Confidential Computing with AMD SEV-SNP

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INTRODUCING SEV-SNP

- ***Secure Nested Paging*** (SEV-SNP) is the latest generation of AMD Secure Encrypted Virtualization (SEV) technology designed for Confidential Computing

- SEV-SNP builds on existing AMD SEV and AMD SEV-ES (Encrypted State) features to provide ***stronger security, additional use models, and more*** to protected VMs
  - SEV and SEV-ES supported in 1st and 2nd generation AMD EPYC Processors (2017)
  - SEV-SNP supported starting in 3rd generation AMD EPYC Processors (2021)

- SEV-SNP is designed to protect a VM from a malicious hypervisor in specific ways
  - Useful in public cloud and any scenario where the hosting environment cannot be trusted

THREAT MODEL

AMD

- SEV-SNP is designed to protect the VM in specific ways
  - **Confidentiality** – Prevent hypervisor from reading guest data
  - **Integrity** – Prevent hypervisor from modifying/replaying guest data
  - **Physical Access** – Prevent “offline” physical attacks (e.g. cold-boot)
  - **Interrupt Control** – Prevent malicious interrupt injection
  - **CPUID** – Prevent hypervisor from lying about HW capabilities
  - **Certain Side Channels** – Prevent certain speculative side channel attacks

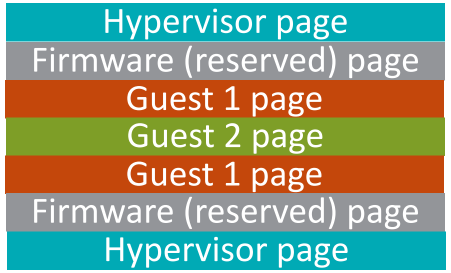
- SEV-SNP does not protect against certain attack vectors, including:
  - **Availability** – Hypervisor retains control of resource allocation and scheduling
  - **Advanced Physical Attacks** – Attacking voltage/data buses while system is running
  - **Certain Side Channels** – Including PRIME+PROBE, page fault side channels, etc.

- *SEV-SNP security is enforced via a combination of hardware and guest software*

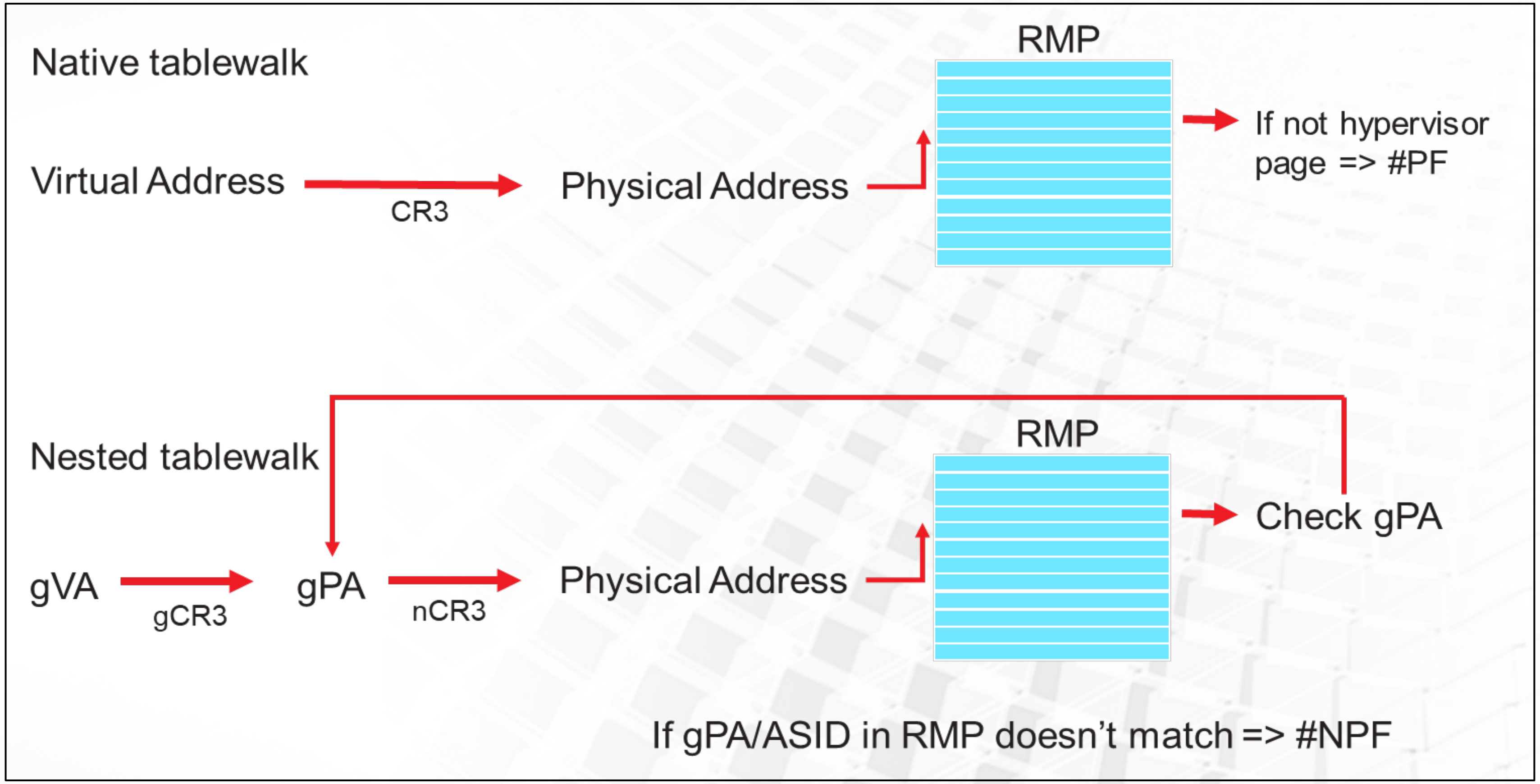
ENFORCING INTEGRITY

- Memory integrity is enforced using a new DRAM structure called the **Reverse Map Table (RMP)**
- There is 1 RMP for the entire system, it is created by software during boot
- Basic properties:
  - RMP contains 1 entry for every 4k of assignable memory
  - RMP is indexed by System Physical Address (SPA)
  - RMP entries may only be manipulated via new x86 instructions
- The RMP indicates **page ownership** and dictates write-ability. Examples:
  - A page assigned to a guest is only writeable by that guest
  - A page assigned to the hypervisor cannot be used as a private (encrypted) guest page
  - A page used by AMD firmware cannot be written by any x86 software

RMP



RMP CHECKS



RMP is checked on:

Writes in any mode

Reads from SEV-SNP guests

The RMP is not checked on reads in certain modes (e.g., HV mode) because memory encryption ensures confidentiality

The RMP directly protects against

Data corruption/replay (only assigned guest can write to a page)

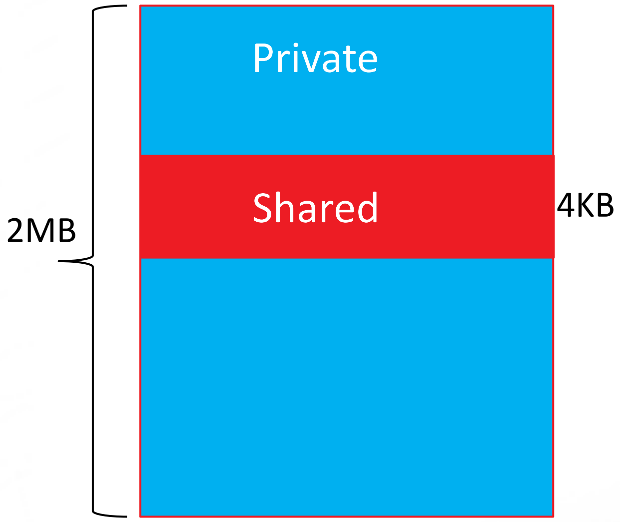
Memory aliasing (one page can only be mapped to one guest at a time)

RMP VIOLATION FAULT (HOST)

- Host RMP fault handler strategy
  - Unmap the guest private pages from the direct map to avoid the RMP violation for the kernel addresses.
  - User space write to guest private raise SIGBUS.
- Host backing page support strategy
  - Keep the host and RMP levels in sync either by splitting the large page or smashing the large RMP entry into multiple of 4K.

Example:

1. VMM allocates guest RAM backing memory from large page.
2. Guest issues a PSC to mark a region as 2MB private in the RMP table.
3. Guest later issues another PSC to make one of the subpages shared.
4. VMM attempts to write to the shared page.
   - The write access will cause #PF due the page size mismatch
5. To resolve the fault, the host page fault handler split the backing pages into 4K .



RMP VIOLATION FAULT (VM)

All the guest memory access go through the RMP checks.

- #NPF is extended to provide cause of an RMP violation
  - BIT 31 (RMP) is set if the fault was due to RMP check
  - BIT 33 (ENC) is set if the guest C-bit is 1, 0 otherwise
  - BIT 34 (SIZEM) is set if the fault was due to the size mismatch on PVALIDATE or RMPADJUST
  - BIT 35 (VMPL) is set if the fault was due to the VMPL check failure.

C-Bit	Type of Access	Check	RMP Fault Handler Strategy
-	Instruction fetch Page table access	Page is private	RMPUPDATE to mark page private
1	Data write	Page is private	RMPUPDATE to mark page private
0	Data write	Page is shared	RMPUPDATE to mark page shared

GHCB V2 CHANGES

- SNP specific new VMGEXITs (spec link: developer.amd.com/sev)
  - GHCB GPA Register
    - Some hypervisors may prefer that a guest use a consistent or specific GPA for the GHCB associated with vCPU
  - Page State Change(PSC)
    - Allows guest to request page state changes using the GHCB protocol.
  - Hypervisor feature query
    - Allows guest to query whether the hypervisor supports the SNP feature.
  - Guest message request
    - Allows guest to send a messages such as attestation report etc. to AMD-SP using the GHCB protocol.
  - AP Creation
    - Allows guest to create or destroy or change the register state of AP using the GHCB protocol
  - #HV doorbell page
    - Allows guest to register a doorbell page for use with the hypervisor injection exception.
  - #HV IPI
    - Allows guest to send IPI to other vCPUs in the guest when the restricted injection feature is enabled.
  - #HV timer
    - Allows guest to request timer support from the hypervisor when the restricted injection feature is enabled.

PAGE VALIDATION

SEV-SNP requires that private pages **must be** validated before the access.

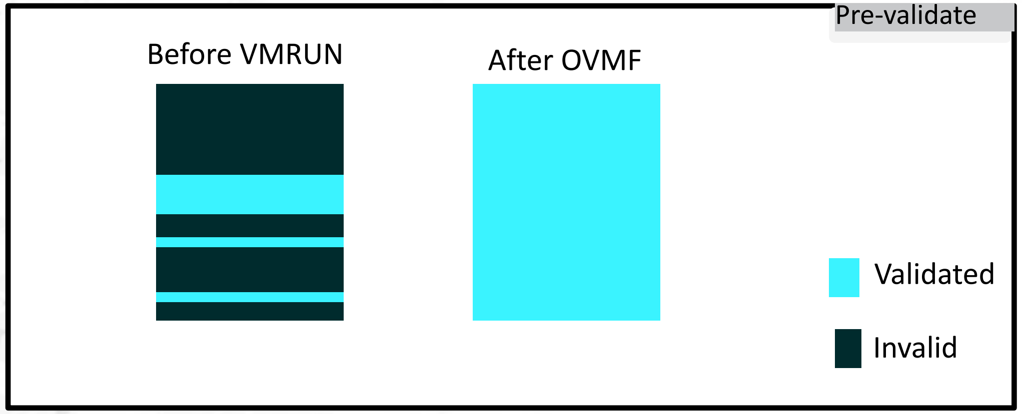
A typical page validation flow:

1. Guest issues a PSC VMGEXIT.
   - Multiple PSC requests can be batched.
   - PSC VMGEXIT takes a RMP page size hint
2. Hypervisor handles the PSC VMGEXIT
   - Try to keep the NPT and RMP page level in sync.
   - Uses the **RMPUPDATE** to add/remove page from the RMP table.
3. Hypervisor resumes the guest.
4. Guest calls **PVALIDATE** to validate the page in the RMP table.

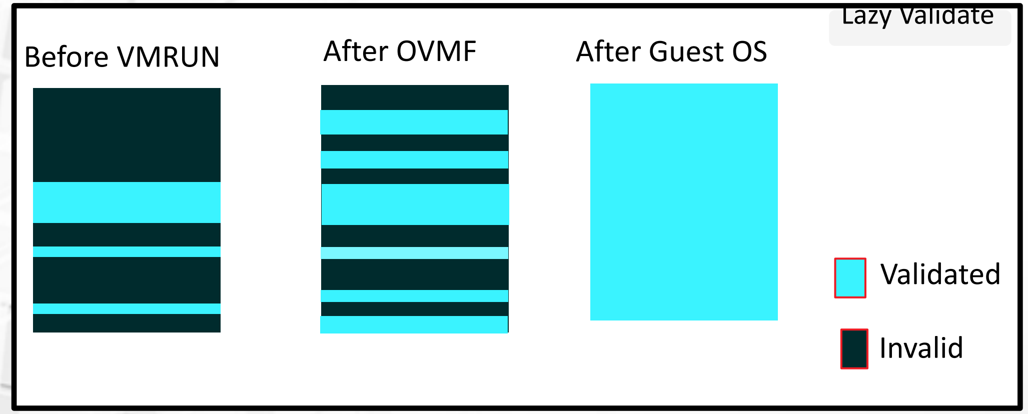
```
struct psc_hdr {
  u16 cur_entry;
  u16  end_entry;
};

struct psc_entry {
  u64   cur_page: 12,
             gfn: 40,
             op: 4,
             pagesize:1,
             rsvd: 7
};

struct snp_psc_desc {
  struct psc_hdr hdr;
  struct psc_entry entry[253];
};
```

PAGE VALIDATION OPTIONS…

- Pre-validate (**current**)
  - Guest BIOS validates the entire system RAM on boot



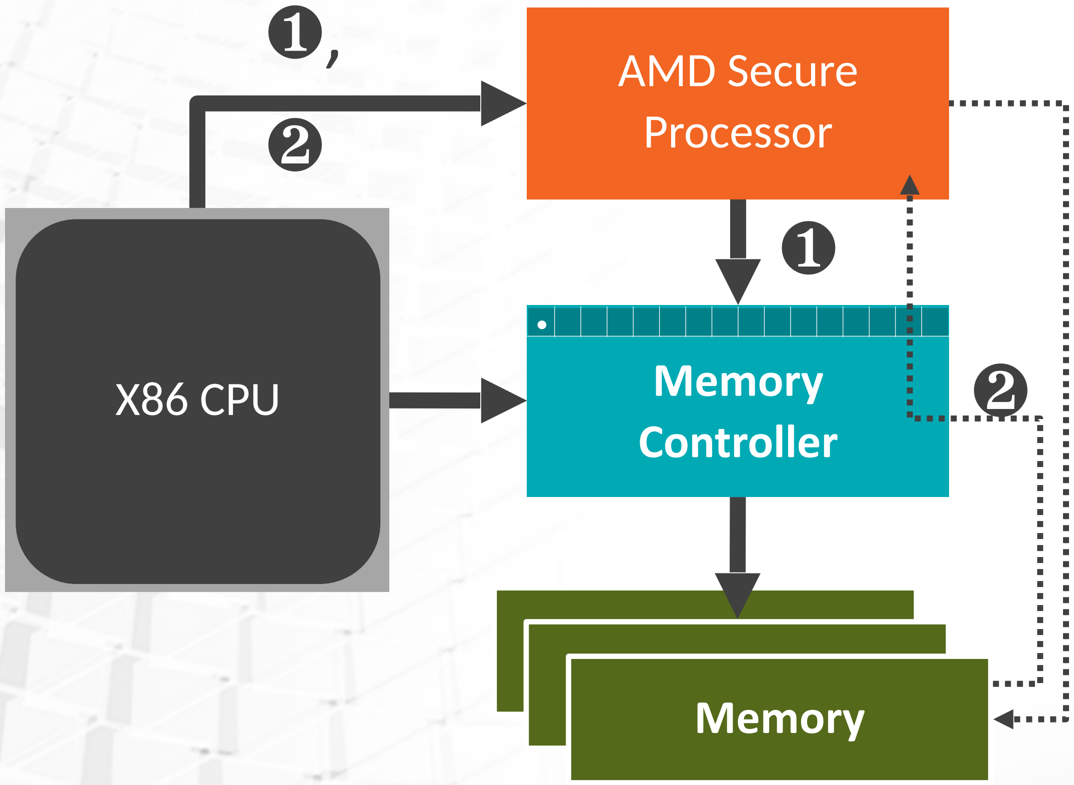
- Lazy Validate (**future**)
  - Guest BIOS validates the memory used by itself.
  - Guest BIOS published invalid memory region through newly added “Unaccepted” memory type..
  - Guest OS validate the remaining memory by going through the EFI memory map. It can validate on-demand or run a thread in background.
  - Guest OS can maintain of validated region and pass it to the kexec’ed kernel to avoid the double validation.



GUEST LAUNCH

AMD

1. **Host OS initializes AMD Secure Processor (AMD-SP)**
   - AMD-SP generates random memory key (VEK)
   - Host OS selects key slot in Memory Controller
2. **Host OS allocates & initializes image memory**
   - Host OS places initial image into DRAM
   - AMD-SP reads memory, writes back out with VEK



◢ Image memory consists of
- Initial guest BIOS (OVMF)
- Initial CPU register state
- Special information

◢ Hypervisor flow:
- **SNP_GCTX_CREATE** – Create guest context
- **ACTIVATE** – Assigned ASID
- **SNP_LAUNCH_START** – Start launch context
- **SNP_LAUNCH_UPDATE** (multiple) – Add page(s) to launch image
- **SNP_LAUNCH_FINISH** – Close launch context, make guest runnable

TYPES OF GUEST PAGES (SEE SNP_LAUNCH_UPDATE)

AMD

- **`PAGE_TYPE_NORMAL`**
  - Standard data or instruction page. Contents and metadata included in Launch Measurement
- **`PAGE_TYPE_VMSA`**
  - Virtual Machine Save Area page. Contents and metadata included in Launch Measurement
- **`PAGE_TYPE_ZERO`**
  - Page of 0's. Identical to PAGE_TYPE_NORMAL with a zero'd page
- **`PAGE_TYPE_UNMEASURED`**
  - Unmeasured (but encrypted) page. Can be used to pass information from the Hypervisor
  - Only metadata measured
- **`PAGE_TYPE_SECRETS`**
  - Special page used to hold AMD-SP provided keys and other information.
  - Only metadata measured
- **`PAGE_TYPE_CPUID`**
  - Special page used to provide secure CPUID information
  - Only metadata measured

VM MANAGEMENT COMMANDS

- New commands to create and manage SEV-SNP VMs
  - SNP_INIT
  - SNP_LAUNCH_START
  - SNP_LAUNCH_UPDATE
  - SNP_LAUNCH_FINISH
  - SNP_GUEST_REQ_{SET,GET}_RATE_LIMIT

- New object in Qemu to launch the SEV-SNP VM
  - $QEMU_CLI -object **sev-snp-guest**,id=sev0,policy=0x3 …

- New host commands to query and control the system-wide configuration
  - SNP_PLATFORM_STATUS – Query the platform information through the AMD-SP (firmware)
  - SNP_{SET,GET}_CONFIG – Set or Get the certificate blob provided during the attestation report and reported TCB version etc

VM ATTESTATION DRIVER

AMD

- New driver (coco/sevguest.ko)
  - The character device “/dev/sev-guest”
  - IOCTLs to query attestation report and key derivation
    - SNP_GET_REPORT - Query the attestation report.
    - SNP_GET_DERIVED_KEY – Derive a key
    - SNP_GET_EXT_REPORT – Same as GET_REPORT with additional certificates imported through the SNP_SET_EXT_CONFIG.

SEV AND SEV-ES

- SEV
  - Guest >= 4.15
  - Hypervisor >= 4.16
  - Qemu >= 2.12
  - OVMF >= vUDK2018
  - Libvirt >= 4.5
- SEV-ES
  - Guest >= 5.10
  - Hypervisor >= 5.11
  - OVMF >= Stable202008
  - Libvirt >= 4.5
  - Qemu >= 6.0
- In progress (patches discussed upstream)
  - Live migration support

SEV-SNP

- SEV-SNP
  - Guest and host kernel patches are **posted** on lkml (latest version 5)
    - https://lore.kernel.org/lkml/20210820155918.7518-1-brijesh.singh@amd.com/
    - https://lore.kernel.org/lkml/20210820151933.22401-1-brijesh.singh@amd.com/
  - Guest BIOS (OVMF) posted on edk2 (latest version 6)
  - Qemu patches are posted on ML (latest rfc v2)
  - Staging tree on github
    - https://github.com/AMDESE/AMDSEV/tree/sev-snp-devel
- Supported Features
  - Guest driver to query the attestation report
  - Guest uses the firmware filtered CPUID values.
  - Guest RAM backing page can be allocated from THP.
  - Guest BIOS validates the entire guest RAM.
  - Multiple vCPUs in Guest

FUTURE SNP DEVELOPMENT

- KVM Unit test and kself test
- Avacado test framework
- Restricted Interrupt Injection
- Lazy validate
- Kexec support in guest
- Live Migration
- Support backing pages from HugeTLB
- vTPM support

Q/A ?