CHAPTER 9

Memory Analysis

Chapter Overview

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Baselines & Memory Sources

Know normal before hunting abnormal

Baselines & Memory Data Sources

Importance of Baselines

Memory analysis requires knowing what is NORMAL

Collect baseline memory images from clean, known-good systems

Compare running processes, loaded DLLs, and network sockets to baseline

Environmental baselines beat generic lists — every org is different

Sources of Memory Data

Full memory dump: WinPmem, DumpIt, Magnet RAM Capture

Hibernation file: hiberfil.sys (compressed RAM image on disk)

Page file: pagefile.sys (swapped-out memory pages)

Crash dump: MEMORY.DMP — may be left by attackers

VM snapshot: includes memory state of running VM

Volatility Framework

The open-source memory forensics standard

Volatility: Setup and Profile Selection

Volatility: Python-based memory analysis framework — open source

Volatility 2: vol.py — mature, wide plugin support

Volatility 3: redesigned architecture, no profile required

Profile selection (Vol2): match OS version and architecture to image

imageinfo plugin: identify correct profile for unknown image

Command syntax: vol.py -f memory.raw --profile=Win10x64 [plugin]

Plugin output: tabular data suitable for grep, sort, and scripted analysis

Volatility 2 vs. Volatility 3

Volatility 2 (vol.py)

Requires explicit profile (--profile=Win10x64)

imageinfo: identifies correct profile for unknown image

Mature ecosystem: hundreds of third-party plugins

Python 2 based — no longer maintained but widely used

Syntax: python vol.py -f mem.raw --profile=Win7SP1x64 pslist

Volatility 3 (vol3)

No profile required — auto-detects OS and builds symbols

Python 3 based — actively maintained and faster

ISF (Intermediate Symbol Files) auto-downloaded on demand

Syntax: python vol3.py -f mem.raw windows.pslist.PsList

Plugin namespaces: windows.*, linux.*, mac.*

Key Volatility Plugin Reference

windows.pslist: process list from EPROCESS doubly-linked list

windows.psscan: pool tag scanning — finds hidden/unlinked processes

windows.pstree: parent-child process hierarchy

windows.dlllist: DLLs loaded by each process

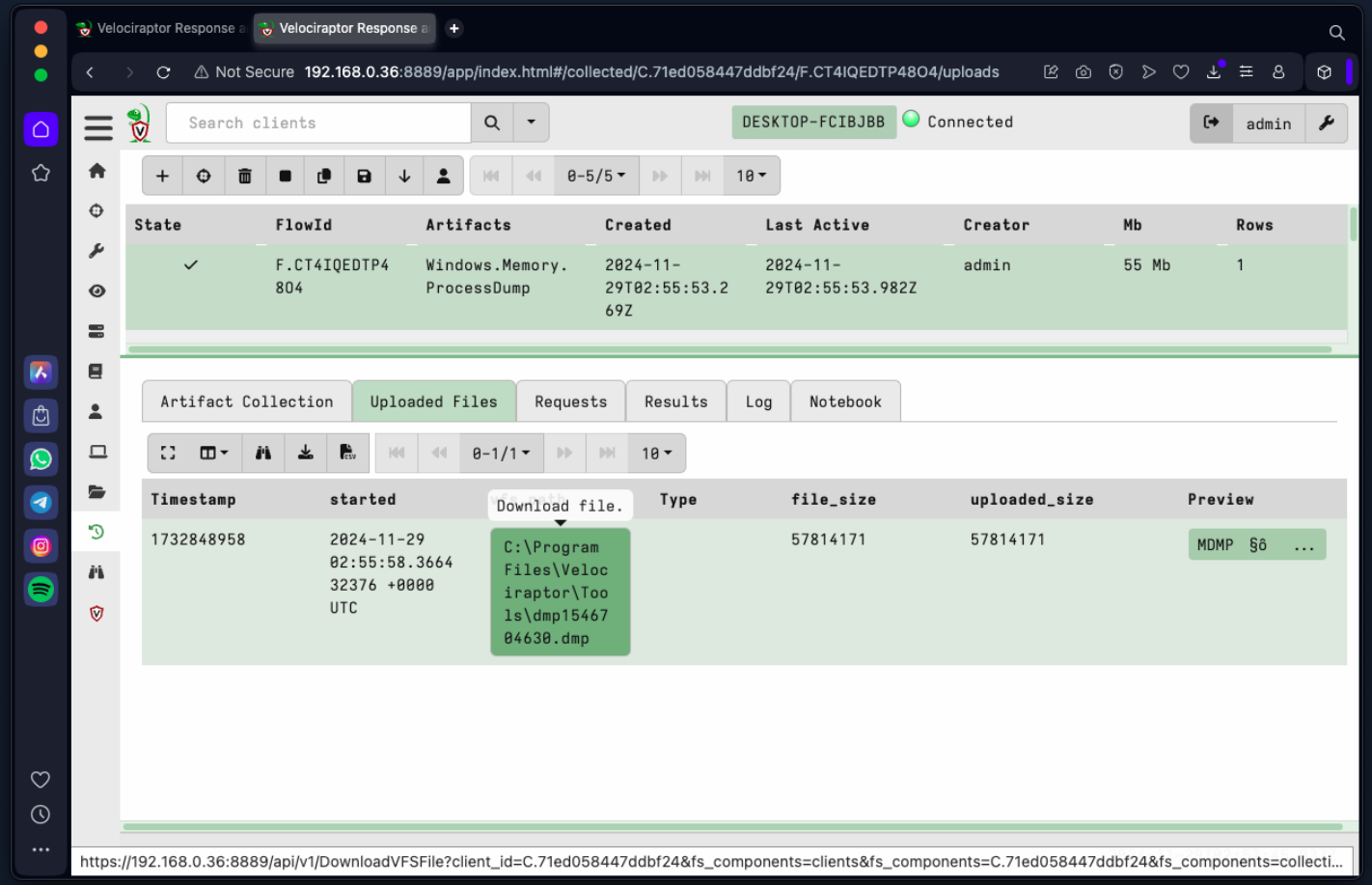
windows.netscan: active and recently-closed network connections

windows.malfind: executable, non-image-backed, writable memory regions

windows.cmdline: command-line arguments for each process

windows.hashdump: extract SAM database hashes (offline cracking)

windows.filescan: cached file objects in memory



Process memory capture with Velociraptor

Examining Processes

Finding malicious processes in memory

Process Analysis Plugins

Listing & Tree View

pslist: standard process list from EPROCESS linked list

pstree: parent-child relationships — spot unusual parents

psscan: find processes using pool tag scanning (finds hidden)

psxview: cross-view comparison — differences = hidden processes

dlllist -p PID: all DLLs loaded by a process

Advanced Detection

malfind: find injected code (executable, not image-backed, RWX)

handles -p PID: open handles — reveals attacker's files/keys

cmdline: command-line arguments — reveals attacker tools run

hollowshell: detect process hollowing (module vs. VAD mismatch)

ldrmodules: detect unlinked/hidden DLLs

Malfind Deep Dive — Detecting Injected Code

malfind identifies: MZ header present + VAD tag = mapped image, but no backing file on disk

Suspicious flags: PAGE_EXECUTE_READWRITE (RWX) permissions on a non-image region

Output: VAD address, page permissions, first 64 bytes as hex+disasm

False positives: .NET JIT-compiled code, some graphics drivers — investigate, don't blindly trust

Extracting injected code: -D /output/dir — dumps each suspicious region to a file

Analyze dumps with: strings, file command, and YARA rules for shellcode patterns

Common injected patterns: shellcode starts with NOP sled + call instruction

Correlate: injected code in process X + network connection from process X = C2 payload

DLL Analysis — dlllist, ldrmodules, dllscan

dlllist -p PID: DLLs in process's PEB (Process Environment Block) loader list

ldrmodules: cross-reference three DLL lists — discrepancies = hidden/reflectively loaded DLL

Hidden DLL: present in VAD but not in any PEB loader list — reflective loading

dlldump -p PID -D /output: extract all DLLs from a process to disk for analysis

Suspicious DLL paths: anything outside C:\Windows, C:\Program Files, or C:\Windows\SysWOW64

DLL search order hijacking: legitimate DLL overridden in application directory

Verify: compare DLL hashes against known-good hashes from clean system images

VirusTotal DLL lookup: hash of suspicious DLL → check reputation before deep analysis

Network, Services & Anomalies

Connecting processes to network activity

Network Connections & Windows Services

netscan: active and recently-closed TCP/UDP connections with owning PID

Correlate PID from netscan → pslist: which process owns each connection?

svcscan: Windows services extracted from memory — find services not in registry

getservicesids: map service names to SIDs

Anomalies to investigate: svchost.exe without ServiceDLL, rundll32 with network conn.

notepad.exe, calc.exe, or explorer.exe with outbound connections

Processes injected into: lsass.exe, explorer.exe, svchost.exe are common targets

Registry Artifacts in Memory

hivelist: find all loaded registry hives and their virtual addresses in memory

printkey: dump a specific registry key from memory

printkey -K 'SOFTWARE\Microsoft\Windows\CurrentVersion\Run': persistence keys

printkey -K 'SAM\Domains\Account\Users': local account information

userassist: decode UserAssist keys (ROT-13 encoded GUI execution history)

shimcache / amcache: application compatibility cache — evidence of execution

Registry analysis advantage: in-memory hives include unsaved changes not yet on disk

dumpregistry -D output/: export all hives for offline analysis with RegRipper

Memory Timeline & Correlation

Timeline: combine process creation times, network connections, and file access into one chronology

mftscan + pstree: correlate files modified during attack with processes active at the time

Timestomp detection: $STANDARD_INFORMATION timestamp earlier than $FILE_NAME timestamp = stomped

Correlate event IDs: memory artifact timestamps + Event 4688 (process create) = ground truth

plaso/log2timeline: ingest memory artifacts, event logs, and filesystem timestamps together

Volatility timeliner plugin: generates unified timeline from memory artifacts alone

Visual tools: Timeline Explorer (Eric Zimmerman), Plaso + Kibana, Timesketch

Goal: reconstruct minute-by-minute attacker activity to answer 'what happened and when'

Memory Analysis Workflow — End to End

Step 1 — Identify image: vol3 -f mem.raw windows.info to confirm OS and architecture

Step 2 — Process list: pslist + psscan + pstree — any process only visible in one list?

Step 3 — Network: netscan — note all ESTABLISHED/LISTEN connections with owning PID

Step 4 — Pivot to process: correlate suspicious PID across pslist, cmdline, dlllist, malfind

Step 5 — Code analysis: malfind — dump suspicious regions, scan with YARA or AV

Step 6 — Credentials: hashdump, lsadump — extract any credentials present in memory

Step 7 — Registry: hivelist + printkey — check persistence and recently written keys

Step 8 — Timeline: timeliner or log2timeline — place all artifacts in chronological order

Conclusion

Memory contains active secrets: credentials, encryption keys, injected code

Baselines are essential — memory analysis without context is guesswork

Volatility's cross-view plugins (psxview, malfind) find what attackers hide

Correlate processes with network connections to identify C2 communications

Modern attackers avoid disk — memory is often the only place malware lives

A structured workflow (list → network → pivot → extract → timeline) produces reliable results

Knowledge Check