Reverse Engineering by Crayon: Game Changing Hypervisor and Visualization Analysis

Game Changing Hypervisor Based Malware Analysis and Visualization

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Blackhat / Defcon USA 2009

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

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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

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Software Armoring

- Compressed, obfuscated, hidden code
- Virtual machine detection
- Debugger detection
- Shifting decode frames

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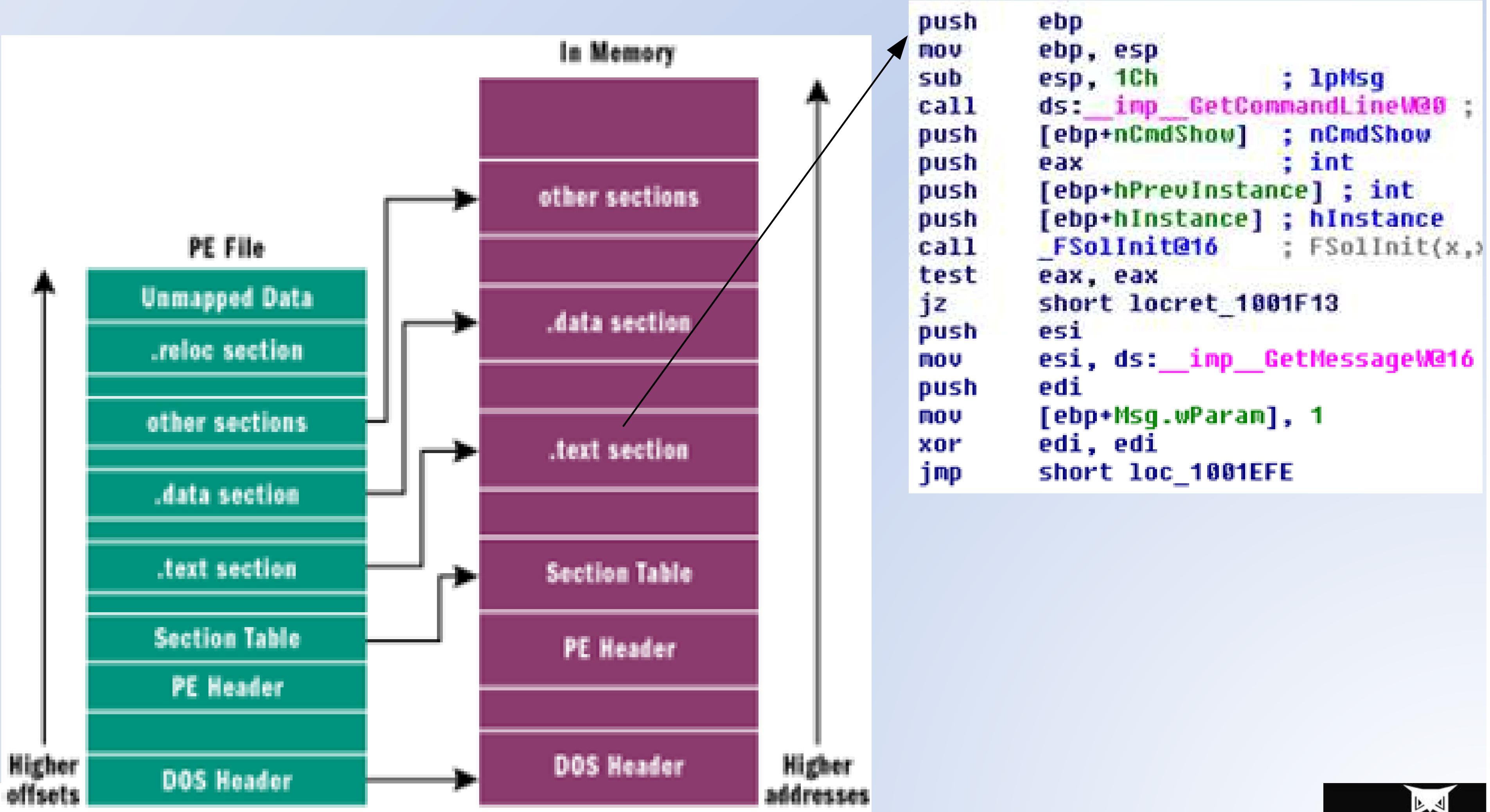
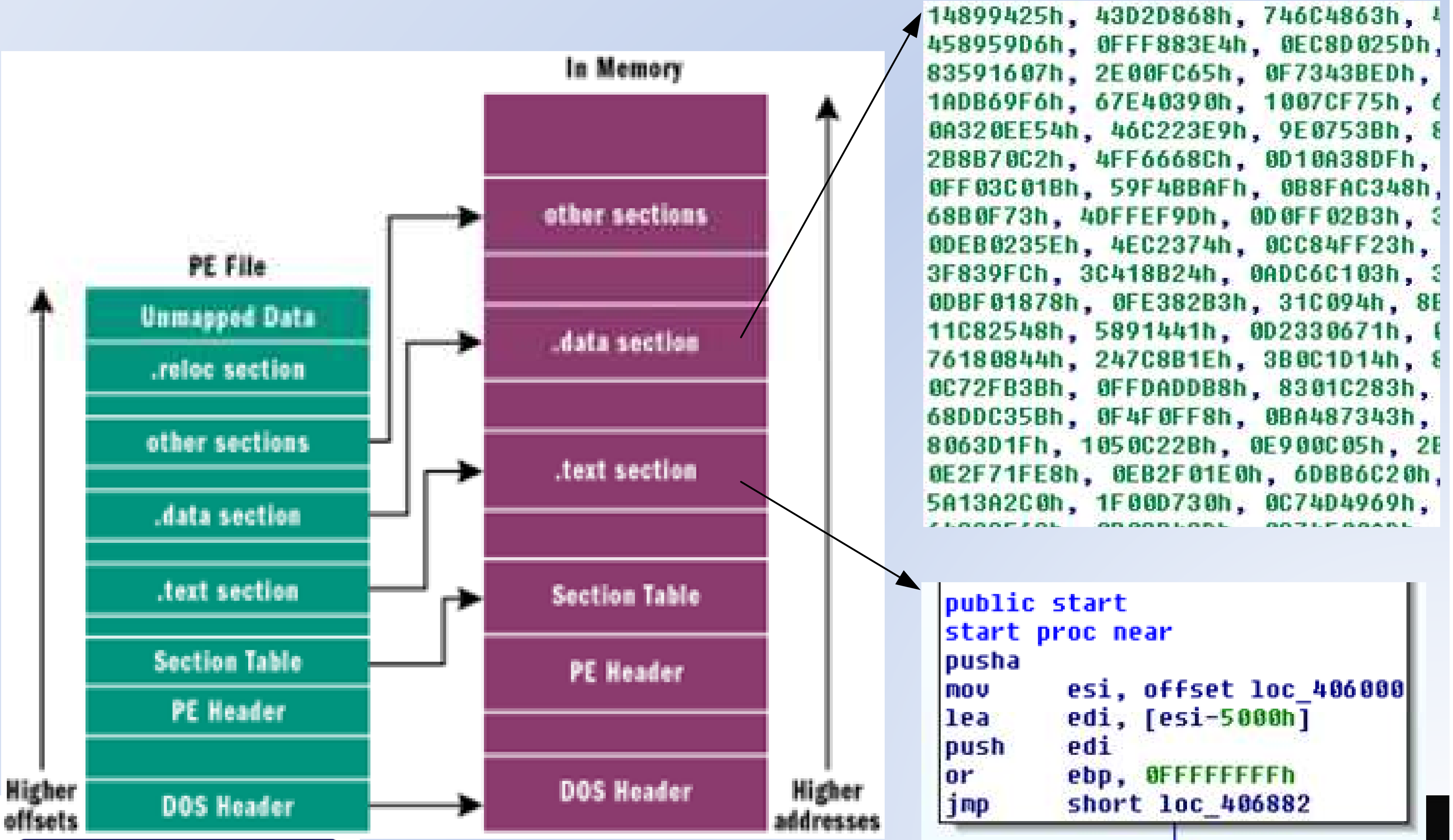
Normal PE File



Packed PE File



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

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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

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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

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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

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Ether Event Tracing

- Detects events on an instrumented system
  - System call execution
  - Instruction execution
  - Memory writes
  - Context switches

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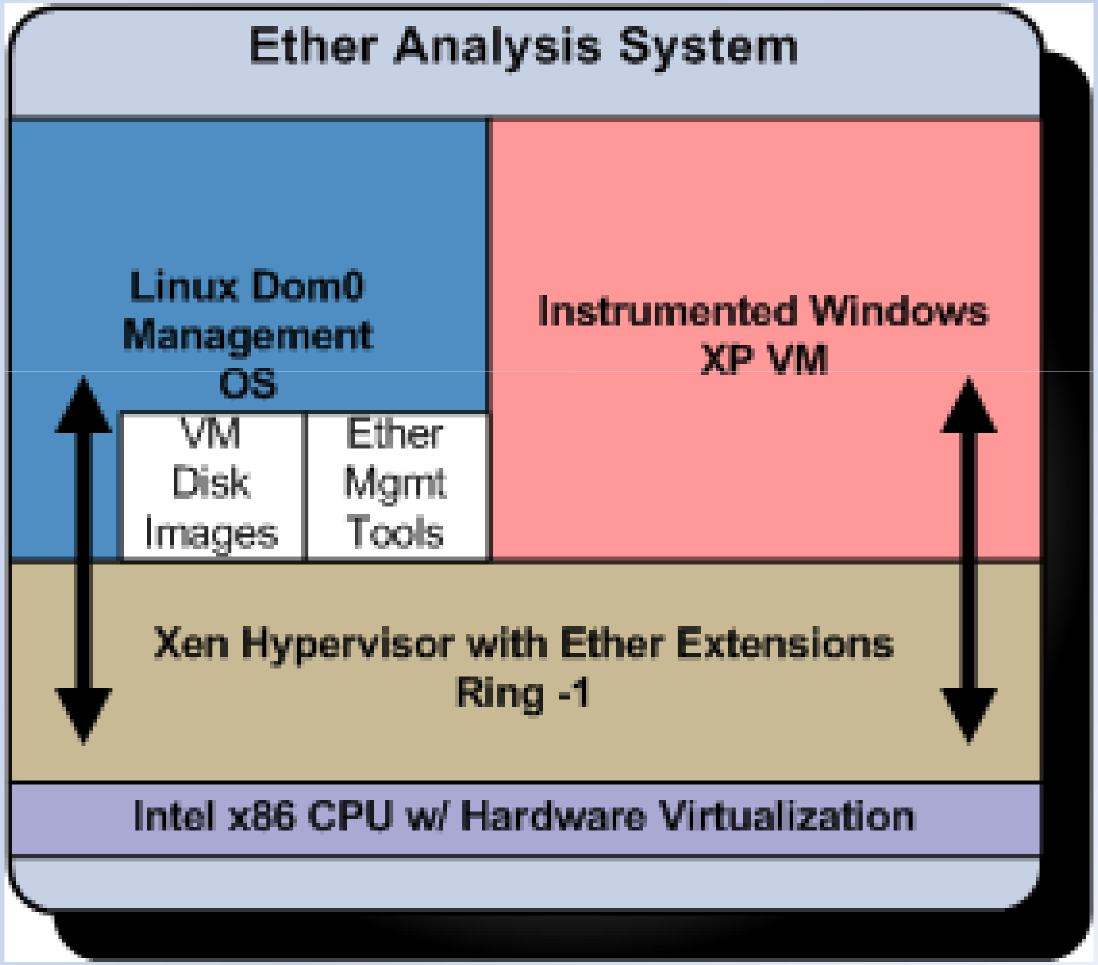
Instruction Tracing

- 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

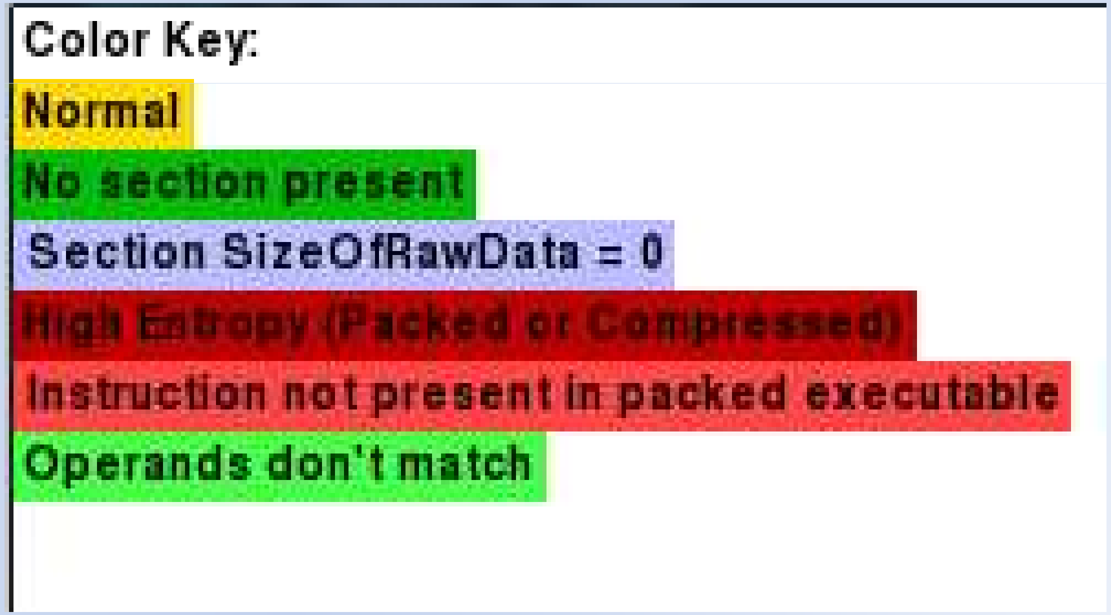
- Each block (vertex) represents a basic block executed in the user mode code
- Each line represents a transition
- The thicker the line, the more it was executed
- Colors represent areas of memory execution

VERA

- Visualization of Executables for Reversing and Analysis
- Windows MFC Application
- Integrates with IDA Pro
- Fast, small memory footprint

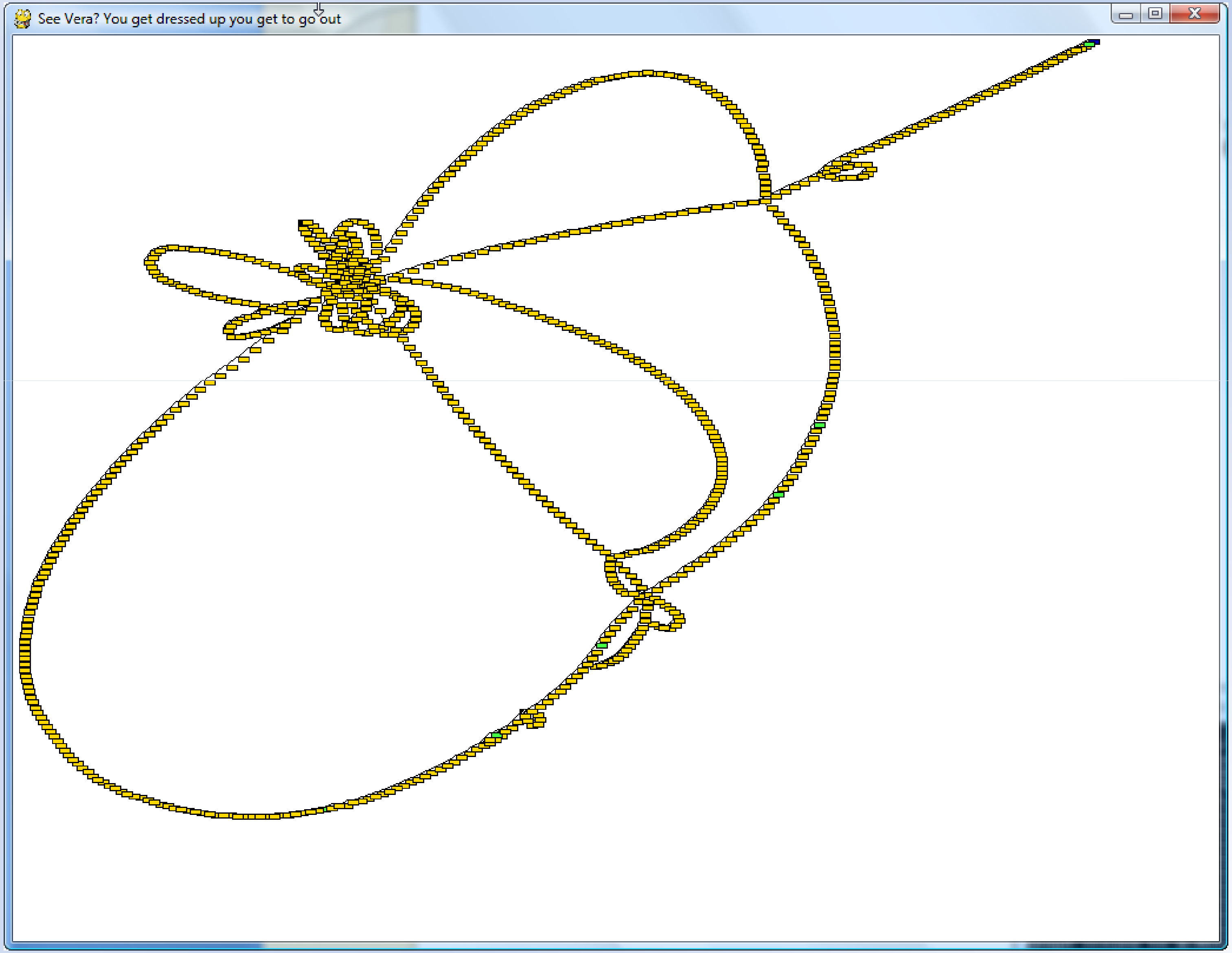
Visualizing Packers

- Memory regions marked for PE heuristics

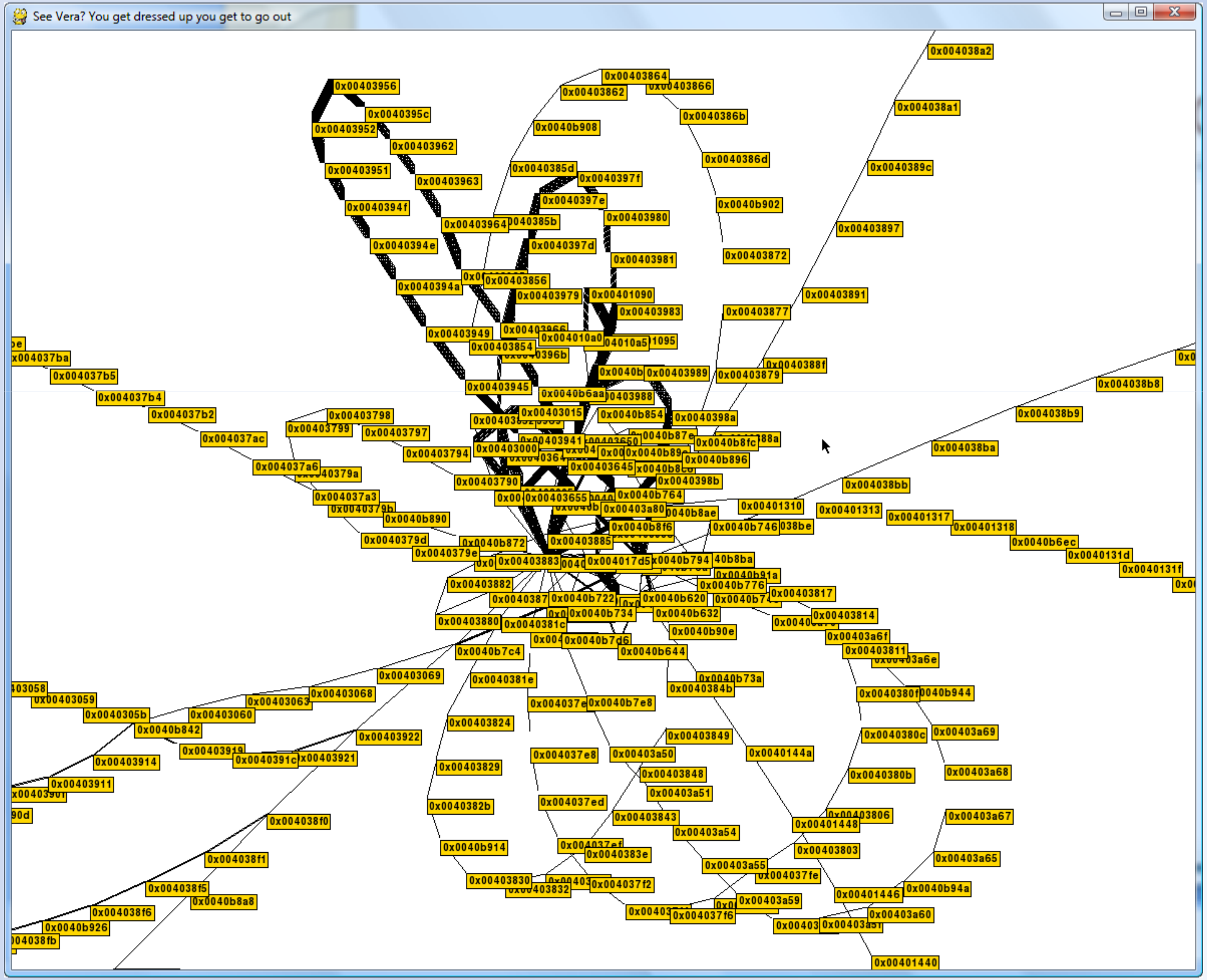


Demo!

Netbull Virus (Not Packed)

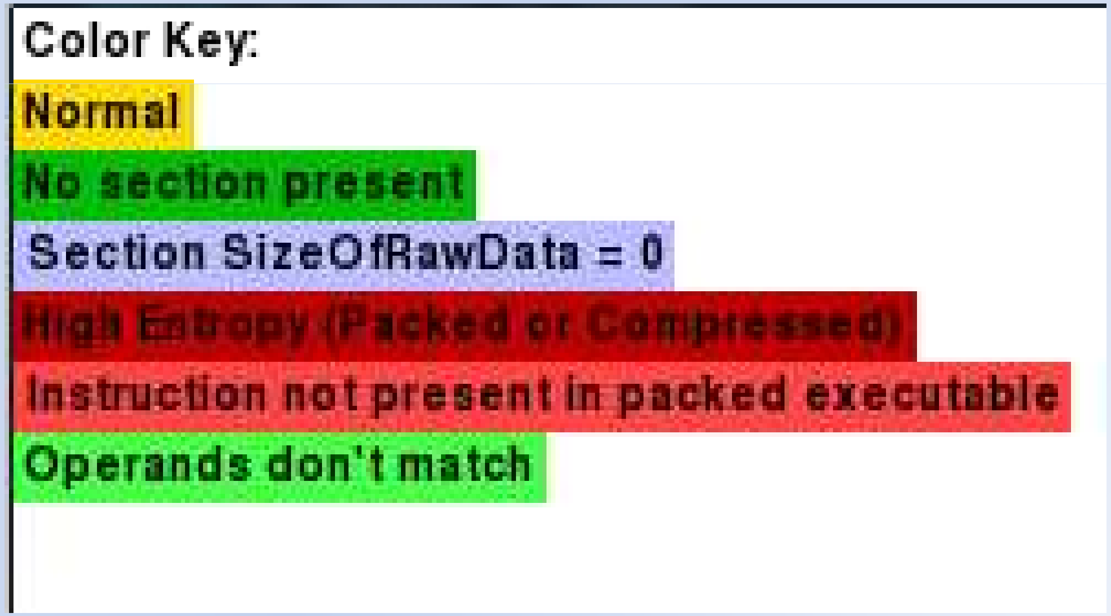


Netbull Zoomed View



Visualizing Packers

- Memory regions marked for PE heuristics



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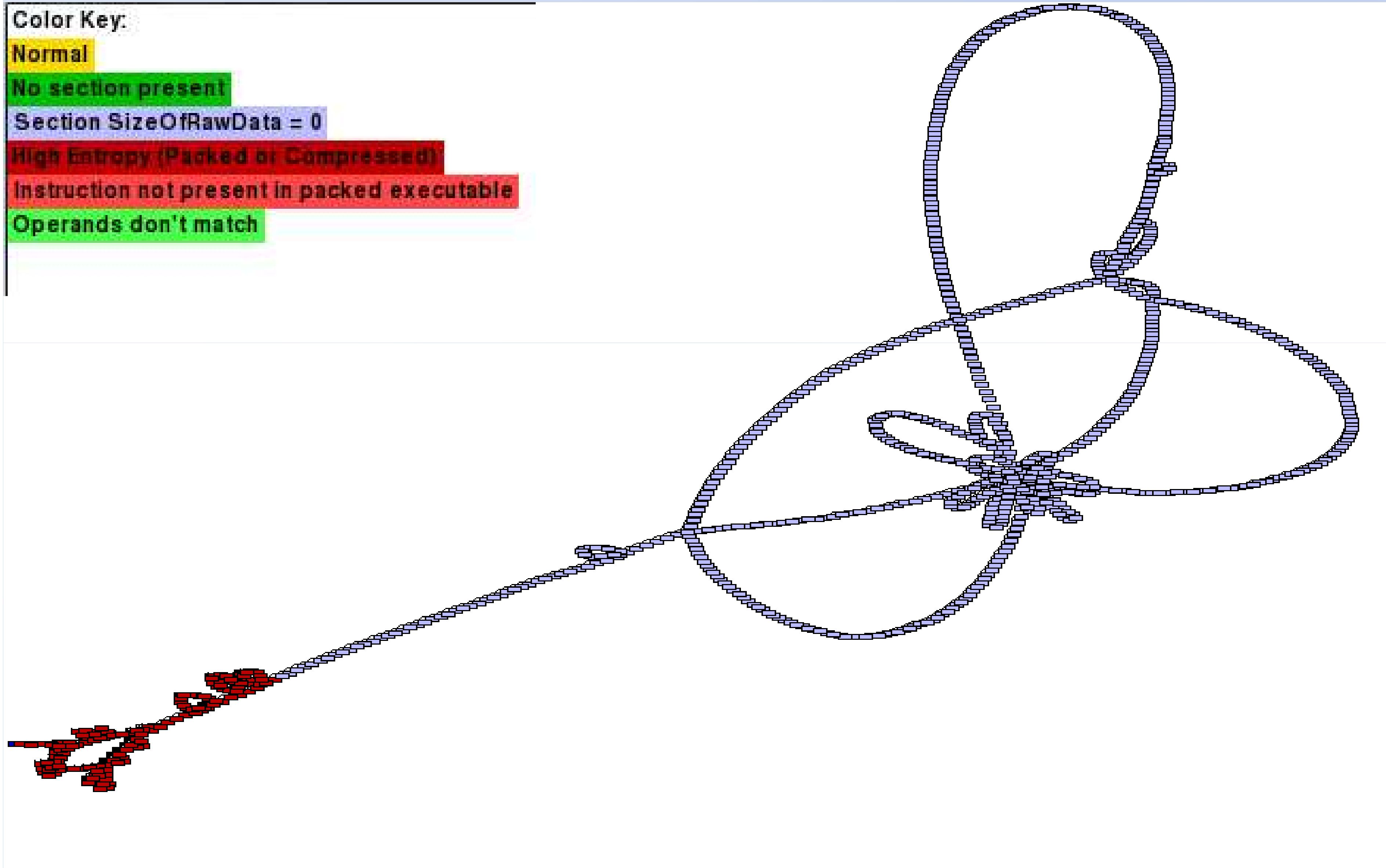
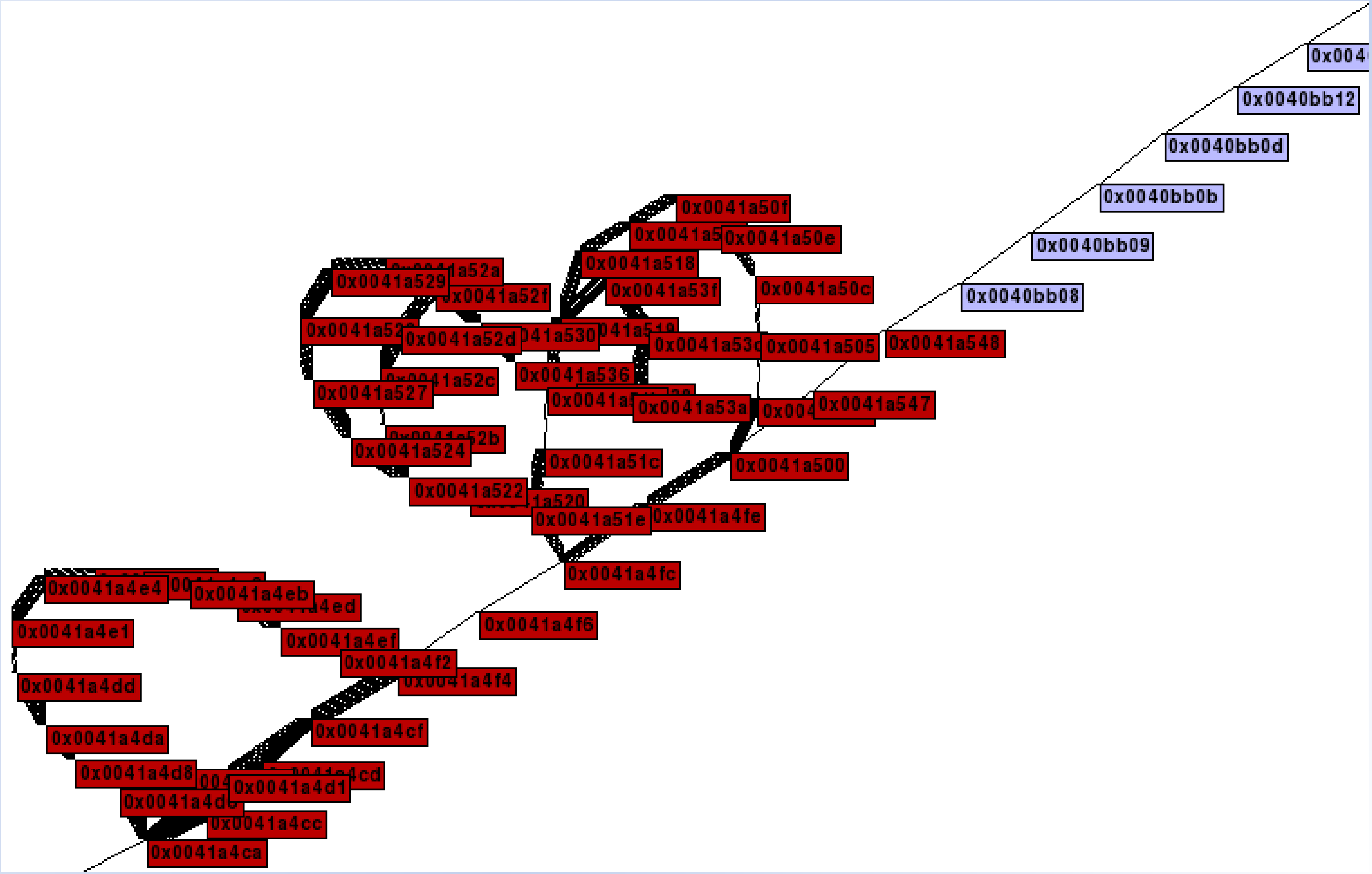
UPX


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

UPX - OEP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0x0040bb0d
0x0040bb0b
0x0040bb09
0x0040bb08
0x0041a50f
0x0041a50e
0x0041a518
0x0041a53f
0x0041a50c
0x0041a529
0x0041a52f
0x0041a52d
0x0041a536
0x0041a505
0x0041a548
0x0041a527
0x0041a53a
0x0041a547
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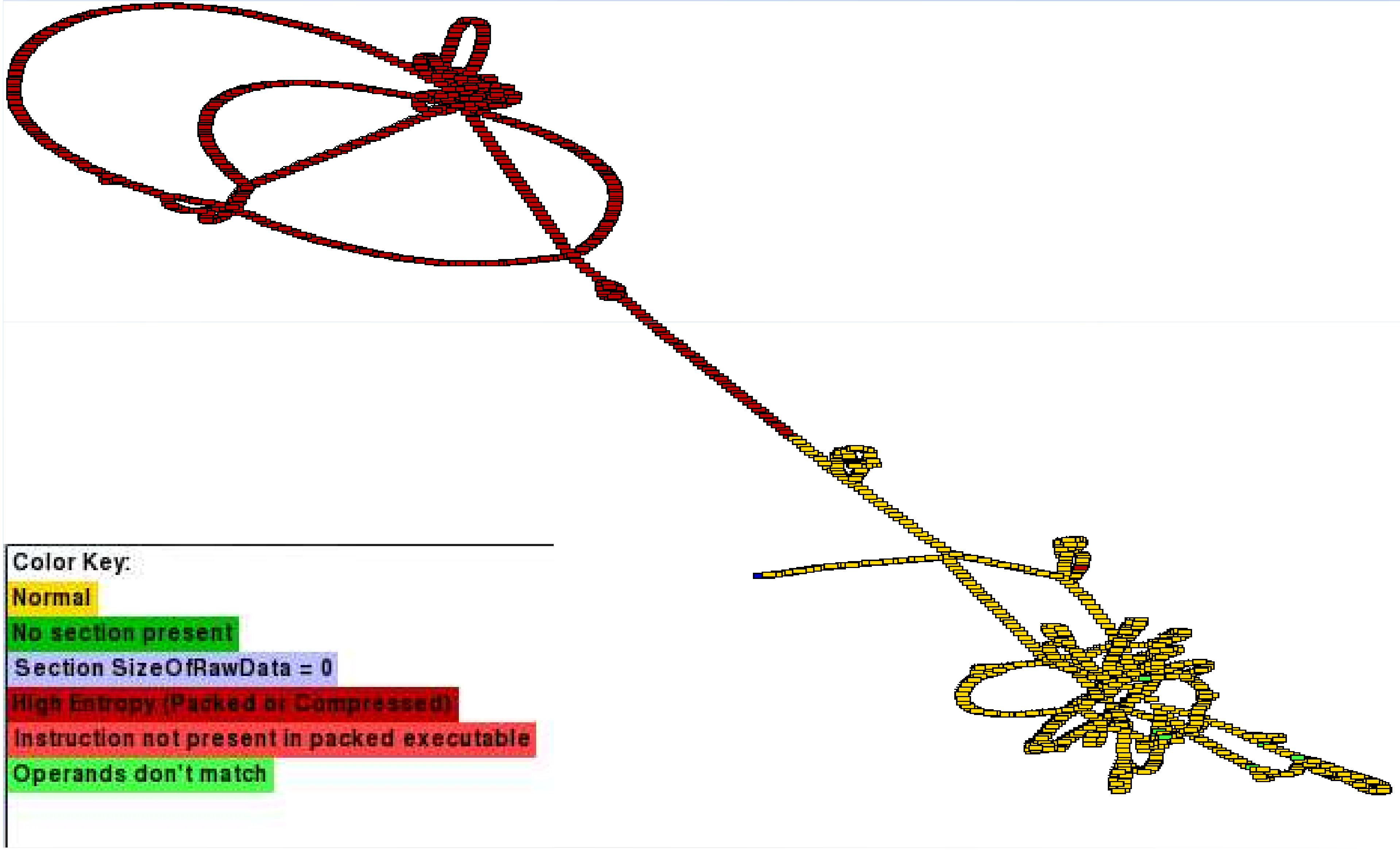
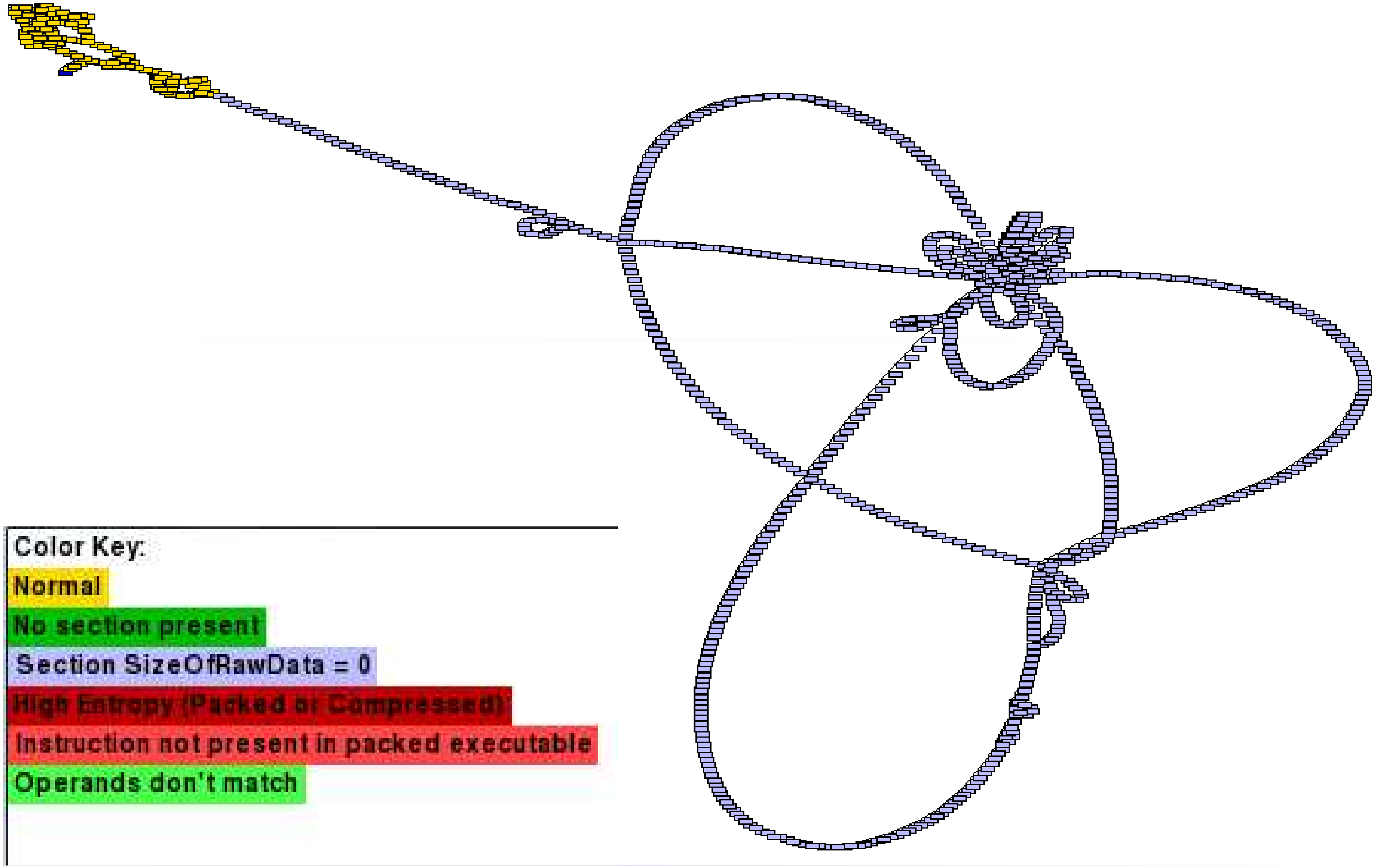
0x0041a522
0x0041a51e
0x0041a4fe
0x0041a4fc
0x0041a4f6
0x0041a4e4
0x0041a4eb
0x0041a4e1
0x0041a4ef
0x0041a4f2
0x0041a4dd
0x0041a4cf
0x0041a4da
0x0041a4d8
0x0041a4d1
0x0041a4cc
0x0041a4ca

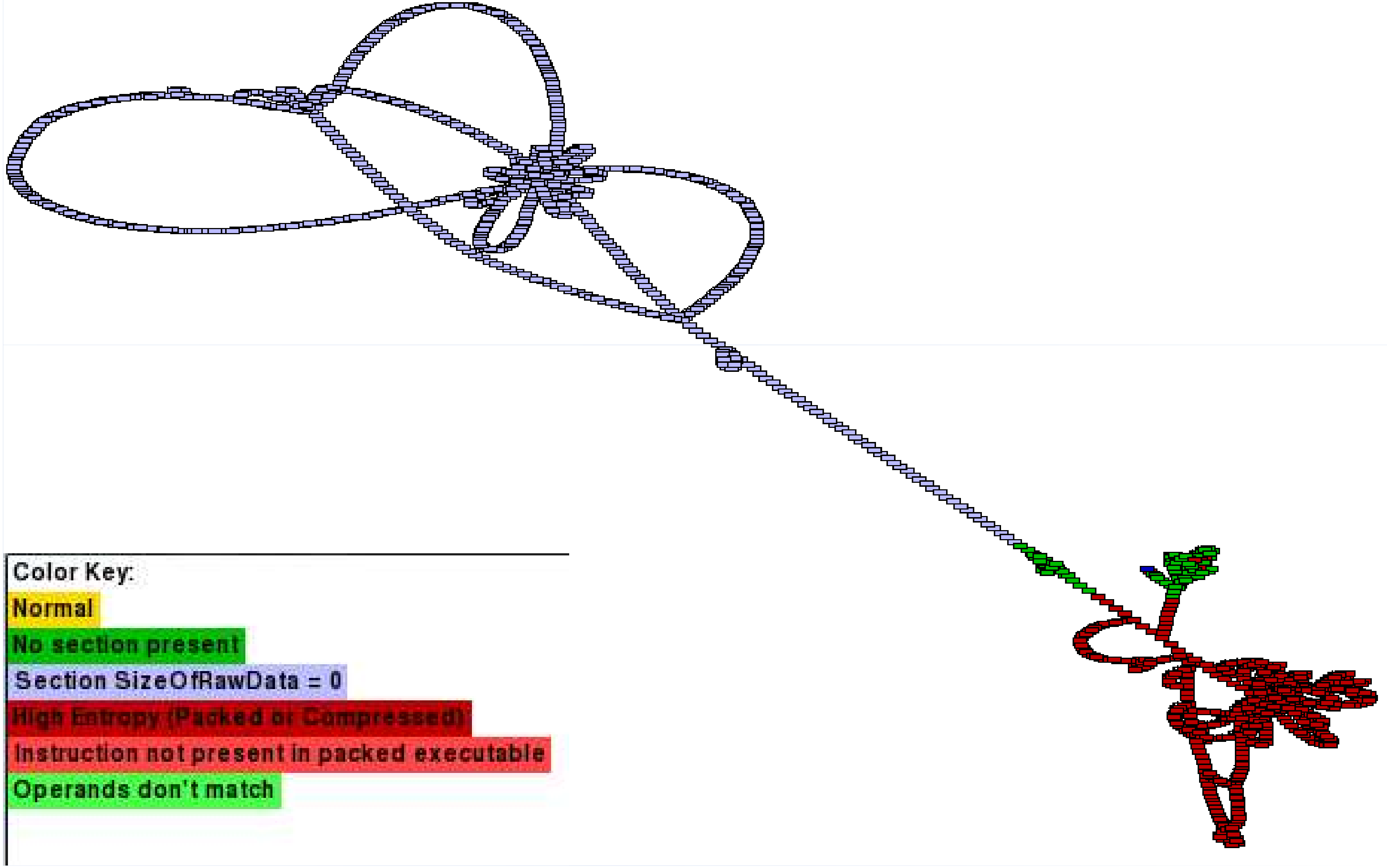
ASPack


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

FSG

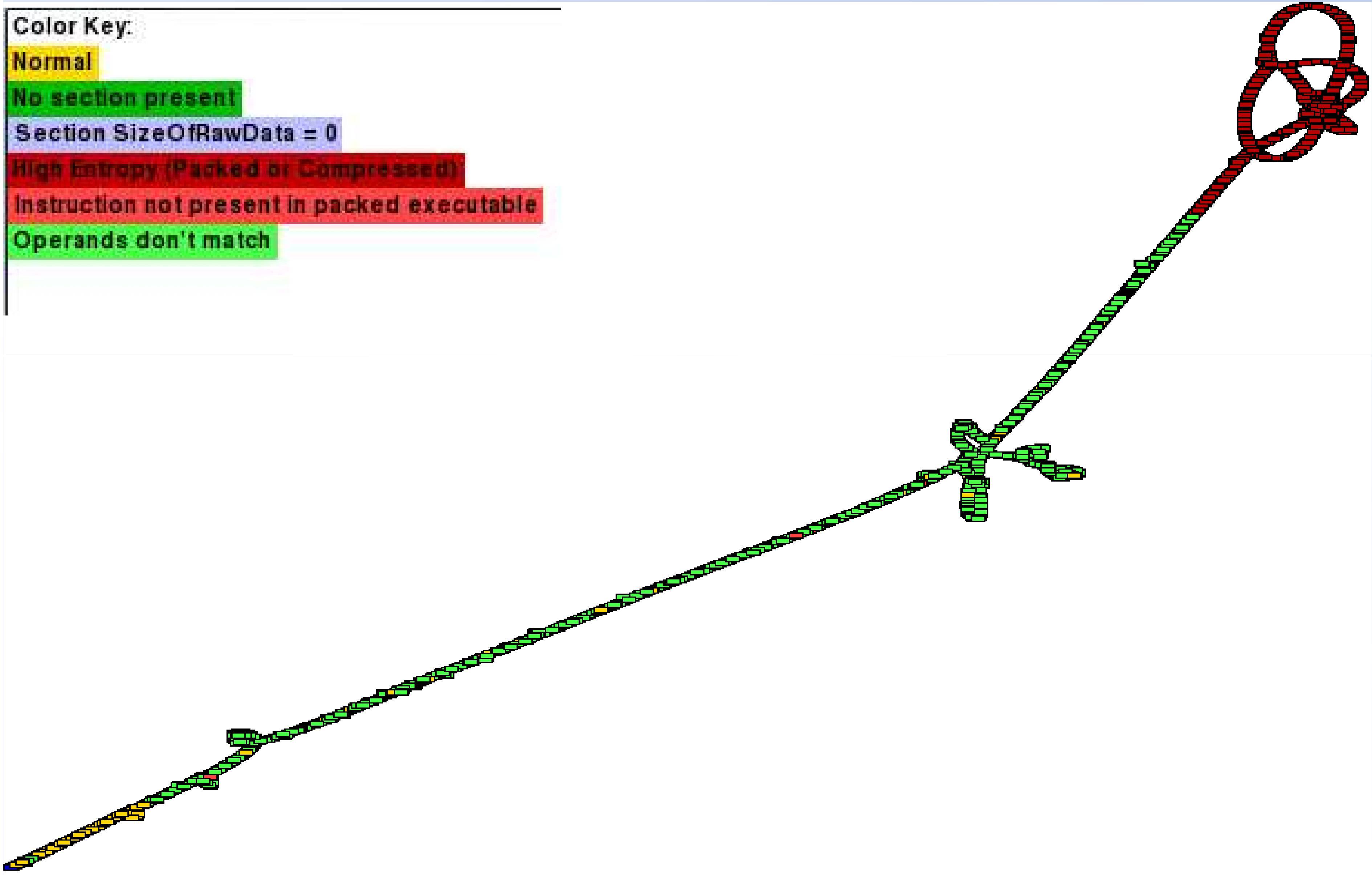

Color Key:
Normal
No section present
Section SizeOfRawData = 0
High Entropy (Packed or Compressed)
Instruction not present in packed executable
Operands don't match

MEW



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

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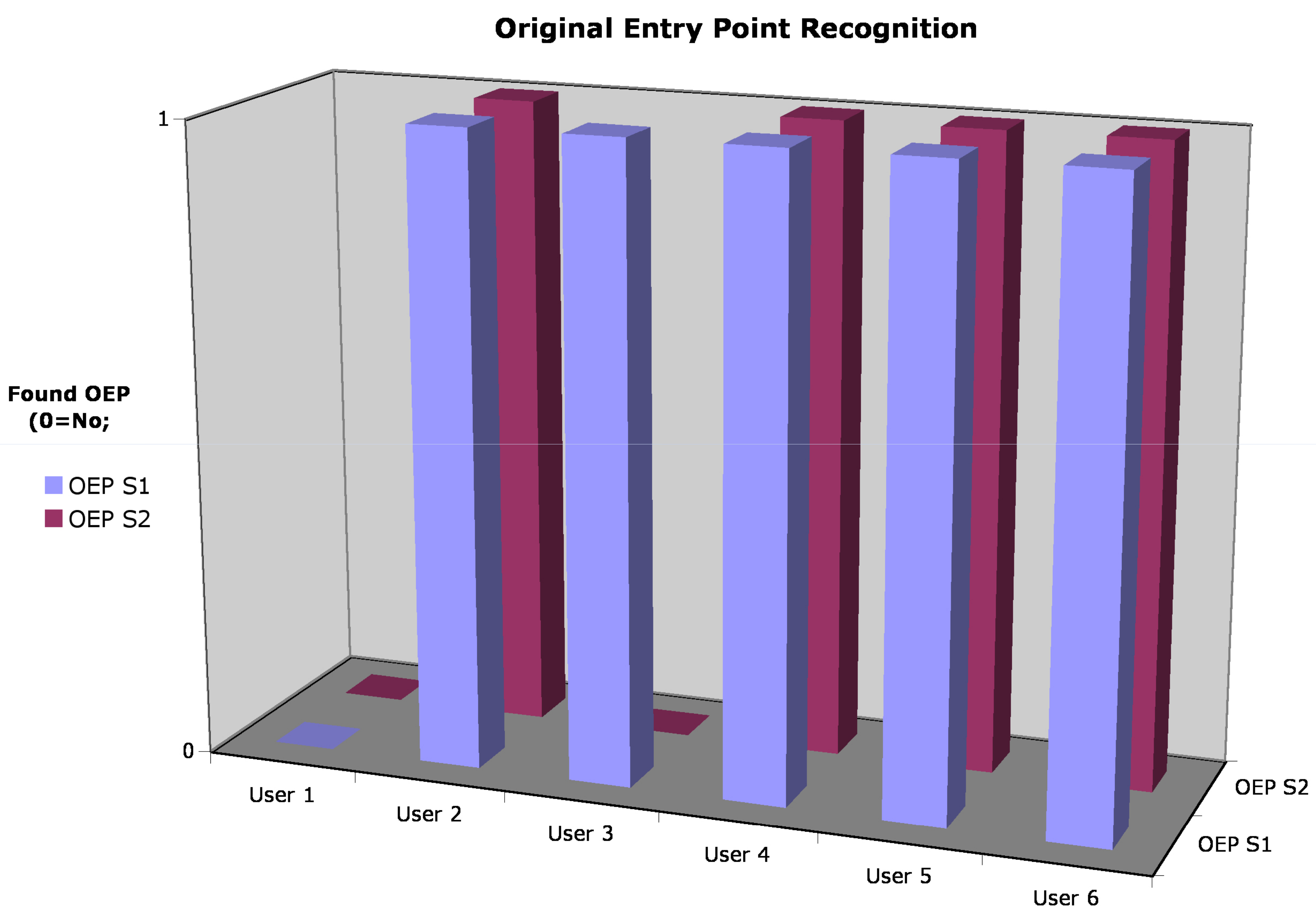
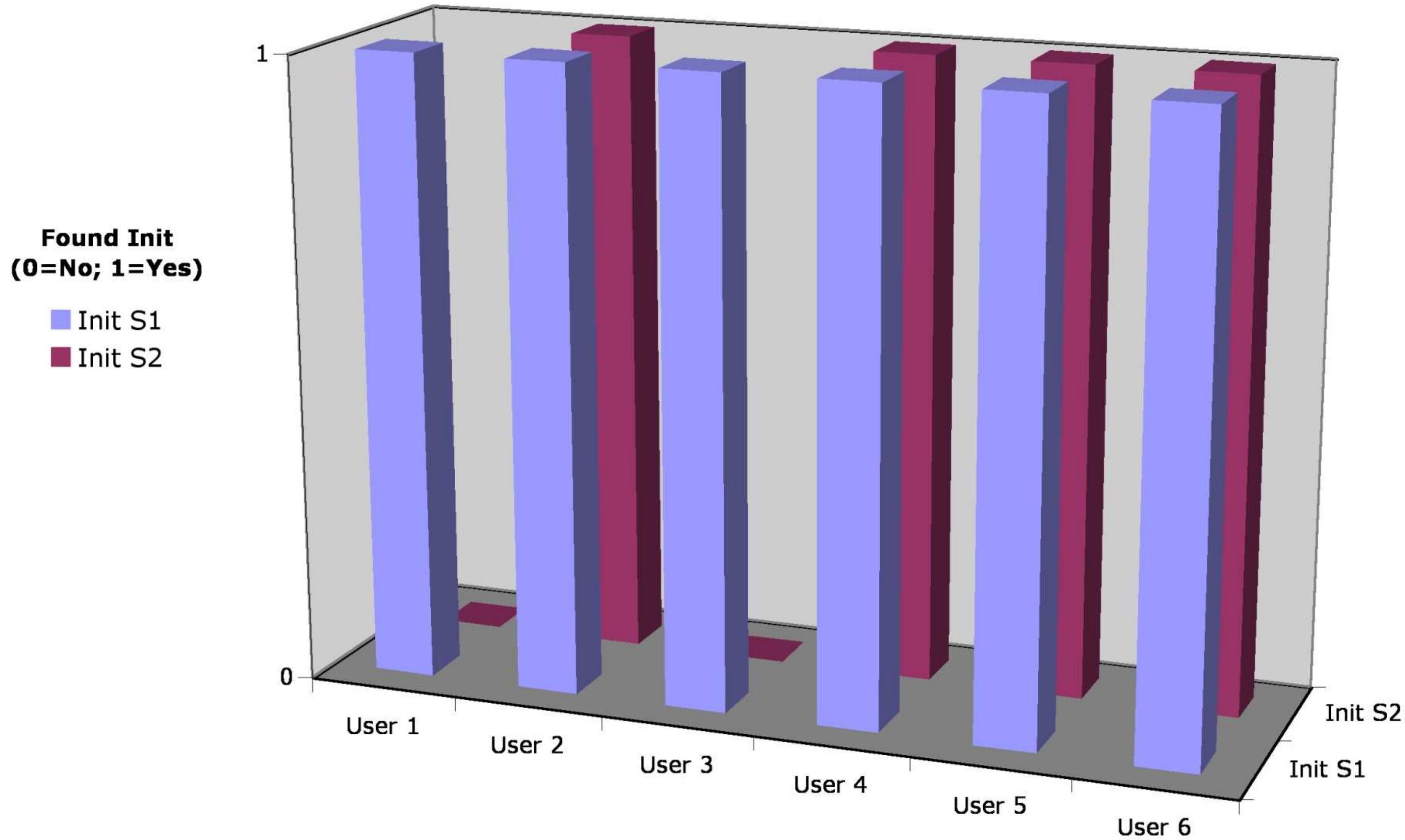
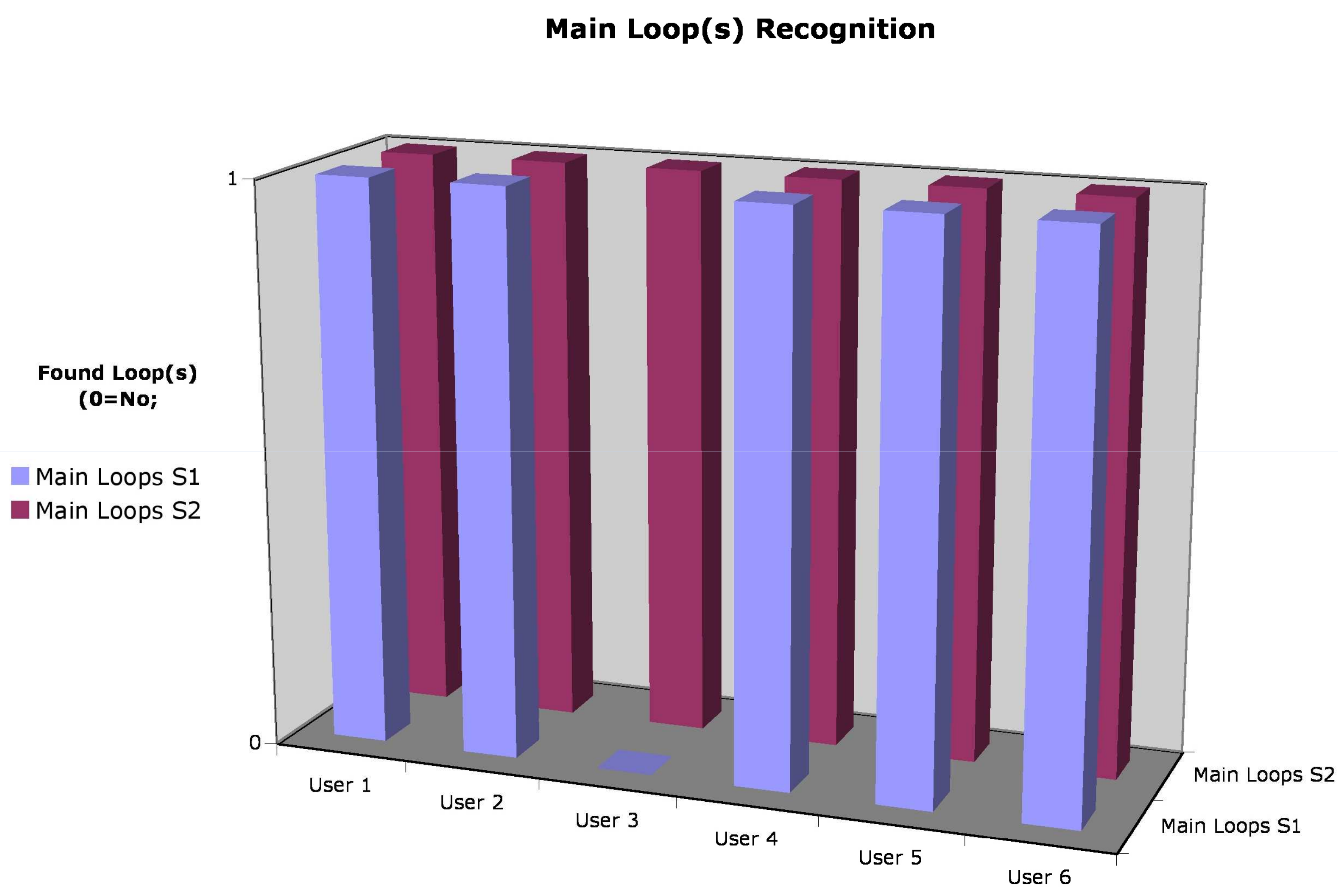
User Study: Tasks Performed

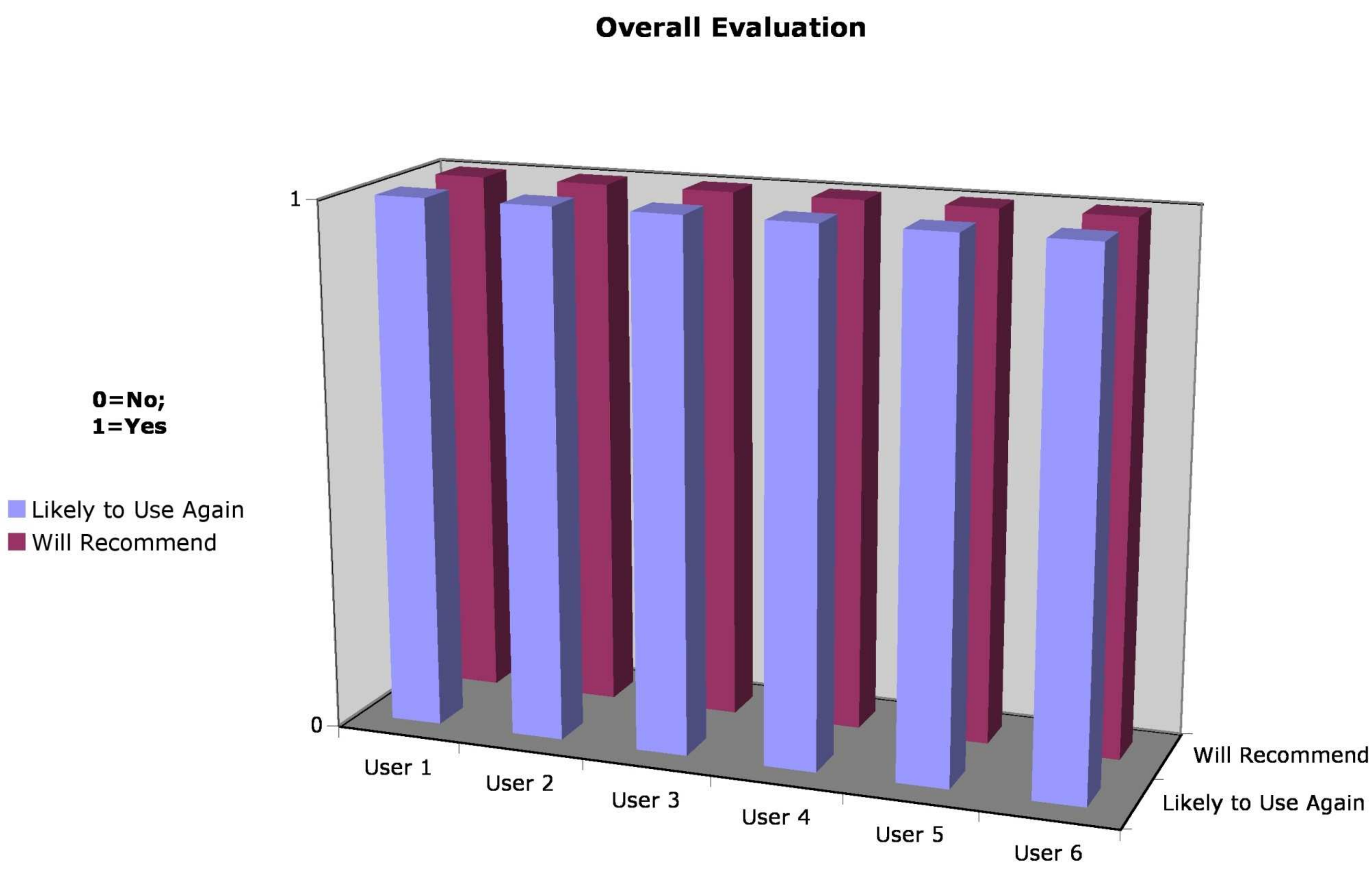
- Find the original entry point (OEP) of the packed samples
- Execute the program to look for any identifying output
- Identify portions of the executable:
  - Packer code
  - Initialization
  - Main loops


Original Entry Point Recognition
1
0
Found OEP
(0=No;
OEP S1
OEP S2
User 1
User 2
User 3
User 4
User 5
User 6
OEP S2
OEP S1

Initialization Recognition




Main Loop(s) Recognition
Found Loop(s)
(0=No;
Main Loops S1
Main Loops S2
1
0
User 1
User 2
User 3
User 4
User 5
User 6
Main Loops S2
Main Loops S1


Overall Evaluation
0=No;
1=Yes
Likely to Use Again
Will Recommend
1
0
User 1
User 2
User 3
User 4
User 5
User 6
Will Recommend
Likely to Use Again

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.”

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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

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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

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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
- If you use the tool, please give feedback
- Look for the paper at Vizsec 2009