SEV-SNP: DEVELOPMENT STATUS UPDATE

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KVM FORUM – 2022

SEV-SNP SECURITY FEATURES

- Introduced with “Zen 3”
- Previously had:
  - SEV, “Secure Encrypted Virtualization”
    - Guest data confidentiality via encrypted guest memory
  - SEV-ES, “Secure Encrypted Virtualization – Encrypted State”
    - Additional guest data confidentiality via encrypted vCPU register state
- SEV-SNP, builds on SEV/SEV-ES to also provide:
  - Guest data integrity
    - Secure Nested Paging
  - Control-flow security (optional)
    - CPUID Security
    - Interrupt Security
    - Secure TSC
- More details later

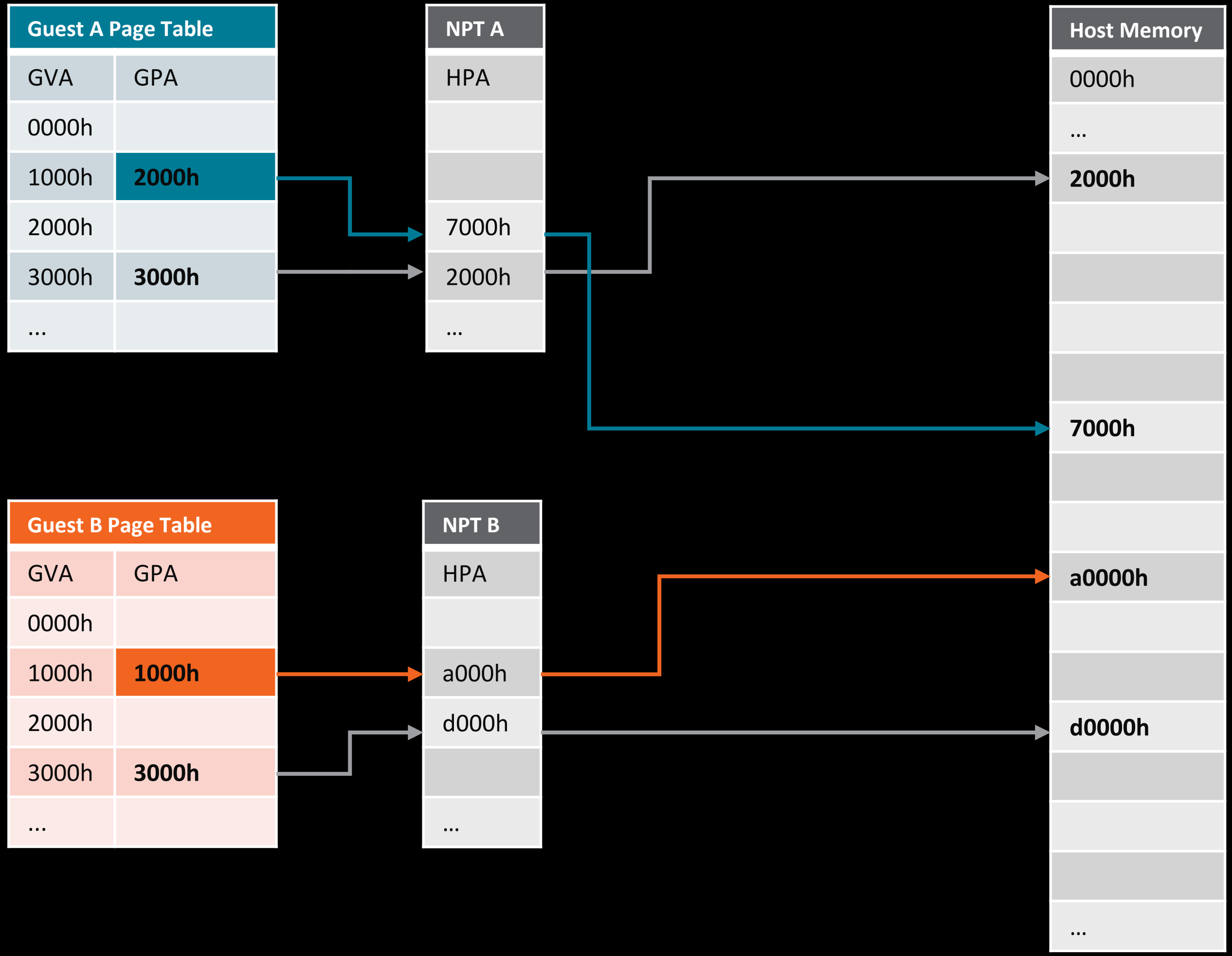
SEV-SNP SECURITY FEATURES: UPSTREAM STATUS

- Guest kernel support upstream
- Guest OVMF support upstream
- Hypervisor support posted (v6)

FEATURE	GUEST SUPPORT	HYPERVISOR SUPPORT
Secure Nested Paging	kernel v5.19 UEFI: edk2-stable202202	v6 posted
CPUID Security (optional)	kernel: v5.19 UEFI: edk2-stable202202	🟩
Interrupt Security (optional)	Future	Future
Secure TSC (optional)	Future	Future

NESTED PAGING

- Guest page table maps GVA -> GPA
- Nested page table maps GPA -> HPA
- For SEV/SEV-ES: C-bit in guest page table determines whether access is encrypted (bit 47 or 51)
- Guest controls C-bit, only ciphertext is stored in memory: provides data confidentiality
- Host controls NPT/memory: things like remap/replay attacks or silently corrupting guest memory still possible



Guest A Page Table	
GVA	GPA
0000h	
1000h	**2000h**
2000h	
3000h	**3000h**
…	

NPT A
HPA
7000h
2000h
…

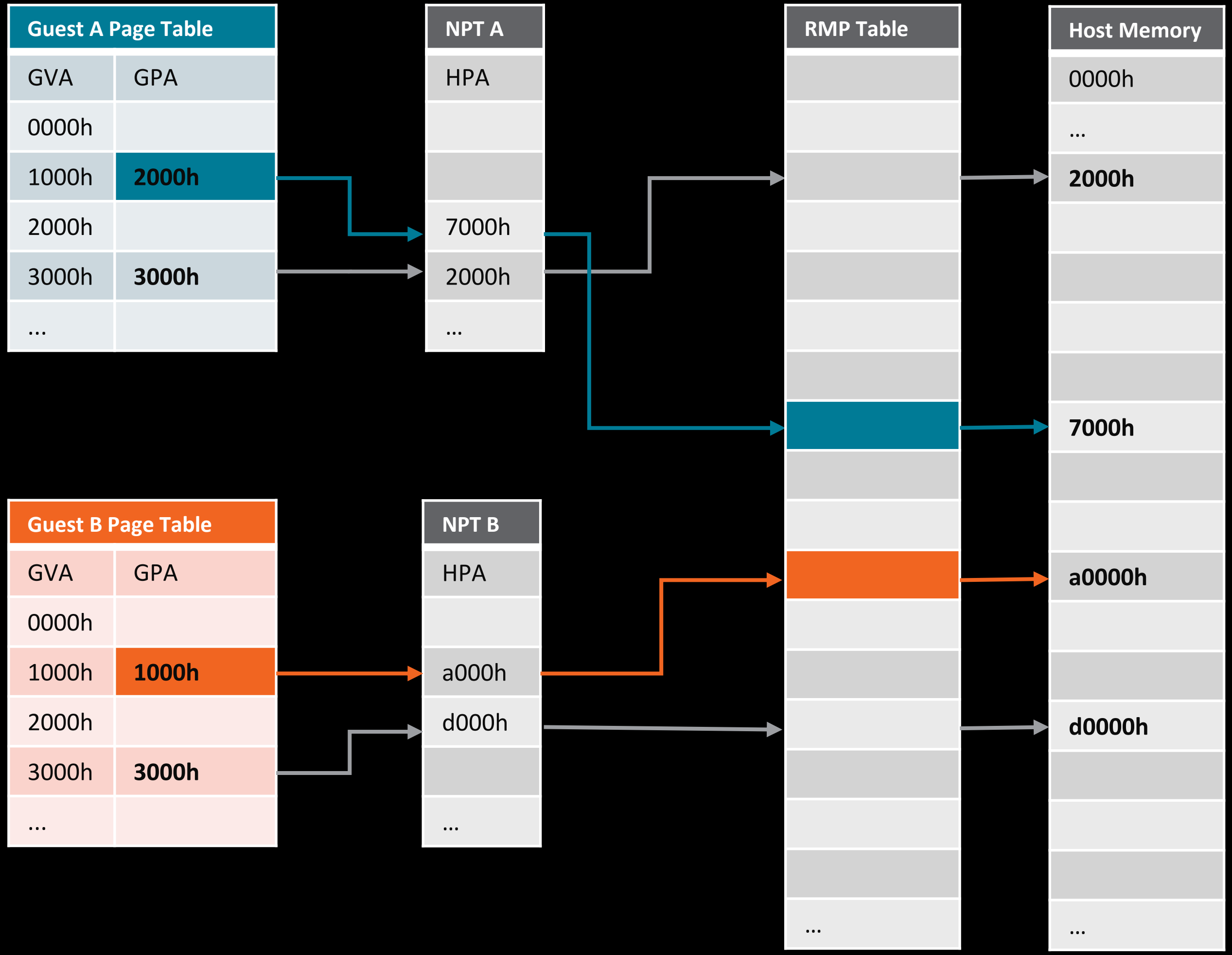
Guest B Page Table	
GVA	GPA
0000h	
1000h	**1000h**
2000h	
3000h	**3000h**
…	

NPT B
HPA
a000h
d000h
…

Host Memory
0000h
…
2000h
7000h
a0000h
d0000h
…

SECURE NESTED PAGING

- Guest page table maps GVA -> GPA
- Nested page table maps GPA -> HPA
- Reverse-map table maps HPA -> GPA
- Also provides additional integrity checks on memory accesses by host/guests
- Provides additional* protection against things like remap/replay/corruption attacks
- How?



Guest A Page Table

GVA	GPA
0000h	
1000h	**2000h**
2000h	
3000h	**3000h**
…	

NPT A

HPA
7000h
2000h
…

Guest B Page Table

GVA	GPA
0000h	
1000h	**1000h**
2000h	
3000h	**3000h**
…	

NPT B

HPA
a000h
d000h
…

RMP Table

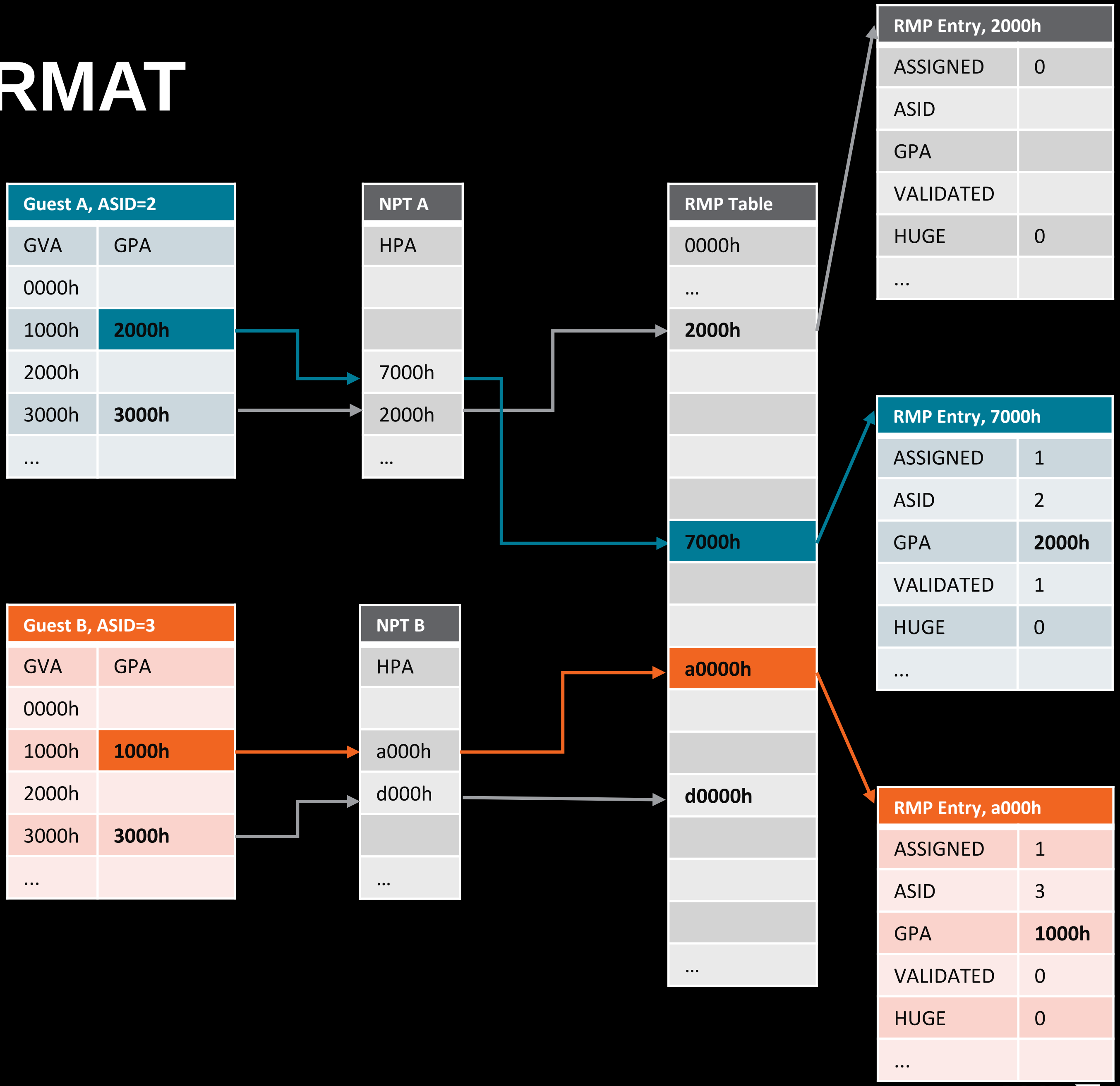
…

Host Memory

0000h
…
2000h
7000h
a0000h
d0000h
…

REVERSE-MAP TABLE FORMAT

- Assigned:
  - 0 -> host-owned, shared
  - 1 -> guest-owned, private (encrypted*)
- ASID: what guest owns it
- GPA: what guest GPA it backs
- Validated: whether guest has PVALIDATED/accepted it yet
  - C-bit=1, but not validated? -> #VC
- Host can modify/set most fields via RMPUPDATE instruction (necessary for guest page-state changes), but only guest can set the validated bit (via PVALIDATE). Important for integrity.



Guest A, ASID=2	
GVA	GPA
0000h	
1000h	2000h
2000h	
3000h	3000h
…	

NPT A
HPA
7000h
2000h
…

Guest B, ASID=3	
GVA	GPA
0000h	
1000h	1000h
2000h	
3000h	3000h
…	

NPT B
HPA
a000h
d000h
…

RMP Table
0000h
…
2000h
7000h
a0000h
d0000h
…

RMP Entry, 2000h	
ASSIGNED	0
ASID	
GPA	
VALIDATED	
HUGE	0
…	

RMP Entry, 7000h	
ASSIGNED	1
ASID	2
GPA	2000h
VALIDATED	1
HUGE	0
…	

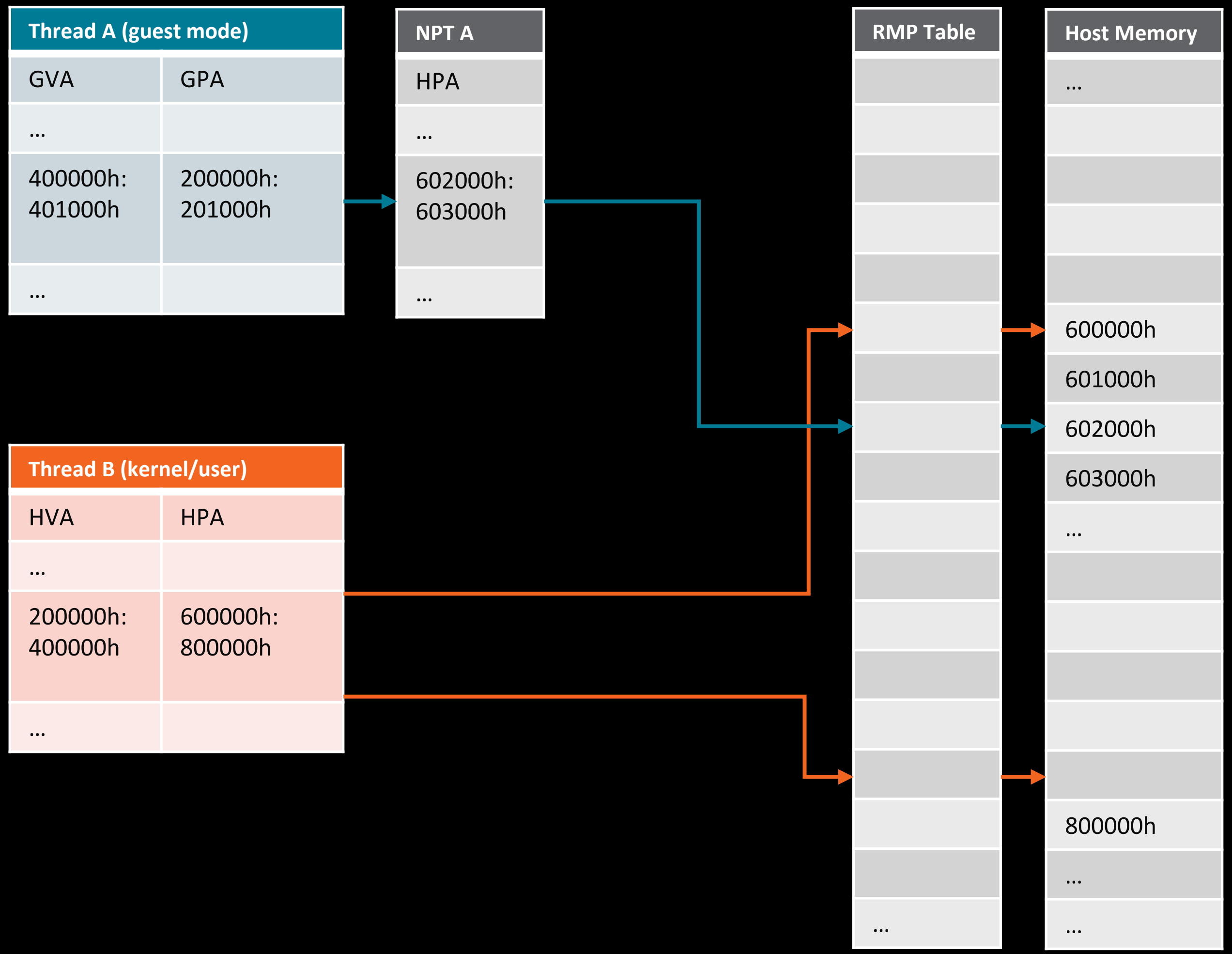
RMP Entry, a000h	
ASSIGNED	1
ASID	3
GPA	1000h
VALIDATED	0
HUGE	0
…	

KVM SUPPORT: SECURE NESTED PAGING

- Host setup/initialization of RMP table
- Guest instance setup/initialization
  - pinning pages (KVM_MEMORY_ENCRYPT_REG_REGION)
  - update RMP entries for guest boot (KVM ioctl) / runtime (GHCB request)
- RMP Fault-handling
  - Host #PF (kernel/userspace)
  - Guest #NPF →

RMP FAULT-HANDLING (HOST, #PF)

- RMP check violations result in #PF for host threads (error bit 31)
- Page overlap checks
  - 2M host mapping cannot overlap with a private page when writing →
  - True for kernel/userspace mappings
  - Kernel direct mappings need handling too (2M and 4K)
- R/W permission checks
  - Cannot write to private pages
  - userspace write -> SIGBUS to kill process
  - kernel write -> crash (buggy/malicious kernel)
  - reads allowed (ciphertext)



Thread A (guest mode)	
GVA	GPA
…	
400000h: 401000h	200000h: 201000h
…	

NPT A
HPA
…
602000h: 603000h
…

Thread B (kernel/user)	
HVA	HPA
…	
200000h: 400000h	600000h: 800000h
…	

RMP Table
…

Host Memory
…
600000h
601000h
602000h
603000h
…
800000h
…
…

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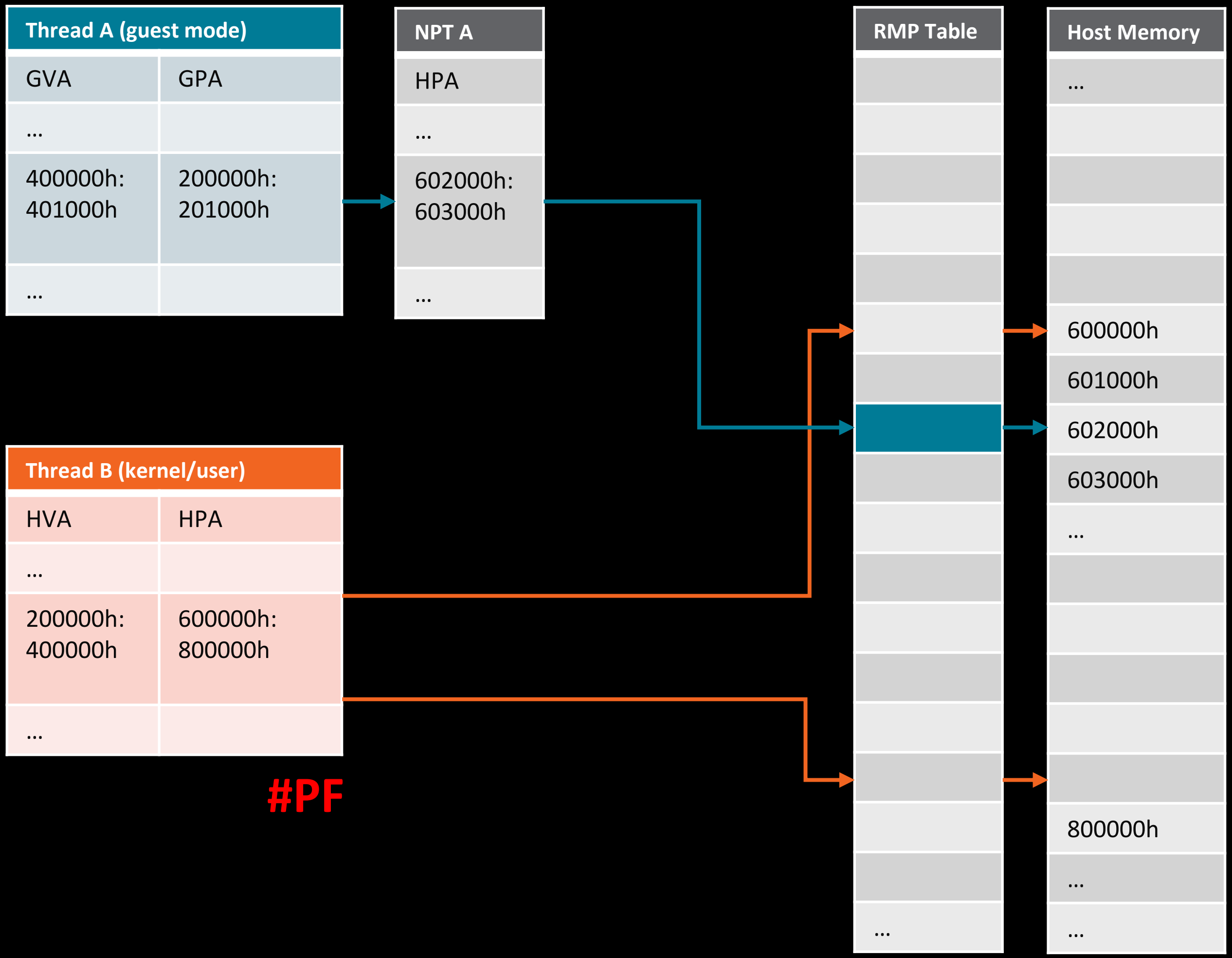

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…	
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…	

NPT A
HPA
…
602000h: 603000h
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Thread B (kernel/user)	
HVA	HPA
…	
200000h: 400000h	600000h: 800000h
…	

#PF

RMP Table
…

Host Memory
…
600000h
601000h
602000h
603000h
…
800000h
…
…

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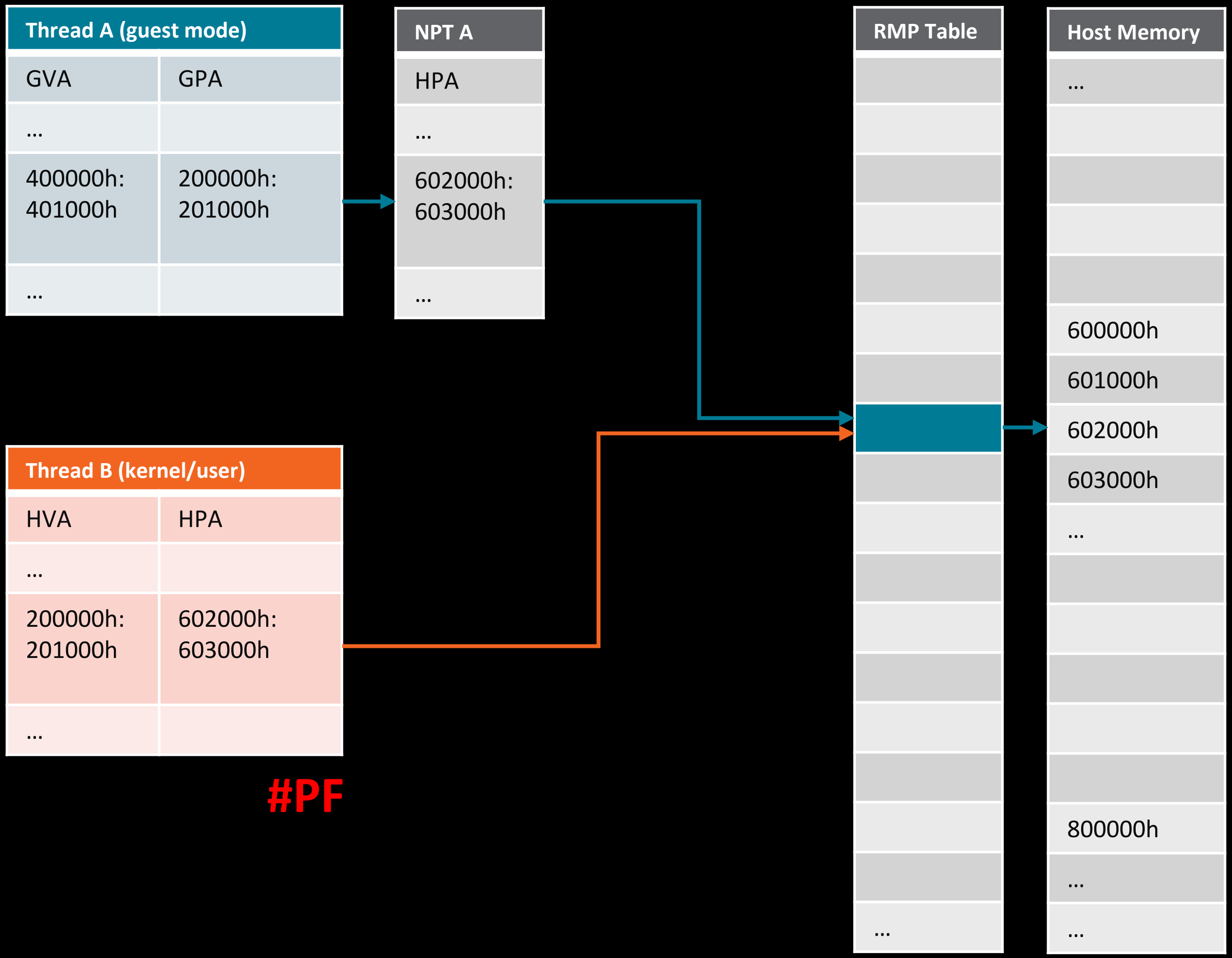
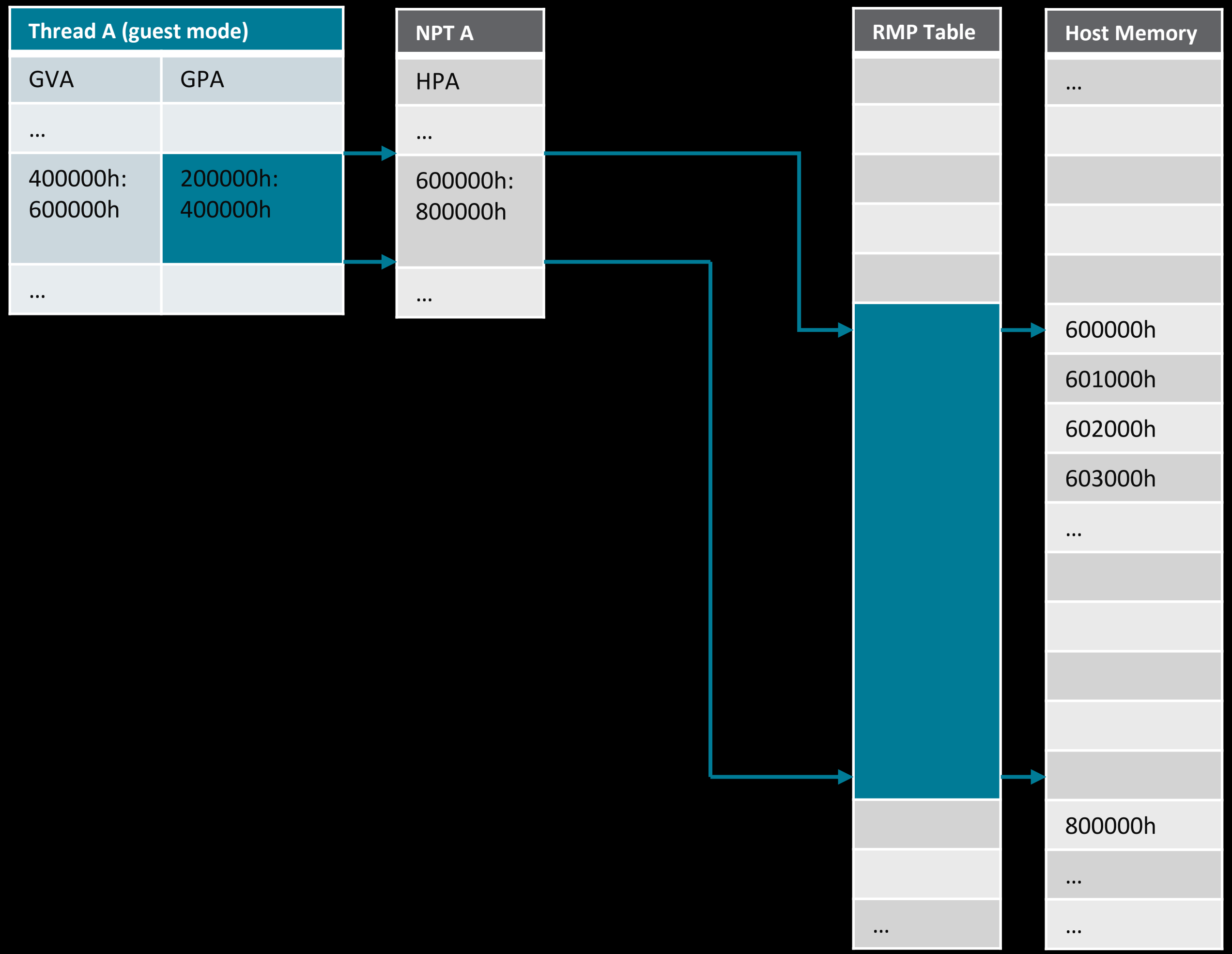


RMP FAULT-HANDLING (KVM MMU, #NPF)

- RMP check violations result in #NPF for guest vcpu threads (error bit 31)
- Page size mismatch checks
  - KVM may optimistically map a 2M private range using huge page/RMP entry
  - Guest can optimistically PVALIDATE 2M ranges to match this →
  - If 4K pvalidate: #NPF with RMP/SIZEM bits set
    - split NPT mapping
    - PSMASH 2M RMP entry
- C-bit mismatch checks
  - if C=1: RMP entry should be private
  - if C=0: RMP entry should be shared
  - Otherwise: #NPF with RMP/ENC bits set
    - Implicit page state change, update RMP entry to match



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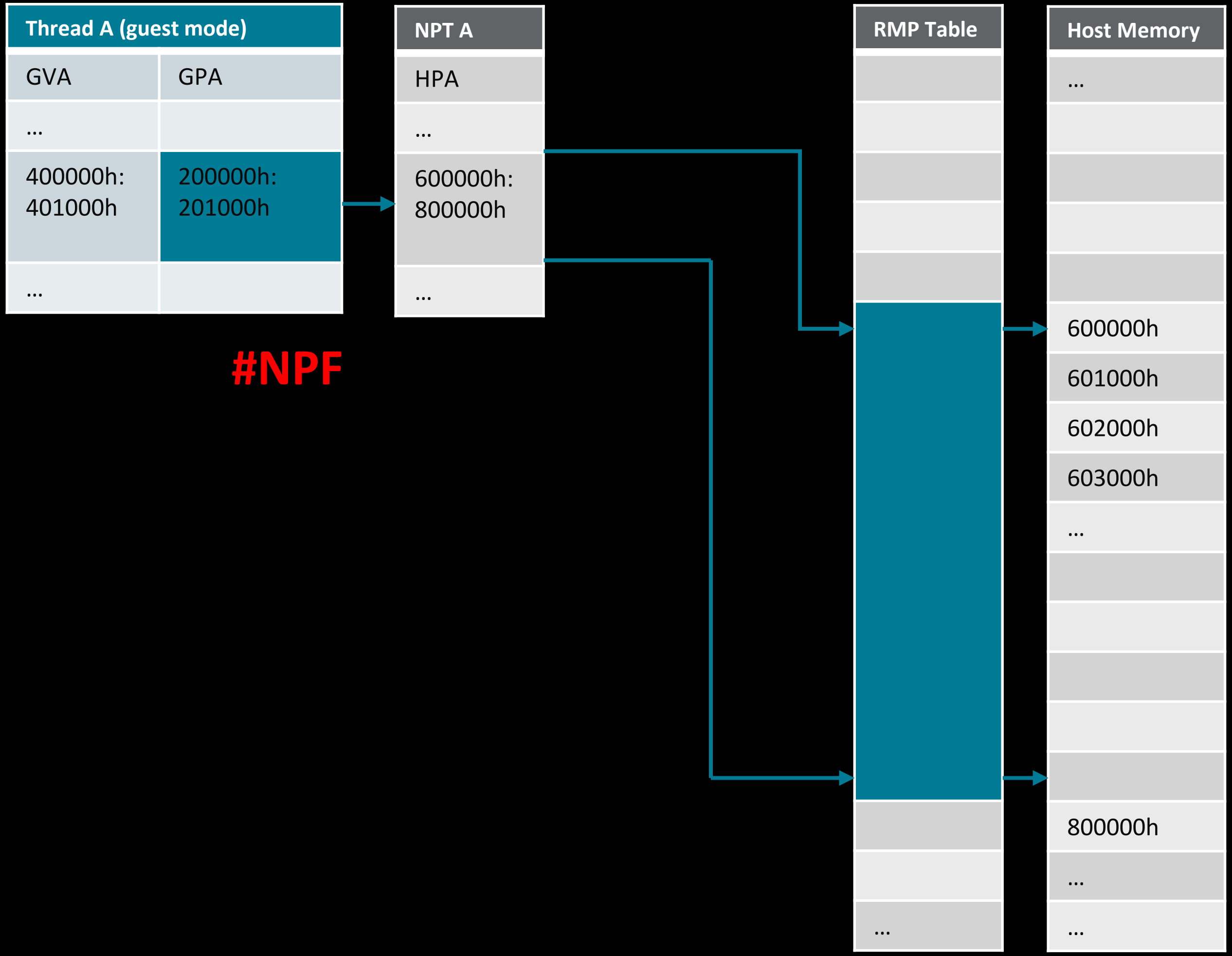

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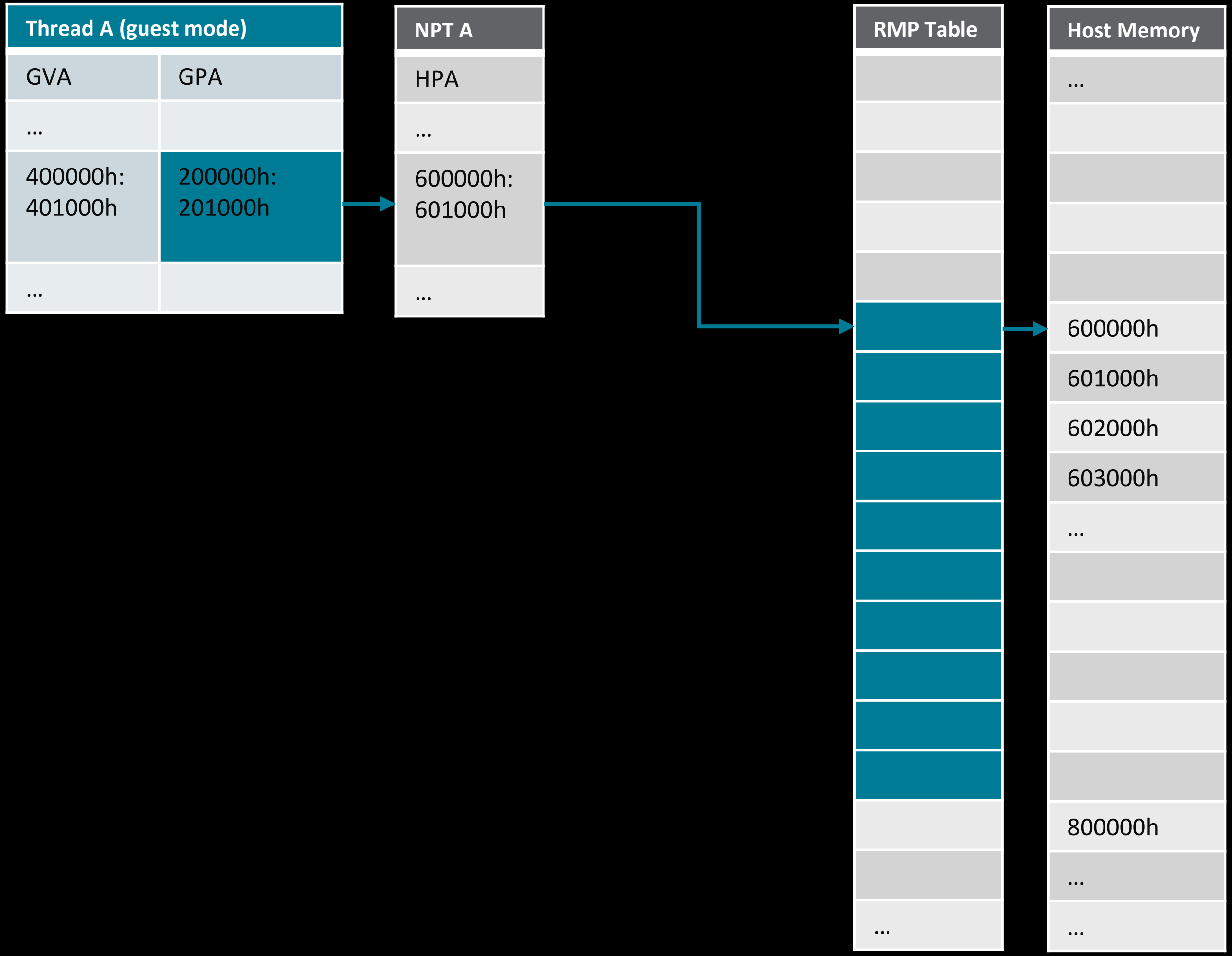

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- RMP Fault-handling
  - Host #PF (kernel/userspace)
  - Guest #NPF
- Fairly minor changes since v5, however:
- New proposal: UPM (Unmapped Private Memory), private FD-backed memory

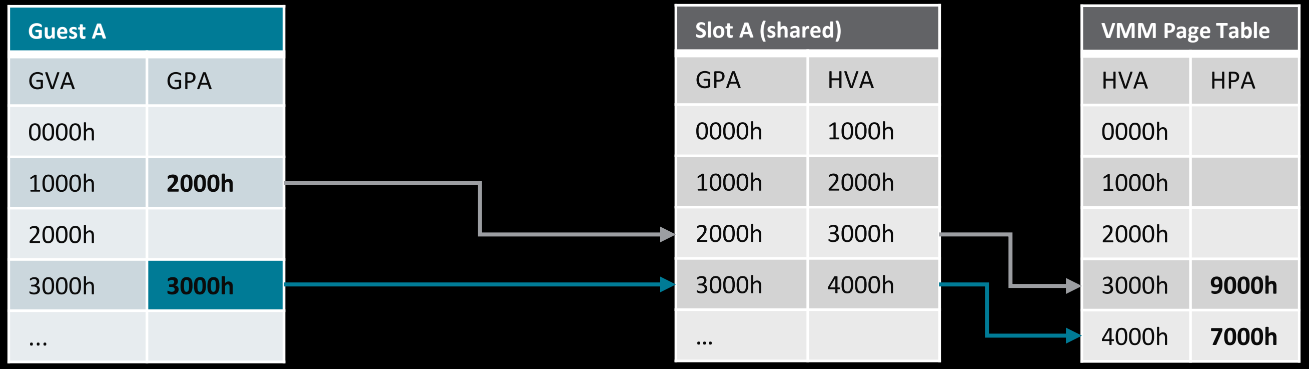
UNMAPPED PRIVATE MEMORY

- Proposed kernel infrastructure to back confidential guests with pages that are not mappable/accessible by userspace
- Generally synonymous with Chao Peng’s private memslot patchset:
  - “KVM: mm: fd-based approach for supporting KVM guest private memory”
- Proposed by a number of a developers for various reasons, but the most prevalent driver is TDX support, where writes to private guest memory by userspace result in #MC
- Also being evaluated for use with SEV-SNP, pKVM, and possibly others

UPM - PRIVATE MEMSLOTS

- Currently both shared/private memory are backed by normal memslots
  - private memory can be mapped into userspace just like normal memory
  - malloc() / mmap() →
- Adds new private memslot struct
  - Provides both shared/private memory
  - private memory allocated separately via memfd
  - memfd uses MFD_INACCESSIBLE
    - Not readable/writable
    - Can’t be mmap()’d into userspace
- KVM MMU uses an xarray to determine whether to map guest memory from shared/private pool

#NPF: GPA->HPA lookup (normal memslot)



Guest A

GVA	GPA
0000h	
1000h	**2000h**
2000h	
3000h	**3000h**
…	

Slot A (shared)

GPA	HVA
0000h	1000h
1000h	2000h
2000h	3000h
3000h	4000h
…	

VMM Page Table

HVA	HPA
0000h	
1000h	
2000h	
3000h	**9000h**
4000h	**7000h**

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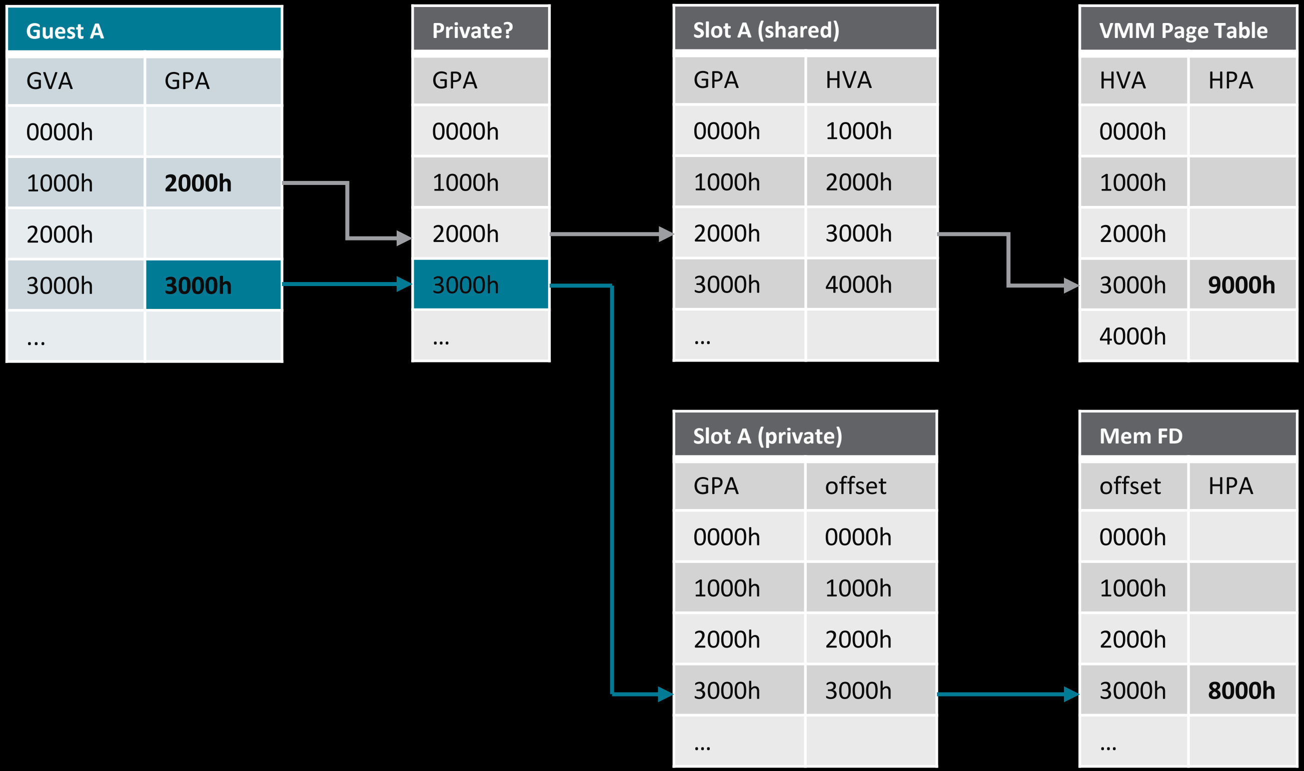


Guest A

GVA	GPA
0000h	
1000h	**2000h**
2000h	
3000h	**3000h**
…	

Private?

GPA
0000h
1000h
2000h
3000h
…

Slot A (shared)

GPA	HVA
0000h	1000h
1000h	2000h
2000h	3000h
3000h	4000h
…	

VMM Page Table

HVA	HPA
0000h	
1000h	
2000h	
3000h	**9000h**
4000h	

Slot A (private)

GPA	offset
0000h	0000h
1000h	1000h
2000h	2000h
3000h	3000h
…	

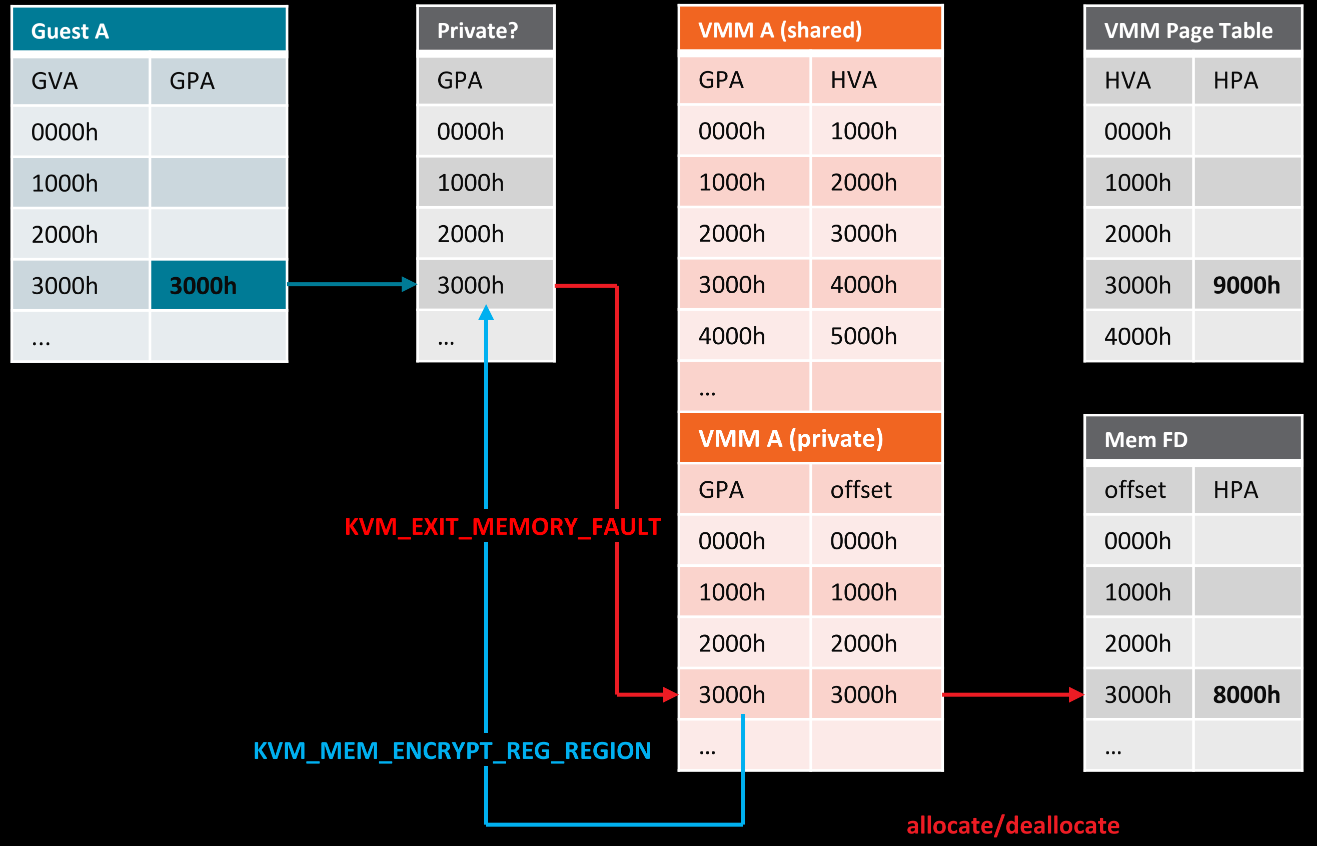
Mem FD

offset	HPA
0000h	
1000h	
2000h	
3000h	**8000h**
…	

UPM – IMPLICIT CONVERSIONS

- KVM MMU uses an xarray to determine whether to map guest memory from shared/private pool
  - xarray controlled purely by userspace
    - KVM_MEM_ENCRYPT_REG_REGION
    - KVM_MEM_ENCRYPT_UNREG_REGION
- Implicit conversion
  - if C-bit does not match xarray state:
    - KVM_EXIT_MEMORY_FAULT
    - alloc/dealloc private/shared memory
    - VMM converts using REG/UNREG ioctl
- Explicit conversion
  - GHCB page-state change request forwarded to userspace
    - KVM_EXIT_VMGEXIT
    - alloc/dealloc private/shared memory
    - VMM converts using REG/UNREG ioctl

#NPF: GPA->HPA lookup/conversion (private memslot)



Guest A

GVA	GPA
0000h	
1000h	
2000h	
3000h	**3000h**
…	

Private?

GPA
0000h
1000h
2000h
3000h
…

VMM A (shared)

GPA	HVA
0000h	1000h
1000h	2000h
2000h	3000h
3000h	4000h
4000h	5000h
…	

VMM A (private)

GPA	offset
0000h	0000h
1000h	1000h
2000h	2000h
3000h	3000h
…	

VMM Page Table

HVA	HPA
0000h	
1000h	
2000h	
3000h	**9000h**
4000h	

Mem FD

offset	HPA
0000h	
1000h	
2000h	
3000h	**8000h**
…	

UPM – EXPLICIT CONVERSIONS

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    - alloc/dealloc private/shared memory
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    - VMM converts using REG/UNREG ioctl

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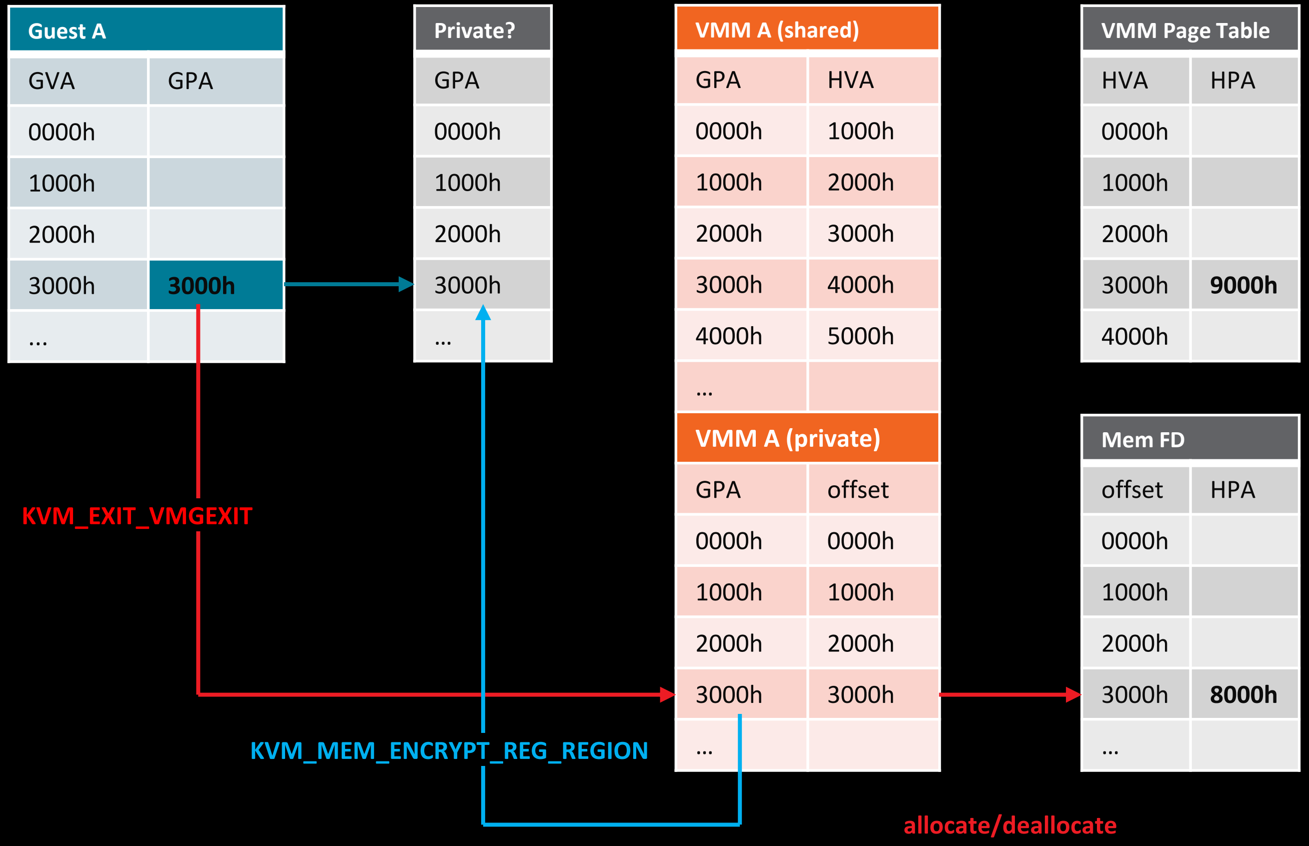

Guest A

GVA	GPA
0000h	
1000h	
2000h	
3000h	3000h
…	

Private?

GPA
0000h
1000h
2000h
3000h
…

VMM A (shared)

GPA	HVA
0000h	1000h
1000h	2000h
2000h	3000h
3000h	4000h
4000h	5000h
…	

VMM A (private)

GPA	offset
0000h	0000h
1000h	1000h
2000h	2000h
3000h	3000h
…	

VMM Page Table

HVA	HPA
0000h	
1000h	
2000h	
3000h	9000h
4000h	

Mem FD

offset	HPA
0000h	
1000h	
2000h	
3000h	8000h
…	

UPM: PROS/CONS

- Pros:
  - Shared infrastructure for managing private guest pages
    - Cross-platform: SNP / TDX, potentially cross-architecture
  - Less chance of guest disruption/exploitation from accessing private memory in userspace
  - Lazy-pinning support
- Cons:
  - More management complexity in VMMs:
    - Allocating/de-allocating private memory
      - Potential for 2X memory usage
        - Lazily-deallocate for performance?
        - Immediately deallocate to reduce memory usage?
    - Handling of new private memslot structure
    - Memory pinning/affinity considerations
  - Performance
    - More exits to userspace, more context switches

KVM SUPPORT: SNP + UPM

- v6 SNP hypervisor patchset uses non-UPM implementation (likely v7 as well)
- Separate tree adds UPM support on top of v6:
  - VMGEXITS for GHCB page-state changes forwarded to userspace
  - Uses UPM to manage memory pinning instead of existing SEV approach
  - KVM_CAP_UPM flag to switch between modes
- Will maintain separate trees until UPM stable/upstream
- Continue to work with community to upstream either solution

FUTURE DEVELOPMENT WORK

- Interrupt Security
- Secure VM Service Modules (SVSM)
  - VMPL0 OS implementation
  - Interrupt security
  - Live migration acceleration
  - vTPM
  - Upcoming talk by Tom Lendacky
- Secure TSC support
- SEV-SNP lazy-pinning support (free with UPM)
- Lazy-PVALIDATE support for SNP guests (patches posted)

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- **Questions?**

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