HookFinder: Identifying and Understanding Malware Hooking Behaviors

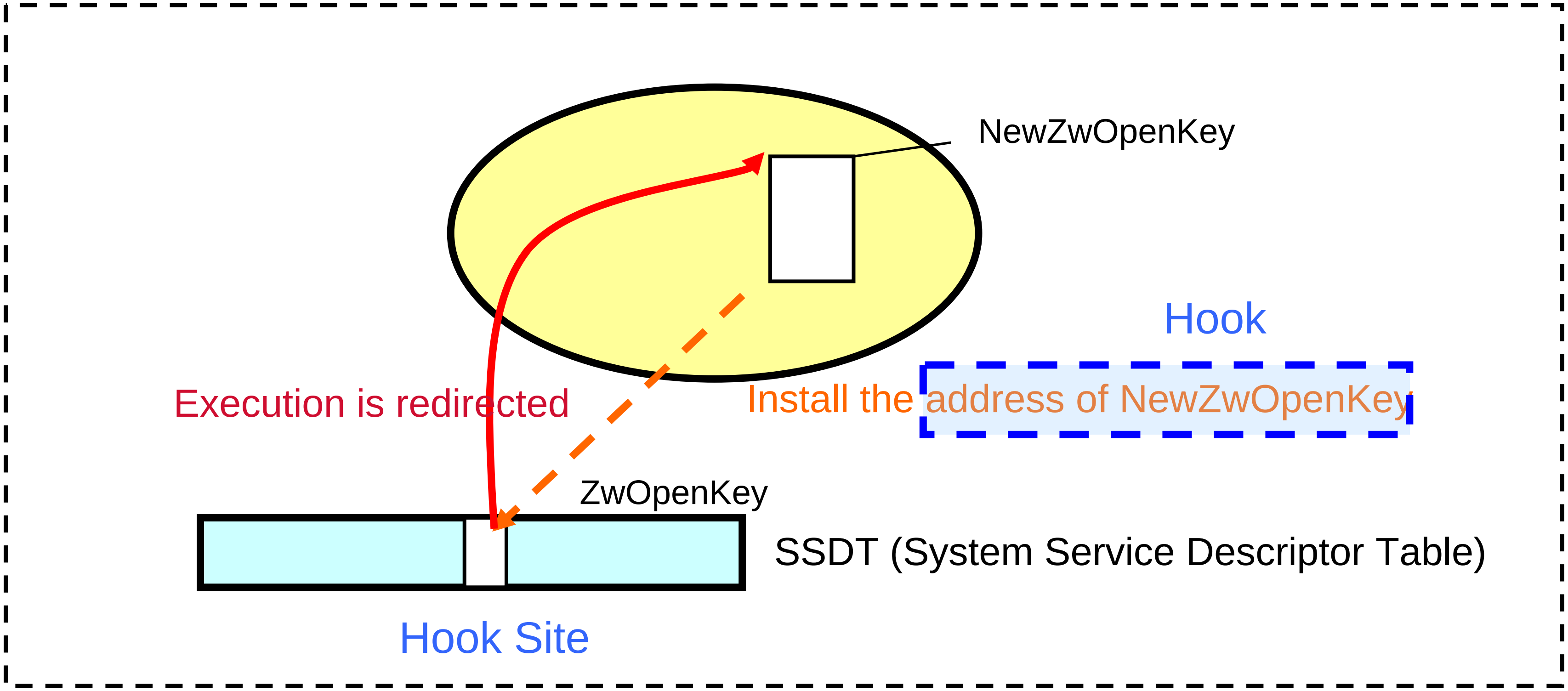
Heng Yin
Carnegie Mellon Univ
Coll Of William and Mary

Zhenkai Liang
Carnegie Mellon Univ

Dawn Song
UC Berkeley
Carnegie Mellon Univ

What is a hook?

- Malware registers its own function (i.e. hook) into the target location (i.e. hook site)
- Later, data in the hook site is loaded into EIP, and the execution is redirected into malware’s own function.



Sony Rootkit: an example of SSDT hooking

Why are hooks important?

- Malware needs to place hooks to achieve its malicious intents:
  - Rootkits want to intercept and tamper with critical system states
  - Network sniffers eavesdrop on incoming network traffic
  - Stealth backdoors intercept network stack to establish stealthy communication channels
  - Spyware, keyloggers and password thieves …

Current techniques are insufficient

- Some tools detect hooks by checking known memory regions for suspicious entries
  - E.g., VICE [Butler:2004], IceSword, System Virginity Verifier[Rukowska:2005]
  - Code sections, IAT/EAT, SSDT, IRP tables
  - **They become futile when malware uses new hooking mechanisms**

- Malware writers strive for new hooking mechanisms
  - E.g., Two kernel backdoors (Deepdoor and Uay) overwrite only a small portion in NDIS (i.e., Network Driver Interface Specification) data block
  - All existing tools cannot detect this kind of hooks

Our Approach

- We propose a system to **automatically** detect and analyze (**previously unknown**) hooks
  - Given an unknown malicious binary
  - Identify if it installs any hooks (with no prior knowledge)
  - Understand hooking mechanism
    - Provide detailed information about how it installs these hooks

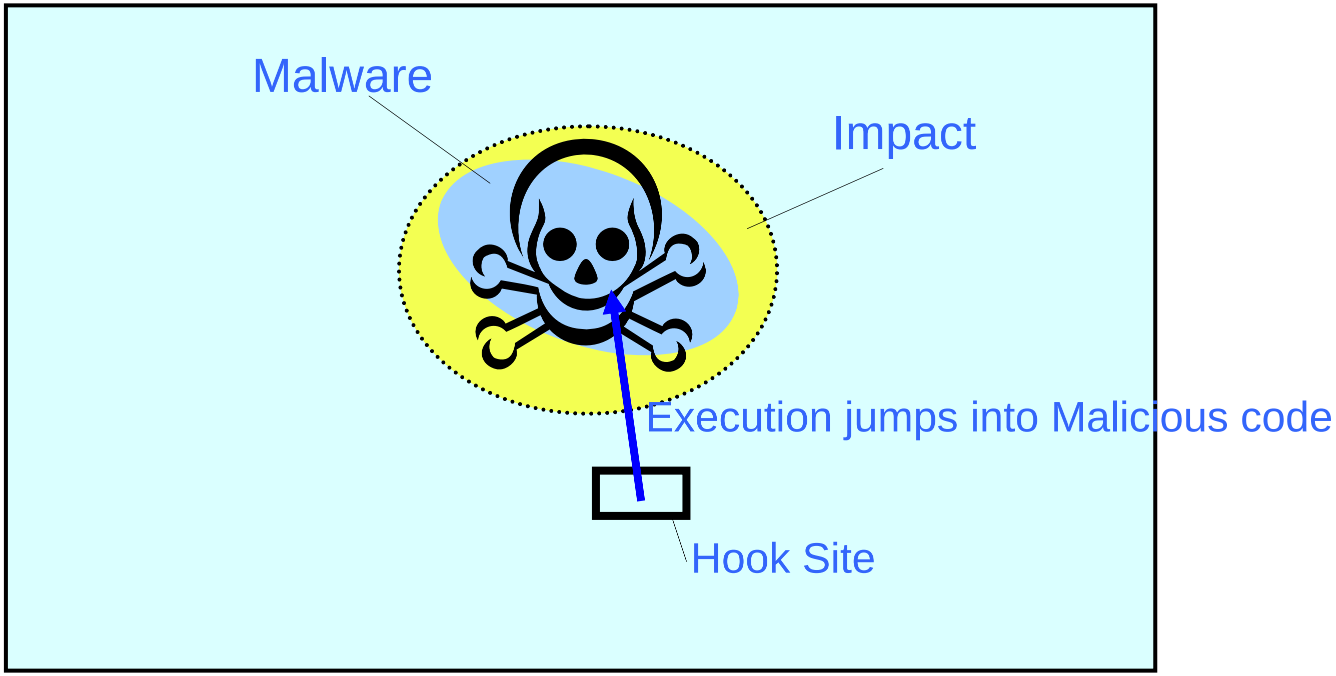
- When a sample employs a novel hooking mechanism, we can identify and understand it instantly
  - Update detection/prevention policy, to detect/prevent the similar hooks in the future

Outline

- Motivation
- Approach Overview
- HookFinder Design and Implementation
- Experimental Evaluation
- Summary

Intuition

- A hook is one of the **impacts** (*i.e., state changes*) to the system made by malware
- This impact redirects the execution into the malicious code.

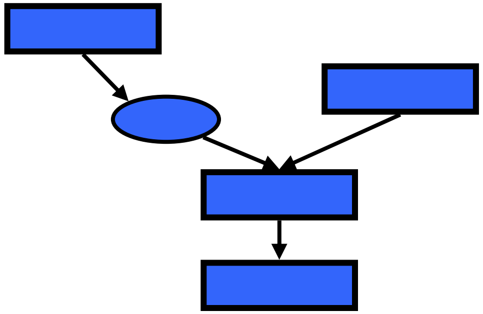


We can detect and analyze hooks by marking and tracking impacts.

Our Techniques

- Hook Detection: Fine-grained Impact Analysis
  - Mark initial impacts
  - Track impacts propagation (and generate Impact Trace)
  - Detect affected control flow

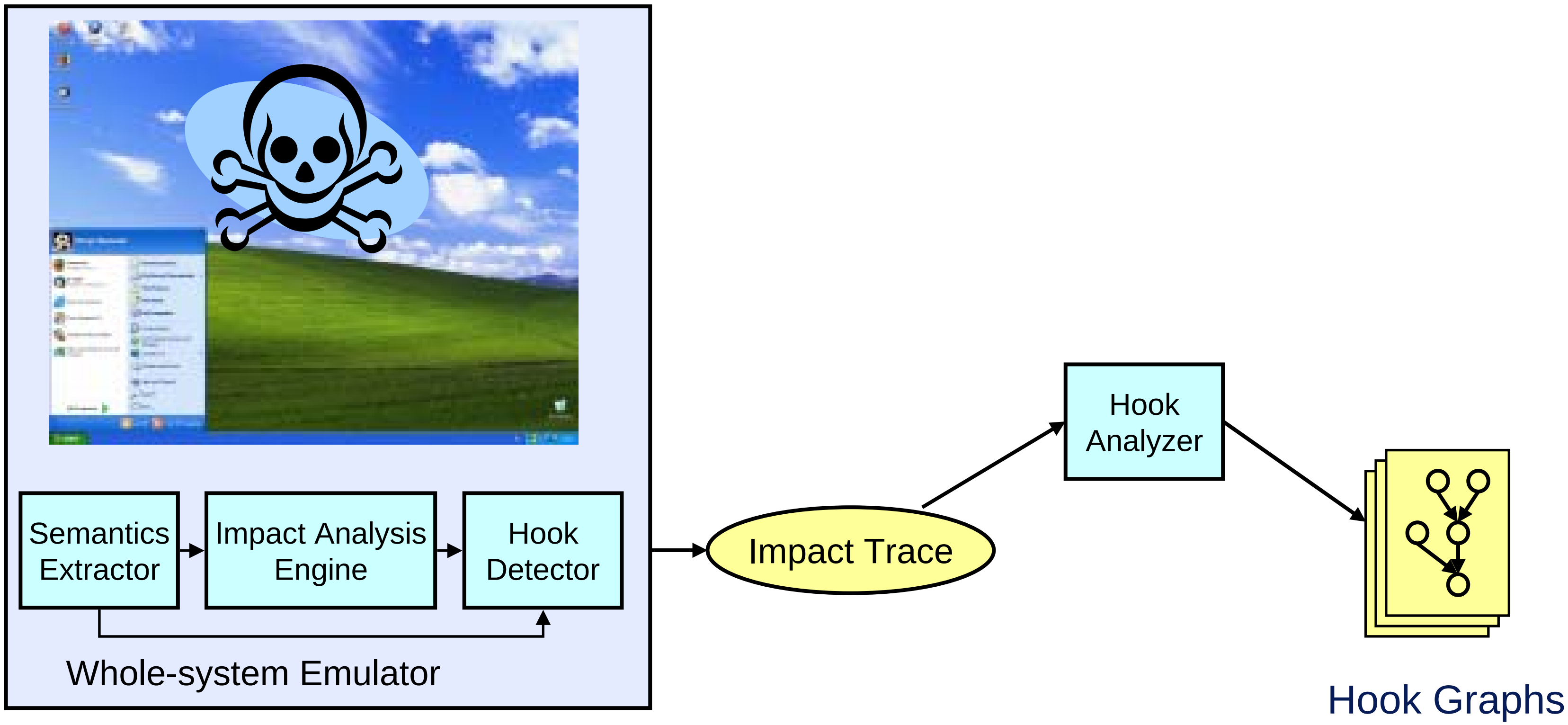
- Hook Analysis: Semantics-aware Impact Dependency Analysis
  - Backward data dependency analysis on Impact Trace
  - Combine OS-level semantics information
  - Generate a dependency graph: Hook Graph



Outline

- Motivation
- Approach Overview
- HookFinder Design and Implementation
- Evaluation
- Summary

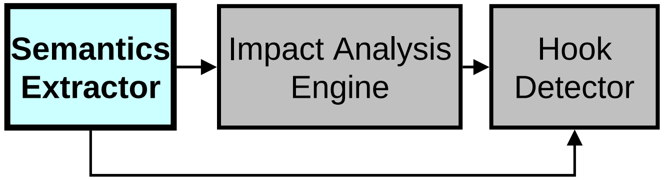
HookFinder – System Overview



We build HookFinder on top of TEMU, which is
a dynamic binary analysis component in the BitBlaze Project

Semantics Extractor

- Whole-system Emulator only provides a hardware-level view
  - E.g., states of memory, registers, and I/O devices
- We need an OS-level view
  - Which process/module/thread is running currently?
  - What is the function name, if malware calls an external function
  - What is the symbol name, if malware reads a symbol
- TEMU provides this functionality
  - See [Yin et al:2007] and this paper for more details

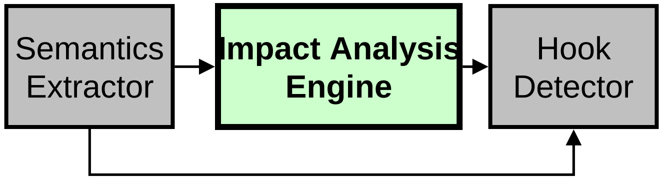


Impact Analysis Engine

- Mark Initial Impacts (memory and register writes)
  - In malware's module
  - In external function calls
  - In dynamically generated code

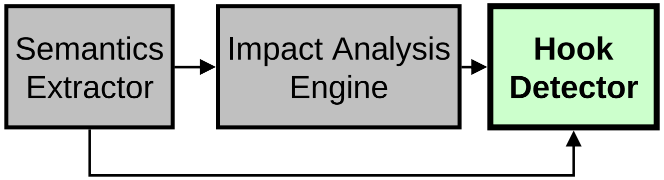
Challenge: identify dynamically generated code
Observation: dynamically generated code is part of impacts made by malware
Solution: check if the code region is marked

- Track impact propagation
  - Track data dependency (like in dynamic taint analysis)
    - » Check propagation through disks
  - Check immediate operands
    - » Because malware can manipulate immediate operands



Hook Detector

- Detect when a hook is used
  - Condition 1: Program counter (i.e, EIP in x86) is marked
  - Condition 2: The execution jumps into the malicious code



How HookFinder Detects Hooks in Sony Rootkit

Syntax: op src, dst

In Malicious Code

```
...
…
aries.sys+ee6:      mov ZwOpenKey, %edi
…
aries.sys+f56:      mov 1(%edi), %eax
aries.sys+f59:      mov KeServiceDescriptorTable, %ecx
aries.sys+f5f:      mov (%ecx), %ecx
aries.sys+f61:      movl aries.sys+66e, (%ecx, %eax, 4)
…
…
ntoskrnl.exe+8051: movl  (%edi, %eax, 4), %ebx
ntoskrnl.exe+8069: call  *%ebx
…
…
```

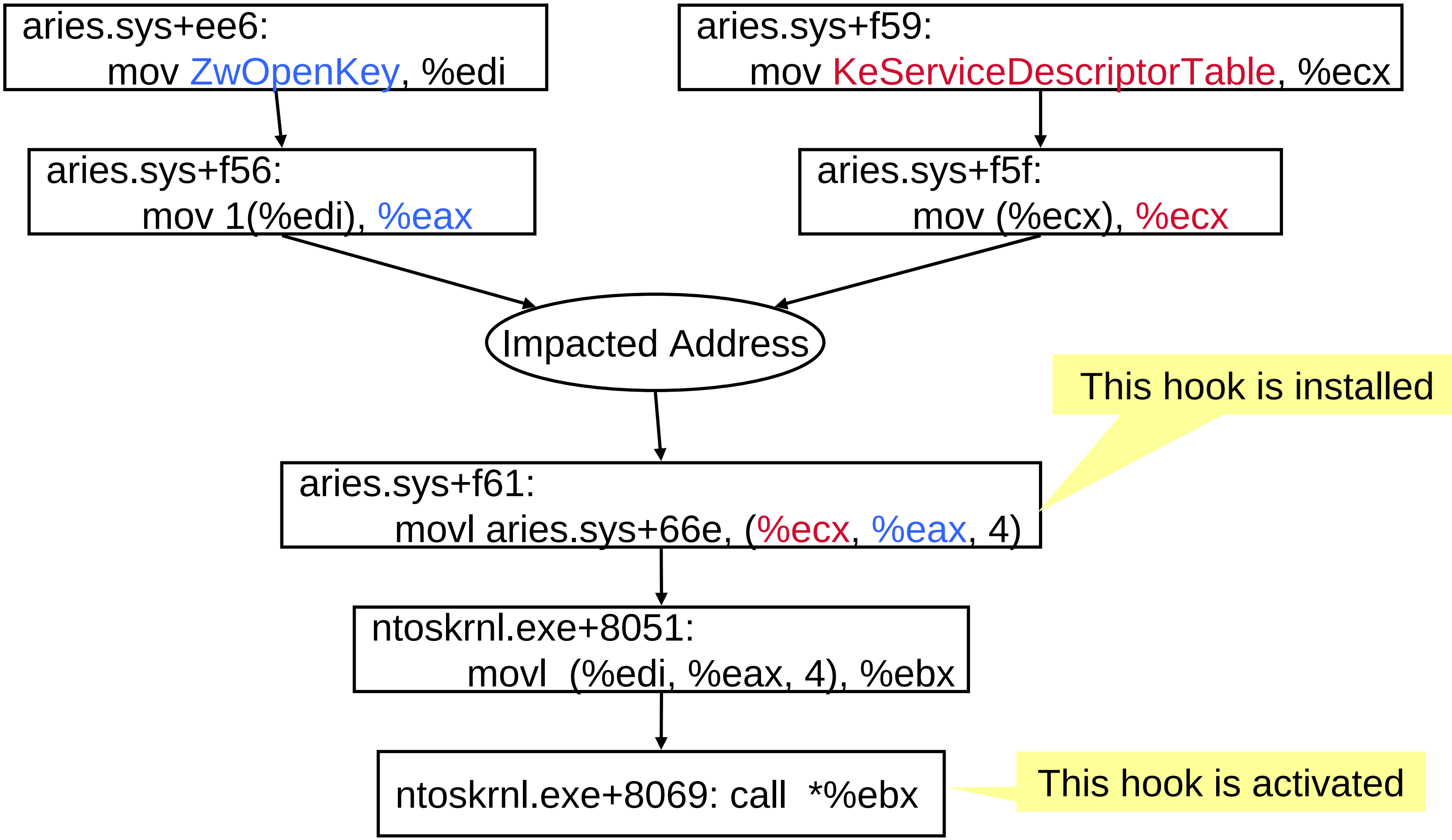
A hook is detected:

1) EIP is marked
2) The execution is redirected into aries.sys

Hook Analyzer

- Generate hardware-level hook graph
  - Perform backward dependency analysis on the impact trace
- Transform into OS-level graph
  - Combine OS-level semantic information
- Simplify hook graph
  - If two adjacent nodes belong to the same external function call, merge them into one node
  - If two adjacent nodes are direct copy instructions (e.g., mov, push, pop), merge them into one node

Hook Graph for Sony Rootkit



Outline

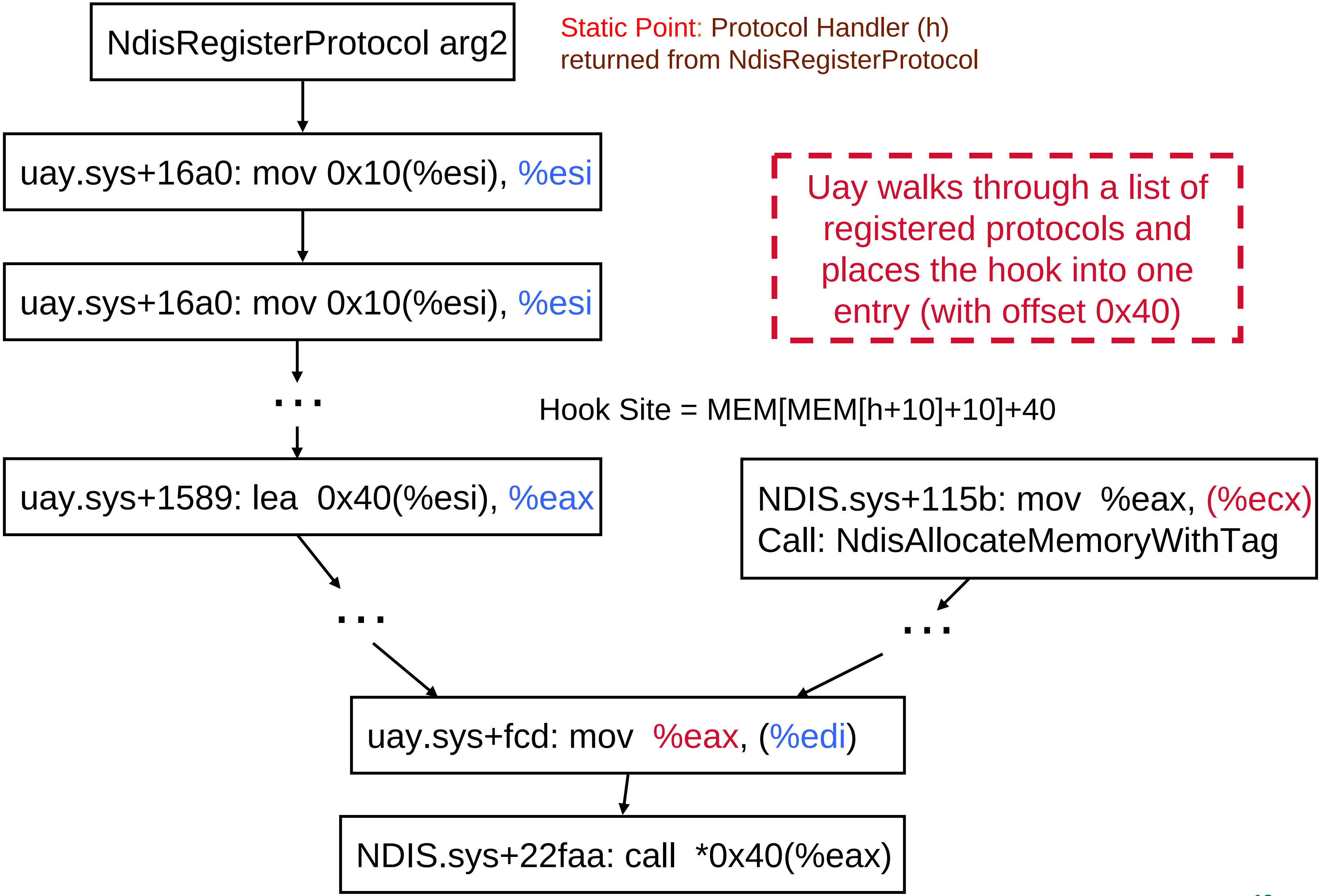
- Motivation
- Approach Overview
- HookFinder Design and Implementation
- Evaluation
- Summary

Summarized Results

Sample	Category	Runtime		Impact Trace	Hooks	
		Online	Offline		Total	Malicious
Troj/Keylogg-LF	Keylogger	6min	9min	3.7G	2	1
Troj/Thief	Password Thief	4min	<1min	143M	1	1
AFXRootkit	Rootkit	6min	33min	14G	4	3
CFSD	Rootkit	4min	2min	2.8G	5	4
Sony Rootkit	Rootkit	4min	<1min	25M	4	4
Vanquish	Rootkit	6min	12min	4.4G	11	11
Hacker Defender	Rootkit	5min	27min	7.4G	4	1
Uay Backdoor	Backdoor	4min	<1min	117M	5	2

Legitimate hooks: PsCreateSystemThread, CreateThread, CreateRemoteThread, StartServiceDispatcher

Detailed Analysis of Uay



Related Work

- Hook Detection
  - VICE [Butler:2004], IceSword, System Virginity Verifier[Rukowska:2005]
- Dynamic Taint Analysis
  - Detect exploits [Costa:sosp05] [Crandall et al:2004] [Newsome et al:2005], [Portokalidis et al:2006], [Suh et al:2004]
  - Data lifetime analysis [Chow et al:2004]
  - Dynamic spyware analysis [Egele et al:2007]
  - Detect and analyze privacy-breaching malware [Yin et al:2007]
  - Extract protocol format [Caballero et al:2007]
  - Prevent cross-site scripting [Vogt et al:2007]

Summary

- We proposed fine-grained impact analysis
  - Characterize malware's impacts on the system environment
  - Observe if one of the impacts is used to redirect the execution into the malicious code
  - Capture **intrinsic characteristics** of hooking behavior, and thus it can identify novel hooks
- We devised semantics-aware impact dependency analysis
  - Extract hooking mechanism in form of hook graphs
- We developed HookFinder
- We analyzed 8 representative malware samples
  - HookFinder is able to identify and analyze new hooks in Uay

Thanks!

For more information and related projects, please visit our **BitBlaze** website at http://bitblaze.cs.berkeley.edu

Discussion 1

- Exploit control dependency

```
switch(a) {
    case 1: b=1; break; case 2: b=3; break; …}
```

  – Not feasible, since we track all initial impacts

Discussion 2

- Not exhibit hooking behavior when tested
  - Bypass redpill test by feeding in fake inputs
  - Slow down the frequency of PIT to disguise the performance slowdown
  - Explore multiple execution paths [Moser:2007, Brumley:2007]

Discussion 3

- “Return-into-libc” attacks: register an address of a system function
  - Hard to find a candidate function
  - Hard to prepare compatible call stack
  - Will consider it in the future work

Key Factors in Hooking Mechanism

- Hook Type
  - Data Hook: interpreted as data (e.g., jump target)
  - Code Hook: interpreted as code (e.g., jump instruction)
- Implanting methods
  - Direct write
    - What is the static point?
      - Global symbol, or result of a function call
    - How to infer the hook site?
  - Call an external function
    - Which function is called?
      - E.g., SetWindowsHookEx, memcpy, WriteProcessMemory
    - What is the argument list?