# Protected Execution Facility:

Secure computing for Linux on Power
and OpenPower

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IBM

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# Contents

# Team

- IBM Research, IBM  Cognitive Systems (POWER) including Linux Technology Centers.
- Our objective is to deliver the technology to the Power and OpenPower communities.
- Those involved in updating (patches) existing components and developing new components and tools will be pushing their commits to GitHub.

# Security Challenges

## Increased prevalence of multi-tenant and cloud computing models amplifies security concerns

- It is increasingly hard to verify the provenance and correctness of all software components like hypervisors, operating systems, privileged SW, etc.
- Components of these systems provide a large attack surface
- Unfortunately, these components can also contain a number of vulnerabilities and zero-day attacks

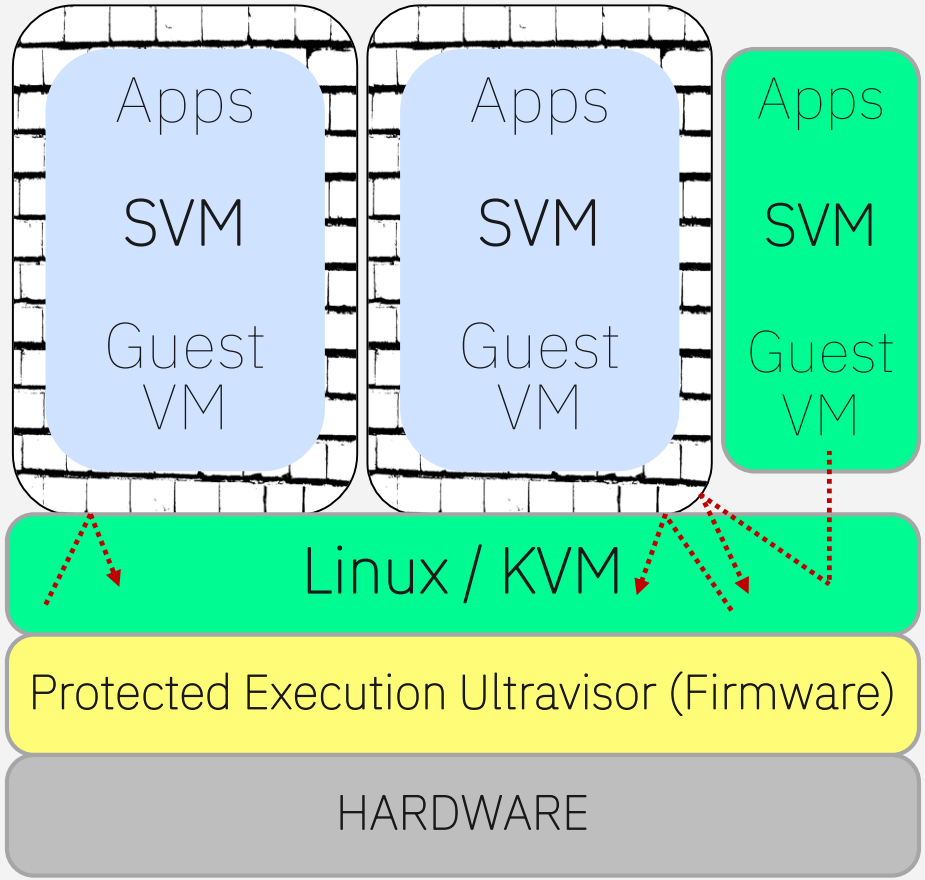
## Objectives

- Minimize the hardware and software that needs to be trusted - the TCB
- Provide provable protection against insider attacks: Malicious, “curious” or ”careless” administrators

# Protected Execution Facility

Provides protection for sensitive code and data:

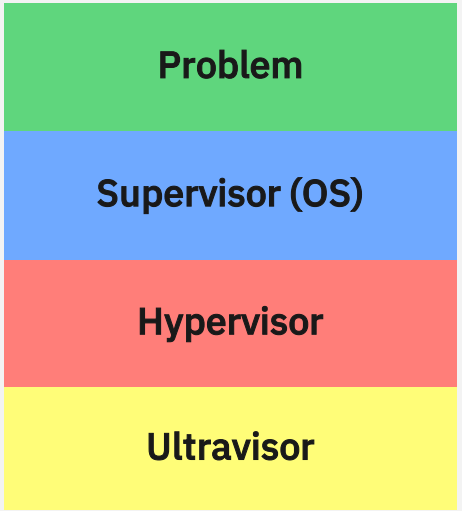
- From other software (applications, systems software)
- Rogue administrators
- Compromised hypervisor
- While in transit, executing, or stored on disk



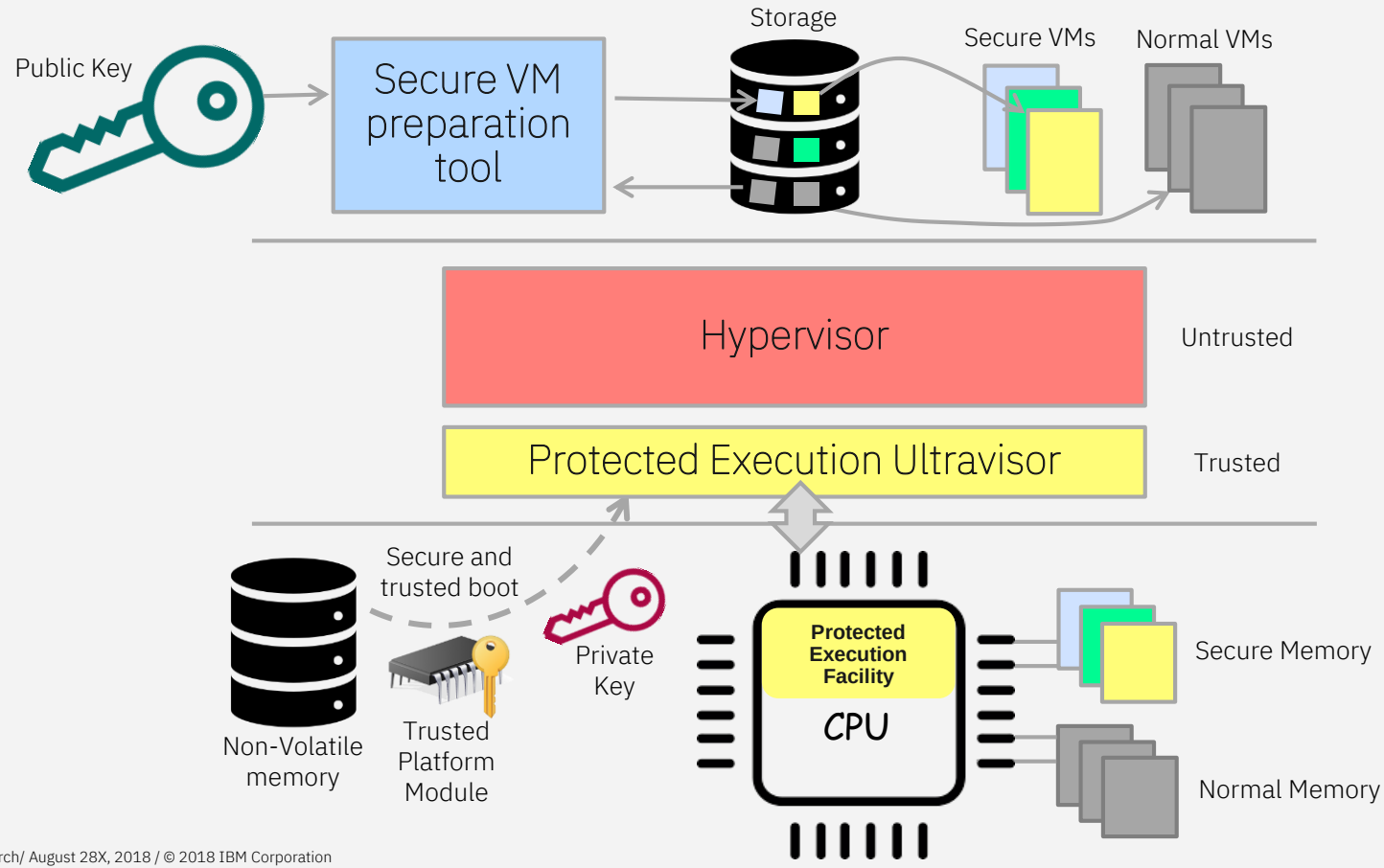
# Architecture Overview

# Base Principles

- Protect integrity and confidentiality of code and data
- Minimize the trusted computing base (TCB)
  - Processor (hardware changes), TPM, and Firmware (Ultravisor)
- Introduce Secure Memory, only accessible by secure VMs and Ultravisor
- Introduce new Power processor mode: “Ultravisor mode”
  - Higher privileged than hypervisor mode
  - Hardware and firmware are used to manage the new security feature
- Enable secure virtual machines (SVMs)
  - Normal VMs run on the same hardware



# Overview of architecture



# Overview of architecture

- Protected Execution facility refers to the changes made to Power/OpenPower architecture
  - Each machine has a public private key pair
- Protected Execution Ultravisor is the firmware (which will be open source) part
- Secure VMs (SVM) and Normal VMs run on the same hardware
- Creating an SVM requires new tooling that will be open source
- SVMs execute in secure memory which is under the control of the Ultravisor
- The hypervisor and normal VMs cannot reference secure memory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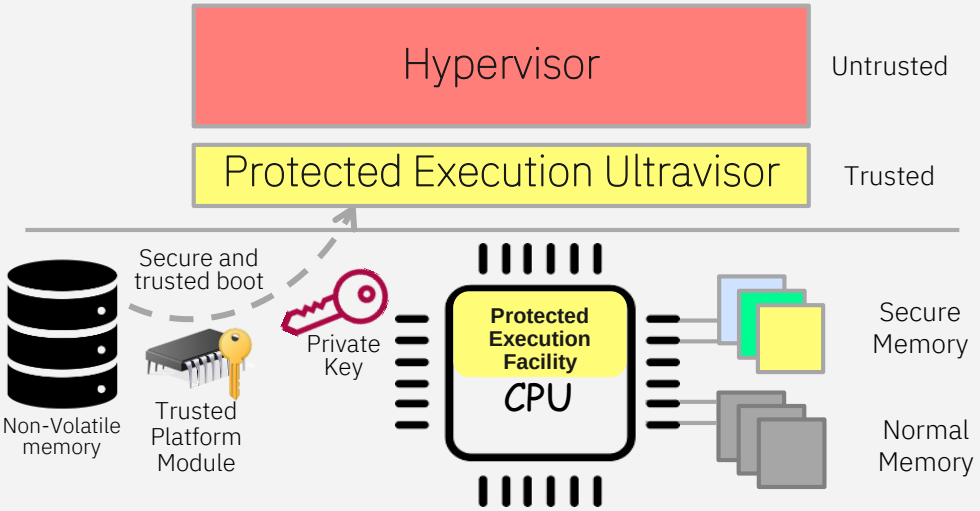
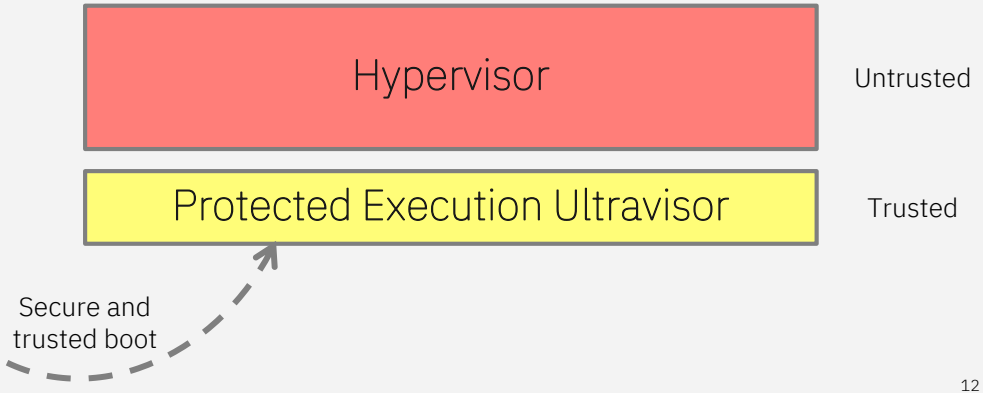
# Architecture at the hardware/firmware level

- The private key of the machine remains in the TPM. The Ultravisor uses the private key for decrypting parts of the SVM.
  - Ultravisor uses a secure channel to talk to the TPM
- The hardware separates memory into secure memory and normal memory
  - Only software running in secure mode can access secure memory
  - After boot, only the SVMs and Ultravisor run in secure mode
- When an ESM call is received, if the calling SVM has not been modified, the Ultravisor will transition it to secure mode



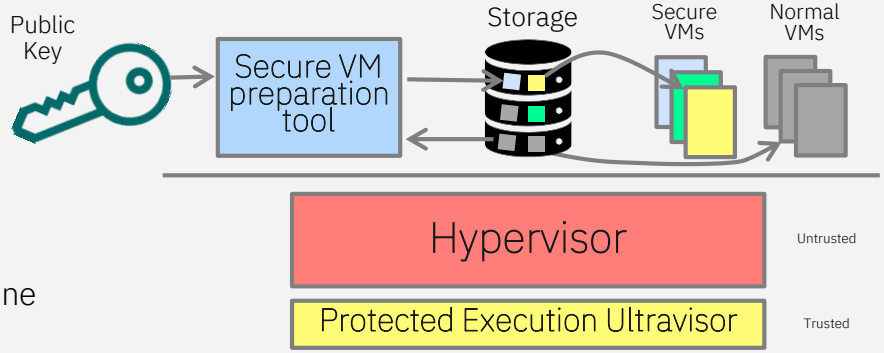
# Architecture  implication for the hypervisor

- The Ultravisor is higher privileged than the hypervisor.
- The hypervisor (Linux/KVM) has to be para virtualized to operate properly with the Ultravisor.
  - Most of these changes are in the architecture dependent sections of the hypervisor
- If the hypervisor needs to update the partitioned scoped page table it will have to ask the Ultravisor for assistance.
- If the hypervisor is returning to a SVM it will have to ask the Ultravisor to complete the return.
- HMM will be updated to help manage secure memory



# Architecture at the VM level

- Secure VMs (SVMs) and Normal VMs run on the same hardware. GRUB is boot loader.
- SVMs and VMs both get services from the hypervisor
  - All hypervisor calls from an SVM go to the Ultravisor which saves and protects state before reflecting the call to the hypervisor.
  - An SVM can share unprotected memory with the hypervisor
- SVMs are created with new tooling.
  - The creator of an SVM supplies the public key of every machine that the SVM is authorized to run on.
- Secure VMs start executing as a normal VM and, at the proper time, use a new syscall instruction directed to the Ultravisor to transition into secure mode.



# Limitations

**First release**

- Will not support
  - Suspend
  - Resume
  - Migration
  - Over commit of SVM memory
  - Dedicated devices to SVMs

**Protected Execution Facility does not support**

- Transaction memory
- VM that use transaction memory if converted to SVMs may crash while executing
  - If the tooling can detect that TM is required the conversion will fail.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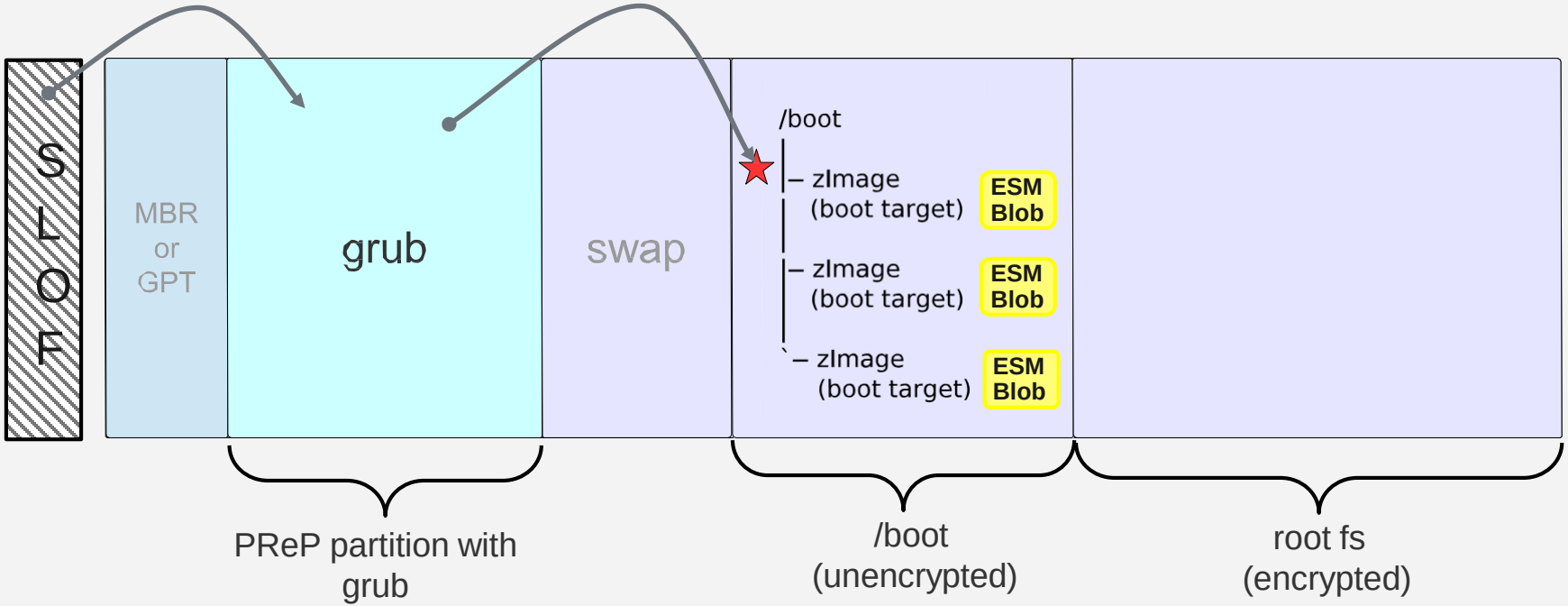
# **Lower Level Details:**
SVM, interfaces, kernel and hardware

# SVM format and Booting

- Target OS kernels/initramfs in /boot are converted to zImage+ESM Blob
- Run “grub2-mkconfig” to point to new boot targets
- Target zimage provides information for Ultravisor to move VM into secure memory



# Boot Changes

**prom_init**

- Changes proposed to ensure that prom_init does not make changes components of the SVM and cause it to fail integrity checks

http://linuxppc.10917.n7.nabble.com/no-subject-td138496.html#a138497

**Wrapper**

- Changes proposed to enable an ESM Blob to be added to a pseries zImage

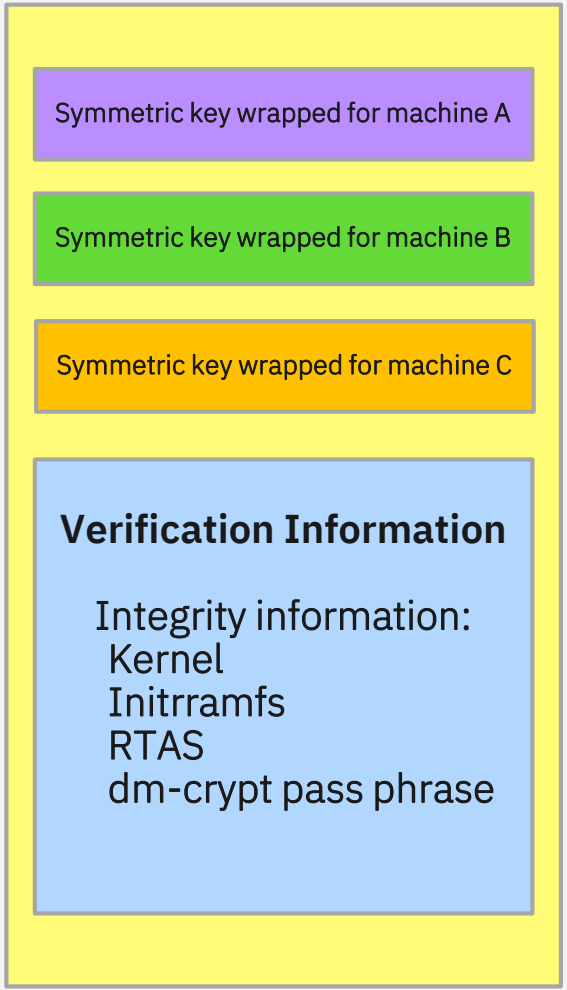
http://linuxppc.10917.n7.nabble.com/RFC-PATCH-powerpc-Add-support-for-adding-an-ESM-blob-to-the-zImage-wrapper-td138507.html

**grub2-mkconfig**

- Patch needed in grub2-mkconfig to discover and configure zImage targets

# Contents of ESM blob

Symmetric key encrypted by one or more public keys and the verification information.



# Interfaces to the Ultravisor: ultra calls

An ultra  call is a syscall instruction with Lev=2

These are the currently defined calls:

- UV_READ _SCOM
- UV_WRITE_SCO
- UV_REGISTER_STOP_STATE
- UV_RESTRICTED_SPR_WRITE
- UV_PAVE_OUT
- UV_PAGE_IN
- UV_PAGE_INVAL
- UV_WRITE_PATE
- UV_RETURN
- UV_REGISTER_MEM_SLOT
- UV_UNREGISTER_MEM_SLOT
- UV_SVM_TERMINATE
- UV_SHARE_PAGE
- UV_UNSHARE_PAGE
- UV_ESM

There probably will be changes to this list as we move forward

# KVM Changes

**New h-calls needed in KVM**

Several new h-calls need to be added to KVM to support the Ultravisor initially:

- H_SVM_INIT_START and H_SVM_INIT_DONE
- H_SVM_TERMINATE
- H_SVM_PAGE_IN and H_SVM_PAGE_OUT
- H_TPM_COMM

Other additions may be required.

**HMM-UV**

An additional ppc-specific driver is required for Ultravisor that exposes the secure memory management to the hypervisor (KVM)

- These changes are in addition to the HMM driver accepted in 4.18-rc6

Initial code is going through review/integration testing and is expected to be posted for external review in September 2018

# Kernel Changes

**virtio**

Changes needed to set up non-secure memory regions and establish bounce buffers in those regions to facilitate virtual I/O flow for SVMs

Proposed changes have been posted as RFC at https://lkml.org/lkml/2018/7/20/30

**VPA**

Changes needed to set up non-secure memory regions and establish private areas for communication between the hypervisor (KVM) and the SVM

Initial/proposed code developed and under discussion internally. Post to external community for discussion expected in August 2018

# Brief introduction to some of the hardware changes

An address bit indicates a reference to secure memory

- Amount of secure memory is configurable

The $MSR_S$ bit indicate running process is secure

MSR $_{S\ HV\ PR}$ determine privilege

Secure

| S | HV | PR | |
|---|---|---|---|
| 1 | 0 | 0 | privileged |
| 1 | 0 | 1 | problem |
| 1 | 1 | 0 | ultravisor |
| 1 | 1 | 1 | (reserved) |

Normal

| S | HV | PR | |
|---|---|---|---|
| 0 | 0 | 0 | privileged |
| 0 | 0 | 1 | problem |
| 0 | 1 | 0 | hypervisor |
| 0 | 1 | 1 | problem |

New registers

- SMFCTRL
- URMOR, USRR0, USRR1, USPRG0, USPRG1

New instruction

- URFID

When $MSR_S$=1, running either the Ultravisor or a secure VM in privilege or problem state.

- All hypervisor calls and interrupts go to the Ultravisor.
- Asynchronous interrupts go to the Ultravisor and are reflected to the hypervisor

# Summary

# Secure Execution Technologies

Minimal work for exiting code

Changes or additional work

Differing approaches to feature

| Step/decision | IBM | AMD | Intel | ARM |
|---|---|---|---|---|
| Name | Protected execution facility | Secure Encrypted Virtualization | Software Guard Extensions | TrustZone |
| Protection | Vulnerable HV, other software, system admin | Physical, vulnerable HV, other software, system admin | Physical, vulnerable HV, other software, system admin | From non secure world |
| Security Domain | VM/Container | VM/Container | Enclave | Secure World |
| Application | No Changes | No Changes | Software changes to use enclave | No Changes |
| Guest OS | changes to exploit | Guest manages encrypted memory pages | Software changes to use enclave | N/A |
| Hypervisor | KVM must be para virtualized | Software changes for keys, etc. | Software changes to use enclave | N/A |
| Secure Memory | Privilege protection | Encrypted | Encrypted | Privilege protection |
| Secure memory Integrity | Yes | No | Yes | N/A |
| Embedded Secrets | Yes | Yes | No | Yes? |

# Value of Protected Execution Facility

- Protects a Secure VM against attacks
- Smaller TCB (Trusted Computing Base) leads to reduced attack surface
- Open Source ecosystem
- Integration with Trusted Computing Tooling
- No limitations in amount of protected memory, no need to change application code, etc.

# Relevant IBM secure processor products and Research

## IBM 4758 cryptographic co-processor

- And it Successors: https://www-03.ibm.com/security/cryptocards/pciecc2/pdf/4767_PCIe_Data_Sheet.pdf

## IBM “Secure Blue” Secure Processor Technology

- https://researcher.watson.ibm.com/researcher/view_page.php?id=6904

## SecureBlue++/

- http://link.springer.com/chapter/10.1007%2F978-3-642-21599-5_13

## Secure Service Container secure execution technology on IBM Linux one

- https://www-03.ibm.com/press/us/en/pressrelease/53129.wss

## Access Control Monitor (ACM): Hardware-Support for end-to-end Trust

- Research project funded by US (DHS/AFRL) and Canadian governments
- Final Report: http://www.dtic.mil/dtic/tr/fulltext/u2/1026470.pdf