Nesting Secure Hosts
Secure VMs in nested hypervisors

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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
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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 Initialize 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 – 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
• 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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