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Basics of a CSIRT: Software environment Digital Forensics – Lab Session

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Motivation for this Research

- There is a good tool for acquisition of memory from Mac machines [1], but no tools for deep analysis of the captured memory
- Only one public tool, Volafox [7], supports Mac analysis, but not as robustly or as thoroughly as we would like
- To fix this, we added full Mac support to Volatility
  - Will have a comparison with Volafox at the end

Memory Forensics Introduction

RAM

- Memory analysis is the process of taking a memory capture (a sample of RAM) and producing higher-level objects that are useful for an investigation
- A memory capture has the entire state of the operating system as well as running applications
  - Including all the related data structures, variables, etc

RAM

- The higher level objects we are interested in are in-memory representations of C structures, custom data structures, and other variables used by the operating system
- With these we can recover processes listings, filesystem information, networking data, etc
- This is what we will be talking about throughout this presentation

The Volatility Architecture

Volatility

- Most popular memory analysis framework
  - Written in Python
  - Open Source
  - Supports Windows {XP, Vista, 7, 2003, 2008}
  - Supports Linux on Intel and ARM
  - And now supports Mac!
- Allows for analysis plugins to be easily written
- Used daily in real forensics investigations

Volatility Terminology - Vtypes

- A representation of structures used in the OS, such as size, names, members, types, and offsets
- Example:

```
'_IMAGE_EXPORT_DIRECTORY': [ 0x28, {
  'Base': [ 0x10, ['unsigned int']],
  'NumberOfFunctions': [ 0x14, ['unsigned int']],
  'NumberOfNames': [ 0x18, ['unsigned int']],
  'AddressOfFunctions': [ 0x1C, ['unsigned int']],
```

Volatilyti Terminology - Profiles

- A profile is set of vtypes and (optionally) symbol addresses that are used to model a particular OS version
- This is what allows Volatility plugins to be generic to all the different versions of Windows, Linux, Mac, etc

Volatility Terminology – Address Spaces

- Address spaces are used to translate virtual addresses into physical offsets
- They also prevent the need to convert all memory captures to a linear format

Current Address Space

- Memory Management Address Spaces
  - x86 / x64
  - Arm (Android)
- Interface (File) Address Spaces
  - Firewire
  - Windows Hibernation Files
  - Crash Dumps
  - EWF Files
  - Lime
  - And a new one for this talk!

Mac Profile

- Mac profiles are built in two steps:

1) The addresses of symbols are gathered from the system's *mach_kernel*
2) The types are gathered by running *dwarfdump* on the debug *mach_kernel*
   - This is contained in the KernelDebugKit
   - This output is then converted into a proper vtype

Mac Memory Acquistion

Native Software Support

- Modern versions of Mac do not support /dev/mem or /dev/kmem
- This means that 3rd party software must be used to access physical memory

Memory Reader

- Main memory acquistion tool
  - Free, but not open source
- Supports capture from 32 and 64 bit systems running on native hardware as well as from Parallels and VirtualBox guests
  - Does not work with VMware Fusion guests
- Loads a driver to recreate /dev/mem and captures from it

The Capture File

- Mac Memory Reader creates a mach-o file of captured memory
  - Mach-o is the standard Mac exe format
- RAM is not contiguousin physical memory so a linear capture wouldbe much bigger than actual RAM size
  - Too big to deal with on 64 bit

Mach- O Address Space

- To handle Mac Memory Reader captures, a mach-o address space was developed
- Supports 32 and 64 bit captures
- It parses mach-o files and for each segment gathers:
  - The offset into the file
  - The size of the offset
  - Its mapped address, which is its physical address

Recovering Runtime Information

Runtime Information

- This rest of this session is focused on orderly recovery of data that was active at the time of the memory capture
- We will be discussing how to find key pieces of information and then use Volatility to recover them

Information to be Recovered

- Processes
- Memory Maps
- Open Files
- Network Connections
- Network Data
- Loaded Kernel Modules
- Rootkit Detection

MaC Overview

- No split address space
- (Almost?) Micro-kernel
  - Only the components that need hardware access run in ring 0
  - Everything else runs as a userland process
  - Mach is the only mainstream kernel like this
  - The mechanisms needed to make this work tend to be annoying as a memory analysis researcher

Processes & Tasks

- A process (*proc)* represents a BSD process
  - Its threads are called *uthreads*
- A task (*task)* represents a Mach task
  - Its threads are called “Mach Threads” and represented by the *thread* structure

Recovering Processes

- The list of processes is stored in the *allproc* list
- Each element of the list is of type *struct proc*
  - The *p_comm* member stores the ASCII name of the binary that was executed
  - The *p_pid* member stores the process ID
  - Other members you would expect:
    - p_uid, p_gid, p_ppid
- The *mac_pslist* plugin enumerates this list and prints out the per-process information

Recovering Command Line Arguments

- *mac_pslist* only recovers the name of the binary that was executed
- *mac_psaux* recovers the command line args (**argv) and optionally the env variables
- The CR3 value for each process is stored in:
  - <proc_structure>.task.map.pmap.pm_cr3
- *user_stack* and *p_argslen* are used to recover where the args and environment arrays are

Recovering Memory Maps

- The *mac_proc_maps* plugin recovers per-task memory maps
  - Mimics *vmmap* or Linux's */proc/<pid>/map*
- For each mapping, it lists:
  - Starting and ending address
  - The mapped file (if any)
- Makes spotting shared library injection easy
- A starting point to malware/unknown binary analysis

Mac_proc_maps aoutput

python vol.py --profile=Mac32 --profile_file=10.7.2.zip _

f 32bit.dump mac_proc_maps –p 1

…

1059cb000	1059ce000	r-x libauditd.0.dylib
1059ce000	1059cf000	rw- libauditd.0.dylib
1059cf000	1059d2000	r-- libauditd.0.dylib

…

Dumping Memory Maps

- The *mac_dump_map* plugin is able to dump the contents of memory mappings inside of particular processes
- Common usages:
  - Check against virus DBs
  - Binary Analysis
  - Further forensics analysis (strings, file carving, etc)

Open Files

- The *mac_lsof* plugin lists the files that are opened for each process
  - Similar to /proc/<pid>/fd on Linux
- Walks the *proc.p_fd.fd_ofiles* array
- Checks the vnode type, if DTYPE_VNODE, then it's a regular file and reported
- Useful to determine file system activity, log files, etc

Mount Points

- The *mac_mount* plugin recovers all mounted devices and their mount points
- Mimics the *mount* command
- Very useful when integrating disk and memory analysis during an investigation
- The mount flags can are also good artifacts (read only, no exec, no atime, etc)

Dmesg

- *mac_dmesg* recovers the kernel's debug buffer
- Contains a wide range of useful information
- Viewed on the live machine with the *dmesg* binary that reads */var/log/kernel.log*
- The contents are very easy to manipulate on disk – not so in memory

Network Connections

- *mac_netstat* emulates the netstat command
- Lists each connection along with relevant information (src/dst IP address & port, state, etc)
- Also walks the list of open files and acts on DTYPE_SOCKET entries
- Obviously useful when investigating network traffic and connections

Ifconfig

- *mac_ifconfig* emulates the *ifconfig* command
- Walks the *dlil_ifnet_head* list in memory to get each interface, which are represented by *ifnet* structures
- For each interface it recovers:
  - The interface name (en0, en1, etc)
  - Any IP addresses
  - MAC Address

ARP Table

- Found in the *llinfo_arp* list
- Recovers the ARP table out of memory
- Useful in IR scenarios to determine which networked devices the investigated machine recently contacted

Routing Cache

- When researching the routing table, I noticed that Mac has a very interesting routing cache
- Keeps track of connections made to remote IP addresses
- Statistics about these connections are kept as well including the **start time** and total packets & bytes

Entry Expiry

- Entries in the cache expire based on the value in *net.inet.ip.rtexpire* for IPv4 and *net.inet6.ip6.rtexpire* for IPv6
- This time is in seconds
- The countdown timer starts when there is no more references to the connection
  - So if the memory capture fits in this window, we can recover it

What are the expiry times?

- I asked Mac users for their sysctl value & OS version on twitter and G+
- Got about 20 responses, but wasn't conclusive
- For IPv4:
  - People with the same exact OS version had widely different values
  - Range was from 10 seconds (bad!) up to an hour
- IPv6 was always 3600 (one hour)

Uses of the Routing Cache

- Malware Analysis & Data Exfil Investgations
  - You know when the current session started
  - You know how much data was sent
- Beating Rootkits
  - How many rootkits hide from netstat/lsof and other tools using easily detectable techniques?
  - vs how many manipulate the kernel's routing cache?
    - Hint: 0

Loaded Kernel Modules

- The mac_lsmod plugin lists all of the loaded kernel modules (extensions) active on the system
- This replicates the output of the *kextstat* command
- This can lead to further investigation by dumping the executable in memory [14]

I/O KIT

- I/O Kit is the framework that allows for development of device drivers as well as the OS’es tracking and handling of hardware devices
- Provides the ability for programmers to hook into a wide range of hardware events and actions

The I/O Registry

- The I/O registry tracks devices that are attached to the computer as well as the classes that represent them
- The *ioreg* binary can list all of the registry contents
- The *mac_ioreg* plugin provides similar functionality to *ioreg*

Rootkit Detection

- Most rootkit discussions, whether offensive or defensive, make a distinction between userland (unprivileged) and kernel (fully privileged) rootkits
- Mac blurs this line with its micro-kernel design
- When referring to “kernel” rootkit detection, I mean core parts of the OS and not individual userland applications or services

Types of Rootkits

- Static
  - Alters data that is set at compile-time and never changes
  - Examples: modifying system call table entries, code (.text) instructions, global data structure function pointers
  - These are generally boring from a research perspective and already covered by other projects (Volafox [7], Phrack article [8], etc)

Types of Rootkits /1

- Dynamic
  - Alters data that is only created and referenced at runtime
  - Generally includes manipulating live data structures (lists, hash tables, trees) used by the operating system for accounting or for core operations
  - Much more interesting from a research perspective

Logkext

- Logkext is a rootkit that uses the IOKit framework to log keystrokes
- It accomplishes this by adding a 'gIOPublishNotification' callback that filters on the 'IOHIKeyboard' service.
- This effectively gives the rootkit control everytime a key is pressed.

Detecting Logkext

- Enumerate the *gNotifications* hash table
  - Keyed by the type of notification: (gIOPublishNotification, gIOFirstPublishNotification, gIOMatchedNotification, gIOFirstMatchNotification, gIOTerminatedNotification)
  - Each element is a IOServiceNotifier
- The handler member of IOServiceNotifier points to the callback function
- We verify that each callback is either:
  1. In the kernel
  2. In a known kernel module

IP Filters

- Part of the Network Kernel Extension framework
- Allows for kernel extension programmers to easily hook incoming and/or outgoing network packets
- These hooks have built-in support for modifying packets in-place!
  - Done with *ipf_inject_input* and *ipf_inject_output*

IP Filter Rootkits

- The potential for abuse of these filters is pretty obvious and existing rootkits take advantage of it in different ways
- We can detect these rootkits by verifying that every IP hook is in a known location
  - Implemented in *mac_ip_filter*

Detecting IP Filter Rootkits

- We walk the *ipv4_filters* & *ipv6_filters* lists
- These lists are of type *ipfilter_list* whose elements are *ipfilter*
- *ipfilter* structures hold the name of the filter (might be empty) as well as pointers to the *input, output,* and *detach* functions
- All three of these functions need to be in the kernel or in a known module if set

Trusted BSD

- The TrustedBSD framework provides hooks into a large number of functions in the kernel related to processes, memory, networking, and much more
- These hooks are meant to be used to enforce security polices & access control
- From my testing, it seems all Macs have “SandBox”, “Quarantine”, and “TMSafetyNet” loaded by default

Abusing Trusted BSD

- As you can imagine, having an “official” way to hook the kernel is an attractive features for rootkits
- The author of the *http://reverse.put.as* blog was the first to think of this method and implemented a POC rootkit named rex that does it [10, 11]
- Works by adding malicious “trusted” policies that allow userland processes to call into the policies in order to gain root privileges

Detecting REX

- All policies are stored in the global *mac_policy_list*
- Each element is of type *mac_policy_list_element*
- Name of the policy - *<element>.mpc.mpc_name*
- Function pointers - *<element>.mpc.mpc_ops*
- We verify that every function pointer is either in the kernel, a known kernel module, or NULL
  - This finds Rex as well as any other malicious policies

```
Andrews-MacBook-Pro:vol $ python vol.py --profile=Mac32 --profile_file=10.7.2-32bit.zip -f rex.dump --no-cache mac_trustedbsd
Volatile Systems Volatility Framework 2.1_alpha
INFO    : volatility.plugins.overlays.mac.mac: Found dsymutil symbol file 10.7.2.32-bit.symbol.dsymutil
INFO    : volatility.plugins.overlays.mac.mac: Found vtypes file: mac32.vtypes
 in module put.as.kext.rexthewonderdog  found hook for mpo_policy_initbsd in policy rex_the_wonder_dog at fdf000
 in module put.as.kext.rexthewonderdog  found hook for mpo_proc_check_get_task in policy rex_the_wonder_dog at fdf010
```

Volafox Comparison

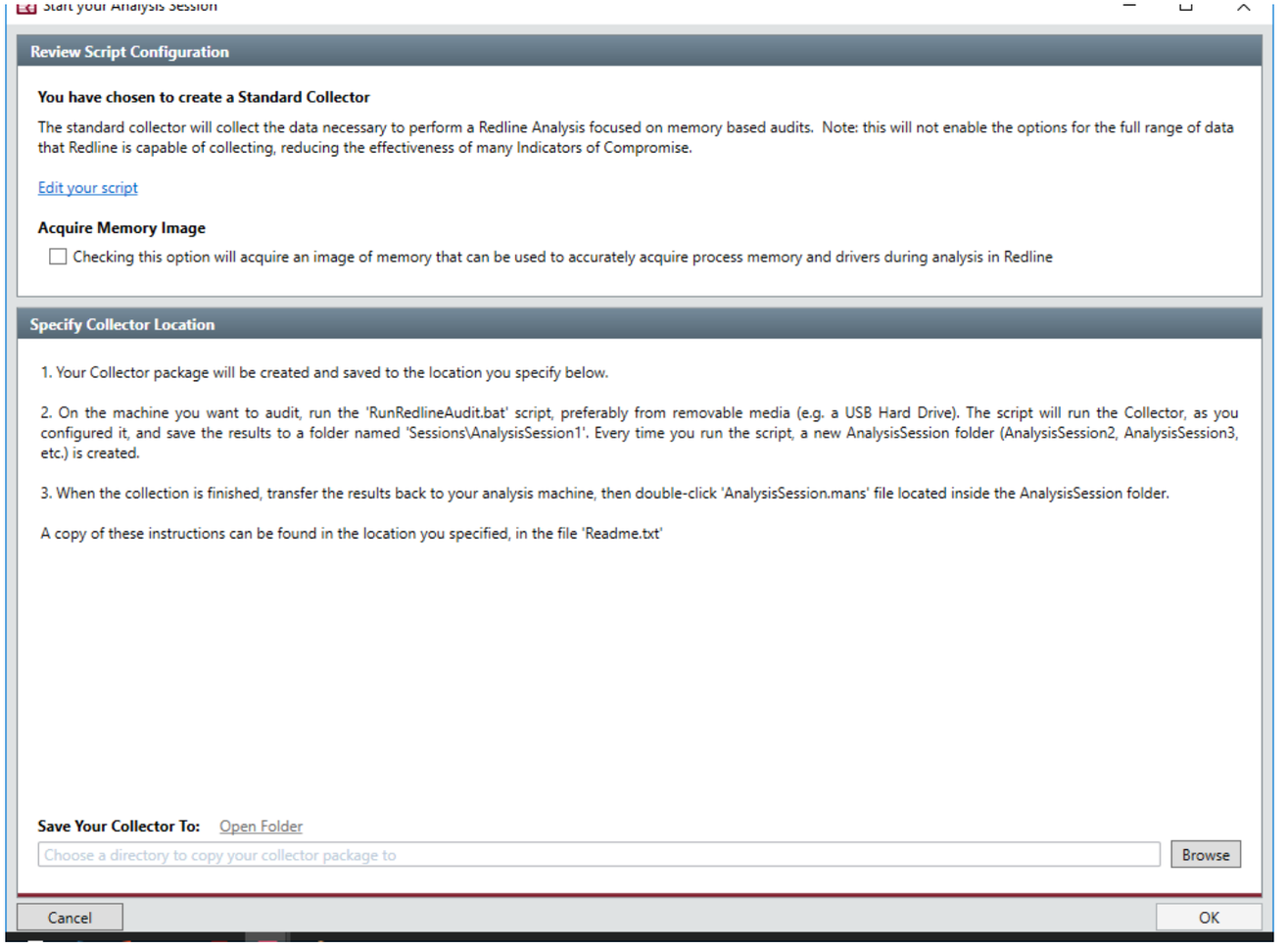
- Based on Volatility, but does not use the profile/object system
  - So it only supports a small number of OS versions and adding support for a new version is difficult
- Only a few plugins:
  - Process list, netstat, lsof, mount
  - Only rootkit detection is syscall hooking (static)
- SVN version supports 32 bit Mac Memory Reader but no 64 bit support

Conclusion

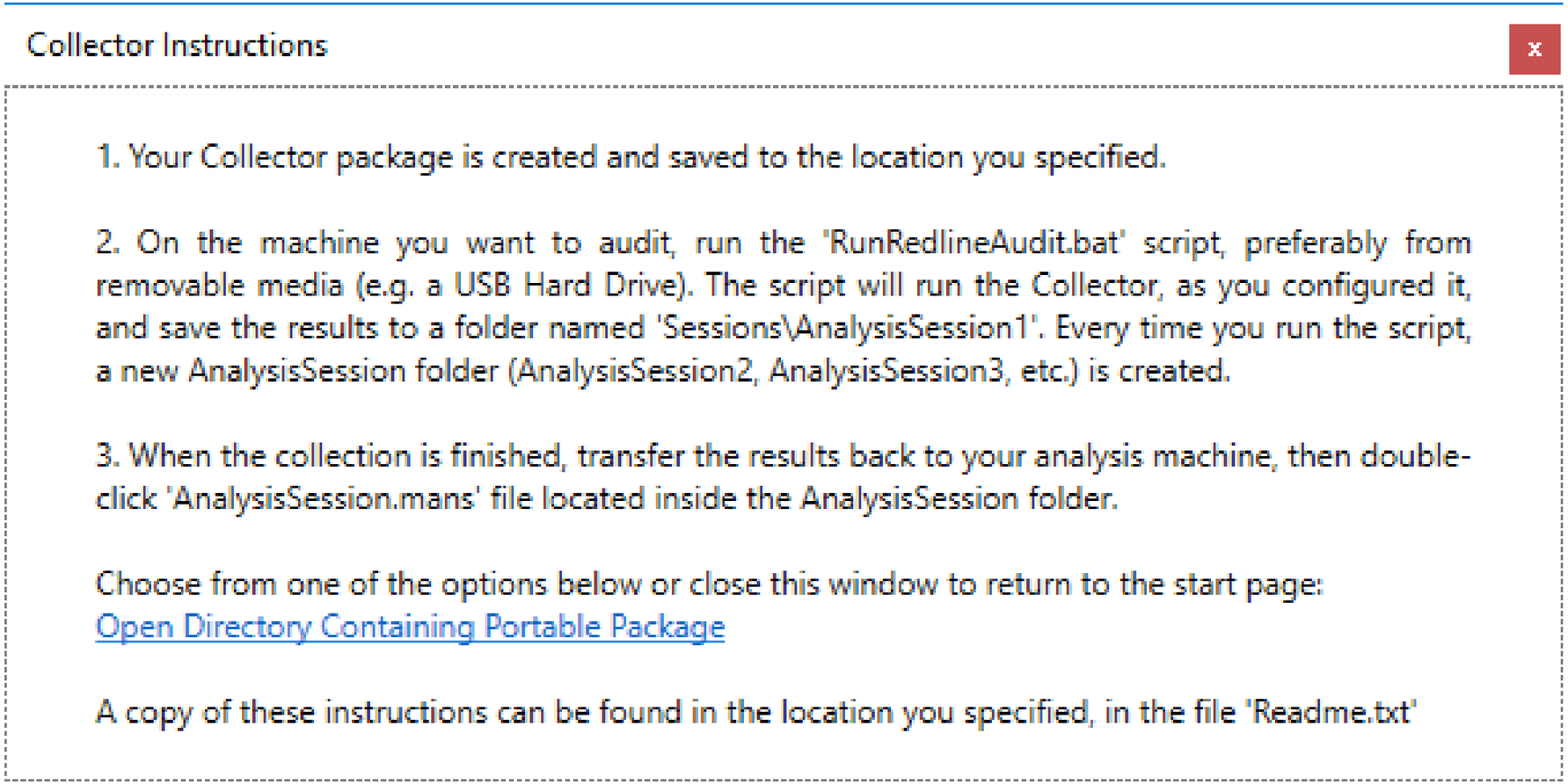
- Volatility now has proper Mac support
- Everything talked about today exists in the open source repository
  - Instructions on how to access can be found at [15]
- Much more new functionality will be added over the next couple months
  - Check [12 & 13] for updates

HANDS-ON SESSION

HANDS-ON SESSION



HANDS-ON SESSION



HANDS-ON SESSION

- Sumuri products
- FOCA
- FAW
- Tsurugi

Thank you

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