KVMIveggur: Flexible, secure, and efficient support for self-service virtual machine introspection

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Outline

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5. Implementation
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Introduction

Introduction

- Virtual machine introspection (VMI)
  ➜ monitoring a virtual machine (VM) from the outside
  ➜ gain information about inner state
- VMI requires interaction with the hypervisor (sensitive)
- VMI has caught traction by hypervisor and anti-virus vendors (VMware, Kaspersky Lab, BitDefender and GData)
- IaaS (Infrastructure-as-a-service) is becoming more popular
- Lack of VMI implementation on public cloud providers
- Our research is to create access control of VMI

Background

Virtual Machine Introspection

- Analyze a guest VM from the outside with help of the hypervisor
- Requires no guest agent
- Two methods:
  - Asynchronous or passive
  - Synchronous or active
- Xen ➔ hypercalls (privileged) ➔ Dom0
- KVM ➔ UNIX domain socket
- Use-cases: malware analysis, deception technology, OS hardening, etc
- Publicly available VMI libraries
  - LibVMI
  - LibKVMi
  - Drakvuf
  - Libvmtrace

Related Works

Current SoTA

- CloudPhylactor → leverage Xen security modules [1]
- TwinPorter → extension of CloudPhylactor → live migration (Xen) [2]
- CloudVMI → expose VMI capabilities over RPC [3]
- Furnace → sand-box the VMI application (with SELinux and Seccomp-BPF) [4]
- FROST → based on OpenStack, predefined digital forensic tools [5]

[1] Taubmann, B., Rakotondravony, N. and Reiser, H.P., 2016, August. Cloudphylactor: Harnessing mandatory access control for virtual machine introspection in cloud data centers. In 2016 IEEE Trustcom/BigDataSE/ISPA (pp. 957-964). IEEE.

[2] Taubmann, B., Böhm, A. and Reiser, H.P., 2019, August. TwinPorter-An Architecture For Enabling the Live Migration of VMI-Based Monitored Virtual Machines. In 2019 18th IEEE International Conference On Trust, Security And Privacy In Computing And Communications/13th IEEE International Conference On Big Data Science And Engineering (TrustCom/BigDataSE) (pp. 427-434). IEEE.

[3] wook Baek, H., Srivastava, A. and Van der Merwe, J., 2014, March. Cloudvmi: Virtual machine introspection as a cloud service. In 2014 IEEE International Conference on Cloud Engineering (pp. 153-158). IEEE.

[4] Bushouse, M. and Reeves, D., 2018, September. Furnace: Self-service tenant vmi for the cloud. In International Symposium on Research in Attacks, Intrusions, and Defenses (pp. 647-669). Springer, Cham.

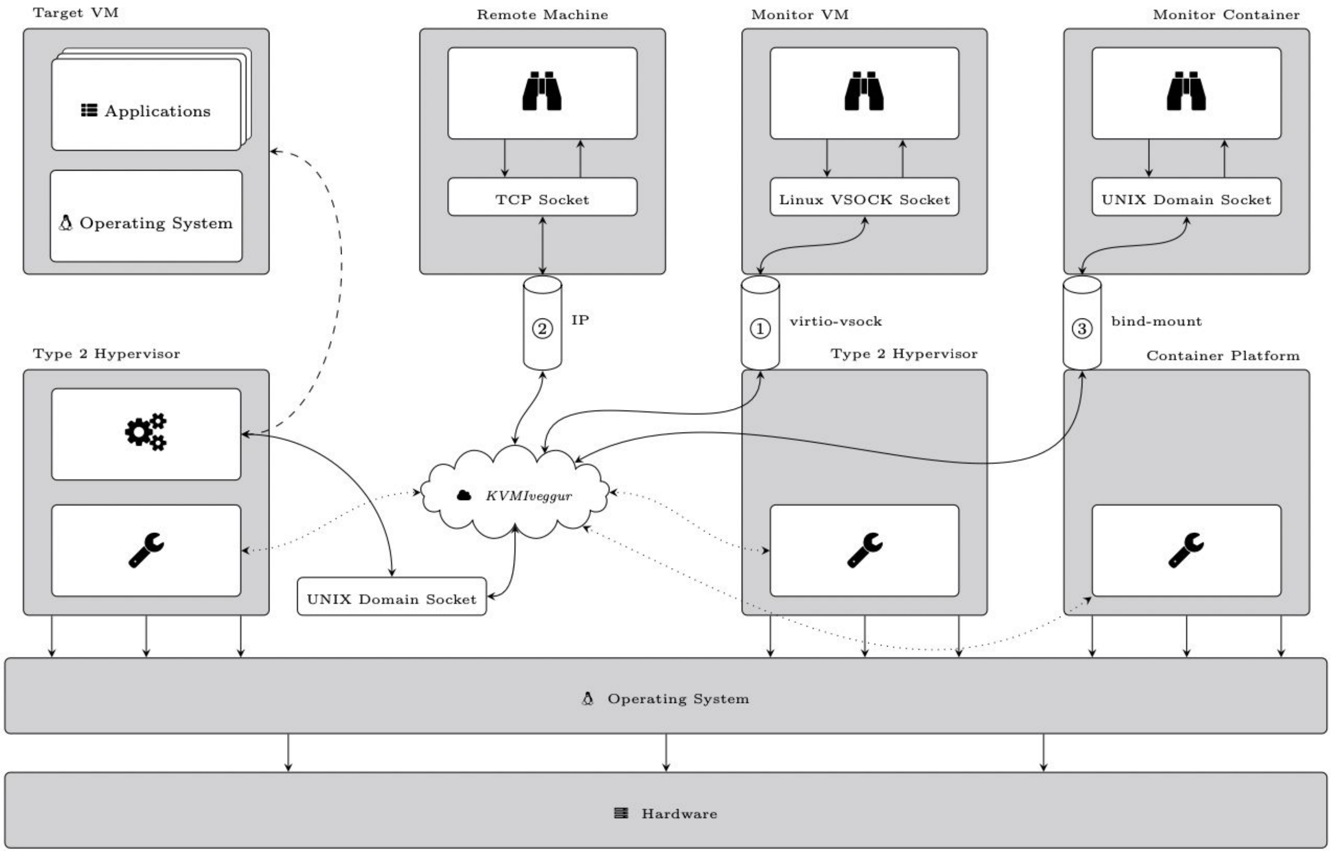
[5] Dykstra, J. and Sherman, A.T., 2013. Design and implementation of FROST: Digital forensic tools for the OpenStack cloud computing platform. Digit. Invest. S87–S95.

KVMIveggur Design

Goals & Assumptions

- Goals
  - Multiple flavors
  - Self-service
  - Secure access
  - Isolation
  - Easy integration
- Assumptions
  - The cloud provider is trusted
  - The operating system is trusted
- Security
  - Access to the monitor system is protected (e.g. via SSH)
  - Unauthorized access will harm only the monitored VM

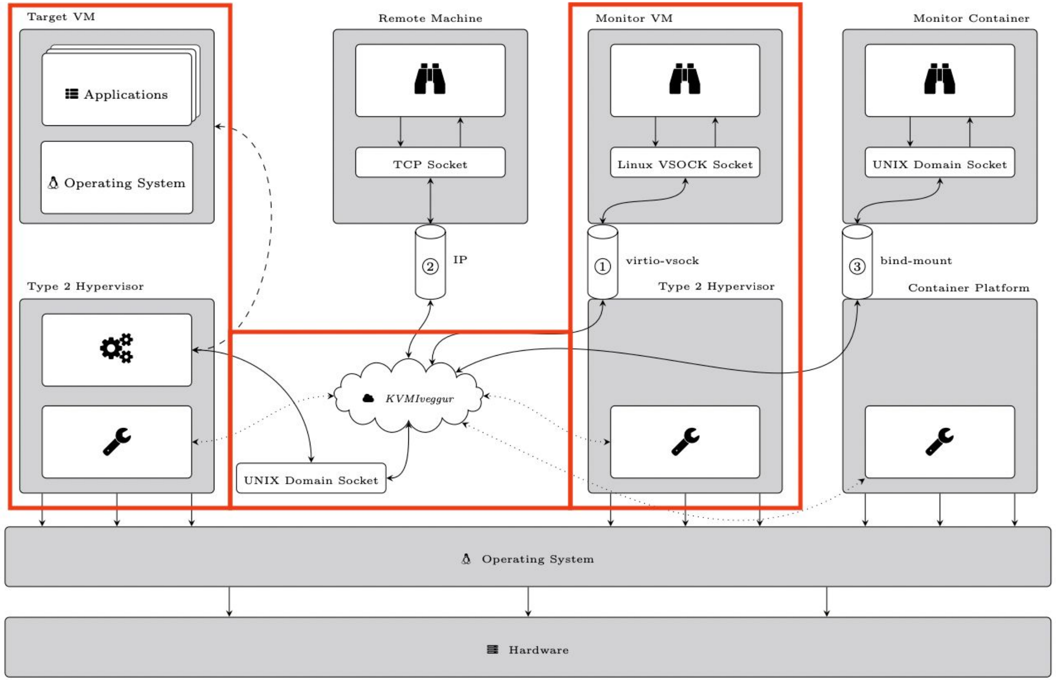
Overview



Target VM
Applications
Operating System
Remote Machine
TCP Socket
Monitor VM
Linux VSOCK Socket
Monitor Container
UNIX Domain Socket
2
IP
1
virtio-vsock
3
bind-mount
Type 2 Hypervisor
Type 2 Hypervisor
Container Platform
KVMIveggur
UNIX Domain Socket
Operating System
Hardware

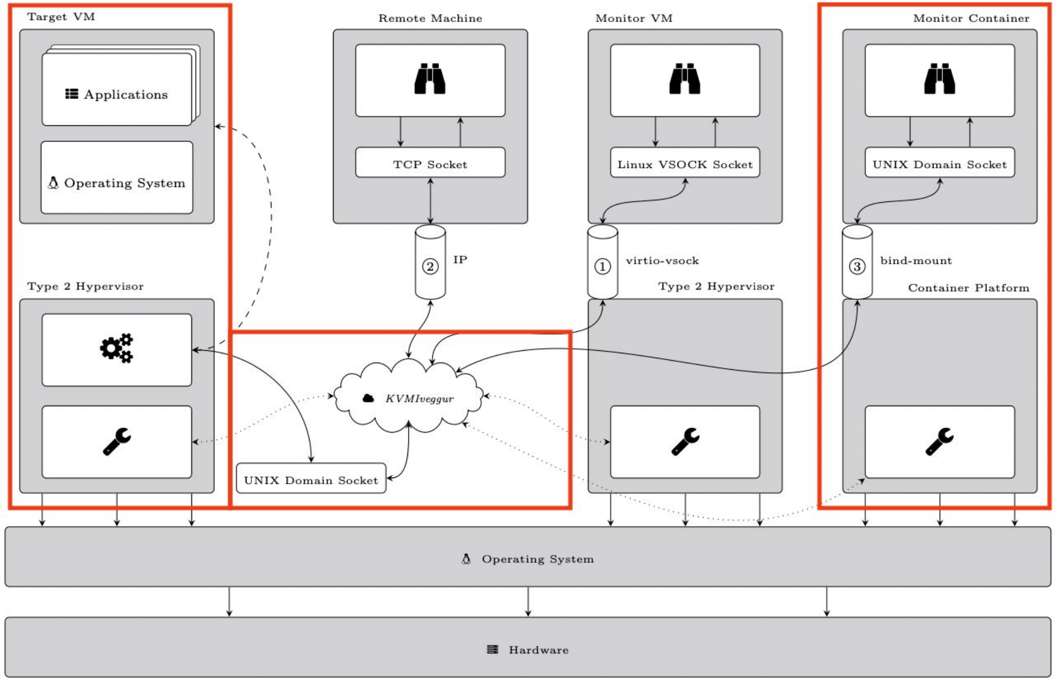
VM-to-VM

- Leverage *virtio-vsock*
- Expose the socket on the hypervisor into the monitor VM



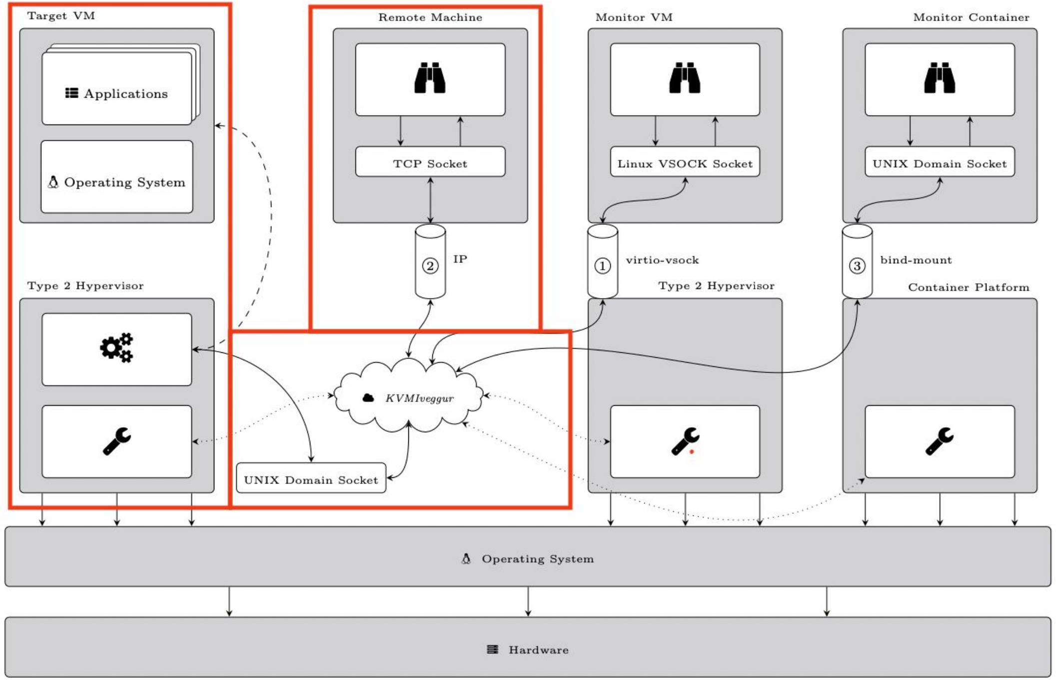
VM-to-Container

- Leverage *bind-mounts*
- Expose the socket on the hypervisor into the monitor Container



Over-the-Network

- Leverage *socat*
- Expose the socket on the hypervisor via the network
- For the current version, not encryption is used



Implementation

On Hardware and Paravirtualized Machine

- On the monitoring VM

```
<vsock model="virtio">
    <cid auto="no" address="{monitoring cid}"/>
    <alias name="{vsock name}"/>
    <address type="pci" domain="0x0000" bus="0x00" slot="0x0b" function="0x0"/>
</vsock>
```

On Hardware and Paravirtualized Machine

- On the target VM

```
<qemu:commandline>
  <qemu:arg value="-chardev"/>
  <qemu:arg value="socket,cid={monitoring cid},port={vsock port},id=chardev0,reconnect=10"/>
  <qemu:arg value="-object"/>
  <qemu:arg value="introspection,id=kvmi,chardev=chardev0"/>
</qemu:commandline>
```

Over the Network

- Transform file-based socket to TCP stream

$ socat UNIX-LISTEN:**{target VM's UDS location}**,unlink-early,fork TCP:**{client's IP address}**:**{target port}**,fork,end-close

- Transform back the TCP stream to file-based socket

$ socat TCP-LISTEN:**{target port}**,reuseaddr,reuseport,fork UNIX-CONNECT:**{UDS new location}**

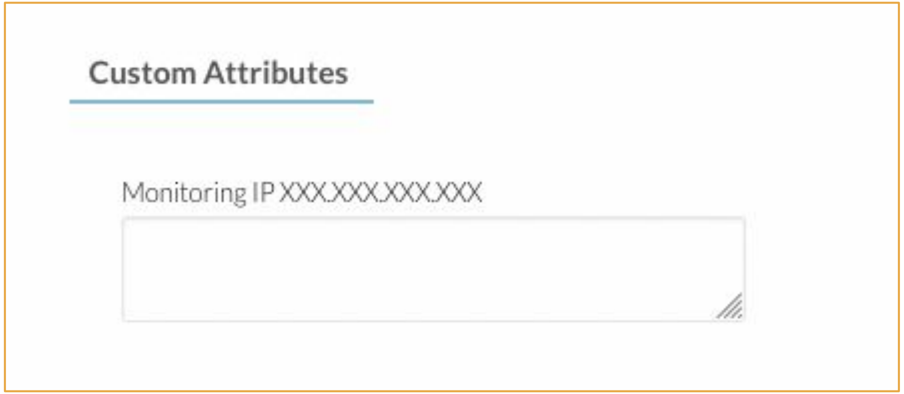
On Docker Container

- Mount the folder that contains the socket to the container

```
$ docker run <related container options> -v <UDS location on the host >:<UDS location on the container >
```

OpenNebula Integration

- Add custom hook script (written in Python)
- Add additional fields on the user interface (using custom attributes)



Evaluation & Discussion

Performance

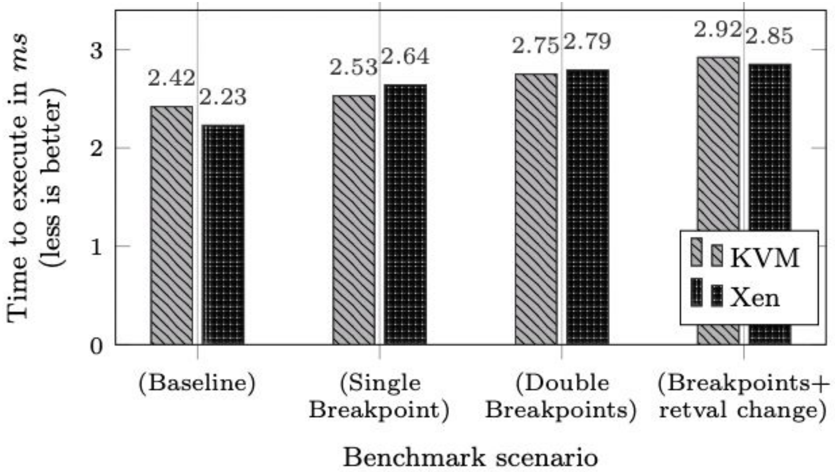
- Legend
  - *NoVMI* → baseline
  - *Native* → native VMI application runs directly on the host OS
  - *Virtio* → VMI application runs on different VM (monitor VM)
  - *NetCoHost* → VMI application over the network, but located on the same host
  - *NetRemote* → VMI application over the network (remote client)
  - *FromDocker* → VMI application runs inside a docker container
- Benchmark environment
  - Intel Xeon E3-1230 v5 CPU at 3.40 Ghz (hyper-threading enabled) – main
  - Intel Xeon E5-2609 v3 CPU at 1.90 Ghz – as migration target
  - 64 GB of RAM
  - Debian 11 (kernel 5.4.24)
  - VM
    - One vCPU
    - 768 MB of RAM
    - Debian 10
  - Over the network: less than 0.6ms latency and 940 Mbps bandwidth (*iperf*)

Performance (Xen vs KVM)

- Using *Sarracenia*[1] honeypot (VMI-based SSH honeypot)
- System-wide tracing

	KVM		XEN	
	Baseline	With Tracing	Baseline	With Tracing
ls	$0.15s$	$0.37s$	$0.13s$	$0.40s$
wget	$0.57s$	$0.99s$	$0.65s$	$0.98s$

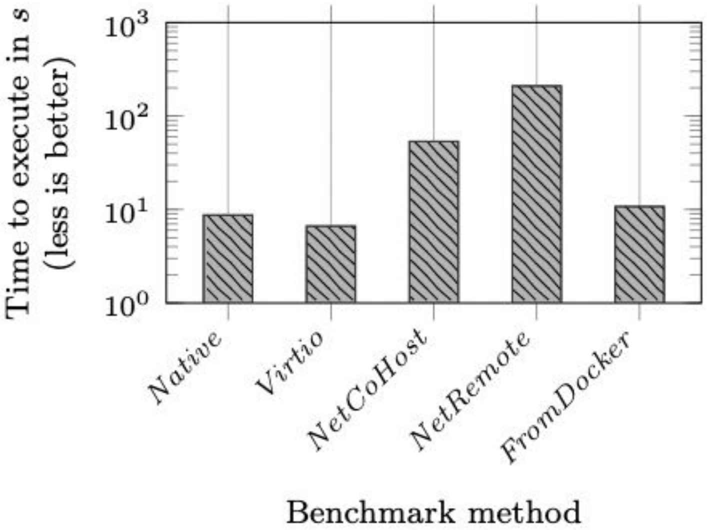
- Function tracing



[1] Sentanoe, S., Taubmann, B. and Reiser, H.P., 2018, November. Sarracenia: enhancing the performance and stealthiness of SSH honeypots using virtual machine introspection. In Nordic Conference on Secure IT Systems (pp. 255-271). Springer, Cham.

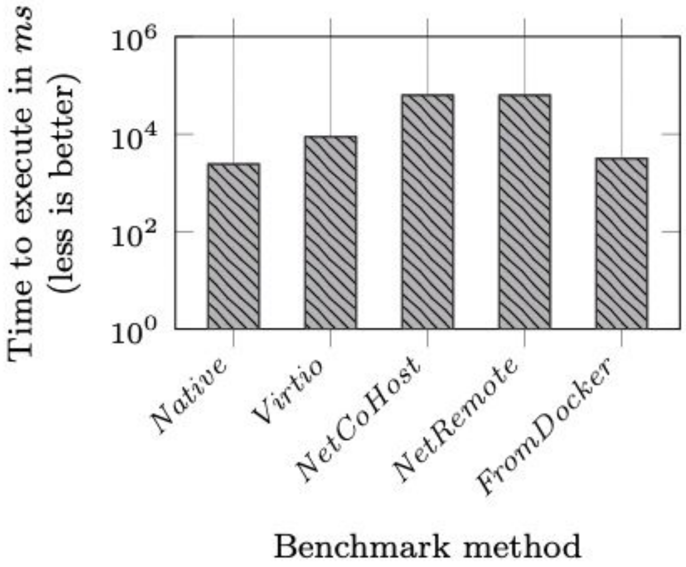
Performance

- Volatility 3 - *lsmod* module
- Created new *DataLayer* so it uses VMI interface
- Runs 50 times



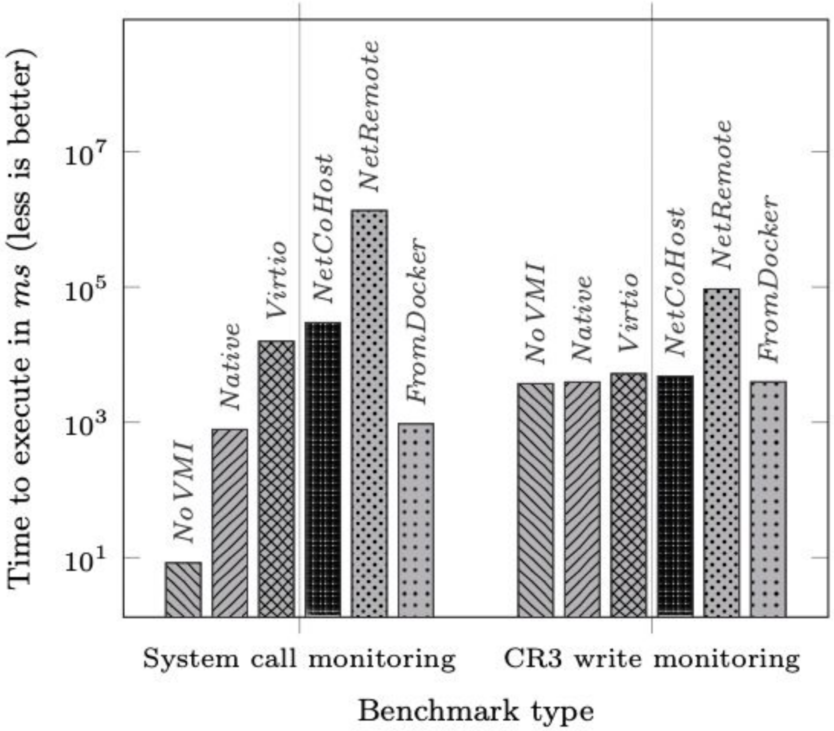
Performance

- Passive VMI
- LibVMI – process list extraction
- Flush cache everytime



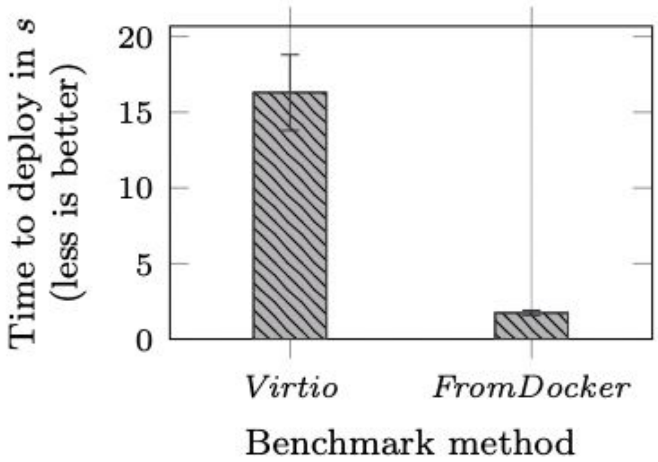
Performance Degradation

- Active VMI – system call handler of *getpid* and *CR3* register



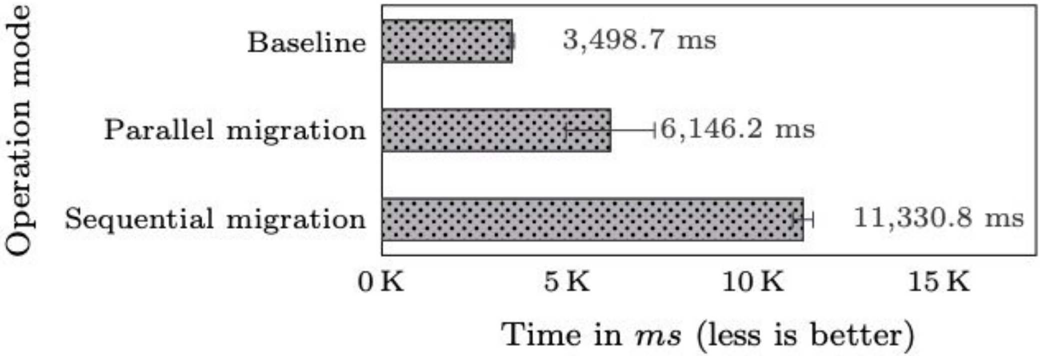
Performance

- *Virtio* and *FromDocker* so far proven to be the best two solutions
- Deployment time of both are acceptable



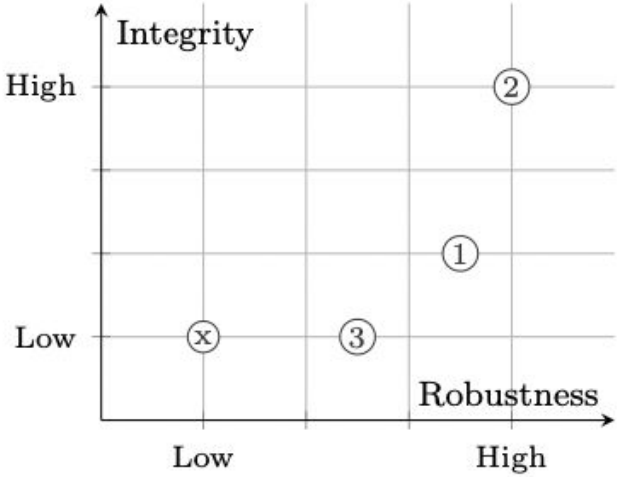
Performance

- VM live migration
- Legend:
  - Baseline ➔ migrate a single VM without any monitor
  - Sequential ➔ migrate monitor VM then target VM
  - Parallel ➔ both at the same time



Robustness & Integrity

- ⓧ → native VMI → neither isolated from the host nor protect integrity
- ① → VM-to-VM → exposes minimum interface
- ② → Over the network → remote access
- ③ → Container → exposes system call interface



Conclusions & Future Work

Conclusions & Future Work

- We introduce *KVMIveggur*
- Flexible and self-service VMI
- Support passive and active
- Integrated to OpenNebula
- Ported several VMI-based applications and Volatility 3

Thank you!

Questions?

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