Nesting Secure Hosts

Secure VMs in nested hypervisors

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Notes

- My experiences with this topic are s390x / IBM Z centric

➔ **If you want to know if something can be implemented in architectures other than s390, then please reach out to the respective developers and maintainers**

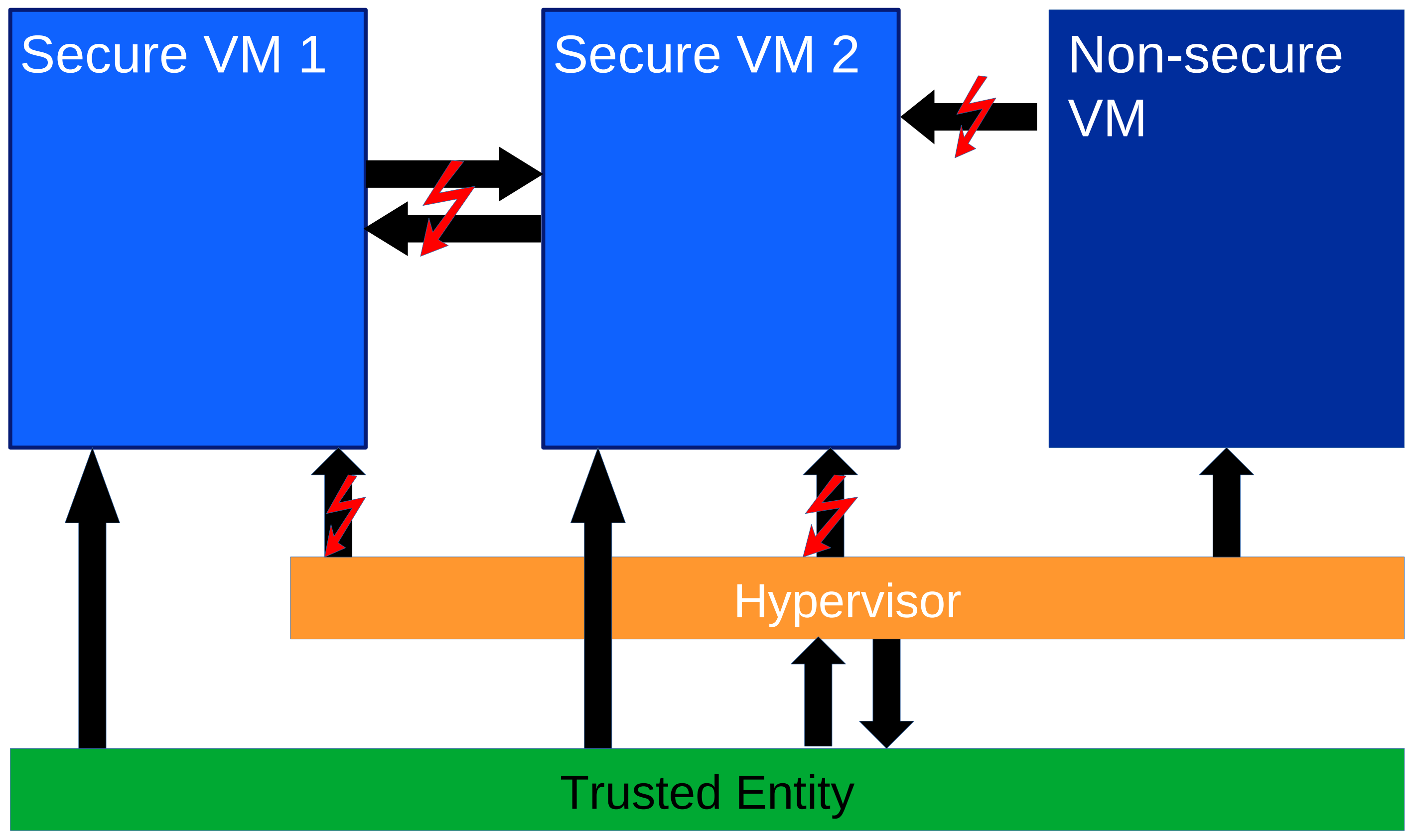
Contents

Introduction

Recap – Secure VMs

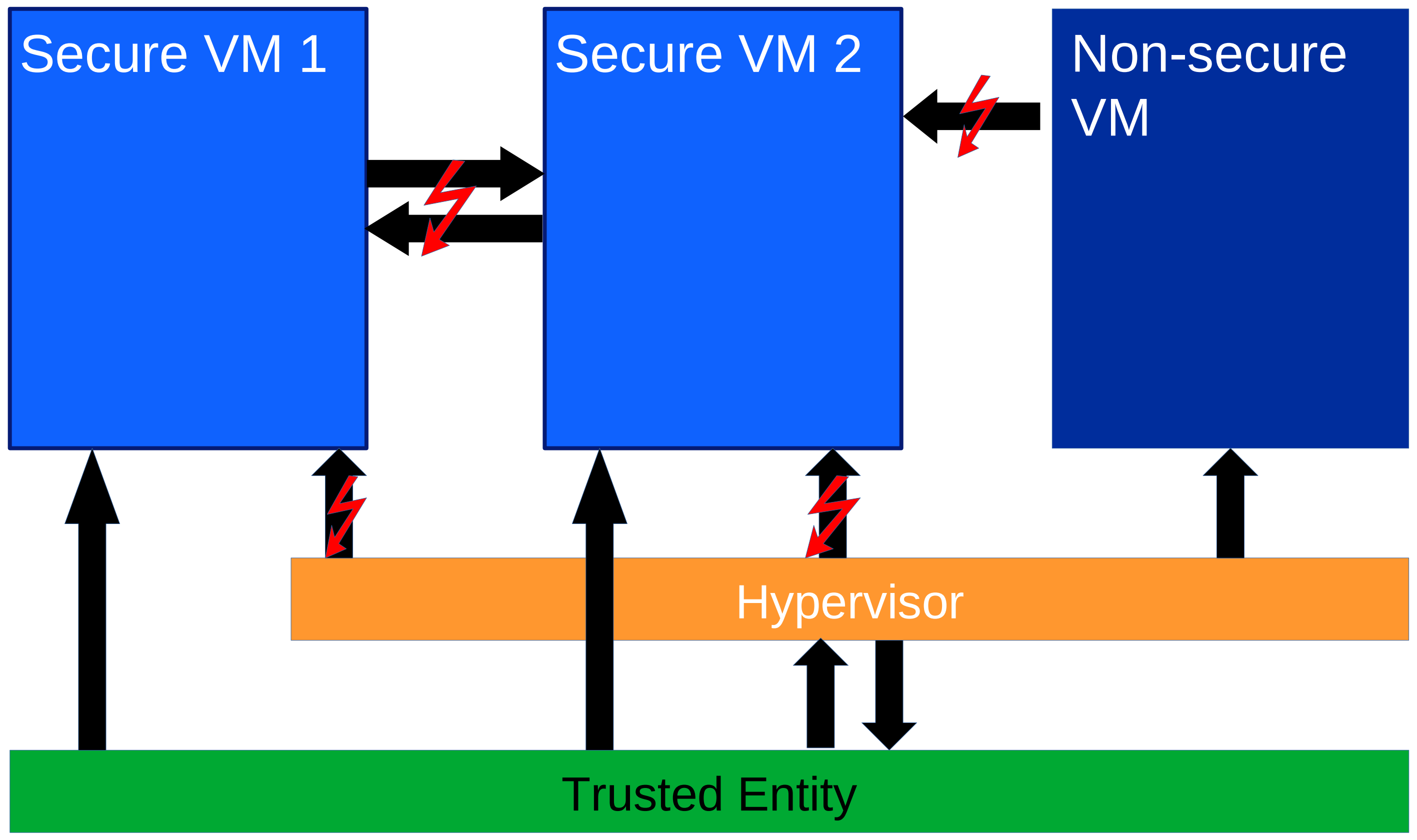
- VM sensitive state: Registers, memory, IRQs, …
- Secure VM’s sensitive state is not accessible from the OS / hypervisor
- Confidentiality and often also integrity protection

- A Trusted Entity manages sensitive VM data
- Hypervisor cooperates with the Trusted Entity to run secure VMs
- Confidential VM == Secure VM



Recap – Secure VMs

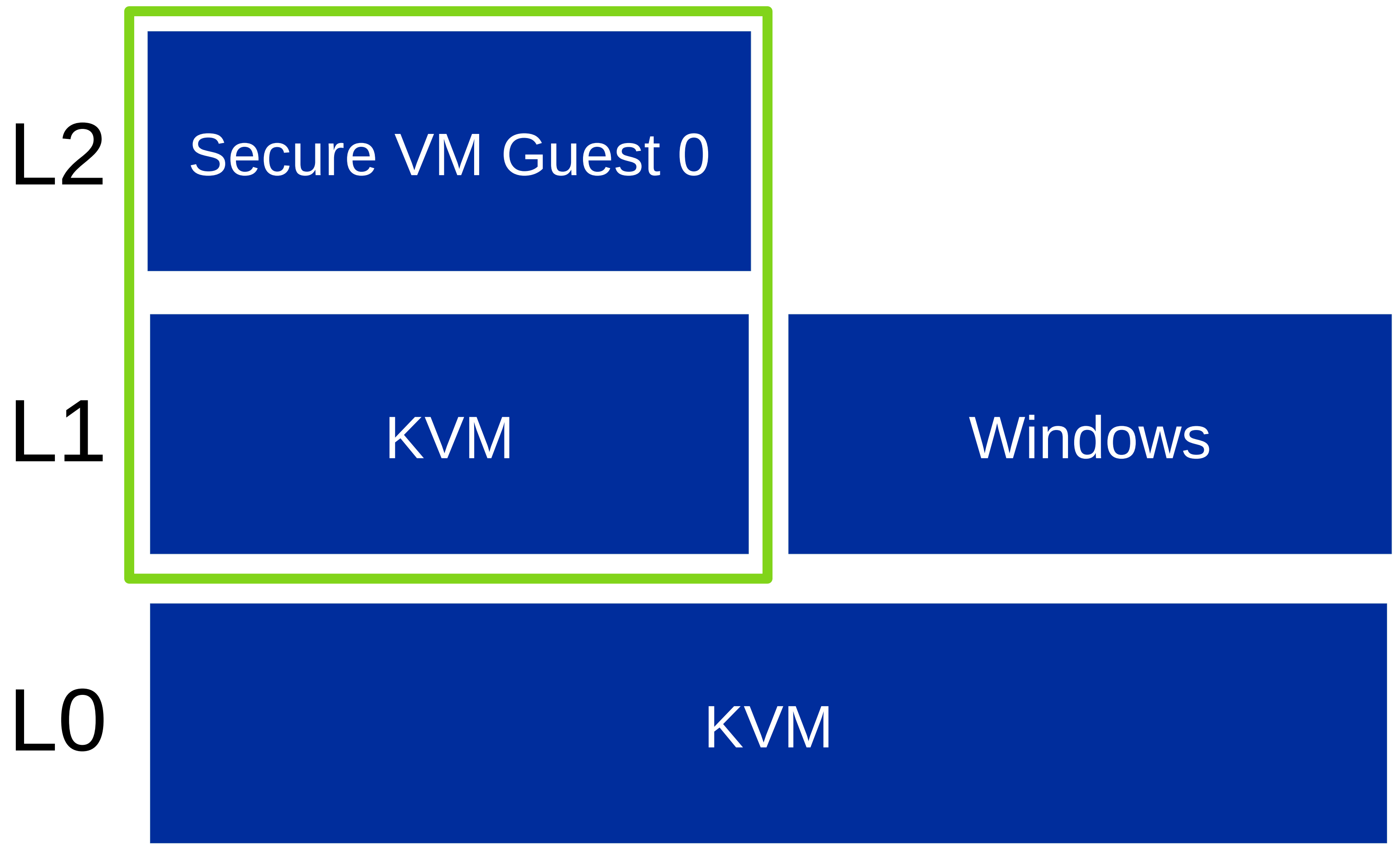
- AMD SEV
- Intel® TDX
- IBM® Z Secure Execution
- IBM® POWER Protected Execution



What are we talking about?

A KVM VM being a host for a secure VM.

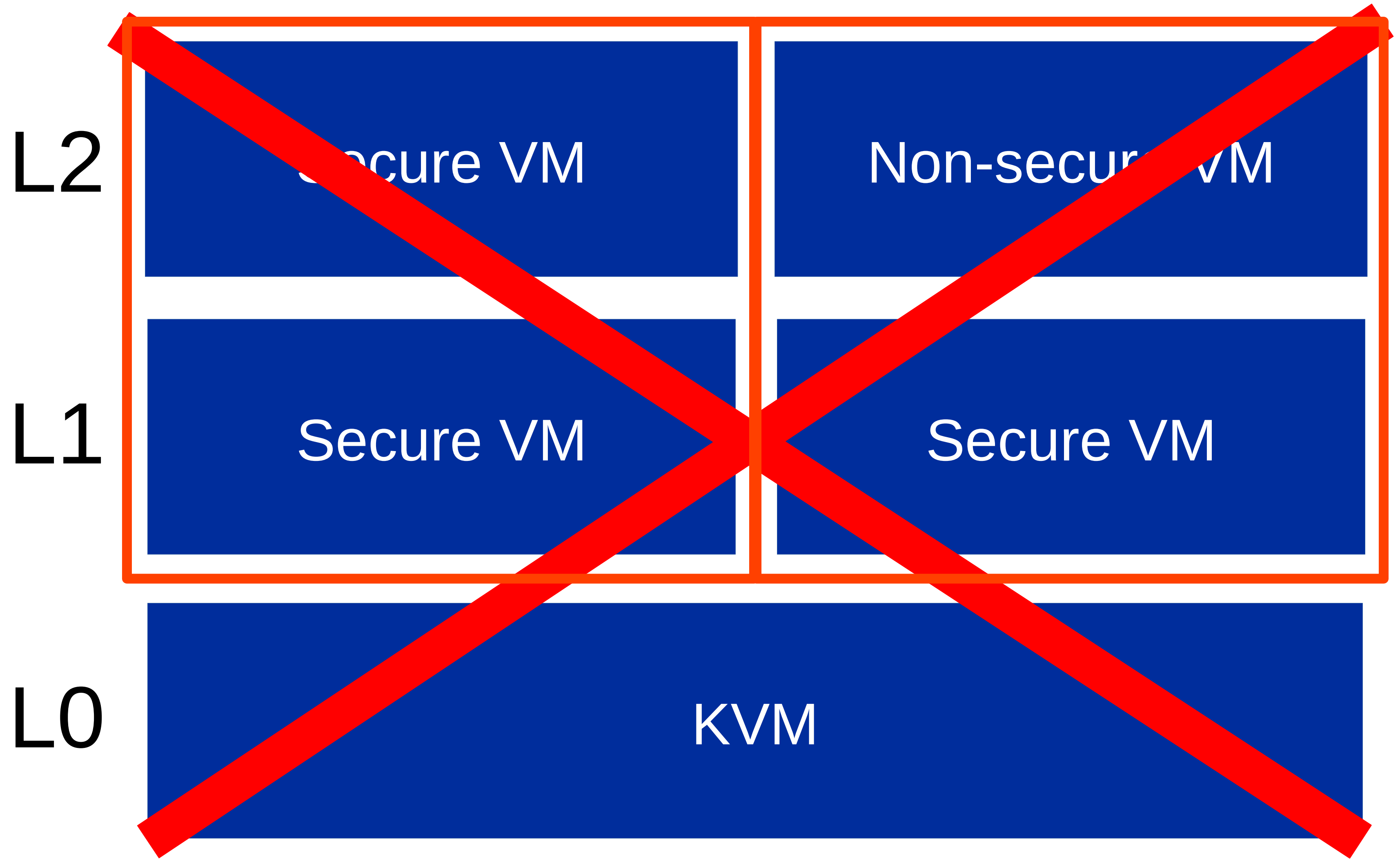
A secure VM being run as a nested guest.



What are we NOT talking about?

We’re not talking about a secure VM being a VM host to:

- Non-secure VM
- Secure VM



What are we NOT talking about?

Nesting works by reading and modifying guest memory in order to emulate virtualization.

But secure VMs don’t allow memory access:

- Nesting secure VMs would only be possible with hardware and Trusted Entity support
- Adding that native nesting support would mean a **massive development effort**

Why?

Use cases are not different from non-secure use cases:

- Hypervisor & test development
- Moving complete computing environments into the cloud
  - Making KVM hosts manageable without hardware access
  - Usage of VM or container management tools

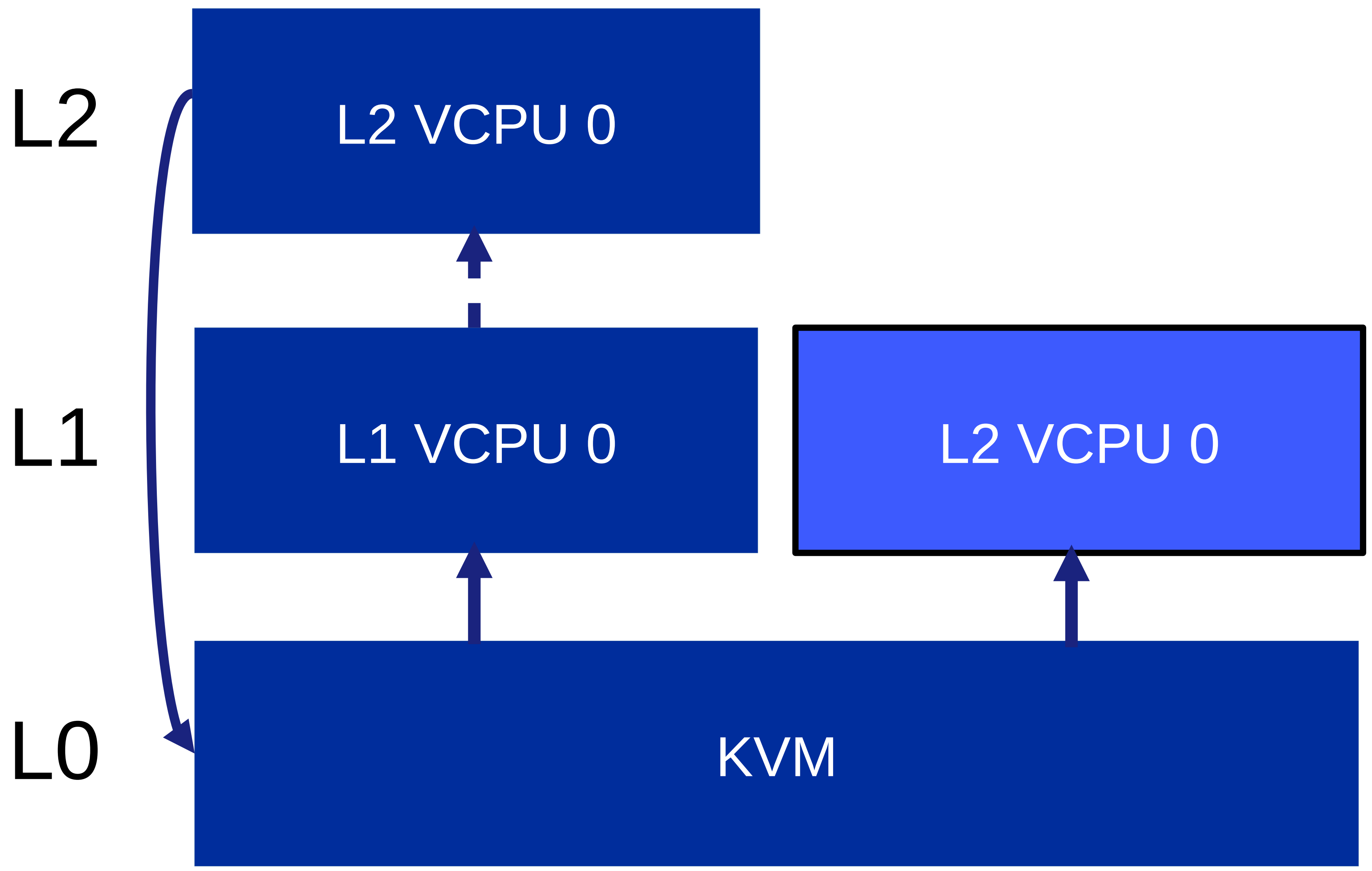
How

Nesting

- Three parts
  - Secure VCPU nesting
  - Trusted Entity ABI emulation
  - Architecture compliance

Nesting - VCPU

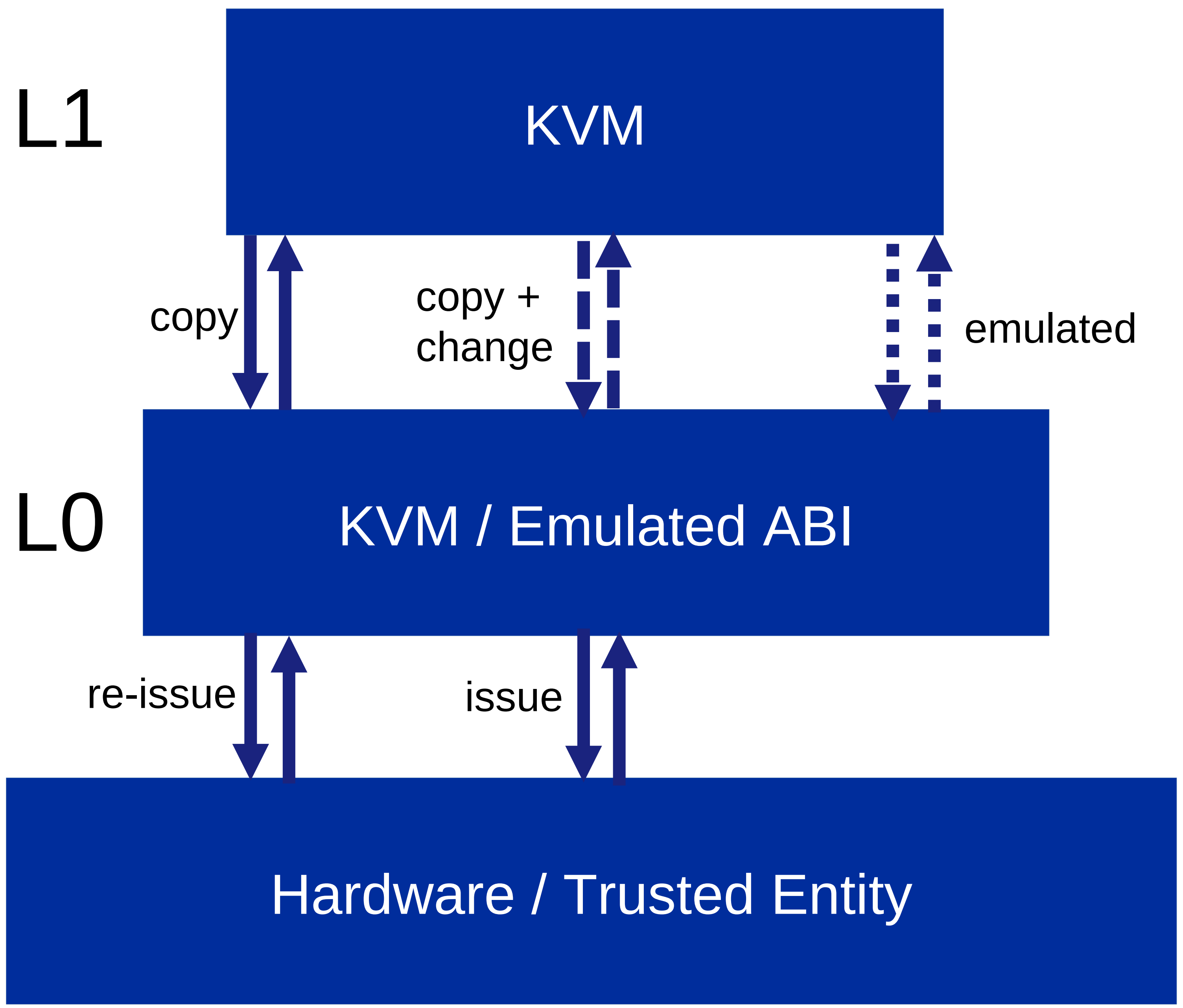
- Running a nested VCPU is a solved problem
  1) The Level 1 VCPU exits to Level 0 KVM when Level 1 tries to run a nested VCPU
  2) KVM shadows the nested VCPU control structures
  3) The shadow control structure is used to run the nested Level 2 VCPU as a normal Level 1 VCPU
- Nesting secure VCPUs is relatively easy if that concept can be maintained



Nesting - ABI emulation

- Emulation of the Level 1 ABI is done by re-using the Level 0 Trusted Entity ABI
- Level 0 KVM tracks secure entities for each Level 1 secure host
- Level 1 ABI requests are then modified so the Level 0 Trusted Entity understands them

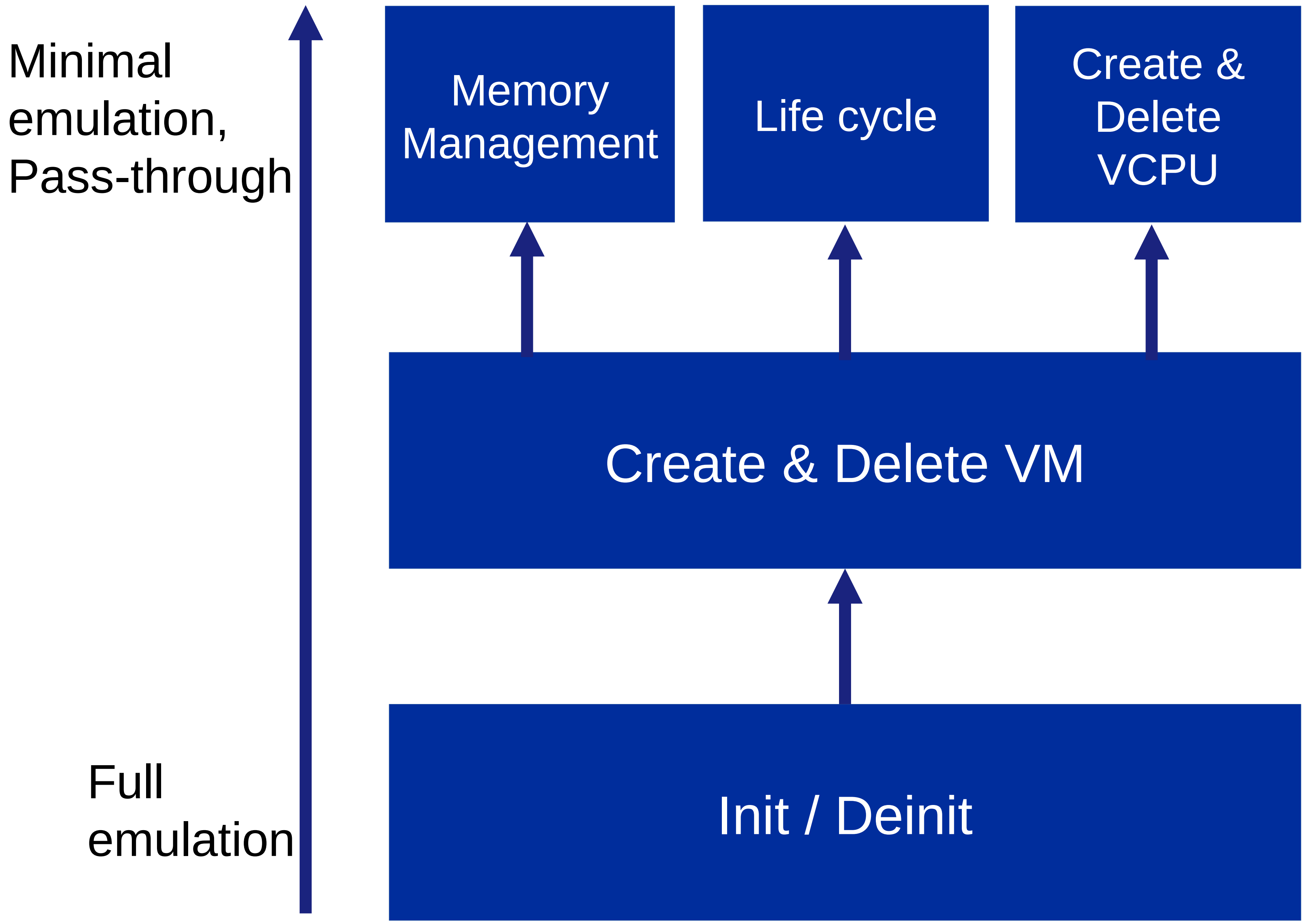
- Some ABI calls can potentially be passed through
- Most are executed with heavily modified data
- A small amount is fully emulated



Nesting - ABI emulation

- Trusted Entity calls can be sorted into the following categories:
  - Initialization & teardown of the Trusted Entity
  - VM management
  - VCPU management
  - VM memory management
  - VM life cycle calls (Dump, resets, IRQs)

  - **The interface is hierarchical**
  - **We tend to need less emulation the higher we go**

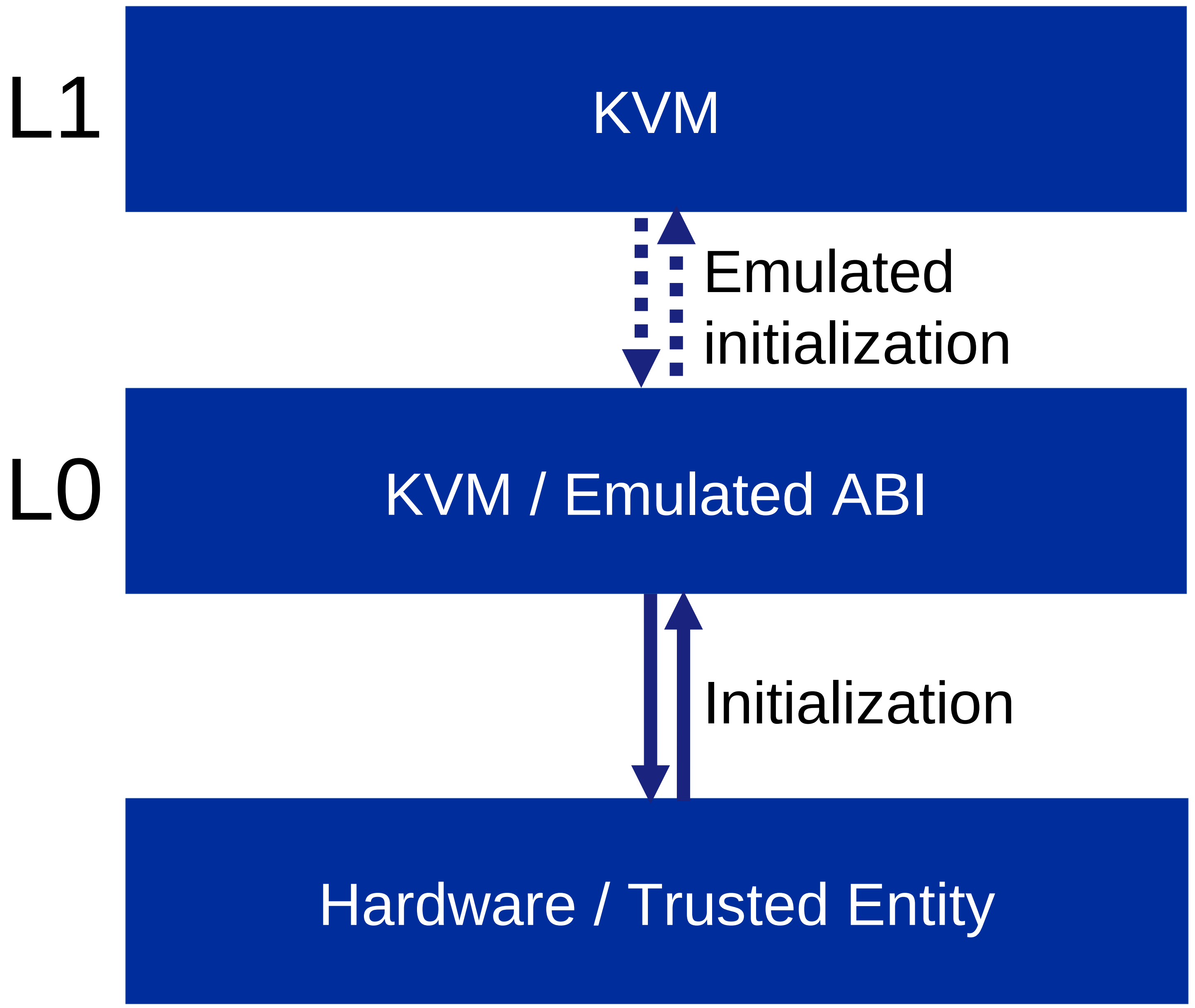


*Approximation of interface

Emulation

Trusted Entity ABI emulation – Host environment

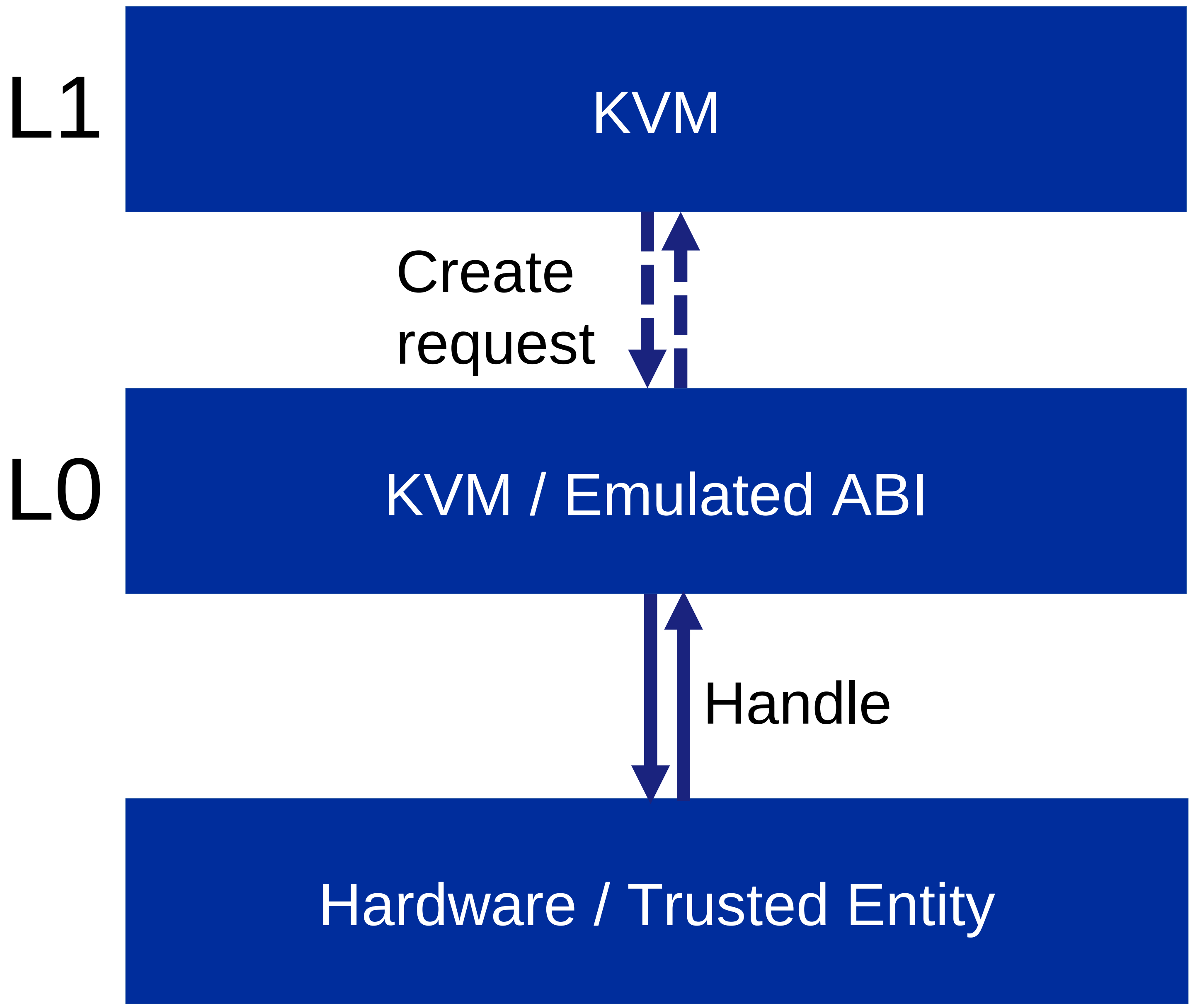
- Trusted Entity has to be initialized in order to create and manage secure VMs
  - S390 Initalize Ultravisor call
  - AMD SEV INIT & SHUTDOWN commands
  - Intel® TDX TDH.SYS.INIT & TDX TDH.SYS.SHUTDOWN
- Level 0 initializes TE on boot or when KVM is loaded
- Therefore these ABI calls will likely be fully emulated for Level 1
- Further configuration of the TE might be a major hurdle to emulation (FW update, key management)



Trusted Entity ABI emulation – VM management

- Secure VMs and their VCPUs are created via ABI calls
- The Trusted Entity will return a handle (s390x, AMD) or an address is used as handle (Intel®)
- The handle is the identifier of the secure VM / VCPU for all following ABI calls

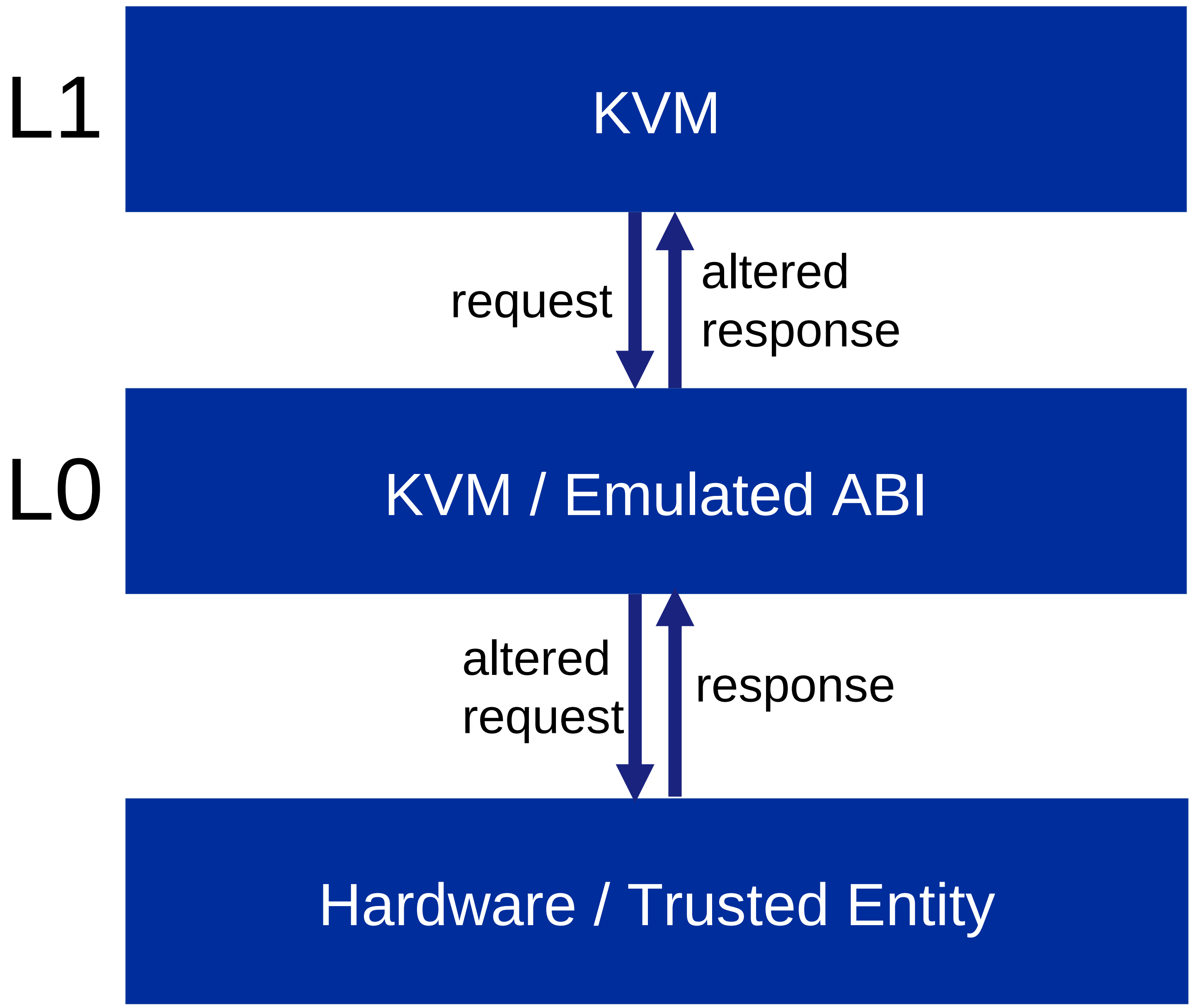
- These calls are re-issued with manipulated data for emulation
- Passing the handles on has its benefits
  - Calls with only the handle as input can likely be passed through unmodified
  - No mapping of emulated handles to real handles



Trusted Entity ABI emulation – Lifecycle calls

- Examples:
  - VCPU state registration (running, stopped)
  - Resets of VM state
  - Dump
  - Migration

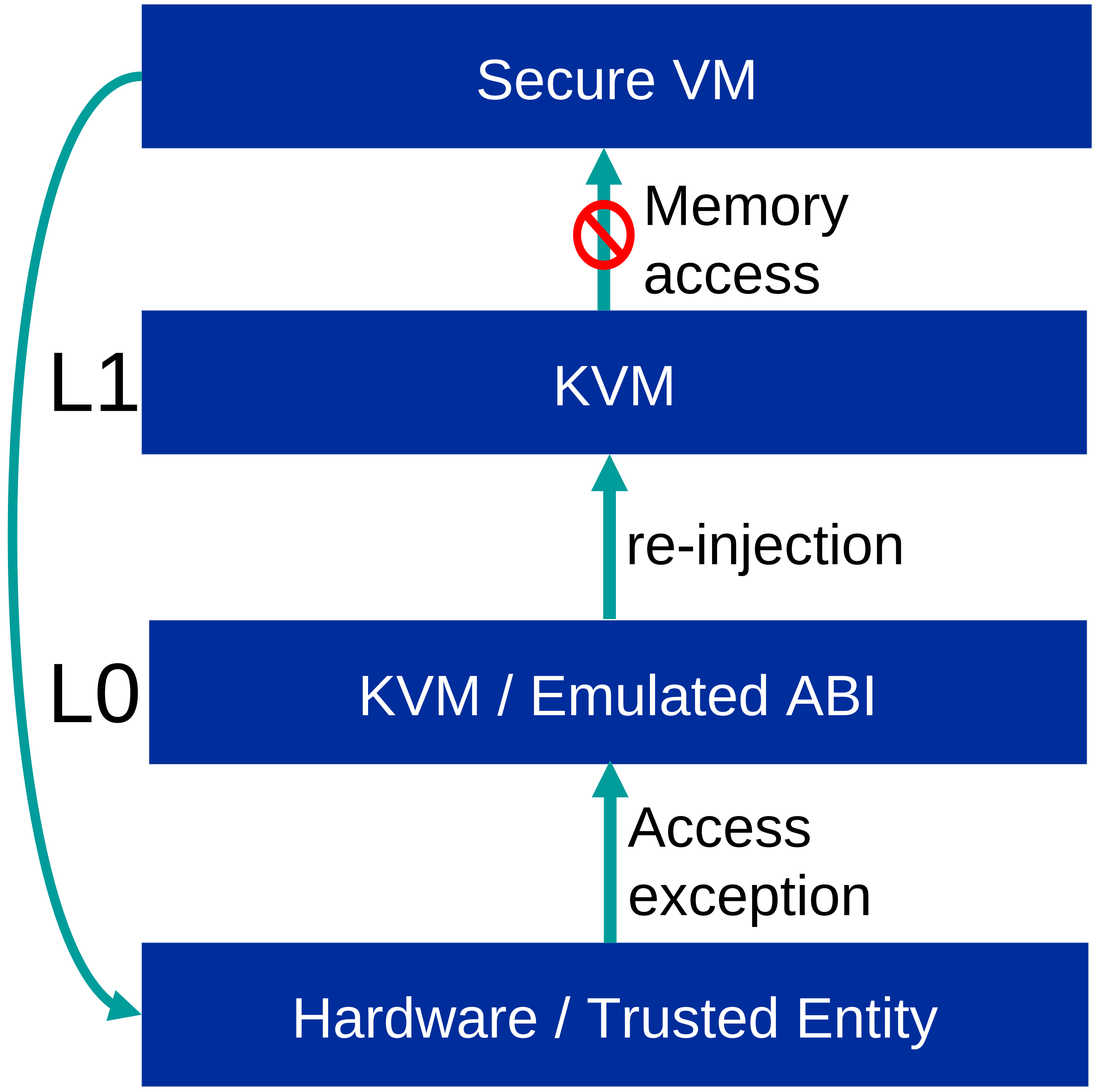
- Most of these are pretty easy to handle
- Especially if the data is only handle + command
- If addresses are involved they will have to be translated or bounce buffered



Architecture Compliance

Architecture Compliance – memory protection

- Secure VM memory is protected against all external accesses
- Protection can be provided via access exceptions
- Depending on architecture, we may need to re-inject access exception into the KVM host



Architecture Compliance – TE structure access

- Some architectures define specific memory areas as owned by the Trusted Entity
- It stores management data for secure VMs or its global state in there
- Once Trusted Entity takes ownership of a memory area any OS access is denied

➔ To fully emulate the architecture KVM needs to restrict access to emulated trusted entity structures

➔ Which means tracking them and removing the possibility of access

Architecture Compliance – TE structure access

- Donations could be disabled entirely
- But then there’s no way for the emulated ABI to re-gain the memory it needs to donate to the real Trusted Entity in order to emulate ABI calls
- Also those donations limit the amount of secure resources that can be created

Problems

Required virtualization features

- Secure VMs often require the usage of virtualization enhancement facilities
- Those facilities have initially been introduced to speed up virtualization
- But they also provide security because handling of sensitive things moves into Trusted Entity

- Examples:
  - Trusted Entity IRQ injection (exceptions, IO, signaling)
  - Trusted Entity handling of complex instructions

Required virtualization features

- Secure VM technology is a recent addition to the architecture
- No need (yet) to fence features
- Therefore enabling as many architecture features as possible made sense

But:

- ➔ Not all of those features are compatible with nesting
- ➔ This can’t be resolved without hardware and / or Trusted Entity changes

Page management

- Secure VMs have page integrity and (re-)map protection
- Page meta data is stored in some kind of table
- Trusted Entity maintains the table
- Hypervisors can request page mapping changes from Trusted Entity, e.g. to map a new page

➔ Every change request is emulated

➔ Each additional exit costs performance

Page management

- Fault driven secure memory management allows a few workarounds
- Pre-fault:
  - Most of the page map requests are processed at the start of a secure VM
  - With a bit of hypervisor code we could fault in and secure all memory in one go with a small number of exits
  - The two faults could be merged into one
    - Either by faulting automatically when making a page secure
    - Or by making a page secure when faulting it in

Migration

- Migration of a secure VM KVM host will be challenging
- Easier to re-create the nested KVM host and then migrate the secure VMs to it instead
- Re-creation would need to be implemented

➔ For now disabling migration of the host VM is more likely

Reboots

- Emulated Trusted Entity might need to be torn down on secure host reboot
- Need to catch sudden reboots of secure host VM
- ABI teardown interface can not be used

- ➔ Initialization and deinitialization are fully emulated
- ➔ Need to destroy all secure VCPUs and VMs via real Trusted Entity
- ➔ Can affect reboot times significantly

Reboots

- If an architecture uses memory donation there’s an additional step
- The access protection for every page of emulated donated storage will also need to be removed

Implementations

Implementations

- S390 has done experiments
  - S390 Trusted Entity ABI is small (currently 28 calls, some are guest only)
  - POC runs Linux secure guests and most KVM unit tests are green
  - It is not fully architecture compliant
  - Two weeks of initial work until Linux was booting / stable

- It will be a **lot** of code and testing
  - Lots of Trusted Entity ABI error checks
  - Each read or write accessing the nested secure VM host needs access exception handling
  - Lots of code to test

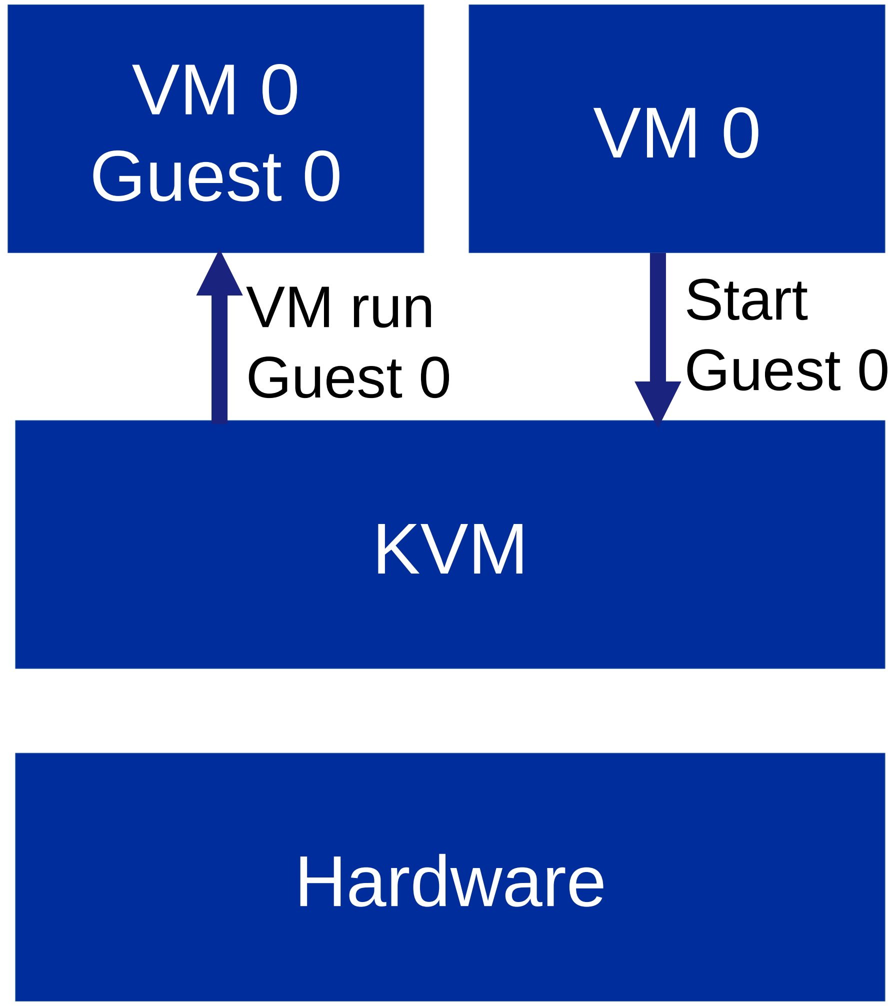
Implementations

S390 Proof of concept:

- 2k lines for KVM
  - 80% interface emulation
  - 10% memory management
  - 10% secure VCPU nesting
- Minimal QEMU changes
  - Feature enablement and indication
  - Migration blocker

Implementations

- Other solutions are providing a virtualization hosting interface
- A VM can request the host to start a VM (VSOCK, network, ...)
- The started VM is a de facto guest of the requesting VM



- ✓ Faster
- ✓ Easier access to host hardware
- ✓ Potentially only a userspace change
- ✗ Less flexible
- ✗ More host tracking

Addressing potential questions

- I wasn't able to measure the performance impact yet
- I haven't even thought about multilevel nesting
- The migration statement is a theoretical one as s390 doesn't support migration right now
- Is this possible on architecture xyz?
  - My current **guess** is that AMD SEV is the next best candidate
  - Encryption vs access protection shouldn't matter

Thank you

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