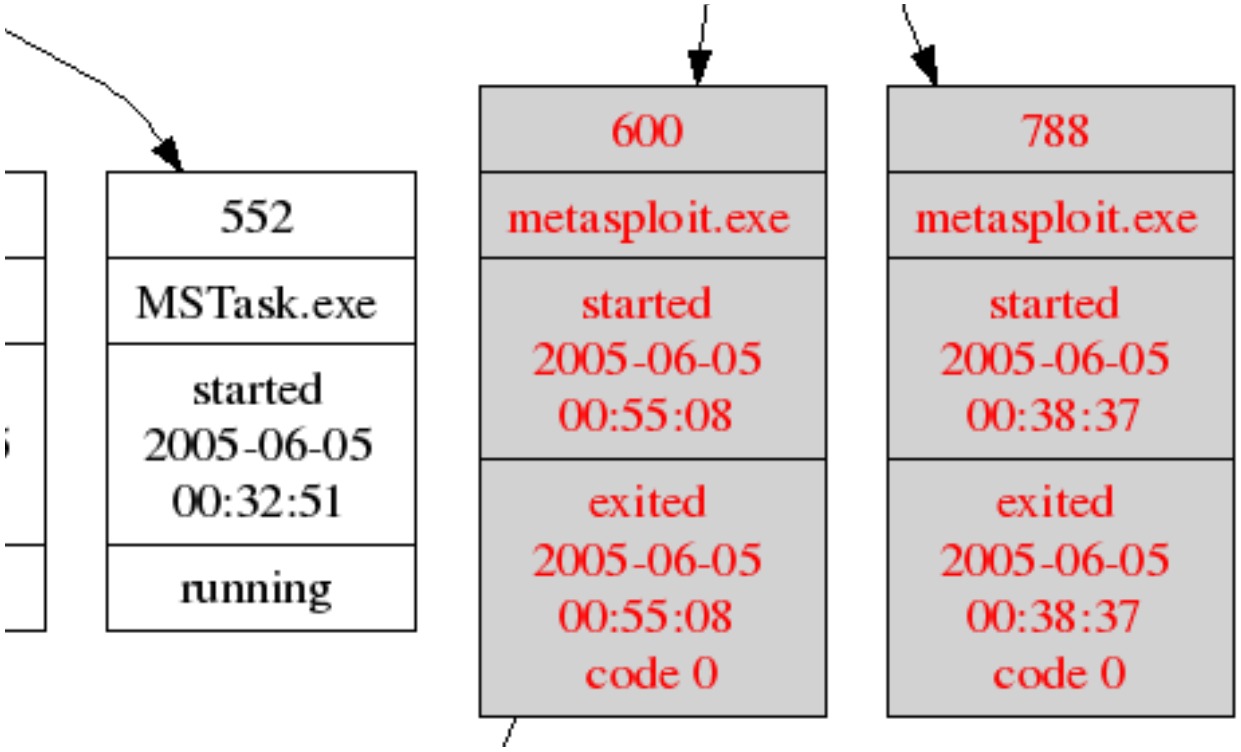




Schuster's PTfinder



Schuster's PTfinder



FACE: Linux Memory Analysis

- Andrew Case, Andrew Cristina, Lodovico Marziale, Golden G. Richard III, and Vassil Roussev. "**FACE: Automated Digital Evidence Discovery and Correlation.**" Digital Investigation 5 (2008): S65-S75. Deep kernel structures analysis
- Correlation between network traces, filesystem, log files, and physical memory dumps
- A step closer to frameworks, rather than "one off" tools

FACE: ps on Memory Dump

 # ./ramparser debian.vmem –x

```
  PID      UID    GID     NAME
    1      0      0       init
    2      0      0       migration/0
    3      0      0       ksoftirqd/0
    4      0      0       watchdog/0
    5      0      0       migration/1
    6      0      0       ksoftirqd/1
                  …
                  …
 2425      0     43       xterm
 2426      0      0       bash
 2515      0      0       pdflush
 2521      0      0       firefox-bin
 2548      0      0       ftp
```

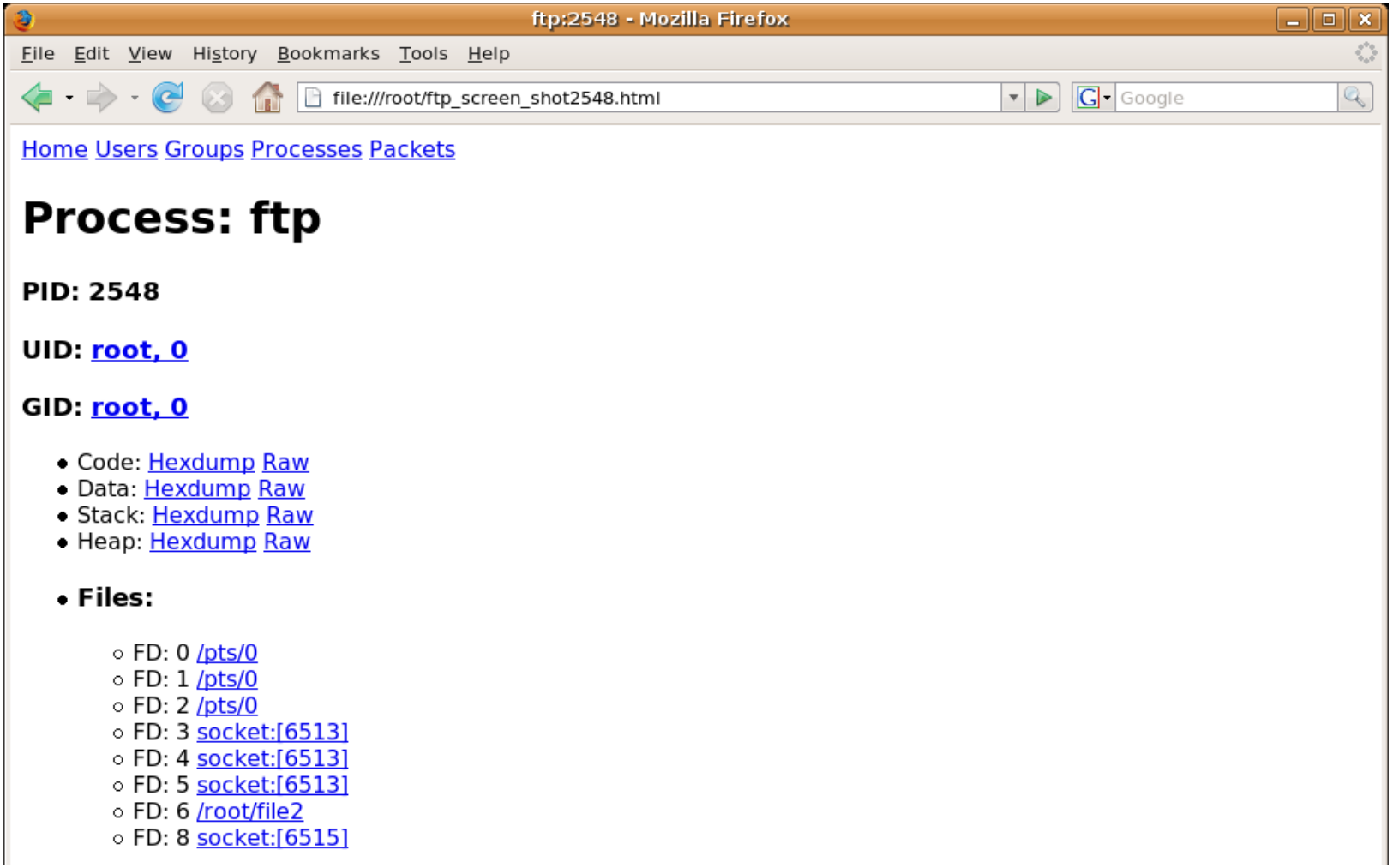
FACE: netstat on Memory Dump

 # ./ramparser debian.vmem –N | sort

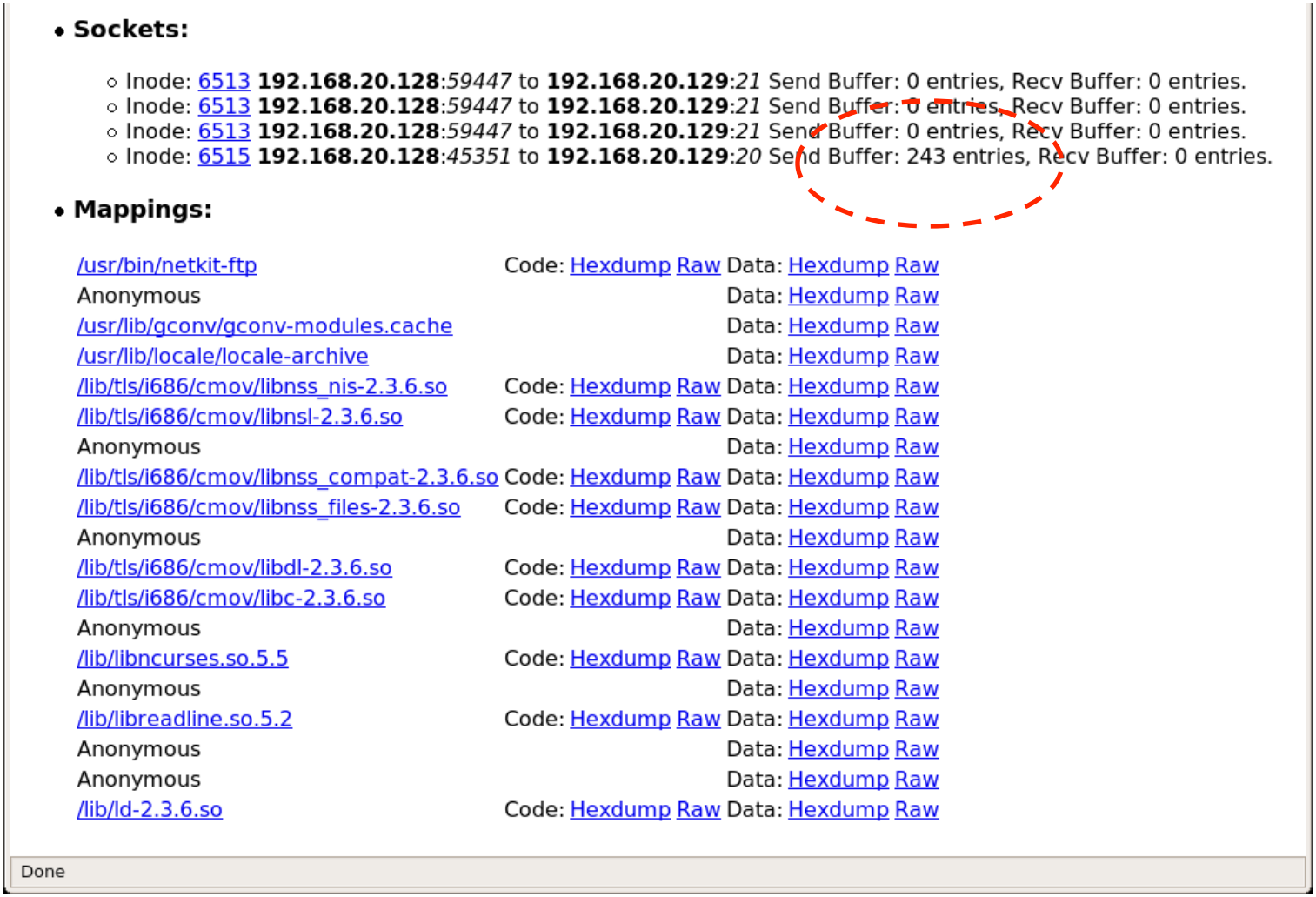
```
Proto      Local Address           Foreign Address         State           PID   Program name
TCP        192.168.20.128:45351    192.168.20.129:20       ESTABLISHED     2548  ftp
TCP        192.168.20.128:55071    192.168.20.129:80       ESTABLISHED     2521  firefox-bin
TCP        192.168.20.128:59447    192.168.20.129:21       ESTABLISHED     2548  ftp
TCP        192.168.20.128:59447    192.168.20.129:21       ESTABLISHED     2548  ftp
TCP        192.168.20.128:59447    192.168.20.129:21       ESTABLISHED     2548  ftp
UDP        0.0.0.0:111             0.0.0.0:0                               1959  portmap
UDP        0.0.0.0:32768           0.0.0.0:0                               2332  rpc.statd
UDP        0.0.0.0:68              0.0.0.0:0                               2301  dhclient3
UDP        0.0.0.0:812             0.0.0.0:0                               2332  rpc.statd
                                        ...
                                        ...
                                        ...

UNIX       /tmp/.X11-unix/X0                                               2417  Xorg
UNIX       /tmp/.X11-unix/X0                                               2417  Xorg
UNIX       /tmp/.X11-unix/X0                                               2417  Xorg
                                        ...
                                        ...
                                        ...
```

FACE: Deep Process Analysis (1)



FACE: Deep Process Analysis (2)



- **Sockets:**
  - Inode: 6513 **192.168.20.128**:*59447* to **192.168.20.129**:*21* Send Buffer: 0 entries, Recv Buffer: 0 entries.
  - Inode: 6513 **192.168.20.128**:*59447* to **192.168.20.129**:*21* Send Buffer: 0 entries, Recv Buffer: 0 entries.
  - Inode: 6513 **192.168.20.128**:*59447* to **192.168.20.129**:*21* Send Buffer: 0 entries, Recv Buffer: 0 entries.
  - Inode: 6515 **192.168.20.128**:*45351* to **192.168.20.129**:*20* Send Buffer: 243 entries, Recv Buffer: 0 entries.
- **Mappings:**

/usr/bin/netkit-ftp	Code: Hexdump Raw	Data: Hexdump Raw
Anonymous		Data: Hexdump Raw
/usr/lib/gconv/gconv-modules.cache		Data: Hexdump Raw
/usr/lib/locale/locale-archive		Data: Hexdump Raw
/lib/tls/i686/cmov/libnss_nis-2.3.6.so	Code: Hexdump Raw	Data: Hexdump Raw
/lib/tls/i686/cmov/libnsl-2.3.6.so	Code: Hexdump Raw	Data: Hexdump Raw
Anonymous		Data: Hexdump Raw
/lib/tls/i686/cmov/libnss_compat-2.3.6.so	Code: Hexdump Raw	Data: Hexdump Raw
/lib/tls/i686/cmov/libnss_files-2.3.6.so	Code: Hexdump Raw	Data: Hexdump Raw
Anonymous		Data: Hexdump Raw
/lib/tls/i686/cmov/libdl-2.3.6.so	Code: Hexdump Raw	Data: Hexdump Raw
/lib/tls/i686/cmov/libc-2.3.6.so	Code: Hexdump Raw	Data: Hexdump Raw
Anonymous		Data: Hexdump Raw
/lib/libncurses.so.5.5	Code: Hexdump Raw	Data: Hexdump Raw
Anonymous		Data: Hexdump Raw
/lib/libreadline.so.5.2	Code: Hexdump Raw	Data: Hexdump Raw
Anonymous		Data: Hexdump Raw
Anonymous		Data: Hexdump Raw
/lib/ld-2.3.6.so	Code: Hexdump Raw	Data: Hexdump Raw

Done

FACE: Socket Buffer Dumps

```
# ./ramparser debian.vmem -k 2548
# ls socks
socket0   socket15  socket21  socket28
socket34  socket40  socket47  socket53
socket1   socket16  socket22  socket29
socket54  socket60  socket67  socket73
…
# head socks/socket28
aplacental
aplanatic
aplanospore
aplasia
aplastic
aplenty
aplite
aplomb
apnoea
```

/usr/dict/words was being transmitted

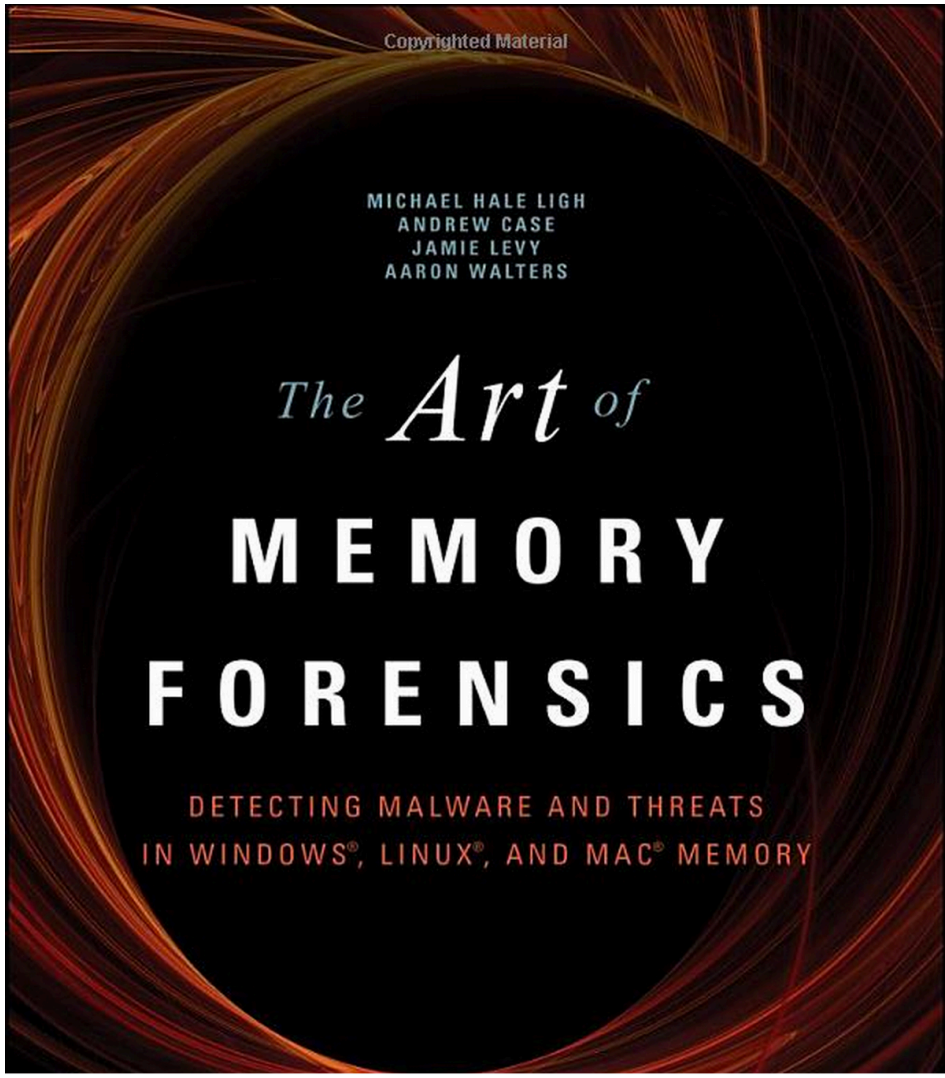
Volatility Framework

- **Now, most work done with a physical memory dump tool + Volatility**
- Most popular memory analysis framework
- Completely open source
- Portable, written in Python 😐
- Supports analysis of Windows, Linux, Mac, Android memory dumps
- Plugins add new functionality, build on vast amount of research that's already been done
- Lots of existing plugins, fairly straightforward to add new ones

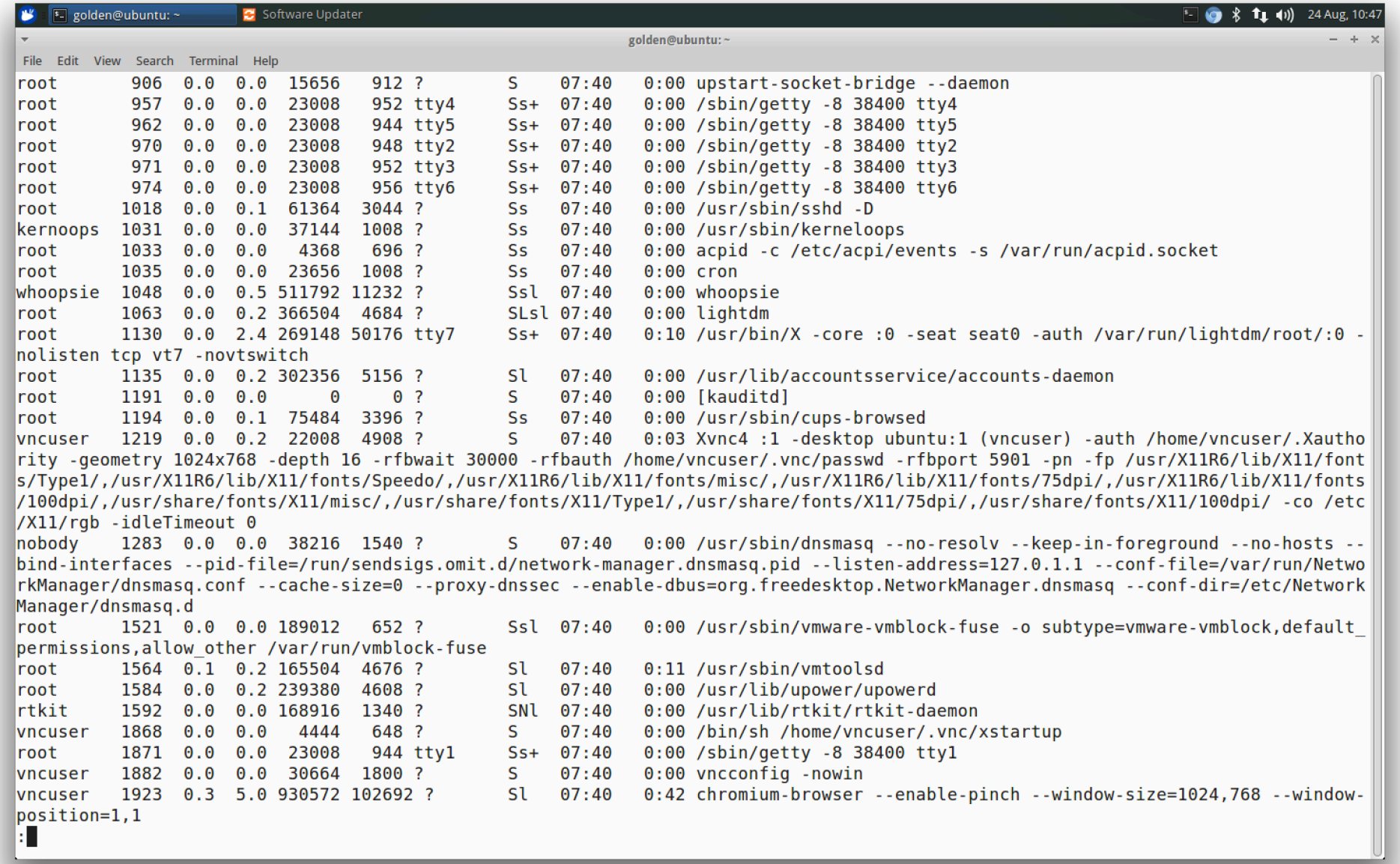
Memory Analysis: Now

Use plugins to analyze:

- Running processes
- Hidden processes
- Hooks that hide malware
- Network connections
- Encryption keys
- Private browsing data
- Clipboard data
- Volatile registry branches
- Command history
- Window hierarchy
- + "easily" develop plugins



ps aux on Ubuntu 14.04



python vol.py linux_pslist

```
0xffff880036b85fc0 upstart-socket-      906          0            0      0x000000006e2ff000 0
0xffff8800798d17f0 getty                957          0            0      0x000000006e30c000 0
0xffff880079c70000 getty                962          0            0      0x000000006e37f000 0
0xffff88006d9047d0 getty                970          0            0      0x000000006c447000 0
0xffff88006d9017f0 getty                971          0            0      0x000000006c455000 0
0xffff88006e3297f0 getty                974          0            0      0x0000000079e82000 0
0xffff88006c6d5fc0 sshd                 1018         0            0      0x000000006dbf3000 0
0xffff88006e2d0000 kerneloops           1031         106          4      0x0000000079eca000 0
0xffff88006d87c7d0 acpid                1033         0            0      0x000000006c51f000 0
0xffff88006c6e47d0 cron                 1035         0            0      0x000000006dbce000 0
0xffff88006d888000 whoopsie             1048         109          116    0x000000006c70b000 0
0xffff88006c6d0000 lightdm              1063         0            0      0x000000006dbf8000 0
0xffff88006c6d47d0 Xorg                 1130         0            0      0x000000006c5fe000 0
0xffff88006b8147d0 accounts-daemon      1135         0            0      0x000000006c79e000 0
0xffff880079c72fe0 kauditd              1191         0            0      ------------------ 0
0xffff88006c5c8000 cups-browsed         1194         0            0      0x000000006b8e9000 0
0xffff88006c5cc7d0 Xvnc4                1219         1001         1001   0x000000006d83a000 0
0xffff88006b815fc0 dnsmasq              1283         65534        30     0x000000006c792000 0
0xffff88006ba6c7d0 vmware-vmblock-      1521         0            0      0x000000006ba78000 0
0xffff8800669e97f0 vmtoolsd             1564         0            0      0x000000006bbb4000 0
0xffff880066b2c7d0 upowerd              1584         0            0      0x0000000066699a000 0
0xffff8800669990000 rtkit-daemon        1592         107          114    0x000000006bae3000 0
0xffff8800668e47d0 xstartup             1868         1001         1001   0x0000000079f8d000 0
0xffff88006b93c7d0 getty                1871         0            0      0x000000006c613000 0
0xffff88007a7e5fc0 vncconfig            1882         1001         1001   0x000000006c6b7000 0
0xffff880066b7c7d0 chromium-browse      1923         1001         1001   0x0000000007a6b9000 0
0xffff880066bc2fe0 chromium-browse      1936         1001         1001   0x000000006c74c000 0
0xffff880066bc17f0 chrome-sandbox       1937         1001         1001   0x0000000079fe6000 0
0xffff880066bc47d0 chromium-browse      1939         1001         1001   0x0000000066a37000 0
0xffff880079810000 chromium-browse      1944         1001         1001   0x000000006c7c0000 0
0xffff88005b50dfc0 dbus-launch          1983         1001         1001   0x000000005b471000 0
0xffff88005fecdfc0 dbus-daemon          1984         1001         1001   0x000000005b48f000 0
0xffff88006d88c7d0 lightdm              2135         0            0      0x0000000066b58000 0
0xffff88006b9c5fc0 colord               2154         113          121    0x0000000066b60000 0
0xffff88005b5d17f0 gnome-keyring-d      2218         1000         1000   0x000000006bb4d000 0
0xffff880066a497f0 init                 2220         1000         1000   0x0000000036e55000 0
0xffff8800668e0000 ssh-agent            2337         1000         1000   0x0000000036c5e000 0
0xffff880066b78000 dbus-daemon          2339         1000         1000   0x0000000066835000 0
```

Installing Volatility: Linux

This recipe for installing Volatility is for Ubuntu or other Debian-based Linux distros:

```
$ sudo apt-get install build-essential -y
$ sudo apt-get install linux-headers-$(uname -r)
$ cd /usr/src
$ sudo apt-get source linux-image-$(uname -r)
$ sudo apt-get install git subversion pcregrep libpcre++-dev -y
$ sudo apt-get install python-dev -y
$ sudo apt-get install dwarfdump -y
```

Installing Volatility: Linux (2)

```
$ git clone
https://github.com/gdabah/distorm.git
$ cd distorm3
$ python setup.py build
$ sudo python setup.py build install
$ cd
```

distorm is a disassembler library

Installing Volatility: Linux (3)

Pattern matching framework

```
$ sudo apt-get install yara python-yara -y
```

```
$ wget
https://ftp.dlitz.net/pub/dlitz/crypto/pycrypto/
pycrypto-2.6.1.tar.gz
$ tar -xvzf pycrypto-2.6.1.tar.gz
$ cd pycrypto-2.6.1
$ python setup.py build
$ sudo python setup.py build install
```

Python crypto framework

Grab latest release of Volatility

```
$ cd
$ git clone
https://github.com/volatilityfoundation/volatility.git
```

```
$ cd volatility
$ python setup.py build
$ python vol.py --info
```

Preliminary setup
and then sanity check

Installing Volatility: Linux (4)

```
$ cd ~/volatility
$ git pull
```

Stay up to date with latest Volatility patches and enhancements
(do this periodically)

Installing Volatility: Mac OS X

First install **macports** via https://guide.macports.org/chunked/installing.macports.html . It's the best way to install Unix packages on Mac OS X. Then:

```
$ sudo port install gmp
```

Install `pip` by:

Downloading and saving `get-ip.py` via https://bootstrap.pypa.io/get-pip.py

```
$ sudo python get-pip.py
```

Then install pycrypto:

```
$ARCHFLAGS=-Wno-error CFLAGS=-I/opt/local/include sudo -E pip
  install pycrypto
```

Installing Volatility: Mac OS X (2)

Next install distorm by downloading **distorm3.zip** from https://code.google.com/p/distorm/downloads/list

Then:

```
$ unzip distorm3.zip
$ cd distorm3
$ ARCHFLAGS=-Wno-error CFLAGS=-I/opt/local/include sudo -E
python setup.py build
$ ARCHFLAGS=-Wno-error CFLAGS=-I/opt/local/include sudo -E
python setup.py install
$ cd
```

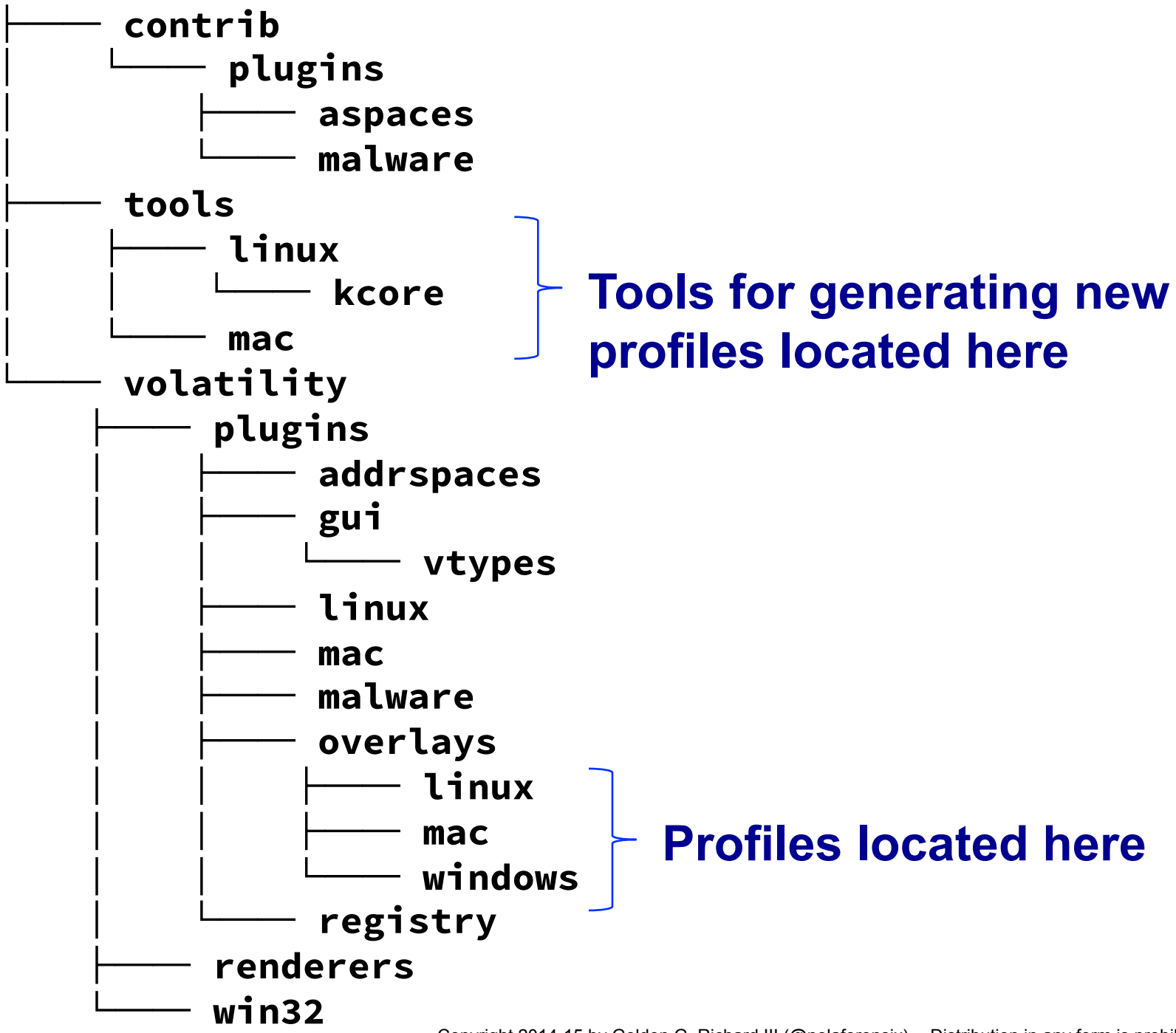
Installing Volatility: Mac OS X (3)

Finally, install yara and python-yara (which rely on libtoolize, et al for configuration, thus the extra steps):

```
$ cd
$ sudo port install libtool
$ sudo port install automake
$ sudo port install autoconf
$ git clone https://github.com/plusvic/yara.git
```

Then:

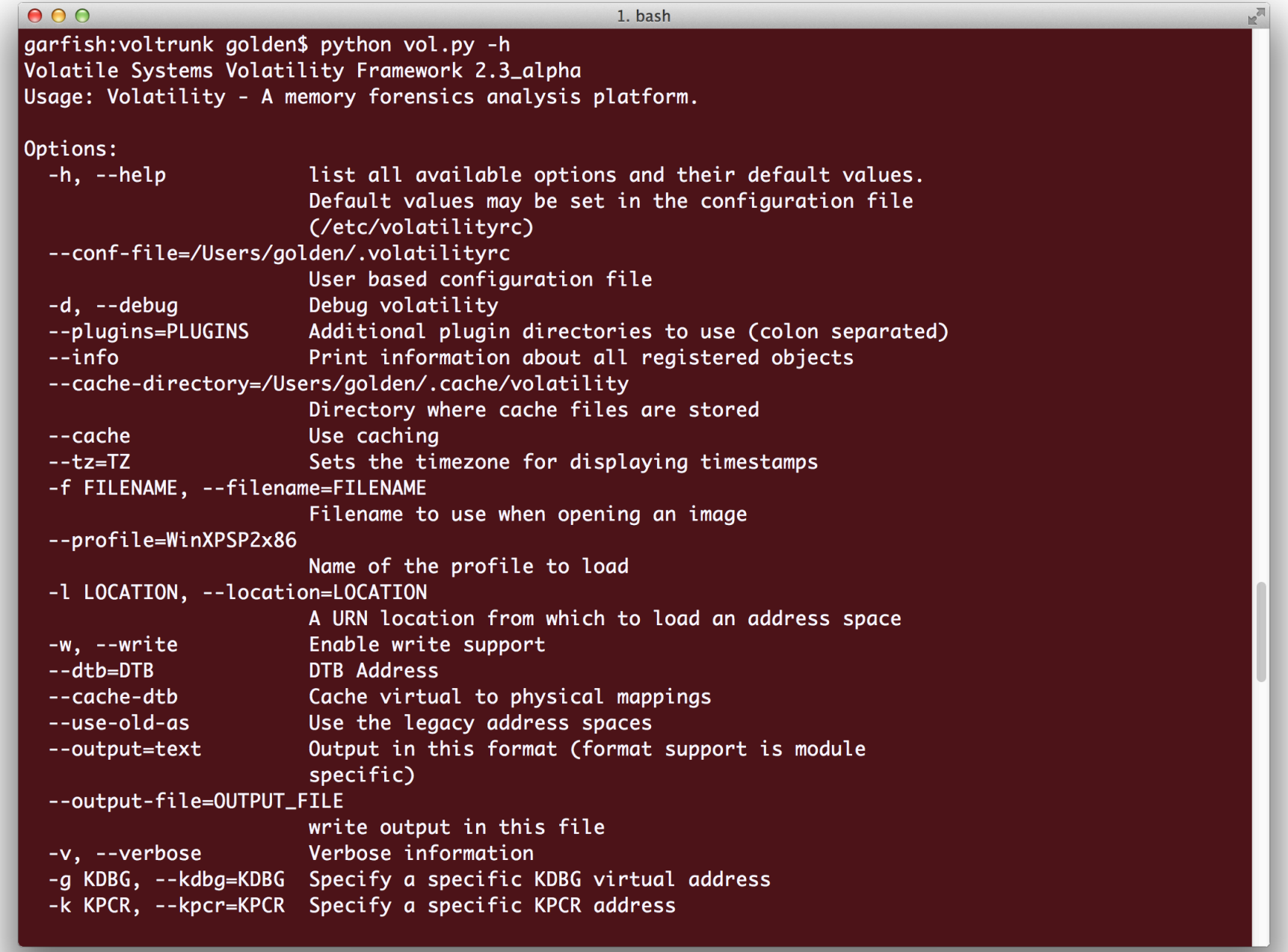
```
$ cd yara
$ ./bootstrap.sh
$ ./configure
$ sudo make install
$ cd yara-python
$ python setup.py build
$ sudo python setup.py install
```

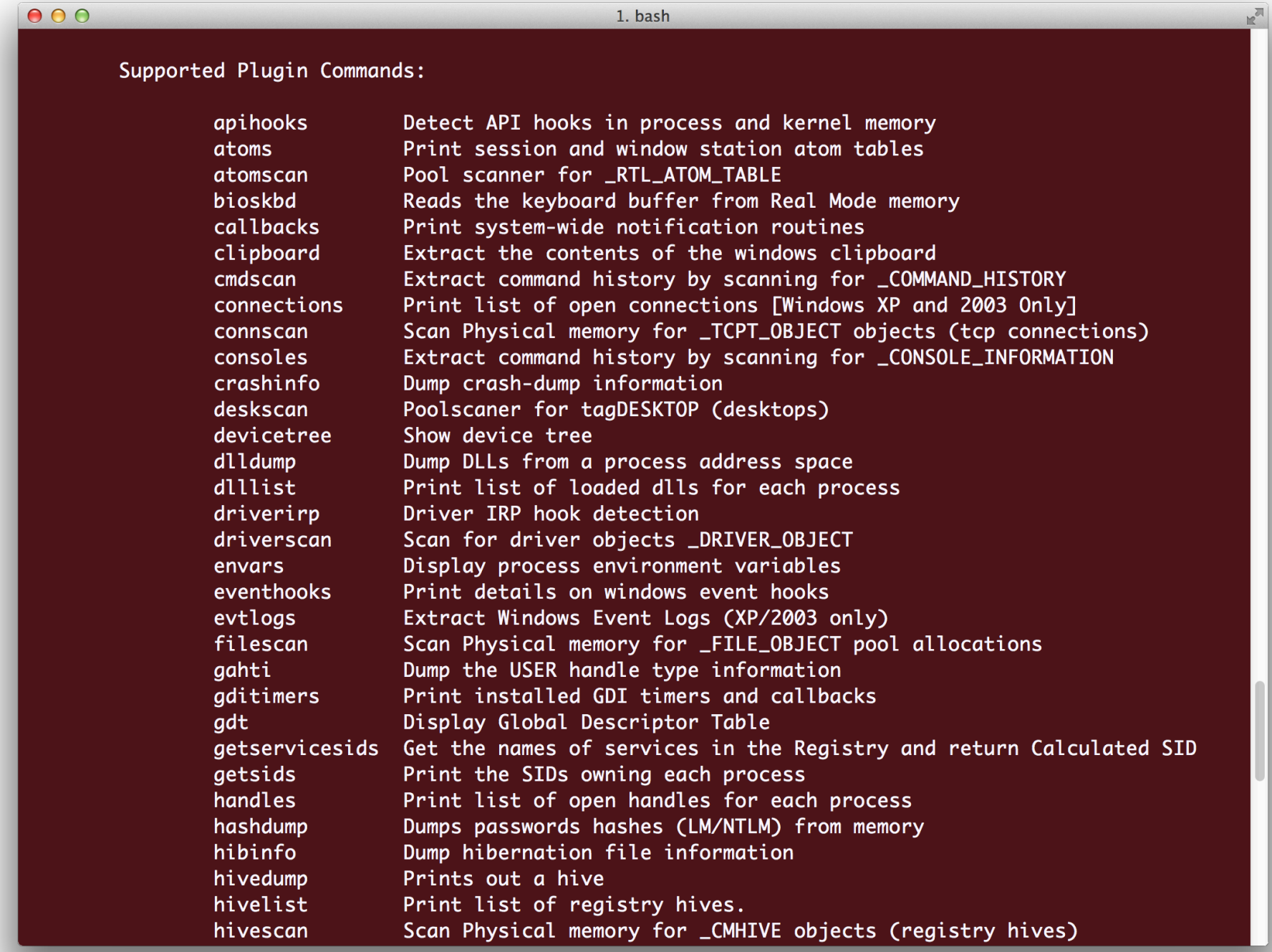


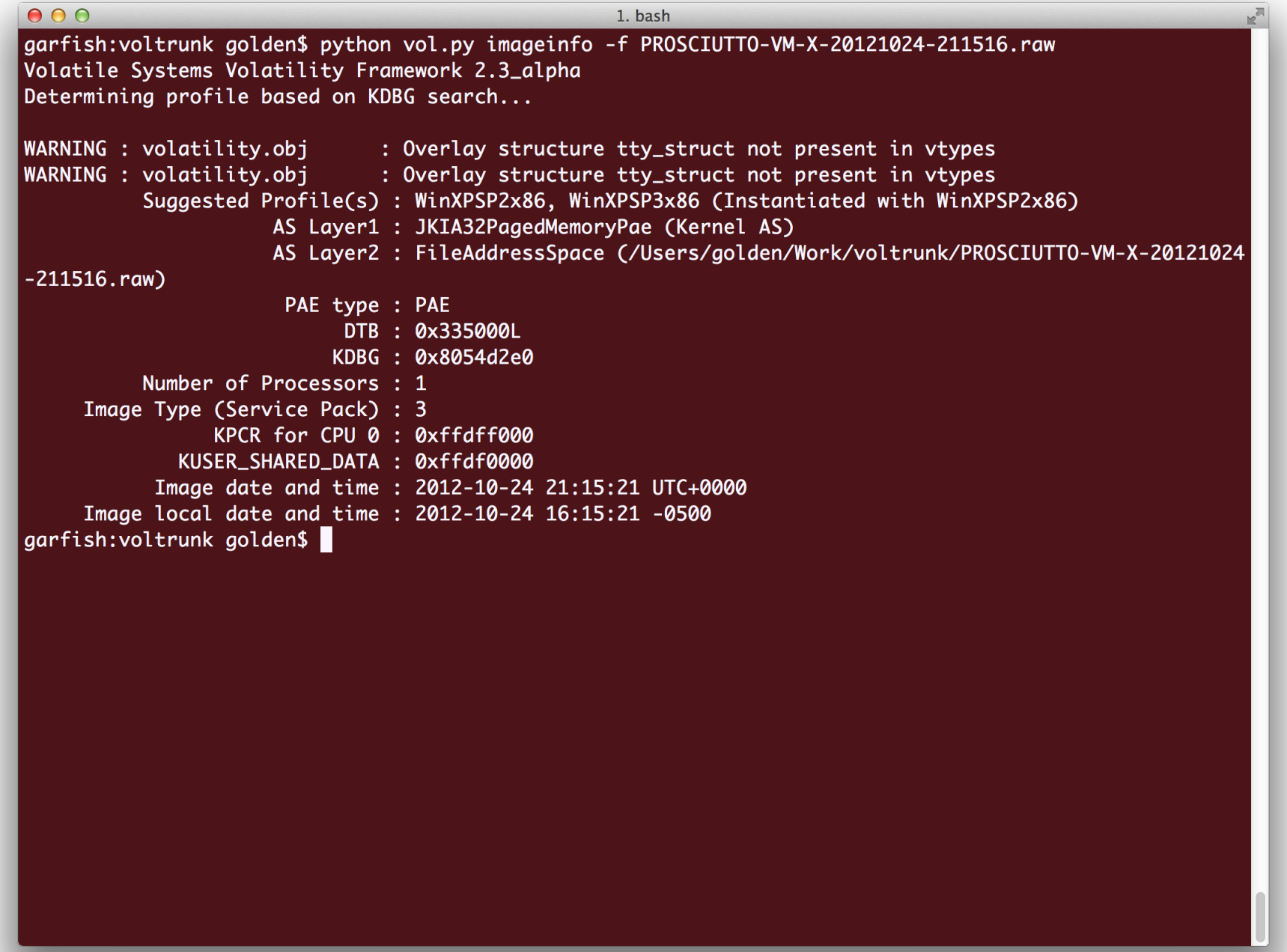
Basic Volatility Usage: Simple Examples

Basic Volatility Usage

- Need physical memory dump
  - More on acquisition soon
- Need a Volatility profile for the OS that was running on the target machine
  - Defines kernel data structures, lots more
  - More on that soon
- Then choose from available commands ("plugins"), write your own, or use volshell







1. bash

```
garfish:voltrunk golden$ python vol.py pslist -f PROSCIUTTO-VM-X-20121024-211516.raw
Volatile Systems Volatility Framework 2.3_alpha
Offset(V)  Name                    PID   PPID   Thds     Hnds   Sess  Wow64 Start                  Exit
---------- -------------------- ------ ------ ------ -------- ------ ------ -------------------- --------------------
0x8ae39830 System                    4      0     64     1322 ------      0
0x8a65cda0 smss.exe                672      4      3       19 ------      0 2012-10-24 12:52:37
0x8a672da0 csrss.exe              1016    672     14      760      0      0 2012-10-24 12:52:39
0x8aa7e888 winlogon.exe           1048    672     18      572      0      0 2012-10-24 12:52:40
0x8aab6da0 services.exe           1144   1048     15      366      0      0 2012-10-24 12:52:40
0x8aa774b0 lsass.exe              1156   1048     23      392      0      0 2012-10-24 12:52:40
0x8aa71da0 vmacthlp.exe           1320   1144      1       25      0      0 2012-10-24 12:52:40
0x8a6f3500 svchost.exe            1332   1144     18      205      0      0 2012-10-24 12:52:41
0x8aad5da0 svchost.exe            1380   1144      9      337      0      0 2012-10-24 12:52:41
0x8aaac7e8 svchost.exe            1572   1144     68     1592      0      0 2012-10-24 12:52:41
0x8aa6ea78 svchost.exe            1616   1144      6       85      0      0 2012-10-24 12:52:41
0x8a709128 svchost.exe            1644   1144     13      177      0      0 2012-10-24 12:52:41
0x8aa70020 spoolsv.exe            1956   1144     16      231      0      0 2012-10-24 12:52:43
0x8aac4da0 explorer.exe            380    332     14      859      0      0 2012-10-24 12:52:51
0x8a48ca90 GrooveMonitor.e         504    380      1      123      0      0 2012-10-24 12:52:52
0x8aa72928 ISUSPM.exe              512    380      4       93      0      0 2012-10-24 12:52:52
0x8a4b3da0 acrobat_sl.exe          520    380      0 --------      0      0 2012-10-24 12:52:52  2012-10-24 12:59:11
0x8a4c6da0 acrotray.exe            536    380      2       44      0      0 2012-10-24 12:52:52
0x8a4cdda0 AdobeARM.exe            544    380      9      322      0      0 2012-10-24 12:52:52
0x8aae5768 rundll32.exe            552    380      4       76      0      0 2012-10-24 12:52:52
0x8a4b6da0 reader_sl.exe           560    380      0 --------      0      0 2012-10-24 12:52:52  2012-10-24 12:59:09
0x8aaa1a48 vmtoolsd.exe            568    380      6      303      0      0 2012-10-24 12:52:52
0x8a497da0 jusched.exe             576    380      4      327      0      0 2012-10-24 12:52:52
0x8a486da0 ctfmon.exe              584    380      1       76      0      0 2012-10-24 12:52:52
0x8ad9e780 wcescomm.exe            784    380      4      134      0      0 2012-10-24 12:52:53
0x8aa8e808 rapimgr.exe             820   1332      6      163      0      0 2012-10-24 12:52:53
0x8aaa71d0 BTTray.exe              860    380      6       97      0      0 2012-10-24 12:52:53
0x8aa88da0 CodeMeterCC.exe         900    380      1      202      0      0 2012-10-24 12:52:53
0x8ad48b00 MagicDisc.exe          1092    380      1       32      0      0 2012-10-24 12:52:54
0x8a3ae3b8 ONENOTEM.EXE           1228    380      4      113      0      0 2012-10-24 12:52:54
0x8a650a20 CodeMeter.exe          1548    900      0 --------      0      0 2012-10-24 12:52:55  2012-10-24 12:53:13
```

1. bash

```
garfish:voltrunk golden$ python vol.py sockets -f PROSCIUTTO-VM-X-20121024-211516.raw
Volatile Systems Volatility Framework 2.3_alpha
Offset(V)     PID   Port  Proto Protocol        Address         Create Time
---------- ------ ------ ------ -------------- --------------- -----------
0x8960ae98    880   1053      6 TCP            0.0.0.0         2012-10-24 12:54:17
0x89b94a68    880   1084      6 TCP            0.0.0.0         2012-10-24 12:54:21
0x89ba2008    880   1101      6 TCP            127.0.0.1       2012-10-24 12:54:23
0x89ae47b0   1644   1900     17 UDP            172.16.156.130  2012-10-24 19:41:20
0x89b331d8    880   1088      6 TCP            0.0.0.0         2012-10-24 12:54:21
0x89bc13d8    880   1105      6 TCP            127.0.0.1       2012-10-24 12:54:23
0x8a678e70    680  22350     17 UDP            0.0.0.0         2012-10-24 12:53:15
0x8a700b00      4      0     47 GRE            0.0.0.0         2012-10-24 12:53:33
0x896a68b8   2780   1047      6 TCP            127.0.0.1       2012-10-24 12:54:06
0x89bd11e0    880   1092      6 TCP            0.0.0.0         2012-10-24 12:54:21
0x8a55fad0   2940     22      6 TCP            0.0.0.0         2012-10-24 12:53:19
0x896cd840    880   1096      6 TCP            0.0.0.0         2012-10-24 12:54:22
0x89bca0b0    880   1051      6 TCP            127.0.0.1       2012-10-24 12:54:17
0x8a07f778   1156    500     17 UDP            0.0.0.0         2012-10-24 12:53:28
0x8a69c2f0      4    139      6 TCP            172.16.156.130  2012-10-24 19:41:20
0x8ab69b70   2300   1039     17 UDP            0.0.0.0         2012-10-24 12:53:20
0x8960ce98    880   1055      6 TCP            127.0.0.1       2012-10-24 12:54:17
0x896b48e0    880   1100      6 TCP            0.0.0.0         2012-10-24 12:54:22
0x89fc6240    736   2077      6 TCP            0.0.0.0         2012-10-24 21:14:33
0x89aed540    880   1059      6 TCP            127.0.0.1       2012-10-24 12:54:17
0x89b7db00    880   1104      6 TCP            0.0.0.0         2012-10-24 12:54:23
0x89c584d0   2556   3306      6 TCP            0.0.0.0         2012-10-24 12:53:53
0x89610918    880   1063      6 TCP            127.0.0.1       2012-10-24 12:54:17
0x89af0758    880   1108      6 TCP            0.0.0.0         2012-10-24 12:54:23
0x89bbd918    736   2085      6 TCP            0.0.0.0         2012-10-24 21:14:33
0x8a699bb0      4    445      6 TCP            0.0.0.0         2012-10-24 12:52:37
0x89a9d528    736   2089      6 TCP            0.0.0.0         2012-10-24 21:14:37
0x89af8a40    880   1067      6 TCP            127.0.0.1       2012-10-24 12:54:18
0x89bca778    964   1050      6 TCP            0.0.0.0         2012-10-24 12:54:17
0x8aaf87e0   1380    135      6 TCP            0.0.0.0         2012-10-24 12:52:41
0x896115b0    880   1071      6 TCP            127.0.0.1       2012-10-24 12:54:18
```

1. bash

```
garfish:voltrunk golden$ python vol.py handles -f PROSCIUTTO-VM-X-20121024-211516.raw | head -40
Volatile Systems Volatility Framework 2.3_alpha
Offset(V)     Pid     Handle     Access Type            Details
---------- ------ ---------- ---------- --------------- -------
0x8ae39830      4        0x4   0x1f0fff Process         System(4)
0x8ae38020      4        0x8        0x0 Thread          TID 12 PID 4
0xe172e1b0      4        0xc    0xf003f Key             MACHINE\SYSTEM\CONTROLSET001\CONTROL\SESSION MANAGER\MEMORY MANA
GEMENT\PREFETCHPARAMETERS
0xe1012490      4       0x10        0x0 Key
0xe173c490      4       0x14    0x2001f Key             MACHINE\SYSTEM\SETUP
0xe1747430      4       0x18    0x20019 Key             MACHINE\HARDWARE\DESCRIPTION\SYSTEM\MULTIFUNCTIONADAPTER
0xe1730188      4       0x1c    0x20019 Key             MACHINE\SYSTEM\WPA\KEY-CJ27J3P2XV9J9JCPB4DVT
0xe173f430      4       0x20    0x20019 Key             MACHINE\SYSTEM\WPA\KEY-4F3B2RFXKC9C637882MBM
0xe1748430      4       0x24    0x20019 Key             MACHINE\SYSTEM\WPA\MEDIACENTER
0xe1750430      4       0x28    0x20019 Key             MACHINE\SYSTEM\WPA\PNP
0xe174e430      4       0x2c    0x20019 Key             MACHINE\SYSTEM\WPA\SIGNINGHASH-6KCM6KFTX6MD62
0xe1751430      4       0x30    0x20019 Key             MACHINE\SYSTEM\WPA\SIGNINGHASH-V44KQMCFXKQCTQ
0xe176a450      4       0x34    0x2001f Key             MACHINE\SYSTEM\CONTROLSET001\CONTROL\PRODUCTOPTIONS
0xe175e430      4       0x38    0x20019 Key             MACHINE\SYSTEM\CONTROLSET001\SERVICES\EVENTLOG
0x8ae325c0      4       0x3c   0x1f0003 Event           TRKWKS_EVENT
0x8aaefeb8      4       0x94   0x12019f File            \Device\Gpc
0x8ae4f458      4       0x98        0x0 Thread          TID 104 PID 4
0x8ae51da8      4       0x9c   0x1f03ff Thread          TID 96 PID 4
0xe17420e8      4       0xa0    0x20019 Key             MACHINE\SYSTEM\CONTROLSET001\SERVICES\ACPI\PARAMETERS
0x8ad95c38      4       0xa4   0x1f03ff Thread          TID 112 PID 4
0x8ae1e2b8      4       0xa8   0x1f0003 Event           VxKernel2VoldEvent
0xe1021d68      4       0xb0    0x2001f Key             MACHINE\HARDWARE\DEVICEMAP\SCSI\SCSI PORT 2\SCSI BUS 0\INITIATOR
 ID 255
0xe175b7a0      4       0xb4    0x2001f Key             MACHINE\HARDWARE\DEVICEMAP\SCSI\SCSI PORT 2
0xe1023ed0      4       0xbc    0x2001f Key             MACHINE\HARDWARE\DEVICEMAP\SCSI
0x8ac97cb0      4       0xc0   0x1f03ff Thread          TID 108 PID 4
0xe1011b58      4       0xc4    0x2001f Key             MACHINE\HARDWARE\DEVICEMAP\SCSI\SCSI PORT 2\SCSI BUS 0
0xe100a558      4       0xd0    0xf000f Directory       WinDfs
0xe177aed8      4       0xe0    0xf000f Directory       Harddisk0
0x8a8c3f08      4      0x358   0x12019f File            \Device\Tcp
```

```
garfish:voltrunk golden$ python vol.py cmdscan -f PROSCIUTTO-VM-X-20121024-211516.raw
Volatile Systems Volatility Framework 2.3_alpha
WARNING : volatility.plugins.malware.malfind: Single strings to search_process_memory is deprecated, use a list instead
**************************************************
CommandProcess: csrss.exe Pid: 1016
CommandHistory: 0x4f43f0 Application: ADEngineW.exe Flags: Allocated
CommandCount: 0 LastAdded: -1 LastDisplayed: -1
FirstCommand: 0 CommandCountMax: 50
ProcessHandle: 0x648
**************************************************
CommandProcess: csrss.exe Pid: 1016
CommandHistory: 0x4f6120 Application: cygrunsrv.exe Flags: Allocated
CommandCount: 0 LastAdded: -1 LastDisplayed: -1
FirstCommand: 0 CommandCountMax: 50
ProcessHandle: 0x8ac
**************************************************
CommandProcess: csrss.exe Pid: 1016
CommandHistory: 0x4f65a0 Application: sshd.exe Flags: Allocated
CommandCount: 0 LastAdded: -1 LastDisplayed: -1
FirstCommand: 0 CommandCountMax: 50
ProcessHandle: 0x90c
**************************************************
CommandProcess: csrss.exe Pid: 1016
CommandHistory: 0x4f7840 Application: DumpIt.exe Flags: Allocated
CommandCount: 0 LastAdded: -1 LastDisplayed: -1
FirstCommand: 0 CommandCountMax: 50
ProcessHandle: 0x9e4
**************************************************
CommandProcess: csrss.exe Pid: 1016
CommandHistory: 0x4f82a0 Application: cmd.exe Flags: Allocated, Reset
CommandCount: 14 LastAdded: 13 LastDisplayed: 13
FirstCommand: 0 CommandCountMax: 50
ProcessHandle: 0xa7c
Cmd #0 @ 0x4f1f68: z;
Cmd #1 @ 0x4f6b58: z:
Cmd #2 @ 0x4f6b68: cd work
Cmd #3 @ 0x4f6b80: dir
Cmd #4 @ 0x4f84c8: cd voltrunk
Cmd #5 @ 0x4f6bf0: dir
Cmd #6 @ 0x4f6c00: cv
```

```
garfish:voltrunk golden$ python vol.py iehistory -f PROSCIUTTO-VM-X-20121024-211516.raw
Volatile Systems Volatility Framework 2.3_alpha
**************************************************
Process: 380 explorer.exe
Cache type "URL " at 0x3ea5000
Record length: 0x100
Location: Visited: Golden@http://www.moonsols.com/favicon.ico
Last modified: 2012-10-24 21:14:35
Last accessed: 2012-10-24 21:14:35
File Offset: 0x100, Data Offset: 0x0, Data Length: 0x9c
**************************************************
Process: 380 explorer.exe
Cache type "URL " at 0x3ea5100
Record length: 0x100
Location: Visited: Golden@https://my.vmware.com/web/vmware/searchresults
Last modified: 2012-10-17 20:56:38
Last accessed: 2012-10-17 20:56:38
File Offset: 0x100, Data Offset: 0x0, Data Length: 0xa8
**************************************************
Process: 380 explorer.exe
Cache type "URL " at 0x3ea5200
Record length: 0x100
Location: Visited: Golden@http://vmware.simplefeed.net/rss
Last modified: 2012-10-17 20:56:26
Last accessed: 2012-10-17 20:56:26
File Offset: 0x100, Data Offset: 0x0, Data Length: 0x9c
**************************************************
Process: 380 explorer.exe
Cache type "URL " at 0x3ea5300
Record length: 0x100
Location: Visited: Golden@file:///Z:/Work/voltrunk/explorer-dump/explorer.exe.9860400.0x6fff0000-0x6fffffff.dmp
Last modified: 2012-10-24 15:31:39
Last accessed: 2012-10-24 15:31:39
File Offset: 0x100, Data Offset: 0x0, Data Length: 0xd0
**************************************************
Process: 380 explorer.exe
Cache type "URL " at 0x3ea5400
Record length: 0x200
Location: Visited: Golden@http://www.vmware.com/support
Last modified: 2012-10-17 20:56:25
```

```
garfish:voltrunk golden$ python vol.py pstree -f PROSCIUTTO-VM-X-20121024-211516.raw
Volatile Systems Volatility Framework 2.3_alpha
Name                                                 Pid   PPid   Thds   Hnds Time
-------------------------------------------------- ------ ------ ------ ------ -------------------
 0x8aac4da0:explorer.exe                             380    332     14    859 2012-10-24 12:52:51
. 0x8aa72928:ISUSPM.exe                              512    380      4     93 2012-10-24 12:52:52
. 0x8a651900:cmd.exe                                2080    380      1     33 2012-10-24 15:24:02
.. 0x89bbc020:DumpIt.exe                             348   2080      1     25 2012-10-24 21:15:16
. 0x8a4b3da0:acrobat_sl.exe                          520    380      0 ------ 2012-10-24 12:52:52
. 0x8ad9e780:wcescomm.exe                            784    380      4    134 2012-10-24 12:52:53
. 0x8a4c6da0:acrotray.exe                            536    380      2     44 2012-10-24 12:52:52
. 0x8aa88da0:CodeMeterCC.exe                         900    380      1    202 2012-10-24 12:52:53
.. 0x8a650a20:CodeMeter.exe                         1548    900      0 ------ 2012-10-24 12:52:55
. 0x8aae5768:rundll32.exe                            552    380      4     76 2012-10-24 12:52:52
. 0x8a4b6da0:reader_sl.exe                           560    380      0 ------ 2012-10-24 12:52:52
. 0x89732020:iexplore.exe                           3600    380     14    397 2012-10-24 21:14:24
.. 0x89b23020:iexplore.exe                           736   3600     33    834 2012-10-24 21:14:24
. 0x8aaa1a48:vmtoolsd.exe                            568    380      6    303 2012-10-24 12:52:52
. 0x8a497da0:jusched.exe                             576    380      4    327 2012-10-24 12:52:52
.. 0x89be3020:jucheck.exe                            728    576      5    262 2012-10-24 12:57:53
. 0x8a4cdda0:AdobeARM.exe                            544    380      9    322 2012-10-24 12:52:52
. 0x8ad48b00:MagicDisc.exe                          1092    380      1     32 2012-10-24 12:52:54
. 0x8a486da0:ctfmon.exe                              584    380      1     76 2012-10-24 12:52:52
. 0x8a3ae3b8:ONENOTEM.EXE                           1228    380      4    113 2012-10-24 12:52:54
. 0x898c1020:idaq.exe                               2820    380      0 ------ 2012-10-24 12:53:42
.. 0x8a10e020:idaq.exe                              1692   2820      4   1018 2012-10-24 15:33:50
. 0x8aaa71d0:BTTray.exe                              860    380      6     97 2012-10-24 12:52:53
. 0x8a48ca90:GrooveMonitor.e                         504    380      1    123 2012-10-24 12:52:52
 0x8ae39830:System                                     4      0     64   1322 1970-01-01 00:00:00
. 0x8a65cda0:smss.exe                                672      4      3     19 2012-10-24 12:52:37
.. 0x8aa7e888:winlogon.exe                          1048    672     18    572 2012-10-24 12:52:40
... 0x8aa774b0:lsass.exe                            1156   1048     23    392 2012-10-24 12:52:40
... 0x8aab6da0:services.exe                         1144   1048     15    366 2012-10-24 12:52:40
.... 0x8a09c598:extjob.exe                          3200   1144      2     33 2012-10-24 12:53:25
.... 0x8a3d8c70:svchost.exe                         2628   1144      2     63 2012-10-24 12:53:17
.... 0x8a10e8b0:btwdins.exe                         3092   1144      5     62 2012-10-24 12:53:33
.... 0x8a951b80:prtk_supervisor                      772   1144      3     31 2012-10-24 12:53:01
..... 0x8a39c020:ADEngineS.exe                       880    772     54    907 2012-10-24 12:53:01
.... 0x8a77a308:svchost.exe                          284   1144      4    108 2012-10-24 12:53:01
.... 0x8a4acda0:cygrunsrv.exe                       2672   1144      4     86 2012-10-24 12:53:17
```

Before and After

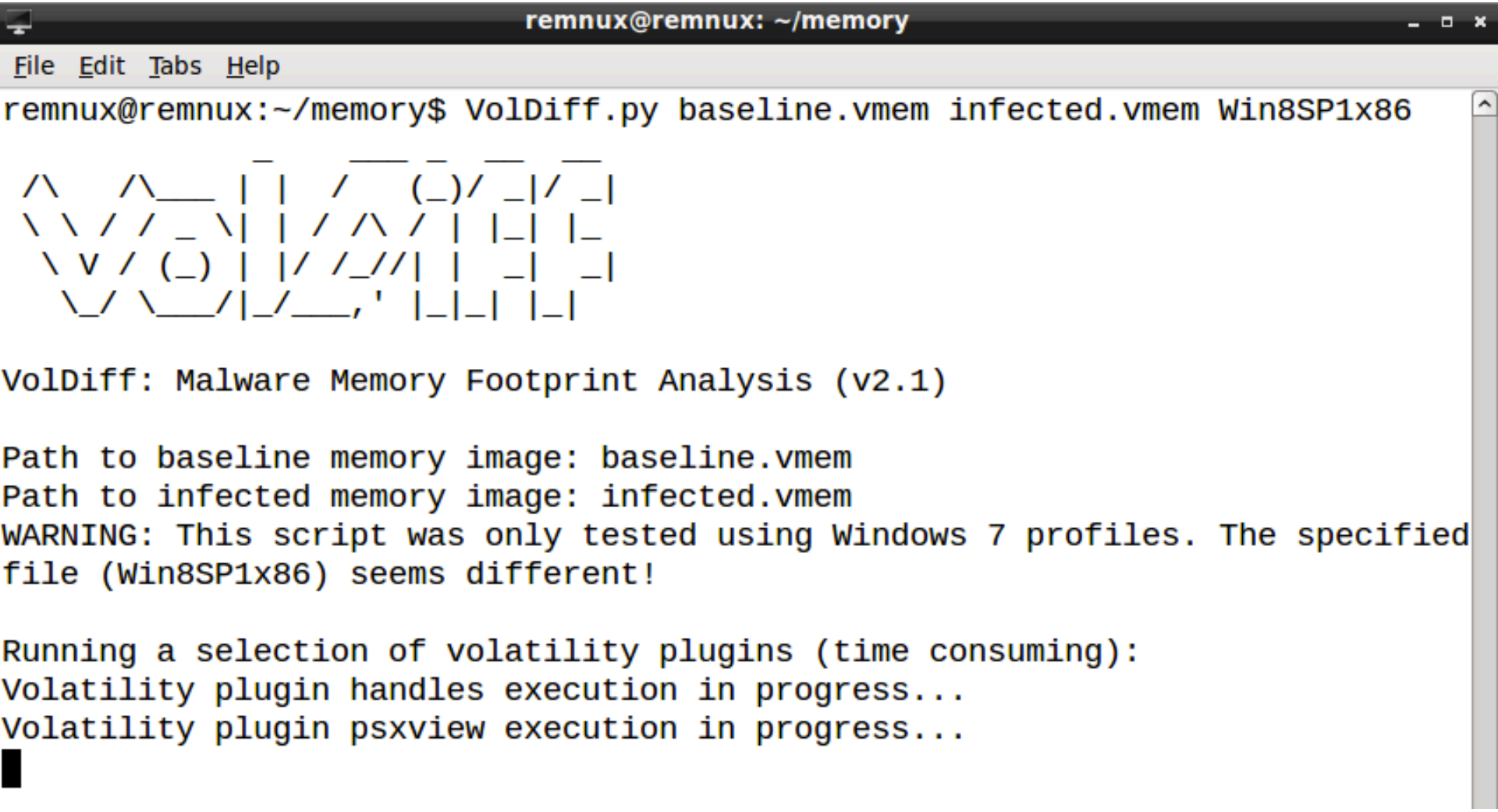
- Having before- and after- memory dumps is very useful
- Especially important in malware forensics

```
$ python vol.py -profile=WinXPSP3x86 -f
  before.vmem pslist > before-pslist
$ python vol.py -profile=WinXPSP3x86 -f
  after.vmem pslist > after-pslist
$ diff -y before-pslist after-pslist
```

- There's some ongoing work to automate this process—check it out and watch for improvements

VolDiff

- Open source project to handle before/after comparisons
- Runs a bunch of plugins and generates nicely formatted report of differences
- https://github.com/aim4r/VolDiff/wiki
- Officially supports Linux as an investigative platform
- Can easily be made to run on Mac OS X
- And Win7 memory images
- But other things will work, but need to hack hardcoded lists of plugins to run
- (e.g., there will be problems with XP as-is unless you adapt it)
- No reason that with some effort it can't be made more flexible and configurable



VolDiff_report.txt - SciTE

File Edit Search View Tools Options Language Buffers Help

1 VolDiff_report.txt

```
New netscan entries.
================================================================================================================
Offset(P)          Proto    Local Address                  Foreign Address      State            Pid      Owner
0x7cadb858         TCPv4    172.16.240.128:49159           -:443                ESTABLISHED      2976     svchost.exe
```

VolDiff_Report.txt - SciTE

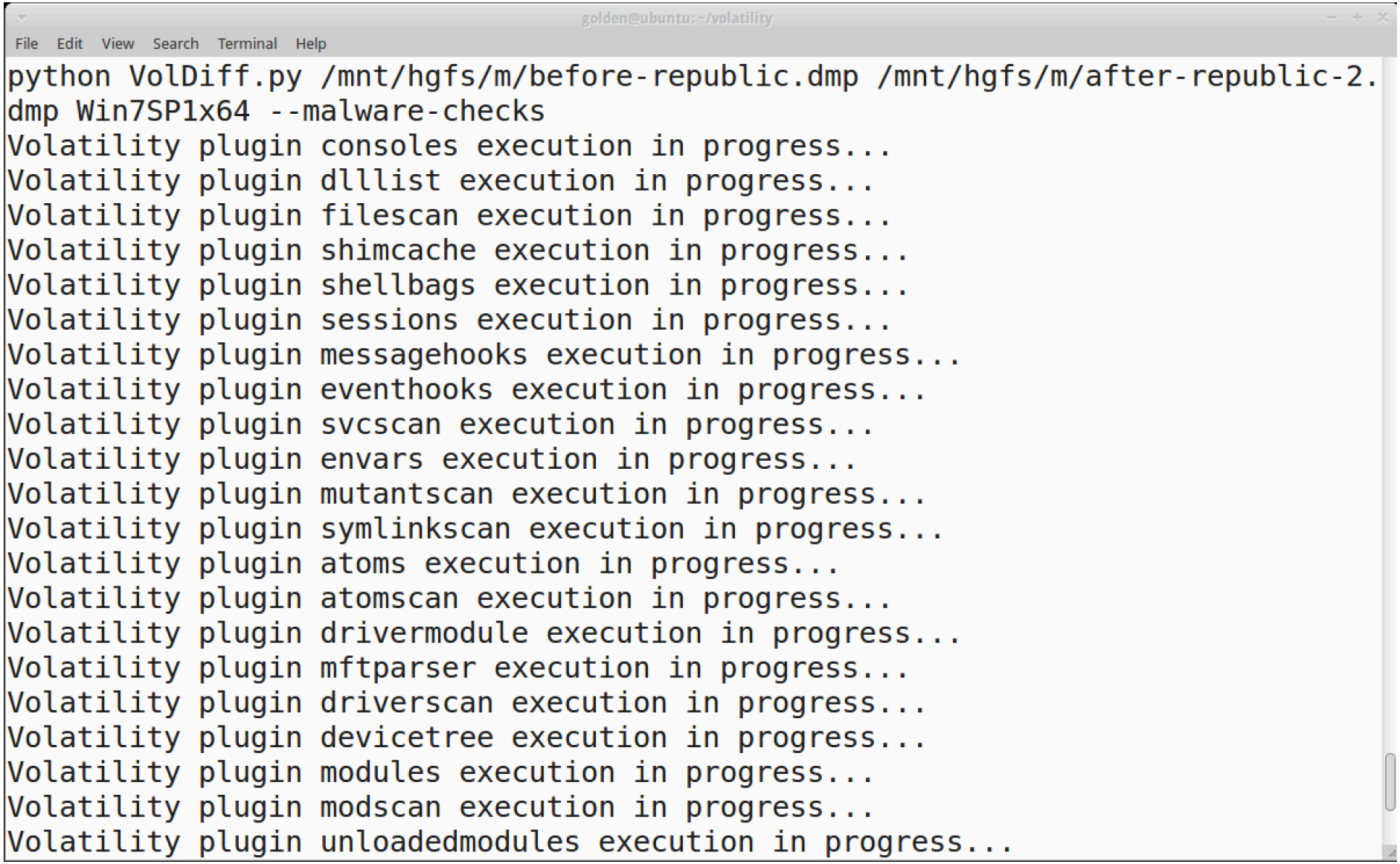
File Edit Search View Tools Options Language Buffers Help

1 VolDiff_Report.txt

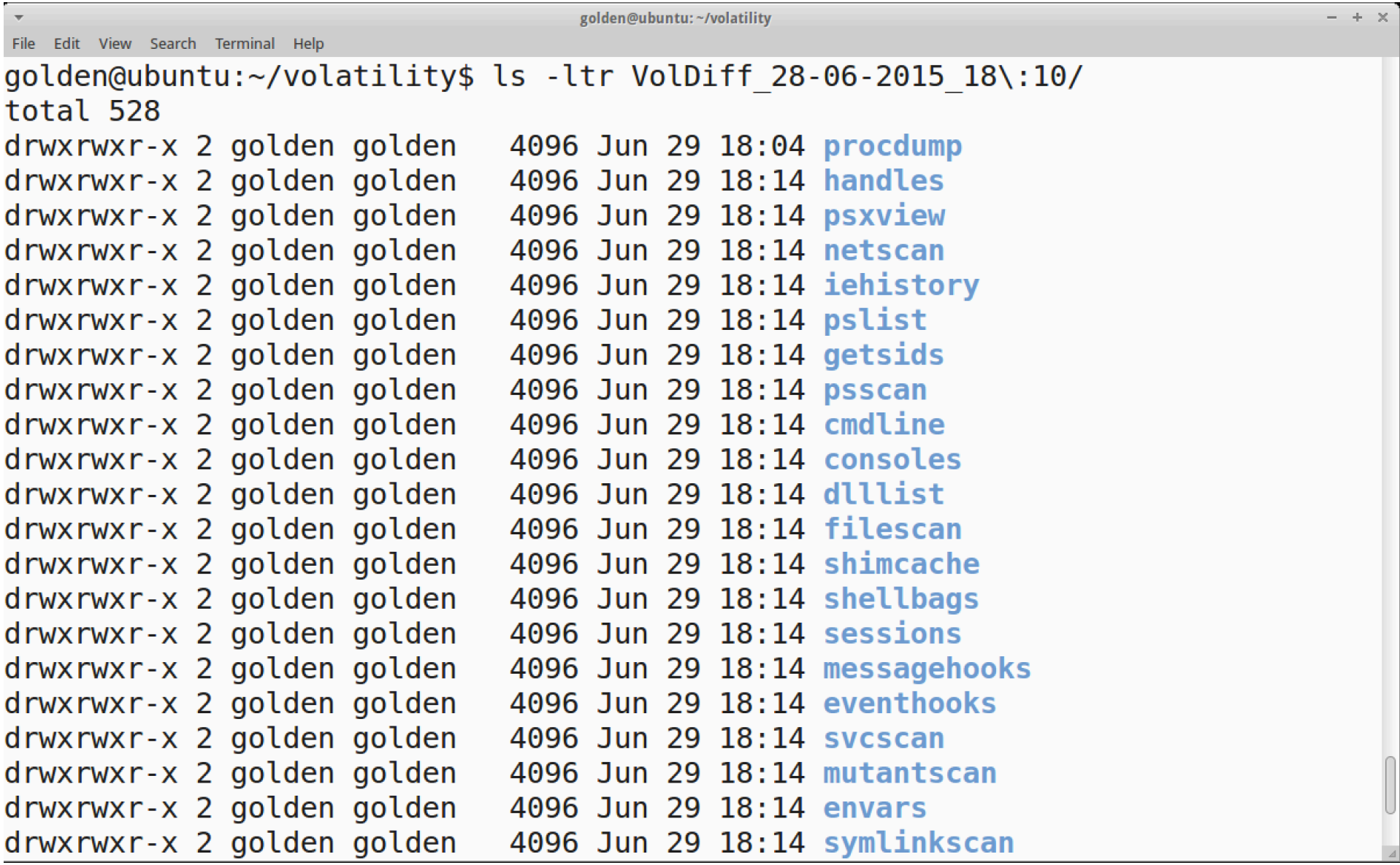
```
Process svchost.exe (2976) is running in unexpected session (1 instead of 0).
================================================================================================================
Offset(V)  Name                    PID   PPID   Thds     Hnds   Sess  Wow64 Start
---------- -------------------- ------ ------ ------ -------- ------ ------ ------------------------------
0x874fecc0 svchost.exe            2976   2968      5        0      1      0 2015-06-14 16:12:10 UTC+0000
```

These examples via:
http://malwology.com/2015/06/25/remnux-v6-for-malware-analysis-part-1-voldiff/

VolDiff



VolDiff



volshell

volshell (linux_volshell, mac_volshell)

- Interactive environment for exploring memory dumps
- Created by Brendan Dolan-Gavitt for Windows memory analysis
- Now available for Linux and Mac, too
- Use Volatility APIs, type Python commands
- Good for prototyping plugin development
- And ad hoc exploration

Using volshell

```
$ python vol.py --info | grep volshell
Volatility Foundation Volatility Framework 2.4
linux_volshell                - Shell in the memory image
mac_volshell                  - Shell in the memory image
volshell                      - Shell in the memory image
```

Thus, e.g.:

```
$ python vol.py -profile=WinXPSP3x86 -f mem.dump volshell
```

Commonly Used Commands

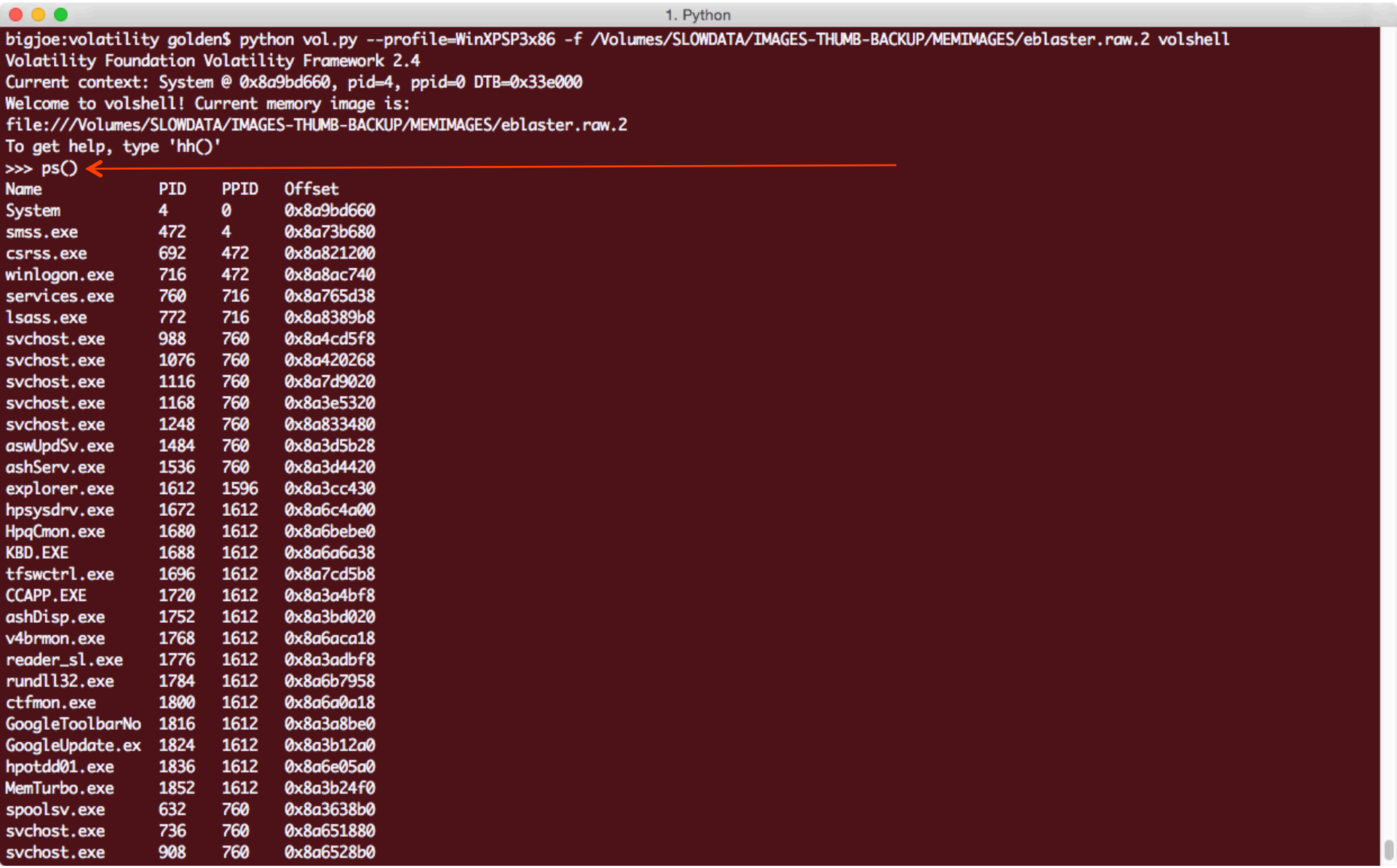
- `hh()`
  - Help
- `cc()`
  - Set process context
  - Can use **pid**, **name**, **offset of process descriptor**
  - `cc(pid=2139)`
  - `cc(name="xmlavipv.exe")`
- `sc()`
  - Show current context
- `dt()`
  - Describe a data structure

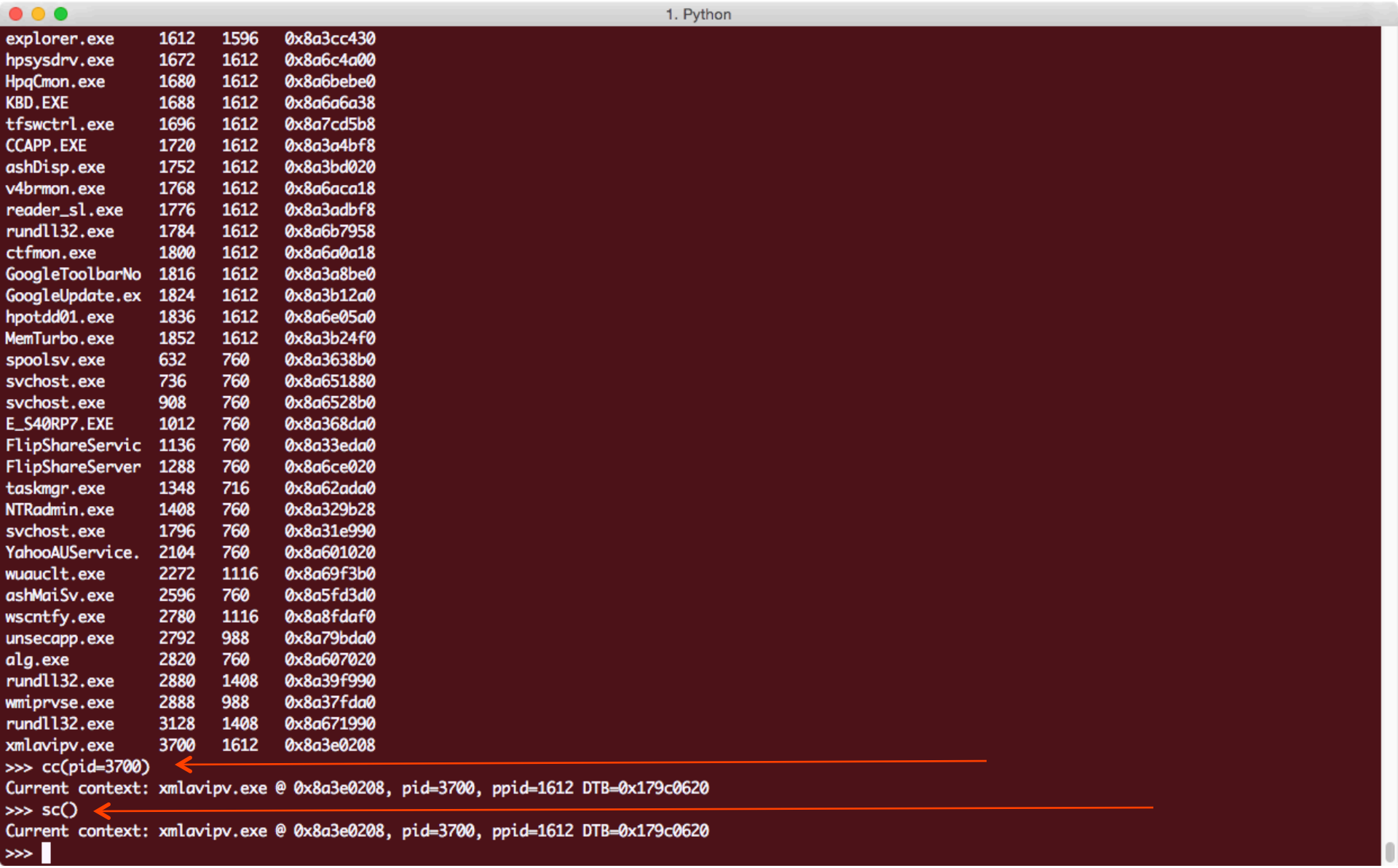
More Commands

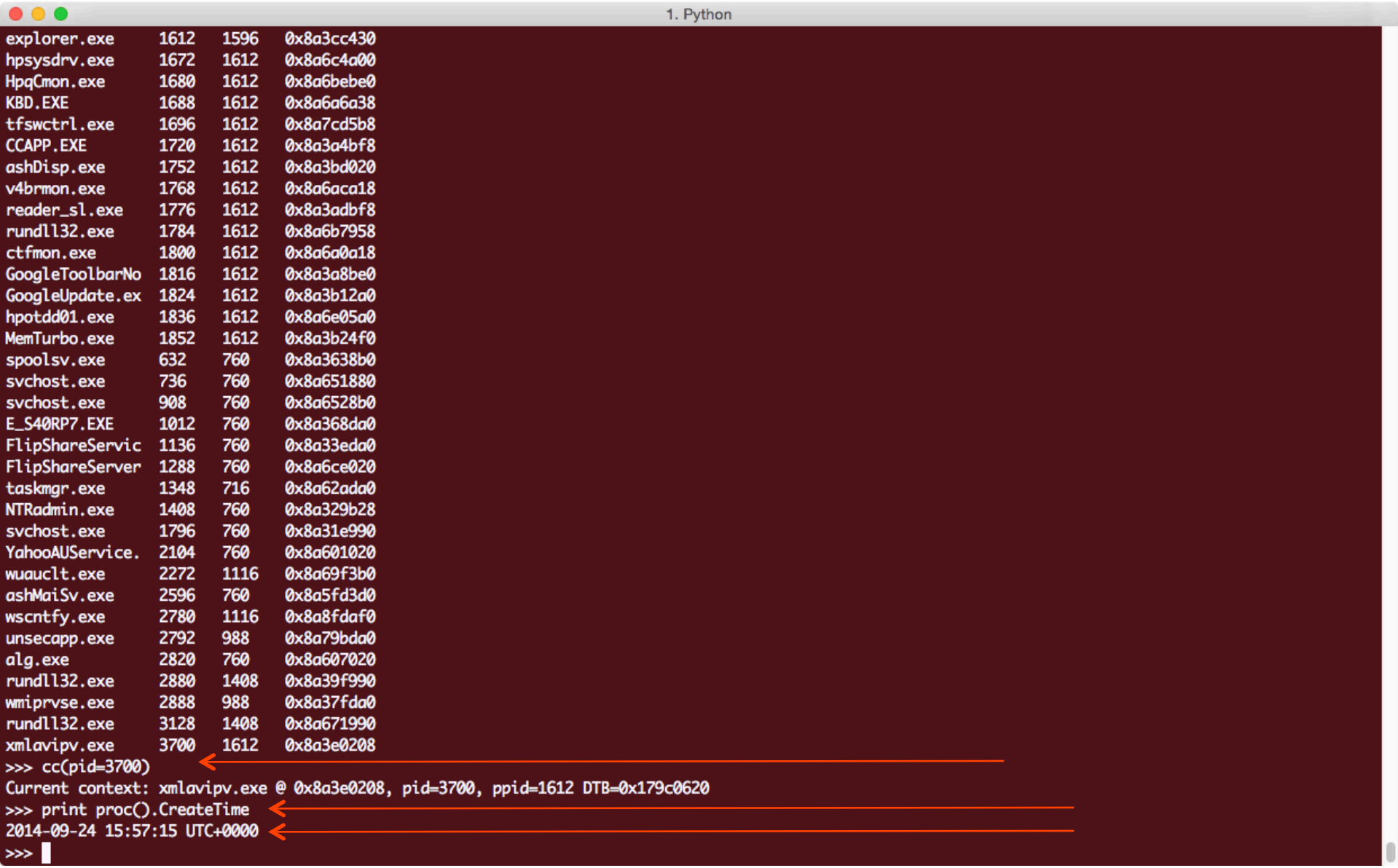
- `addrspace()`
  - Access current address space object
- `ps()`
  - List active processes
- `getprocs()`
  - Generator for active processes
- `modules()`
  - List kernel modules
- `getmods()`
  - Generator for kernel modules

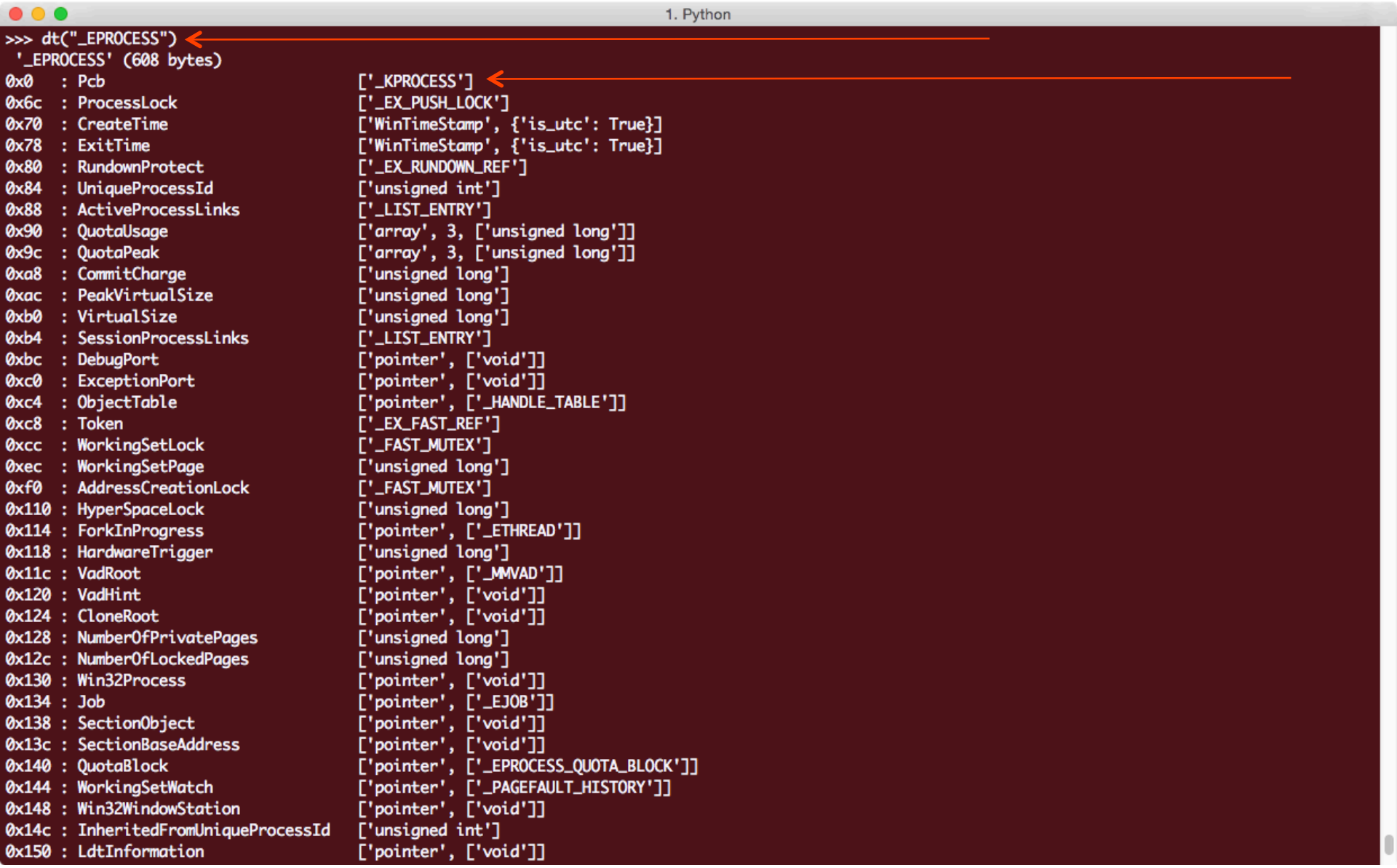
More Commands

- `db(addr)`
  - Dump bytes
- `dd(addr)`
  - Dump doublewords (32-bit quantities)
- `dq(addr)`
  - Dump quadwords (64-bit quantities)
- `dis(addr)`
  - Disassemble at address quantities)



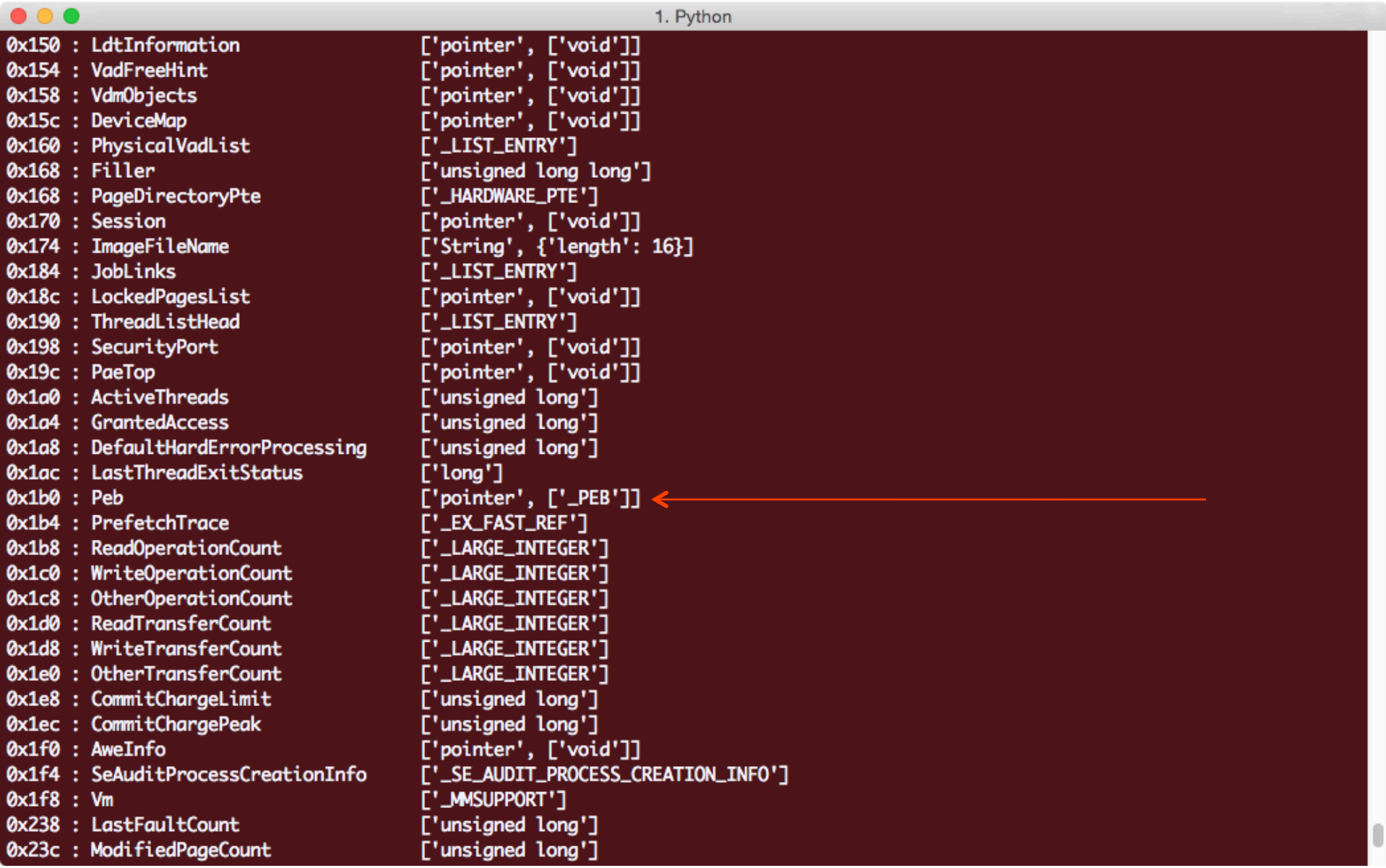


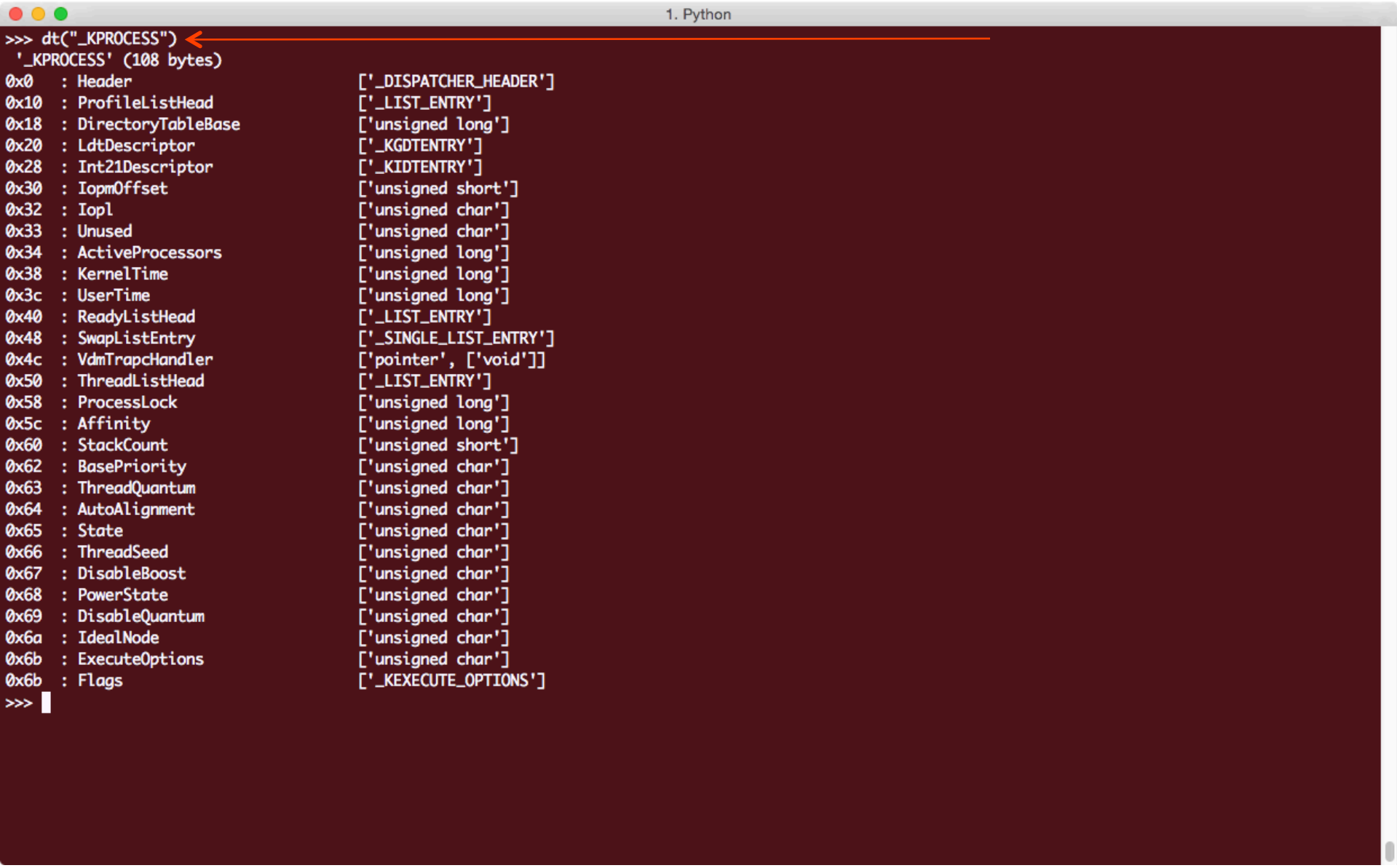




Command - Local kernel - WinDbg:6.12.0002.633 X86

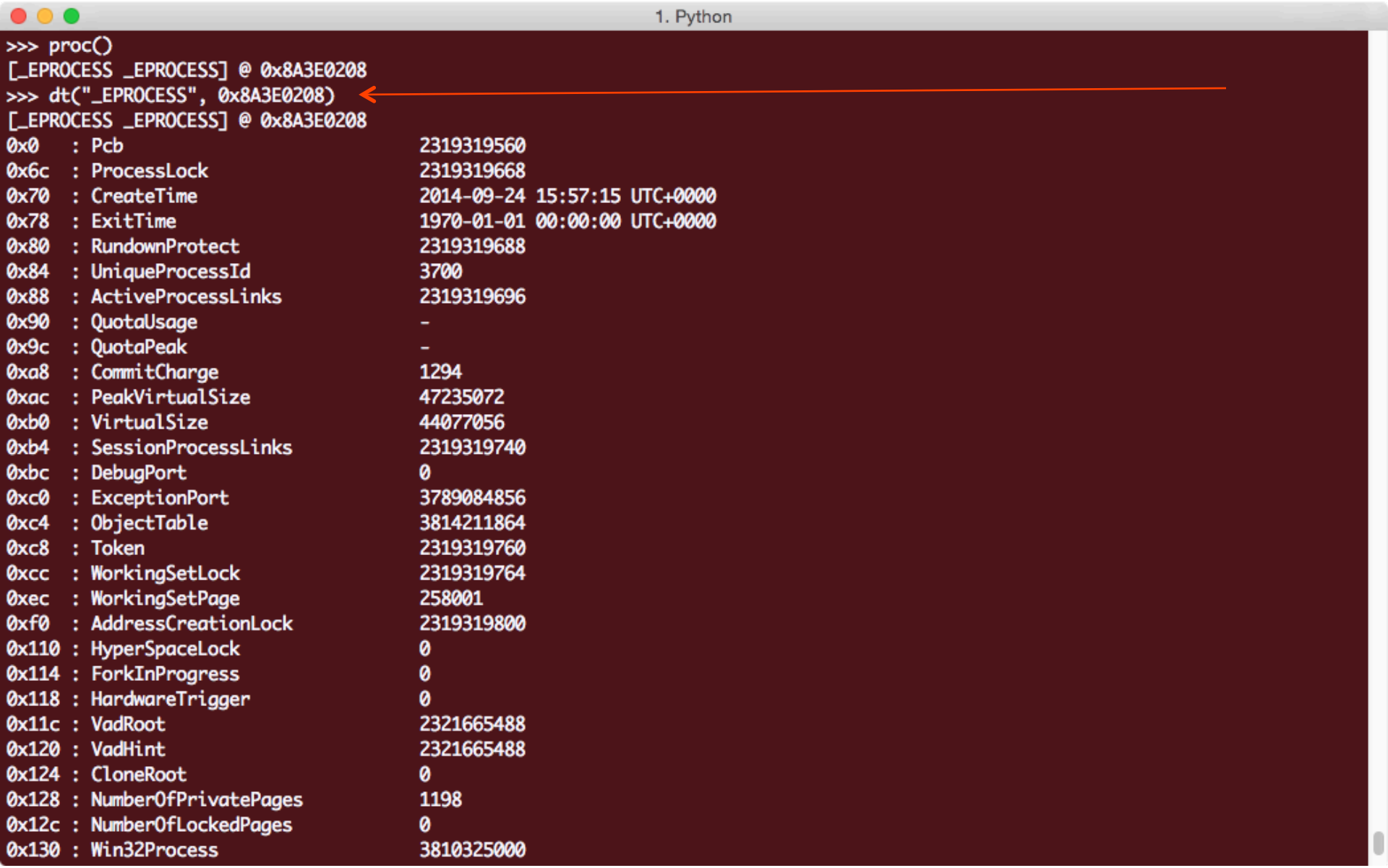
```
Windows XP Kernel Version 2600 (Service Pack 3) UP Free x86 compatible
Product: WinNt, suite: TerminalServer SingleUserTS
Built by: 2600.xpsp_sp3_qfe.130704-0421
Machine Name:
Kernel base = 0x804d7000 PsLoadedModuleList = 0x805541c0
Debug session time: Mon Jun 22 20:50:06.133 2015 (UTC - 5:00)
System Uptime: 0 days 0:53:51.083
lkd> dt _ETHREAD
nt!_ETHREAD
   +0x000 Tcb              : _KTHREAD
   +0x1c0 CreateTime       : _LARGE_INTEGER
   +0x1c0 NestedFaultCount : Pos 0, 2 Bits
   +0x1c0 ApcNeeded        : Pos 2, 1 Bit
   +0x1c8 ExitTime         : _LARGE_INTEGER
   +0x1c8 LpcReplyChain    : _LIST_ENTRY
   +0x1c8 KeyedWaitChain   : _LIST_ENTRY
   +0x1d0 ExitStatus       : Int4B
   +0x1d0 OfsChain         : Ptr32 Void
   +0x1d4 PostBlockList    : _LIST_ENTRY
   +0x1dc TerminationPort  : Ptr32 _TERMINATION_PORT
   +0x1dc ReaperLink       : Ptr32 _ETHREAD
   +0x1dc KeyedWaitValue   : Ptr32 Void
   +0x1e0 ActiveTimerListLock : Uint4B
   +0x1e4 ActiveTimerListHead : _LIST_ENTRY
   +0x1ec Cid              : _CLIENT_ID
   +0x1f4 LpcReplySemaphore : _KSEMAPHORE
   +0x1f4 KeyedWaitSemaphore : _KSEMAPHORE
   +0x208 LpcReplyMessage  : Ptr32 Void
   +0x208 LpcWaitingOnPort : Ptr32 Void
   +0x20c ImpersonationInfo : Ptr32 _PS_IMPERSONATION_INFORMATION
   +0x210 IrpList          : _LIST_ENTRY
   +0x218 TopLevelIrp      : Uint4B
   +0x21c DeviceToVerify   : Ptr32 _DEVICE_OBJECT
   +0x220 ThreadsProcess   : Ptr32 _EPROCESS
   +0x224 StartAddress     : Ptr32 Void
   +0x228 Win32StartAddress : Ptr32 Void
   +0x228 LpcReceivedMessageId : Uint4B
   +0x22c ThreadListEntry  : _LIST_ENTRY
   +0x234 RundownProtect   : _EX_RUNDOWN_REF
   +0x238 ThreadLock       : _EX_PUSH_LOCK
   +0x23c LpcReplyMessageId : Uint4B
   +0x240 ReadClusterSize  : Uint4B
   +0x244 GrantedAccess    : Uint4B
   +0x248 CrossThreadFlags : Uint4B
   +0x248 Terminated       : Pos 0, 1 Bit
```

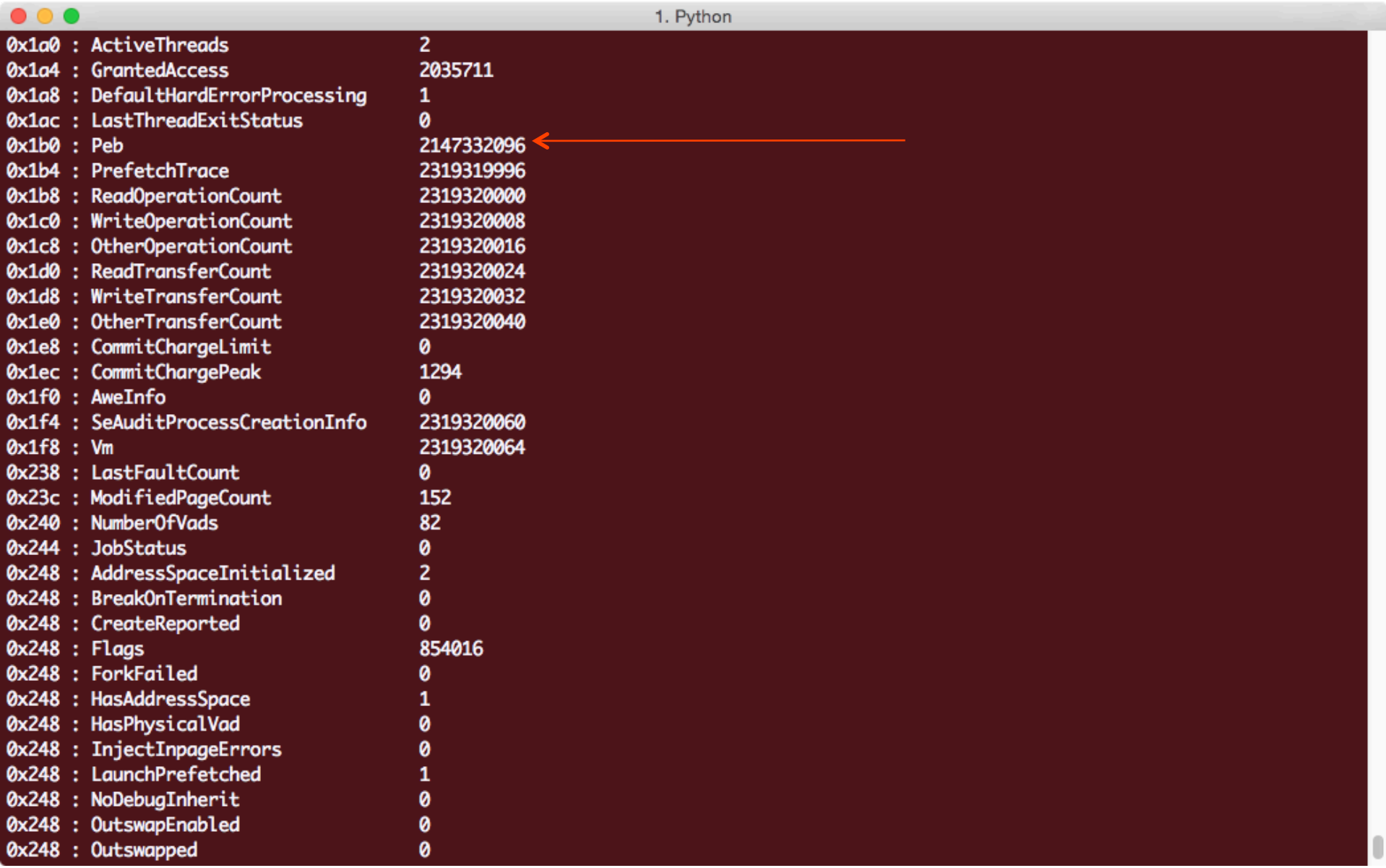


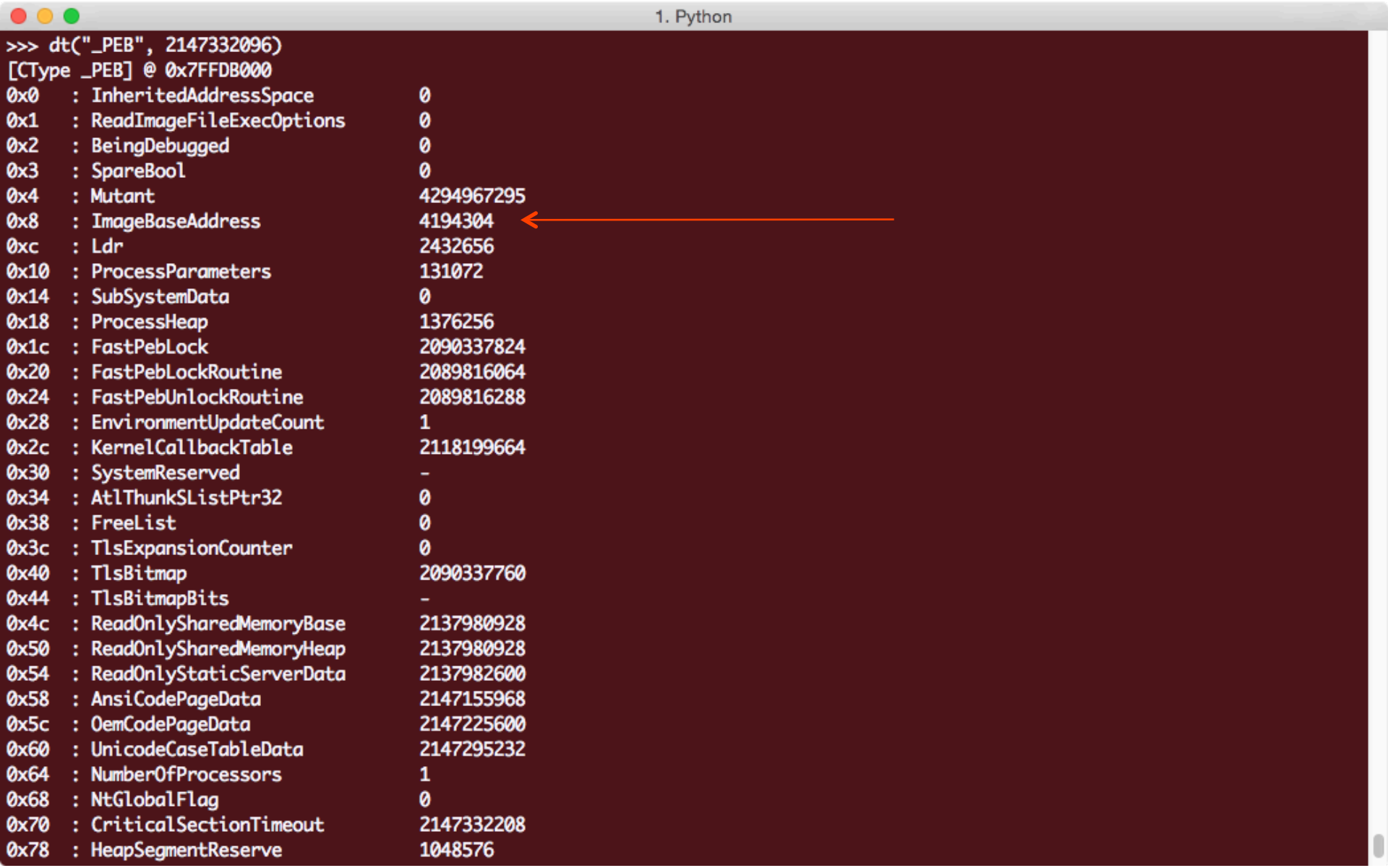


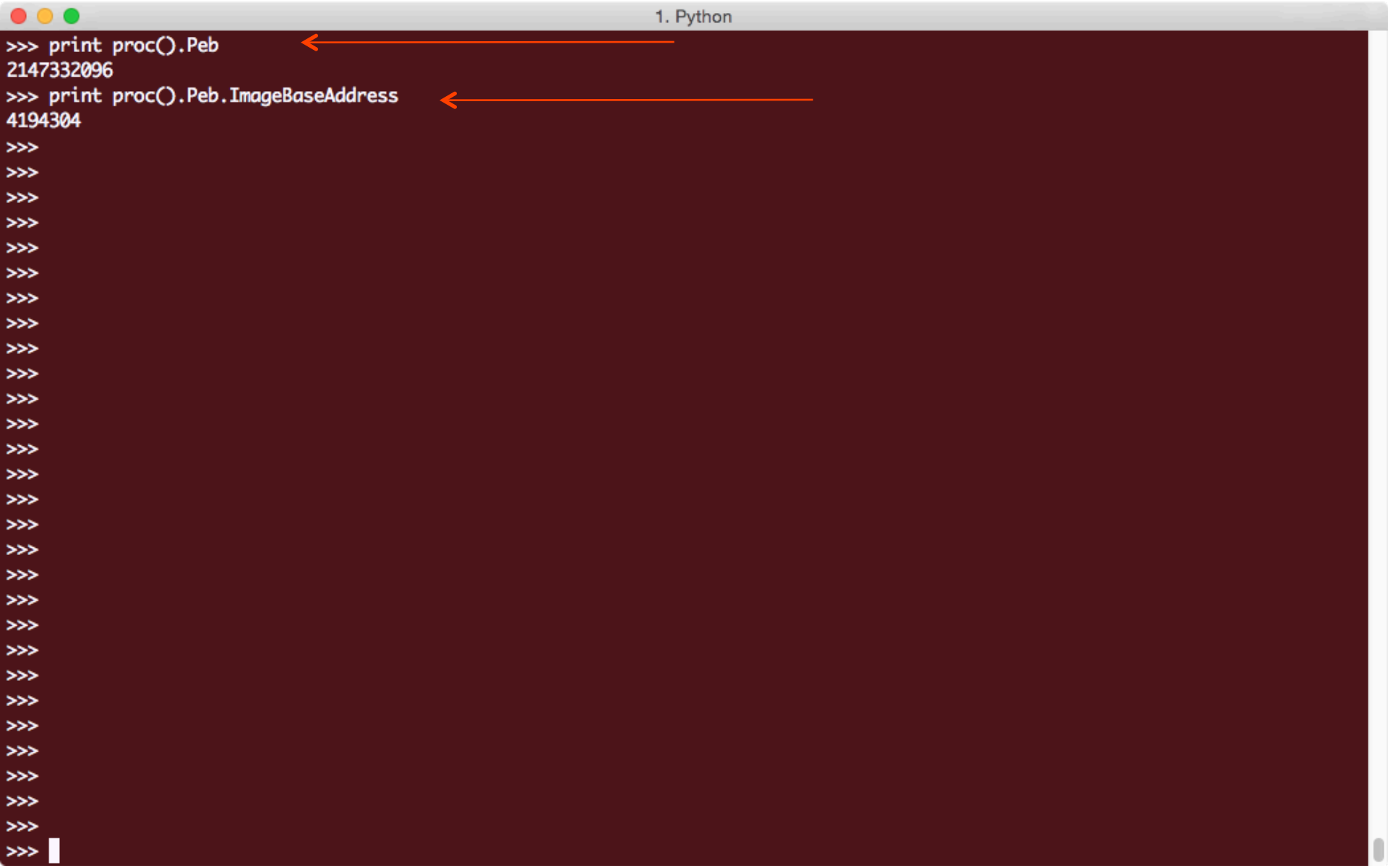
1. Python

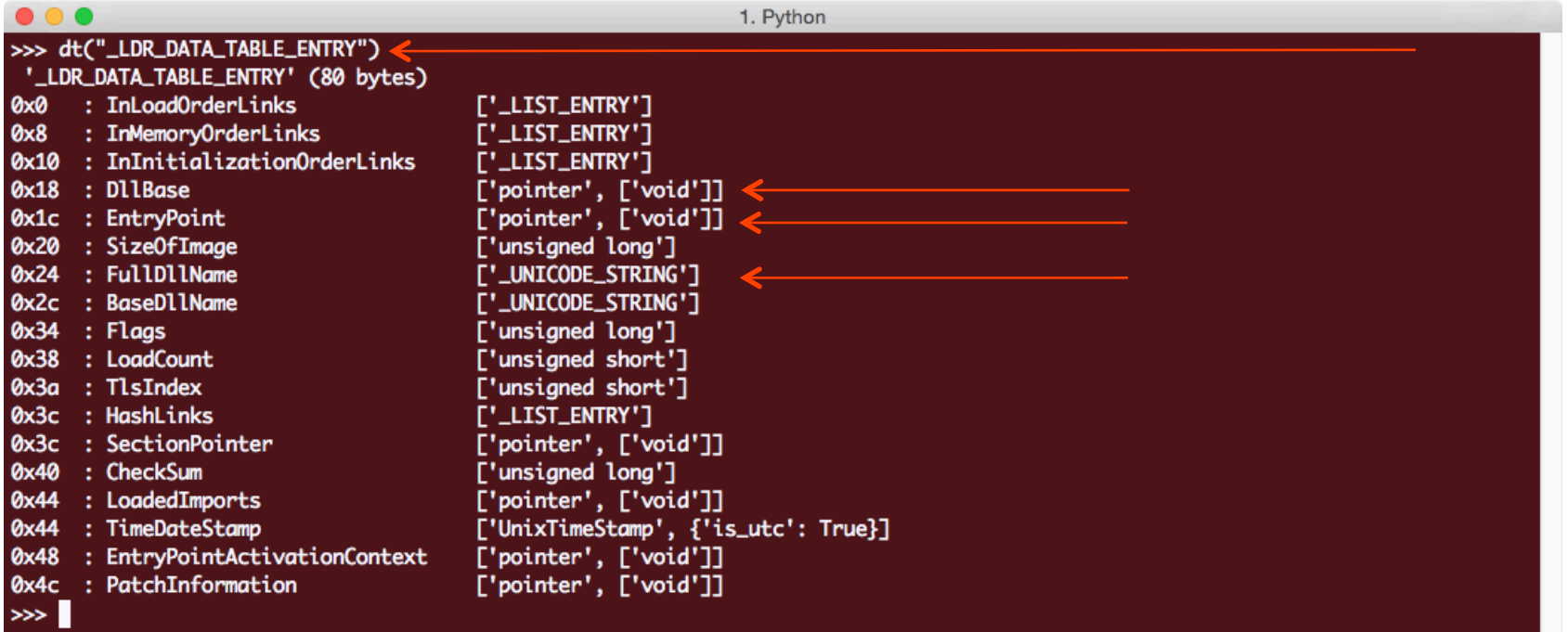
```
>>> dt("_PEB")
 '_PEB' (528 bytes)
0x0   : InheritedAddressSpace          ['unsigned char']
0x1   : ReadImageFileExecOptions       ['unsigned char']
0x2   : BeingDebugged                  ['unsigned char']
0x3   : SpareBool                      ['unsigned char']
0x4   : Mutant                         ['pointer', ['void']]
0x8   : ImageBaseAddress               ['pointer', ['void']]
0xc   : Ldr                            ['pointer', ['_PEB_LDR_DATA']]
0x10  : ProcessParameters              ['pointer', ['_RTL_USER_PROCESS_PARAMETERS']]
0x14  : SubSystemData                  ['pointer', ['void']]
0x18  : ProcessHeap                    ['pointer', ['void']]
0x1c  : FastPebLock                    ['pointer', ['_RTL_CRITICAL_SECTION']]
0x20  : FastPebLockRoutine             ['pointer', ['void']]
0x24  : FastPebUnlockRoutine           ['pointer', ['void']]
0x28  : EnvironmentUpdateCount         ['unsigned long']
0x2c  : KernelCallbackTable            ['pointer', ['void']]
0x30  : SystemReserved                 ['array', 1, ['unsigned long']]
0x34  : AtlThunkSListPtr32             ['unsigned long']
0x38  : FreeList                       ['pointer', ['_PEB_FREE_BLOCK']]
0x3c  : TlsExpansionCounter            ['unsigned long']
0x40  : TlsBitmap                      ['pointer', ['void']]
0x44  : TlsBitmapBits                  ['array', 2, ['unsigned long']]
0x4c  : ReadOnlySharedMemoryBase       ['pointer', ['void']]
0x50  : ReadOnlySharedMemoryHeap       ['pointer', ['void']]
0x54  : ReadOnlyStaticServerData       ['pointer', ['pointer', ['void']]]
0x58  : AnsiCodePageData               ['pointer', ['void']]
0x5c  : OemCodePageData                ['pointer', ['void']]
0x60  : UnicodeCaseTableData           ['pointer', ['void']]
0x64  : NumberOfProcessors             ['unsigned long']
0x68  : NtGlobalFlag                   ['unsigned long']
0x70  : CriticalSectionTimeout         ['_LARGE_INTEGER']
0x78  : HeapSegmentReserve             ['unsigned long']
0x7c  : HeapSegmentCommit              ['unsigned long']
0x80  : HeapDeCommitTotalFreeThreshold ['unsigned long']
0x84  : HeapDeCommitFreeBlockThreshold ['unsigned long']
0x88  : NumberOfHeaps                  ['unsigned long']
0x8c  : MaximumNumberOfHeaps           ['unsigned long']
0x90  : ProcessHeaps                   ['pointer', ['array', <function <lambda> at 0x110500140>, ['pointer', ['_HEAP']]]]
0x94  : GdiSharedHandleTable           ['pointer', ['void']]
0x98  : ProcessStarterHelper           ['pointer', ['void']]
0x9c  : GdiDCAttributeList             ['unsigned long']
0xa0  : LoaderLock                     ['pointer', ['void']]
0xa4  : OSMajorVersion                 ['unsigned long']
0xa8  : OSMinorVersion                 ['unsigned long']
0xac  : OSBuildNumber                  ['unsigned short']
```











```
In [4]: dt("task_struct", recursive=True)
 'task_struct' (6120 bytes)
0x0   : state                                  ['long']
0x8   : stack                                  ['pointer', ['void']]
0x10  : usage                                  ['__unnamed_0x346']
... '__unnamed_0x346' (4 bytes)
...0x0   : counter                                ['int']
0x14  : flags                                  ['unsigned int']
0x18  : ptrace                                 ['unsigned int']
0x20  : wake_entry                             ['llist_node']
... 'llist_node' (8 bytes)
...0x0   : next                                   ['pointer', ['llist_node']]
0x28  : on_cpu                                 ['int']
0x30  : last_wakee                             ['pointer', ['task_struct']]
0x38  : wakee_flips                            ['unsigned long']
0x40  : wakee_flip_decay_ts                    ['unsigned long']
0x48  : wake_cpu                               ['int']
0x4c  : on_rq                                  ['int']
0x50  : prio                                   ['int']
0x54  : static_prio                            ['int']
0x58  : normal_prio                            ['int']
0x5c  : rt_priority                            ['unsigned int']
```

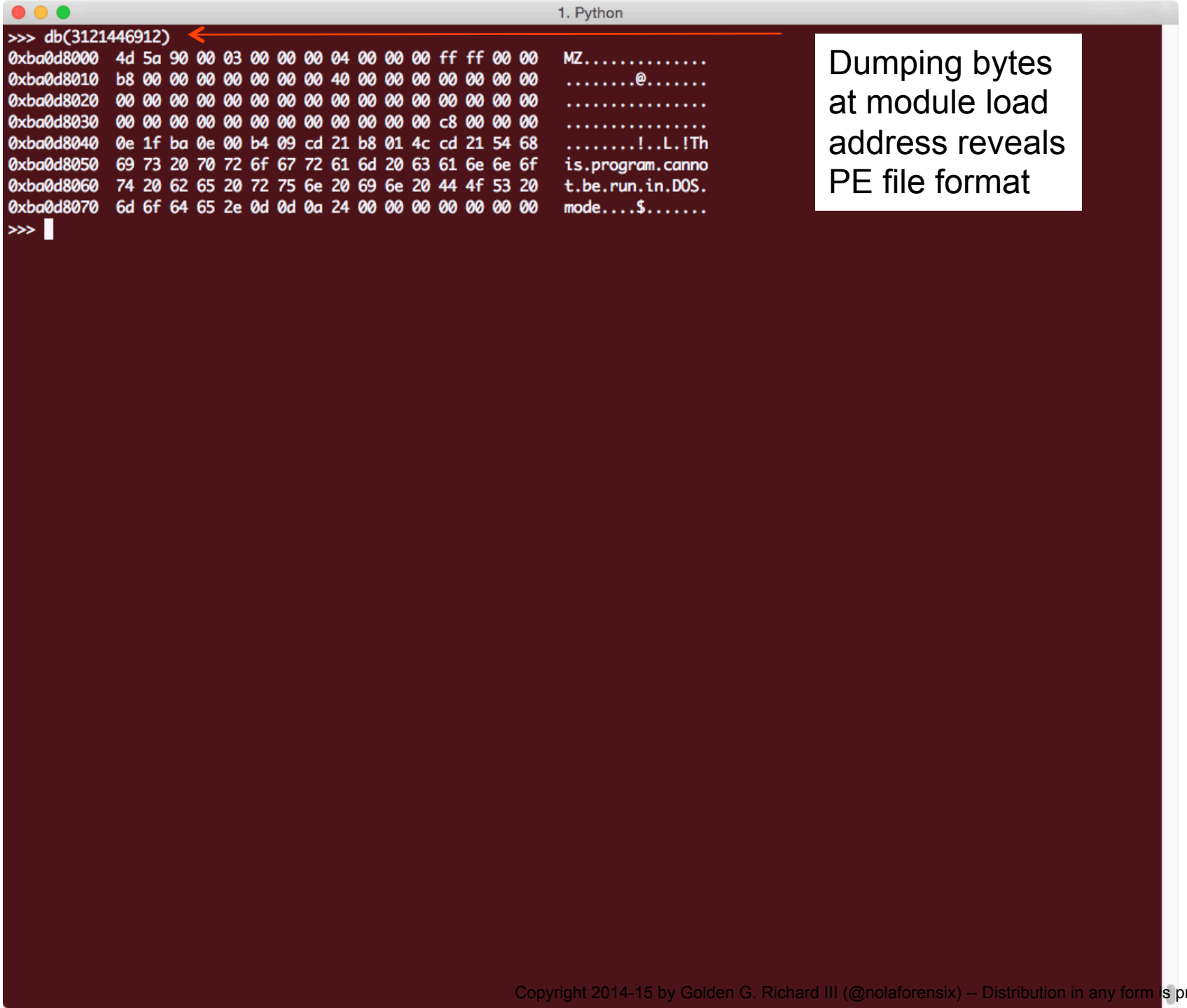
```
0x4d0 : thread                          ['thread_struct']
... 'thread_struct' (184 bytes)
...0x0   : tls_array                       ['array', 3, ['desc_struct']]
...0x18  : sp0                             ['unsigned long']
...0x20  : sp                              ['unsigned long']
...0x28  : usersp                          ['unsigned long']
...0x30  : es                              ['unsigned short']
...0x32  : ds                              ['unsigned short']
...0x34  : fsindex                         ['unsigned short']
...0x36  : gsindex                         ['unsigned short']
...0x38  : fs                              ['unsigned long']
...0x40  : gs                              ['unsigned long']
...0x48  : ptrace_bps                      ['array', 4, ['pointer', ['perf_event']]]
...0x68  : debugreg6                       ['unsigned long']
...0x70  : ptrace_dr7                      ['unsigned long']
...0x78  : cr2                             ['unsigned long']
...0x80  : trap_nr                         ['unsigned long']
...0x88  : error_code                      ['unsigned long']
...0x90  : fpu                             ['fpu']
..... 'fpu' (16 bytes)
.....0x0   : last_cpu                         ['unsigned int']
.....0x4   : has_fpu                          ['unsigned int']
.....0x8   : state                            ['pointer', ['thread_xstate']]
...0xa0  : io_bitmap_ptr                   ['pointer', ['unsigned long']]
...0xa8  : iopl                            ['unsigned long']
...0xb0  : io_bitmap_max                   ['unsigned int']
...0xb4  : fpu_counter                     ['unsigned char']
```

1. Python

```
>>> for x in getmods():
...     y=x.dereference_as("_LDR_DATA_TABLE_ENTRY")
...     print y.FullDllName,y.DllBase,y.EntryPoint
...
\WINDOWS\system32\ntkrnlpa.exe 2152558592 2154366176
\WINDOWS\system32\hal.dll 2154631168 2154750136
\WINDOWS\system32\KDCOM.DLL 3126493184 3126496486
\WINDOWS\system32\BOOTVID.dll 3125510144 3125516402
ACPI.sys 3120009216 3120177241
\WINDOWS\System32\DRIVERS\WMILIB.SYS 3126501376 3126504320
pci.sys 3119939584 3119996932
isapnp.sys 3121250304 3121281538
compbatt.sys 3125526528 3125533907
\WINDOWS\system32\DRIVERS\BATTC.SYS 3125542912 3125550341
pciide.sys 3127312384 3127313950
\WINDOWS\System32\DRIVERS\PCIIDEX.SYS 3123871744 3123892741
viaide.sys 3126509568 3126513285
intelide.sys 3126517760 3126521605
MountMgr.sys 3121315840 3121353268
ftdisk.sys 3119812608 3119924450
PartMgr.sys 3123904512 3123920011
VolSnap.sys 3121381376 3121421630
atapi.sys 3119714304 3119802871
disk.sys 3121446912 3121477805
\WINDOWS\System32\DRIVERS\CLASSPNP.SYS 3121512448 3121557007
fltmgr.sys 3119583232 3119702108
sr.sys 3119509504 3119574996
PxHelp20.sys 3125559296 3125560443
drvmcdb.sys 3119427584 3119481551
KSecDD.sys 3119333376 3119419827
Ntfs.sys 3118755840 3119301508
NDIS.sys 3118571520 3118739717
viaagp1.sys 3123937280 3123952320
SISAGP.sys 3123970048 3123984478
ohci1394.sys 3121577984 3121624965
\WINDOWS\System32\DRIVERS\1394BUS.SYS 3121643520 3121691781
nv_agp.sys 3125575680 3125581478
Mup.sys 3118465024 3118559542
agp440.sys 3121709056 3121745285
\SystemRoot\System32\DRIVERS\i8042prt.sys 3107885056 3107922565
\SystemRoot\System32\DRIVERS\PS2.sys 3117744128 3117754264
\SystemRoot\System32\DRIVERS\kbdclass.sys 3125084160 3125102096
\SystemRoot\System32\DRIVERS\mouclass.sys 3125116928 3125133365
\SystemRoot\System32\DRIVERS\parport.sys 3105828864 3105900293
\SystemRoot\System32\DRIVERS\serial.sys 3122036736 3122081467
\SystemRoot\System32\DRIVERS\serenum.sys 3117727744 3117740577
```

Scripting inside volshell—quick and dirty list of information about loaded kernel modules

Imagine disk.sys is of interest…



1. Python

```
>>> dis(3121477805)
0xba0df8ad 8bff                  MOV EDI, EDI
0xba0df8af 55                    PUSH EBP
0xba0df8b0 8bec                  MOV EBP, ESP
0xba0df8b2 a140a90dba            MOV EAX, [0xba0da940]
0xba0df8b7 85c0                  TEST EAX, EAX
0xba0df8b9 b940bb0000            MOV ECX, 0xbb40
0xba0df8be 7404                  JZ 0xba0df8c4
0xba0df8c0 3bc1                  CMP EAX, ECX
0xba0df8c2 7523                  JNZ 0xba0df8e7
0xba0df8c4 8b1598a40dba          MOV EDX, [0xba0da498]
0xba0df8ca b840a90dba            MOV EAX, 0xba0da940
0xba0df8cf c1e808                SHR EAX, 0x8
0xba0df8d2 3302                  XOR EAX, [EDX]
0xba0df8d4 25ffff0000            AND EAX, 0xffff
0xba0df8d9 a340a90dba            MOV [0xba0da940], EAX
0xba0df8de 7507                  JNZ 0xba0df8e7
0xba0df8e0 8bc1                  MOV EAX, ECX
0xba0df8e2 a340a90dba            MOV [0xba0da940], EAX
0xba0df8e7 f7d0                  NOT EAX
0xba0df8e9 a33ca90dba            MOV [0xba0da93c], EAX
0xba0df8ee 5d                    POP EBP
0xba0df8ef e992f7ffff            JMP 0xba0df086
0xba0df8f4 b879000000            MOV EAX, 0x79
0xba0df8f9 0000                  ADD [EAX], AL
0xba0df8fb 0000                  ADD [EAX], AL
0xba0df8fd 0000                  ADD [EAX], AL
0xba0df8ff 0016                  ADD [ESI], DL
0xba0df901 810000082400          ADD DWORD [EAX], 0x240800
0xba0df907 0030                  ADD [EAX], DH
0xba0df909 7900                  JNS 0xba0df90b
0xba0df90b 0000                  ADD [EAX], AL
0xba0df90d 0000                  ADD [EAX], AL
0xba0df90f 0000                  ADD [EAX], AL
0xba0df911 0000                  ADD [EAX], AL
0xba0df913 008e84000080          ADD [ESI-0x7fffff7c], CL
0xba0df919 2300                  AND EAX, [EAX]
0xba0df91b 0000                  ADD [EAX], AL
0xba0df91d 0000                  ADD [EAX], AL
0xba0df91f 0000                  ADD [EAX], AL
0xba0df921 0000                  ADD [EAX], AL
0xba0df923 0000                  ADD [EAX], AL
0xba0df925 0000                  ADD [EAX], AL
0xba0df927 0000                  ADD [EAX], AL
0xba0df929 0000                  ADD [EAX], AL
0xba0df92b 0000                  ADD [EAX], AL
```

Disassembly at module entry point

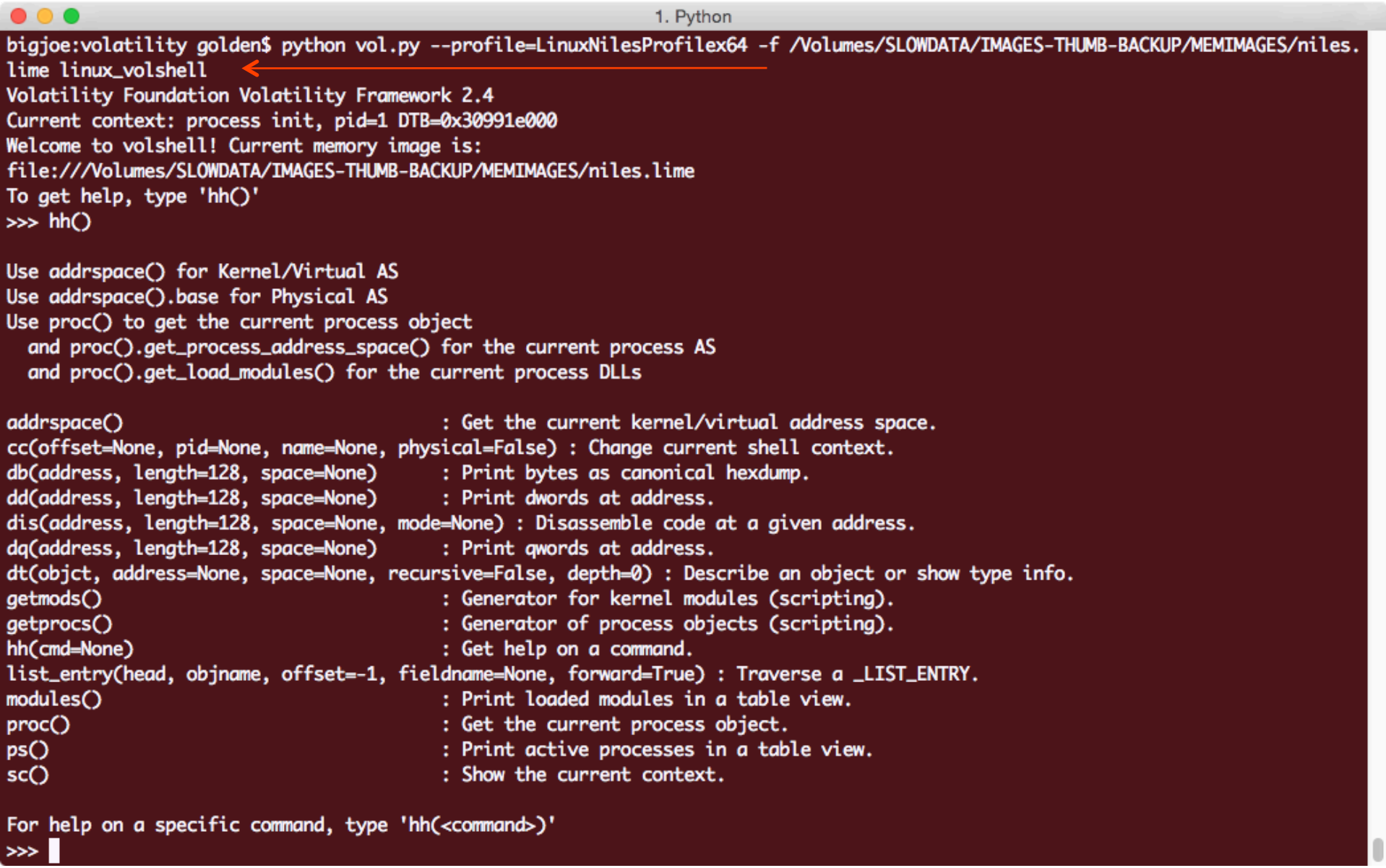
Automatic Dereferencing!

1. Python

```
>>> for x in getmods():
...     y=x.dereference_as("_LDR_DATA_TABLE_ENTRY")
...     print y.FullDllName,y.DllBase,y.EntryPoint
...
\WINDOWS\system32\ntkrnlpa.exe 2152558592 2154366176
\WINDOWS\system32\hal.dll 2154631168 2154750136
\WINDOWS\system32\KDCOM.DLL 3126493184 3126496486
\WINDOWS\system32\BOOTVID.dll 3125510144 3125516402
ACPI.sys 3120009216 3120177241
```

1. Python

```
>>> for x in getmods():
...     print x.FullDllName,x.DllBase, x.EntryPoint
...
\WINDOWS\system32\ntkrnlpa.exe 2152558592 2154366176
\WINDOWS\system32\hal.dll 2154631168 2154750136
\WINDOWS\system32\KDCOM.DLL 3126493184 3126496486
\WINDOWS\system32\BOOTVID.dll 3125510144 3125516402
ACPI.sys 3120009216 3120177241
```



1. Python

```
>>> dt("task_struct")
 'task_struct' (6120 bytes)
0x0   : state                     ['long']
0x8   : stack                     ['pointer', ['void']]
0x10  : usage                     ['__unnamed_0x346']
0x14  : flags                     ['unsigned int']
0x18  : ptrace                    ['unsigned int']
0x20  : wake_entry                ['llist_node']
0x28  : on_cpu                    ['int']
0x30  : last_wakee                ['pointer', ['task_struct']]
0x38  : wakee_flips               ['unsigned long']
0x40  : wakee_flip_decay_ts       ['unsigned long']
0x48  : wake_cpu                  ['int']
0x4c  : on_rq                     ['int']
0x50  : prio                      ['int']
0x54  : static_prio               ['int']
0x58  : normal_prio               ['int']
0x5c  : rt_priority               ['unsigned int']
0x60  : sched_class               ['pointer', ['sched_class']]
0x68  : se                        ['sched_entity']
0x1e0 : rt                        ['sched_rt_entity']
0x210 : sched_task_group          ['pointer', ['task_group']]
0x218 : preempt_notifiers         ['hlist_head']
0x220 : btrace_seq                ['unsigned int']
0x224 : policy                    ['unsigned int']
0x228 : nr_cpus_allowed           ['int']
0x230 : cpus_allowed              ['cpumask']
0x250 : sched_info                ['sched_info']
0x270 : tasks                     ['list_head']
0x280 : pushable_tasks            ['plist_node']
0x2a8 : mm                        ['pointer', ['mm_struct']]
0x2b0 : active_mm                 ['pointer', ['mm_struct']]
```

1. Python

```
>>> cc(name="bash")
Multiple processes match name bash, please specify by PID or offset
Matching processes:
Name             PID    Offset
bash             1403   0xffff880035a3c7d0
bash             1464   0xffff8803098d8000
bash             1542   0xffff8802fec42fe0
bash             1565   0xffff8802fec447d0
bash             1635   0xffff8802ff6a5fc0
bash             1714   0xffff88030d9147d0
bash             1767   0xffff880309ee0000
bash             1566   0xffff880035fd8000
>>> cc(pid=1542)
Current context: process bash, pid=1542 DTB=0x2fec09000
>>> print proc().pid
1542
>>>
```

Acquiring Memory Dumps

Physical Memory Acquisition

- **dd** command
  - Windows, use \\.\PhysicalMemory device
    - Not usable in user-space in XP SP2+
  - Linux:
    - /dev/mem
      - Physical memory
    - /proc/kcore
      - Kernel virtual memory
    - Problematic or gone
- Mostly deprecated
- Might be useful on very old machines
- Now, mostly custom tools

Generating Physical Memory Dumps

- Typical operation:
  - Load kernel driver
  - Discover ranges of physical address space associated with RAM
  - Avoid areas associated with, e.g., devices!
  - Map pages into virtual memory
  - Copy pages to removable storage
- Some tools, like LiME, dump directly from kernel module
- Others expose device and then dd is used

Physical Memory Acquisition

- Linux (all open source):
  - LiME (Joe Sylve, UNO, M.S. work)
    - Read source code to better understand dumping
    - Which we'll do…in three minutes
  - fmem
- Mac:
  - OSXPmem
  - Memoryze
  - ATC memory dumper
  - One problem is slow support for Mavericks →
- Windows gets its own slide

Physical Memory Acquisition (2)

- Mandiant Memoryze
- HBGary FastDump
- GMG Systems, Inc. KnTTools
- F-Response
- MoonSols Windows Memory Toolkit
- AccessData FTK Imager
- Belkasoft Live RAM Capturer
- ATC-NY Windows Memory Reader
- Windows pmem
- others

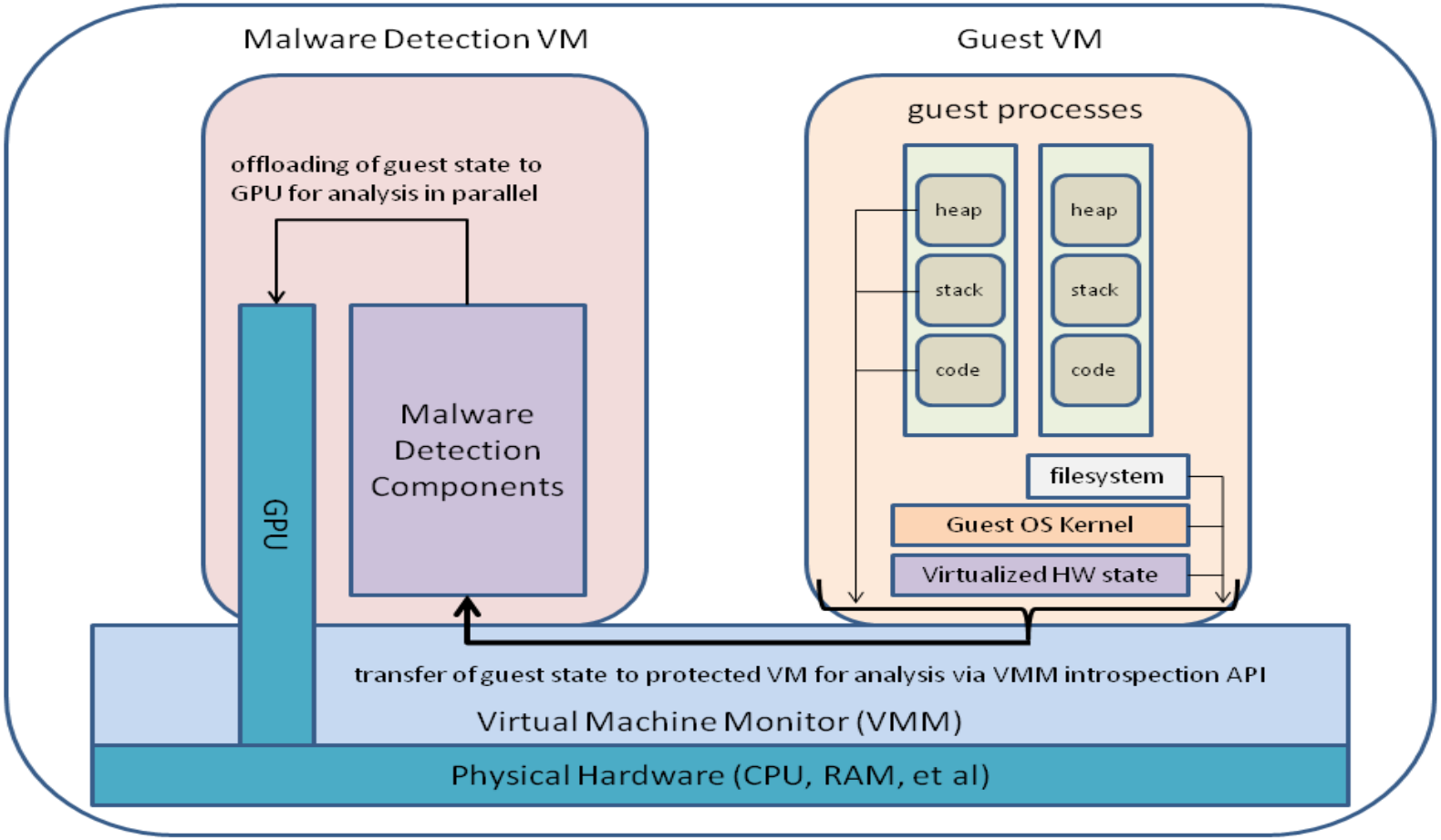
Memory Acquisition Issues

- Software-based solutions for memory imaging typically require loading software
- Probably erases some evidence
- Requires at least limited trust of the OS
- Malware, etc.
- Hardware-based solutions
  - Tribble
    - Brian Carrier
  - Firewire hacks
    - Maximillian Dornseif, metlstorm
  - Hardware must typically be in place

A Special Case: Virtualization

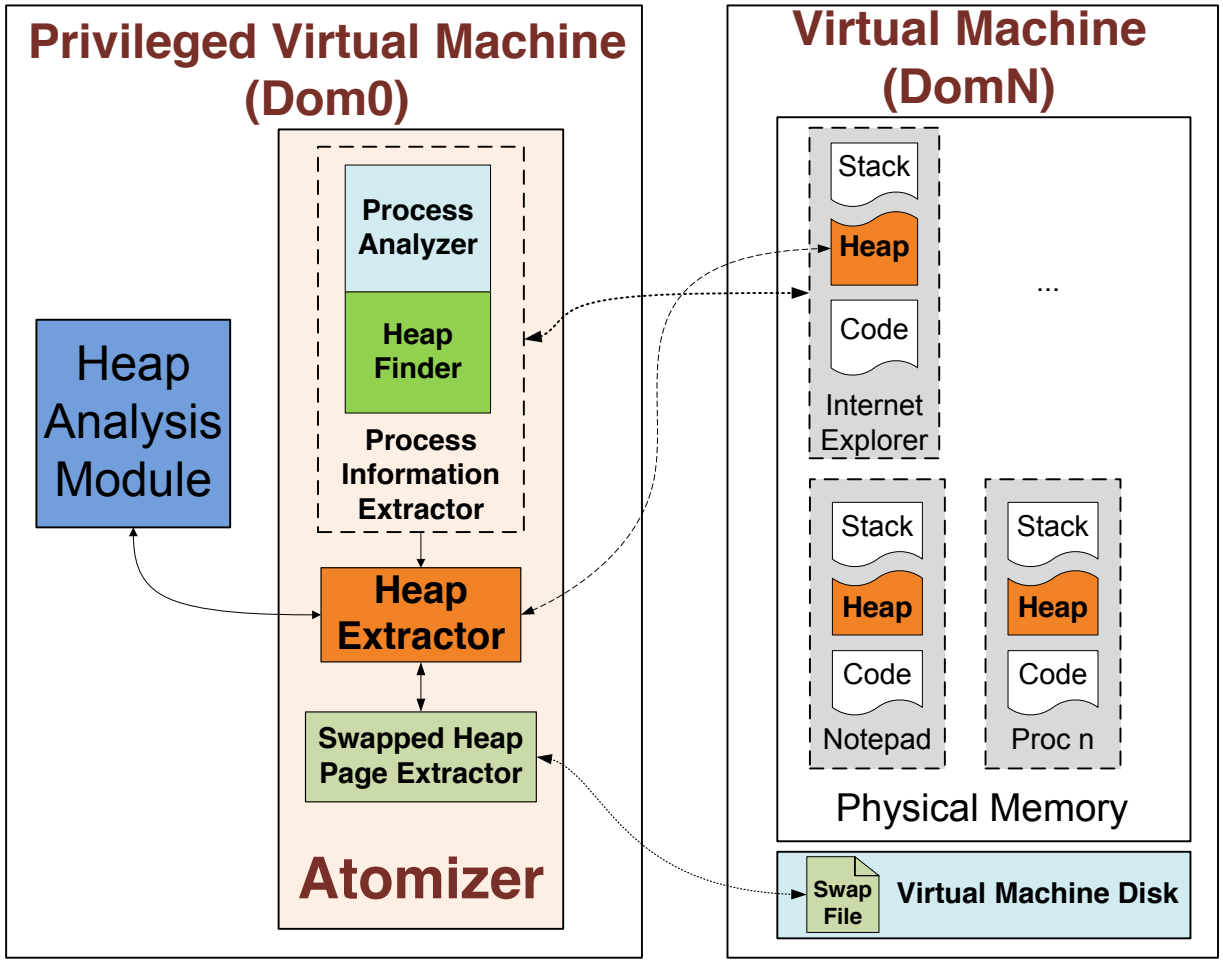
- Target is virtualized:
  - Suspending VM on VMWare Workstation / Fusion yields physical memory dump (*.vmem)
  - Can clone to investigate
  - Or use introspection (next slides)
  - And use the VM's memory dump with Volatility
  - .vmem file is also memory mapped!
- Target is a traditional computer
  - Also consider conversion of copies of physical disks to virtual disks via `raw2vmdk`, so a clone of system can be booted for investigative purposes

VM Introspection



"TC-Small-Virtual Machine Introspection-based Live Forensics for Detection of Software,"
National Science Foundation, PI: Golden G. Richard III.

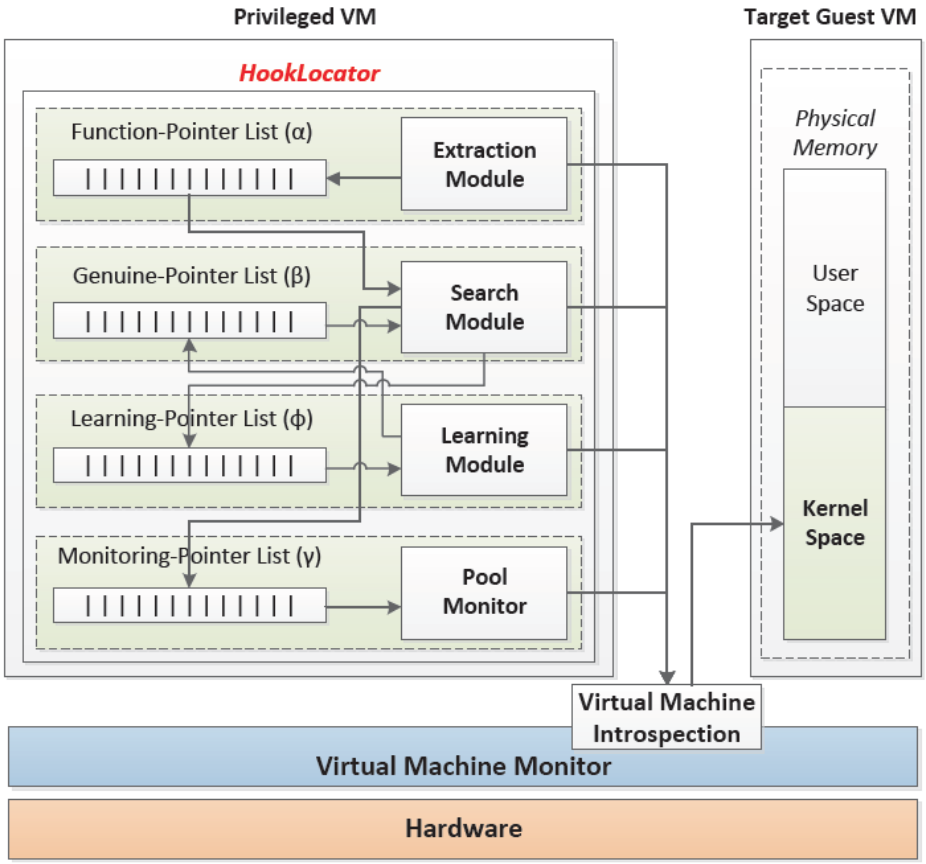
Application Analysis via VM Introspection



e.g., to detect heap spraying attacks

S. Javaid, A. Zoranic, I. Ahmed, G. G. Richard III, "Atomizer: A Fast, Scalable and Lightweight Heap Analyzer for Virtual Machines in a Cloud Environment," Proceedings of the 6th Layered Assurance Workshop (LAW'12), December 2012, Orlando, Florida.

OS Analysis via VM Introspection



I. Ahmed, G. G. Richard III, A. Zoranic, V. Roussev, "Integrity Checking of Function Pointers in Kernel Pools via Virtual Machine Introspection," Proceedings of the 16th Information Security Conference (ISC 2013), Best Paper Award, Dallas, TX.

Memory Acquisition Hazards

- Can't just scan entire physical address and copy
- Areas of physical address space dedicated to memory-mapped device I/O
- Touching these areas can freak out the devices and cause reboots, hangs, etc.
- Typically, touch only areas dedicated to OS / applications

For critical situations / real investigations:

Test tools on similar non-critical hardware!

They don’t all work (surprise)!

LiME Internals

Understanding how the tools work is important, too…

$ git clone https://github.com/504ensicsLabs/LiME.git

$ less /proc/iomem on a Linux machine to get an idea of what LiME is up to…

```
int init_module (void) {
        if(!path) {
                DBG("No path parameter specified");
                return -EINVAL;
        }
        if(!format) {
                DBG("No format parameter specified");
                return -EINVAL;
        }
        memset(zero_page, 0, sizeof(zero_page));
        if (!strcmp(format, "raw")) mode = LIME_MODE_RAW;
        else if (!strcmp(format, "lime"))
             mode = LIME_MODE_LIME;
        else if (!strcmp(format, "padded"))
             mode = LIME_MODE_PADDED;
        else {
                DBG("Invalid format parameter specified.");
                return -EINVAL;
        }
        method = (sscanf(path, "tcp:%d", &port) == 1)
             ? LIME_METHOD_TCP : LIME_METHOD_DISK;
        return init();
}
```

```
static int init() {
    struct resource *p;
    int err = 0;
    if((err = setup())) {
        cleanup();
        return err;
    }
    for (p = iomem_resource.child; p ; p = p->sibling) {
        if (strcmp(p->name, LIME_RAMSTR))  // "System RAM"
            continue;
        if (mode == LIME_MODE_LIME &&
            (err = write_lime_header(p))) {
            break;
        } else if (mode == LIME_MODE_PADDED &&
            (err = write_padding(
              (size_t)((p->start - 1)-p_last)))) {
            break;
        }
        if ((err = write_range(p))) {
            break;
        }
        p_last = p->end;
    }
    cleanup();
    return err;
}
```

```
static int write_lime_header(struct resource * res) {
        long s;

        lime_mem_range_header header;

        memset(&header,0,sizeof(lime_mem_range_header));
        header.magic = LIME_MAGIC;
        header.version = 1;
        header.s_addr = res->start;
        header.e_addr = res->end;

        s = write_vaddr(&header,
            sizeof(lime_mem_range_header));

        if (s != sizeof(lime_mem_range_header)) {
                DBG("Error sending header %ld", s);
                return (int) s;
        }

        return 0;
}
```

```
static int write_range(struct resource * res) {
    struct page *p;
    void *v;
    int s;
    for (i = res->start; i <= res->end; i += is) {
        p = pfn_to_page((i) >> PAGE_SHIFT);
        is = min((size_t) PAGE_SIZE,
                 (size_t) (res->end - i + 1));
        if (is < PAGE_SIZE) {
            write_padding(is);
        } else {
            v = kmap(p);
            s = write_vaddr(v, is);
            kunmap(p);
        }
    }
    return 0;
}
```

```
static int write_vaddr(void * v, size_t is) {
    return (method == LIME_METHOD_TCP) ?
      write_vaddr_tcp(v, is) :
      write_vaddr_disk(v, is);
}

static int setup(void) {
    return (method == LIME_METHOD_TCP) ?
      setup_tcp() :
      setup_disk();
}

static void cleanup(void) {
    return (method == LIME_METHOD_TCP) ?
      cleanup_tcp() : cleanup_disk();
}
```

```
int setup_disk() {
    mm_segment_t fs;
    int err;
    fs = get_fs();
    set_fs(KERNEL_DS);
    f = filp_open(path,
        O_WRONLY |
        O_CREAT |
        O_LARGEFILE |
        O_TRUNC |
        O_SYNC |
        O_DIRECT, 0444);
      …
    set_fs(fs);
    return 0;
}
```

```
int write_vaddr_disk(void * v, size_t is) {
        mm_segment_t fs;
        long s;
        loff_t pos;

        fs = get_fs();
        set_fs(KERNEL_DS);
        pos = f->f_pos;
        s = vfs_write(f, v, is, &pos);
        if (s == is) {
                f->f_pos = pos;
        }
        set_fs(fs);
        return s;
}
```

```
void cleanup_disk() {
        mm_segment_t fs;

        fs = get_fs();
        set_fs(KERNEL_DS);
        if(f) filp_close(f, NULL);
        set_fs(fs);
}
```

winpmem

```
/*
   Copyright 2012 Michael Cohen <scudette@gmail.com>

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   you may not use this file except in compliance with the License.
   You may obtain a copy of the License at

       http://www.apache.org/licenses/LICENSE-2.0

   Unless required by applicable law or agreed to in writing, software
   distributed under the License is distributed on an "AS IS" BASIS,
   WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
   See the License for the specific language governing permissions and
   limitations under the License.
*/
```

```
30
31 NTSTATUS IoUnload(IN PDRIVER_OBJECT DriverObject) {
32   UNICODE_STRING DeviceLinkUnicodeString;
33   NTSTATUS NtStatus;
34   PDEVICE_OBJECT pDeviceObject = DriverObject->DeviceObject;
35
36   RtlInitUnicodeString (&DeviceLinkUnicodeString, L"\\DosDevices\\"
37                         PMEM_DEVICE_NAME);
38   NtStatus = IoDeleteSymbolicLink (&DeviceLinkUnicodeString);
39
40   if (DriverObject != NULL) {
41     IoDeleteDevice(pDeviceObject);
42   }
43
44   return NtStatus;
45 }
46
```

```
/*
  Gets information about the memory layout.

  - The Physical memory address ranges.
 */
int AddMemoryRanges(struct PmemMemroyInfo *info, int len) {
  PPHYSICAL_MEMORY_RANGE MmPhysicalMemoryRange;
  int number_of_runs = 0;
  int required_length;

  // Enumerate address ranges.
  MmPhysicalMemoryRange = MmGetPhysicalMemoryRanges();

  if (MmPhysicalMemoryRange == NULL) {
    return -1;
  };

  /** Find out how many ranges there are. */
  for(number_of_runs=0;
      (MmPhysicalMemoryRange[number_of_runs].BaseAddress.QuadPart) ||
        (MmPhysicalMemoryRange[number_of_runs].NumberOfBytes.QuadPart);
      number_of_runs++);

  required_length = (sizeof(struct PmemMemroyInfo) +
                     number_of_runs * sizeof(PHYSICAL_MEMORY_RANGE));

```

```
74    /* Do we have enough space? */
75    if(len < required_length) {
76      return -1;
77    };
78
79    // Ensure exception bubbles up here to be caught by our caller.
80    //ProbeForWrite(info, required_length, 1);
81
82    RtlZeroMemory(info, required_length);
83
84    info->NumberOfRuns.QuadPart = number_of_runs;
85    RtlCopyMemory(&info->Run[0], MmPhysicalMemoryRange,
86                  number_of_runs * sizeof(PHYSICAL_MEMORY_RANGE));
87
88    ExFreePool(MmPhysicalMemoryRange);
89
90    return required_length;
91  };
```

```
94  static NTSTATUS wddCreate(IN PDEVICE_OBJECT DeviceObject, IN PIRP Irp) {
95    PDEVICE_EXTENSION ext=(PDEVICE_EXTENSION)DeviceObject->DeviceExtension;
96    PIO_STACK_LOCATION IrpStack = IoGetCurrentIrpStackLocation(Irp);
97
98    ext->MemoryHandle = 0;
99
100   Irp->IoStatus.Status = STATUS_SUCCESS;
101   Irp->IoStatus.Information = 0;
102
103   IoCompleteRequest(Irp,IO_NO_INCREMENT);
104   return STATUS_SUCCESS;
105 };
106
107 static NTSTATUS wddClose(IN PDEVICE_OBJECT DeviceObject, IN PIRP Irp) {
108  PDEVICE_EXTENSION ext=(PDEVICE_EXTENSION)DeviceObject->DeviceExtension;
109  PIO_STACK_LOCATION IrpStack = IoGetCurrentIrpStackLocation(Irp);
110
111  if(ext->MemoryHandle != 0) {
112    ZwClose(ext->MemoryHandle);
113  };
114
115  Irp->IoStatus.Status = STATUS_SUCCESS;
116  Irp->IoStatus.Information = 0;
117
118  IoCompleteRequest(Irp,IO_NO_INCREMENT);
119  return STATUS_SUCCESS;
120 }
```

```
122 NTSTATUS wddDispatchDeviceControl(IN PDEVICE_OBJECT DeviceObject,
123                                   IN PIRP Irp)
124 {
125   UNICODE_STRING DestinationPath;
126   PIO_STACK_LOCATION IrpStack;
127   NTSTATUS status = STATUS_SUCCESS;
128   ULONG IoControlCode;
129   PVOID IoBuffer;
130   PULONG OutputBuffer;
131   PDEVICE_EXTENSION ext;
132   ULONG InputLen, OutputLen;
133
134   ULONG Level;
135   ULONG Type;
136
137   // We must be running in PASSIVE_LEVEL or we bluescreen here. We
138   // theoretically should always be running at PASSIVE_LEVEL here, but
139   // in case we ended up here at the wrong IRQL its better to bail
140   // than to bluescreen.
141   if(KeGetCurrentIrql() != PASSIVE_LEVEL) {
142     status = STATUS_ABANDONED;
143     goto exit;
144   };
145
146   ext = (PDEVICE_EXTENSION)DeviceObject->DeviceExtension;
147
```

```
148   Irp->IoStatus.Information = 0;
149
150   IrpStack = IoGetCurrentIrpStackLocation(Irp);
151
152   IoBuffer = Irp->AssociatedIrp.SystemBuffer;
153   OutputLen = IrpStack->Parameters.DeviceIoControl.OutputBufferLength;
154   InputLen = IrpStack->Parameters.DeviceIoControl.InputBufferLength;
155   IoControlCode = IrpStack->Parameters.DeviceIoControl.IoControlCode;
156
157   switch ((IoControlCode & 0xFFFFFF0F)) {
158
159     // Return information about memory layout etc through this ioctrl.
160   case IOCTL_GET_INFO: {
161     struct PmemMemroyInfo *info = (void *)IoBuffer;
162     int res;
163     IMAGE_DOS_HEADER *KernBase;
164
165     // Check we have enough room here.
166     if (OutputLen < sizeof(struct PmemMemroyInfo)) {
167       status = STATUS_INFO_LENGTH_MISMATCH;
168       break;
169     };
170
171     __try {
172       res = AddMemoryRanges(info, OutputLen);
173     } __except(EXCEPTION_EXECUTE_HANDLER) {
174       status = STATUS_INFO_LENGTH_MISMATCH;
175       break;
176     }
```

```
178     WinDbgPrint("Returning info on the system memory.\n");
179     if(res > 0) {
180       KernBase = KernelGetModuleBaseByPtr(NtBuildNumber, "NtBuildNumber");
181
182       // We are currently running in user context which means __readcr3() will
183       // return the process CR3. So we return the kernel CR3 we found
184       // when loading. Alternatively we could get the kernel DTB from
185       // the KDBG but that is less accurate.
186       info->CR3.QuadPart = CR3.QuadPart;
187
188       info->NtBuildNumber.QuadPart = *NtBuildNumber;
189
190       // Fill in KPCR.
191       GetKPCR(info);
192
193       // The kernel base.
194       info->KernBase.QuadPart = (uintptr_t)KernBase;
195       info->KDBG.QuadPart = (uintptr_t)KDBGScan(KernBase);
196
197       Irp->IoStatus.Information = res;
198       status = STATUS_SUCCESS;
199     } else {
200       status = STATUS_INFO_LENGTH_MISMATCH;
201     };
202   }; break;
```

```
204   case IOCTL_SET_MODE: {
205     WinDbgPrint("Setting Acquisition mode.\n");
206
207     if (InputLen == sizeof(struct PmemMemoryControl)) {
208       struct PmemMemoryControl *ctrl = (void *)IoBuffer;
209
210       ext->mode = ctrl->mode;
211
212       switch(ctrl->mode) {
213       case ACQUISITION_MODE_PHYSICAL_MEMORY:
214         WinDbgPrint("Using physical memory device for acquisition.\n");
215         break;
216
217       case ACQUISITION_MODE_MAP_IO_SPACE:
218         WinDbgPrint("Using MmMapIoSpace for acquisition.\n");
219         break;
220
221       default:
222         WinDbgPrint("Invalid acquisition mode %d.\n", ctrl->mode);
223         status = STATUS_INVALID_PARAMETER;
224       };
225
226     } else {
227       status = STATUS_INFO_LENGTH_MISMATCH;
228     };
229   }; break;
230
```

```
231 #if PMEM_WRITE_ENABLED
232   case IOCTL_WRITE_ENABLE: {
233     ext->WriteEnabled = !ext->WriteEnabled;
234     WinDbgPrint("Write mode is %d. Do you know what you are doing?\n",
235                 ext->WriteEnabled);
236   }; break;
237 #endif
238
239   default: {
240     WinDbgPrint("Invalid IOCTRL %d\n", IoControlCode);
241     status = STATUS_INVALID_PARAMETER;
242   };
243   }
244
245  exit:
246   Irp->IoStatus.Status = status;
247   IoCompleteRequest(Irp,IO_NO_INCREMENT);
248   return status;
249 }
```

```
252 NTSTATUS DriverEntry (IN PDRIVER_OBJECT DriverObject,
253                       IN PUNICODE_STRING RegistryPath)
254 {
255   UNICODE_STRING DeviceName, DeviceLink;
256   NTSTATUS NtStatus;
257   PDEVICE_OBJECT DeviceObject = NULL;
258   PDEVICE_EXTENSION extension;
259
260   WinDbgPrint("WinPMEM - " PMEM_VERSION " - Physical memory acquisition\n");
261
262 #if PMEM_WRITE_ENABLED
263   WinDbgPrint("WinPMEM write support available!");
264 #endif
265
266   WinDbgPrint("Copyright (c) 2012, Michael Cohen <scudette@gmail.com> based "
267               "on win32dd code by Matthieu Suiche <http://www.msuiche.net>\n");
268
269   RtlInitUnicodeString (&DeviceName, L"\\Device\\" PMEM_DEVICE_NAME);
270
```

```
271   // We create our secure device.
272   // http://msdn.microsoft.com/en-us/library/aa490540.aspx
273   NtStatus = IoCreateDeviceSecure(DriverObject,
274                                   sizeof(DEVICE_EXTENSION),
275                                   &DeviceName,
276                                   FILE_DEVICE_UNKNOWN,
277                                   FILE_DEVICE_SECURE_OPEN,
278                                   FALSE,
279                                   &SDDL_DEVOBJ_SYS_ALL_ADM_ALL,
280                                   &GUID_DEVCLASS_PMEM_DUMPER,
281                                   &DeviceObject);
282
283   if (!NT_SUCCESS(NtStatus)) {
284     WinDbgPrint ("IoCreateDevice failed. => %08X\n", NtStatus);
285     return NtStatus;
286   }
287
288   DriverObject->MajorFunction[IRP_MJ_CREATE] = wddCreate;
289   DriverObject->MajorFunction[IRP_MJ_CLOSE] = wddClose;
290   DriverObject->MajorFunction[IRP_MJ_DEVICE_CONTROL] = wddDispatchDeviceControl;
291   DriverObject->MajorFunction[IRP_MJ_READ] = PmemRead;
292
293 #if PMEM_WRITE_ENABLED == 1
294   // Support writing.
295   DriverObject->MajorFunction[IRP_MJ_WRITE] = PmemWrite;
296 #endif
297   DriverObject->DriverUnload = IoUnload;
```

```
299   // Use buffered IO - a bit slower but simpler to implement, and more
300   // efficient for small reads.
301   SetFlag(DeviceObject->Flags, DO_BUFFERED_IO );
302   ClearFlag(DeviceObject->Flags, DO_DIRECT_IO );
303   ClearFlag(DeviceObject->Flags, DO_DEVICE_INITIALIZING);
304
305   RtlInitUnicodeString (&DeviceLink, L"\\DosDevices\\" PMEM_DEVICE_NAME);
306
307   NtStatus = IoCreateSymbolicLink (&DeviceLink, &DeviceName);
308
309   if (!NT_SUCCESS(NtStatus)) {
310     WinDbgPrint ("IoCreateSymbolicLink failed. => %08X\n", NtStatus);
311     IoDeleteDevice (DeviceObject);
312   }
313
314   // Populate globals in kernel context.
315   CR3.QuadPart = __readcr3();
316
317   // Initialize the device extension with safe defaults.
318   extension = DeviceObject->DeviceExtension;
319   extension->mode = ACQUISITION_MODE_PHYSICAL_MEMORY;
320
321   return NtStatus;
322 }
```

```
19 static int EnsureExtensionHandle(PDEVICE_EXTENSION extension) {
20   NTSTATUS NtStatus;
21   UNICODE_STRING PhysicalMemoryPath;
22   OBJECT_ATTRIBUTES MemoryAttributes;
23
24   /* Make sure we have a valid handle now. */
25   if(!extension->MemoryHandle) {
26     RtlInitUnicodeString(&PhysicalMemoryPath, L"\\Device\\PhysicalMemory");
27
28     InitializeObjectAttributes(&MemoryAttributes,
29                                &PhysicalMemoryPath,
30                                OBJ_KERNEL_HANDLE,
31                                (HANDLE) NULL,
32                                (PSECURITY_DESCRIPTOR) NULL);
33
34     NtStatus = ZwOpenSection(&extension->MemoryHandle,
35                              SECTION_MAP_READ, &MemoryAttributes);
36
37     if (!NT_SUCCESS(NtStatus)) {
38       WinDbgPrint("Failed ZwOpenSection(MemoryHandle) => %08X\n", NtStatus);
39       return 0;
40     }
41   };
42
43   return 1;
44 }
```

```
130 NTSTATUS PmemRead(IN PDEVICE_OBJECT  DeviceObject, IN PIRP  Irp) {
131   PVOID Buf;       //Buffer provided by user space.
132   ULONG BufLen;    //Buffer length for user provided buffer.
133   LARGE_INTEGER BufOffset; // The file offset requested from userspace.
134   ULONG DataLen;  //Buffer length for Driver Data Buffer
135   PIO_STACK_LOCATION pIoStackIrp;
136   PDEVICE_EXTENSION extension;
137   NTSTATUS status = STATUS_SUCCESS;
138
139   // We must be running in PASSIVE_LEVEL or we bluescreen here. We
140   // theoretically should always be running at PASSIVE_LEVEL here, but
141   // in case we ended up here at the wrong IRQL its better to bail
142   // than to bluescreen.
143   if(KeGetCurrentIrql() != PASSIVE_LEVEL) {
144     status = STATUS_ABANDONED;
145     goto exit;
146   };
147
148   extension = DeviceObject->DeviceExtension;
149
150   pIoStackIrp = IoGetCurrentIrpStackLocation(Irp);
151   BufLen = pIoStackIrp->Parameters.Read.Length;
152   BufOffset = pIoStackIrp->Parameters.Read.ByteOffset;
153   Buf = (PCHAR)(Irp->AssociatedIrp.SystemBuffer);
```

```
155   switch(extension->mode) {
156
157     // Read using the physical memory handle.
158   case ACQUISITION_MODE_PHYSICAL_MEMORY:
159     status = DeviceRead(extension, BufOffset, Buf, &BufLen,
160                         PhysicalMemoryPartialRead);
161     Irp->IoStatus.Information = pIoStackIrp->Parameters.Read.Length;
162     break;
163
164   case ACQUISITION_MODE_MAP_IO_SPACE:
165     status = DeviceRead(extension, BufOffset, Buf, &BufLen,
166                         MapIOPagePartialRead);
167     Irp->IoStatus.Information = pIoStackIrp->Parameters.Read.Length;
168     break;
169
170   default:
171     WinDbgPrint("Acquisition mode %u not supported.\n", extension->mode);
172     status = STATUS_NOT_IMPLEMENTED;
173     BufLen = 0;
174   }
175
176  exit:
177   Irp->IoStatus.Status = status;
178   IoCompleteRequest(Irp, IO_NO_INCREMENT);
179
180   return status;
181 }
```

```
107 static NTSTATUS DeviceRead(IN PDEVICE_EXTENSION extension, LARGE_INTEGER offset,
108                             PCHAR buf, ULONG *count,
109                             LONG (*handler)(IN PDEVICE_EXTENSION, LARGE_INTEGER,
110                                             PCHAR, ULONG)) {
111   int remaining = *count;
112
113   while(remaining > 0) {
114     int result = handler(extension, offset, buf, remaining);
115
116     /* Error Occured. */
117     if(result < 0) return result;
118     /* No data available. */
119     if(result==0) break;
120
121     offset.QuadPart += result;
122     buf += result;
123     remaining -= result;
124   };
125
126   return STATUS_SUCCESS;
127 };
```

```
47 static LONG PhysicalMemoryPartialRead(IN PDEVICE_EXTENSION extension,
48                                        LARGE_INTEGER offset, PCHAR buf,
49                                        ULONG count) {
50   ULONG page_offset = offset.QuadPart % PAGE_SIZE;
51   ULONG to_read = min(PAGE_SIZE - page_offset, count);
52   PUCHAR mapped_buffer = NULL;
53   SIZE_T ViewSize = PAGE_SIZE;
54   NTSTATUS NtStatus;
55
56
57   if (EnsureExtensionHandle(extension)) {
58     /* Map page into the Kernel AS */
59     NtStatus = ZwMapViewOfSection(extension->MemoryHandle, (HANDLE) -1,
60                                   &mapped_buffer, 0L, PAGE_SIZE, &offset,
61                                   &ViewSize, ViewUnmap, 0, PAGE_READONLY);
62
63     if (NT_SUCCESS(NtStatus)) {
64       RtlCopyMemory(buf, mapped_buffer + page_offset, to_read);
65       ZwUnmapViewOfSection((HANDLE)-1, mapped_buffer);
66
67     } else {
68       WinDbgPrint("Failed to Map page at 0x%llX\n", offset.QuadPart);
69       RtlZeroMemory(buf, to_read);
70     };
71   };
72
73   return to_read;
74 };
```

```
77  // Read a single page using MmMapIoSpace.
78  static LONG MapIOPagePartialRead(IN PDEVICE_EXTENSION extension,
79                                   LARGE_INTEGER offset, PCHAR buf,
80                                   ULONG count) {
81    ULONG page_offset = offset.QuadPart % PAGE_SIZE;
82    ULONG to_read = min(PAGE_SIZE - page_offset, count);
83    PUCHAR mapped_buffer = NULL;
84    SIZE_T ViewSize = PAGE_SIZE;
85    NTSTATUS NtStatus;
86    LARGE_INTEGER ViewBase;
87
88    // Round to page size
89    ViewBase.QuadPart = offset.QuadPart - page_offset;
90
91    // Map exactly one page.
92    mapped_buffer = MmMapIoSpace(ViewBase, PAGE_SIZE, MmNonCached);
93
94    if (mapped_buffer) {
95      RtlCopyMemory(buf, mapped_buffer + page_offset, to_read);
96    } else {
97      // Failed to map page, null fill the buffer.
98      RtlZeroMemory(buf, to_read);
99    };
100
101   MmUnmapIoSpace(mapped_buffer, PAGE_SIZE);
102
103   return to_read;
104 };
```

Volatility Memory Image Support

- Volatility supports a bunch of different memory formats, to cover output of most available tools
  - Raw
  - LiME format
  - ATC-NY Mac format
  - VirtualBox, VMWare, Fusion, Qemu, etc.
  - Windows crash dump
  - Hibernation files

Virtual←→Physical Address Translation

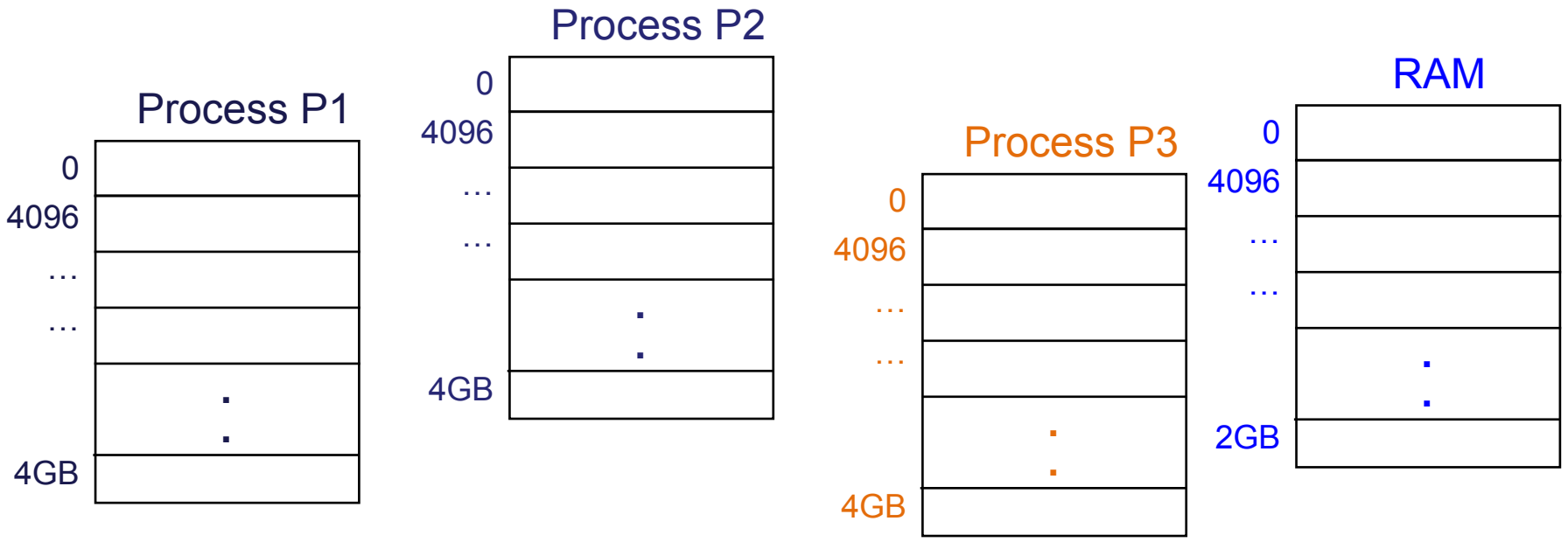
- Address translation is **crucial** in memory analysis
- Applications and OS use virtual addresses
- Must translate between virtual and physical addresses to provide context for physical memory dump regions
- Normally, largely handled by memory management hardware

Virtual Memory

- Provides contiguous, linear address space for processes
- Virtual address space is divided into fixed-size pages
  - Physical memory is divided into pages of same size
  - On x86 Intel, these are normally 4K
- OS keeps track of free and allocated pages
- Processes get only as many pages as they need

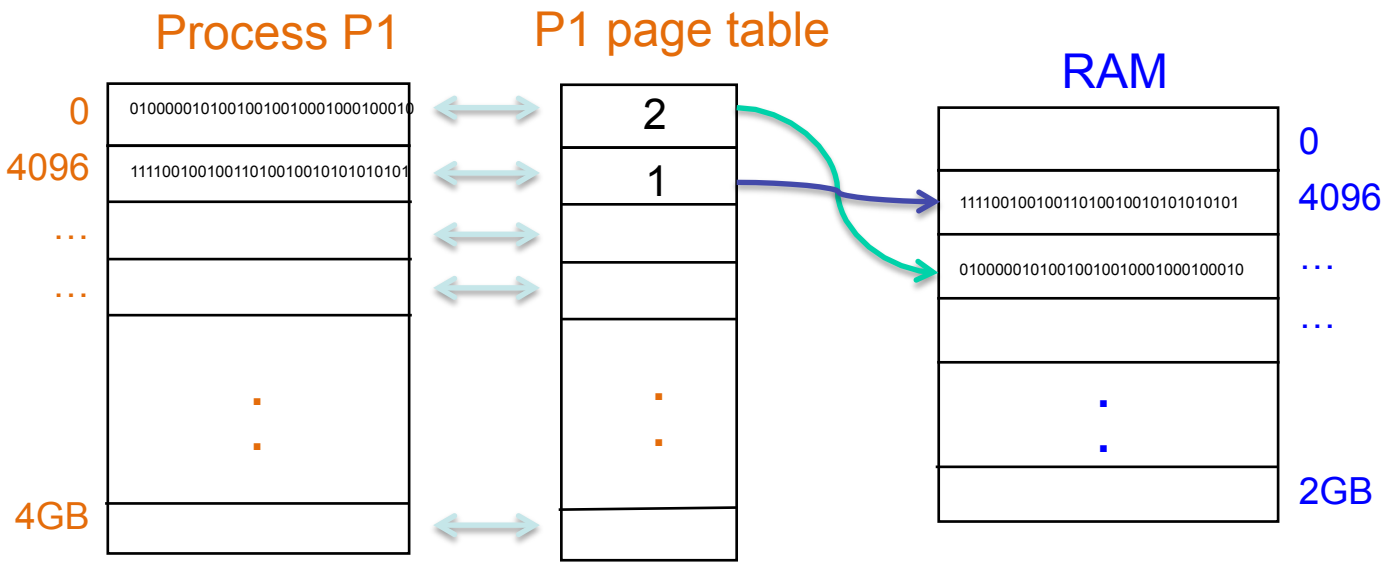
Logical vs. Physical Addresses

- Virtual address: Address whose scope is a particular process or OS kernel
- Physical address: Location in physical RAM

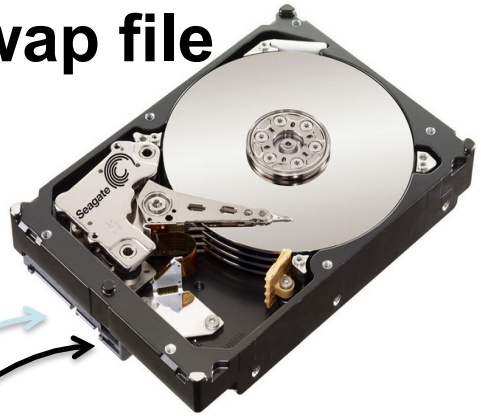


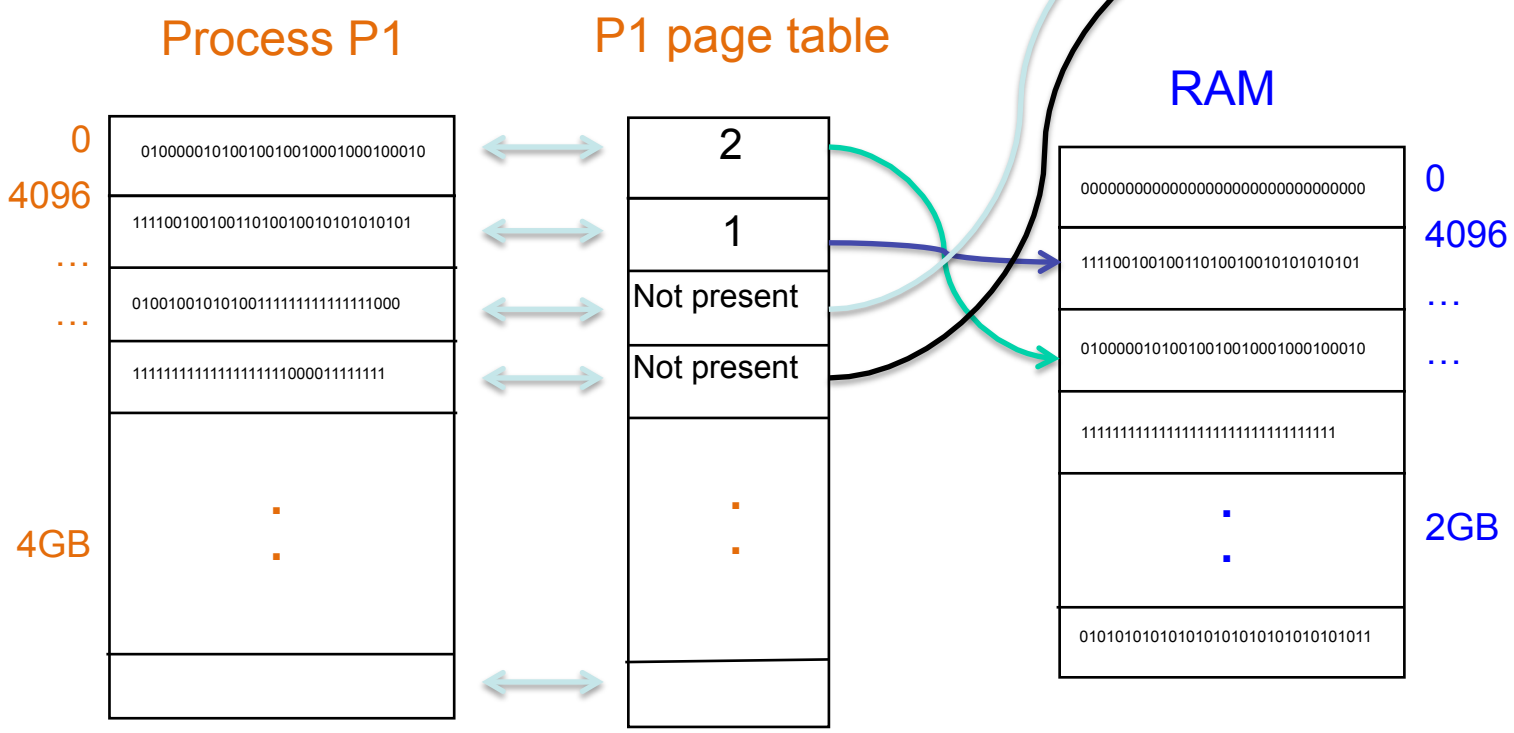
Paging: (Very) Simplified View

- Page tables (per process) are used to translate logical to physical addresses
- Pages for a particular process are generally not in contiguous order in RAM



Virtual Memory and Address Translation: Simplified Version





32-bit mode: 4K Pages

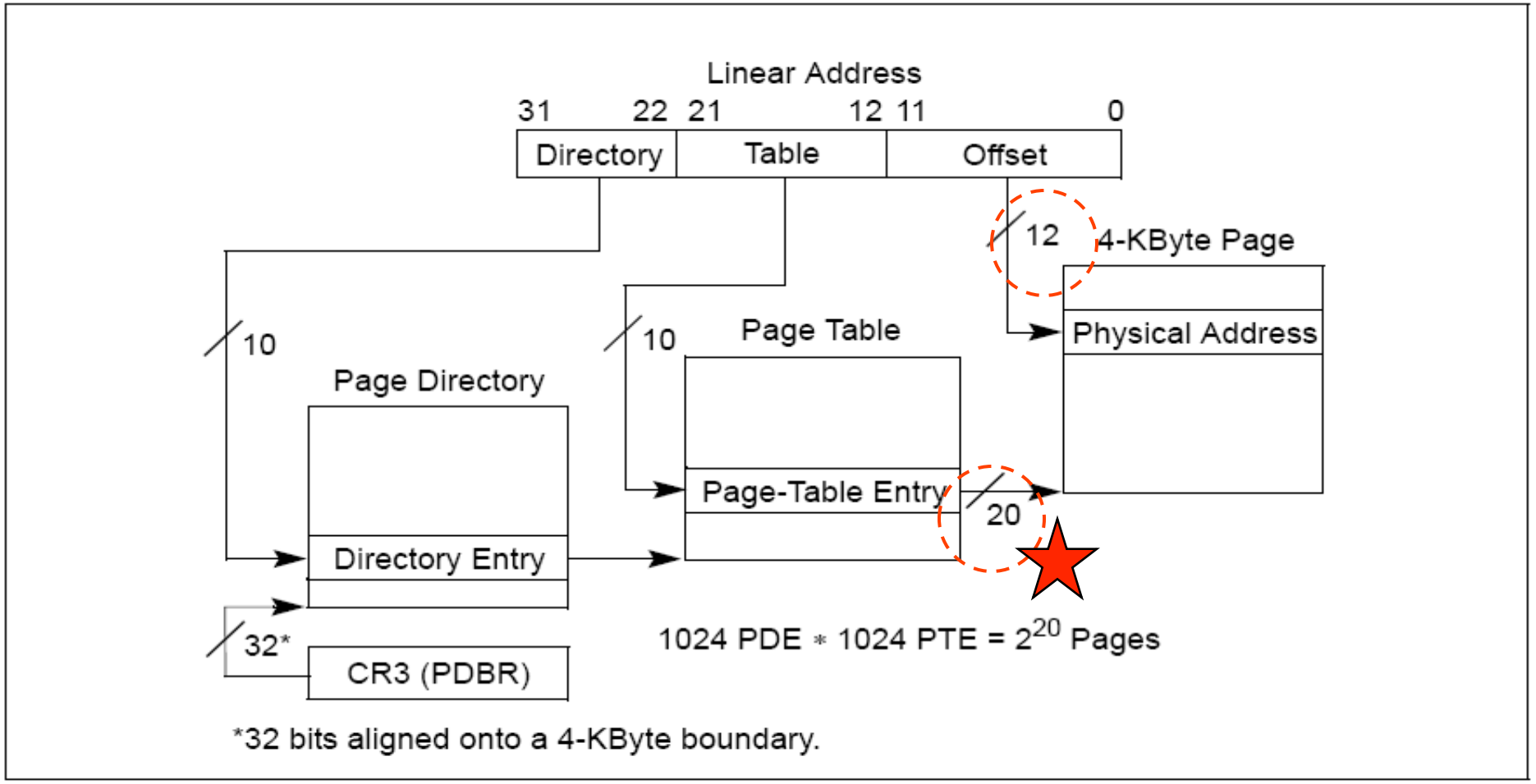


Figure 3-12. Linear Address Translation (4-KByte Pages)

```
struct task_struct {
        …
  struct mm_struct *mm;
        …
}
```

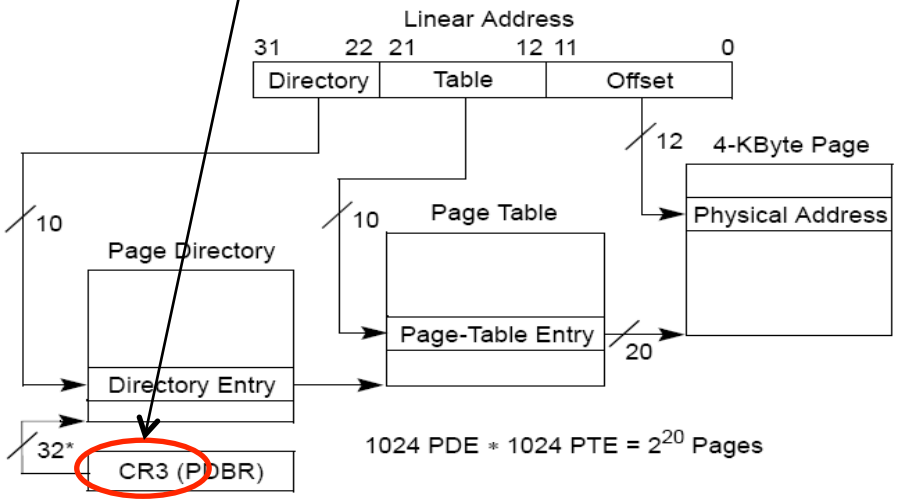
```
struct mm_struct {
  struct vm_area_struct *mmap;
        …
  pgd_t *pgd;
        …
}
```

```
struct vm_area_struct {
  unsigned long vm_start;
  unsigned long vm_end;
        …
  struct vm_area_struct *vm_next,
                        *vm_prev;
        …
}
```

```
struct vm_area_struct {
  unsigned long vm_start;
  unsigned long vm_end;
        …
  struct vm_area_struct *vm_next,
                        *vm_prev;
        …
}
```

…

…



32-bit mode: 4MB Pages

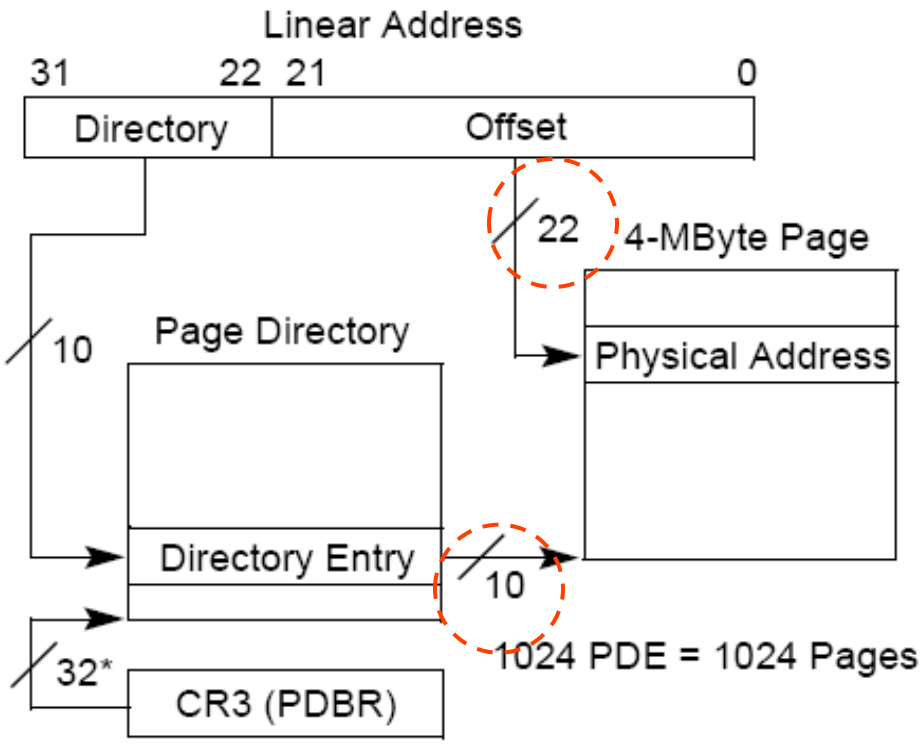


Figure 3-13. Linear Address Translation (4-MByte Pages)

32-bit Mode w/ PAE: 4K pages

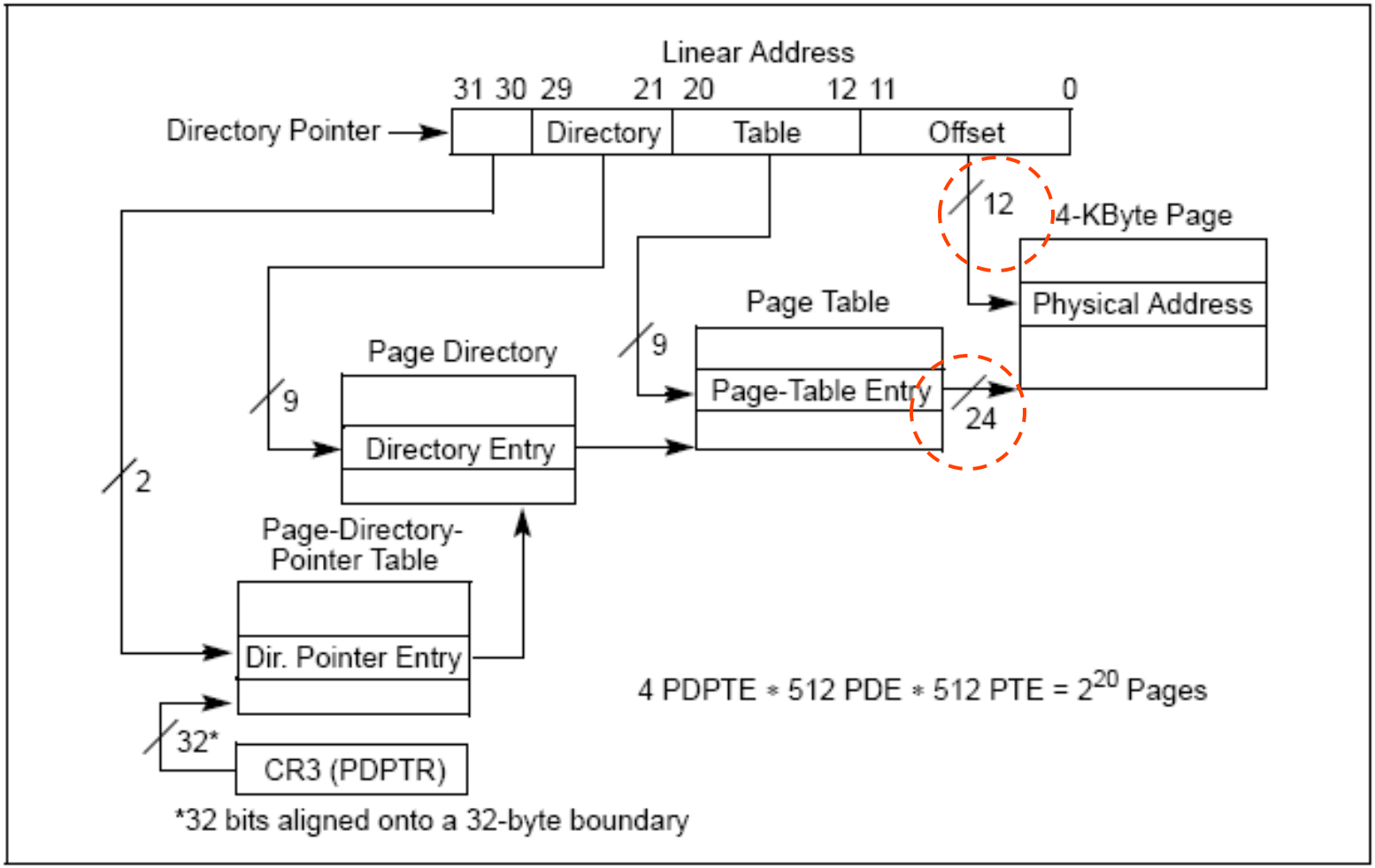


Figure 3-18. Linear Address Translation With PAE Enabled (4-KByte Pages)

32-bit Mode w/ PAE: 2MB pages

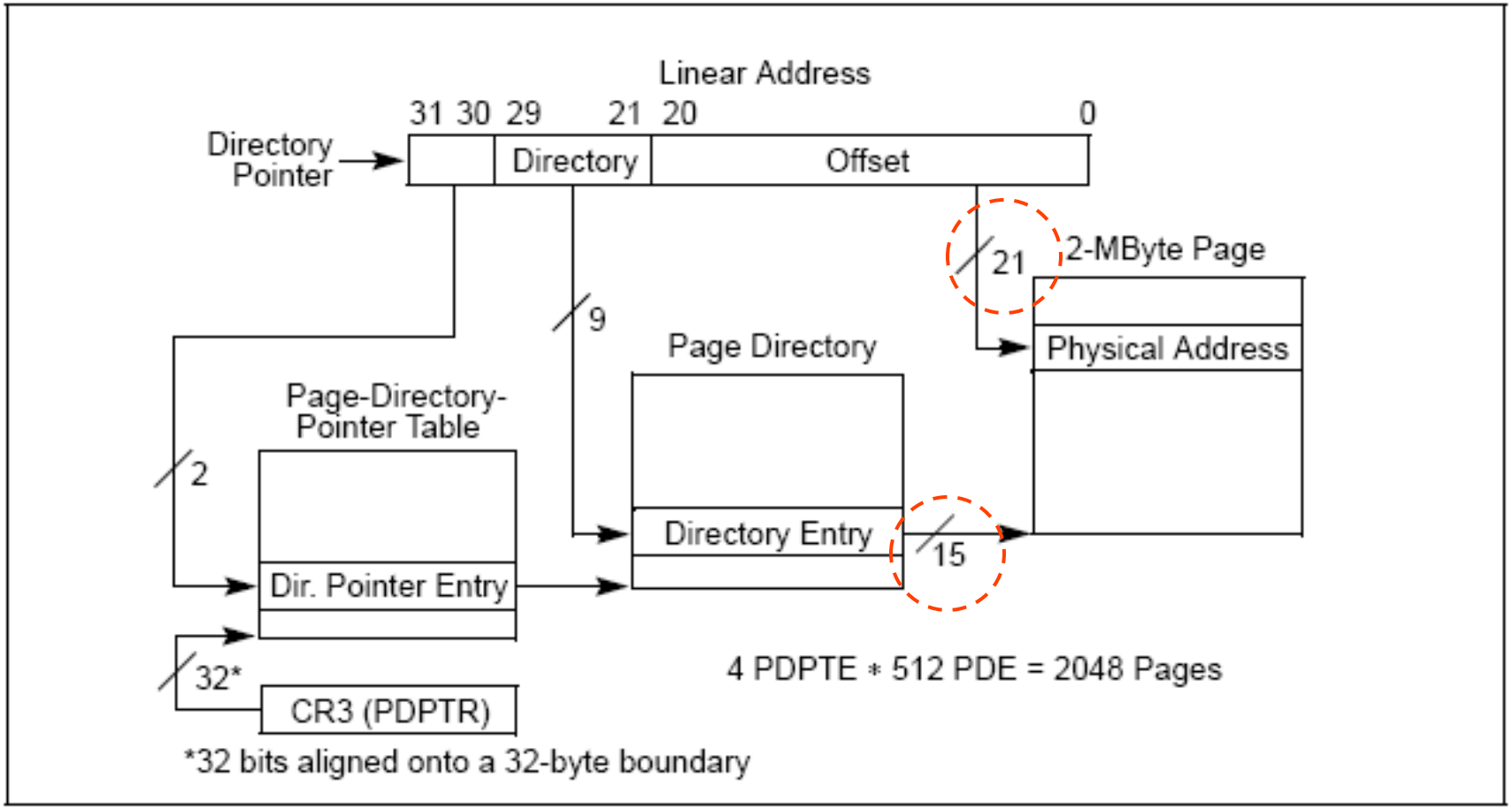


Figure 3-19. Linear Address Translation With PAE Enabled (2-MByte Pages)

64-bit Mode: 4-level Page Tables: 4K Pages

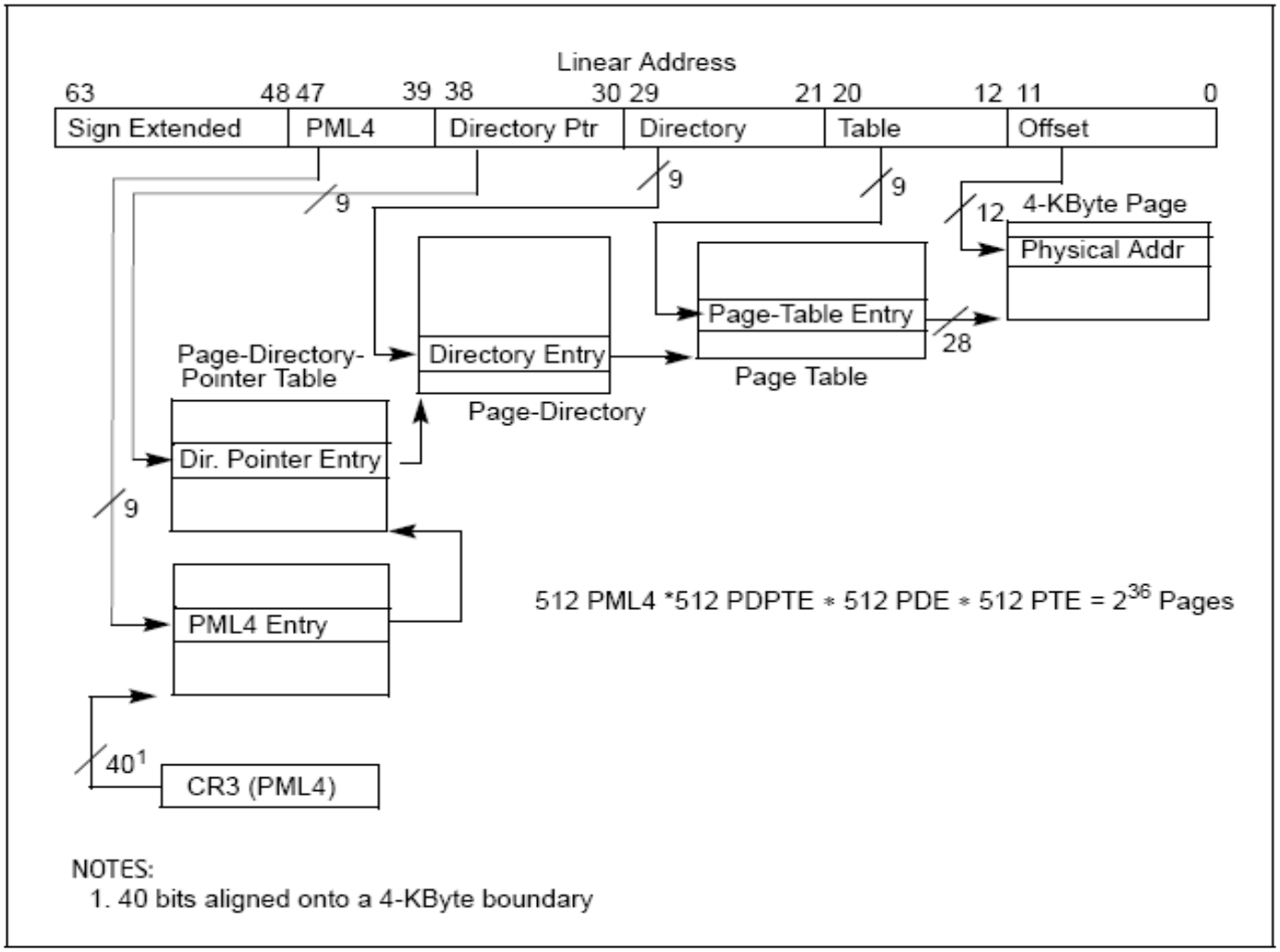


Figure 3-24. IA-32e Mode Paging Structures (4-KByte Pages)

64-bit Mode: 4-level Page Tables: 2MB Pages

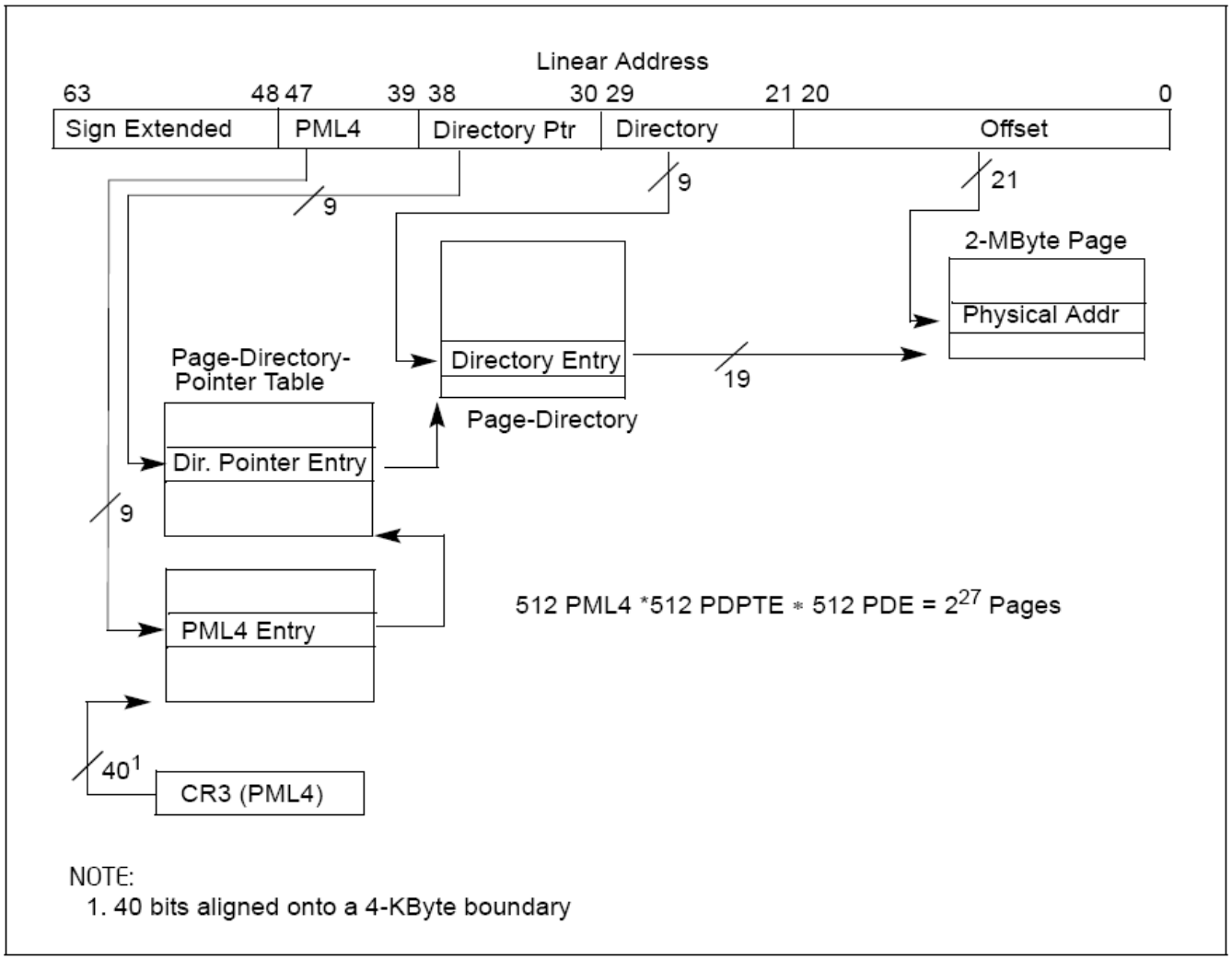


Figure 3-25. IA-32e Mode Paging Structures (2-MByte pages)

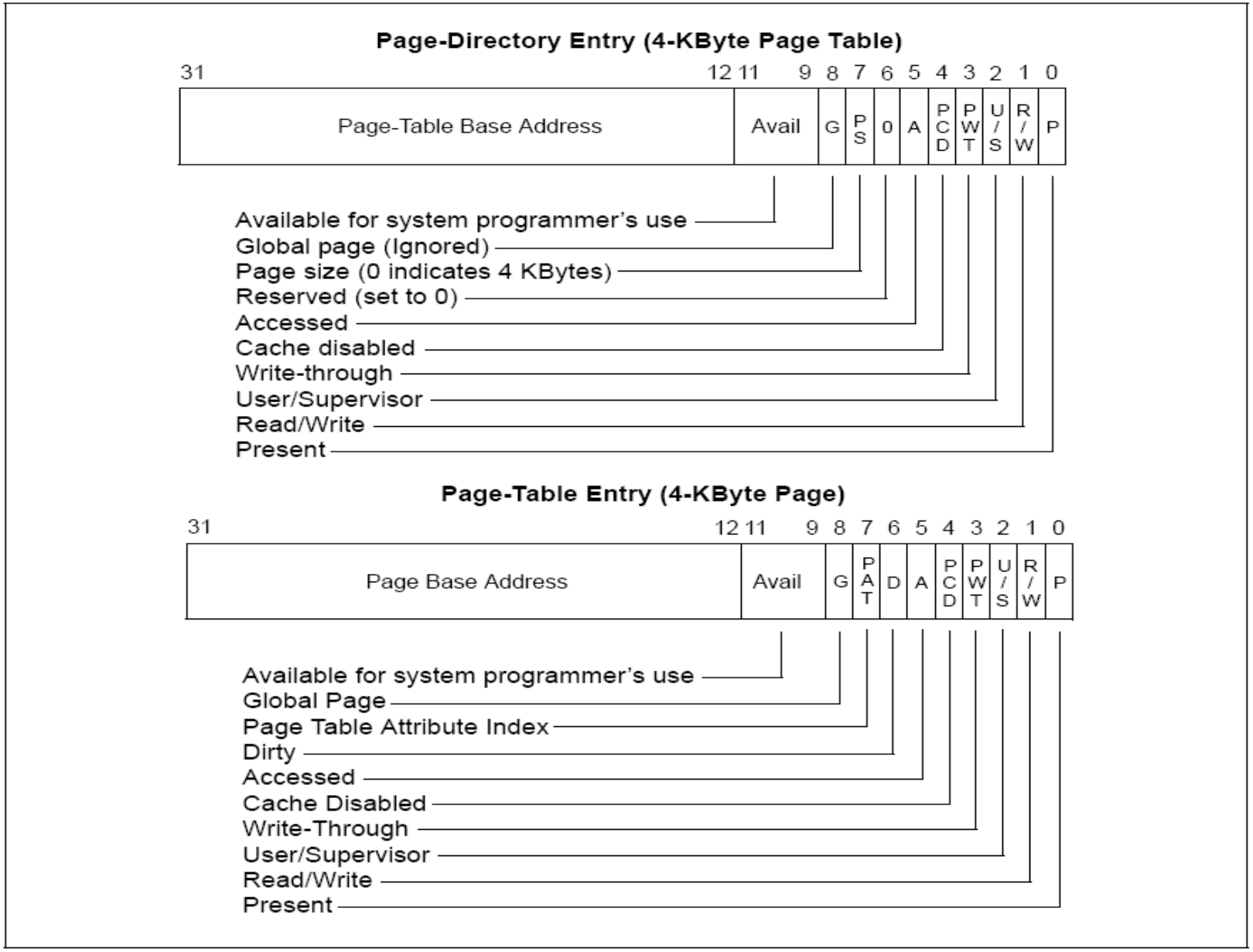


Figure 3-14. Format of Page-Directory and Page-Table Entries for 4-KByte Pages and 32-Bit Physical Addresses

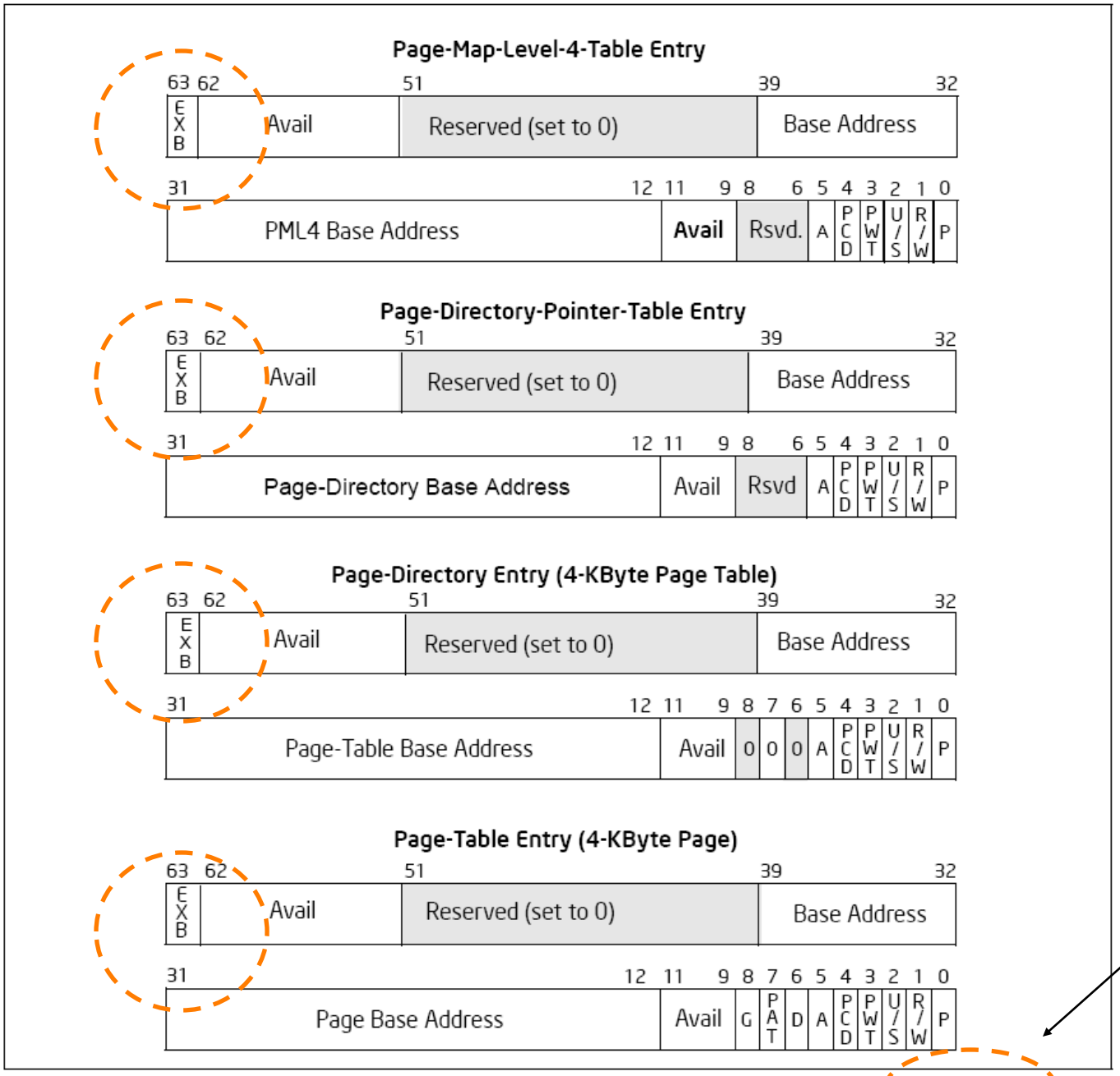


Figure 3-26. Format of Paging Structure Entries for 4-KByte Pages in IA-32e Mode

Data Structures

- Basic OS (and application) data types are often C data types
  - char, int, unsigned int, short, long, pointers, etc.
- Plus structures built on these types
- Abstract data types provide models for data and the operations that can be performed
- Accurately modeling OS and application structures is essential for memory analysis tools

Strings

- Simple null-terminated arrays of characters (ASCII or Unicode)
- Microsoft's _UNICODE_STRING type is a special case where length is tracked separately
- Extracting strings from memory dumps can often provide clues and useful evidence, but associating context is difficult (without virtual address translation)

Linked Lists

- Singly and doubly linked lists are commonly used for tracking collections of objects
- Track processes, DLLs, loaded modules, etc.
- Memory forensics tools often find pointers to “list heads” (beginning of the lists)
- Rootkits commonly “hide” elements by manipulating the lists, removing elements, adjusting pointers

Additional Structures

- Hash tables store data in <key, element> pairs and provide efficient searching and insertion operations
  - e.g., Linux PID Hash Table
- Trees are composed of a set of nodes that store data and links that connect the nodes
  - Hierarchical, binary trees have a root node with children that connect to at most 2 other nodes
  - The actual nodes can be any data type
  - e.g., process memory allocations on Windows are stored in a tree data structure

Memory Dump Analysis

- Once you have a memory dump, then what?
- Analyze dump to extract information about processes, threads, open files, sockets, etc.
- Most interesting things in the kernel are “objects” (e.g., structures)
- Objects likely have many pointers to other objects

Discovering Objects

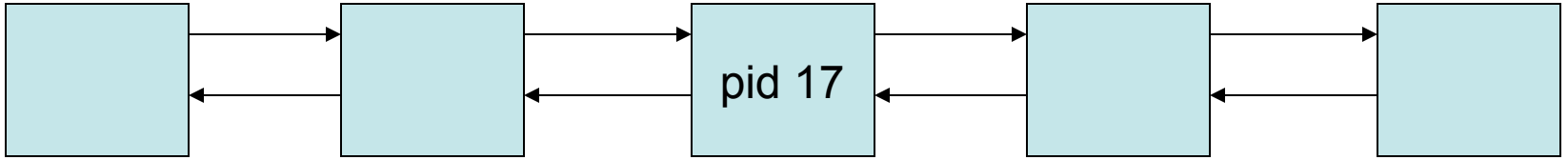
- Method # 1:
  - **List Walking**: Find start, then analyze lists/tables of kernel structures
- Method # 2:
  - **Carving**: Discover locations of individual, interesting objects
- Hybrid:
  - Combine these approaches

Finding Objects: List-Walking

- Basic idea beyond list-based memory analysis
  - From symbol table for kernel or other source, determine location of interesting tables/lists and enumerate
  - e.g., for Linux, use `/boot/System.map` file created when kernel is compiled
  - Can locate system call table, first process, etc.
- One challenge for list walking: **DKOM**
- Another challenge is that **deallocated structures are (typically) not in the lists**
- e.g., won't find representations of terminated processes

DKOM: FU "Rootkit" under Windows

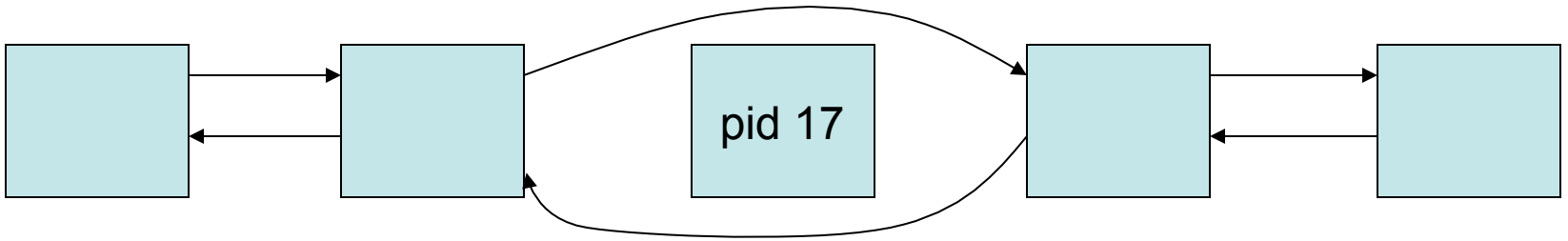
Doubly-linked process list in Windows kernel



Example of **DKOM**:
Direct **K**ernel **O**bject **M**anipulation

```
C:\> fu -ph 17
```

Processes continue to run because Windows scheduler handles threads, not processes



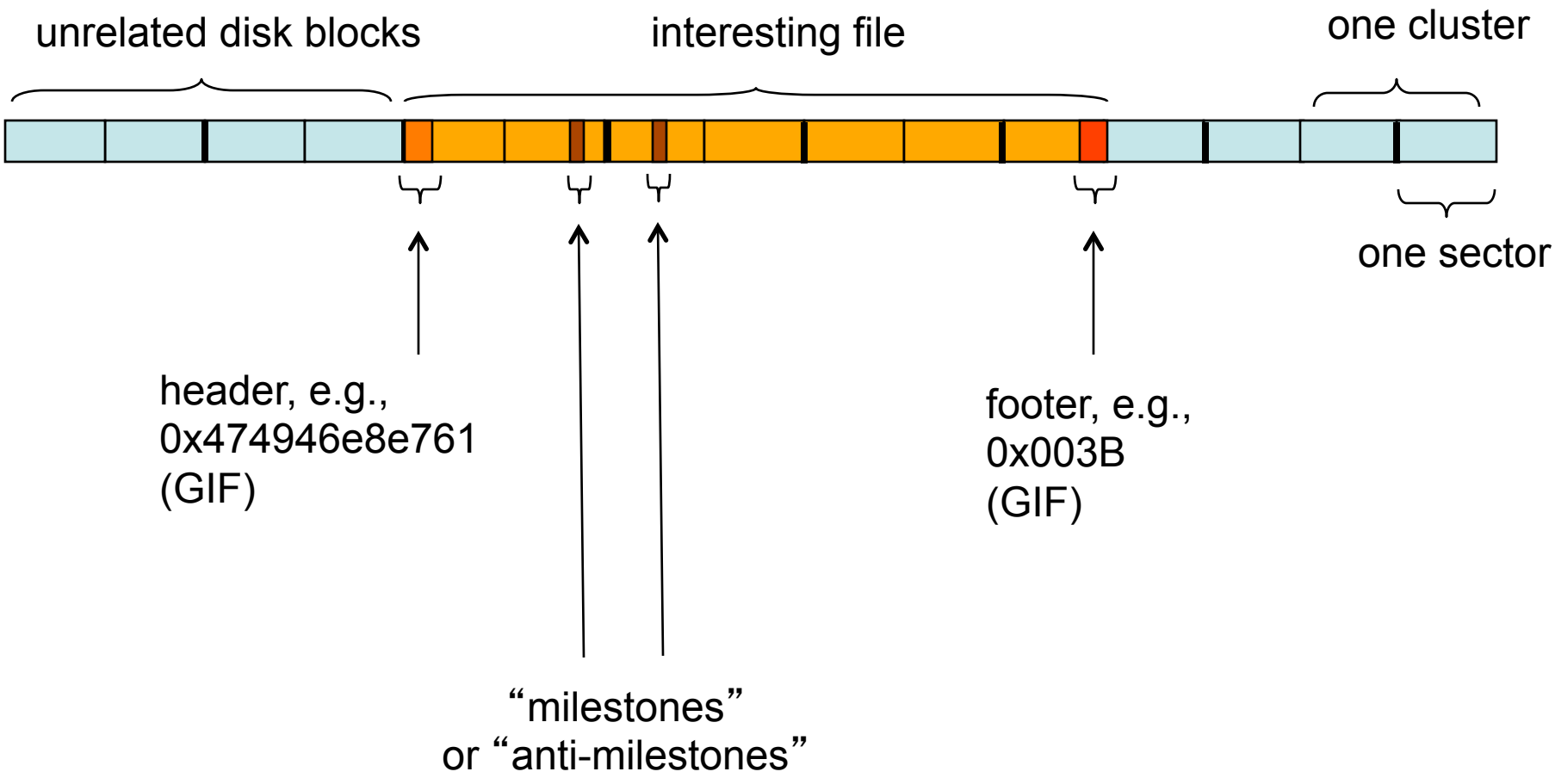
Aside: Lists and DKOM

- Not hopeless
- For process hiding case, can look deeper than the process list
- Correlate with other sources of process information (threads, handles, etc.)
- Can also supplement with carving approaches

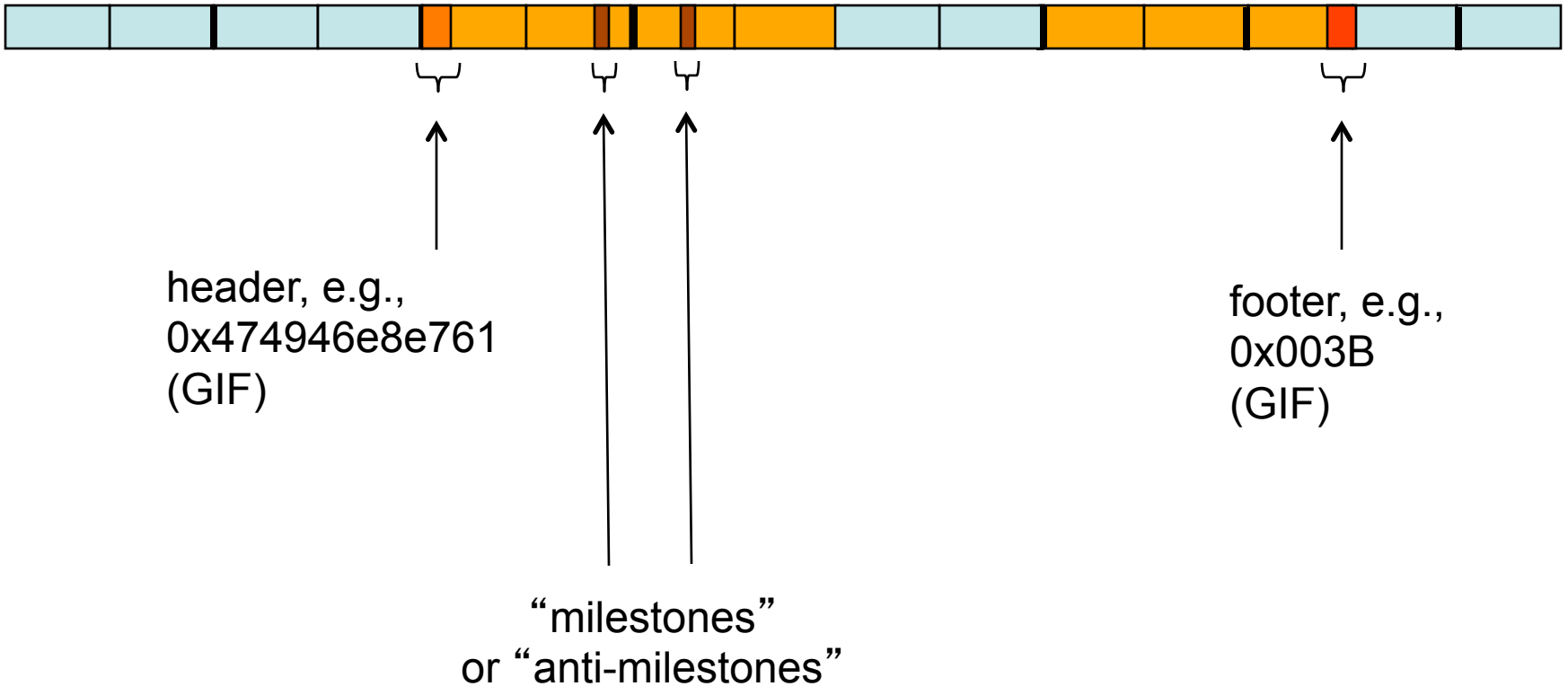
Data Carving

- In storage forensics, carving identifies begin / end of deleted files
- In memory analysis, use patterns or templates to discover structures in dump
- Not fooled by DKOM
- Can potentially identify deallocated structures
- e.g., can potentially find representations of terminated processes

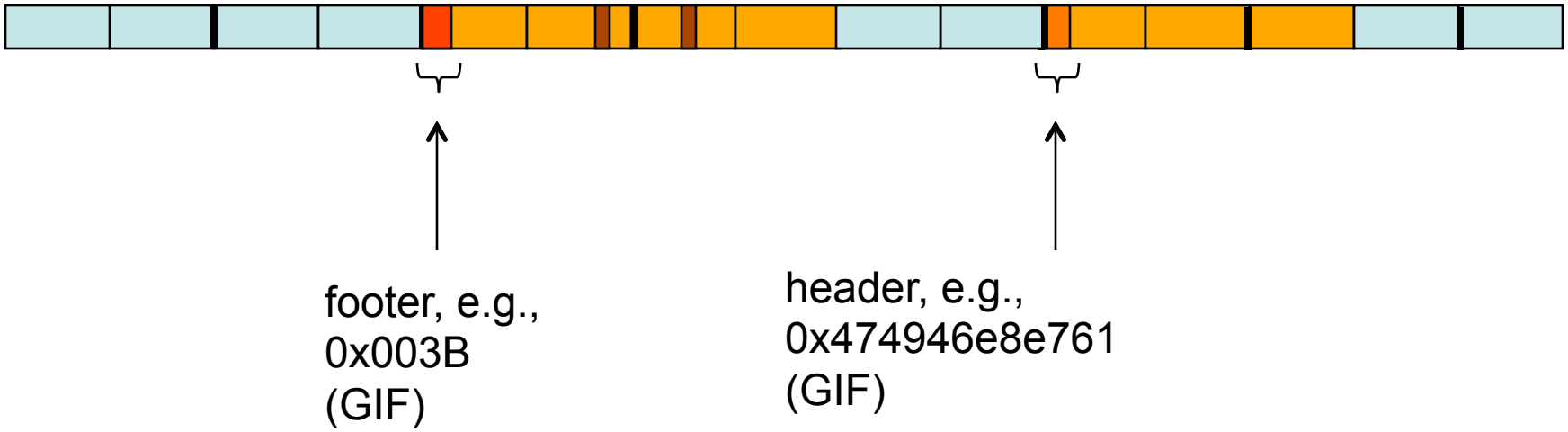
File Carving: Basic Idea



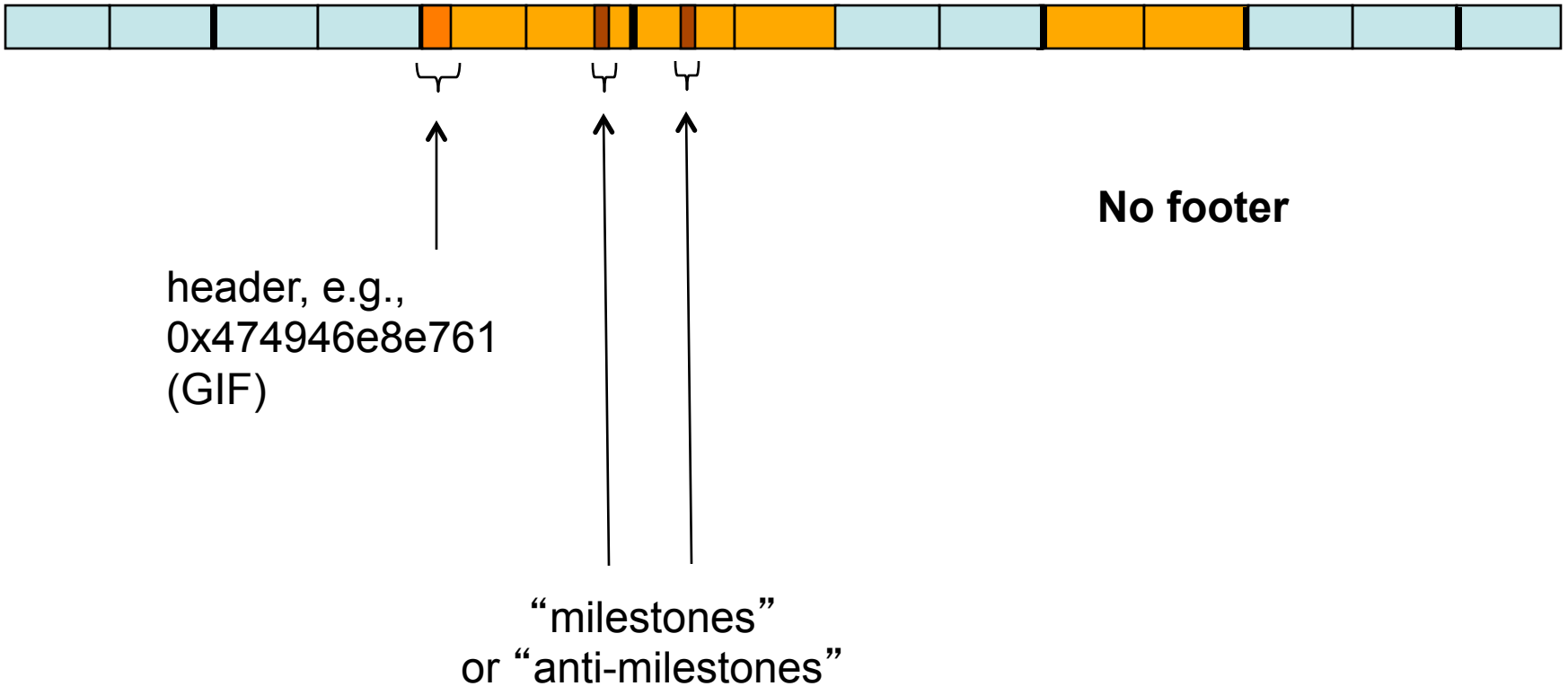
File Carving: Fragmentation



File Carving: Fragmentation



File Carving: Damaged Files



Carving Example

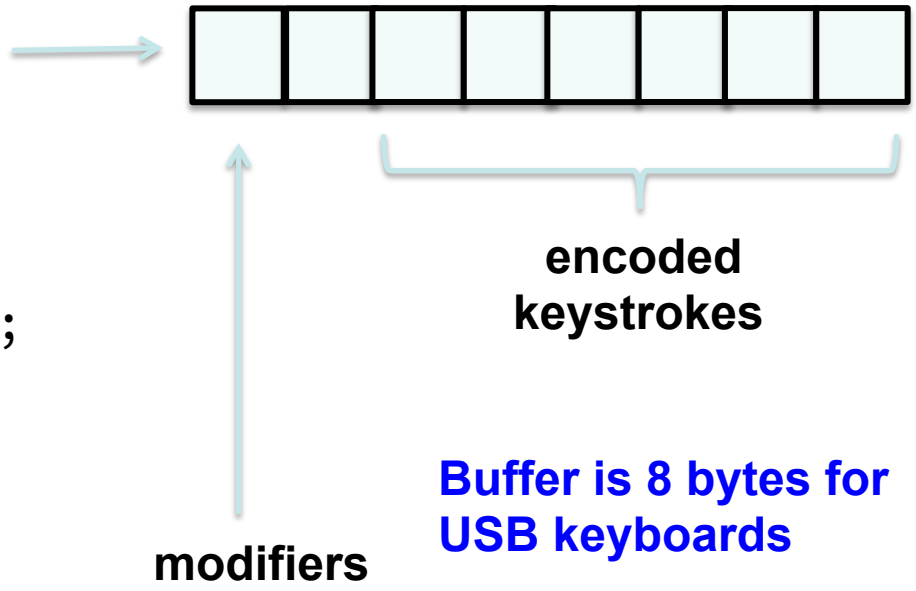
- Idea: Search Linux memory dump to find USB keyboard DMA buffer
- Often targeted by keystroke loggers
- Used in recent POCs of GPU malware
- Evaluate known characteristics of associated structure to discover location of buffer

```
struct urb {
      struct list_head urb_list;
      struct list_head anchor_list;
      struct usb_anchor * anchor;
      struct usb_device * dev;
      struct usb_host_endpoint * ep;
      unsigned int pipe;
      unsigned int stream_id;
      int status;
      unsigned int transfer_flags;
      void * transfer_buffer;
      dma_addr_t transfer_dma;
      struct scatterlist * sg;
      int num_mapped_sgs;
      int num_sgs;
      u32 transfer_buffer_length;
      u32 actual_length;
      unsigned char * setup_packet;
      dma_addr_t setup_dma;
…
};
```

Linux
USB
Request Buffer

```
struct urb {
        struct list_head urb_list;
        struct list_head anchor_list;
        struct usb_anchor *anchor;
        struct usb_device *dev;
        struct usb_host_endpoint *ep;
        unsigned int pipe;
        unsigned int stream_id;
        int status;
        unsigned int transfer_flags;
        void *transfer_buffer;
        dma_addr_t transfer_dma;
        struct scatterlist *sg;
        int num_mapped_sgs;
        int num_sgs;
        u32 transfer_buffer_length;
        u32 actual_length;
        unsigned char *setup_packet;
        dma_addr_t setup_dma;
…
};
```

Linux USB Request Buffer is a `struct urb`



Search RAM page by page

```
for (res = iomem_resource.child; res ; res = res->sibling) {
  if (! strncmp(res->name, RAMSTR, sizeof(RAMSTR))) {
    for (i = (void *)res->start; i < (void *)res->end; i += PAGE_SIZE) {
      is = min(PAGE_SIZE, ((unsigned long)res->end - (unsigned long)i + 1));
      if (is == PAGE_SIZE) {
        p = pfn_to_page(((unsigned long)i) >> PAGE_SHIFT);
        v=kmap(p);
        if (v) {
          for (j = v; j < v + PAGE_SIZE - sizeof(struct urb); j++) {
            urbp = (struct urb *)j;
            if (((unsigned long)urbp->dev) % 0x400 == 0 &&
              __virt_addr_valid((unsigned long)urbp->dev) &&
              ((unsigned long)urbp->transfer_dma) % 0x20 == 0 &&
              urbp->transfer_buffer_length == 8 &&
              __virt_addr_valid((unsigned long)urbp->dev->product)&&
              (strnstr(urbp->dev->product, "Keyboard", 32)) {
                usb_dma_addr = urbp->transfer_dma;
                goto almostdone;
            }
          }
        }
        kunmap(p);
      }
    }
  }
}
```

for `struct urb` pattern

And remember *physical* address of keyboard DMA buffer

```
if (((unsigned long)urbp->dev) % 0x400 == 0 &&
    __virt_addr_valid((unsigned long)urbp->dev) &&
    ((unsigned long)urbp->transfer_dma) % 0x20 == 0 &&
    urbp->transfer_buffer_length == 8 &&
    __virt_addr_valid((unsigned long)urbp->dev->product)&&
    (strnstr(urbp->dev->product, "Keyboard", 32)) {
      usb_dma_addr = urbp->transfer_dma;
      goto almostdone;
}
```

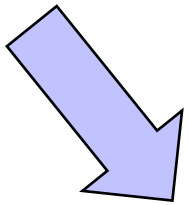
```
if (urbp->dev is aligned on 0x400 boundary &&

     urbp->transfer_dma is aligned on 0x20 boundary &&

     urbp->transfer_buffer_length is 8 bytes in length &&

     urbp->dev->product contains "Keyboard") {

      // found the DMA buffer for keyboard
 }
```

Vtypes in Volatility

- **Used to accurately represent C structures in Python**
- **One of the key reasons that writing plugins in Volatility is so straightforward**
- Automatically generated from debugging symbols when possible
  - Microsoft PDB files
  - Linux/Mac DWARF information
- If debugging symbols aren't available,…
- Then they must be created manually via source code analysis or reverse engineering ☹
- Objects and classes subsystem allows "attaching" methods or behaviors to instances of a structure

```
struct process {
  int pid;
  int parent_pid;
  char name[10];
  char *command_line;
  void *ptv;
};
```

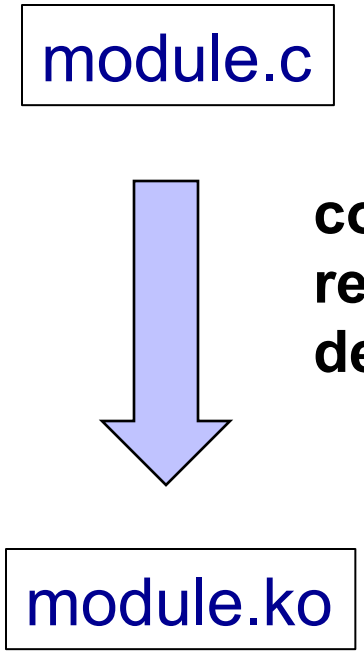
C type



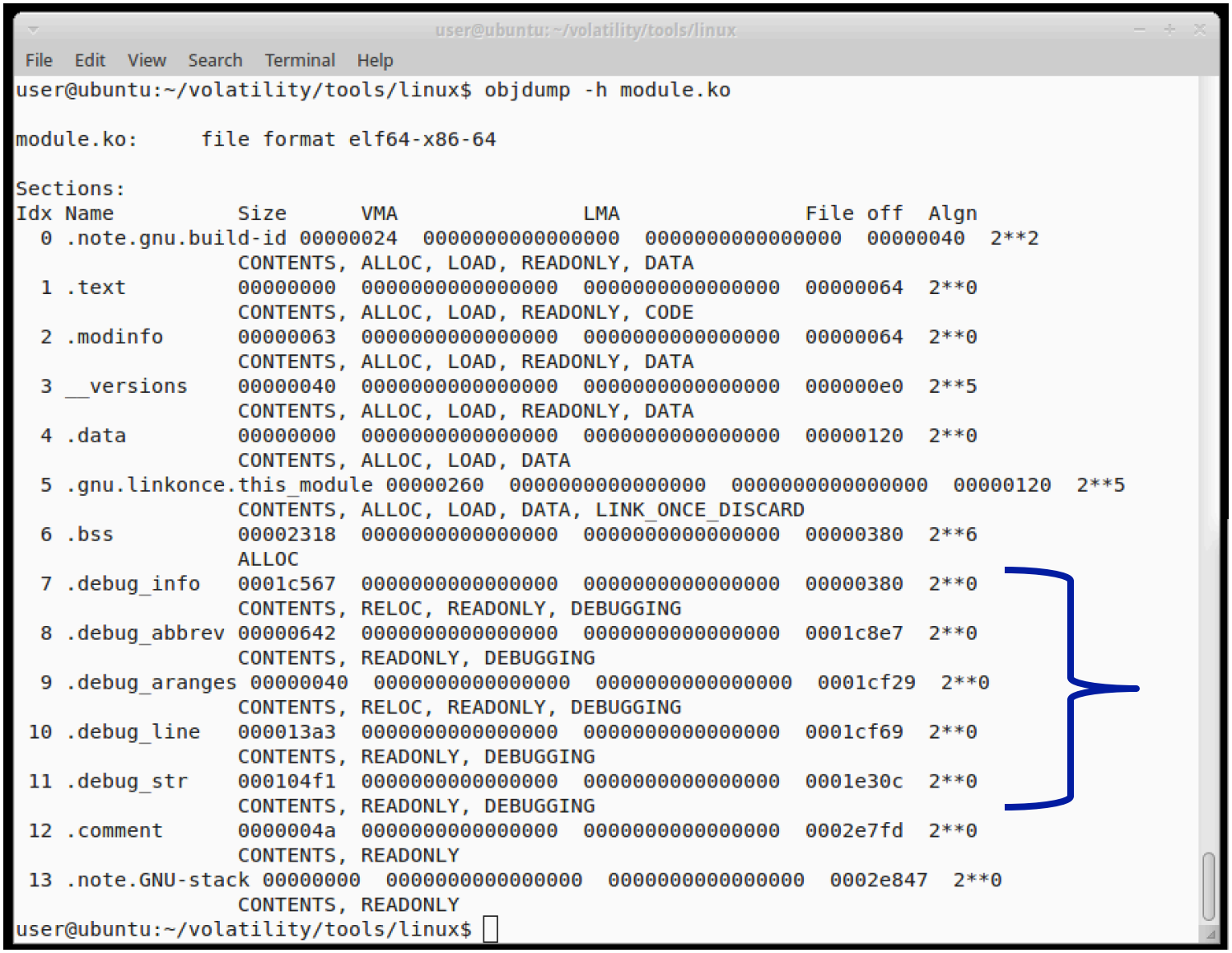
Volatility Vtype

```
'process' : [ 26, {
    'pid' : [ 0, ['int']],
    'parent_pid' : [ 4, ['int']],
    'name' : [ 8, ['array', 10, ['char']]],
    'command_line' : [ 18, ['pointer', ['char']]],
    'ptv' : [ 22, ['pointer', ['void']]],
}]
```

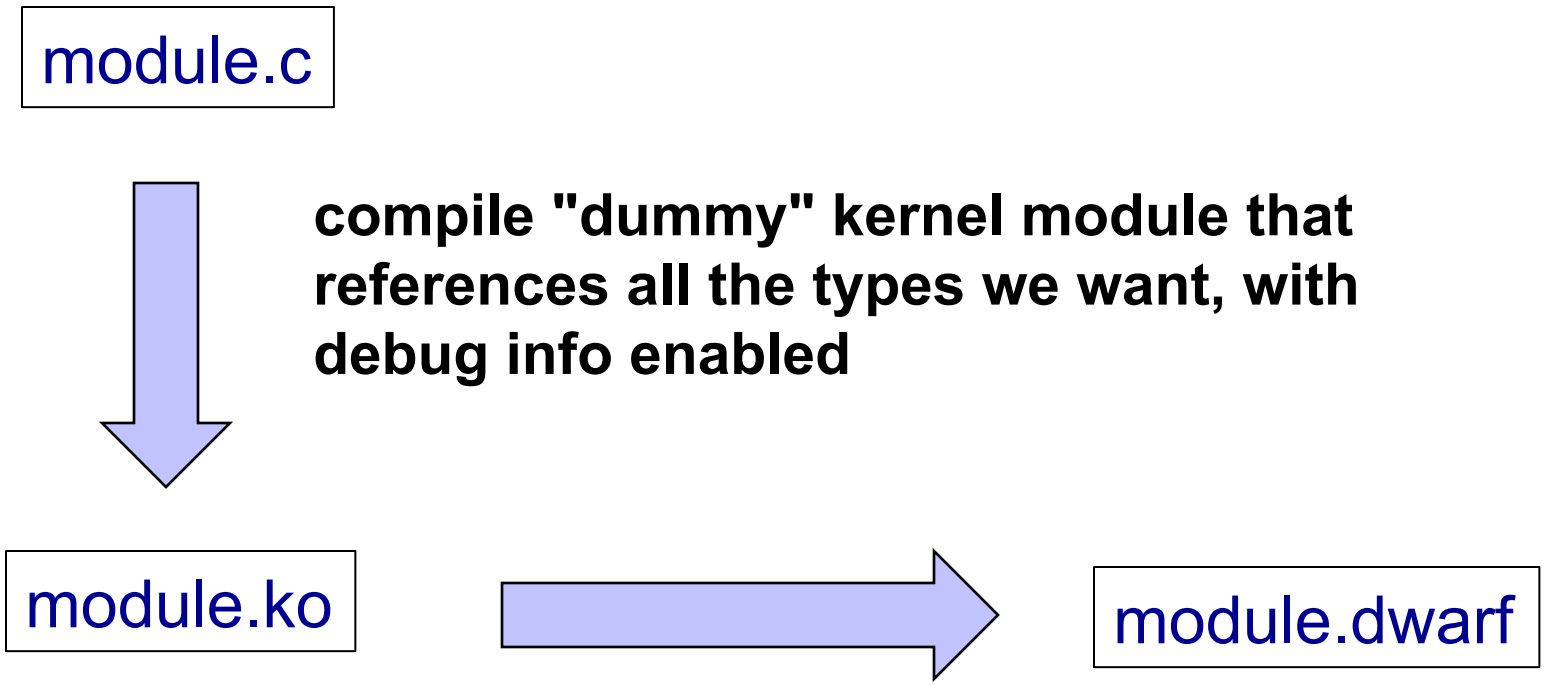
Extraction of DWARF Debugging Info



DWARF Debugging Data in ELF File



Extraction of DWARF Debugging Info



DWARF (!)

…
…
<1><0x10eb><DW_TAG_structure_type> DW_AT_name<"task_struct"> DW_AT_byte_size<0x000006f8>
DW_AT_decl_file<0x0000000f /usr/src/linux-headers-3.2.0-4-common/include/linux/sched.h>
DW_AT_decl_line<0x000004c9> DW_AT_sibling<<0x000019e7>>
<2><0x10f9><DW_TAG_member> DW_AT_name<"state"> DW_AT_decl_file<0x0000000f /usr/src/linux-headers-3.2.0-4-common/include/linux/sched.h> DW_AT_decl_line<0x000004ca>
DW_AT_type<<0x0000bedf>> DW_AT_data_member_location<DW_OP_plus_uconst 0>
<2><0x1108><DW_TAG_member> DW_AT_name<"stack"> DW_AT_decl_file<0x0000000f /usr/src/linux-headers-3.2.0-4-common/include/linux/sched.h> DW_AT_decl_line<0x000004cb>
DW_AT_type<<0x000004a2>> DW_AT_data_member_location<DW_OP_plus_uconst 8>
<2><0x1117><DW_TAG_member> DW_AT_name<"usage"> DW_AT_decl_file<0x0000000f /usr/src/linux-headers-3.2.0-4-common/include/linux/sched.h> DW_AT_decl_line<0x000004cc>
DW_AT_type<<0x000003a5>> DW_AT_data_member_location<DW_OP_plus_uconst 16>
<2><0x1126><DW_TAG_member> DW_AT_name<"flags"> DW_AT_decl_file<0x0000000f /usr/src/linux-headers-3.2.0-4-common/include/linux/sched.h> DW_AT_decl_line<0x000004cd>
DW_AT_type<<0x00000092>> DW_AT_data_member_location<DW_OP_plus_uconst 20>
<2><0x1135><DW_TAG_member> DW_AT_name<"ptrace"> DW_AT_decl_file<0x0000000f /usr/src/linux-headers-3.2.0-4-common/include/linux/sched.h> DW_AT_decl_line<0x000004ce>
DW_AT_type<<0x00000092>> DW_AT_data_member_location<DW_OP_plus_uconst 24>
<2><0x1144><DW_TAG_member> DW_AT_name<"wake_entry"> DW_AT_decl_file<0x0000000f /usr/src/linux-headers-3.2.0-4-common/include/linux/sched.h> DW_AT_decl_line<0x000004d1>
DW_AT_type<<0x0000ad52>> DW_AT_data_member_location<DW_OP_plus_uconst 32>
<2><0x1153><DW_TAG_member> DW_AT_name<"on_cpu"> DW_AT_decl_file<0x0000000f /usr/src/linux-headers-3.2.0-4-common/include/linux/sched.h> DW_AT_decl_line<0x000004d2>
…
…

<1><0x10eb><**DW_TAG_structure_type**> **DW_AT_name<"task_struct">**
DW_AT_byte_size<0x000006f8> DW_AT_decl_file<0x0000000f /usr/src/linux-headers-3.2.0-4-common/include/linux/sched.h>

…
<2><0x1269><**DW_TAG_member**> DW_AT_name<"**mm**"> DW_AT_decl_file<0x0000000f /usr/src/linux-headers-3.2.0-4-common/include/linux/sched.h> DW_AT_decl_line<0x00000509>
DW_AT_type<<0x00001d27>>
DW_AT_data_member_location<DW_OP_plus_uconst 424>
…

<1><**0x1d27**><**DW_TAG_pointer_type**> DW_AT_byte_size<0x00000008>
DW_AT_type<<0x00001d2d>>
<1><**0x1d2d**><**DW_TAG_structure_type**>
DW_AT_name<"mm_struct"> **DW_AT_byte_size<0x00000398>**
DW_AT_decl_file<0x0000000c /usr/src/linux-headers-3.2.0-4-common/include/linux/mm_types.h> DW_AT_decl_line<0x00000121> DW_AT_sibling<<0x000020ad>>
<2><0x1d3b>**<DW_TAG_member> DW_AT_name<"mmap">**
DW_AT_decl_file<0x0000000c /usr/src/linux-headers-3.2.0-4-common/include/linux/mm_types.h> DW_AT_decl_line<0x00000122> DW_AT_type<<0x00005bfb>>
DW_AT_data_member_location<DW_OP_plus_uconst 0>
<2><0x1dc2>**<DW_TAG_member> DW_AT_name<"pgd">**
DW_AT_decl_file<0x0000000c /usr/src/linux-headers-3.2.0-4-common/include/linux/mm_types.h> DW_AT_decl_line<0x0000012f> DW_AT_type<<0x0000212e>>
DW_AT_data_member_location<DW_OP_plus_uconst 72>

Volatility Overlays

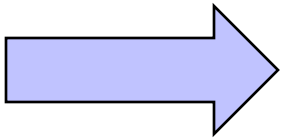
- Overlays allow automated **patching** of Vtypes
- Used to fix problematic situations where insufficient debugging information is available
- One serious offender: null pointers as structure members

```
struct process {
  int pid;
  int parent_pid;
  char name[10];
  char *command_line;
  void *ptv;
};
```

Overlays (2)

Analysis of source or reverse engineering may reveal that the dereferenced member (always) has a predictable type

```
struct process {
  int pid;
  int parent_pid;
  char name[10];
  char *command_line;
  void *ptv;
};
```

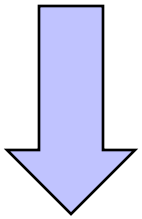


```
struct process {
  int pid;
  int parent_pid;
  char name[10];
  char *command_line;
  struct process *ptv;
};
```

Overlays (3)

```
'process' : [ 26, {
    'pid' : [ 0, ['int']],
    'parent_pid' : [ 4, ['int']],
    'name' : [ 8, ['array', 10, ['char']]],
    'command_line' : [ 18, ['pointer', ['char']]],
    'ptv' : [ 22, ['pointer', ['void']]],
}]
```

I'm an overlay, and I'm OK.



OVERLAY

```
'process' : [ None, {
   'ptv' : [ None, ['pointer', ['process']]],
}
```

```
'process' : [ 26, {
    'pid' : [ 0, ['int']],
    'parent_pid' : [ 4, ['int']],
    'name' : [ 8, ['array', 10, ['char']]],
    'command_line' : [ 18, ['pointer', ['char']]],
    'ptv' : [ 22, ['pointer', ['process']]],
}]
```

Profiles

- A Volatility **profile** is a a collection of **vtypes, overlays**, and **object classes** for a specific OS version and hardware architecture
  - System call information
  - Constant values, global variables
  - Native types
  - System.map (Linux/Mac only)
- …all bundled up in a nice ZIP file
- Profiles for Windows are distributed with Volatility
- Generally build them for each Linux/Mac instance
- Typically follow a naming convention (for example, Win7SP1x86 or Win2003SP0x64)
- **`$ python vol.py -info`** to see which are available
- Build others as needed

Creating a New Linux Profile

The following builds a kernel module solely to get debugging info:

```
$ cd ~/volatility/tools/linux
$ make
$ head module.dwarf
```

```
.debug_info
<0><0+11><DW_TAG_compile_unit> ....
<1><45><DW_TAG_typedef> DW_AT_name<__s8> ...
```

Now gather the debug info and kernel symbols for the currently executing kernel into a single ZIP file. The name for the ZIP file is descriptive—use the name of the distribution for a Linux profile:

```
$ cd
$ sudo zip ~/volatility/volatility/plugins/overlays/linux/
Ubuntu1404.zip  ~/volatility/tools/linux/module.dwarf  /boot/
System.map-$(uname -r)
```

Creating a New Mac OS X Profile

Grab the kernel debug kits from Apple for the appropriate kernels via https://developer.apple.com/downloads/. Put them all in the same directory, e.g., ~/Desktop. While you're there, install the latest Xcode via the same link. Then type the following to install the OS X command line developer tools:

```
$ xcode-select -install
```

Then:

```
$ cd ~/volatility/tools/mac
$ mkdir tmp
$ python mac_create_all_profiles.py ~/Desktop  tmp  \
   ~/volatility  ~/volatility/volatility/plugins/overlays/mac
```

This creates a profile for each of the debug kits discovered in the specified directory (in this case, ~/Desktop), in one step.

Checking New Profile

To check proper installation of your new profile, do:

```
$ cd ~/volatility/
$ python vol.py --info
```

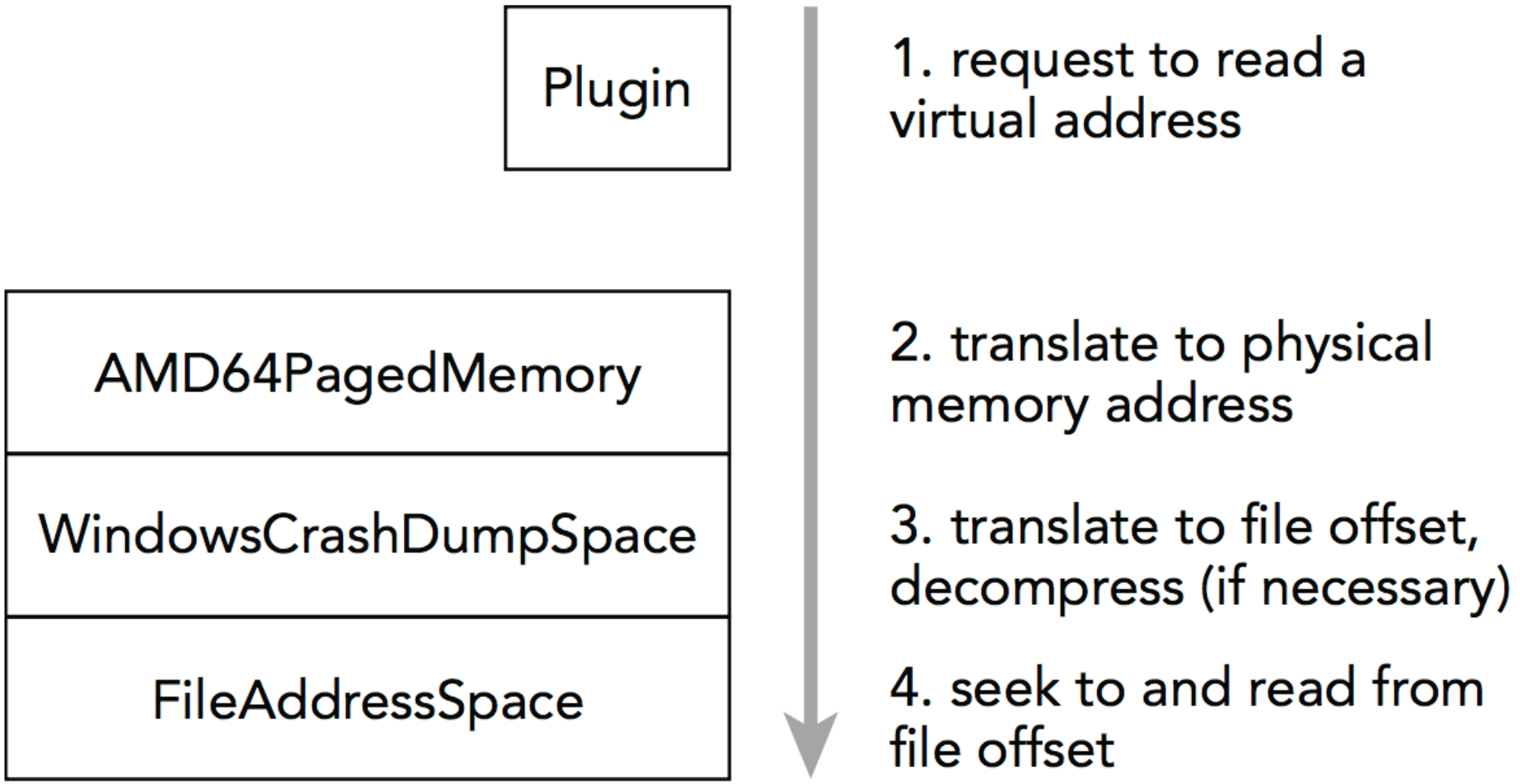
In the Profiles area, you should see the official name of your new profile:

```
...
Profiles
--------
LinuxXubuntu1404x64 - A Profile for Linux Xubuntu1404 x64
VistaSP0x64         - A Profile for Windows Vista SP0 x64
VistaSP0x86         - A Profile for Windows Vista SP0 x86
VistaSP1x64         - A Profile for Windows Vista SP1 x64
...
```

Address Spaces (AS)

- A Volatility address space:
  - Provides a flexible and consistent interface to data in RAM
  - Handles virtual to physical address translation as necessary
  - Transparently accounts for differences in memory dump file formats (proprietary headers, compression, etc.)
- Paged address spaces include IA32 and AMD64 (32- and 64-bit Intel)
- Volatility automatically detects the proper AS to use for a memory sample
- AS's are stacked on top of one another

Address Spaces Stack



Plugins

- Entire Volatility framework is expandable
  - Add address spaces to support new hardware architectures or memory dump formats
  - Add profiles to support new operating systems or new operating system versions
  - Add new plugins to analyze new types of data from the kernel, processes, etc.
- e.g., when LiME was developed, introduced `volatility/plugins/addrspaces/lime.py`
- Understands LiME memory format headers, etc.

Plugins (2)

- Plugins have `calculate()` and `render_text()` methods
- Data gathering is performed in calculate() and it yields results to the rendering function
  - Can also add renderers for output to CSV, XML, database, etc.
- **Flexibility** is the most important difference between Volatility and previous memory analysis efforts

Another Carving Example

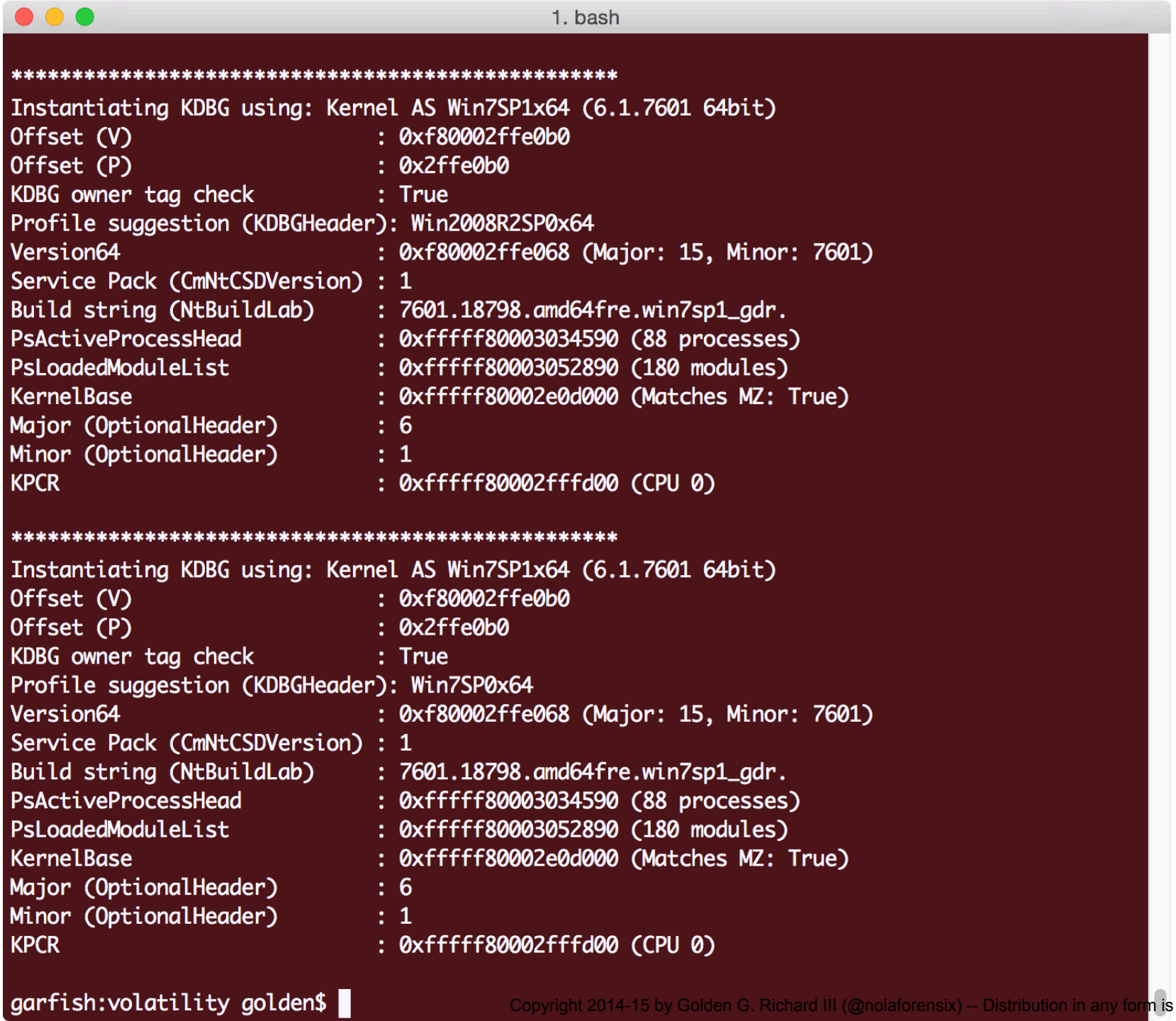
- Finding the right Windows profile
- Volatility can often (help) identify the correct Windows profile for a memory dump
- Windows XP → along with various service packs
- Uses kernel debugger data block (KDBG) structure to discover Windows version
- We'll look at `kdbgscan` to understand this a bit better

Identifying Windows Profiles

- Use **`imageinfo`** or **`kdbgscan`** plugins
- Some profiles look similar (for example, XP SP2 and XP SP3), use the Service Pack details in `kdbgscan` output to choose the right one
- If `kdbgscan` finds multiple KDBG structures, look at the number of processes and modules to determine the best choice
- Keep in mind the values are nonessential to the stability of the OS, so they can be manipulated by attackers

1. bash

```
garfish:volatility golden$ python vol.py --profile=Win7SP1x64 -f ~/Documents/Virtual\ Machine
s.localized/Windows\ 7\ x64/Windows\ 7\ x64-1e433ca5.vmem kdbgscan
Volatility Foundation Volatility Framework 2.4
**************************************************
Instantiating KDBG using: Kernel AS Win7SP1x64 (6.1.7601 64bit)
Offset (V)                    : 0xf80002ffe0b0
Offset (P)                    : 0x2ffe0b0
KDBG owner tag check          : True
Profile suggestion (KDBGHeader): Win7SP1x64
Version64                     : 0xf80002ffe068 (Major: 15, Minor: 7601)
Service Pack (CmNtCSDVersion) : 1
Build string (NtBuildLab)     : 7601.18798.amd64fre.win7sp1_gdr.
PsActiveProcessHead           : 0xfffff80003034590 (88 processes)
PsLoadedModuleList            : 0xfffff80003052890 (180 modules)
KernelBase                    : 0xfffff80002e0d000 (Matches MZ: True)
Major (OptionalHeader)        : 6
Minor (OptionalHeader)        : 1
KPCR                          : 0xfffff80002fffd00 (CPU 0)

**************************************************
Instantiating KDBG using: Kernel AS Win7SP1x64 (6.1.7601 64bit)
Offset (V)                    : 0xf80002ffe0b0
Offset (P)                    : 0x2ffe0b0
KDBG owner tag check          : True
Profile suggestion (KDBGHeader): Win2008R2SP1x64
Version64                     : 0xf80002ffe068 (Major: 15, Minor: 7601)
Service Pack (CmNtCSDVersion) : 1
Build string (NtBuildLab)     : 7601.18798.amd64fre.win7sp1_gdr.
PsActiveProcessHead           : 0xfffff80003034590 (88 processes)
PsLoadedModuleList            : 0xfffff80003052890 (180 modules)
KernelBase                    : 0xfffff80002e0d000 (Matches MZ: True)
Major (OptionalHeader)        : 6
Minor (OptionalHeader)        : 1
KPCR                          : 0xfffff80002fffd00 (CPU 0)
```



imageinfo Plugin

```
bigjoe:volatility golden$ python vol.py --profile=WinXPSP3x86 -f /Volumes/SLOWDATA/IMAGES-THUMB-BAC
KUP/MEMIMAGES/6623/evilprofessor.vmem imageinfo
Volatility Foundation Volatility Framework 2.4
INFO    : volatility.plugins.imageinfo: Determining profile based on KDBG search...
          Suggested Profile(s) : WinXPSP2x86, WinXPSP3x86
                     AS Layer1 : IA32PagedMemoryPae (Kernel AS)
                     AS Layer2 : FileAddressSpace (/Volumes/SLOWDATA/IMAGES-THUMB-BACKUP/MEMIMAGES/
6623/evilprofessor.vmem)
                      PAE type : PAE
                           DTB : 0x32a000L
                          KDBG : 0x80545ce0L
          Number of Processors : 1
     Image Type (Service Pack) : 3
                KPCR for CPU 0 : 0xffdff000L
             KUSER_SHARED_DATA : 0xffdf0000L
           Image date and time : 2014-10-29 17:20:02 UTC+0000
     Image local date and time : 2014-10-29 12:20:02 -0500
bigjoe:volatility golden$
```

Quick Case Study:
Memory Analysis vs. Spyware

eBlaster

- Simple but real case
- Computer infected with eBlaster
- Commercial spyware from SpectorSoft
- Very stealthy
- Uses code injection, hooks system calls, and other hiding techniques to avoid detection
- Affected party (“Jane”) noticed purchase of eBlaster on credit card statement and researched
- Jane wasn’t sure if it was installed or not
- Jane and her lawyer initiated forensic investigation

eBlaster

- Collects extensive information on computer activities
- Chat logs, email, web surfing, keystrokes, et al
- Emails reports to designated email address
- Reports and configuration are encrypted
- No access to configuration without password
- Questions:
  - What's being collected?
  - Where are the eBlaster reports being sent?

Hotkey sequence brings up bare authentication dialog: <CTRL><SHIFT><ALT>-T.

This sequence can be changed. Can't access configuration screen without the password.

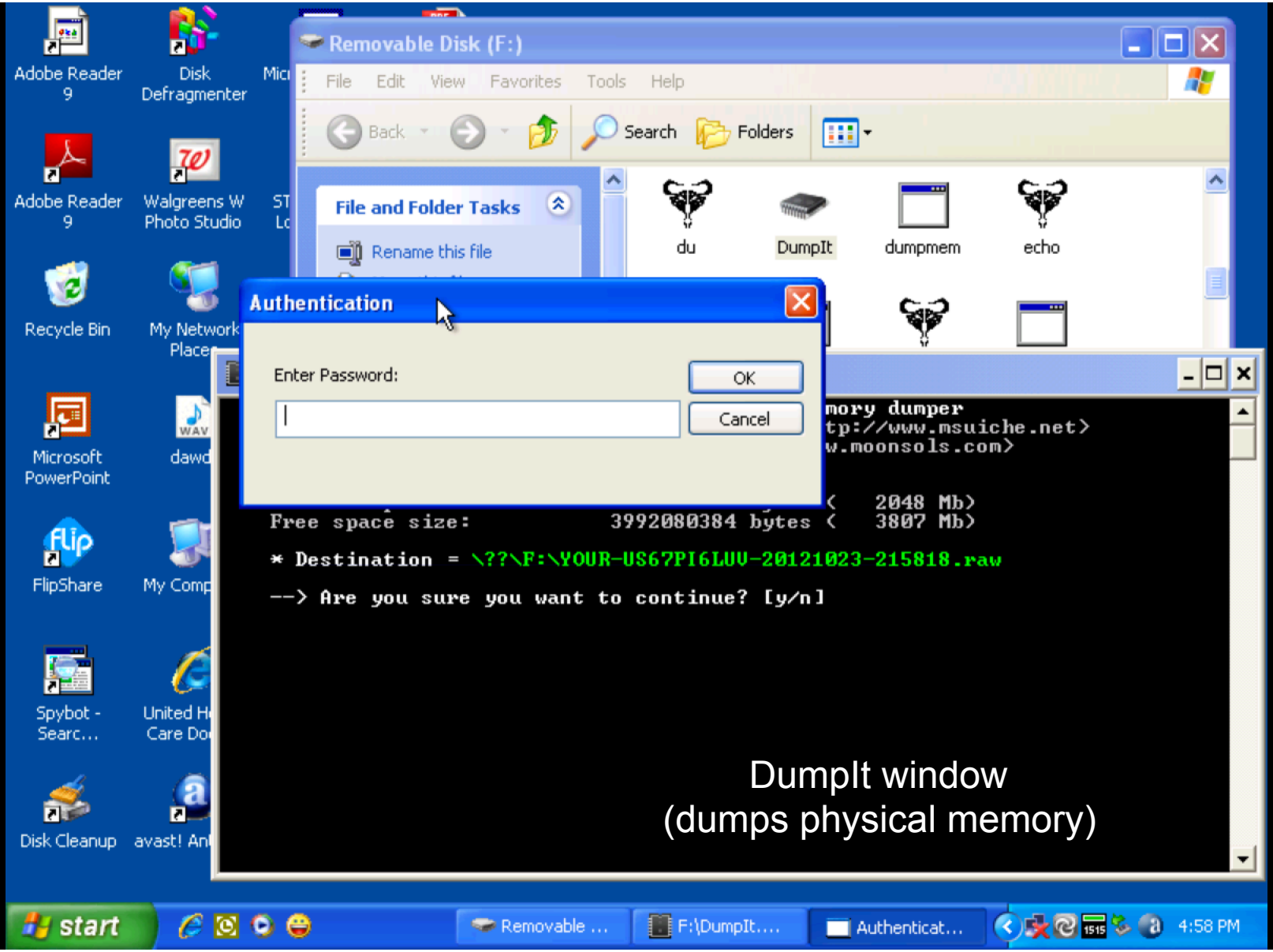
Process is spawned to handle this dialog.

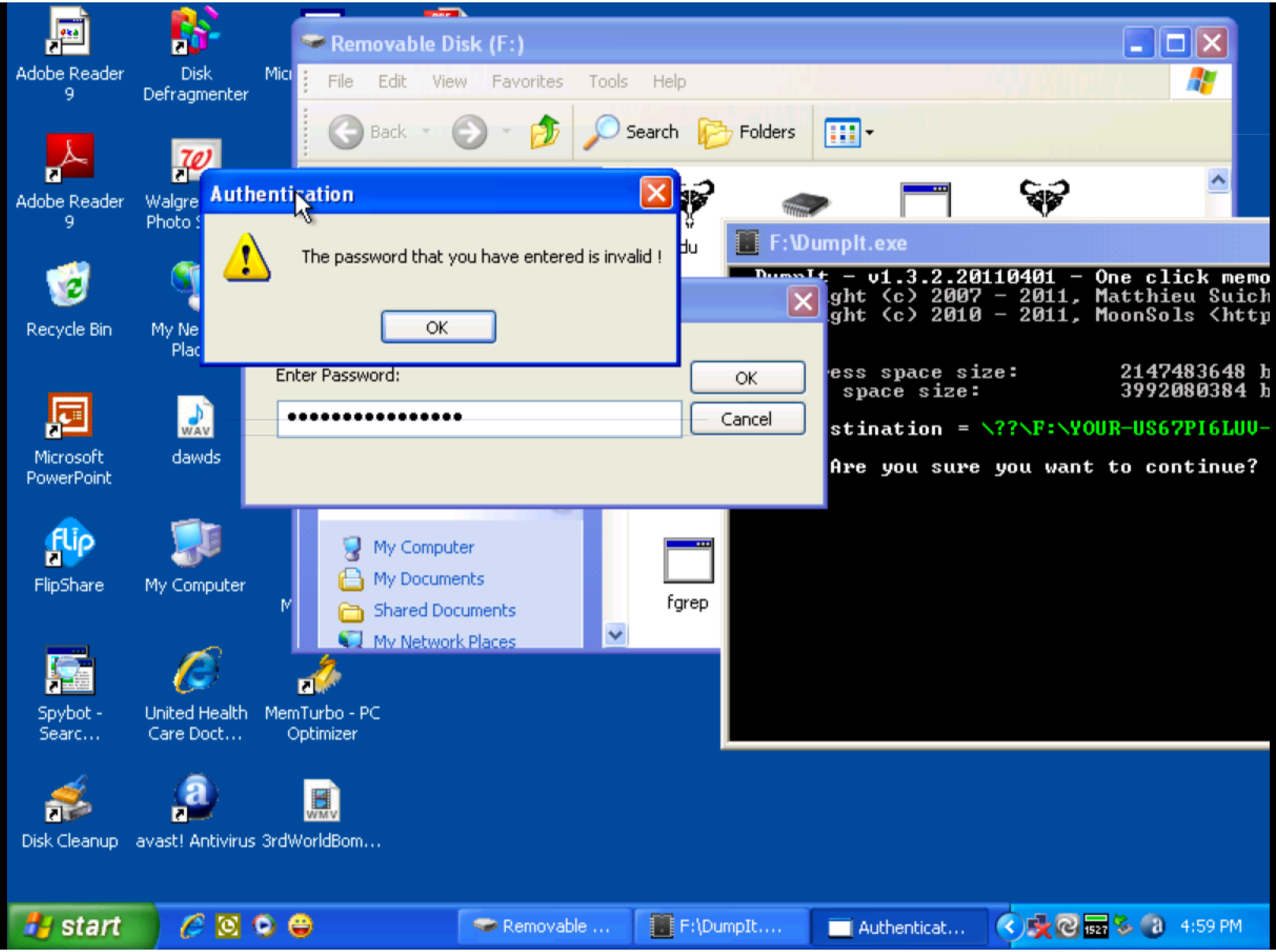
Process is terminated when dialog is dismissed.

Computer powered off, but eBlaster is persistent.

Clone and virtualize system to investigate.

dd image → **raw2vmdk** → **VMWare virtual machine** → **Live forensics analysis**





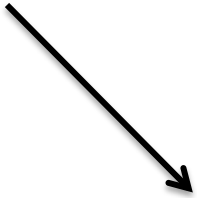
Hope: **quickly** reveal password w/o full reverse engineering effort.

Did developers leak the plaintext password?

Enter sample password “VERYUNIQUE” in password dialog.

Don’t dismiss the “invalid password” dialog.

Dump memory in the VM while the dialog box is displayed.



YOUR-US67PI6LUV-20121017-214253.raw

```
# gstrings -a -t d YOUR-US67PI6LUV-20121017-214253.raw | grep VERYUNIQUE > strings.txt
# gstrings -a -t d -e l YOUR-US67PI6LUV-20121017-214253.raw | grep VERYUNIQUE >> strings.txt
```

467105092:VERYUNIQUE

Search memory dump for invalid password VERYUNIQUE

```
# python vol.py --profile=WinXPSP3x86 -f YOUR-US67PI6LUV-20121017-214253.raw strings -s
strings.txt --output-file=stringslocation.txt -S
```

Map location of invalid pw to owning process

1bd77544 [3772:0012f544] VERYUNIQUE

PID of process whose address space includes string

```
# python vol.py --profile=WinXPSP3x86 -f YOUR-US67PI6LUV-20121017-214253.raw  pslist
                                    ...
0x82c24bf0 xmlavipv.exe        3772   1592      2       78      0      0 2012-10-17 21:41:20
```

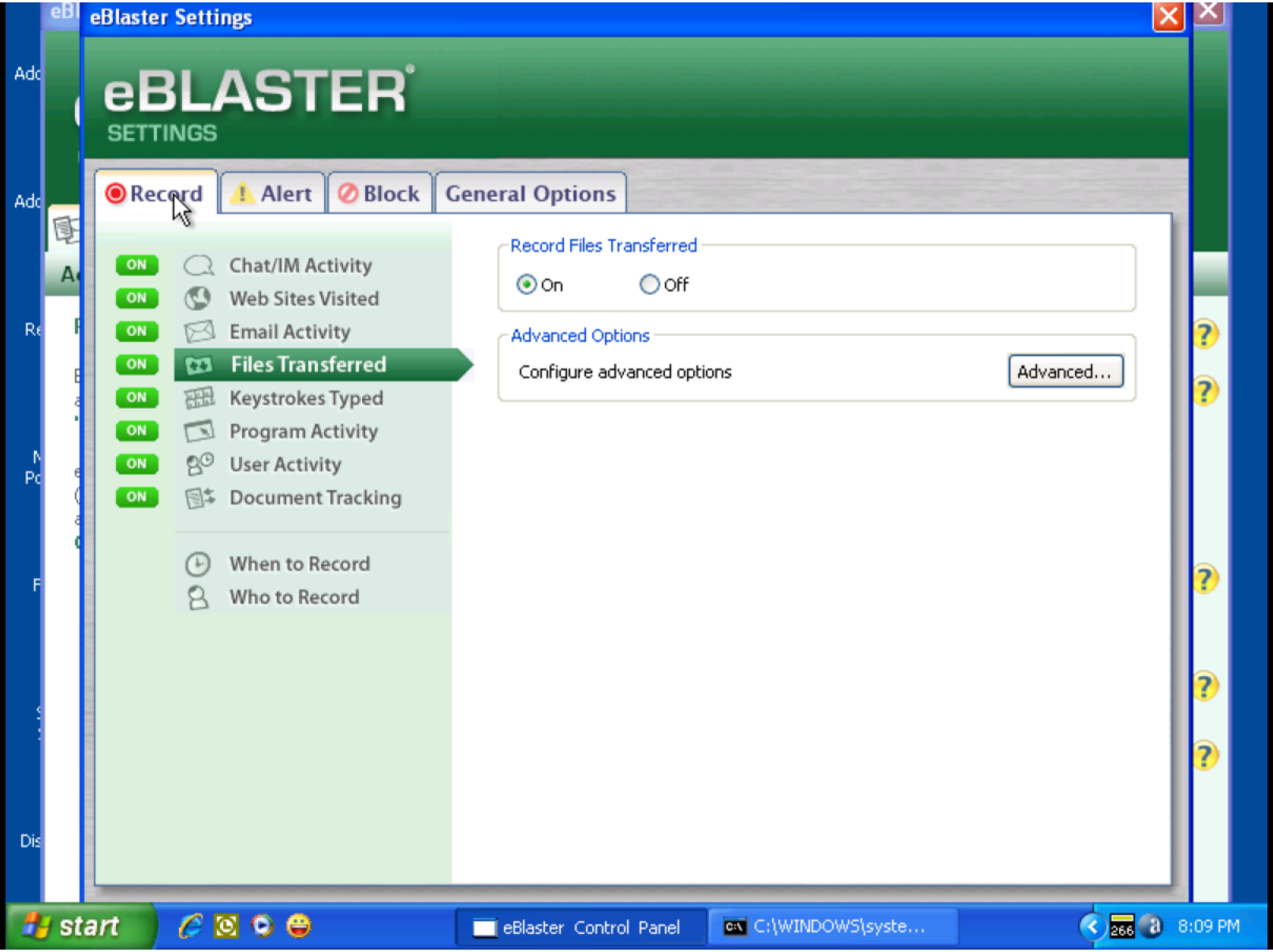
Verify that it's the process that gets spawned when dialog opens

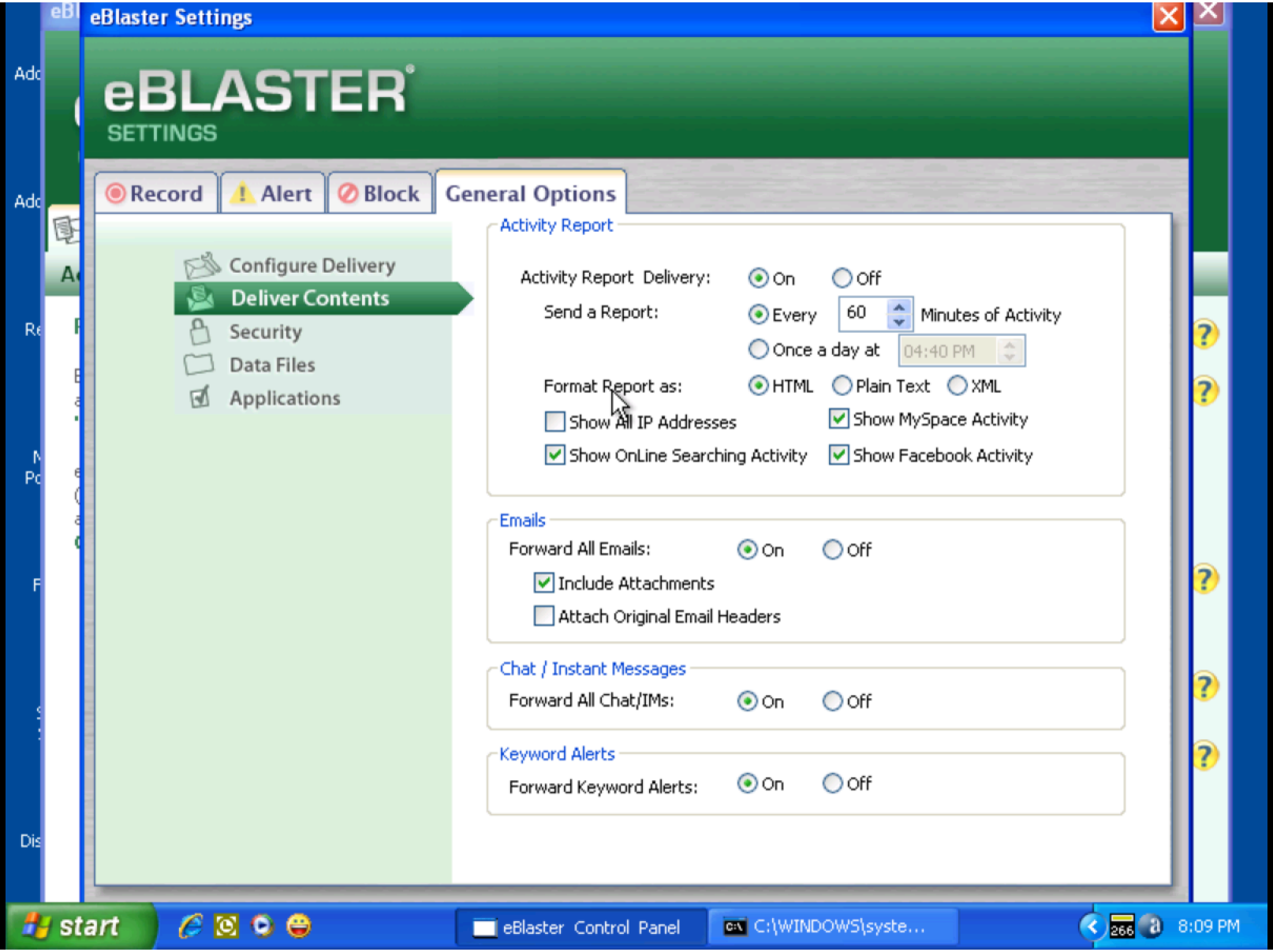
```
# python vol.py --profile=WinXPSP3x86 -f YOUR-US67PI6LUV-20121017-214253.raw  -p 3772 memdump
    -D dumpdir
```

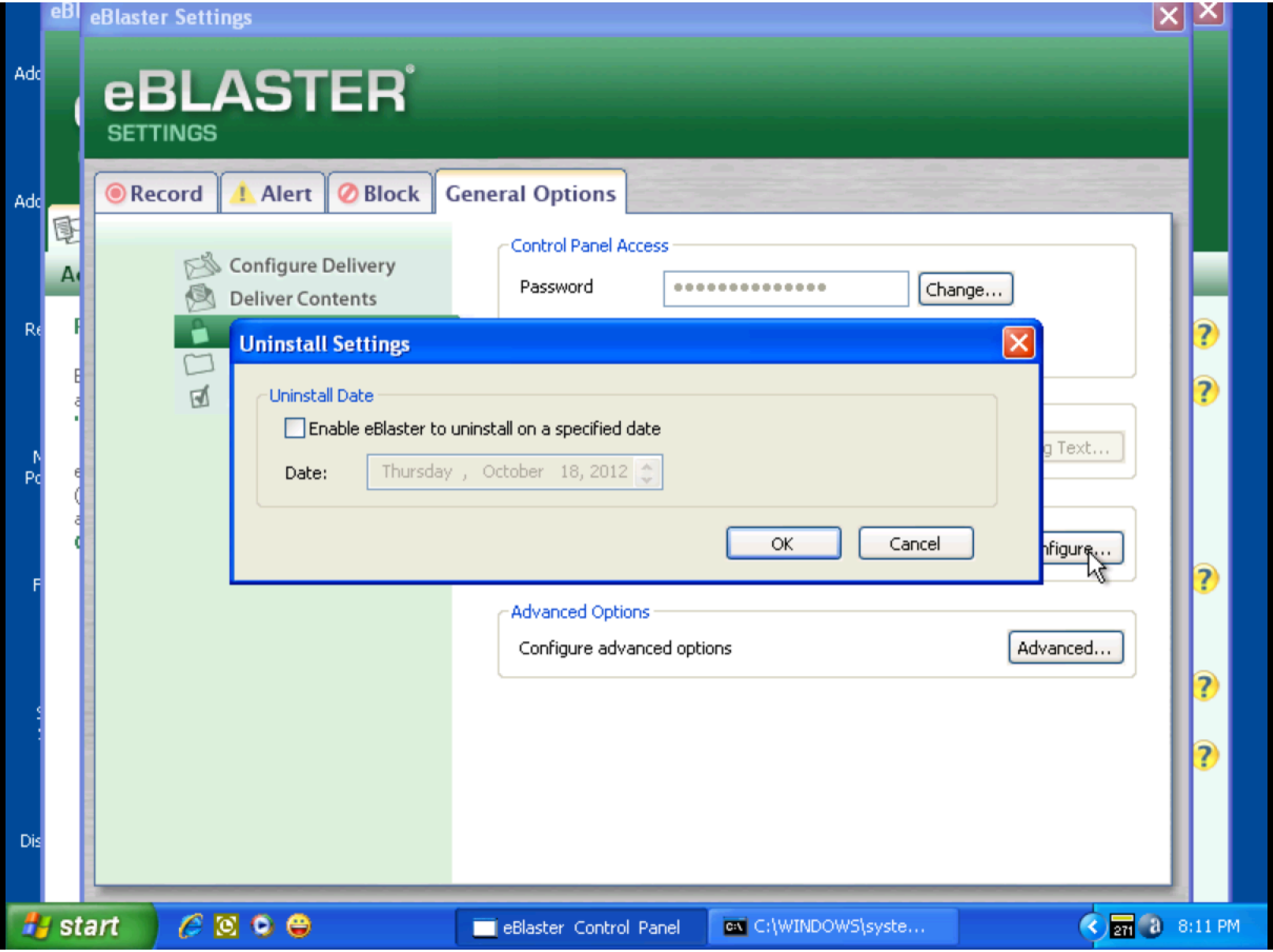
Dump memory of that process

Then run `strings` on dumped process memory

```
A 00004662: LEACCRC.DLL
A 00004757: WINDOWS\system32\OLEACCRC.DLL
A 00004e3c: bo 4l
A 00004ec0: P0G~8
A 00004f94: Program Files\MemTurbo 4\cpurock
A 00005104: +)Bw(2
A 0000511d: >?w(2
A 000051d0:   ! (
A 000053cf: ^?  !
A 000058e5: I6ic\t4
A 00005c54: VERYUNIQUE
A 0000641c: The password that you have entered is invalid !
A 000064b8: Authentication
A 000064f1:
A 00006544: VERYUNIQUE
A 0000667c: wdlgthis#2143
A 00006c4c:
A 00009310: ACTUALPASSWORD                    nlavipv.exe"
A 000097be:  !"#$%&'()*+,-./0123456789:;<=>?@ABCDEFGHIJKLMNOPQRSTUVWXYZ[\]^_`abc
defghijklmnopqrstuvwxyz{|}~^?
A 0000a4d5: ]q+D[o
A 0000ade8: C:\WINDOWS\system32\xmlavipv.exe
A 0000b0d0: WinSta0\Default
A 0000b905: r`w`J
A 0000d380: High Contrast Black (large)
A 00011bf1:  &   !
A 00012311:  &   !
A 0001253c: d0vth
A 00013b3c: %SystemRoot%\system32\mswsock.dll
A 00013c4c: temRoot%\system32\mswsock.dll
A 0001424c: %SystemRoot%\system32\mswsock.dll
```







Voila! Federal Wiretapping Charges!

Process Representations

Processes

- On all commodity operating systems, each executing application runs inside a process
- Basically, a “container” for:
  - Code
  - Data
  - Threads of execution
- Different representations on different operating systems
- But basic information is similar

Process Information

- Process state (running, stopped, etc.)
- Priority
- Links to next, previous processes
- PID
- Pointers to parent, children
- Permissions
- Accounting info
- Limits
- Filesystem stuff
- Memory management

Windows Processes

Windows 7 _EPROCESS structure

See pp. 151 in AMF

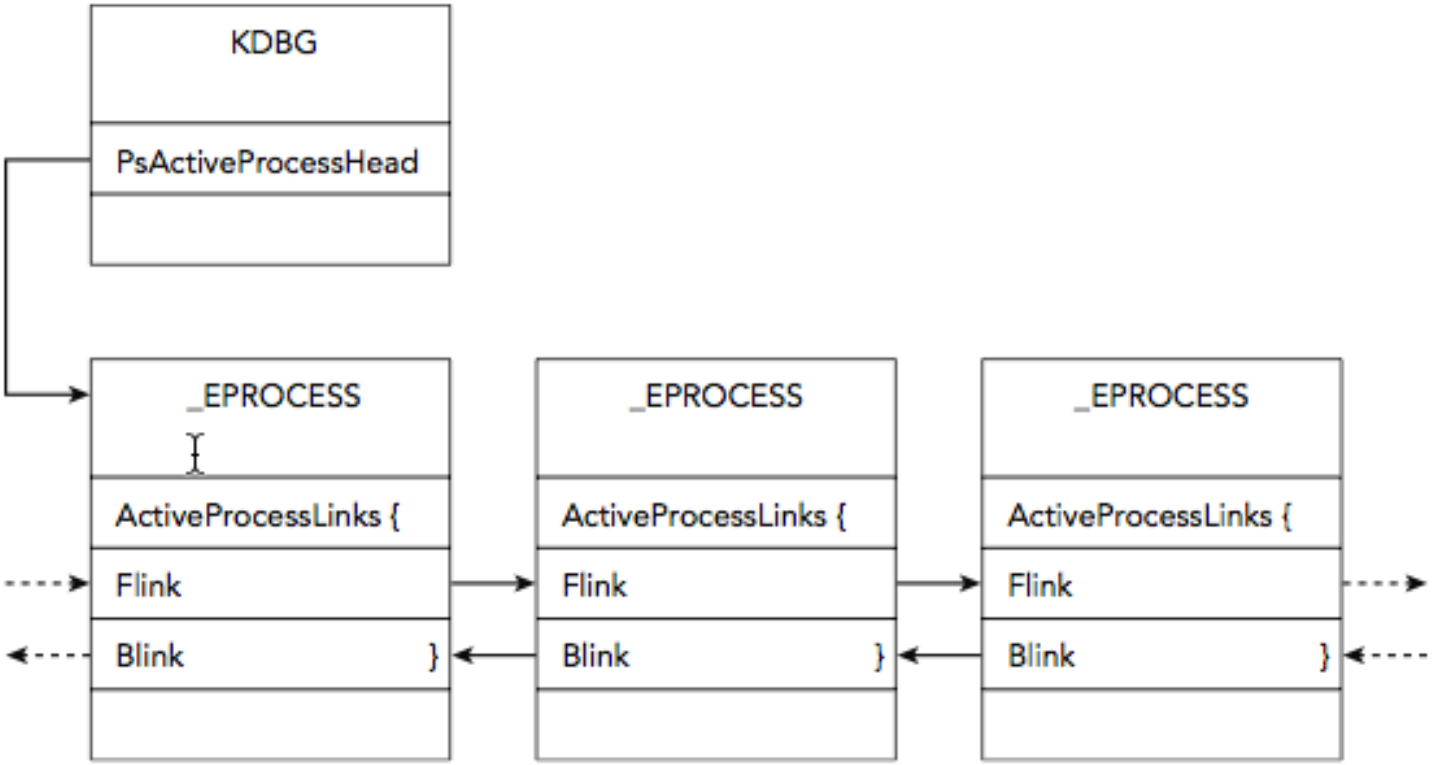
```
>>> dt("_EPROCESS")
'_EPROCESS' (1232 bytes)
0x0   : Pcb                          ['_KPROCESS']
0x160 : ProcessLock                  ['_EX_PUSH_LOCK']
0x168 : CreateTime                   ['WinTimeStamp', {'is_utc': True}]
0x170 : ExitTime                     ['WinTimeStamp', {'is_utc': True}]
0x178 : RundownProtect               ['_EX_RUNDOWN_REF']
0x180 : UniqueProcessId              ['unsigned int']
0x188 : ActiveProcessLinks           ['_LIST_ENTRY']
0x198 : ProcessQuotaUsage            ['array', 2, ['unsigned long long']]
0x1a8 : ProcessQuotaPeak             ['array', 2, ['unsigned long long']]
0x1b8 : CommitCharge                 ['unsigned long long']
0x1c0 : QuotaBlock                   ['pointer64', ['_EPROCESS_QUOTA_BLOCK']]
0x1c8 : CpuQuotaBlock                ['pointer64', ['_PS_CPU_QUOTA_BLOCK']]
0x1d0 : PeakVirtualSize              ['unsigned long long']
0x1d8 : VirtualSize                  ['unsigned long long']
0x1e0 : SessionProcessLinks          ['_LIST_ENTRY']
0x1f0 : DebugPort                    ['pointer64', ['void']]
[snip]
0x200 : ObjectTable                  ['pointer64', ['_HANDLE_TABLE']]
0x208 : Token                        ['_EX_FAST_REF']
0x210 : WorkingSetPage               ['unsigned long long']
0x218 : AddressCreationLock          ['_EX_PUSH_LOCK']
[snip]
0x290 : InheritedFromUniqueProcessId   ['unsigned int']
[snip]
0x2d0 : PageDirectoryPte             ['_HARDWARE_PTE']
0x2d8 : Session                      ['pointer64', ['void']]
0x2e0 : ImageFileName                ['String', {'length': 16}]
0x2ef : PriorityClass                ['unsigned char']
0x2f0 : JobLinks                     ['_LIST_ENTRY']
0x300 : LockedPagesList              ['pointer64', ['void']]
0x308 : ThreadListHead               ['_LIST_ENTRY']
0x318 : SecurityPort                 ['pointer64', ['void']]
0x320 : Wow64Process                 ['pointer64', ['void']]
0x328 : ActiveThreads                ['unsigned long']
```

```
0x32c : ImagePathHash                ['unsigned long']
0x330 : DefaultHardErrorProcessing   ['unsigned long']
0x334 : LastThreadExitStatus         ['long']
0x338 : Peb                          ['pointer64', ['_PEB']]
[snip]
0x444 : ExitStatus                   ['long']
0x448 : VadRoot                      ['_MM_AVL_TABLE']
0x488 : AlpcContext                  ['_ALPC_PROCESS_CONTEXT']
0x4a8 : TimerResolutionLink          ['_LIST_ENTRY']
0x4b8 : RequestedTimerResolution     ['unsigned long']
0x4bc : ActiveThreadsHighWatermark   ['unsigned long']
0x4c0 : SmallestTimerResolution      ['unsigned long']
```

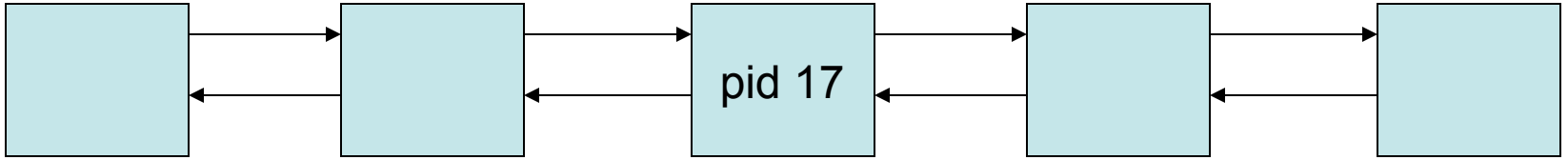
Windows Processes

- Windows organizes active processes using a doubly linked list pointed to by PsActiveProcessHead
  - Rootkits can unlink entries to hide processes from tools on the running system
  - Does not interrupt process execution because the CPU scheduler is thread-based

Linked List of Processes



DKOM: FU "Rootkit" under Windows

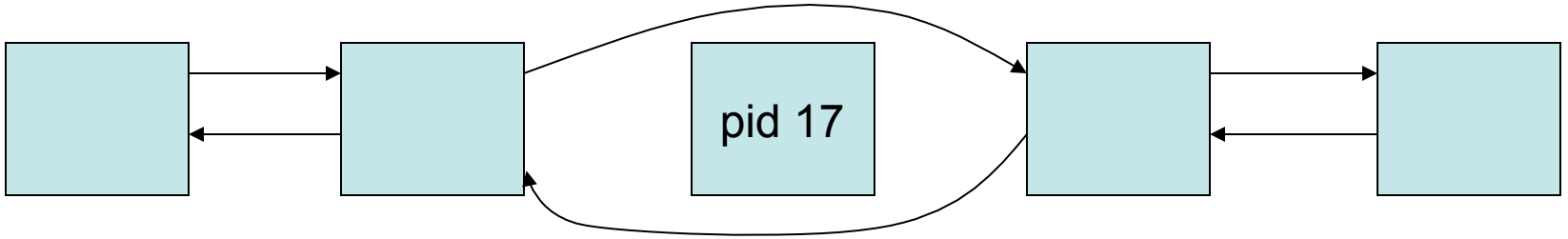


Doubly-linked process list in Windows kernel

Example of **DKOM**:
Direct **K**ernel **O**bject **M**anipulation

C:\> fu –ph 17

Processes continue to run because Windows scheduler handles threads, not processes



Identifying System Processes

- Important to be able to identify (real!) system processes to eliminate them from suspicion

pp. 155-156 in AMF

- `Idle` and `System`: These are not real processes (in the sense that they have no corresponding executable on disk). `Idle` is just a container that the kernel uses to charge CPU time for idle threads. Similarly, `System` serves as the default home for threads that run in kernel mode. Thus, the `System` process (PID 4) appears to own any sockets or handles to files that kernel modules open.
- `csrss.exe`: The client/server runtime subsystem plays a role in creating and deleting processes and threads. It maintains a private list of the objects that you can use to cross-reference with other data sources. On systems before Windows 7, this process also served as the broker of commands executed via `cmd.exe`, so you can extract command history from its memory space. Expect to see multiple CSRSS processes because each session gets a dedicated copy; however, watch out for attempts to exploit the naming convention (`csrsss.exe` or `cssrs.exe`). The real one is located in the system32 directory.

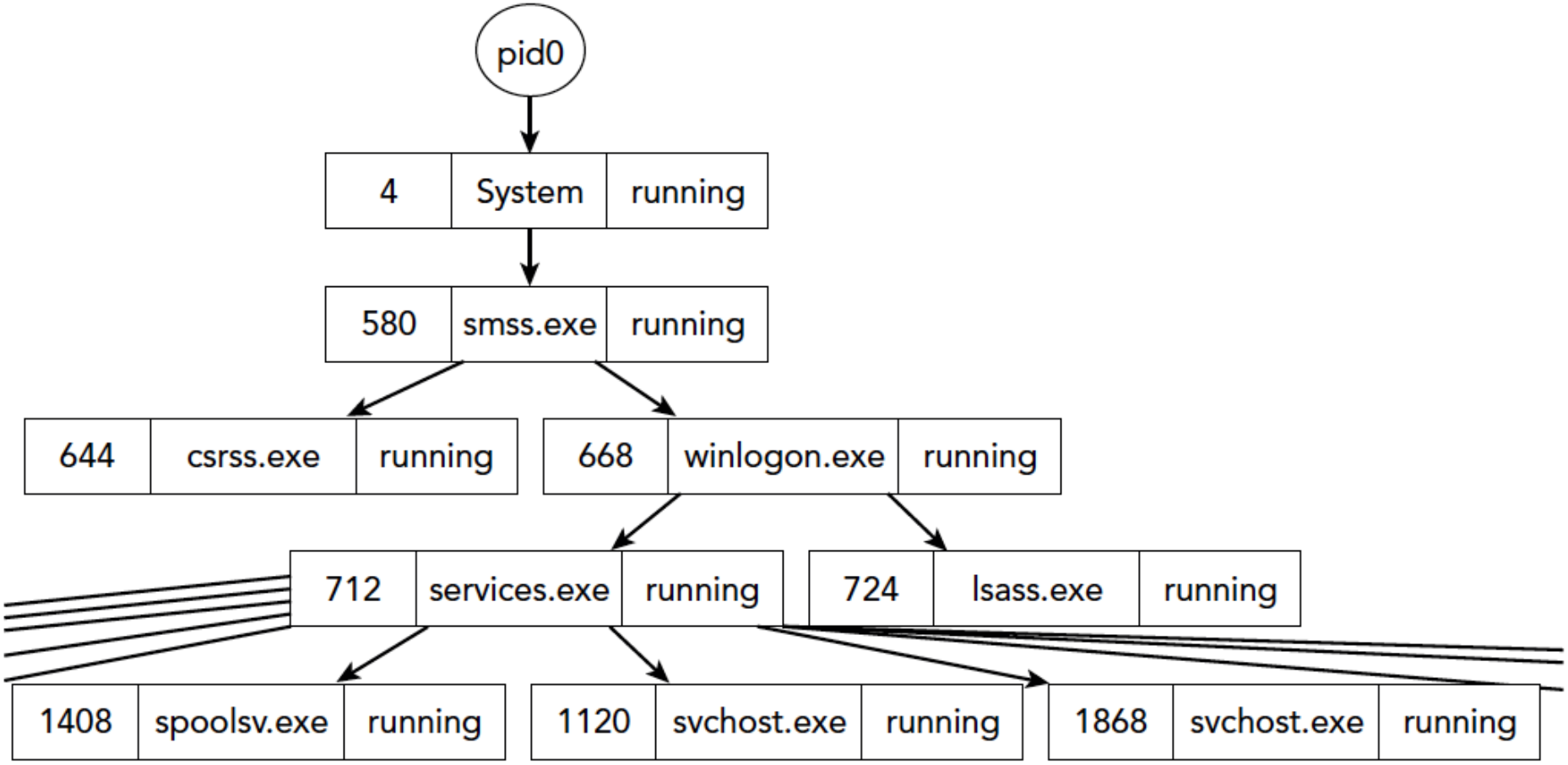
Identifying (2)

- `services.exe`: The Service Control Manager (SCM) is described more thoroughly in Chapter 12, but in short, it manages Windows services and maintains a list of such services in its private memory space. This process should be the parent for any `svchost.exe` (service host) instances that you see, in addition to processes such as `spoolsv.exe` and `SearchIndexer.exe` that implement services. There should be only one copy of `services.exe` on a system, and it should be running from the system32 directory.
- `svchost.exe`: A clean system has multiple shared host processes running concurrently, each providing a container for DLLs that implement services. As previously mentioned, their parent should be `services.exe`, and the path to their executable should point to the system32 directory. In his blog, Patrick identifies a few of the common names (such as `scvhost.exe` and `svch0st.exe`) used by malware to blend in with these processes.
- `lsass.exe`: The local security authority subsystem process is responsible for enforcing the security policy, verifying passwords, and creating access tokens. As such, it's often the target of code injection because the plaintext password hashes can be found in its private memory space. There should be only one instance of `lsass.exe` running from the system32 directory, and its parent is `winlogon.exe` on pre-Vista machines, and `wininit.exe` on Vista and later systems. Stuxnet created two fake copies of `lsass.exe`, which caused them to stick out like a sore thumb.

Identifying (3)

- `winlogon.exe`: This process presents the interactive logon prompt, initiates the screen saver when necessary, helps load user profiles, and responds to Secure Attention Sequence (SAS) keyboard operations such as `CTRL+ALT+DEL`. Also, this process monitors files and directories for changes on systems that implement Windows File Protection (WFP). As with most other critical processes, its executable is located in the system32 directory.
- `explorer.exe`: You'll see one Windows Explorer process for each logged-on user. It is responsible for handling a variety of user interactions such as GUI-based folder navigation, presenting the start menu, and so on. It also has access to sensitive material such as the documents you open and credentials you use to log in to FTP sites via Windows Explorer.
- `smss.exe`: The session manager is the first real user-mode process that starts during the boot sequence. It is responsible for creating the sessions (see Chapter 14) that isolate OS services from the various users who may log on via the console or Remote Desktop Protocol (RDP).

Visualization of Clean Systems



Windows Process Listing Plugins

- **`pslist`**
  - enumerates processes by walking the active list
  - will miss unlinked processes
- **`psscan`**
  - enumerates processes using the pool tag scanning technique
  - finds unlinked processes
  - can output a Graphviz-compatible diagram
- **`pstree`**
  - shows a tree of parent/child relationships
- **`psxview`**
  - enumerates processes 7 different ways and compares them to show discrepancies

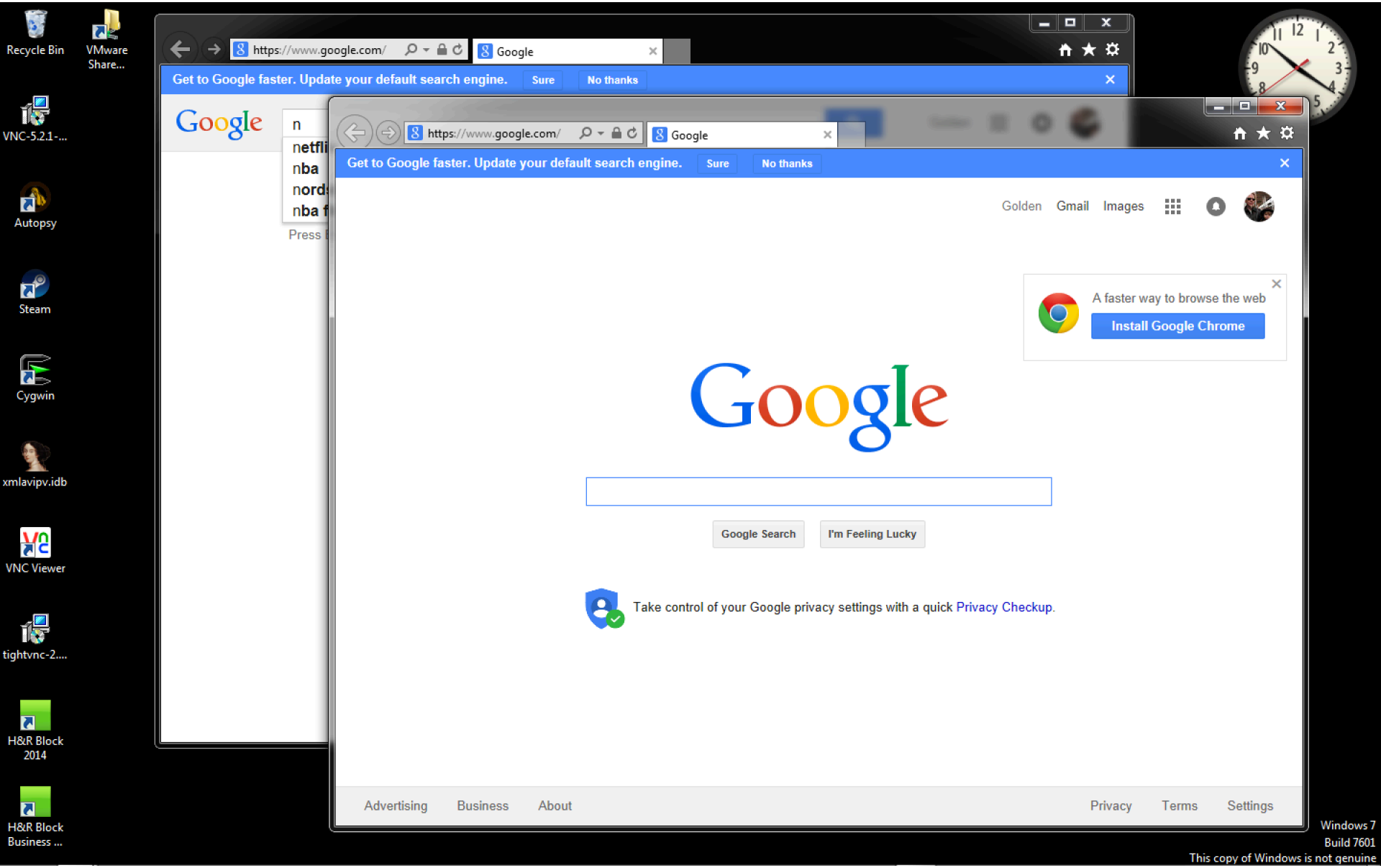
Windows Process Lists

```
$ python vol.py -f lab.mem --profile=WinXPSP3x86 pslist
Volatility Foundation Volatility Framework 2.4
Offset(V)  Name                PID   PPID   Thds     Hnds   Sess  Start
---------- ------------- ------ ----- ----- ------- -----  -------------------
0x823c8830 System                4      0     56      537 -----
0x81e7e180 smss.exe            580      4      3       19 -----  2013-03-14 03:02:22
0x82315da0 csrss.exe           644    580     10      449      0  2013-03-14 03:02:25
0x81f37948 winlogon.exe        668    580     18      515      0  2013-03-14 03:02:26
0x81fec128 services.exe        712    668     15      281      0  2013-03-14 03:02:27
[snip]
0x81eb4300 vmtoolsd.exe       1684   1300      6      213      0  2013-03-14 03:02:45
0x8210b9c8 IEXPLORE.EXE       1764   1300     16      642      0  2013-03-14 03:03:04
0x81e79020 firefox.exe         180   1300     27      447      0  2013-03-14 03:03:05
0x81cb63d0 wuauclt.exe        1576   1072      3      104      0  2013-03-14 03:03:40
0x81e86bf8 alg.exe            1836    712      5      102      0  2013-03-14 03:04:00
0x8209eda0 wscntfy.exe        2672   1072      1       28      0  2013-03-14 03:04:01
0x82013340 jucheck.exe        2388   1656      2      104      0  2013-03-14 03:07:45
0x81e79418 thunderbird.exe    3832   1300     30      339      0  2013-03-14 03:12:54
0x8202b398 AcroRd32.exe       3684    180      0 -------      0  2013-03-14 14:19:16
0x81ecd3c0 cmd.exe            3812   3684      1       33      0  2013-03-14 14:19:29
0x81f55bd0 a[1].php           2280   3812      1      139      0  2013-03-14 14:19:30
0x8223b738 IEXPLORE.EXE       2276   2280      7      280      0  2013-03-14 14:19:32
0x822c8a58 AcroRd32.exe       2644    180      0 -------      0  2013-03-14 14:40:16
```

Parent / Child Relationships

```
$ python vol.py -f lab.mem --profile=WinXPSP3x86 pstree
Volatility Foundation Volatility Framework 2.4

[snip]

0x82263378:explorer.exe              1300   1188     11    363 2013-03-14 03:02:42
. 0x81e85da0:TSVNCache.exe           1556   1300      7     53 2013-03-14 03:02:43
. 0x81e79020:firefox.exe              180   1300     27    447 2013-03-14 03:03:05
.. 0x8202b398:AcroRd32.exe           3684    180      0 ------ 2013-03-14 14:19:16
... 0x81ecd3c0:cmd.exe               3812   3684      1     33 2013-03-14 14:19:29
.... 0x81f55bd0:a[1].php             2280   3812      1    139 2013-03-14 14:19:30
..... 0x8223b738:IEXPLORE.EXE        2276   2280      7    280 2013-03-14 14:19:32
```

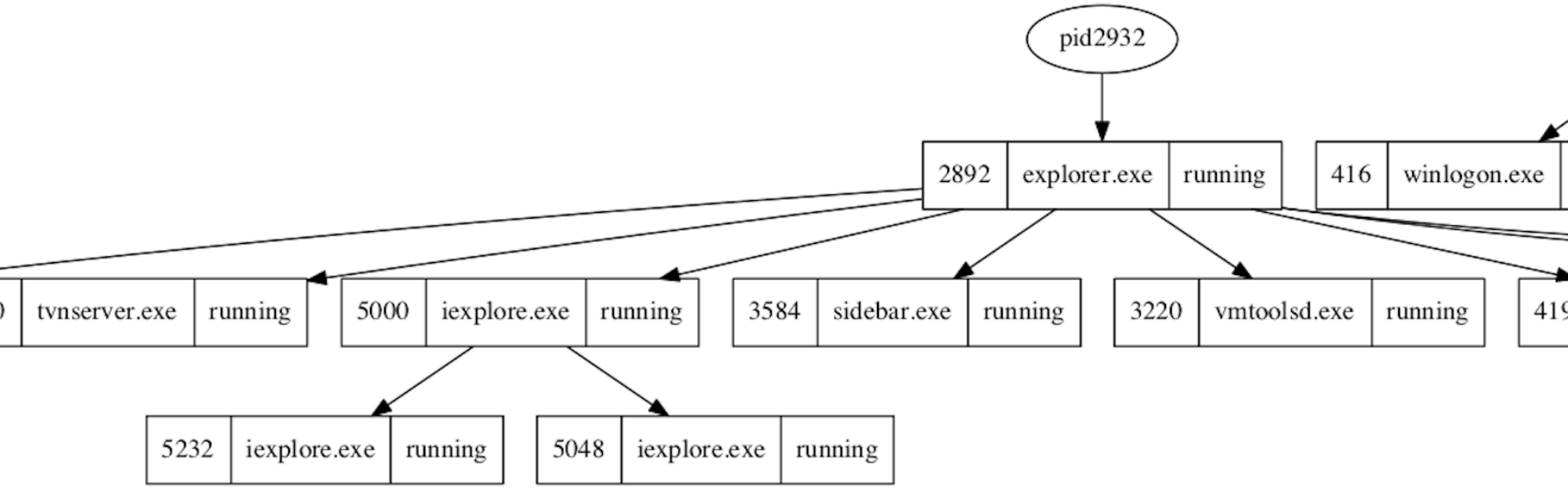
```
bigjoe:volatility golden$ python vol.py --profile=Win7SP1x64 -f /Volumes/malware/winpmem-1.4/after-republic-2.dmp pstree
Volatility Foundation Volatility Framework 2.4
Name                                                 Pid   PPid   Thds   Hnds Time
-------------------------------------------------- ------ ------ ------ ------ ----
 0xfffffa8008f1eb30:iexplore.exe                     1240   1100     21    384 2015-06-11 19:38:07 UTC+0000
. 0xfffffa8008a12b30:taskmgr.exe                     2176   1240      6    129 2015-06-11 19:38:08 UTC+0000
 0xfffffa80072fe740:System                              4      0    103    325 2015-06-11 19:37:53 UTC+0000
. 0xfffffa800855a170:smss.exe                        264      4      2     36 2015-06-11 19:37:53 UTC+0000
 0xfffffa80087a96c0:wininit.exe                      392    336      3     82 2015-06-11 19:37:55 UTC+0000
. 0xfffffa80088b9420:lsm.exe                         504    392      9    142 2015-06-11 19:37:56 UTC+0000
. 0xfffffa80088cf4d0:services.exe                    488    392      9    198 2015-06-11 19:37:56 UTC+0000
.. 0xfffffa8008be9a30:spoolsv.exe                   1036    488     12    313 2015-06-11 19:37:59 UTC+0000
.. 0xfffffa80089ffa30:svchost.exe                    856    488     23    848 2015-06-11 19:37:57 UTC+0000
.. 0xfffffa80089d4060:svchost.exe                    772    488     17    430 2015-06-11 19:37:57 UTC+0000
.. 0xfffffa800744a060:svchost.exe                   2076    488     11    339 2015-06-11 19:40:02 UTC+0000
.. 0xfffffa800899f690:svchost.exe                    676    488      6    219 2015-06-11 19:37:57 UTC+0000
.. 0xfffffa80089ed6a0:svchost.exe                    812    488     20    533 2015-06-11 19:37:57 UTC+0000
... 0xfffffa8008df8860:WUDFHost.exe                 1800    812      8    231 2015-06-11 19:38:02 UTC+0000
... 0xfffffa8008dceb30:dwm.exe                      1660    812      3     77 2015-06-11 19:38:01 UTC+0000
.. 0xfffffa80073ba060:sppsvc.exe                    3032    488      4    163 2015-06-11 19:40:02 UTC+0000
.. 0xfffffa8008c07b30:svchost.exe                   3004    488      5     75 2015-06-11 19:40:01 UTC+0000
.. 0xfffffa8008c246a0:svchost.exe                   1080    488     18    333 2015-06-11 19:37:59 UTC+0000
.. 0xfffffa8008d00910:taskhost.exe                  1364    488      7    136 2015-06-11 19:38:01 UTC+0000
.. 0xfffffa8008976060:svchost.exe                    600    488      9    372 2015-06-11 19:37:57 UTC+0000
.. 0xfffffa8008dd62f0:svchost.exe                   1680    488      6    100 2015-06-11 19:38:01 UTC+0000
.. 0xfffffa8008a7ab30:svchost.exe                    996    488     10    250 2015-06-11 19:37:58 UTC+0000
.. 0xfffffa8008ac56a0:svchost.exe                    340    488     13    343 2015-06-11 19:37:59 UTC+0000
. 0xfffffa80088b1b30:lsass.exe                       496    392      7    458 2015-06-11 19:37:56 UTC+0000
 0xfffffa8008360a60:csrss.exe                        344    336     11    264 2015-06-11 19:37:55 UTC+0000
 0xfffffa8008738780:csrss.exe                        400    384      9    147 2015-06-11 19:37:55 UTC+0000
. 0xfffffa8009020b30:conhost.exe                     2660    400      2     53 2015-06-11 19:38:27 UTC+0000
 0xfffffa80088a9b30:winlogon.exe                     440    384      3    116 2015-06-11 19:37:56 UTC+0000
 0xfffffa8008e0d060:explorer.exe                    1784   1532     17    684 2015-06-11 19:38:02 UTC+0000
. 0xfffffa8009021060:cmd.exe                        2652   1784      1     20 2015-06-11 19:38:27 UTC+0000
.. 0xfffffa800743bb30:winpmem_1.4.ex                2848   2652      1     29 2015-06-11 19:39:04 UTC+0000
 0xfffffa8008f0a060:iexplore.exe                    1916   1140      4     73 2015-06-11 19:38:06 UTC+0000
 0xfffffa8008ca3b30:iexplore.exe                    1908   1140     10    127 2015-06-11 19:38:06 UTC+0000
bigjoe:volatility golden$ python vol.py --profile=Win7SP1x64 -f /Volumes/malware/winpmem-1.4/after-republic-2.dmp iehistory
Volatility Foundation Volatility Framework 2.4
bigjoe:volatility golden$ mkdir DUMP && python vol.py --profile=Win7SP1x64 -f /Volumes/malware/winpmem-1.4/after-republic-2.dmp procdump -p 1240 -D DUMP
Volatility Foundation Volatility Framework 2.4
Process(V)         ImageBase          Name                 Result
------------------ ------------------ -------------------- ------
0xfffffa8008f1eb30 0x0000000008b0000 iexplore.exe         OK: executable.1240.exe
```



1. bash

```
.. 0xfffffa8049cd0060:CodeMeter.exe          1516    464     11    131 2015-06-19 03:16:05 UTC+0000
.. 0xfffffa804a229630:dllhost.exe            3328    464     17    204 2015-06-19 03:18:02 UTC+0000
.. 0xfffffa8049ecdb30:svchost.exe            2088    464     11    199 2015-06-19 03:16:08 UTC+0000
.. 0xfffffa8049dea240:rpcld.exe              1908    464     10    252 2015-06-19 03:16:06 UTC+0000
.. 0xfffffa80495b1060:eEBSvc.exe             1300    464     33    177 2015-06-19 03:16:04 UTC+0000
.. 0xfffffa8049ba9b30:svchost.exe             892    464     25    496 2015-06-19 03:16:03 UTC+0000
... 0xfffffa8048526b30:dwm.exe               4024    892      6    138 2015-06-19 03:18:40 UTC+0000
.. 0xfffffa8049f66b30:tvnserver.exe          2344    464     17    164 2015-06-19 03:16:09 UTC+0000
.. 0xfffffa8049da6b30:svchost.exe            1824    464      4     61 2015-06-19 03:16:06 UTC+0000
. 0xfffffa80495aeb30:lsass.exe                476    348      8    770 2015-06-19 03:16:02 UTC+0000
. 0xfffffa80495b6b30:lsm.exe                  484    348     13    212 2015-06-19 03:16:02 UTC+0000
 0xfffffa804958db30:csrss.exe                 308    296      9    889 2015-06-19 03:16:01 UTC+0000
. 0xfffffa804aa7d060:conhost.exe             5540    308      1     33 2015-06-19 03:20:45 UTC+0000
 0xfffffa804847c890:System                      4      0     95    530 2015-06-19 03:15:57 UTC+0000
. 0xfffffa8048c2a040:smss.exe                 224      4      2     30 2015-06-19 03:15:57 UTC+0000
 0xfffffa804a42a630:explorer.exe             2892   2932     28    676 2015-06-19 03:18:40 UTC+0000
. 0xfffffa8048ebc060:tvnserver.exe           3600   2892      4     65 2015-06-19 03:18:45 UTC+0000
. 0xfffffa8049f54410:iexplore.exe            5000   2892     35    626 2015-06-19 03:19:29 UTC+0000
.. 0xfffffa804a54a800:iexplore.exe           5048   5000     34    686 2015-06-19 03:19:29 UTC+0000
.. 0xfffffa8049ef1060:iexplore.exe           5232   5000     32    648 2015-06-19 03:20:25 UTC+0000
. 0xfffffa8049fa0270:hpqtra08.exe            4212   2892      9    165 2015-06-19 03:18:49 UTC+0000
. 0xfffffa8049b7eb30:vmtoolsd.exe            3220   2892      9    256 2015-06-19 03:18:44 UTC+0000
. 0xfffffa8049f9c740:netsession_win          4128   2892      5    102 2015-06-19 03:18:46 UTC+0000
.. 0xfffffa804a032b30:netsession_win         4148   4128     12    339 2015-06-19 03:18:46 UTC+0000
. 0xfffffa8049cb7060:MSASCui.exe             3464   2892     15    389 2015-06-19 03:18:44 UTC+0000
. 0xfffffa804a199060:CodeMeterCC.ex          4192   2892      7    148 2015-06-19 03:18:48 UTC+0000
. 0xfffffa8049cb6b30:sidebar.exe             3584   2892     18    313 2015-06-19 03:18:45 UTC+0000
 0xfffffa804a2e23f0:hpwuschd2.exe            4348   4164      2     36 2015-06-19 03:18:50 UTC+0000
 0xfffffa80499b49e0:acrobat_sl.exe           4268   4164      6     61 2015-06-19 03:18:49 UTC+0000
 0xfffffa804a300870:acrotray.exe             4288   4164      3     62 2015-06-19 03:18:49 UTC+0000
 0xfffffa804a6deb30:Steam.exe                4084   4156     23    451 2015-06-19 03:19:36 UTC+0000
. 0xfffffa804a71a9e0:steamwebhelper          4012   4084     26    290 2015-06-19 03:19:37 UTC+0000
 0xfffffa8049461880:winlogon.exe              416    340      6    132 2015-06-19 03:16:02 UTC+0000
 0xfffffa8049421b30:csrss.exe                 356    340     10    498 2015-06-19 03:16:02 UTC+0000
garfish:volatility golden$
```

```
garfish:volatility golden$ python vol.py --profile=Win7SP1x64 -f ~/Documents/Virtual\ Machines.localized/Windo
ws\ 7\ x64/Windows\ 7\ x64-1e433ca5.vmem psscan --output=dot --output-file=win7-clean.dot
Volatility Foundation Volatility Framework 2.4
garfish:volatility golden$
```



Cross-referencing Kernel Structures

- Malware can easily hide from analysis tools which rely on one information source
- e.g., process list
- Expand scope by cross-referencing kernel structures that provide similar information
- **`psxview`** plugin accomplishes this

psxview Sources

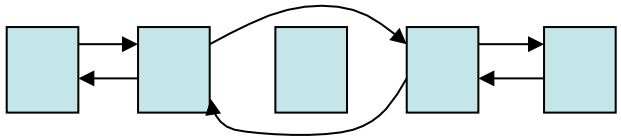
- Scan for process objects using **pool scanning** (e.g., carving)
- Scan for _ETHREAD objects and backtrace to _EPROCESS
- Structures maintained by csrss process
  - Maintains handles to created processes
- PspCID table
  - References active processes and threads
- Login session and desktop data structures
  - Also reference groups of processes

Windows XP SP3

Offset(P)	Name	PID	pslist	psscan	thrdproc	pspcid	csrss	session	deskthrd	ExitTime
0x0a96f558	GrooveMonitor.e	592	True	True	False	True	True	True	True	
0x0a72b280	GoogleUpdateSet	1492	True	True	False	True	True	True	True	
0x0a527a48	MagicDisc.exe	1476	True	True	False	True	True	True	True	
0x0a539248	AdobeARM.exe	624	True	True	False	True	True	True	True	
0x0a402da0	hasplms.exe	3228	True	True	False	True	True	True	True	
0x09f82308	jqs.exe	3392	True	True	False	True	True	True	True	
0x0a7e3c10	vmacthlp.exe	1316	True	True	False	True	True	True	True	
0x0a98e558	winlogon.exe	1084	True	True	False	True	True	True	True	
0x0a9a39a0	BTTray.exe	948	True	True	False	True	True	True	True	
0x0a8c6da0	svchost.exe	1560	True	True	False	True	True	True	True	
0x0a5a5b20	svchost.exe	3608	True	True	False	True	True	True	True	
0x0a9a8da0	services.exe	1144	True	True	False	True	True	True	True	
0x0aa44af0	mdm.exe	3496	True	True	False	True	True	True	True	
0x0a48dda0	prtk_worker_ser	1608	True	True	False	True	True	True	False	
0x0aa3d928	svchost.exe	1660	True	True	False	True	True	True	True	
0x0a58bda0	jusched.exe	708	True	True	False	True	True	True	True	
0x0a222830	vmtoolsd.exe	700	True	True	False	True	True	True	True	
0x0a53eac8	ctfmon.exe	716	True	True	False	True	True	True	True	
0x0a981da0	ISUSPM.exe	600	True	True	False	True	True	True	True	
0x0a81a808	svchost.exe	1616	True	True	False	True	True	True	True	
0x0a46dda0	GoogleUpdate.ex	2892	True	True	False	True	True	True	True	
0x0a7d67b8	ONENOTEM.EXE	1500	True	True	False	True	True	True	True	
0x0a49aad0	svchost.exe	1688	True	True	False	True	True	True	True	
0x0a96fda0	explorer.exe	452	True	True	False	True	True	True	True	
0x0a801da0	lsass.exe	1156	True	True	False	True	True	True	True	
0x0a370da0	rundll32.exe	360	True	True	False	True	True	True	True	
0x0a865020	acrotray.exe	616	True	True	False	True	True	True	True	
0x0a7e0648	svchost.exe	1328	True	True	False	True	True	True	True	
0x0a499c90	prtk_supervisor	1596	True	True	False	True	True	True	False	
0x0a569248	rundll32.exe	684	True	True	False	True	True	True	True	
0x0a993558	rapimgr.exe	912	True	True	False	True	True	True	True	
0x0a973da0	WgaTray.exe	432	True	True	False	True	True	True	True	
0x09fb6250	cvpnd.exe	3164	True	True	False	True	True	True	True	
0x0a7bc020	mysqld-nt.exe	3556	True	True	False	True	True	True	True	
0x0a8045d8	svchost.exe	1708	True	True	False	True	True	True	True	
0x0a8b6da0	ADEngineW.exe	1704	True	True	False	True	True	True	True	
0x0a8bad08	ADEngineS.exe	1644	True	True	False	True	True	True	True	
0x0a36cae0	acrobat_sl.exe	608	True	True	False	True	True	True	True	
0x09f991d0	svchost.exe	3336	True	True	False	True	True	True	True	
0x09fb7120	InstallShield L	3360	True	True	False	True	True	True	True	
0x0a9892f0	svchost.exe	1420	True	True	False	True	True	True	True	
0x0a95e528	CodeMeterCC.exe	996	True	True	False	True	True	True	True	
0x0a7dd578	spoolsv.exe	2000	True	True	False	True	True	True	True	
0x0a4b6da0	CodeMeter.exe	1756	True	True	False	True	True	True	True	
0x0a846020	wcescomm.exe	840	True	True	False	True	True	True	True	
0x0a6a79e0	CodeMeter.exe	1536	True	True	False	True	False	False	False	2013-12-01 06:03:32 UTC+0000
0x0ac39830	System	4	True	True	False	True	False	False	False	
0x0a8123b8	csrss.exe	1016	True	True	False	True	False	True	True	
0x0a839020	smss.exe	672	True	True	False	True	False	False	False	

Windows XP SP3

FU on PID 2260



Offset(P)	Name	PID	pslist	psscan	thrdproc	pspcid	csrss	session	deskthrd	ExitTime
0x0a720180	prtk_worker_ser	360	True	True	False	True	True	True	False	
0x097e0c68	vmtoolsd.exe	3932	True	True	False	True	True	True	True	
0x0a4e0da0	InstallShield L	1292	True	True	False	True	True	True	True	
0x0aad9888	services.exe	1152	True	True	False	True	True	True	True	
0x09852490	wcescomm.exe	4052	True	True	False	True	True	True	True	
0x09ec2da0	wmiprvse.exe	2984	True	True	False	True	True	True	True	
0x09f15810	wdfmgr.exe	2316	True	True	False	True	True	True	True	
0x09f32960	sshd.exe	2080	True	True	False	True	True	True	True	
0x09b49020	CodeMeterCC.exe	1372	True	True	False	True	True	True	True	
0x097a6c28	cmd.exe	2164	True	True	False	True	True	True	True	
0x09f2e518	oracle.exe	2096	True	True	False	True	True	True	True	
0x098185a8	rundll32.exe	3840	True	True	False	True	True	True	True	
0x0a926da0	vmacthlp.exe	1332	True	True	False	True	True	True	True	
0x0a86bb20	svchost.exe	1228	True	True	False	True	True	True	True	
0x0a785da0	winlogon.exe	1056	True	True	False	True	True	True	True	
0x0938f370	GoogleUpdate.ex	1104	True	True	False	True	True	True	True	
0x09f30020	ctfmon.exe	3952	True	True	False	True	True	True	True	
0x0aad9608	svchost.exe	1628	True	True	False	True	True	True	True	
0x09f49da0	cygrunsrv.exe	1596	True	True	False	True	True	True	True	
0x0a607228	CodeMeter.exe	436	True	True	False	True	True	True	True	
0x09f32020	extjob.exe	2072	True	True	False	True	True	True	True	
0x0a509b30	vmtoolsd.exe	2476	True	True	False	True	True	True	True	
0x0a841a88	svchost.exe	1744	True	True	False	True	True	True	True	
0x0a640da0	svchost.exe	1432	True	True	False	True	True	True	True	
0x09f14020	svchost.exe	2240	True	True	False	True	True	True	True	
0x0aa947b8	svchost.exe	396	True	True	False	True	True	True	True	
0x0a76eda0	svchost.exe	564	True	True	False	True	True	True	True	
0x09796020	MagicDisc.exe	2260	False	True	False	True	True	True	True	
0x09cd0928	wuauclt.exe	2776	True	True	False	True	True	True	True	
0x097f7020	AdobeARM.exe	3804	True	True	False	True	True	True	True	
0x0a5fdda0	lsass.exe	1164	True	True	False	True	True	True	True	
0x09e4d020	BTTray.exe	2880	True	True	False	True	True	True	True	
0x09dd1d38	GoogleUpdate.ex	4028	True	True	False	True	True	True	True	
0x098121e8	jusched.exe	3880	True	True	False	True	True	True	True	
0x09c2ab20	alg.exe	3244	True	True	False	True	True	True	True	
0x0a562020	hasplms.exe	880	True	True	False	True	True	True	True	
0x0a726248	spoolsv.exe	2012	True	True	False	True	True	True	True	
0x0a777da0	jqs.exe	1380	True	True	False	True	True	True	True	
0x0981a020	TPAutoConnect.e	3752	True	True	False	True	True	True	True	
0x09849da0	explorer.exe	2808	True	True	False	True	True	True	True	
0x09e13da0	rapimgr.exe	1092	True	True	False	True	True	True	True	
0x0ab265d0	svchost.exe	312	True	True	False	True	True	True	True	
0x09c56bf8	TPAutoConnSvc.e	2276	True	True	False	True	True	True	True	
0x097e57b8	acrotray.exe	3780	True	True	False	True	True	True	True	
0x097b0c08	ONENOTEM.EXE	1156	True	True	False	True	True	True	True	
0x097f1a58	acrobat_sl.exe	3744	True	True	False	True	True	True	True	
0x0a91c670	ADEngineS.exe	368	True	True	False	True	True	True	True	
0x0989b6f0	wscntfy.exe	240	True	True	False	True	True	True	True	
0x0a597da0	svchost.exe	1772	True	True	False	True	True	True	True	
0x0a8c93e0	prtk_supervisor	348	True	True	False	True	True	True	False	
0x0981ed10	GrooveMonitor.e	3264	True	True	False	True	True	True	True	
0x0a951b20	mysqld-nt.exe	1912	True	True	False	True	True	True	True	
0x093623a0	wuauclt.exe	2828	True	True	False	True	True	True	True	
0x0a725568	svchost.exe	712	True	True	False	True	True	True	True	
0x0a5fb460	ADEngineW.exe	404	True	True	False	True	True	True	True	
0x09819020	ISUSPM.exe	3720	True	True	False	True	True	True	True	
0x094eb020	GoogleUpdate.ex	4064	True	True	False	True	True	True	True	
0x09368870	wmiprvse.exe	2392	True	True	False	True	True	True	True	
0x09f4c2e8	svchost.exe	2132	True	True	False	True	True	True	True	
0x09ea4020	btwdins.exe	192	True	True	False	True	True	True	True	
0x0a619578	cvpnd.exe	568	True	True	False	True	True	True	True	
0x093bd878	wmiadap.exe	3732	True	True	False	True	True	True	True	
0x0a978b20	mdm.exe	1884	True	True	False	True	True	True	True	
0x0a71fda0	svchost.exe	1348	True	True	False	True	True	True	True	
0x0a983680	smss.exe	688	True	True	False	True	False	False	False	
0x0ac39830	System	4	True	True	False	True	False	False	False	
0x09f3c550	cygrunsrv.exe	2056	True	True	False	True	False	False	False	2014-09-03 17:12:07 UTC+0000
0x0a5ffda0	csrss.exe	1024	True	True	False	True	False	True	True	

Windows Process Tokens

- Process tokens store the SIDs (user and group contexts) and privileges for a process
- **`getsids`** and **`privs`** dump token information
- Helps detect privilege escalation attacks
- e.g., can see Domain Admin or Enterprise Admin in the SIDs list
- Examining privileges helps detect unusual behavior
  - Debug privilege → code injection is possible
  - Load driver privilege → obvious
  - Backup privilege → can read sensitive files

_TOKEN structure (2003 Server)

```
>>> dt("_TOKEN")
'_TOKEN' (208 bytes)
0x0    : TokenSource          ['_TOKEN_SOURCE']
0x10   : TokenId              ['_LUID']
0x18   : AuthenticationId     ['_LUID']
[snip]
0x4c   : UserAndGroupCount    ['unsigned long']
0x50   : RestrictedSidCount   ['unsigned long']
0x54   : PrivilegeCount       ['unsigned long']
[snip]
0x68   : UserAndGroups        ['pointer', ['array',
    lambda x: x.UserAndGroupCount, ['_SID_AND_ATTRIBUTES']]]
0x70   : RestrictedSids       ['pointer64', ['_SID_AND_ATTRIBUTES']]
0x78   : PrimaryGroup         ['pointer64', ['void']]
0x80   : Privileges           ['pointer', ['array',
    lambda x: x.PrivilegeCount, ['_LUID_AND_ATTRIBUTES']]]
```

_TOKEN structure (64-bit Win 7)

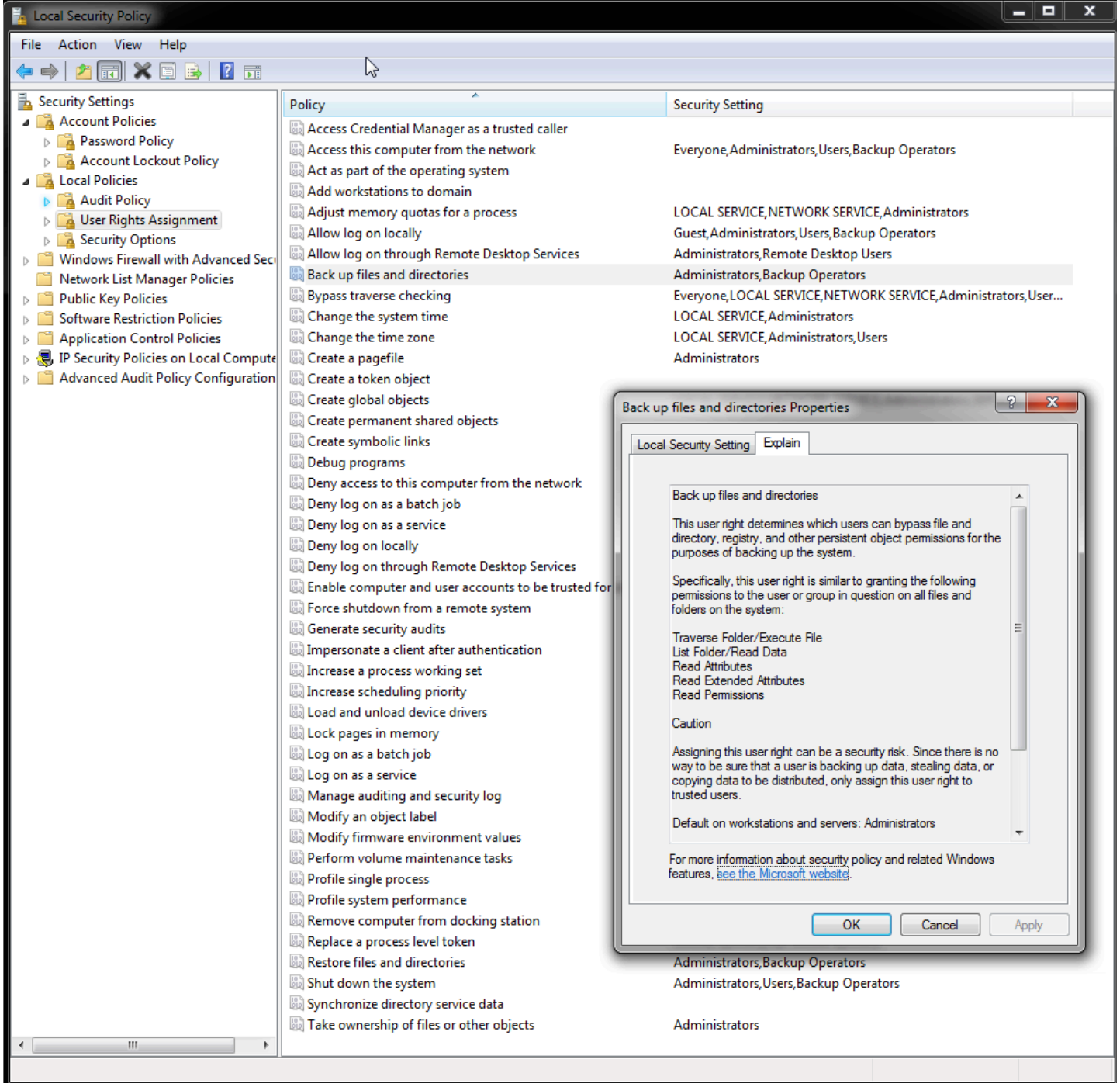
```
$ python vol.py --profile=Win7SP1x64 -f win7-64bit.vmem volshell
>>> dt("_TOKEN")
 '_TOKEN' (784 bytes)
0x0   : TokenSource              ['_TOKEN_SOURCE']
0x10  : TokenId                  ['_LUID']
0x18  : AuthenticationId         ['_LUID']
0x20  : ParentTokenId            ['_LUID']
0x28  : ExpirationTime           ['_LARGE_INTEGER']
0x30  : TokenLock                ['pointer64', ['_ERESOURCE']]
0x38  : ModifiedId               ['_LUID']
0x40  : Privileges               ['_SEP_TOKEN_PRIVILEGES']
0x58  : AuditPolicy              ['_SEP_AUDIT_POLICY']
0x74  : SessionId                ['unsigned long']
0x78  : UserAndGroupCount        ['unsigned long']
0x7c  : RestrictedSidCount       ['unsigned long']
0x90  : UserAndGroups          ['pointer', ['array',
       <function <lambda> at 0x107b120c8>, ['_SID_AND_ATTRIBUTES']]]
0x98  : RestrictedSids         ['pointer64', ['_SID_AND_ATTRIBUTES']]
0xe0  : SidHash                  ['_SID_AND_ATTRIBUTES_HASH']
0x1f0 : RestrictedSidHash        ['_SID_AND_ATTRIBUTES_HASH']
```

Token Analysis

```
$ python vol.py  -f grrcon.img   getsids   -p 1096
Volatility Foundation Volatility Framework 2.4

explorer.exe (1096): S-1-5-21-2682149276-1333600406-3352121115-500 (administrator)
explorer.exe (1096): S-1-5-21-2682149276-1333600406-3352121115-513 (Domain Users)
explorer.exe (1096): S-1-1-0 (Everyone)
explorer.exe (1096): S-1-5-32-545 (Users)
explorer.exe (1096): S-1-5-32-544 (Administrators)
explorer.exe (1096): S-1-5-4 (Interactive)
explorer.exe (1096): S-1-5-11 (Authenticated Users)
explorer.exe (1096): S-1-5-5-0-206541 (Logon Session)
explorer.exe (1096): S-1-2-0 (Local (Users with the ability to log in locally))
explorer.exe (1096): S-1-5-21-2682149276-1333600406-3352121115-519 (Enterprise
Admins)
explorer.exe (1096): S-1-5-21-2682149276-1333600406-3352121115-1115
explorer.exe (1096): S-1-5-21-2682149276-1333600406-3352121115-518 (Schema Admins)
explorer.exe (1096): S-1-5-21-2682149276-1333600406-3352121115-512 (Domain Admins)
explorer.exe (1096): S-1-5-21-2682149276-1333600406-3352121115-520 (Group Policy
Creator Owners)
```

User Account Privileges

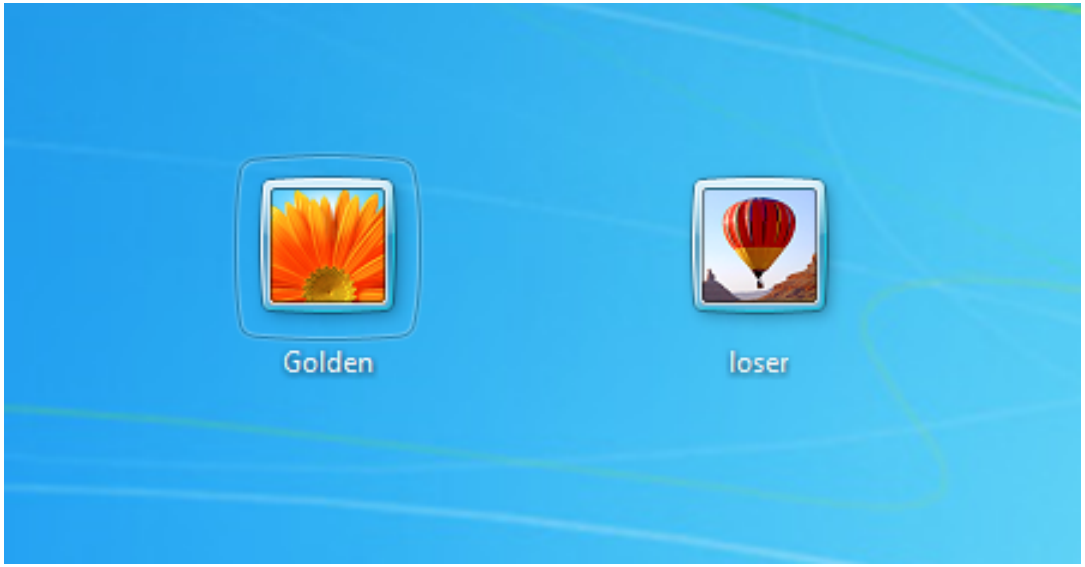
via `secpol.msc`



Privilege Analysis To Detect Malware

```
$ python vol.py -f grrcon.img privs -p 1096
Volatility Foundation Volatility Framework 2.4
```

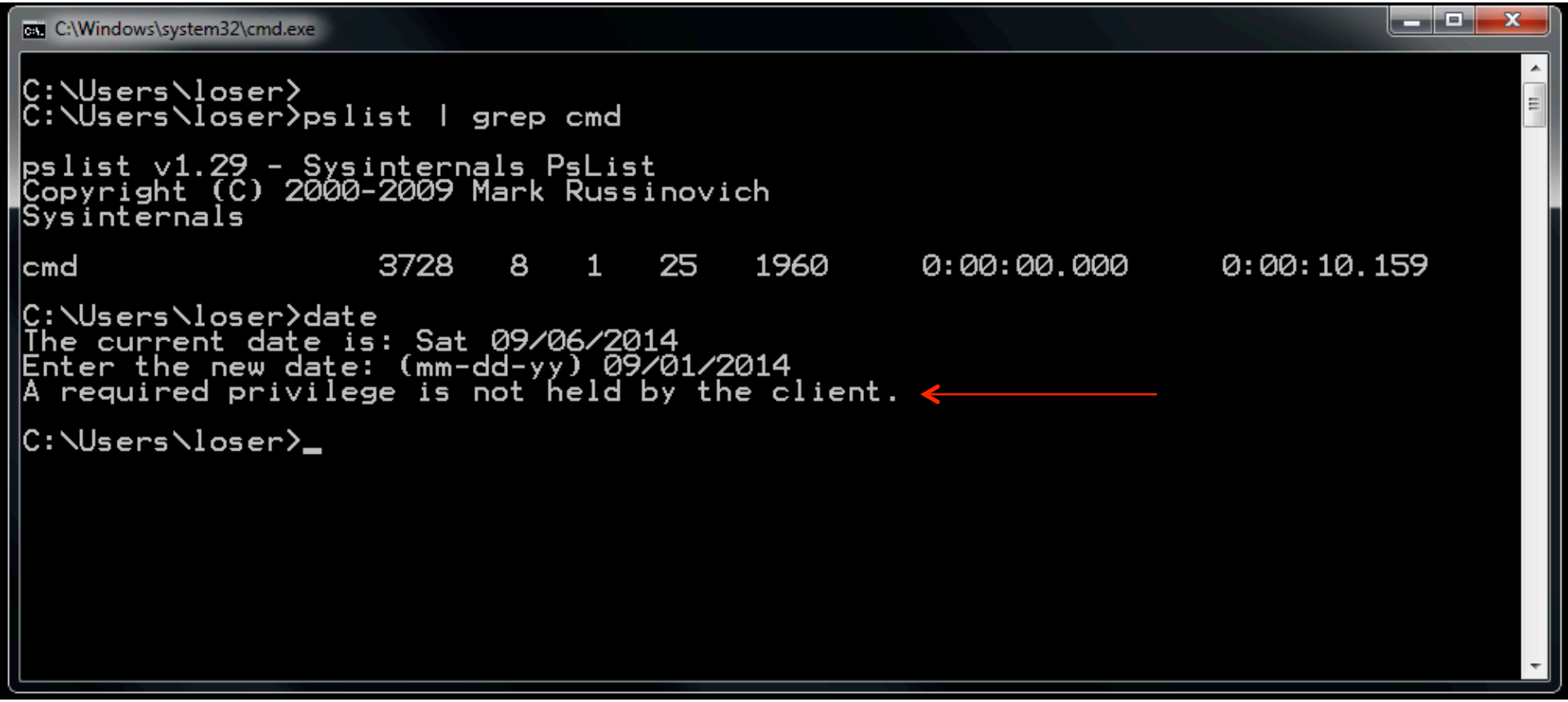
Pid	Process	Value	Privilege	Attributes
1096	explorer.exe	23	SeChangeNotifyPrivilege	Present,Enabled,Default
1096	explorer.exe	19	SeShutdownPrivilege	Present
1096	explorer.exe	25	SeUndockPrivilege	Present,Enabled
1096	explorer.exe	8	SeSecurityPrivilege	Present
1096	explorer.exe	17	SeBackupPrivilege	Present
1096	explorer.exe	18	SeRestorePrivilege	Present
1096	explorer.exe	12	SeSystemtimePrivilege	Present
1096	explorer.exe	24	SeRemoteShutdownPrivilege	Present
1096	explorer.exe	9	SeTakeOwnershipPrivilege	Present
1096	explorer.exe	20	**SeDebugPrivilege**	**Present,Enabled**
1096	explorer.exe	22	SeSystemEnvironmentPrivilege	Present
1096	explorer.exe	11	SeSystemProfilePrivilege	Present
1096	explorer.exe	13	SeProfileSingleProcessPrivilege	Present
1096	explorer.exe	14	SeIncreaseBasePriorityPrivilege	Present
1096	explorer.exe	10	**SeLoadDriverPrivilege**	**Present,Enabled**
1096	explorer.exe	15	SeCreatePagefilePrivilege	Present
1096	explorer.exe	5	SeIncreaseQuotaPrivilege	Present
1096	explorer.exe	28	SeManageVolumePrivilege	Present
1096	explorer.exe	30	SeCreateGlobalPrivilege	Present,Enabled,Default
1096	explorer.exe	29	SeImpersonatePrivilege	Present,Enabled,Default



Logged in as “golden”, administrative account

```
bigjoe:volatility golden$ python vol.py --profile=Win7SP1x64 -f ~/Documents/Virtual\ Machines.localized/Windows\ 7\ x64/Windows\ 7\ x64-1e433ca5.vmem privs -p 1736
Volatility Foundation Volatility Framework 2.4
Pid      Process          Value  Privilege                         Attributes                Description
-------- ---------------- ------ --------------------------------- ------------------------- -----------
    1736 cmd.exe               2 SeCreateTokenPrivilege                                      Create a token object
    1736 cmd.exe               3 SeAssignPrimaryTokenPrivilege                               Replace a process-level token
    1736 cmd.exe               4 SeLockMemoryPrivilege             Present                   Lock pages in memory
    1736 cmd.exe               5 SeIncreaseQuotaPrivilege          Present                   Increase quotas
    1736 cmd.exe               6 SeMachineAccountPrivilege                                   Add workstations to the domain
    1736 cmd.exe               7 SeTcbPrivilege                                              Act as part of the operating system
    1736 cmd.exe               8 SeSecurityPrivilege               Present                   Manage auditing and security log
    1736 cmd.exe               9 SeTakeOwnershipPrivilege          Present                   Take ownership of files/objects
    1736 cmd.exe              10 SeLoadDriverPrivilege             Present                   Load and unload device drivers
    1736 cmd.exe              11 SeSystemProfilePrivilege          Present                   Profile system performance
    1736 cmd.exe              12 SeSystemtimePrivilege             Present                   Change the system time
    1736 cmd.exe              13 SeProfileSingleProcessPrivilege   Present                   Profile a single process
    1736 cmd.exe              14 SeIncreaseBasePriorityPrivilege   Present                   Increase scheduling priority
    1736 cmd.exe              15 SeCreatePagefilePrivilege         Present                   Create a pagefile
    1736 cmd.exe              16 SeCreatePermanentPrivilege                                 Create permanent shared objects
    1736 cmd.exe              17 SeBackupPrivilege                 Present                   Backup files and directories
    1736 cmd.exe              18 SeRestorePrivilege                Present                   Restore files and directories
    1736 cmd.exe              19 SeShutdownPrivilege               Present                   Shut down the system
    1736 cmd.exe              20 SeDebugPrivilege                  Present                   Debug programs
    1736 cmd.exe              21 SeAuditPrivilege                                           Generate security audits
    1736 cmd.exe              22 SeSystemEnvironmentPrivilege      Present                   Edit firmware environment values
    1736 cmd.exe              23 SeChangeNotifyPrivilege           Present,Enabled,Default   Receive notifications of changes to files or directories
    1736 cmd.exe              24 SeRemoteShutdownPrivilege         Present                   Force shutdown from a remote system
    1736 cmd.exe              25 SeUndockPrivilege                 Present                   Remove computer from docking station
    1736 cmd.exe              26 SeSyncAgentPrivilege                                       Synch directory service data
    1736 cmd.exe              27 SeEnableDelegationPrivilege                                Enable user accounts to be trusted for delegation
    1736 cmd.exe              28 SeManageVolumePrivilege           Present                   Manage the files on a volume
    1736 cmd.exe              29 SeImpersonatePrivilege            Present,Enabled,Default   Impersonate a client after authentication
    1736 cmd.exe              30 SeCreateGlobalPrivilege           Present,Enabled,Default   Create global objects
    1736 cmd.exe              31 SeTrustedCredManAccessPrivilege                            Access Credential Manager as a trusted caller
    1736 cmd.exe              32 SeRelabelPrivilege                                         Modify the mandatory integrity level of an object
    1736 cmd.exe              33 SeIncreaseWorkingSetPrivilege     Present                   Allocate more memory for user applications
    1736 cmd.exe              34 SeTimeZonePrivilege               Present                   Adjust the time zone of the computer's internal clock
    1736 cmd.exe              35 SeCreateSymbolicLinkPrivilege     Present                   Required to create a symbolic link
```

Logged in as “loser”, regular account



```
bigjoe:volatility golden$ python vol.py --profile=Win7SP1x64 -f ~/Documents/Virtual\ Machines.localized/Windows\ 7\ x64/Windows\ 7\ x64-1e433ca5.vmem privs -p 3728
Volatility Foundation Volatility Framework 2.4
Pid      Process          Value  Privilege                         Attributes                Description
-------- ---------------- ------ --------------------------------- ------------------------- -----------
    3728 cmd.exe               2 SeCreateTokenPrivilege                                      Create a token object
    3728 cmd.exe               3 SeAssignPrimaryTokenPrivilege                               Replace a process-level token
    3728 cmd.exe               4 SeLockMemoryPrivilege                                       Lock pages in memory
    3728 cmd.exe               5 SeIncreaseQuotaPrivilege                                    Increase quotas
    3728 cmd.exe               6 SeMachineAccountPrivilege                                   Add workstations to the domain
    3728 cmd.exe               7 SeTcbPrivilege                                              Act as part of the operating system
    3728 cmd.exe               8 SeSecurityPrivilege                                         Manage auditing and security log
    3728 cmd.exe               9 SeTakeOwnershipPrivilege                                    Take ownership of files/objects
    3728 cmd.exe              10 SeLoadDriverPrivilege                                       Load and unload device drivers
    3728 cmd.exe              11 SeSystemProfilePrivilege                                    Profile system performance
    3728 cmd.exe              12 SeSystemtimePrivilege                                       Change the system time
    3728 cmd.exe              13 SeProfileSingleProcessPrivilege                             Profile a single process
    3728 cmd.exe              14 SeIncreaseBasePriorityPrivilege                             Increase scheduling priority
    3728 cmd.exe              15 SeCreatePagefilePrivilege                                   Create a pagefile
    3728 cmd.exe              16 SeCreatePermanentPrivilege                                  Create permanent shared objects
    3728 cmd.exe              17 SeBackupPrivilege                                           Backup files and directories
    3728 cmd.exe              18 SeRestorePrivilege                                          Restore files and directories
    3728 cmd.exe              19 SeShutdownPrivilege            Present                      Shut down the system
    3728 cmd.exe              20 SeDebugPrivilege                                            Debug programs
    3728 cmd.exe              21 SeAuditPrivilege                                            Generate security audits
    3728 cmd.exe              22 SeSystemEnvironmentPrivilege                                Edit firmware environment values
    3728 cmd.exe              23 SeChangeNotifyPrivilege        Present,Enabled,Default      Receive notifications of changes to files or directories
    3728 cmd.exe              24 SeRemoteShutdownPrivilege                                   Force shutdown from a remote system
    3728 cmd.exe              25 SeUndockPrivilege              Present                      Remove computer from docking station
    3728 cmd.exe              26 SeSyncAgentPrivilege                                        Synch directory service data
    3728 cmd.exe              27 SeEnableDelegationPrivilege                                 Enable user accounts to be trusted for delegation
    3728 cmd.exe              28 SeManageVolumePrivilege                                     Manage the files on a volume
    3728 cmd.exe              29 SeImpersonatePrivilege                                      Impersonate a client after authentication
    3728 cmd.exe              30 SeCreateGlobalPrivilege                                     Create global objects
    3728 cmd.exe              31 SeTrustedCredManAccessPrivilege                             Access Credential Manager as a trusted caller
    3728 cmd.exe              32 SeRelabelPrivilege                                          Modify the mandatory integrity level of an object
    3728 cmd.exe              33 SeIncreaseWorkingSetPrivilege  Present                      Allocate more memory for user applications
    3728 cmd.exe              34 SeTimeZonePrivilege            Present                      Adjust the time zone of the computer's internal clock
    3728 cmd.exe              35 SeCreateSymbolicLinkPrivilege                               Required to create a symbolic link
```

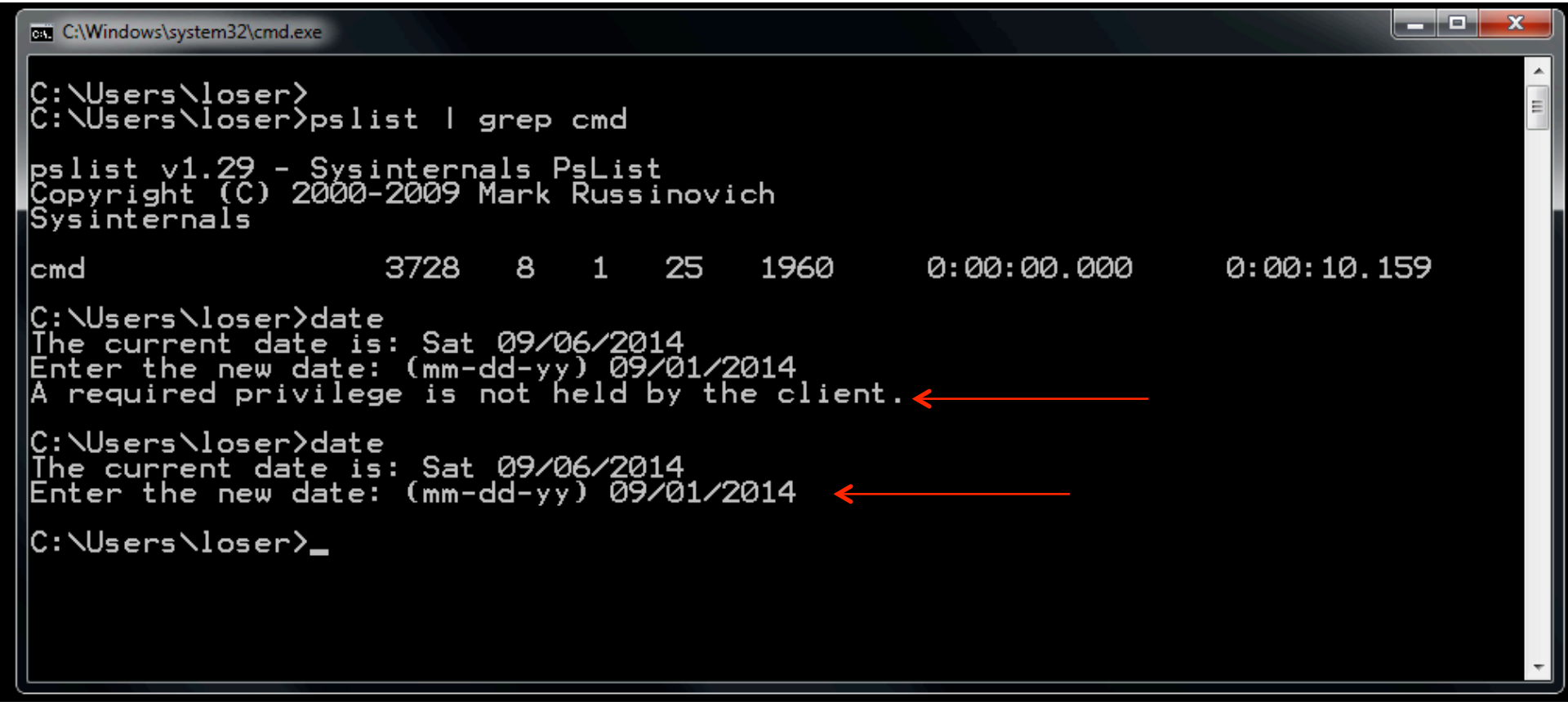
Simulating Privilege Escalation Using volshell

```
bigjoe:volatility golden$ python vol.py --profile=Win7SP1x64 -f ~/Documents/Virtual\ Machines.localized/Windows\ 7\ x64/Windows\ 7\ x64-1e433ca5.vmem volshell --write
Volatility Foundation Volatility Framework 2.4
Write support requested.  Please type "Yes, I want to enable write support" below precisely (case-sensitive):
Yes, I want to enable write support
cc(Current context: System @ 0xfffffa804847c9e0, pid=4, ppid=0 DTB=0x187000
Welcome to volshell! Current memory image is:
file:///Users/golden/Documents/Virtual%20Machines.localized/Windows%207%20x64/Windows%207%20x64-1e433ca5.vmem
To get help, type 'hh()'
>>> cc(pid=3728)
Current context: cmd.exe @ 0xfffffa804a8d3060, pid=3728, ppid=3820 DTB=0x970fa000
>>> token=proc().get_token()
>>> bin(token.Privileges.Present)
'0b11000000010100010000000000000000'
>>> bin(token.Privileges.Enabled)
'0b10000000000000000000000'
>>> token.Privileges.Enabled=0xFFFFFFFFFFFFFFFF
>>> token.Privileges.Present=0xFFFFFFFFFFFFFFFF
>>> quit()
bigjoe:volatility golden$
```

This is for Win7 SP1—note that the trick outlined in AMF on p.174 that suggests that **`Privileges.Present`** need not be modified along with **`Privileges.Enabled`** doesn't work using this methodology.

(We're investigating.)

Logged in as “nobody”, regular account



END of Part I