## **Contents**

Introduction	xvii
An Introduction to Memory Forensics	1
1 Systems Overview	
Digital Environment	
PC Architecture	
Physical Organization.	
CPU and MMU	
North and Southbridge	
ĕ	
Direct Memory Access	
Volatile Memory (RAM)	
Address Spaces	
Registers	
Segmentation	
Paging.	
Address Translation	
Physical Address Extension.	
Intel 64 Architecture	
Interrupt Descriptor Table	
Operating Systems	
Privilege Separation	
System Calls	
Process Management	
Threads	
CPU Scheduling	
System Resources	
Memory Management	
Virtual Memory	
Demand Paging	21

	Shared Memory	22
	Stacks and Heaps	23
	File System	24
	I/O Subsystem	25
	Device Drivers	25
	I/O Controls (IOCTLs)	25
	Summary	26
2	Data Structures	27
	Basic Data Types	27
	C Programming Language	28
	Abstract Data Types	29
	Arrays	30
	Bitmaps	31
	Records	32
	Strings	
	Linked Lists	
	Singly Linked List	
	Doubly Linked List	
	Circular Linked List	
	Embedded Doubly Linked Lists	
	Lists in Physical and Virtual Memory	
	Hash Tables	
	Trees	
	Hierarchical Trees	
	Tree Traversal	
	Analyzing Trees in Memory	
	Summary	43
3	The Volatility Framework	45
	Why Volatility?	45
	What Volatility Is Not	46
	Installation	47
	Standalone Windows Executable	47
	Windows Python Module Installer	48
	Source Code Packages	
	Development Branch (Code Repository)	49
	Dependencies	50

	The Framework	51
	VTypes	51
	Generating VTypes	52
	Overlays	53
	Objects and Classes	54
	Profiles	55
	Address Spaces	56
	Virtual/Paged Address Spaces	56
	Physical Address Spaces.	56
	Address Space Stacking	57
	Plugin System	58
	Core Plugins	59
	Using Volatility	59
	Basic Commands	59
	Displaying Help	60
	Selecting a Profile	61
	Issues with Profile Selection	63
	Alternatives to Command-Line Options	65
	Controlling Plugin Output	66
	<i>Summary</i>	67
4	Memory Acquisition	69
	Preserving the Digital Environment	69
	Acquisition Overview	70
	The Risk of Acquisition	73
	Atomicity	73
	Device Memory	74
	Cache Coherency	76
	Cache Coherency	
	· ·	76
	When to Acquire Memory	76 77
	When to Acquire Memory	76 77 77
	When to Acquire Memory  How to Acquire Memory  Local Acquisition to Removable Media	76 77 77 78
	When to Acquire Memory	76 77 77 78 79
	When to Acquire Memory  How to Acquire Memory  Local Acquisition to Removable Media  Remote Acquisition.  Runtime Interrogation	76 77 77 78 79 79
	When to Acquire Memory  How to Acquire Memory  Local Acquisition to Removable Media  Remote Acquisition  Runtime Interrogation  Hardware Acquisition	76 77 78 78 79 79
	When to Acquire Memory  How to Acquire Memory  Local Acquisition to Removable Media  Remote Acquisition.  Runtime Interrogation  Hardware Acquisition  Software Tools  Tool Evaluation  Tool Selection	76 77 78 79 79 79 80 81
	When to Acquire Memory  How to Acquire Memory  Local Acquisition to Removable Media  Remote Acquisition.  Runtime Interrogation  Hardware Acquisition  Software Tools  Tool Evaluation  Tool Selection  Memory Acquisition with KnTDD	76 77 78 79 79 80 81 83
	When to Acquire Memory  How to Acquire Memory  Local Acquisition to Removable Media  Remote Acquisition.  Runtime Interrogation  Hardware Acquisition  Software Tools  Tool Evaluation  Tool Selection	76 77 78 79 79 79 80 81 83 84

	Runtime Interrogation with F	Response	. 89
	General Steps for Using F	-Response	. 90
	Connecting from Mac OS	X and Linux	. 90
	MoonSols Windows Memory	Toolkit	. 92
	Local Collection		. 92
	Remote Collection		. 94
	Memory Dump Formats		. 95
	Raw Memory Dump		. 96
	Windows Crash Dump		. 96
	Windows Hibernation File		. 98
	Expert Witness Format (EWF	")	. 99
	HPAK Format		100
	Virtual Machine Memory		101
	VMware		101
	VirtualBox		103
	QEMU		104
	Xen/KVM		105
	Microsoft Hyper-V		105
	7 1	CS	
	e ,		
	ě .	File	
		Profile	
	Recovering the Page File(s)		109
	Analyzing the Page File(s)		110
	*		
	Summary		114
	_		
Ш	Windows Memory Foren	sics	15
	E ME L OLI I LD LAN		447
	5 Windows Objects and Pool Allo	cations	117
	Windows Executive Objects		117
	Object Headers		119
	Optional Headers		121
	Object Type Objects		122
	Kernel Pool Allocations		125
	Allocation APIs		126
	De-allocation and Reuse		128

Pool-Tag Scanning	129
Pool Tag Sources	. 130
Pooltag File	. 131
PoolMon Utility	. 132
Pool Tracker Tables	134
Building a Pool Scanner	136
Extending the PoolScanner	. 136
Extending AbstractScanCommand	. 137
Pool Scanner Algorithm	. 138
Finding Terminated Processes	. 139
Limitations of Pool Scanning	140
Non-malicious Limitations	. 141
Malicious Limitations (Anti-Forensics)	. 141
Big Page Pool	142
Big Page Track Tables	143
Bigpools Plugin	. 144
Exploring Big Page Pools	145
Pool-Scanning Alternatives	146
Dispatcher Header Scans	146
Robust Signature Scans	. 147
Robust Signature Scans	
<u> </u>	148
Summary     Processes, Handles, and Tokens	. 148 . 149
Summary     Processes, Handles, and Tokens     Processes	. 148 . <b>149</b>
Summary	. 148 . 149 . 149 . 153
Summary     Processes, Handles, and Tokens     Processes	. 148 . 149 . 149 . 153 . 154
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory	. 148 . 149 . 153 . 154 . 154
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory  Critical System Processes	. 148 . 149 . 153 . 154 . 154 . 156
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory  Critical System Processes  Analyzing Process Activity	. 148 . 149 . 149 . 153 . 154 . 154 . 156 . 158
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory  Critical System Processes  Analyzing Process Activity  Process Tree Visualizations	. 148 . 149 . 153 . 154 . 154 . 156 . 158
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory  Critical System Processes  Analyzing Process Activity  Process Tree Visualizations  Detecting DKOM Attacks	. 148 . 149 . 153 . 154 . 154 . 156 . 158 . 160
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory  Critical System Processes  Analyzing Process Activity  Process Tree Visualizations  Detecting DKOM Attacks  The Case of Prolaco	. 148 . 149 . 153 . 154 . 156 . 156 . 160 . 160 . 162
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory  Critical System Processes  Analyzing Process Activity  Process Tree Visualizations  Detecting DKOM Attacks  The Case of Prolaco  Alternate Process Listings	. 148 . 149 . 149 . 153 . 154 . 156 . 156 . 160 . 160 . 162 . 163
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory  Critical System Processes  Analyzing Process Activity  Process Tree Visualizations  Detecting DKOM Attacks  The Case of Prolaco  Alternate Process Listings  Process Cross-View Plugin	148 149 153 154 154 156 160 160 162 163
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory  Critical System Processes  Analyzing Process Activity  Process Tree Visualizations  Detecting DKOM Attacks  The Case of Prolaco  Alternate Process Listings  Process Tokens	. 148 . 149 . 153 . 154 . 156 . 158 . 160 . 162 . 163 . 164 . 167
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory  Critical System Processes  Analyzing Process Activity  Process Tree Visualizations  Detecting DKOM Attacks  The Case of Prolaco  Alternate Process Listings  Process Tokens  Live Response: Accessing Tokens	148 149 149 153 154 156 158 160 160 162 163 164 167
Processes, Handles, and Tokens  Processes  Process Organization  Enumerating Processes in Memory  Critical System Processes  Analyzing Process Activity  Process Tree Visualizations  Detecting DKOM Attacks  The Case of Prolaco  Alternate Process Listings  Process Cross-View Plugin  Process Tokens  Live Response: Accessing Tokens  Extracting and Translating SIDs in Memory	148 149 153 154 154 156 158 160 162 163 164 167 168
	Pool-Tag Scanning Pool Tag Sources Pooltag File PoolMon Utility Pool Tracker Tables Building a Pool Scanner Extending the PoolScanner Extending AbstractScanCommand Pool Scanner Algorithm Finding Terminated Processes  Limitations of Pool Scanning Non-malicious Limitations Malicious Limitations (Anti-Forensics)  Big Page Pool Big Page Track Tables Bigpools Plugin Exploring Big Page Pools  Pool-Scanning Alternatives Dispatcher Header Scans

	Analyzing Explicit Privileges
	Detecting Token Manipulation
	Attack Simulation with Volshell
	Revealing the Truth
	Process Handles
	Lifetime of a Handle
	Reference Counts and Kernel Handles
	Handle Table Internals
	Enumerating Handles in Memory
	Finding Zeus Indicators
	Detecting Registry Persistence
	Identifying Remote Mapped Drives
	<i>Summary</i>
7	Process Memory Internals
	What's in Process Memory?
	Address Space Layout Details
	Memory Allocation APIs
	Permissions
	Scope and Flexibility
	Enumerating Process Memory
	Process Page Tables
	Exploring Process Memory
	Virtual Address Descriptors
	VAD Structures
	VAD Tags
	VAD Flags
	Volatility VAD Plugins
	Traversing the VAD in Python
	Passwords in Browser Memory
	Scanning Memory with Yara
	Zeus Encryption Keys in Memory
	<i>Summary</i>
8	Hunting Malware in Process Memory219
	Process Environment Block
	Process Heaps
	Finding Text on Notepad's Heap
	Environment Variables 226

Coreflood Presence Marking.228Standard Handles.230Dynamic Link Libraries (DLLs)233
Dynamic Link Libraries (DLLs)
Dynamic Link Libraries (DLLs)
How DLLs Are Loaded
Enumerating DLLs on Live Systems
Hiding DLLs
Listing DLLs in Memory
Detecting Unlinked DLLs
PE Files in Memory
PE File Slack Space
Parsing PE Headers in Memory
PE Extraction Plugins
Caveats and Workarounds244
Packing and Compression
Unpacking Malicious Code
Common Unpacking Issues
Unpacking 64-bit DLLs248
Code Injection
Remote DLL Injection
DLL Injection Detection
Remote Code Injection
Code Injection Detection
Reflective DLL Injection
Reflective DLL Injection Detection
Hollow Process Injection
How to Hollow a Process
Detection
Postprocessing Dumped Code
<i>Summary</i>
Event Logs
Event Logs in Memory
Windows 2000, XP, and 2003 Event Logs
Finding Event Log Files
Extracting Event Logs
Logging Policies
Windows Vista, 2008, and 7 Event Logs
Caveats About Event Logs in Memory

9

## viii Contents

	Real Case Examples	275
	The Case of the Unsuccessful Listener	275
	The Case of the Unsuccessful Logon	276
	The Case of the Impatient Brute Forcer	277
	The Case of the Log Wiper	278
	Summary	279
10	Registry in Memory	281
	Windows Registry Analysis	281
	Data in the Registry	283
	Stable and Volatile Data	284
	Finding Registry Hives	285
	Address Translations	286
	Printing Keys and Values	288
	Detecting Malware Persistence	289
	Volatility's Registry API	292
	Parsing Userassist Keys	295
	Detecting Malware with the Shimcache	
	Reconstructing Activities with Shellbags	298
	Shellbags in Memory	
	Finding TrueCrypt Volumes with Shellbags	300
	Timestomping Registry Keys	303
	Dumping Password Hashes	304
	Obtaining LSA Secrets	305
	Summary	307
11	Networking	309
	Network Artifacts	309
	Windows Sockets API (Winsock)	
	Active Sockets and Connections	315
	Attributing Connections to Code	318
	Inactive Sockets and Connections	321
	Hidden Connections	
	IP Packets and Ethernet Frames	323
	DKOM Attacks	
	Raw Sockets and Sniffers	325
	Creating Raw Sockets	
	Detecting Raw Sockets	
	Next Generation TCP/IP Stack	327

	Working Backward from netstat.exe	. 328
	Volatility's Netscan Plugin	. 328
	Partition Tables	. 330
	Port Pools and Bitmaps	. 332
	Internet History	. 333
	Carving IE History Records	. 336
	IE History in Malware Investigations	. 337
	Brute Force URL Scans	. 338
	DNS Cache Recovery	. 339
	Summary	. 341
12	Windows Services	.343
	Service Architecture	
	Installing Services	. 345
	Tricks and Stealth	
	Investigating Service Activity	. 347
	Scanning Memory	. 351
	Volatility's SvcScan Plugin	
	Recently Created Services	
	Detecting Hijacked Services	. 356
	Registry-based Hijacks	. 356
	Disk-based Hijacks	. 358
	Detecting Disk-based Hijacks	. 362
	Revealing Hidden Services	
	<i>Summary</i>	. 366
13	Kernel Forensics and Rootkits	.367
	Kernel Modules	. 367
	Classifying Modules	
	How Modules Are Loaded	. 370
	Enumerating Modules on Live Systems	. 371
	Modules in Memory Dumps	. 372
	Ordered List of Active Modules	. 373
	Brute Force Scanning for Modules	. 374
	Recently Unloaded Modules	. 374
	Extracting Kernel Modules	. 375
	Threads in Kernel Mode	. 378
	Tigger's Kernel Threads	. 379
	Detecting Ornhan Threads	379

	Driver Objects and IRPs	. 381
	Scanning for Driver Objects	. 382
	Hooking and Hook Detection	. 382
	Stealthy Hooks	. 384
	High Value Targets	. 386
	Device Trees	. 386
	Auditing Device Trees	. 388
	Stuxnet's Malicious Devices	. 389
	Auditing the SSDT	. 390
	Enumerating the SSDT	. 391
	Attacking the SSDT	. 393
	Pointer Replacement	. 393
	Inline Hooking	. 394
	Table Duplication	. 394
	SSDT Hook Disadvantages	. 395
	Kernel Callbacks	. 396
	Callbacks in Memory	. 396
	Malicious Callbacks	. 397
	Kernel Timers	. 399
	Finding Timer Objects	. 400
	Malware Analysis with Timers	. 400
	Putting It All Together	. 402
	Summary	. 406
14	Windows GUI Subsystem, Part I	.407
	The GUI Landscape	
	GUI Memory Forensics	
	The Session Space	
	Detecting Remote Logged-in Users over RDP	
	Window Stations	
	Analyzing the Frequency of Clipboard Usage	
	How to Detect Clipboard Snooping	
	Clipboard Viewers and Listeners	
	Snooping with Clipboardic.exe	. 420
	Daglebana	122
	Desktops.	
	Enumerating Desktops and Associated Threads	. 424
	Enumerating Desktops and Associated Threads	. 424 . 425
	Enumerating Desktops and Associated Threads	. 424 . 425 . 425

	Atoms and Atom Tables. 429	9
	Atoms and Atomscan	
	Detecting Window Class Names	
	Registered Window Messages	
	Atoms Are the New Mutexes	
	Windows	
	IEFrame: Currently Displayed IE Web Page	
	HH Parent: CHM File Exploit Titles	
	Current Local Time and Logged-in Username	
	Visualizing Parent and Child Windows	
	Taking Screen Shots from Memory Dumps	
	Malicious Window Abuse	
	Killing KAV with Rogue Window Messages	
	Secretly Dismissing Alerts/Prompts	
	Simulating Keystrokes and Mouse Movements44	
	Window Procedure Callbacks	
	Malicious Window Subclassing	
	<i>Summary</i>	
15	Windows GUI Subsystem, Part II453	3
	Window Message Hooks	3
	Message Hook Installation	
	Detecting Message Hooks for DLL Injection	
	User Handles	9
	Enumerating USER Object Types	1
	The Shared Info Structure	
	Algorithm for Finding Shared Info	3
	Handle Table Entries464	
	Enumerating a Cassion's LICED Handles	Ξ
	Enumerating a Session's USER Handles	
	Event Hooks	6
	Event Hooks	6 8
	Event Hooks460Windows Clipboard460Algorithm for Clipboard Extraction470	6 8 0
	Event Hooks460Windows Clipboard460Algorithm for Clipboard Extraction470Recovering Text from the Clipboard470	6 8 0
	Event Hooks460Windows Clipboard460Algorithm for Clipboard Extraction470Recovering Text from the Clipboard470Recovering Binary Data from the Clipboard470	6 8 0 1
	Event Hooks460Windows Clipboard460Algorithm for Clipboard Extraction470Recovering Text from the Clipboard470	6 8 0 1

<b>16</b> Disk Artifacts in Memory	477
Master File Table	477
The MFTParser Plugin	479
Alternate Data Streams	482
The Case of the Illicit File Access	484
Files and Shortcuts	
Searching in the Trash	
Translating the Embedded Timestamp	486
The Case of Data Exfiltration	
Proof of Execution	
The Fake "systems" Directory	
Surveying the Network	
WinRAR Archive Exfiltration	
MFT-Resident Data	
Timestomping the MFT	
Disadvantages of MFT Scanning	
Extracting Files	
Executable (Image) and Data Files	
Shared Cached Files	
Volatility's Dumpfiles Plugin	
Targeted File Extraction	
Detecting Modified Code	
Defeating TrueCrypt Disk Encryption	
Password Caching	
Encrypted Volume Identification	
The Cache Manager and NTFS Metadata	
Extracting (AES) Master Keys	
Non-Default Encryption Algorithms	
Summary	510
17 Event Reconstruction	511
Strings	511
Extracting Strings	512
Windows	513
Linux	513
Mac OS X	514
Example Output	514
Translating Strings	515

	String-Based Analysis	516
	Finding Prefetch Files	517
	Spatial Proximity with IOCs	517
	Strings in Free Memory	518
	Detecting Shared Pages	519
	Command History	523
	Windows Command Architecture	524
	Console Modules and Functions	525
	Data Structure Map	525
	Default Settings	529
	Finding Commands in Memory	530
	CmdScan Plugin	531
	Consoles Plugin	532
	Summary	536
18	Timelining	537
	-	
	Finding Time in Memory	
	Timestamp Formats	
	Timestamp Sources	
	Generating Timelines	
	Timeliner Plugin	
	Timeliner Output Formats	
	Processing Timelines Using Mactime	
	Where to Begin	
	Gh0st in the Enterprise	
	Scripting Registry Timelines	
	Adding Packet Capture Data	
	Finding the Initial Infection Vector	
	Tracking Executed Programs	
	Phishing E-mail Artifacts	
	Examining the 6to4 Service	
	Finding an Active Attacker	
	Mapping Remote File Shares	
	Scheduled Jobs for Hash Dumping	
	Overlaying Attack Artifacts	
	Decoding the Network Data	
	Correlating the Traffic with the Timeline	
	Wrapping Up the Case	
	Summaru	573

Ш	Linux Memory Forensics	575
	19 Linux Memory Acquisition	577
	Historical Methods of Acquisition	577
	/dev/mem	
	/dev/kmem	
	ptrace	
	Modern Acquisition	
	fmem	
	Linux Memory Extractor (LiME)	580
	Compiling LiME	
	Loading LiME and Dumping Memory	582
	/proc/kcore	
	Volatility Linux Profiles	583
	Software Setup	584
	Creating a Profile	584
	Creating VTypes	584
	Getting Symbols	585
	Making the Profile	586
	Using the Profile	586
	Enterprise Linux Memory Forensics	587
	Caveats to Cross Compiling	587
	Cross Compiling for Ubuntu	587
	Summary	589
	<b>20</b> Linux Operating System	591
	ELF Files	591
	ELF Header.	
	Sections	
	Displaying Sections with readelf	
	Packed ELF Binaries	
	Program Headers	
	Listing Program Headers	
	UPX Effect on Program Headers	
	Shared Library Loading	
	Global Offset Table	
	Using the GOT to Locate APIs	
	Overwriting GOT Entries	

	GOT and PLT Internals	599
	Procedure Linkage Table	601
1	Linux Data Structures	503
	Lists	603
	Hash Tables	605
	Trees	605
	Handling Embedded Structures	606
1	Linux Address Translation	607
	Kernel Identity Paging	607
	Finding the Kernel DTB	608
	Validating the Address Space	608
1	procfs and sysfs	509
(	Compressed Swap	610
	Summary	610
21	Processes and Process Memory	511
ì	Processes in Memory	611
	Enumerating Processes	
	Active Process List	
	Linking Processes to Users	615
	Parent and Child Relationships	
	PID Hash Table	
1	Process Address Space	616
	Enumerating Process Mappings	618
	Recovering Sections of Memory	
	Analyzing Command-line Arguments	621
	Manipulating Command-line Arguments	623
1	Process Environment Variables	625
(	Open File Handles	626
(	Saved Context State	630
1	Bash Memory Analysis	630
	Bash History	631
	Linux Bash Plugin	631
	Bash Command Hash Table	
	The Fake rm Command	633
	Detecting the Fake Binary	634
	Summary	635
<b>22</b> i	Networking Artifacts	37

## xvi Contents

	Network Socket File Descriptors	637
	Network Connections	640
	TCP and UDP Connections	641
	Recovering Unix Sockets	643
	Queued Network Packets	643
	Network Interfaces	646
	Listing Interface Information	648
	Interface Naming Conventions	648
	Interface Aliases	648
	Finding Processes with Raw Sockets	649
	The Route Cache	650
	ARP Cache	652
	Summary	655
23	Kernel Memory Artifacts	657
	Physical Memory Maps	657
	Hardware Resources	658
	Verifying Acquisition Tools	660
	Virtual Memory Maps	661
	Kernel Debug Buffer	663
	Loaded Kernel Modules	667
	Enumerating LKMs	669
	Extracting Kernel Modules	670
	Summary	673
24	File Systems in Memory	675
	Mounted File Systems	675
	Linux Mount Plugin	
	Common File System Types	678
	Mount Options	679
	Temporary File Systems	680
	Listing Files and Directories	681
	Extracting File Metadata	684
	Duplicating File Systems from Memory	685
	Building Timelines	689
	Recovering File Contents	691
	File Extraction Algorithm	692
	Find File Plugin	693
	Summary	695

25	Userland Rootkits	697
	Shellcode Injection	698
	Step 1: Attaching to a Process with PTrace	
	Step 2: Finding/Allocating Memory	
	Overwriting Existing Code	
	Foreign Memory Allocation	
	Step 3: Writing Shellcode into a Process	
	Step 4: Controlling Foreign Process Execution	
	Detecting Shellcode Injection	
	Process Hollowing	
	The Detection Algorithm	
	An Example of Detection	
	Shared Library Injection	
	Injecting a Library from Disk	
	Detecting Disk–Based Shared Library Injections	
	Listing Libraries in Userland	
	Cross-Referencing Mappings	
	Injecting a Library from Memory	
	Extracting Executables from Memory	
	LD_PRELOAD Rootkits	
	Hooking Functions with LD_PRELOAD	
	Detecting LD_PRELOAD Rootkits	
	Extracting Preload Files	
	Analyzing Preload Variables	
	Checking the GOT/PLT	
	Comparative Symbol Analysis	
	GOT/PLT Overwrites	
	PLT Tampering	
	Detecting GOT Overwrites	
	Inline Hooking	
	Summary	
26	Kernel Mode Rootkits	721
	Accessing Kernel Mode	721
	Hidden Kernel Modules	
	Hiding from sysfs	723
	Detecting KBeast	723
	Examining the Disassembly	724

## xviii Contents

Carving for Hidden Modules	725
Finding Modules by File Handles	726
Kernel-Mode Code Injection	727
Hidden Processes	728
Sources of Process Listings	728
Cross View Exceptions	730
Elevating Privileges	730
Hijacked Credentials	731
Average Coder Rootkit	732
System Call Handler Hooks	734
Keyboard Notifiers	735
Malicious Keyboard Notifiers	736
Resolving Malicious Functions	738
TTY Handlers	739
Network Protocol Structures	742
Network Sequence Operations	743
Finding Network Protocol Hooks	744
Netfilter Hooks	745
Netfilter Subsystem	746
Abusing Netfilter	747
Enumerating Netfilter Hooks	748
File Operations	748
Sources of File Operations	749
Frustrating Live Forensics	750
Hiding Logged-in Users	751
Inline Code Hooks	752
Summary	754
27 Case Study: Phalanx2	755
Phalanx2	755
Analysis Setup	
Installation	
Phalanx2 Memory Analysis	
Kernel Tampering	
Baseline Analysis	
Inspecting the Xnest Process	
Revealing the Fake Kernel Thread	
Determining the True Binary Path	
Socket File Descriptors	

	Reverse Engineering Phalanx2
	Kernel Module
	Extracting Shell Commands
	Bypassing the /dev/mem Restriction
	Detecting Existing Infections
	Dynamic Analysis with strace
	Symlink Hook770
	Final Thoughts on Phalanx2
	Summary772
IV	Mac Memory Forensics 773
	<b>28</b> Mac Acquisition and Internals
	Mac Design
	Mach and BSD Layers
	Kernel/Userland Virtual Address Split777
	Kernel ASLR
	Process Address Spaces
	Memory Acquisition
	Locating RAM Regions
	Mac Memory Reader (MMR)781
	Mac Memoryze
	OSXPmem
	Mac Volatility Profiles784
	Downloading Profiles
	Building Profiles
	Mach-O Executable Format787
	Mach-O Header
	Command Structures
	Segment Commands and Sections
	Mach-O Address Space
	Summary
	<b>29</b> Mac Memory Overview793
	Mac versus Linux Analysis793
	Process Analysis
	Enumerating Processes
	Process Relationships
	Address Space Mappings799
	1 11 0

	Listing and Recovering Mappings	01
	Dynamic Loader Shared Cache8	02
N	Setworking Artifacts8	04
	Process File Descriptors	06
	Networking Subsystem	07
	Cross-Reference Advantage 8	07
	Classifying Network Connections	07
S	LAB Allocator	08
R	Recovering File Systems from Memory8	11
L	oaded Kernel Extensions	15
	Enumerating Kernel Modules	16
	Recovering Modules from Memory	18
C	Other Mac Plugins	18
Λ	Mac Live Forensics   8	19
S	ummary	21
<b>30</b> N	Malicious Code and Rootkits82	23
ι	Iserland Rootkit Analysis8.	23
	Code Injection Techniques	
	Macterpreter – Bundle Files 8	
	Detecting Code Injections 8	
	Crisis Injected Bundles 8	
	Extracting Executables	26
	Detecting API Hooks 8	
	Inline Hooking 8	27
	Hooking Relocation Tables 8	27
	Library Search Order Hijacking	27
	API Hook Detection	27
K	Cernel Rootkit Analysis8.	28
	Hidden Kernel Extensions	28
	Kernel Extension Map 8	29
	Hidden Processes 8	29
	Sysctl Handlers	30
	System Call and Trap Table Hooks	31
	Shadow System Call Tables	32
	IOKit Notifiers	32
	Detecting LogKext	33
	TrustedBSD	34
	IPC Handlers 8	35

	Network Kernel Extensions	836
	IP Filters	837
	Socket Filters	837
	Common Mac Malware in Memory	838
	OSX.GetShell	839
	OSX.FkCodec	840
	Detecting Persistence	842
	Summary	844
31	Tracking User Activity	845
	Keychain Recovery	845
	Volafox and Chainbreaker	
	Breaking Keychains in Memory	846
	Mac Application Analysis	849
	Apple Mail and GPG	850
	Finding Plaintext Messages	850
	Locating E-mail Attachments	852
	Mail Account Passwords	853
	Apple Contacts.	853
	Apple Calendar	855
	Apple Notes	856
	Adium Chat Messages	
	Summary	858
	Index	950