LO-PHI

Low-Observable Physical Host Instrumentation for Malware Analysis

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Outline

- **Overview of LO-PHI**
- **Instrumentation**
- **Semantic Gap Reconstruction**
- **Automated Binary Analysis**
- **Evaluation (Windows Malware)**
- **Summary**
- **Demo** (Time Permitting)

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The Problem

- **Binary dynamic analysis is becoming increasingly difficult in security-critical scenarios**
  - **Environment-aware malware** can detect various ***artifacts*** exposed by most existing dynamic analysis frameworks and leverage them to avoid detection, or subvert the analysis all together
  - **The observer effect**, i.e. the effects of the measurement itself, can interfere with the analysis, making the results untrustworthy
    - E.g., software-based instrumentation may result in a different memory layout

The Problem

- ***Introspection*** techniques offer solutions that have fewer artifacts, but must also bridge the ***semantic gap***
  - i.e., translate low-level data to semantically rich output for analysis

Introspection Options

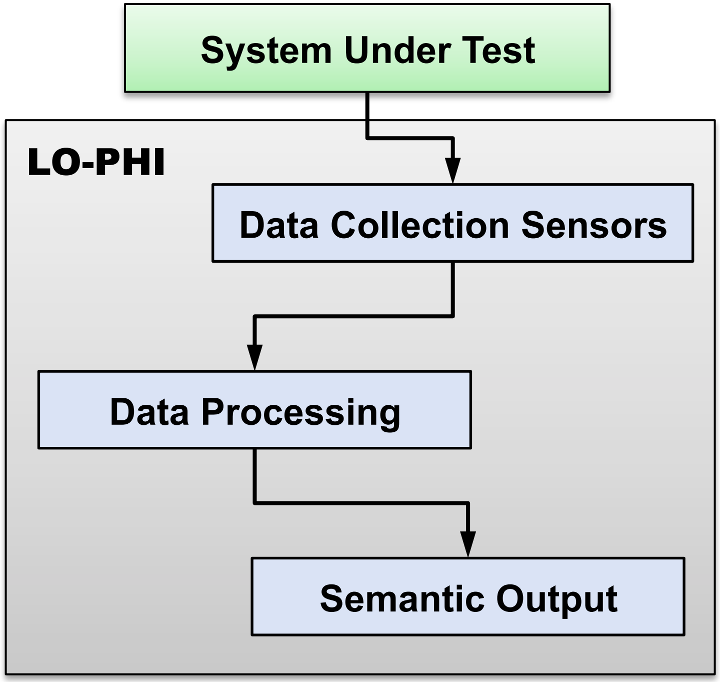
- Software
  - Pros: cheap, easy to implement
  - Cons: OS dependent, can affect analysis, easily subverted

- Virtual machines
  - Pros: development in software, scalable
  - Cons: easily detectable artifacts (E.g. *Redpill*)

- Hardware
  - Pros: potentially very few artifacts, better ground truth
  - Cons: difficult to implement, expensive

Goals

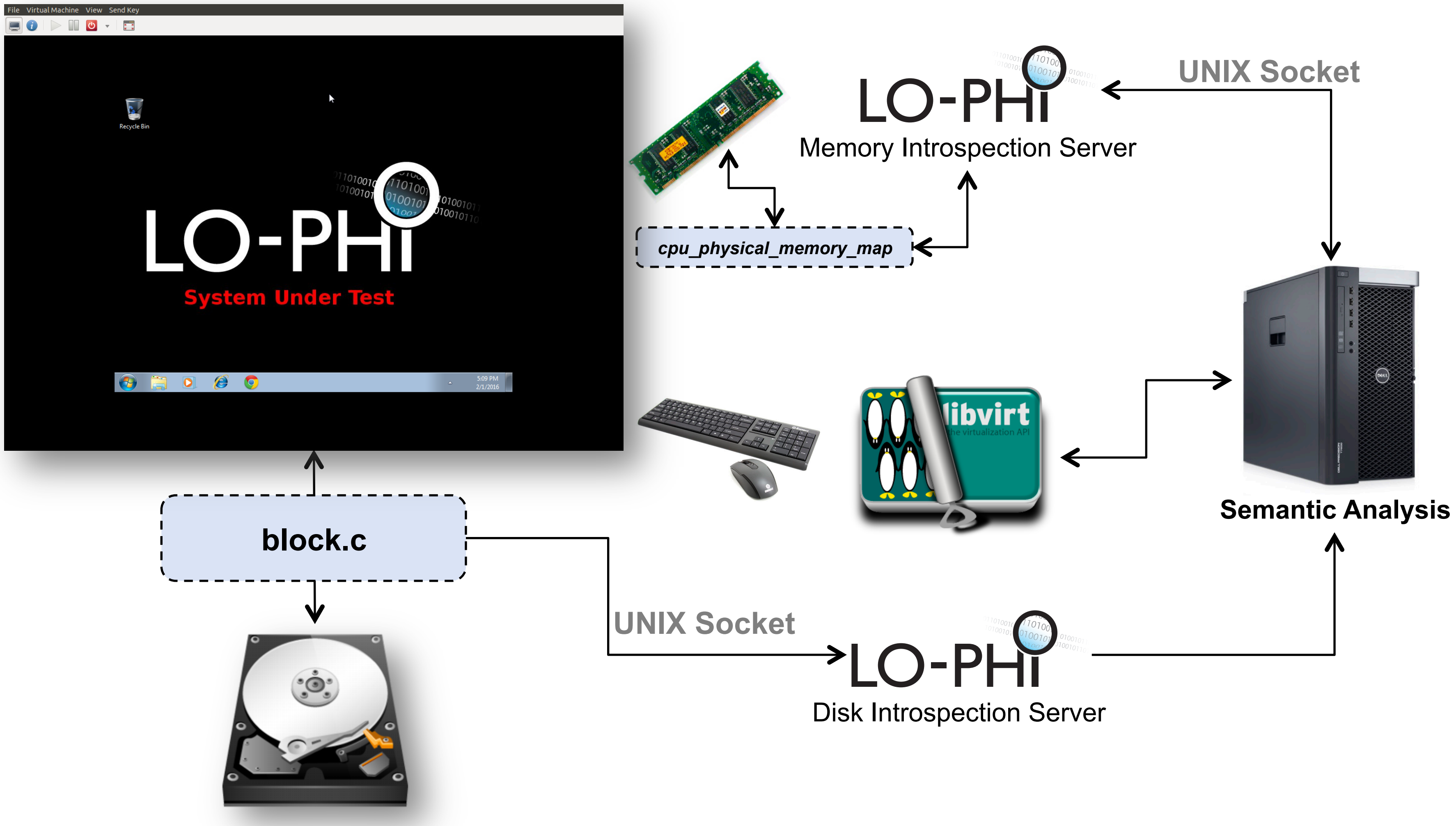
- **Primary goal**
  - ***Low-Observable Physical Host Instrumentation (LO-PHI)*** aims to obtain ground truth information about a system under test (SUT) while introducing as few artifacts as possible



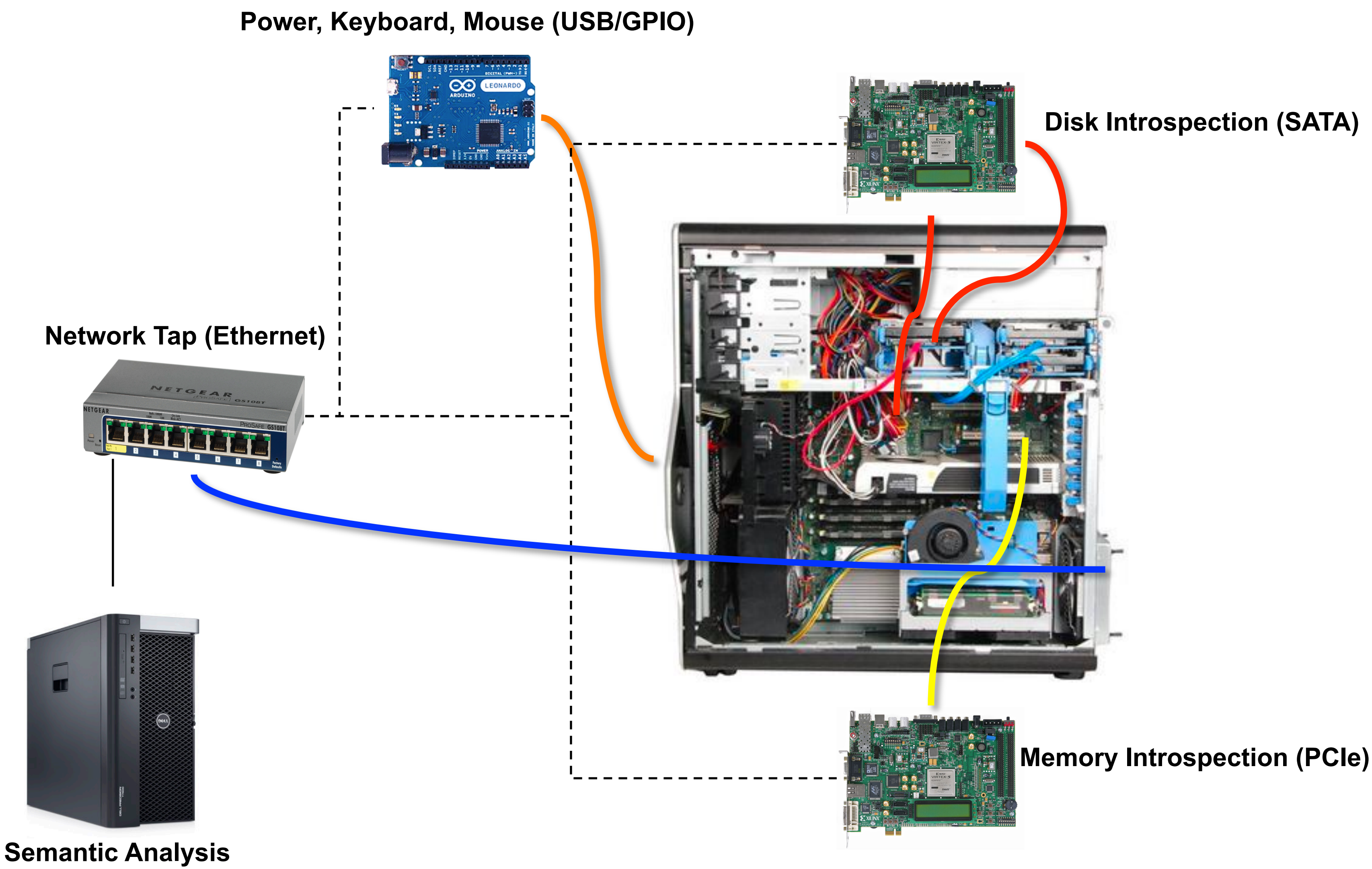
Overview

- **Zero software-based artifacts**
- **Simple Python APIs to interact with a system under test**
  - Same code for either physical or virtual machines
- **A suite of both sensors and actuators**
- **A suite of semantic-gap reconstruction tools**
- **Python-based framework for automated binary analysis**
  - Analysis “scripts” can be submitted and executed on automatically provisioned machines

Virtual Instrumentation

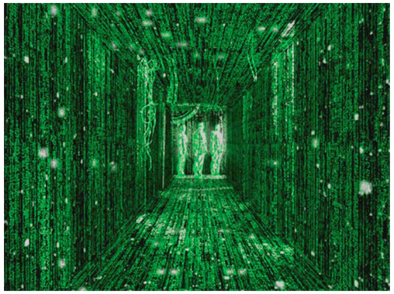


Physical Instrumentation



Semantic Gap

- **Fictional Hollywood example: *The Matrix***



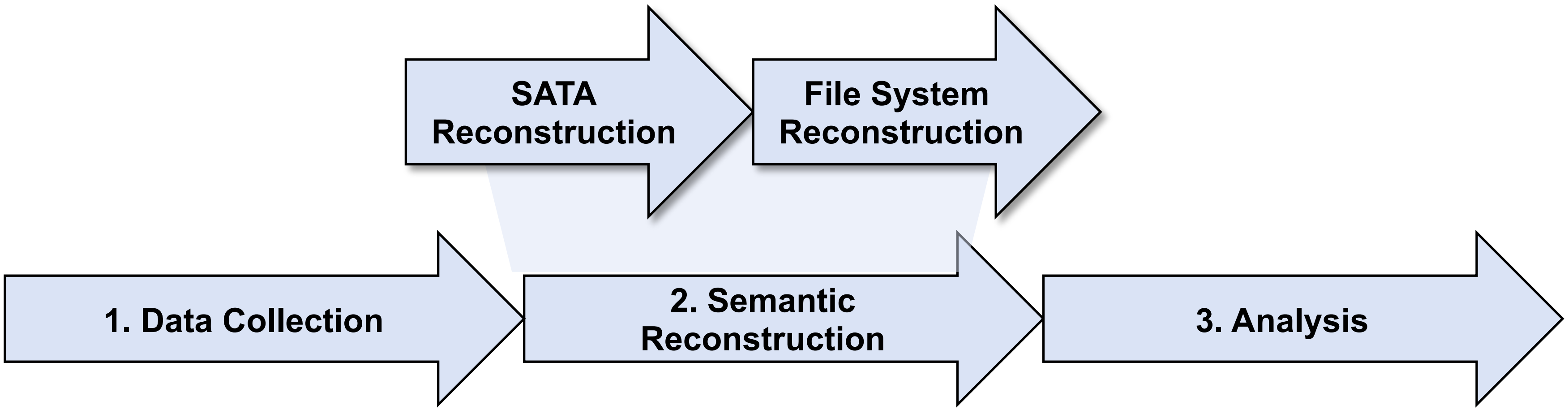
1. Input Raw Data **2. Parse Data Structures** **3. Extract Features**

- **Memory** (Volatility)
  - Reader raw memory to extract attributes of the system
    - E.g., running processes, kernel modules, descriptor tables
- **Hard Disk** (Sleuthkit)
  - Translate low-level disk activity into file system activities
    - E.g., file creation, deletion, read, write

Stream-based Disk Forensics

Bare Metal

- **Multiple layers of abstraction that we must bridge**
  - ✓ Analog Signal → Digital bits
  - ✓ Digital bits → SATA Frames
    } **Xilinx ML507 FPGA**
  - ✓ SATA Frames → Sector manipulation — **SATA Reconstruction**
  - ✓ Sector manipulation → File System Manipulation — **Sleuthkit (TSK) analyzeMFT**



SATA Reconstruction

A Brief Primer on SATA

- **Serial ATA – bus interface that replaces older IDE/ATA standards**
- **SATA uses frames (FIS) to communicate between host and device**

HIGH SPEED SERIALIZED AT ATTACHMENT
Serial ATA International Organization

Type field value	Description
27h	Register FIS – Host to Device
34h	Register FIS – Device to Host
39h	DMA Activate FIS – Device to Host
41h	DMA Setup FIS – Bi-directional
46h	Data FIS – Bi-directional
58h	BIST Activate FIS – Bi-directional
5Fh	PIO Setup FIS – Device to Host
A1h	Set Device Bits FIS – Device to Host
A6h	Reserved for future Serial ATA definition
B8h	Reserved for future Serial ATA definition
BFh	Reserved for future Serial ATA definition
C7h	Vendor specific
D4h	Vendor specific
D9h	Reserved for future Serial ATA definition

10.3.4 Register - Host to Device

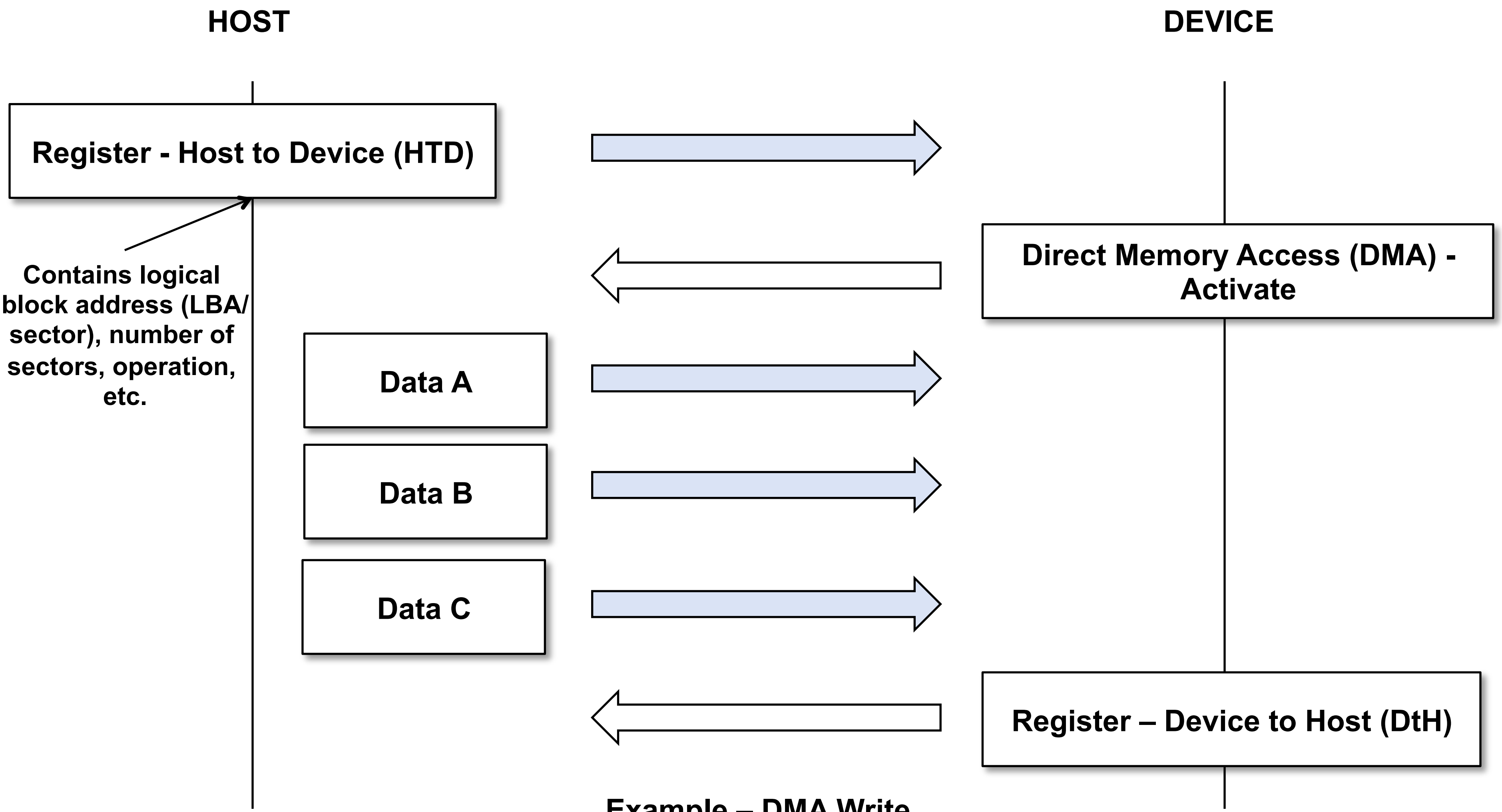
0	Features(7:0)	Command	C R R R PM Port	FIS Type (27h)
1	Device	LBA(23:16)	LBA(15:8)	LBA(7:0)
2	Features(15:8)	LBA(47:40)	LBA(39:32)	LBA(31:24)
3	Control	ICC 7 6 5 4 3 2 1 0	Count(15:8)	Count(7:0)
4	Reserved (0)	Reserved (0)	Reserved (0)	Reserved (0)

Figure 194 – Register - Host to Device FIS layout

FIS – Frame Information Structure

SATA Reconstruction

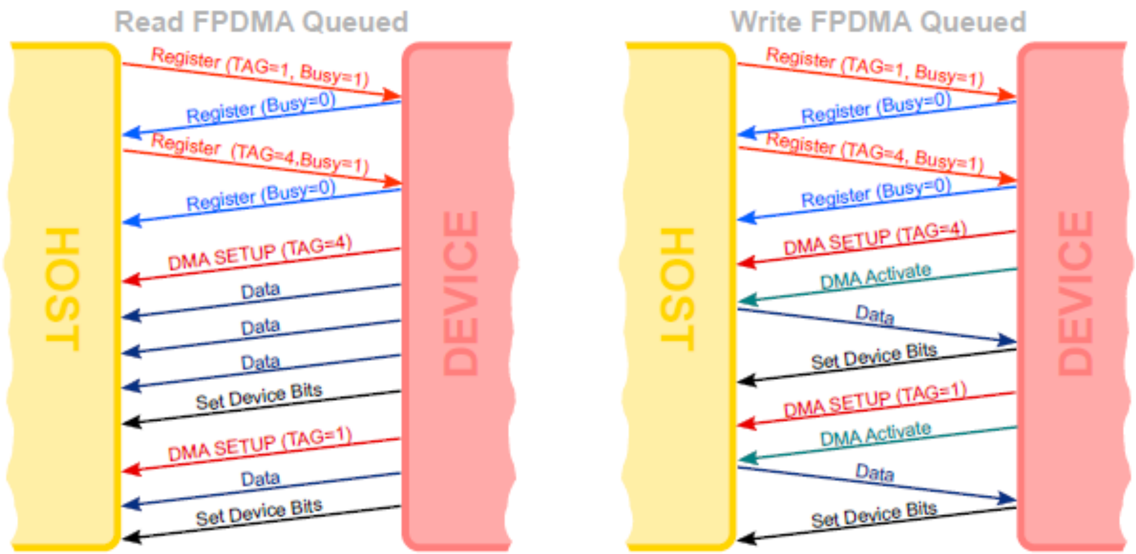
A Brief Primer on SATA



Example – DMA Write

SATA Reconstruction

Native Command Queuing



- **Native Command Queuing (NCQ) complicates reconstruction**
- **NCQ allows for up to 32 separate, concurrent, asynchronous disk transactions**
  - Many SATA devices implement NCQ
- **NCQ identifies transactions by 5-bit TAG field (0-31)**

SATA Reconstruction

- **Wrote a Python module to handle all of these transactions**
  - Consumes raw SATA frames
  - Supports all of the existing SATA versions
  - Outputs stream of logical sector operations

- **Traditional SATA analyzers are expensive and don't provide analysis-friendly interfaces**

Lecroy Catalyst Stx230 2 Port **Sata** Serial Bus Protocol **Analyzer** W/
$1,550.00 used from eBay
Lecroy Catalyst STX230 2 Port **SATA** Serial Bus Protocol **Analyzer** Includes:• Carrying Case • USB

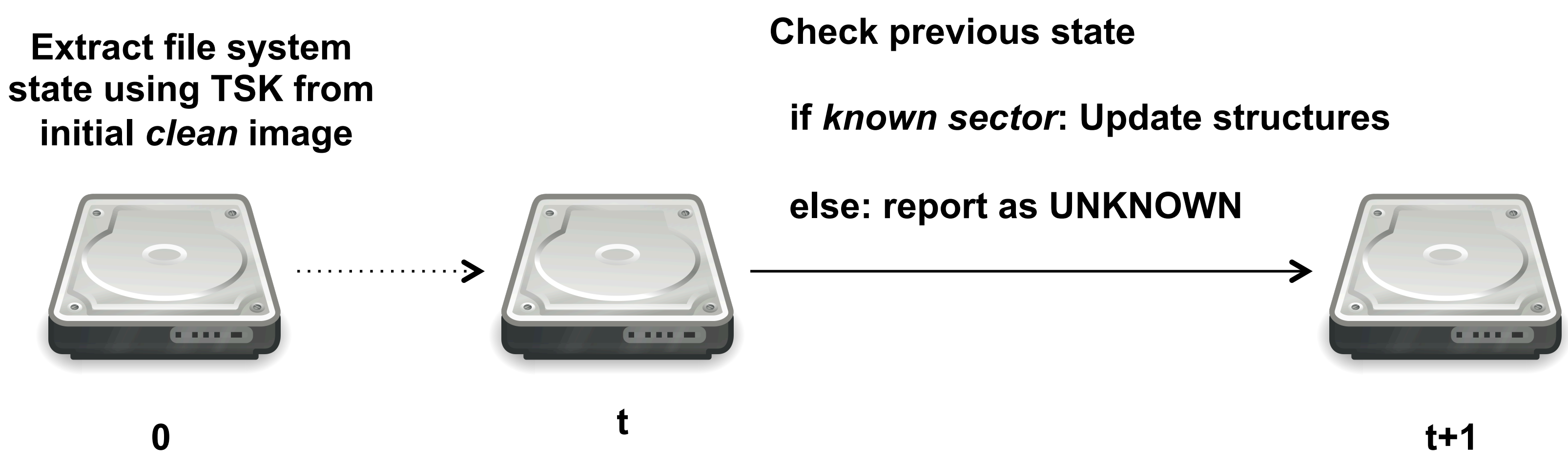
Finisar Xgig-C004 XGIG-C041 w/ 2X Xgig-B830Sa 8-Port SAS/**SATA** ...
$3,995.00 used from 2 stores

Lecroy St2-31-2a **Sata** 1.5g/3g Bus
$4,000.00 refurbished from eBay
LeCroy ST2-31-2A **SATA** 1.5G/3G Bus **Analyzer** Buffer Size:1GB,1port:(Host/Device),Real Time Ev
STTAP2 ...

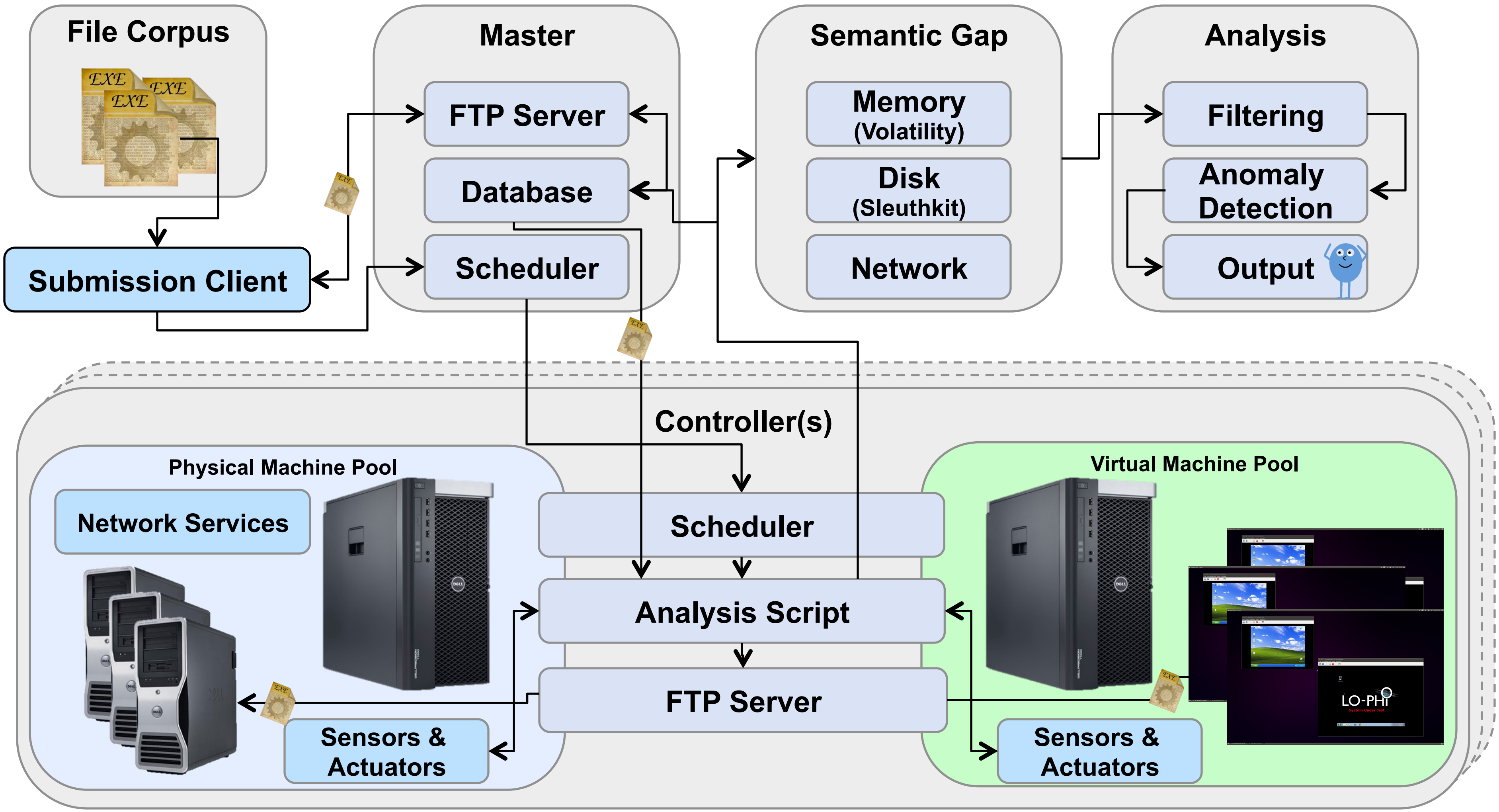
File System Reconstruction

- **Current Solution**
  - Uses PyTSK to keep a unified codebase in Python
  - Naïve approach requires analyzing the *entire* image at every interval

- **Optimization:** Uses AnalyzeMFT for NTFS optimization



Automated Binary Analysis



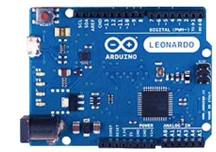
Automated Binary Analysis

Physical Machines

- **Machine/hard disk reset**

1. Power down machine

2. Re-image disk with selected OS (CloneZilla)



Controller

DHCP/PXE

TFTP

DNS

LO-PHI Network Services

System Under Test

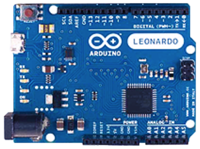
Automated Binary Analysis

Physical Machines

- **Download binary onto SUT**

3. Wait for OS to appear on the network (ping)

4. Download binary from controller using ftp (key presses)



DHCP/PXE

FTP

Controller

LO-PHI Network Services

System Under Test

Automated Binary Analysis

Physical Machines

- **Execute binary**

5. Dump clean state of memory

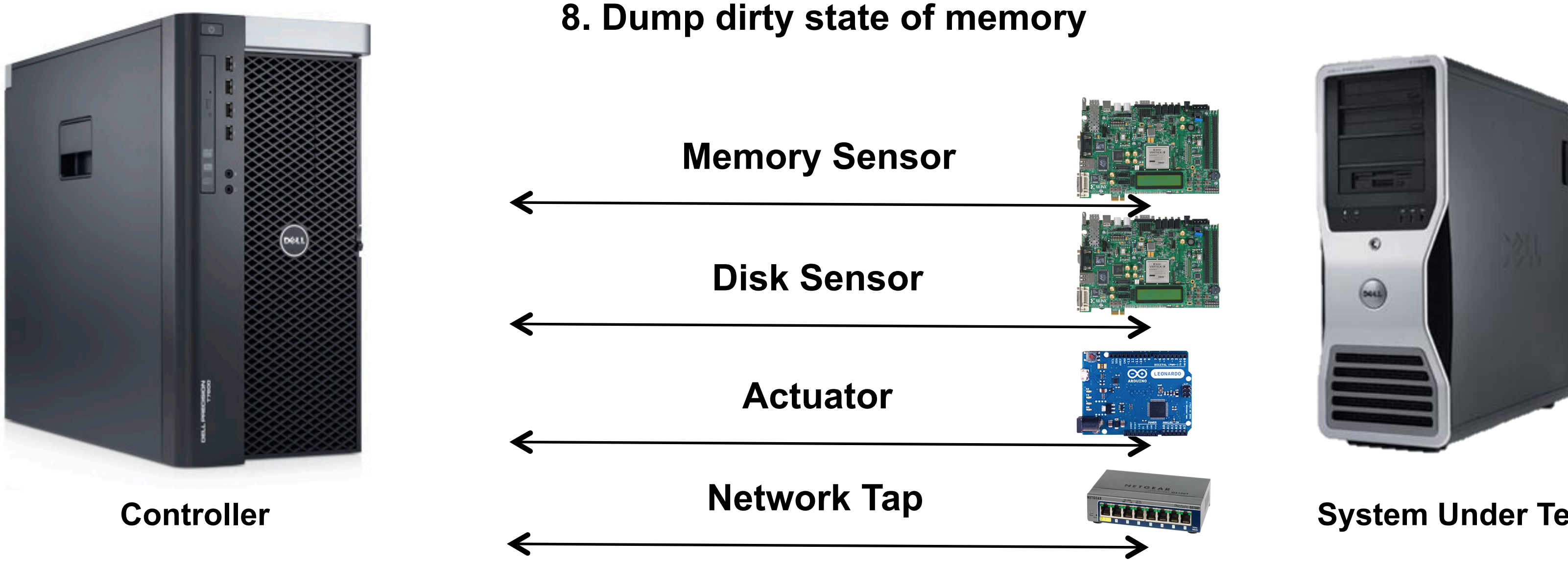
6. Start capturing network and disk activity

7. Run Binary (Start moving mouse)

8. Dump interim state of memory

7. Identify and click all buttons (Volatility)

8. Dump dirty state of memory



Evaluation: Semantic Output

(on WinXPSP3)

LO-PHI

- **Homemade Rootkit**
  - **Comparison:** Anubis failed to execute the binary, and Cuckoo sandbox failed to detect/execute our ftp server
- **Labeled Malware** *(213 well-labeled samples)*
  - Blind analysis identified various behaviors, all of which were confirmed by ground truth
- **Unlabeled Malware** *(1091 samples)*
  - Similar findings

Observed Behavior	Number of Samples
Created new process(es)	765
Opened socket(s)	210
Started service(s)	300
Loaded kernel modules	20
Modified GDT	58
Modified IDT	10

Evaluation: Evasive Malware

(on Windows 7)

- **Paranoid Fish** *(Evasive malware proof-of-concept)*
  - Failed to detect LO-PHI
  - **Comparison:** Anubis and Cuckoo sandbox were both detected due to virtualization artifacts

- **Labeled Malware** (429 coarsely-labeled samples)
  - LO-PHI detected *suspicious activity* in almost every sample
    - Some appeared to be targeting a different OS version

Technique Employed	# Samples
Wait for keyboard	3
Bios-based	6
Hardware id-based	28
Processor feature-based	62
Exception-based	79
Timing-based	251

Malware Label	Volatility Module: envars	netscan	ldrmodules	psxview	buttons
Keyboard	0	3	1	0	1
Bios	3	6	6	6	0
Hardware	28	27	28	26	11
Processor	53	54	59	51	7
Exception	76	79	77	76	7
Timing	229	247	231	239	4

Summary

- **Deployed and tested LO-PHI an extremely low-artifact, hardware and VM-based, dynamic-analysis environment**
- **Developed hardware, and supporting tools, for stream-based disk forensics on SATA-based physical machines[1]**
- **Constructed a framework, and accompanying infrastructure, for automating analysis of binaries on both physical and virtual machines**
  - Open Source (BSD License): http://github.com/mit-ll/LO-PHI
- **Demonstrated the scalability and fidelity of LO-PHI by analyzing thousands of labeled and unlabeled malware samples**

[1]http://www.osdfcon.org/presentations/2014/Hu-Spensky-OSDFCon2014.pdf

Demo

Demonstration of VM-based binary analysis.