# Binary analysis: Malware Detection & Analysis

Yue Duan

# Outline

- Malware basics
- Research papers:
  - Semantics-Aware Malware Detection
  - Panorama: Capturing System-wide Information Flow for Malware Detection and Analysis
  - BareCloud: Bare-metal Analysis-based Evasive Malware Detection

# Malware Detection Basics

- Malware
    - software intentionally designed to cause damage
- Malware Detection techniques
    - Static analysis
    - Dynamic analysis

# Malware Detection Basics

- Static analysis
  - testing and evaluation of an application by examining the code without executing the application
  - Pros:
    - Good code coverage
    - Time efficiency
  - Cons:
    - False positives
    - code obfuscation
    - Encryption

# Malware Detection Basics

- Dynamic analysis
  - testing and evaluation of an application during runtime
  - Pros:
    - Capture behaviors accurately
  - Cons:
    - Poor code coverage
    - High runtime overhead

# Semantics-Aware Malware Detection

Mihai Christodorescu, Somesh Jha, Sanjit A. Seshia, Dawn Song, Randal E. Bryant

IEEE S&P 2005

# Semantics-Aware Malware Detection

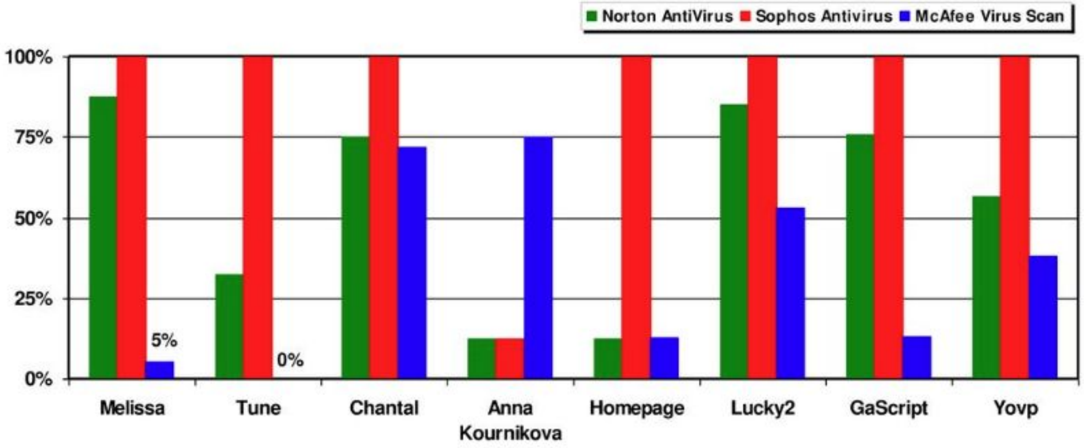
- State-of-the-art techniques - pattern matching
  - susceptible to obfuscations
  - purely syntactic
  - ignore the semantics of instructions

- Attacker's goal - preserve behaviors
  - Transformation of code and data
  - Addition of new code and data

# Semantics-Aware Malware Detection

## No Resilience to Obfuscations

*False Negative Rate for Obfuscated Worms*




*Source: "Testing Malware Detectors" (ISSTA 2004)*

# Semantics-Aware Malware Detection

- Major contributions
  - Introduce semantic signatures
    - Combine syntactic and semantic information
  - Develop a prototype based on the signatures
  - Empirical study shows that one semantic signature can detection a malware family

# Semantics-Aware Malware Detection

- Example: detect mass-mailing virus
  - Detect email capability
  - Detect self-propagation

```
s = socket (...);
connect (s);

…

sprintf (buf, “EHLO %S”, dnsname);
send (s, buf);
```

Possible syntactic signature:

```
socket()
connect()

“EHLO”
send()
```

# Semantics-Aware Malware Detection

- Variant 1: string manipulation
  - Hide known constants
  - Syntactic signature does not match

```
s = socket (...);
connect (s);

…
char str [80];
strcpy (str, “EH”);
strcat (str, “LO %S”);
sprintf (buf, str, dnsname);
send (s, buf);
```

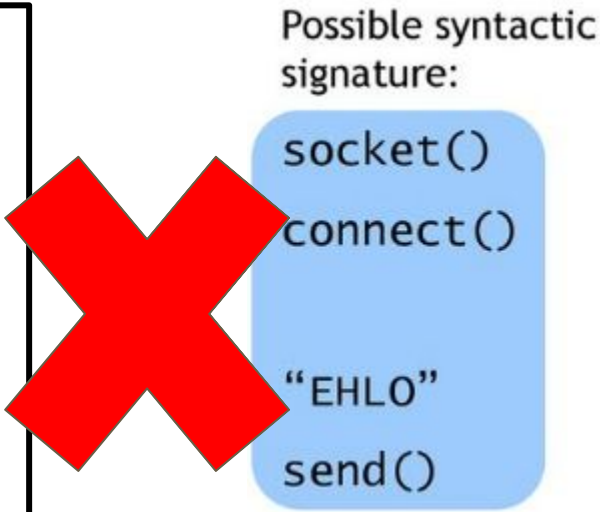
Possible syntactic signature:

```
socket()
connect()

“EHLO”
send()
```

# Semantics-Aware Malware Detection

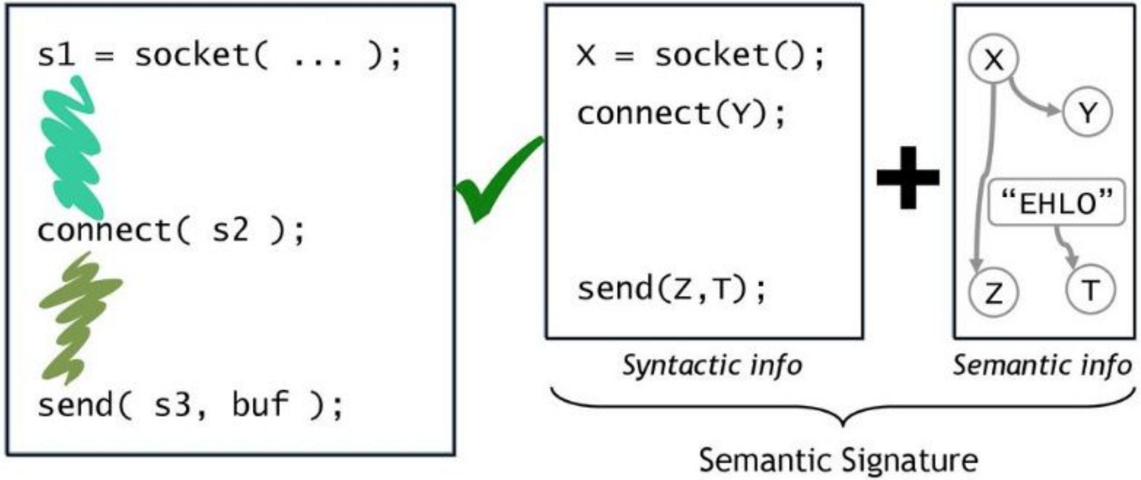
- Variant 2: string obfuscation
  - Hide known constants using simple encryption techniques

```
s = socket (...);
connect (s);

…
char* str = decrypt (encrypted string);
sprintf (buf, str, dnsname);
send (s, buf);
```



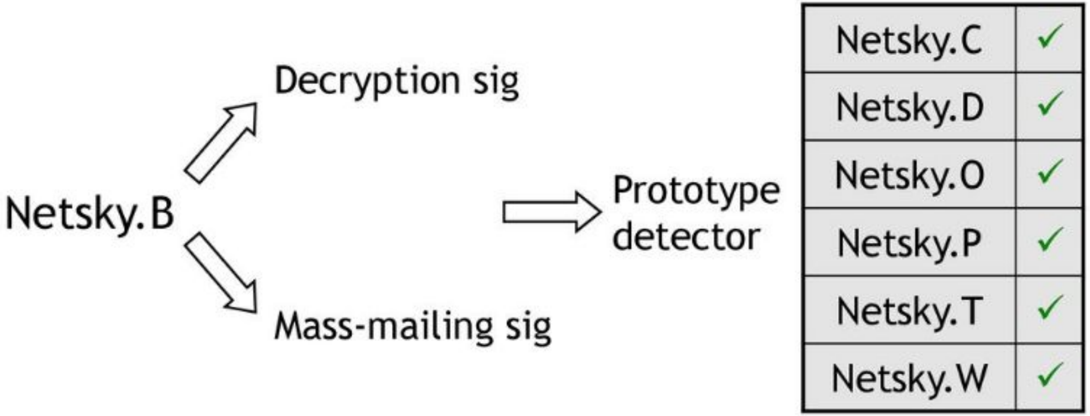
# Semantics-Aware Malware Detection

- Attackers
  - Same behavior in different forms
  - contain same semantics
- Semantic signatures
  - Combine syntactic info and semantic info
  - Detect any variant



# Semantics-Aware Malware Detection

- Evaluation




McAfee uses individual signatures for each worm.

Semantic signatures provide forward detection.

# Semantics-Aware Malware Detection

- Evaluation: Obfuscation resilient

| *Obfuscation Type* | ***Semantics-Aware Detection*** | | *McAfee* |
|---|---|---|---|
| | *Average Time* | ***Detection Rate*** | |
| Nop insertion | 74.81 s | **100%** | 75% |
| Stack op. insertion | 159.10 s | **100%** | 25% |
| Math op. insertion | 186.50 s | **95%** | 5% |

# Panorama: Capturing System-wide Information Flow for Malware Detection and Analysis

Heng Yin, Dawn Song, Manuel Egele, Christopher Kruegel, Engin Kirda

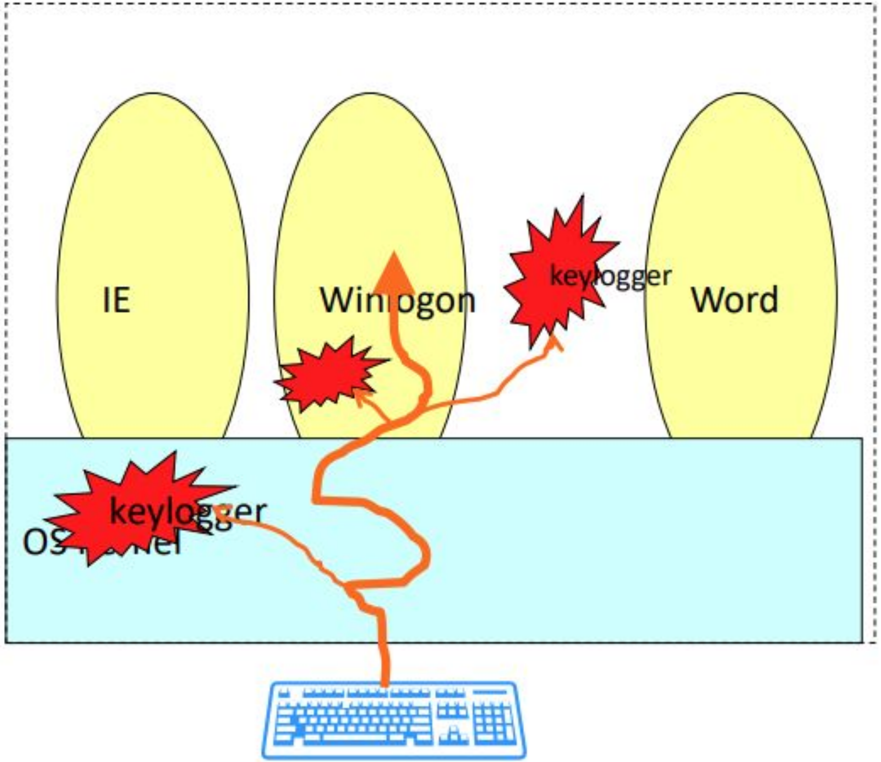
ACM CCS 2007

# Panorama

- Malware detection
  - Signature based detection
    - Cannot detect new malware and variants
    - Semantic-aware signature can detect some
  - Behavior based
    - Heuristics: high false positives and false negatives
    - Hooking-based
- Malware analysis
  - Manual process

# Panorama

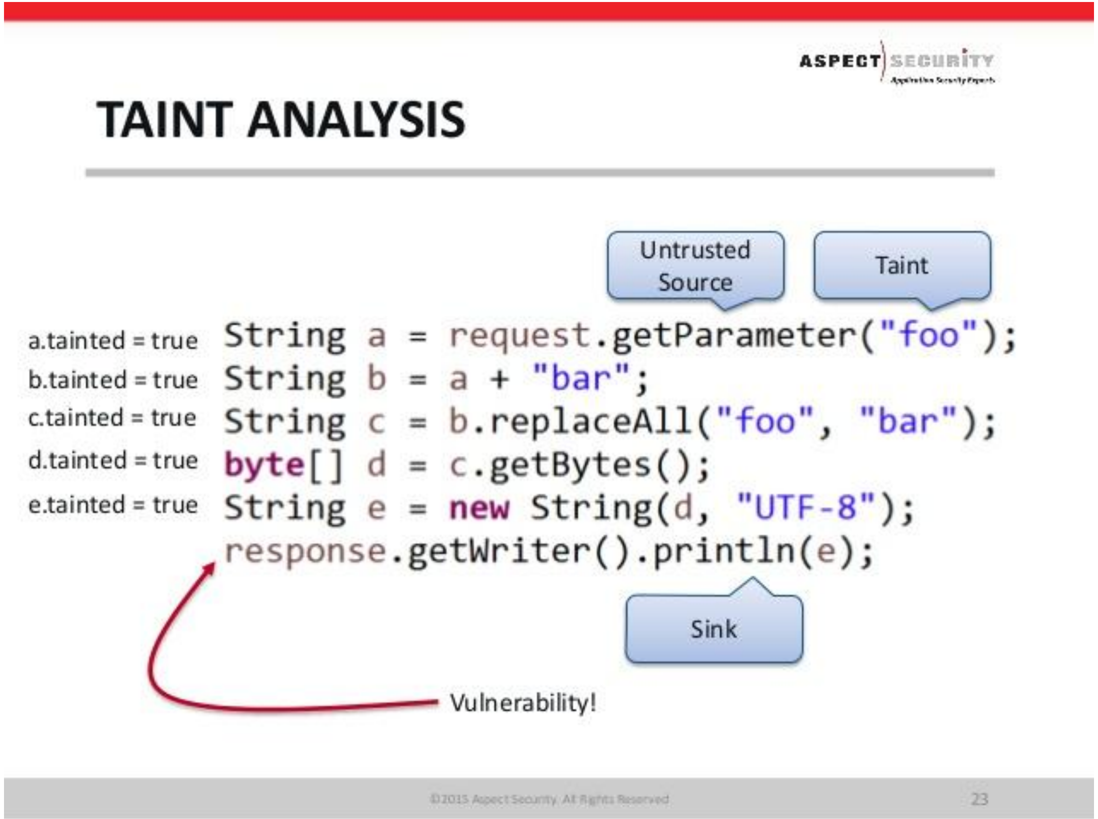
- Observation
  - Information access and processing (IAP) behavior
    - malicious/suspicious IAP behaviors as traces for malware detection and analysis
    - Steal, tamper, or leak sensitive information



# Panorama

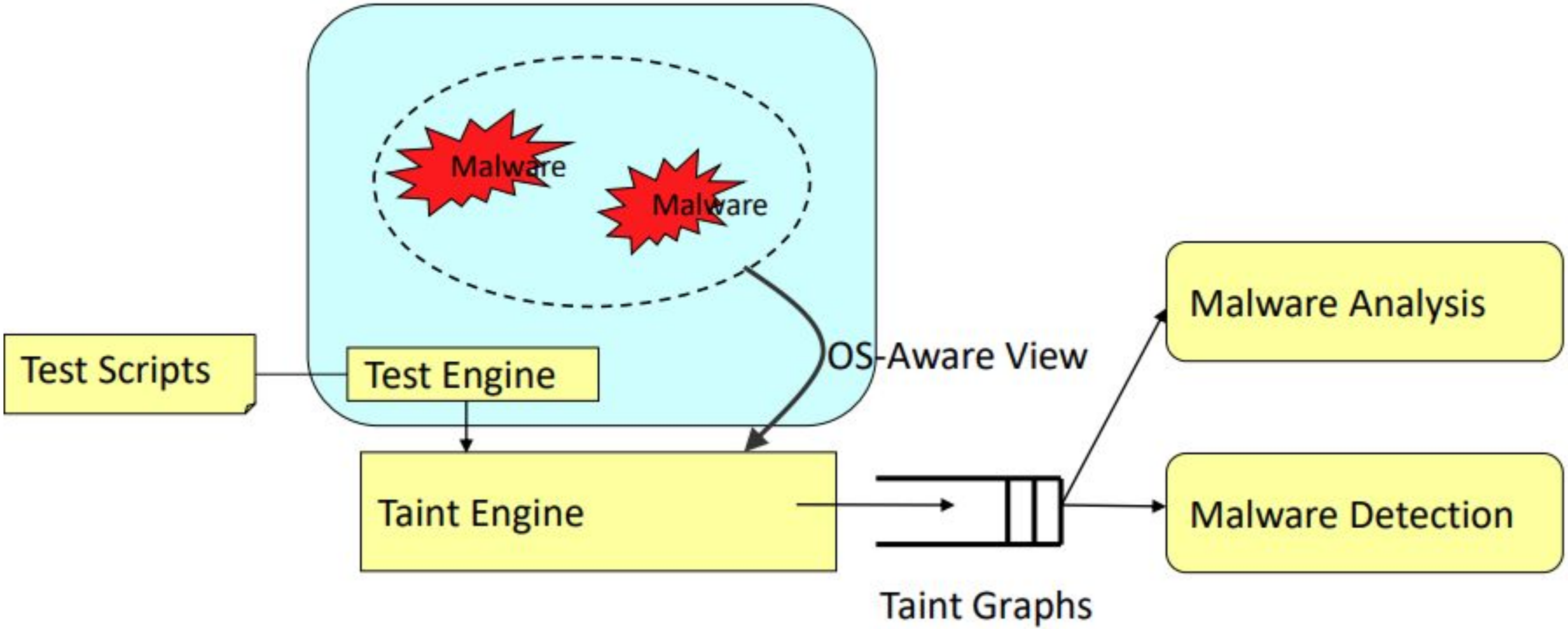
- Approach: Whole-system dynamic taint analysis
    - Run the system in an emulator
    - Selectively mark data as tainted
    - Monitor taint propagation
    - Extract OS-level knowledge
    - Generate taint graphs
    - Graph based detection and analysis

# Panorama



ASPECT SECURITY
TAINT ANALYSIS
Untrusted Source
Taint
a.tainted = true
b.tainted = true
c.tainted = true
d.tainted = true
e.tainted = true
String a = request.getParameter("foo");
String b = a + "bar";
String c = b.replaceAll("foo", "bar");
byte[] d = c.getBytes();
String e = new String(d, "UTF-8");
response.getWriter().println(e);
Sink
Vulnerability!
©2015 Aspect Security. All Rights Reserved
23

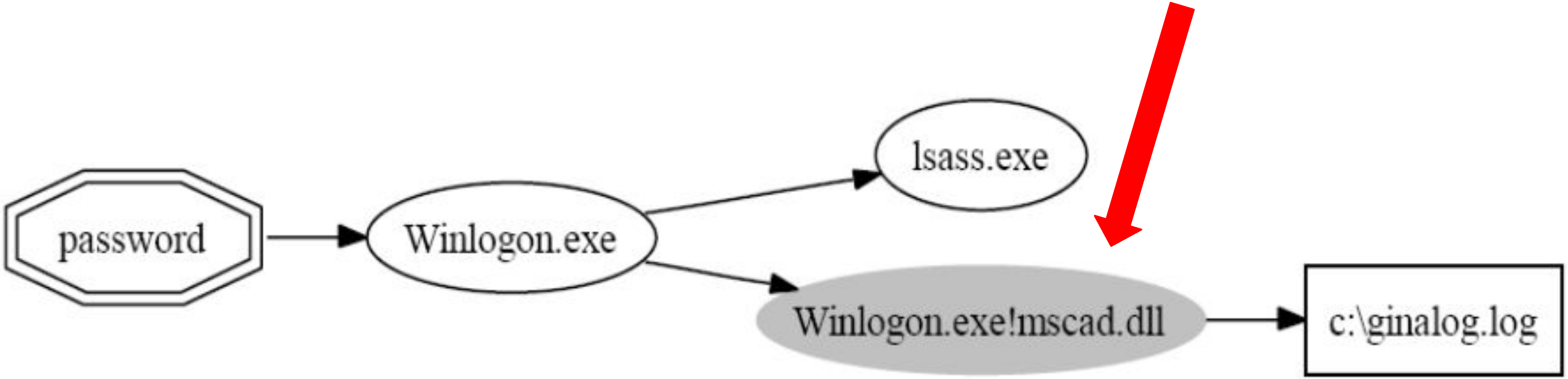
# Panorama


Malware
Malware
Test Scripts
Test Engine
OS-Aware View
Malware Analysis
Taint Engine
Malware Detection
Taint Graphs

# Panorama

- Taint Graph
    - Instruction and hardware level raw events
    - OS-level knowledge

A password stealer catches the password and saves it into a log



# Panorama

- Graph-based Detection and Analysis
    - Anomalous information access
        - Keyloggers:
            - Text: when sending keystrokes to a text editor
            - Password: when sending password to a web form
        - Backdoors:
            - ICMP: when pinging a remote host
            - FTP: when logging into a server
            - etc
    - Anomalous information leakage
        - URL: the keystrokes sent to the address bar
        - HTTP: the incoming HTTP traffic

# Panorama

- Evaluation: effectiveness

| Category | Total | FNs | FPs |
|---|---|---|---|
| Keyloggers | 5 | 0 | - |
| Password thieves | 2 | 0 | - |
| Network sniffers | 2 | 0 | - |
| Stealth backdoors | 3 | 0 | - |
| Spyware/adware | 22 | 0 | - |
| Rootkits | 8 | 0 | - |
| Browser plugins | 16 | - | 1 |
| Multi-media | 9 | - | 0 |
| Security | 10 | - | 2 |
| System utilities | 9 | - | 0 |
| Office productivity | 4 | - | 0 |
| Games | 4 | - | 0 |
| Others | 4 | - | 0 |
| Sum | 98 | 0 | 3 |

Browser accelerator

Personal firewall

- Evaluation: performance
  - Curl, scp, gzip: 20x slowdown on average
  - Test cases: 10-15 mins

# Panorama

- Evaluation: Case study


Google Desktop obtains the incoming HTTP traffic, saves it into two index files, and then sends it out though an HTTPS connection, to a remote Google Server

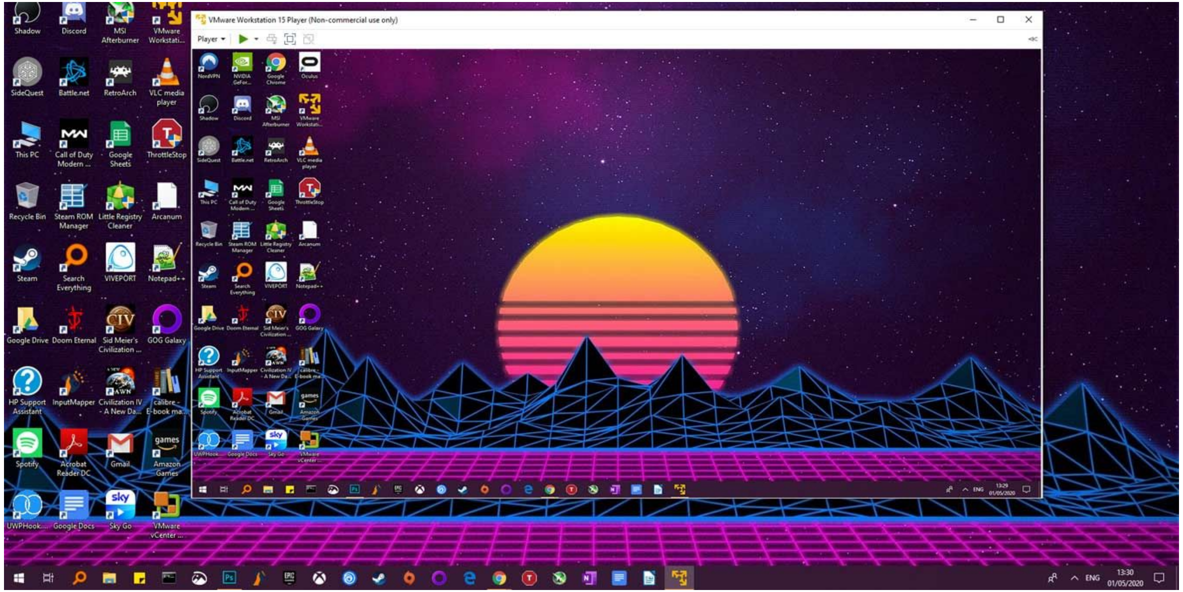
# BareCloud: Bare-metal Analysis-based Evasive Malware Detection

Dhilung Kirat, Giovanni Vigna, and Christopher Kruegel

Usenix Security 2014

# BareCloud

- VM environment is different from real machine.

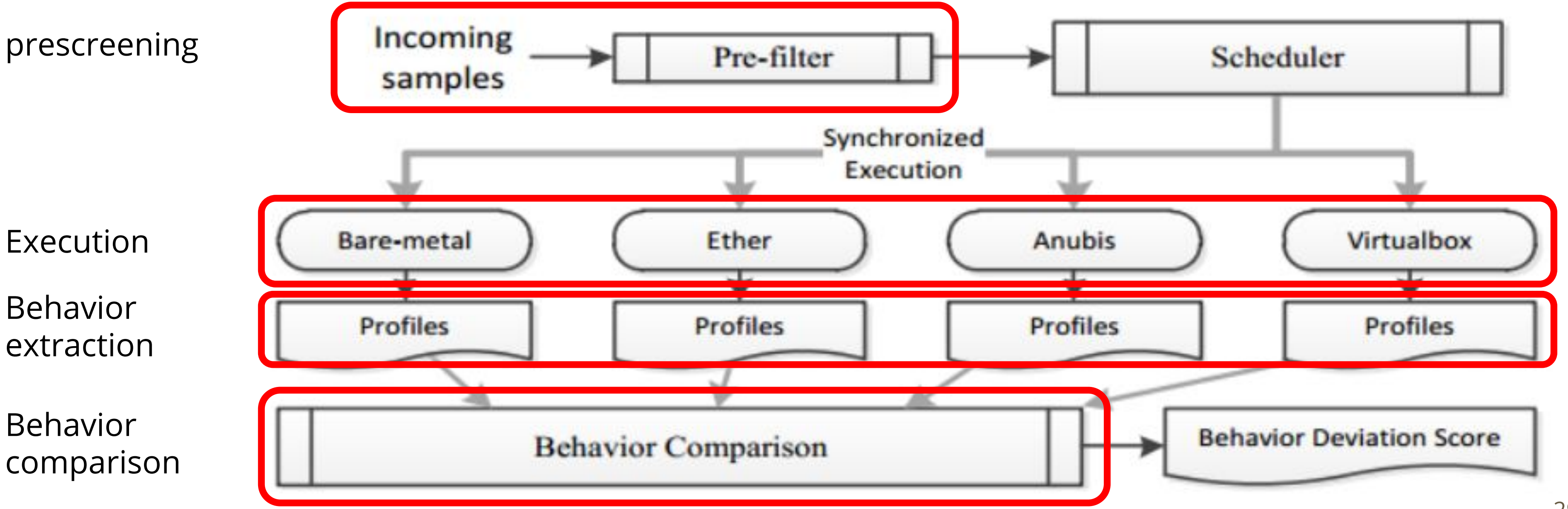


# BareCloud

- VM detection and evasion:
  - CPU instruction semantics
  - Timing attacks
  - VM bugs
  - Etc
- Motivation:
  - Can we automatically identify evasive malware while preserving transparency?
- Key idea:
  - Collect behavioral information on multiple platforms and compare the behaviors

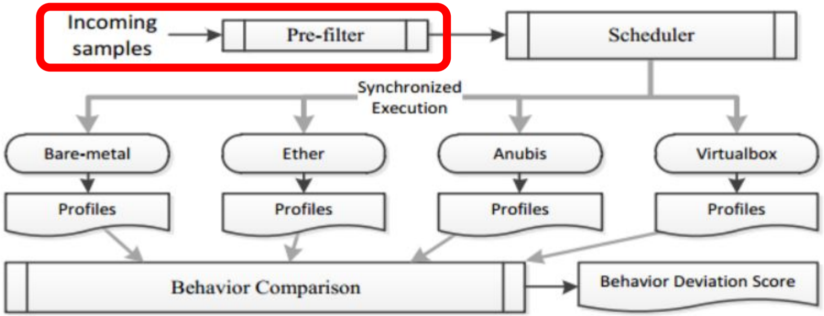
# BareCloud

- System overview



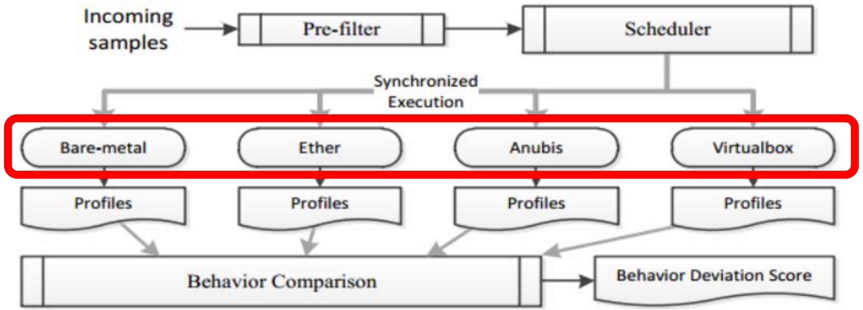
# BareCloud

- Prescreening
  - Select interesting samples
    - Likely to have environment-sensitive behaviors
    - Use Anubis platform



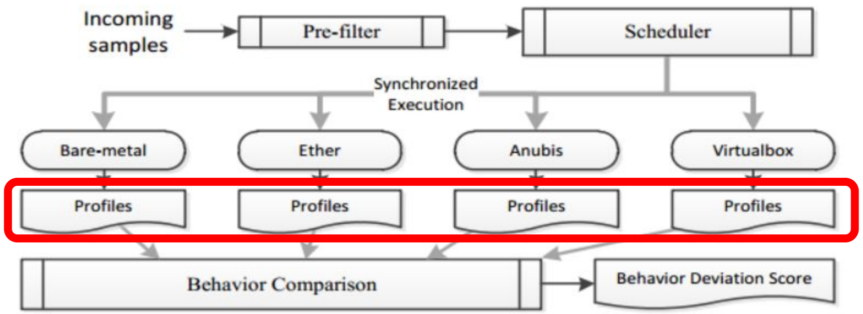
# BareCloud

- Execution
  - Run malware sample on 4 platforms simultaneously
    - Bare-metal
    - Anubis (emulator)
    - Ether (Intel VT)
    - Virtualbox (Type2 hypervisor)



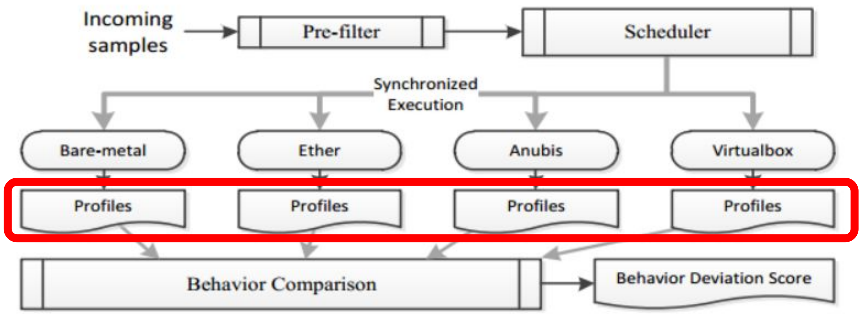
# BareCloud

- Behavior extraction
  - Two common ways
    - VMI based approach
    - In-guest monitoring
  - Problem:
    - Not transparent enough



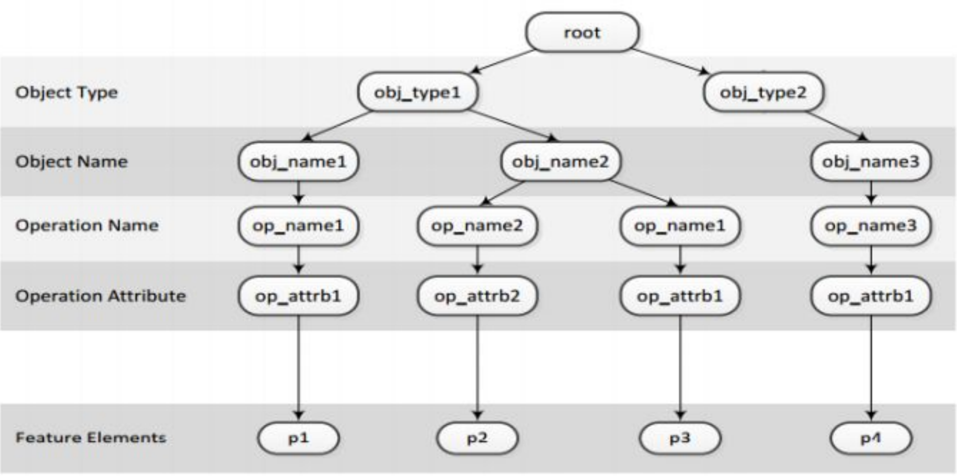
# BareCloud

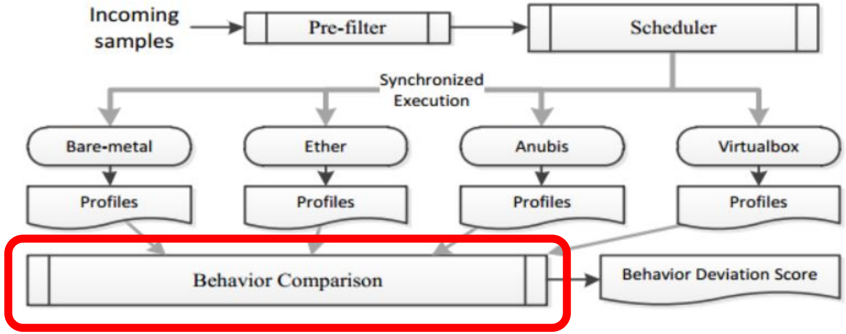
- Behavior extraction
  - BareCloud extracts file system behaviors and network behaviors
    - File system: compare the disk contents from before and after the malware execution
    - Network: use an external traffic capture component



# BareCloud

- Behavior comparison
  - Compare the behavior profiles in a hierarchical way



# BareCloud

- Evaluation
  - 110,000+ malware samples
  - 5835 evasive malware samples are found

| Environment | Detection count | Percentage |
|---|---|---|
| Anubis | 4,947 | 84.78 |
| Ether | 4,562 | 78.18 |
| VirtualBox | 3,576 | 61.28 |
| All | 2,530 | 43.35 |
| Total | 5,835 | |

# Summary

- Malware detection and analysis
  - Static analysis
  - Dynamic analysis
- Semantics-Aware Malware Detection, *IEEE S&P 2005*
- Panorama: Capturing System-wide Information Flow for Malware Detection and Analysis, *ACM CCS 2007*
- BareCloud: Bare-metal Analysis-based Evasive Malware Detection, *Usenix Security 2015*

# Thank you!

# Question?