Microsoft

Linux Virtualization Based Security (LVBS)

Linux Plumbers Conference 2023

Thara Gopinath, Mickaël Salaün, James Morris

Agenda

- Architecture Overview
- Hyper-V Implementation
- KVM Implementation (Heki)
- Q&A

Architecture Overview

James Morris

Linux Virtualization Based Security (LVBS)

Use virtualization to provide enhanced security for the guest OS, leveraging the hypervisor security boundary.

Linux Virtualization Based Security (LVBS)

Protect the integrity of security-critical guest structures.

Linux Virtualization Based Security (LVBS)

Prevent bypass of guest security mechanisms and policies.

Linux Virtualization Based Security (LVBS)

Support a Trusted Execution Environment (TEE) for running security applications

- Executable code integrity
- Key management
- Others

Rationale

- Bring mainline Linux to state of the art.
- Linux is trailing proprietary solutions across Linux and other OSs.
- Attacks continue to evolve, along with motivation levels.

LVBS Architecture

Open-source **architecture** for Linux.

Independent of:

- ISA
- Hypervisor
- VMM
- Security monitor
- TEE implementation

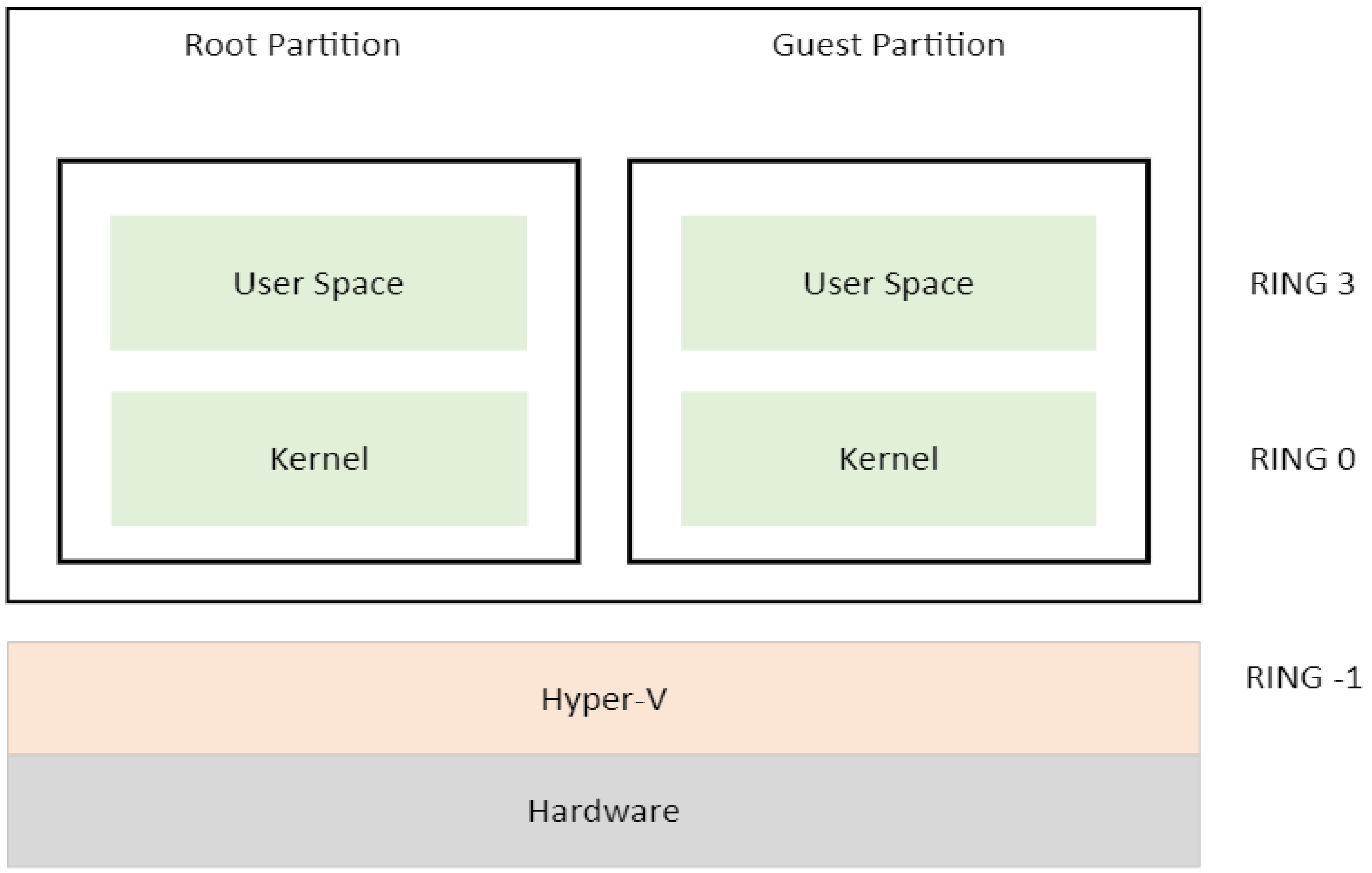
Approach

- Mainline acceptance across ecosystem is critical to success
- Reference implementation (HEKI):
  - KVM
  - Linux kernel API
  - Flexible kernel hardening policy
- We are seeking feedback and collaboration.

Hyper-V Implementation

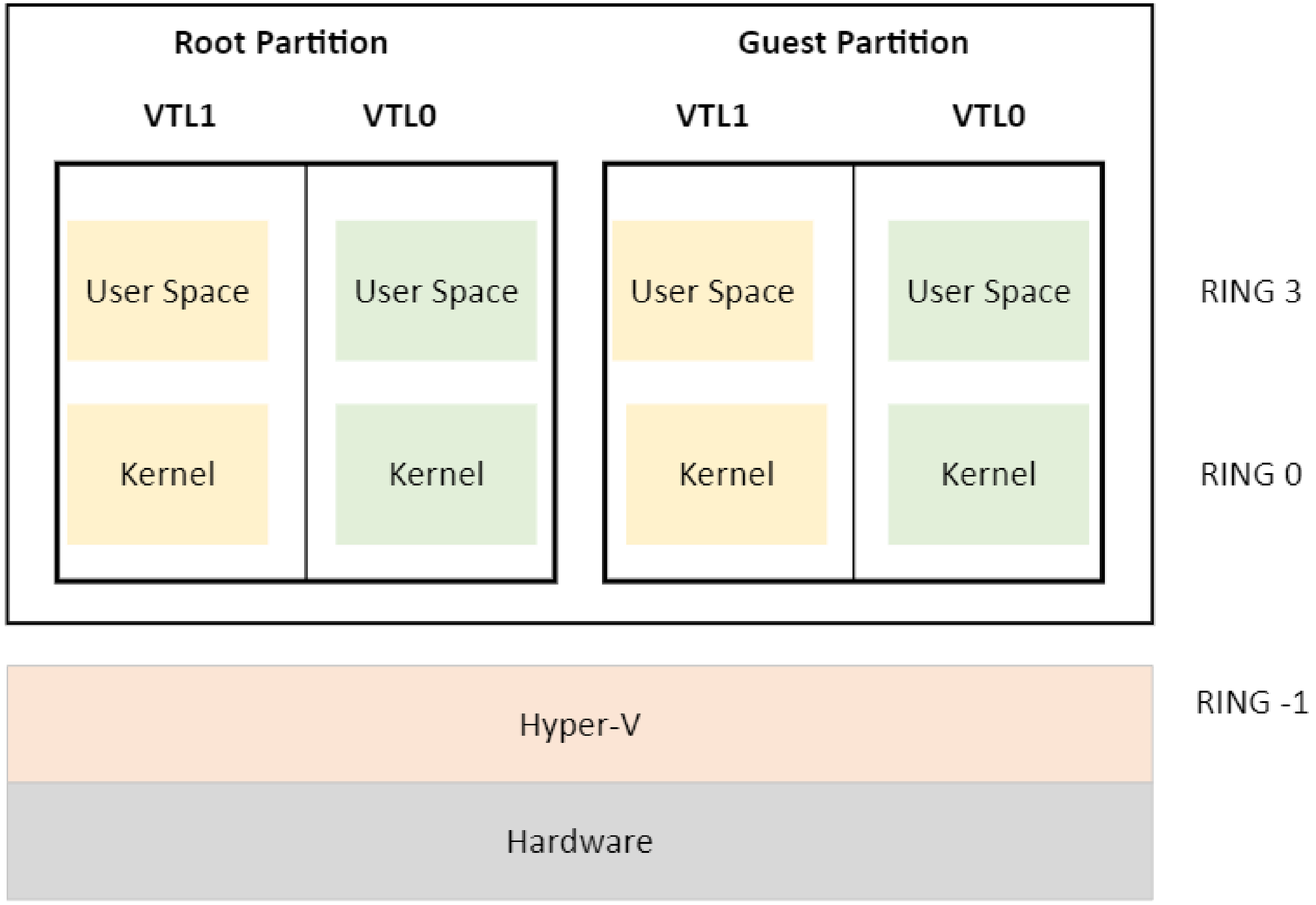
Thara Gopinath

Hyper-V based System



Virtual Secure Mode (VSM)

Separate privileged execution environment within a partition : Virtual Trust Level (VTL)



VSM Features

- Virtual Processor state isolation
- Memory access hierarchy and protection
- Virtual Interrupt and Intercept handling

- https://learn.microsoft.com/en-us/virtualization/hyper-v-on-windows/tlfs/vsm

LVBS and VSM

- Kernel Hardening
  - Hardening memory permissions (HVCI)
  - Monitoring critical system registers and MSRs
  - Monitoring critical kernel data structures
- Offloading policies (control flow integrity, authentication)
- Offloading secure services (trustlets)
- Initial Target : Basic Kernel Hardening.

Threat Model:

Kernel Hardening

- Protect kernel from a user space attacker exploiting a kernel vulnerability
  - Assume that the attacker has arbitrary read write access to guest kernel thanks to exploited vulnerability by malicious
    - User space process
    - Network Packet
    - Block Device
  - Secure Boot is trusted.
  - Defence in Depth ; but no extra features!!!

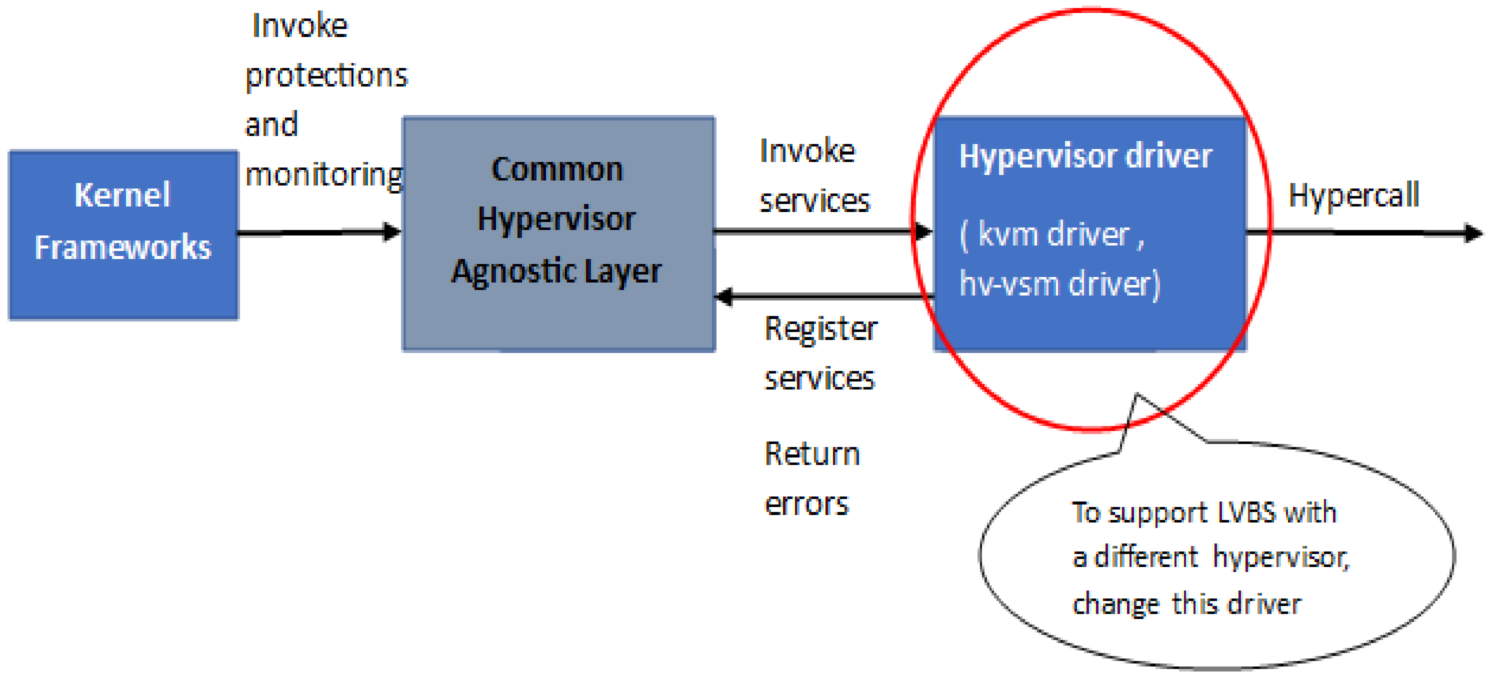
H/W Requirements:

- Second Level Address Translation (SLAT, Two-Dimensional Paging, AMD's RVI/NPT)
  - Enable to manage VM memory and add a secondary complementary layer of permissions only controlled by the hypervisor)

- CPU features that allow to differentiate between kernel space and user space memory (MBEC)

Architecture:

(Common Layer)



e.g. Hypervisor Enforced Kernel Integrity (Heki)

Architecture:

Secure Kernel

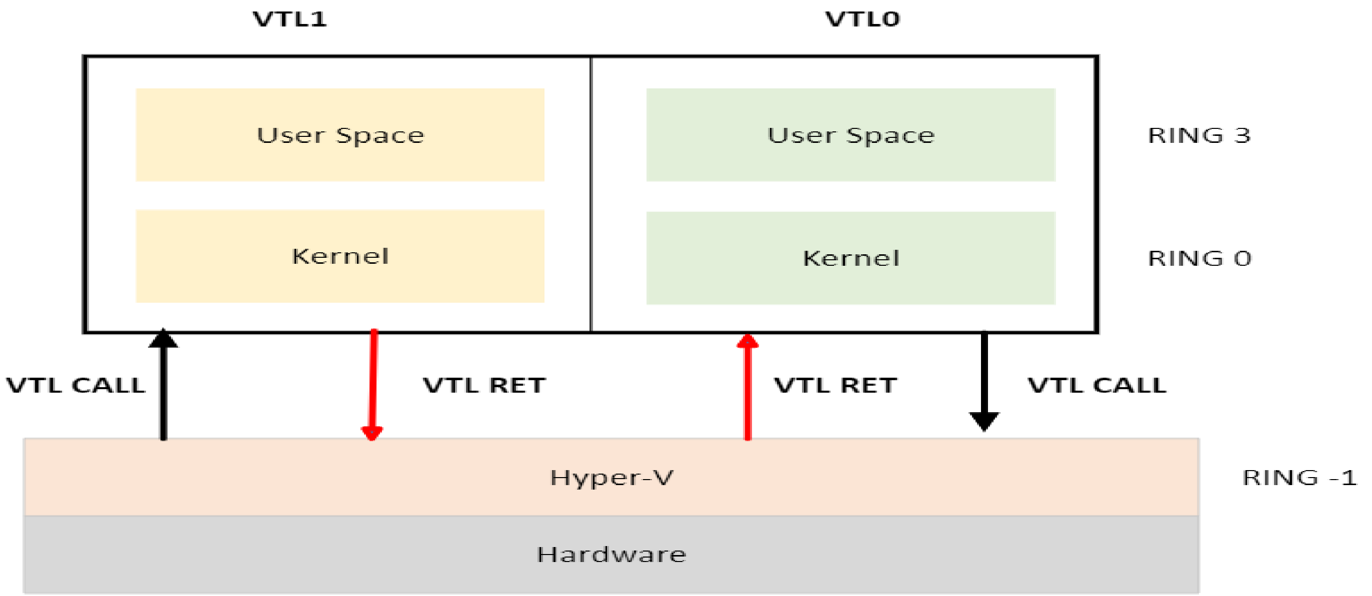
- Small TCB
- Maintainability
- Ability to support secure interfaces

- Initial choice for secure kernel : Minimal Linux Kernel

Architecture:

Control Interfaces

Synchronous : Explicit VTL Call and Return



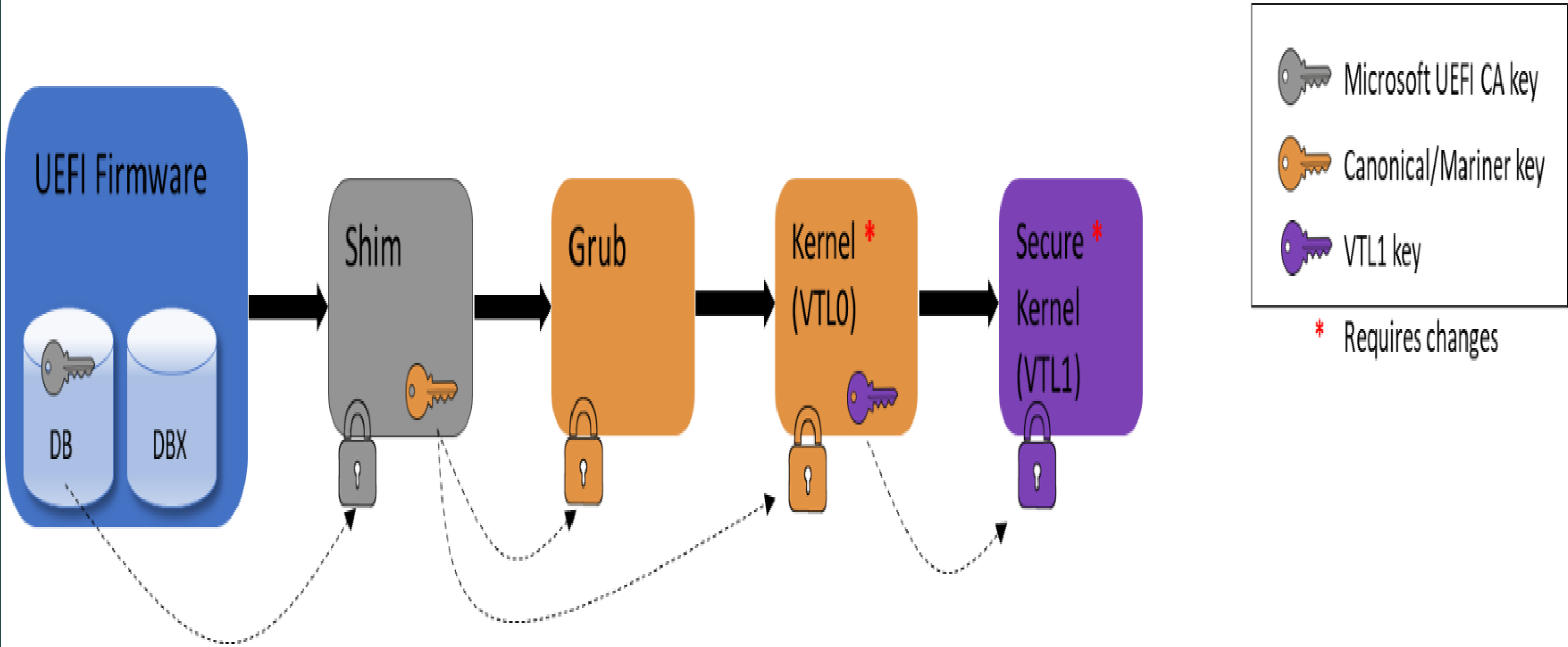
Asynchronous : Interrupt based entry and exit

Higher VTL gets precedence over lower VTL

Architecture:

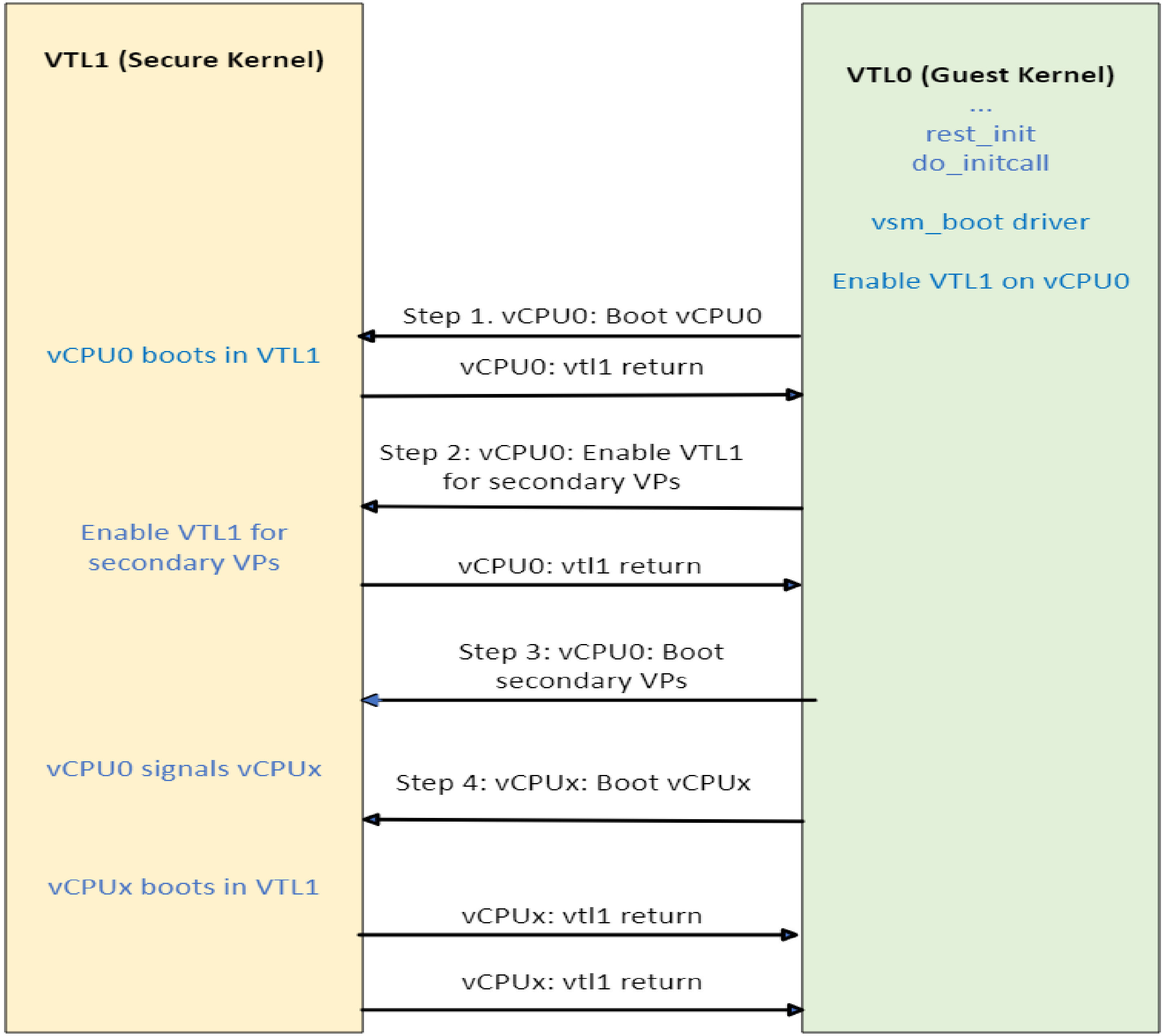
Boot

- We trust secure boot !
- VTL0 guest kernel boots up VTL1 secure kernel
- Establish kernel hardening and other policies with secure kernel prior to init process.



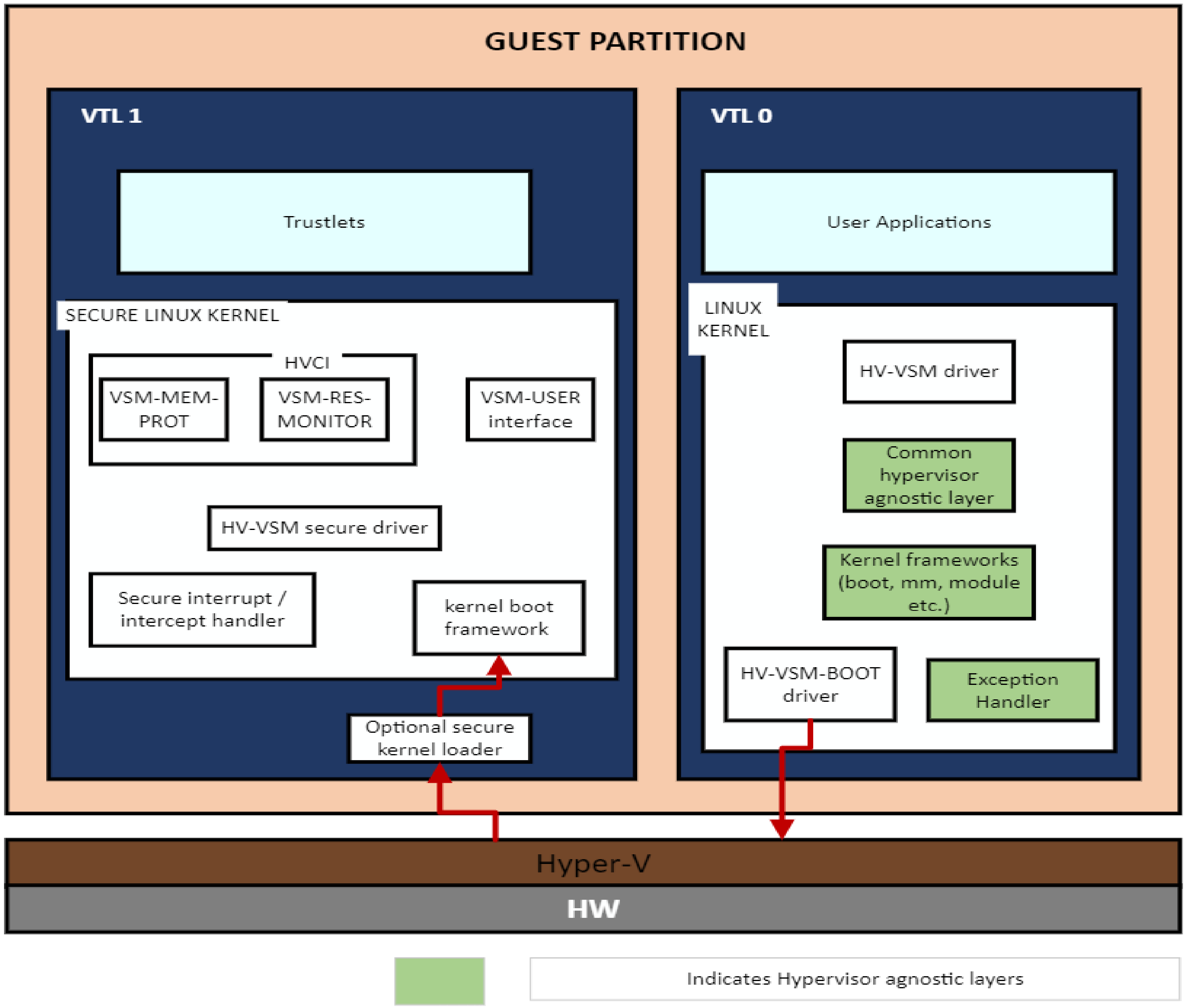
Architecture:

Boot Sequence



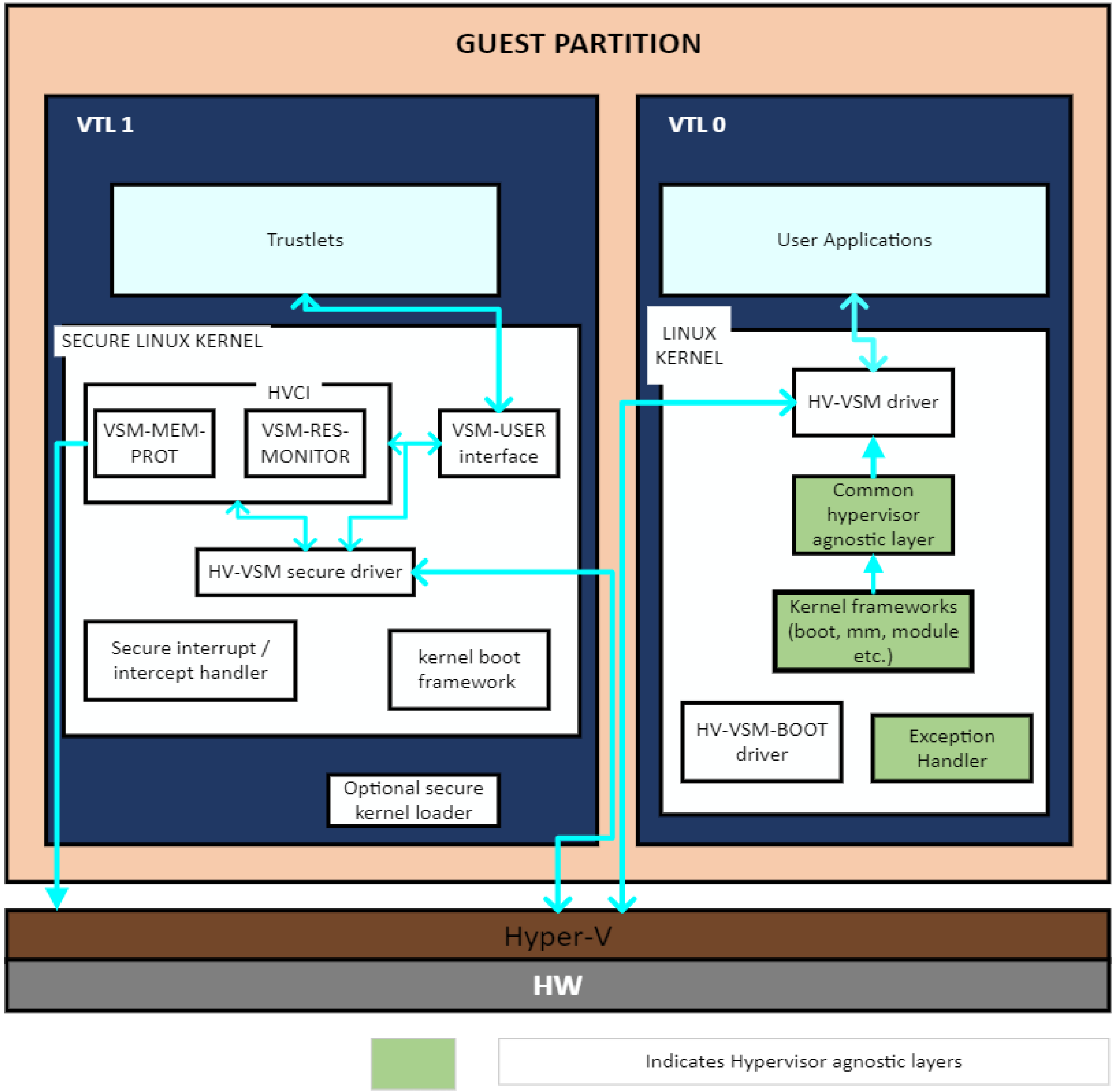
Architecture :

The Big Picture (Boot)



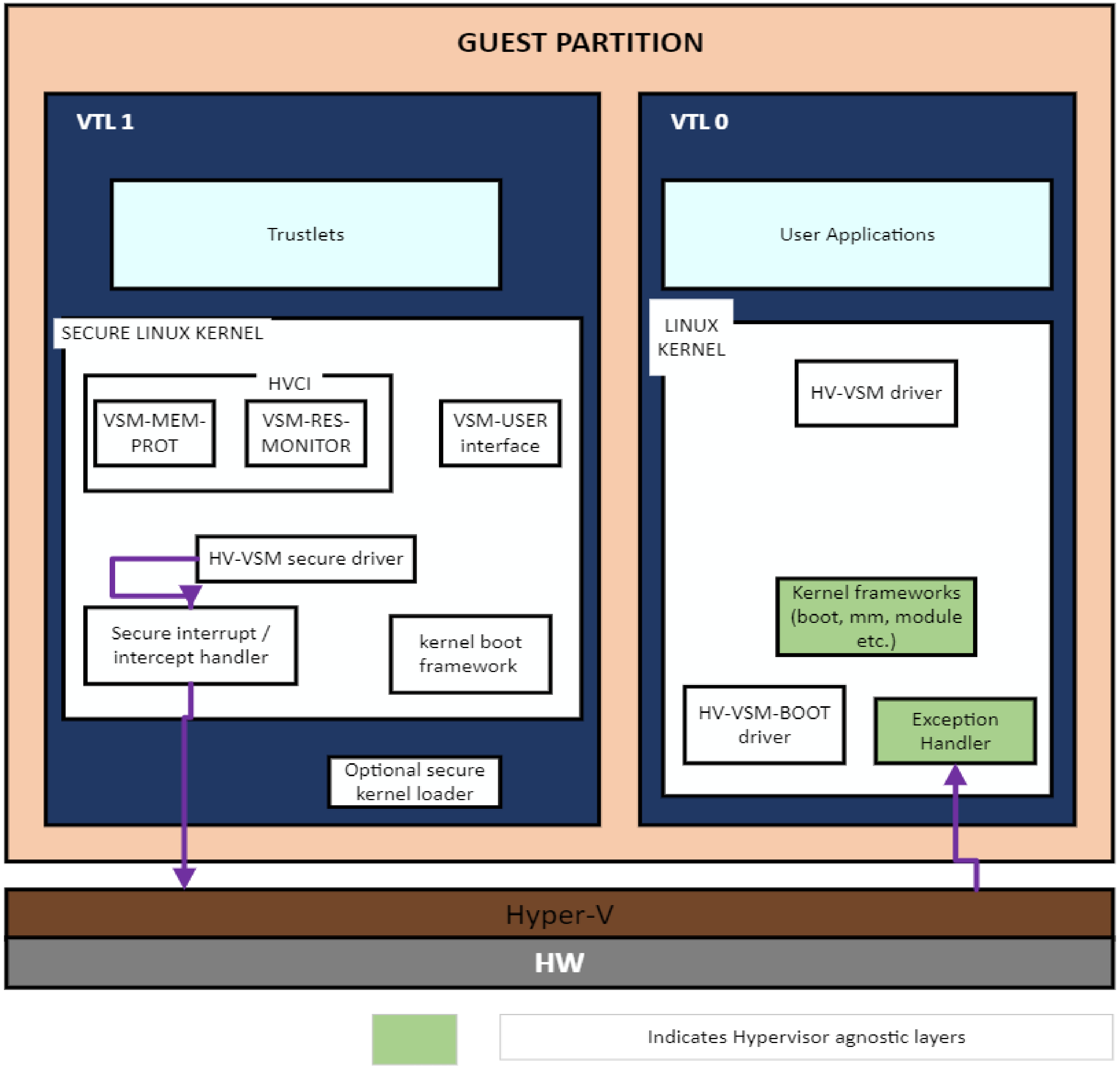
Architecture:

The Big Picture (Late Boot)



Architecture

(Access / Policy Violation)



Code

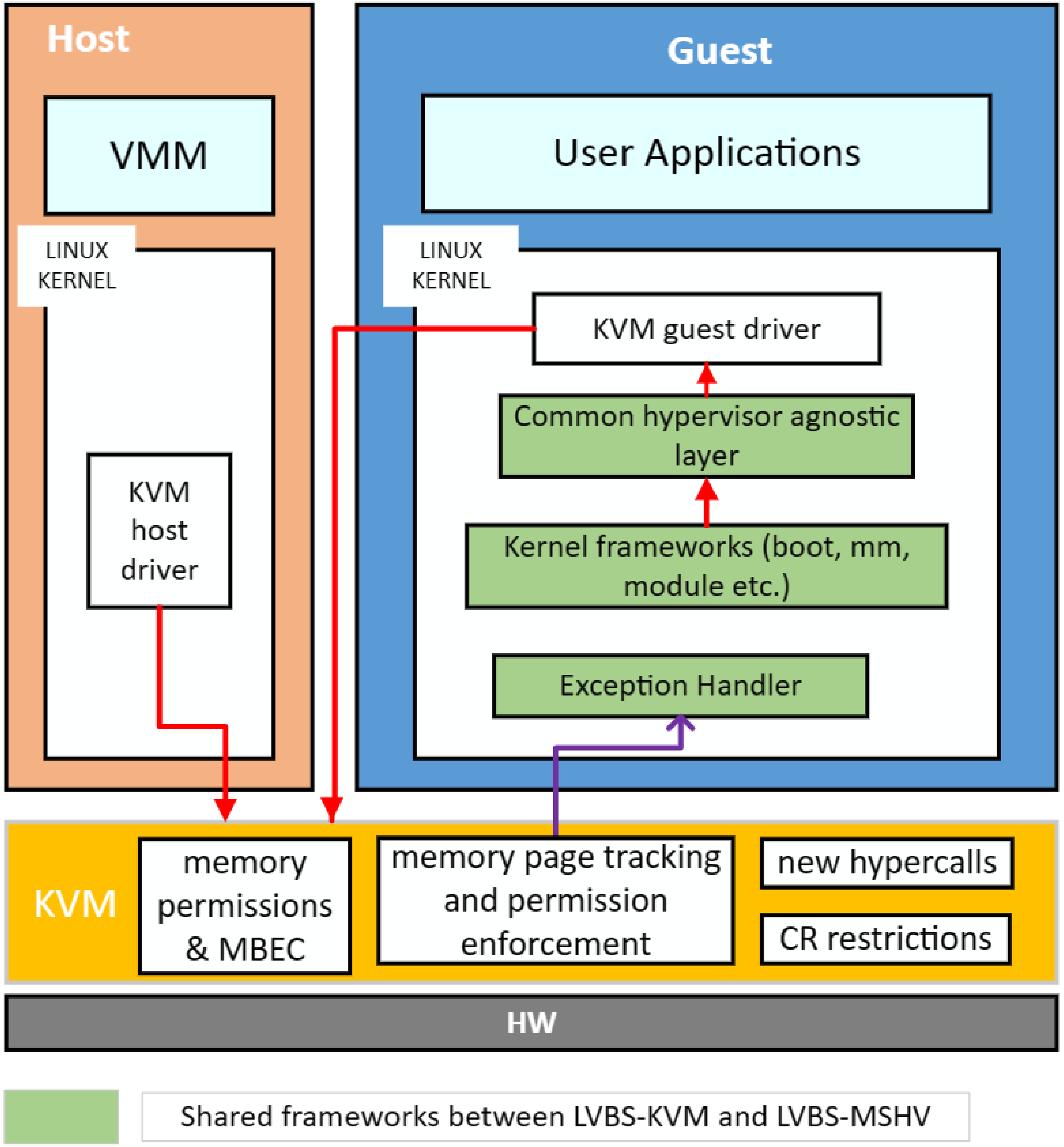
- https://github.com/heki-linux/lvbs-linux/tree/secure-kernel-lvbs
- https://github.com/heki-linux/lvbs-linux/tree/ubuntu-lvbs

KVM Implementation (Heki)

Mickaël Salaün

Architecture :

The Big Picture



RFC v2 patches

Sent RFC v2:

- Guest kernel implementation of the common API
- Two new KVM hypercalls: CR-pinning and memory permission
- KVM interface with the VMM: dedicated VM exits and related capabilities

CR-pinning hypercall

Enforce a bitmask on **control registers** to guard against locked features (e.g. SMEP)

```
kvm_hypercall3(KVM_HC_LOCK_CR_UPDATE,
               0, // control register
               X86_CR0_WP, // flag to pin
               flags); // options
```

Can create a **VM exit** on configuration or policy violation for the VMM to be able to do something.

Generate a **GP fault** on policy violation.

Memory protection hypercall

Configure (a subset of) EPT permissions.

```
kvm_hypercall1(KVM_HC_PROTECT_MEMORY,
               pa);  // address of a pagelist
```

The pagelist atomically maps a set of memory ranges with read, write and execute permissions.

Generate a **synthetic page fault** on policy violation.

Executable permission(s)

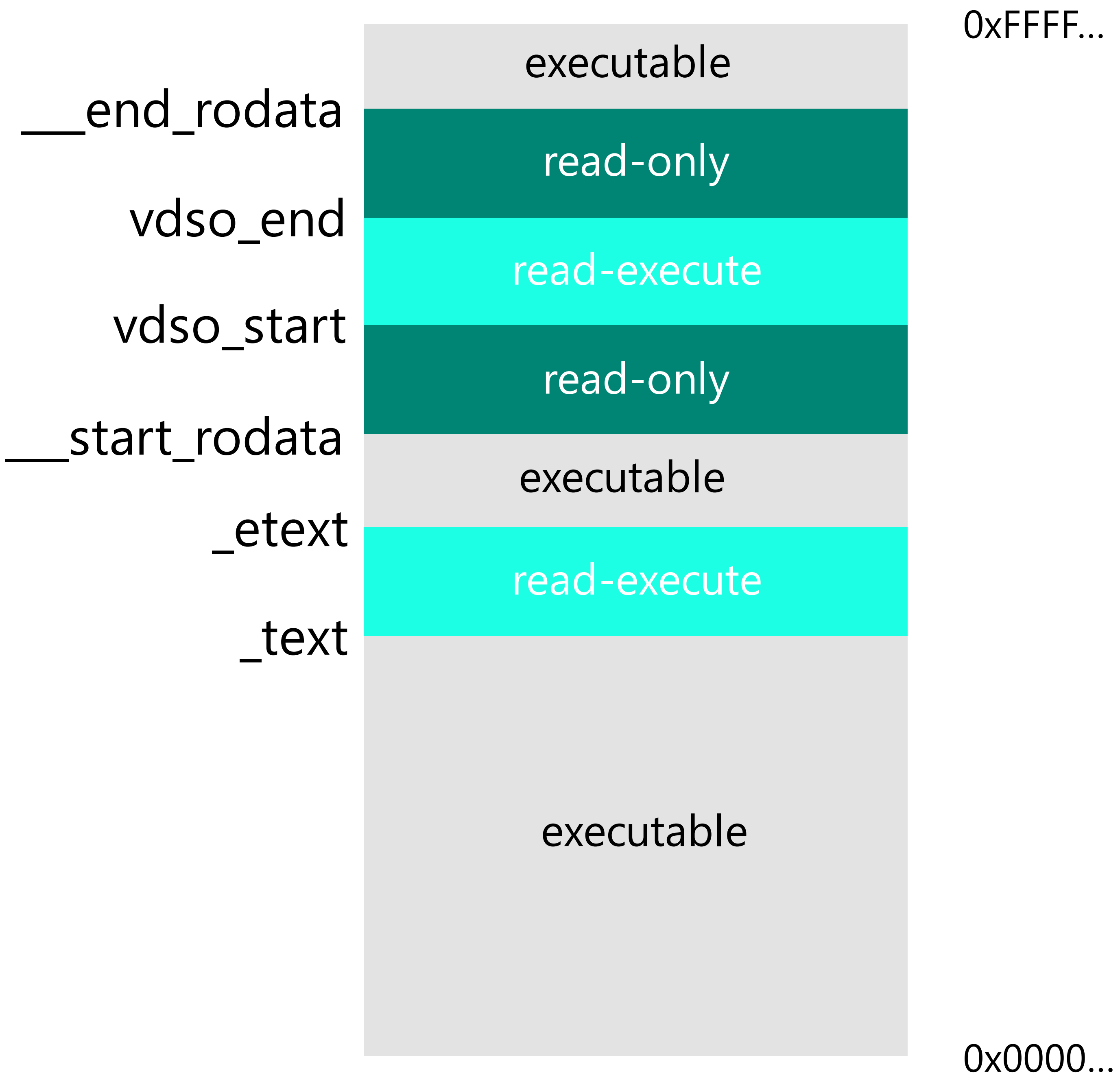
<u>Issue</u>: efficiently enforce restriction on kernel executable pages without impacting access to user space pages

<u>Solution</u>: leverage Intel's Mode Based Execution Control (**MBEC**)

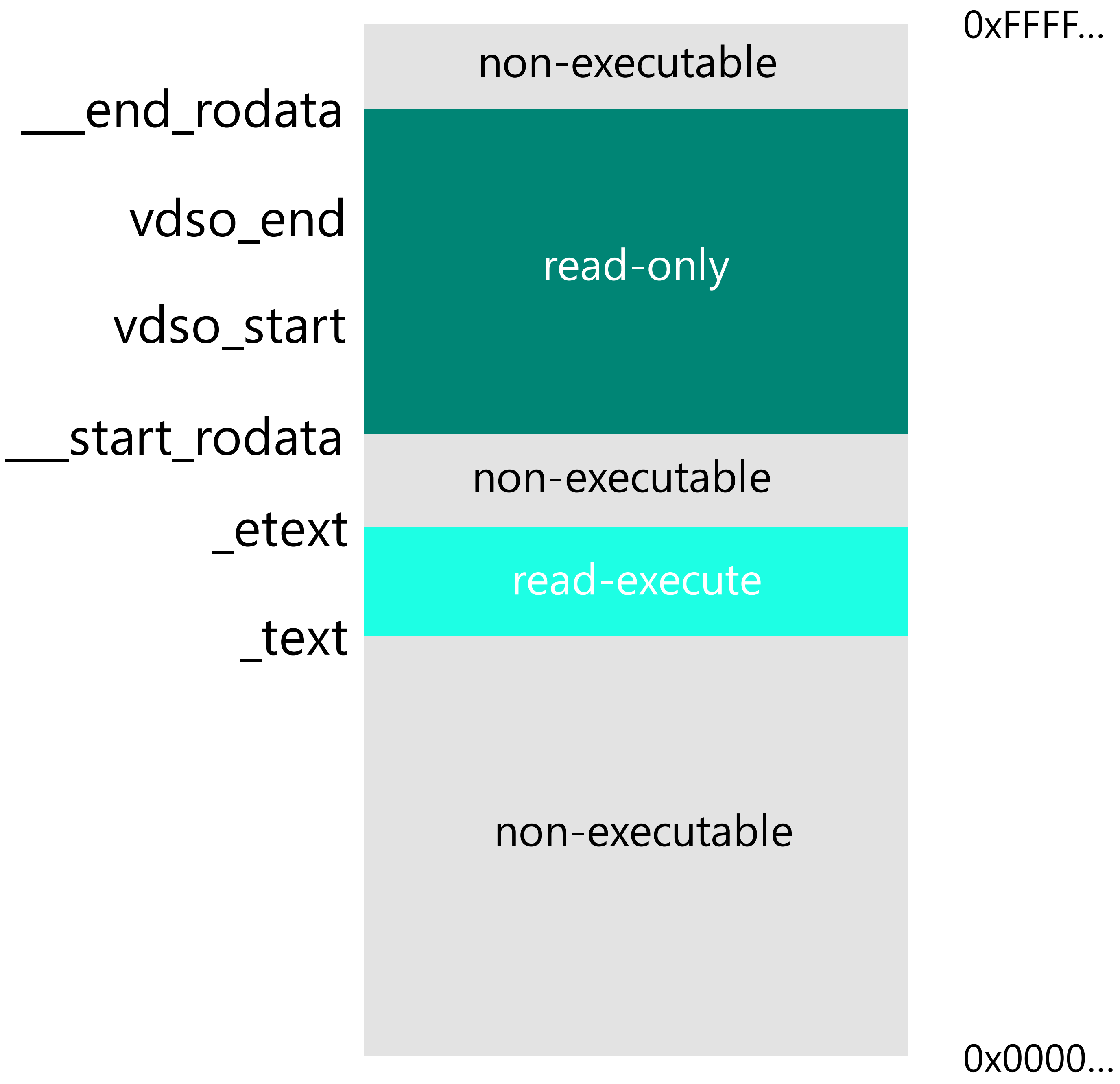
Split the execution permission into:

- Kernel mode execution
- User mode execution

Kernel memory permissions without MBEC



Kernel memory permissions with MBEC



Code

https://github.com/heki-linux/linux

branch heki-v2

Wrap up

KVM and Hyper-V supports:

- defense-in-depth mechanism leveraging hardware virtualization
- common API layer across hypervisors

Any feedback?

https://github.com/heki-linux

Q&A

Thank you

Demo: control-register pinning (SMEP)

```
user@heki-host$
```

```c
static void heki_test_cr_disable_smep(struct kunit *test)
{
	unsigned long cr4;

	/* SMEP should be initially enabled. */
	KUNIT_ASSERT_TRUE(test, __read_cr4() & X86_CR4_SMEP);

	kunit_warn(test,
		   "Starting control register pinning tests with SMEP check\n")
;

	/*
	 * Trying to disable SMEP, bypassing kernel self-protection by not
	 * using cr4_clear_bits(X86_CR4_SMEP).
	 */
	cr4 = __read_cr4() & ~X86_CR4_SMEP;
	asm volatile("mov %0,%%cr4" : "+r"(cr4) : : "memory");

	/* SMEP should still be enabled. */
	KUNIT_ASSERT_TRUE(test, __read_cr4() & X86_CR4_SMEP);
                                                      62,2-9        25%
```