Reverse Engineering by Crayon: Game Changing Hypervisor and Visualization Analysis

Game Changing Hypervisor Based Malware Analysis and Visualization

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Overview

• Reverse Engineering Process
• Hypervisors and You
• Xen and Ether
• Modifying the Process
• VERA
• Real! Live! Reversing!
• Results
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Process for Reverse Engineering

• Setup an isolated run-time environment
• Execution and initial analysis
• Deobfuscate compressed or packed code
• Disassembly / Code-level Analysis
• Identify and analyze relevant and interesting portions of the program
Isolated Analysis Environment

• Setup an Isolated Runtime Environment

  – Virtual machines: VMWare, Xen, KVM, ...

  – Need to protect yourself from malicious code

  – Create a known-good baseline environment

  – Quickly allows backtracking if something bad happens
Execution and Initial Analysis

- **Goal**: Quickly figure out what the program is doing without looking at assembly

- **Look for**:
  - Changes to the file system
  - Changes to the behavior of the system
    - Network traffic
    - Overall performance
    - Ads or changed browser settings
Remove Software Armoring

- Program protections to prevent reverse engineering
- Done via packers – Small encoder/decoder
- Self-modifying code
- Lots of research about this
  - OllyBonE, Saffron, Polyunpack, Renovo, Ether, Azure
  - My research uses Ether
Packing and Encryption

• Self-modifying code
  – Small decoder stub
  – Decompress the main executable
  – Restore imports

• Play “tricks” with the executable
  – OS Loader is inherently lazy (efficient)
  – Hide the imports
  – Obscure relocations
  – Use bogus values for various unimportant fields
Software Armoring

– Compressed, obfuscated, hidden code

– Virtual machine detection

– Debugger detection

– Shifting decode frames
Normal PE File

```
push ebp
mov ebp, esp
sub esp, 1Ch ; lpMsg

; call
; [ebp+nCmdShow] ; nCmdShow
; eax ; int
push [ebp+hPrevInstance]; int
push [ebp+hInstance]; hInstance

; call
_FsollInit@16 ; FsollInit(x,

; test
eax, eax
jz short locret_1001F13
push esi
mov esi, ds:_imp_GetMessageW@16
push edi
mov [ebp+Msg.wParam], 1
xor edi, edi
jmp short loc_1001EFE
```
Packed PE File

In Memory

other sections

.data section

.text section

Section Table

PE Header

DOS Header

Higher offsets

DOS Header

Higher addresses

Unmapped Data

.reloc section

other sections

.data section

.text section

Section Table

PE Header

DOS Header

Higher offsets

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Troublesome Protections

• Virtual Machine Detection
  – Redpill, ocvmdetect, Paul Ferrie’s paper

• Debugger Detection
  – IsDebuggerPresent()
  – EFLAGS bitmask

• Timing Attacks
  – Analyze value of RDTSC before and after
  – Really effective
Thwarting Protections

Two methods for circumvention

1. Know about all the protections before hand and disable them

2. Make yourself “invisible”
Virtual Machine Monitoring

• Soft VM Based systems
  – Renovo
  – Polyunpack
  – Zynamics Bochs unpacker

• Problems
  – Detection of virtual machines is easy
  – Intel CPU never traditionally designed for virtualization
  – Do not emulate x86 bug-for-bug
OS Integrated Monitoring

• Saffron, OllyBonE
  – Page-fault handler based debugger
  – Abuses the supervisor bit on memory pages
  – High-level executions per page

• Problems
  – Destabilizes the system
  – Need dedicated hardware
  – Fine-grain monitoring not possible
Fully Hardware Virtualizations

- Ether: A. Dinaburg, P. Royal
  - Xen based hypervisor system
  - Base functions for monitoring
    - System calls
    - Instruction traces
    - Memory Writes
    - All interactions done by memory page mapping
- Problems
  - Old version of Xen hypervisor
  - Requires dedicated hardware
Disassembly and Code Analysis

• Most nebulous portion of the process
• Largely depends on intuition
• Looking at assembly is tedious
• Suffers from “not seeing the forest from the trees” syndrome
• Analyst fatigue – Level of attention required yields few results
Find Interesting and Relevant Portions of the Executable

• Like disassembly, this relies on a lot of intuition and experience

• Typical starting points:
  – Look for interesting strings
  – Look for API calls
  – Examine the interaction with the OS

• This portion is fundamentally imprecise, tedious, and often frustrating for beginners and experts
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Hypervisors

• Lots of hype over the past few years

• New hypervisor rootkits lead defensive tools

• Covert methods for analyzing runtime behavior are extremely useful

• Detection of hardware virtualization not widely implemented
Useful Hypervisor Technology

• VMWare ESX Server
  – Commercial grade solution for VMs
  – Avoids VM detection issues (mostly)

• Linux Kernel Virtual Machines (KVM)
  – Separates analysis OS from target OS (slightly safer?)
  – Uses well-tested Linux algorithms for analysis

• Xen
  – Excellent set of tools for introspection
  – Uses standard QEMU image formats
  – API Controlled via Python – Integration into tools is easier
Contributions

• Modifications to Ether
  – Improve malware unpacking
  – Enable advanced tracing mechanisms
  – Automate much of the tedious portions

• Visualizing Execution for Reversing and Analysis (VERA)
  – Speed up disassembly and finding interesting portions of an executable
  – Faster identification of the Original Entry Point
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What is Ether?

• Patches to the Xen Hypervisor
• Instruments a windows system
• Base modules available
  – Instruction tracing
  – API Tracing
  – Unpacking
• “Ether: Malware Analysis via Hardware Virtualization Extensions”
  Dinaburg, Royal, Sharif, Lee

ACM CCS 2008
Ether Event Tracing

• Detects events on an instrumented system
  – System call execution
  – Instruction execution
  – Memory writes
  – Context switches
Instruction Tracing

- EFLAGS register modified for single-step (trap flag)

- PUSHF and POPF instructions are intercepted

- Modifications to this single-stepping effectively hidden (except
Memory and System Calls

• Memory Writes
  – Tracked by manipulating the shadow page table
  – Gives access to the written and read memory addresses

• System Calls
  – Modifies the SYSENTER_EIP register to point to non-paged address space
  – Logged, returned to ether
  – Overrides 0x2e interrupt to catch older syscalls
Ether System Architecture
Extensions to Ether

- Removed unpacking code from hypervisor into user-space
- Better user mode analysis
- PE Repair system – Allows for disassembly of executables
- Added enhanced monitoring system for executables
User mode Unpacking

• Watch for and monitor all memory writes

• Allow program to execute

• When execution occurs in written memory, dump memory

• Each dump is a candidate for the OEP

• Not perfect, but very close

• Scaffolding for future modifications
PE Repair

• Dumped PE files had problems
  – Sections were not file aligned
  – Address of Entry Point invalid
  – Would not load in IDA correctly

• Ported OllyDump code to Ether user mode
  – Fix section offsets to match data on disk
  – Repair resources as much as possible
  – Set AddressOfEntryPoint to be the candidate OEP
Results

• Close to a truly covert analysis system
  – Ether is nearly invisible
  – Still subject to bluepill detections
• Fine-grain resolution of program execution
• Application memory monitoring and full analysis capabilities
• Dumps from Ether can now be loaded in IDA Pro without modification
Ether Unpacking Demo!
Open Problems

• Unpacking process produces lots of candidate dump files

• Better Original Entry Point discovery method

• Import rebuilding is still an issue

• Now that there is a nice tool for tracing programs covertly, we need to do analysis
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Modifying the Process

• Knowing what to look for is often the portion that most new reversers have trouble with
• Having an idea of the execution flow of a program is extremely useful
  – IDA is focused on the function view
  – Extend to the basic block view
• Software armoring removal made easy
Visualization of Trace Data

• Goals:
  – Quickly visually subvert software armoring
  – Identify modules of the program
    • Initialization
    • Main loops
    • End of unpacking code
  – Figure out where the self-modifying code ends (OEP detection)
  – Discover dynamic runtime program behavior
  – Integrate with existing tools
Visualizing the OEP Problem

- Each block (vertex) represents a basic block executed in the user mode code
- Each line represents a transition
- The thicker the line, the more it was executed
- Colors represent areas of memory execution
VERA

• Visualization of Executables for Reversing and Analysis

• Windows MFC Application

• Integrates with IDA Pro

• Fast, small memory footprint
Visualizing Packers

- Memory regions marked for PE heuristics
Demo!
Netbull Virus (Not Packed)
Visualizing Packers

- Memory regions marked for PE heuristics

Color Key:
- Normal
- No section present
- Section SizeOfRawData = 0
- High Entropy (Packed or Compressed)
- Instruction not present in packed executable
- Operands don’t match
ASPack

Color Key:
- Normal
- No section present
- Section SizeOfRawData = 0
- High Entropy (Packed or Compressed)
- Instruction not present in packed executable
- Operands don’t match
TeLock

Color Key:
- Normal
- No section present
- Section SizeOfRawData = 0
- High Entropy (Packed or Compressed)
- Instruction not present in packed executable
- Operands don't match
User Study

- Students had just completed week long reverse engineering course
- Analyzed two packed samples of the Netbull Virus with UPX and MEW
- Asked to perform a series of tasks based on the typical reverse engineering process
- Asked about efficacy of visualization tool
User Study: Tasks Performed

• Find the original entry point (OEP) of the packed samples
• Execute the program to look for any identifying output
• Identify portions of the executable:
  – Packer code
  – Initialization
  – Main loops
Main Loop(s) Recognition

Found Loop(s) (0=No;)

- Main Loops S1
- Main Loops S2
Overall Evaluation

0 = No; 1 = Yes

- Likely to Use Again
- Will Recommend

User 1, User 2, User 3, User 4, User 5, User 6
Selected Comments

- “Wonderful way to visualize analysis and to better focus on areas of interest”

- “Fantastic tool. This has the potential to significantly reduce analysis time.”

- “It rocks. Release ASAP.”
Recommendations for improvement

• Need better way to identify beginning and end of loops

• Many loops overlap and become convoluted

• Be able to enter memory address and see basic blocks that match
Future Work

• General GUI / bug fixes
• Memory access visualization
• System call integration
• Function boundaries
• Interactivity with unpacking process
• Modify hypervisor to work with WinDBG, OllyDbg, IDA Debugger
Conclusions

• Visualizations make it easy to identify the OEP
• No statistical analysis of data needed
• Program phases readily identified
• Graphs are relatively simple
• Preliminary user study shows tool holds promise for speeding up reverse engineering
Thanks!

- Artem Dinaburg
- Paul Royal
- Cort Dougan
- Moses Schwartz
- Alan Erickson
- Alex Kent
- New Mexico Tech SFS Program
Closing thoughts

• Ether is awesome. Thanks Artem Dinaburg and Paul Royal.

• Source, tools, and latest slides can be found at:
  [http://www.offensivecomputing.net](http://www.offensivecomputing.net)

• If you use the tool, please give feedback

• Look for the paper at Vizsec 2009