From The Tunnels Below Gotham

Anti-Forensics
The Rootkit Connection

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$$-k_B \sum_i P_i \log_e(P_i)$$

Introduction

Introduction

The Quandary of Live Response
Another Option: Post-Mortem Analysis
Anti-Forensic Strategies

Tactics & Countermeasures

Forensic Duplication
Recovering Files
Recovering Deleted Files
Capturing a Metadata Snapshot
Identifying Known Files
File Signature Analysis
Static Analysis of an .EXE
Runtime Analysis of an .EXE

Data Source Elimination

Memory-Resident Rootkits
Firmware-Based Rootkits

Operational Issues

Footprint and Fault-Tolerance
Launching a Rootkit
Conclusions

The Quandary of Live Response

Fundamental Issue → A rootkit can interfere with runtime data collection

The Athens Affair

Rootkit monitored digitized voice traffic on Ericsson AXE switches
Patched the commands that listed active code blocks
Integrity checking code was subverted (patch suspected)

http://www.spectrum.ieee.org/telecom/security/the-athens-affair

The DDefy Rootkit

Vendors downplay the threat to live disk imaging as unlikely
DDefy Injects a filter driver to feed bad data to forensic tools

http://www.ruxcon.org.au/files/2006/anti_forensic_rootkits.ppt

Defeating Hardware-Based RAM Capture on AMD64

Vendors attempt to sidestep OS entirely to avoid interference
Rutkowska defeated this by manipulating Northbridge map table

http://invisiblethings.org/papers/cheating-hardware-memory-acquisition-updated.ppt

Another Option: Post-Mortem Analysis

$$-k_B \sum_i P_i \log_e(P_i)$$

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- Forensic Duplication
- Recover Files
- Recover Other FS Objects
- Take Metadata Snapshot
- Remove Known Files
- File Signature Analysis
- Static .EXE Analysis
- Runtime .EXE Analysis

An Aside: Assume the Worst-Case

Assumption

For the sake of keeping things interesting:

Let’s assume we’re facing off against a highly skilled, well-armed, adversary

The “they’re all idiots” mentality is dangerous (don’t underestimate your opponent!)

Richard Bejtlich

Director of Incident Response, GE

Former MI officer (AFCERT, AFIWC, AIA)

http://taosecurity.blogspot.com/

In High-Security Environments

- Compromise may be assumed a priori
- Security professionals may employ forensic analysis *preemptively*

Anti-Forensic Strategies

Primary Goal: Outlast the investigator (exhaust their budget, e.g. *THX 1138*)

Strategy	Tactical Implementations
Data Source Elimination	Memory-Resident Code, Autonomy
Data Destruction	Data and Metadata Shredding, Encryption
Data Concealment	In-Band, Out-of-Band, & Application Level
Data Transformation	Encryption, Compression, Obfuscation
Data Fabrication	Leave False Audit Trails, Introduce Known Files

Institute Defense in Depth
Implement strategies concurrently to augment their effectiveness

Use Custom Implementations
Want to frustrate attempts to rely on automation to save time

Tactics and Countermeasures

$$-k_B \sum_i P_i \log_e(P_i)$$

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Forensic Duplication

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Reserved Disk Regions

One way to undermine forensic duplication is to avoid being captured on the image
Reserved regions like the HPA and DCOs were tenable hideouts (at one point in time)

Bad News

HPA/DCO-sensitive tools are now commonplace

Example: FastBloc 3 Field Edition

Write blocker that can detect and access HPAs and DCOs
http://forensics.marshall.edu/MISDE/Pubs-Hard/FastblocFE.pdf

Recovering Files

Tactics that Hamper File Recovery

Encrypted Volumes

Nothing to carve, looks like random bytes
Plausible Deniability → Nested encrypted volumes
Conspicuous, use as part of an exit strategy

File System Attacks

Won’t necessarily obstruct file carvers
Can lead to erratic behavior (do NOT want this)
Conspicuous, use as part of an exit strategy

Concealment

Definitely has potential (at least in the short-term)

- **In-Band Concealment**
- **Out-of-Band Concealment**
- **Application Layer Concealment**

In-Band Concealment

In-Band — **Use regions described by the FS specification**

Examples

- Reserved space in file system metadata structures
- Alternate Data Streams
- Clusters allocated to `$BadClus`

Implementations

- Data Mule FS
  - Developed by the grugq, targets the `ext2fs` file system
  - Stores data in inode reserved space

http://www.blackhat.com/presentations/bh-europe-04/bh-eu-04-grugq.pdf

Issues

- Surviving file system integrity checks
- Allocating a sufficient amount of storage (managing many small chunks)

An Aside: In-Band on Windows

$$-k_B \sum_i P_i \log_e(P_i)$$

The NTFS Master File Table (MFT)

Central repository for all NTFS file system meta-data
Is a relational database consisting of a series of records
Each file/directory corresponds to one or more 1 KB records in the MFT

Hiding Data in The MFT: FragFS

Rootkit presented at Black Hat Federal 2006 by Thompson and Monroe
Identified available reserved space and slack space in MFT records

NTFS is a Licensed Specification

Microsoft provides an incomplete Technical Reference
http://technet.microsoft.com/en-us/library/cc758691.aspx
For (free) low-level details, we must rely on the Linux-NTFS project
http://sourceforge.net/projects/linux-ntfs/
Brian Carrier also wrote a book that relates many details
http://www.digital-evidence.org/fsfa/index.html

Out-of-Band Concealment

Out-of-Band **Use regions NOT described by the FS specification**

Examples

The HPA, DCOs
Slack Space (file-based, partition-based, etc.)

Implementation

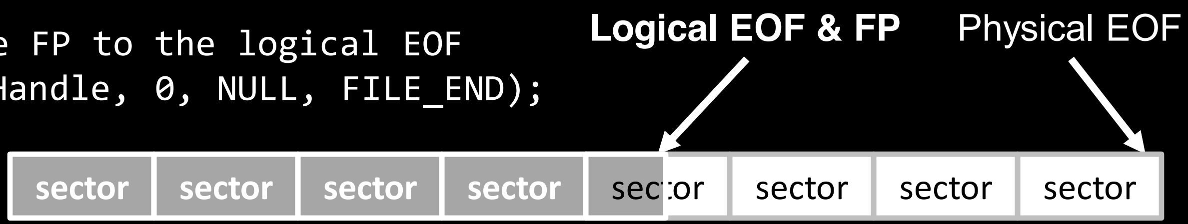
Metasploit's `slacker.exe`
http://www.metasploit.com/research/projects/antiforensics/

Issues

Finding storage space that's unlikely to be overwritten or re-allocated
Beware of slack-space wiping tools (PGP Desktop Professional 9.0.4+)
http://www.metasploit.com/research/vulnerabilities/pgp_slackspace/

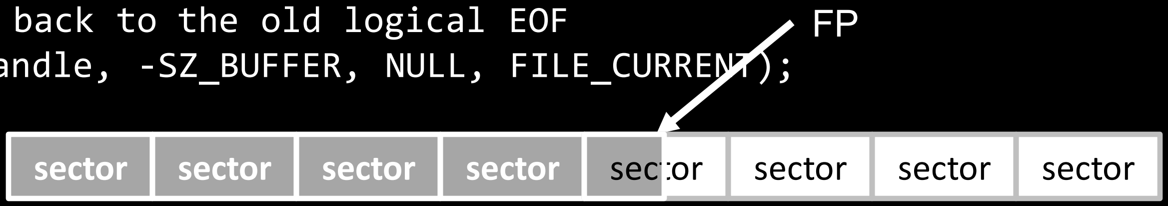
An Aside: Slacker.exe

```
//Step [1] - set the FP to the logical EOF
SetFilePointer(fileHandle, 0, NULL, FILE_END);
```



```
//Step [2] - write data between the logical EOF and physical EOF
WriteFile(fileHandle, buffer, SZ_BUFFER, &nBytesWritten, NULL);
FlushFileBuffers(fileHandle);
```

```
//Step [3] - move FP back to the old logical EOF
SetFilePointer(fileHandle, -SZ_BUFFER, NULL, FILE_CURRENT);
```



```
//Step [4] - truncate the file nondestructively (on XP)
SetEndOfFile(fileHandle);
```

An Aside: Microsoft Responds

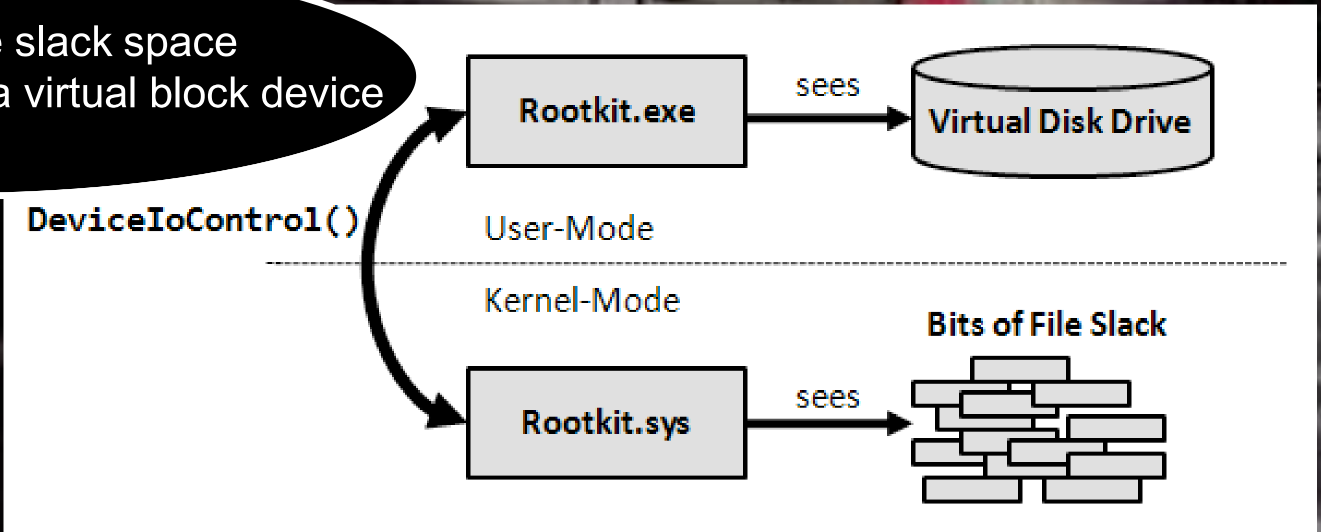
Microsoft Addresses this Issue in Vista

Calls to `SetEndOfFile()` zero out file slack space before returning

One Solution

Design a rootkit that manages file slack space from Kernel-Space
Place metadata in a known location to avoid using an external tracking file
Be Warned: don’t leave this metadata in plaintext format!

KMD manages file slack space
User-Mode code sees a virtual block device



Application Layer Concealment

Application Layer **Use regions defined by a particular file format**

Examples

- Steganography
  - http://www.blackhat.com/presentations/bh-usa-04/bh-us-04-raggo/bh-us-04-raggo-up.pdf
- Rogue Database Entries
- Injecting code to create a Trojan Executable
  - Dawid Golunski, “Rogue Binaries - How to Own the Software,” *hakin9*, 1/2008

Issues

- Not very effective with static files, a binary diff will expose alteration
- Must identify files that are normally subject to constant updates
- Modifying database files through official channels leaves an audit trail
- If possible, see if you can navigate the database file manually
  - http://helios.miel-labs.com/downloads/registry.pdf

Recovering Deleted Files

Tactics that Impede Recovery of Deleted Data

File Wiping

Software-based wiping tools often rely on overwriting data in place
Not always effective on journaling and RAID-based file systems

Metadata Shredding

Deleting data isn’t enough, must also clean up the file system
Example: The Defiler’s Toolkit (TDT) built by the grugq

http://www.phrack.org/issues.html?issue=59&id=6

Encryption

1st Prize

Encrypt data before it’s persisted to disk storage
Destroy the key and the data becomes random junk

How do we protect the key
From being intercepted?

An Aside: Key Management

Hints on Protecting Encryption Keys

Don’t Store Keys on Disk

If you do, encrypt it with another encryption key

Minimize Runtime Key Exposure

You should assume that debuggers will be brought into play

Lock the Memory Containing the Key

Need to prevent recovery of the key from the page file/partition
On Unix: `mlock()` (see `sys/mman.h`)
On Windows: `VirtualLock()` (see `Winbase.h`)
Note: you’ll need to obfuscate these calls because they’re beacons

Capturing a Metadata Snapshot

$$-k_B \sum_i P_i \log_e(P_i)$$

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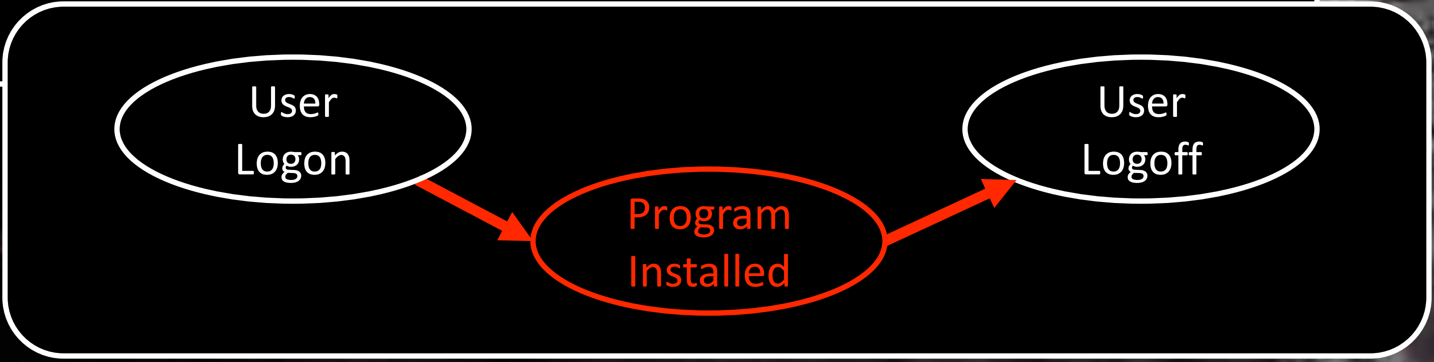
Tactics that Undermine the Integrity of Metadata

Binary Modification

- This will place a known good file into the "unknown" category
- Too conspicuous for the scenario of preemptive forensics
- As part of an exit strategy, serves as a diversionary measure

Timestamp Modification

- Can be applied to non-system files to fabricate a false trail
- **Note:** On NTFS, more than one attribute has timestamp data!
  - `$STANDARD_INFORMATION` and `$FILE_NAME`



An Aside: `TimeStomp.exe`

The `FILE_BASIC_INFORMATION` argument stores four `LARGE_INTEGER` values

- These values represent the number of 100-nanosecond intervals since 1601

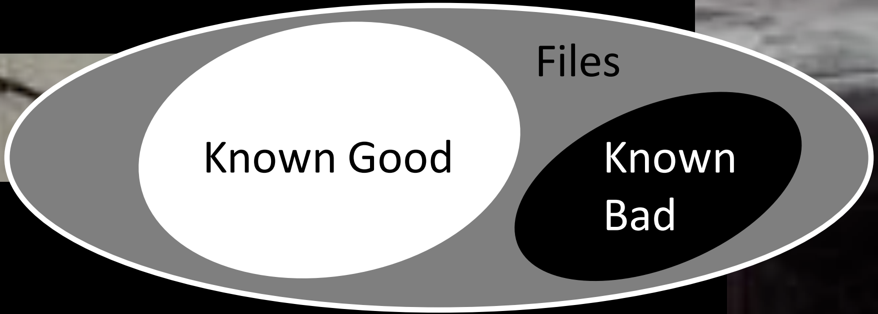
When these values are small, the Windows API doesn't translate them correctly

```
if(modTimeStamp)
{
        fileBasicInfo.CreationTime.LowPart  = 1;
        fileBasicInfo.CreationTime.HighPart = 0;
        ...
}
ntstatus = ZwSetInformationFile
(
        handle,                 //IN HANDLE FileHandle
        &ioStatusBlock,         //OUT PIO_STATUS_BLOCK IoStatusBlock
        &fileBasicInfo,         //IN PVOID FileInformation
        sizeof(fileBasicInfo),  //IN ULONG Length
        FileBasicInformation    //IN FILE_INFORMATION_CLASS
);
```

Identifying Known Files

Investigator Performs a *Cross-Time Diff*

Eliminate known good and known bad files, identify unknown files



How Can We Sabotage this Stage?

Preimage Attack

Files altered in this manner can be discovered via a binary diff

Inject Known Good and Known Bad Files

Consumes bandwidth, but is definitely conspicuous

(e.g. time needed to get reference check sums)

Has potential as part of an exit strategy

(e.g. Decrypt a known bad file, let it act as a decoy)

File Signature Analysis

$$-k_B \sum_i P_i \log_e(P_i)$$

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Tactics that Subvert File Signature Analysis

Transmogrification

Alter the file header so that it doesn't match the predefined signature

Keep in mind that an investigator can always crank up a hex editor

http://www.metasploit.com/data/antiforensics/BlueHat-Metasploit_AntiForensics.ppt

Steganography and Encryption

Can encrypt an executable → no signature whatsoever

Encode a configuration text file and wrap it in an executable

```
[Hidden Processes]
hxdef*
mstftp.exe
keylogger.exe
```

→

```
<StringData><HP>
aHhkZWYqDQptc3RmdHAuZX
hlDQprZXlsb2dnZXIuZXhl
</HP></StringData>
```

Static Analysis of an .EXE

Static Analysis Tools	Example
File Header Readers	`dumpbin.exe`
Disassemblers	IDA Pro
Hex Editors	HxD

Countermeasures

Store the `.EXE` in a format that cannot be readily analyzed

Countermeasure Tools	Description
Cryptor (e.g. EXECryptor)	Encrypts the original application
Packer (e.g. UPX)	Compresses the original application
Bytecode Compiler	Recasts the machine code as p-code

Basic Operation

$$-k_B \sum_i P_i \log_e(P_i)$$

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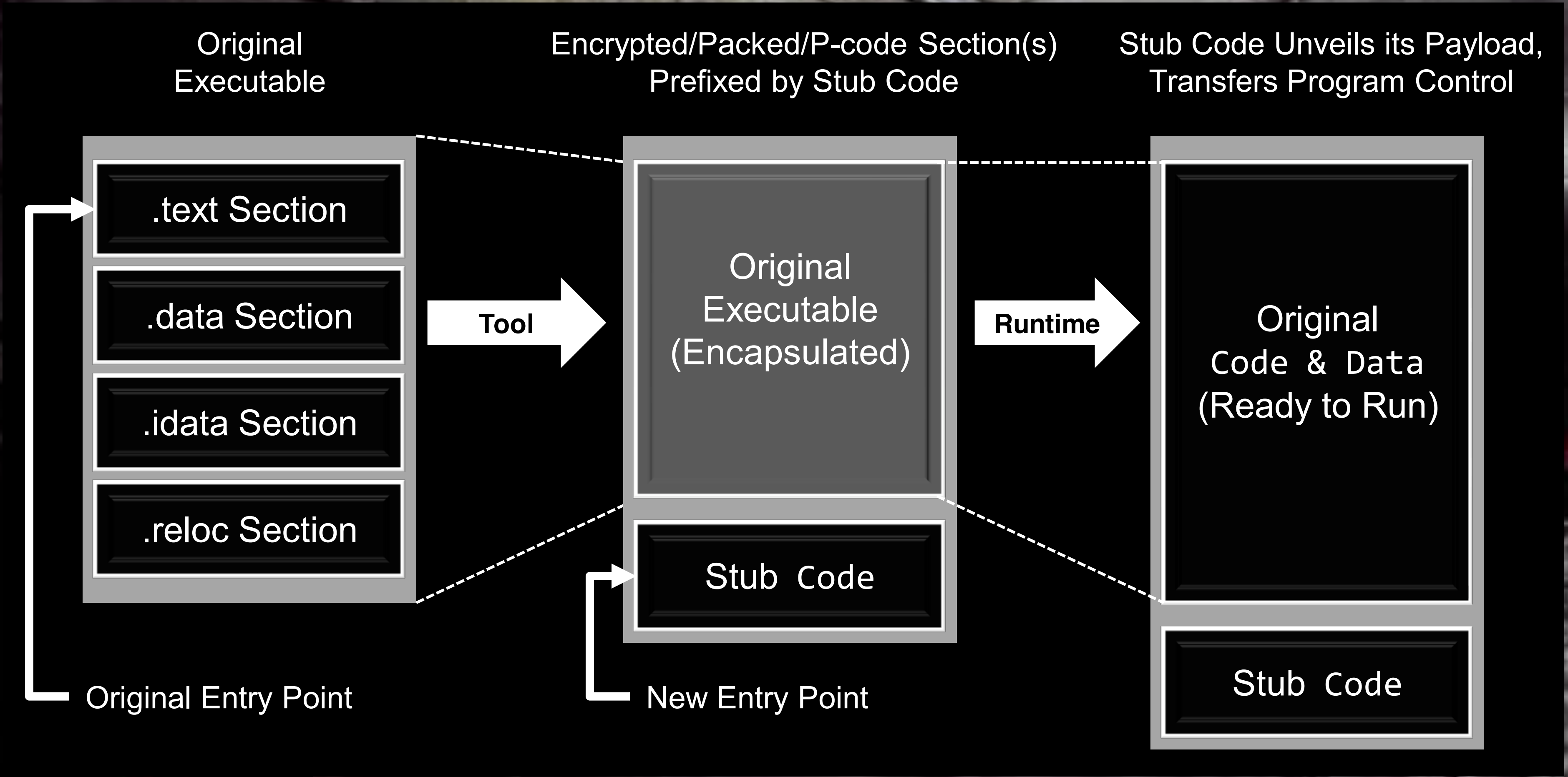

Original Executable

Encrypted/Packed/P-code Section(s) Prefixed by Stub Code

Stub Code Unveils its Payload, Transfers Program Control

.text Section

.data Section

.idata Section

.reloc Section

Tool

Original Executable (Encapsulated)

Stub Code

Runtime

Original Code & Data (Ready to Run)

Stub Code

Original Entry Point

New Entry Point

Recurring Theme: Userland Exec

Origins

Standard family of exec functions on Unix systems

```
int execv(const char *path, char *const argv[]);
int execve(const char *path, char *const argv[], char *const envp[]);
int execvp(const char *file, char *const argv[]);
```

Replace the current process image with a new process image
Core functionality is provided by facilities in the kernel

Stub Code ≈ Userland Exec

Loads an arbitrary byte stream (from disk)
Makes adjustments so that the byte stream can execute
Doesn't use the native OS loader (e.g. it's a User-Mode loader)
This sort of functionality will prove useful later on…

Stub Code Issues – Part I

If Key Material is Stored in the Stub

- Break the payload into segments, use a different key for each one
- Use multiple keys that are generated at runtime from a seed value

Storing Key Material Outside of the Stub

- Hide key material in a reserved region (MFT, HPA, BIOS, etc.)
- Use an *environmental key*, that's specific to the target machine
    - http://papers.weburb.dk/archive/00000136/01/eicar05final.pdf

Use Custom Tools

- Public tools leave a signature (http://www.peid.info/)
- This enables automated tools that unpack/decrypt the payload
- Implement a combination of packing, encrypting, and bytecode
    - For example: bytecode is encrypted and then compressed
- Use multiple packing/encrypting algorithms to buy time
    - But, be aware of the size penalty you will pay

Stub Code Issues – Part II

$$-k_B \sum_i P_i \log_e(P_i)$$

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Camouflage

Stub code has only a few sections, not many imports, and very little string data

```
Section Table
01 UPX0      VirtSize: 00052000  VirtAddr:  00001000
02 UPX1      VirtSize: 0001B000  VirtAddr:  00053000
03 .rsrc     VirtSize: 00008000  VirtAddr:  0006E000
```

Look familiar?

This scarcity of data is a dead giveaway to the investigator

Can Fabricate extra code and data to make the stub appear legitimate

Example: `VERSIONINFO` resource-definition statement

http://msdn.microsoft.com/en-us/library/aa381058.aspx

Runtime Exposure

Foiling static analysis is a temporary countermeasure at best

It should be used as part of a defense in depth approach

Ultimately, the stub will unveil its payload at runtime

This leads us to the next topic…

Runtime Analysis of an .EXE

Runtime Analysis Tools	Example
Debuggers (User & Kernel-Mode)	OllyDbg, WinDBG, KD
Resource Monitors	SysInternals Suite
API Tracers	Windows `Logger.exe`
Network Packet Analyzers	Wireshark
System Logs	Windows Event Logs

Countermeasures

The very same tools that vendors used to defend against crackers (role reversal!)

Countermeasure	Description
Tamperproofing	Detect and respond to patching (e.g. a debugger)
Obfuscation	Make code/data difficult to interpret and reverse
Autonomy	Rely as little as possible on the official channels

Tamperproofing

Step 1 — Detecting Modifications

Want to know when a debugger has set a breakpoint or disabled a routine with NOPs

Official API Calls (are relatively easy to subvert)

```
BOOL WINAPI IsDebuggerPresent();            //user-mode
BOOLEAN KdRefreshDebuggerNotPresent();     //kernel-mode
```

Checksums are a more robust approach

- Avoid a centralized checksum API, implement redundant integrity checks
- Create integrity checking routines to monitor your integrity checks
- Plant decoy integrity checks to mislead the investigator
- Periodically reinstate code to prevent it from being overwritten with NOPs

Step 2 — Responding to Modifications

Disassociate integrity checks from response (delayed trigger)

Embed subtle bugs and have the integrity checks correct them

Do NOT crash and burn, send them on a goose chase (buy time)

Obfuscation

$$-k_B \sum_i P_i \log_e(P_i)$$

Code Morphing is preferable, has less impact on the source base
http://www.strongbit.com/execryptor_inside.asp

Obfuscation Strategy	Tactics
Reduce Code Abstraction	In-line expansion, central routine dispatching
Rearrange Code	Code interleaving
Break Conventions	Using exceptions to transfer program control
Encrypt Code	Use code checksums as a decryption key

Note - encrypted routines are inherently not thread-safe

Microsoft uses obfuscation to implement Kernel Patch Protection
http://uninformed.org/index.cgi?v=3&a=3&p=4

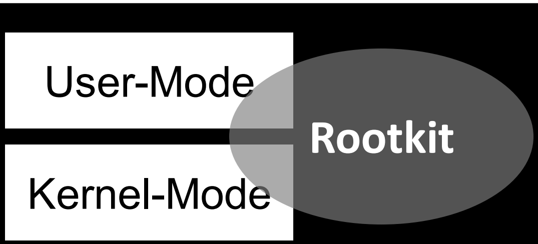
Skype also relies heavily on obfuscation to hamper reversing
http://www.blackhat.com/presentations/bh-europe-06/bh-eu-06-biondi/bh-eu-06-biondi-up.pdf

Autonomy

Official Channels → Windows API → Audit Trail (Event Logs)

Countermeasure

Minimize the interface between rootkit and OS
Less dependence means more stealth



Rootkit	Implementation Details
Athens Affair	Maintained its own database instance
Deepdoor	Modified a couple of `DWORDS` in the NDIS data section
Deeper Door	Established a direct channel to local NIC hardware
Blue Pill	Hypervisor-based, lies outside of child partition

Data Source Elimination

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Memory-Resident Rootkits

The best way to defeat disk analysis → Never write to the disk to begin with

This strategy has so much potential that it deserves special attention

Several ways to implement

Memory-Resident Variant
Syscall Proxying
Memory-Resident Development Tools
Data Contraception
In-Memory Library Injection
Persistence by Re-Infection

An Aside: Userland Exec Reloaded

From Earlier: Cryptors and Packers

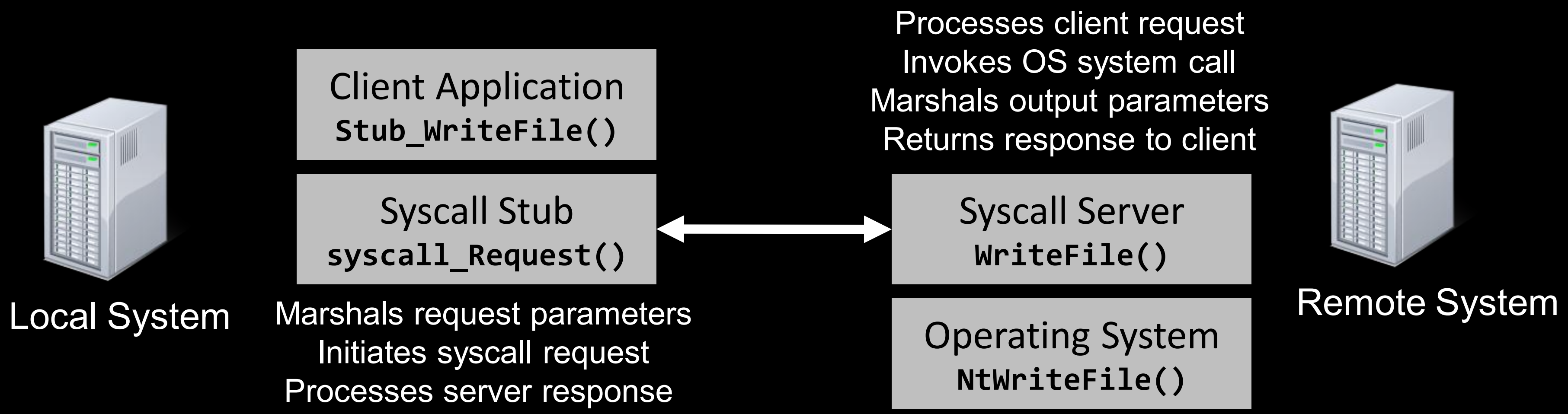
The stub loaded a byte stream that originally resided on disk

A Full-Blown Userland Exec

Is essentially a stub that can load code from a memory buffer
The buffer usually receives its byte stream from a network connection
Sidesteps restrictions imposed by the native OS loader (e.g. disk residence)

Implementations	Description
Nebbett's Shuttle	Uses Win32 API to overwrite a suspended process
ul_exec	Library that loads ELF binaries into an address space
SHELF	Revised version of `ul_exec` for use in exploits

Syscall Proxying



Local System

Client Application
`Stub_WriteFile()`

Syscall Stub
`syscall_Request()`

Marshals request parameters
Initiates syscall request
Processes server response

Processes client request
Invokes OS system call
Marshals output parameters
Returns response to client

Syscall Server
`WriteFile()`

Operating System
`NtWriteFile()`

Remote System

Example

Core Security Technologies, CORE IMPACT Pen Testing Tool

http://www.coresecurity.com/content/syscall-proxying-simulating-remote-execution

Issues

Network Chatter

The average application makes lots, and lots, of system calls

Low-Level Nature of the Technique

Portability becomes an issue, marshalling is a royal pain

Memory-Resident Tools

$$-k_B \sum_i P_i \log_e(P_i)$$

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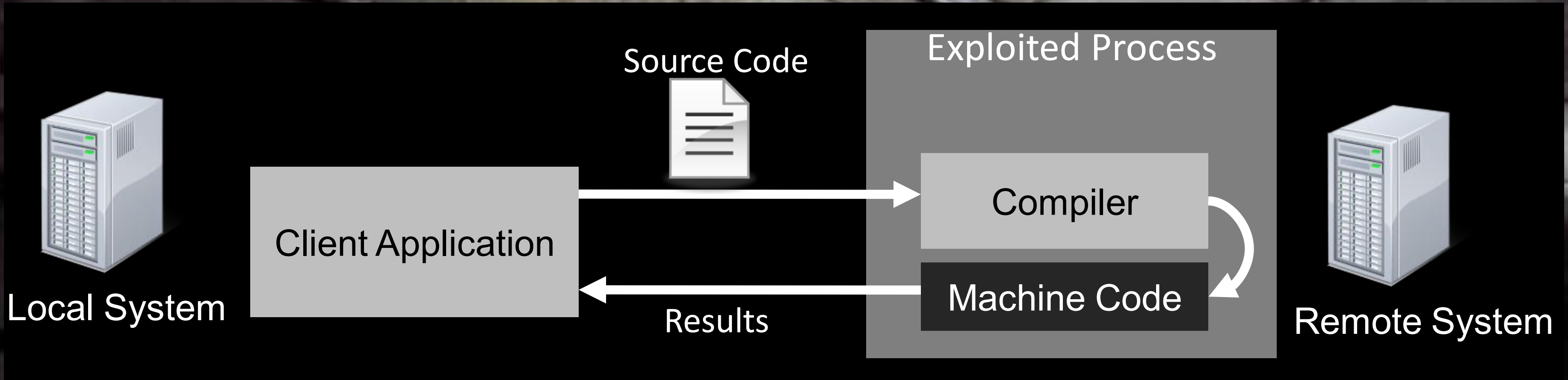


Example

Immunity, Inc., CANVAS Penetration Testing Tool

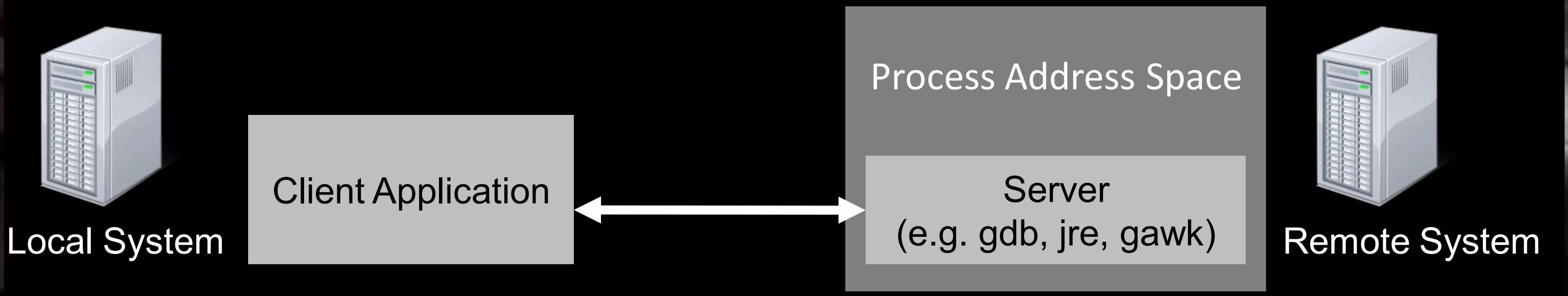
Uses MOSDEF, a memory-resident C compiler that generates position independent code

http://www.immunitysec.com/products-canvas.shtml
http://www.immunitysec.com/downloads/MOSDEF2dot0.tar.gz

Variations

Compiler could output bytecode to be run by an *injected* virtual machine
Replace compiler by an interpreter, send it bytecode from client side

Data Contraception



Local System

Client Application

Process Address Space

Server
(e.g. gdb, jre, gawk)

Remote System

Example

Remote Exec: Built by the grugq, uses the GNU debugger and his `ul_exec` library

http://www.phrack.org/issues.html?issue=62&id=8#article
http://archive.cert.uni-stuttgart.de/bugtraq/2004/01/msg00002.html

Requirements

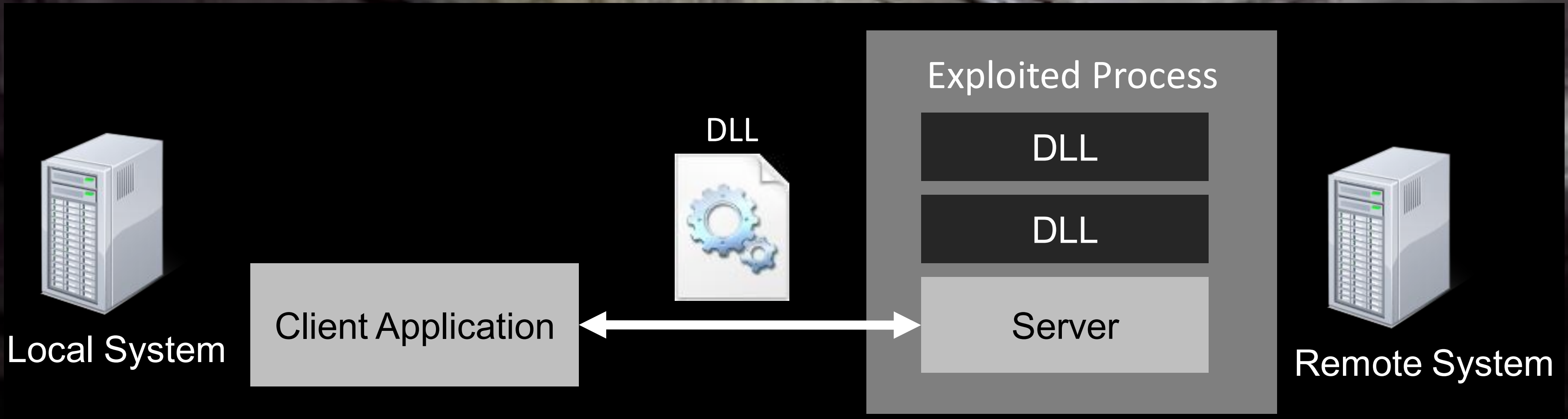
Use a Common Utility for the Server

Minimizes the amount of forensic evidence

Necessitates a “Smart” Client

Compensates for general nature of the server

In-Memory Library Injection



Local System

Client Application

DLL

Exploited Process

DLL

DLL

Server

Remote System

Example

Metasploit's Meta-Interpreter (Meterpreter)

Extensible remote shell that's delivered in an exploit payload

Extensions are implemented as DLLs rather than as raw machine code

Sam Juicer: a Meterpreter extension that dumps password hashes without disk writes

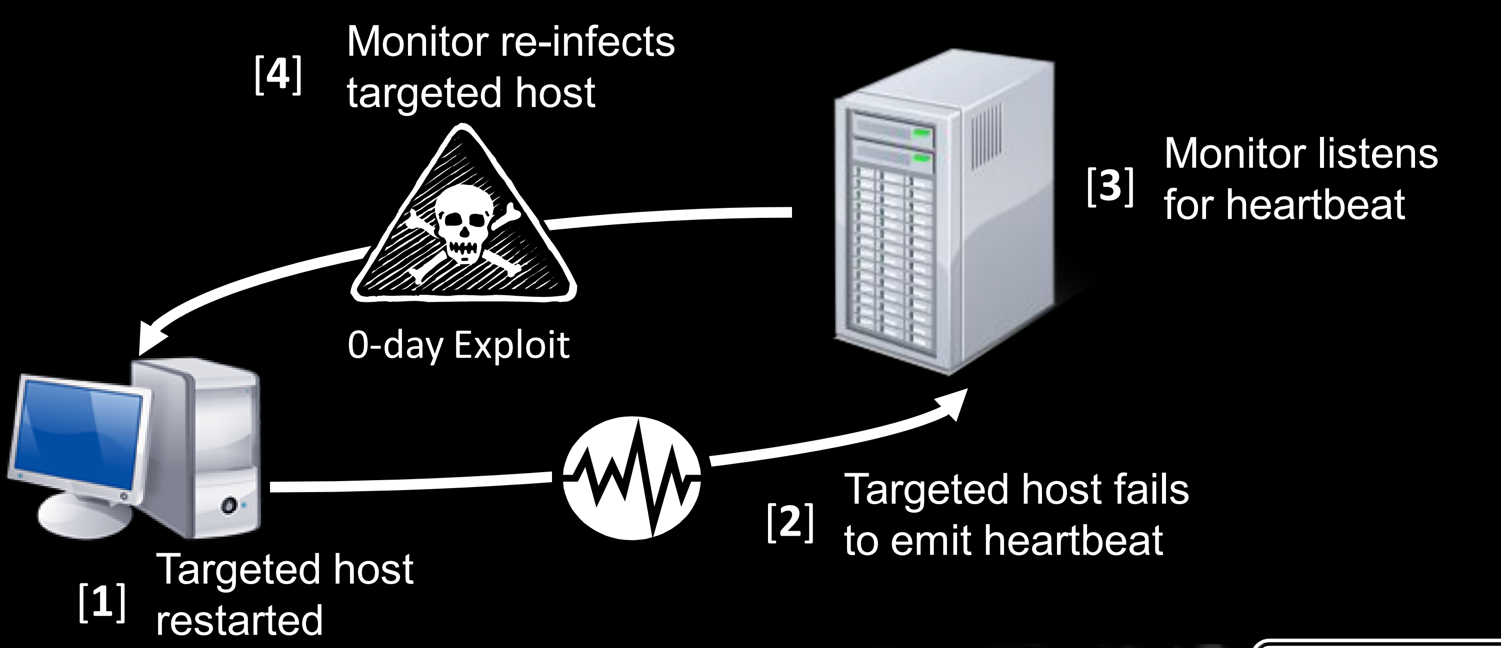
Implementation

Routines used by the dynamic loader are hooked

Enables a DLL's byte stream to be loaded from memory

http://www.nologin.org/Downloads/Papers/remote-library-injection.pdf

Persist via Re-Infection



[4] Monitor re-infects targeted host

0-day Exploit

[3] Monitor listens for heartbeat

[2] Targeted host fails to emit heartbeat

[1] Targeted host restarted

Notes

Heartbeat could be a signal transmitted over a *passive* covert channel (PCC)
Don't generate any traffic of our own, merely alter existing packet streams
http://invisiblethings.org/papers/passive-covert-channels-linux.pdf

Based on ideas presented by Joanna Rutkowska
http://www.blackhat.com/presentations/bh-federal-06/BH-Fed-06-Rutkowska/BH-Fed-06-Rutkowska-up.pdf

Firmware-Based Rootkits

Can also avoid the disk by hiding in firmware

Public Research

John Heasman, http://www.blackhat.com/presentations/bh-federal-06/BH-Fed-06-Heasman.pdf
Anibal Sacco and Alfredo Ortega, http://cansecwest.com/csw09/csw09-sacco-ortega.pdf
Darmawan Salihun, *BIOS Disassembly Ninjutsu Uncovered*, A-List Publishing, 2006

Commercial

Absolute Software sells Computrace, which includes a BIOS-based persistence agent
http://developernet.absolute.com/products-core-technology.asp
Several OEMs have embedded this agent at the firmware level
http://www.absolute.com/partners/bios-compatibility

Scenario

Someone figures out how to commandeer Computrace…

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Footprint and Fault Tolerance

$$-k_B \sum_i P_i \log_e(P_i)$$

The Tradeoff

Minimize Footprint → Sacrifice Restart Survival

May need to balance the two based on:

- The type of environment being targeted
- The value of the data to be acquired
- The skill level of your opponent(s)

Caveats

If the value of the data warrants the necessary R&D, you can have both

Periodic shutdowns can occur even in high-end environments
The Chicago Stock Exchange reboots its machines every evening

http://staging.glg.com/tourwindowsntserver/CHX/pdf/tech_road.pdf

Launching a Rootkit

$$-k_B \sum_i P_i \log_e(P_i)$$

Below Gotham Laboratories

Assuming a knowledgeable, well-armed, adversary…

Preferred Vector: Install a Memory-Resident Rootkit via an Exploit

Everything happens inside of an existing process (no need to launch a new one)

Can avoid disk modification entirely (though traces may reside in the page file)

Less Attractive Vector: Install an Agent in the Firmware

Firmware launches a bare-bones server that loads the rootkit proper over a socket

Leaves a minimal amount of code on the system, in a spot that's often ignored

Least Attractive Vector: Persist Somewhere on Disk

Initiating code will, by necessity, be naked and accessible

You can expect that your code will, with enough effort, be discovered

Leverage the five anti-forensic strategies with defense in depth to buy time

Conclusions

Bottom Line

State of the art anti-forensics can defeat disk analysis
(Perhaps this explains why this is a relatively inactive sub-field?)

Observation

A rootkit may never use disk storage…
But it still has to *execute in memory*
And it will almost always *talk to the outside*

Corollary

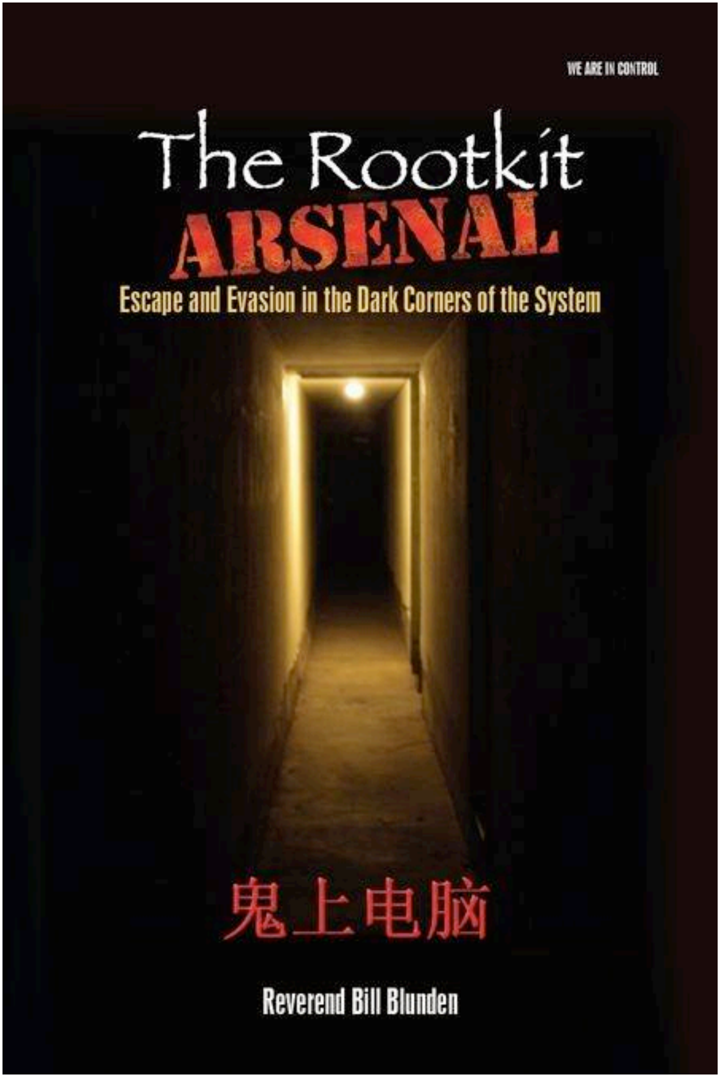
The arms race continues in the domains of live response and NSM

For More Information…

The Rootkit Arsenal

Jones & Bartlett Publishers (May 4, 2009)

ISBN-10: 1598220616



Thanks and Greetings

To Security Researchers Who Shared with the Rest of Us

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Questions?

Thank You for Your Time