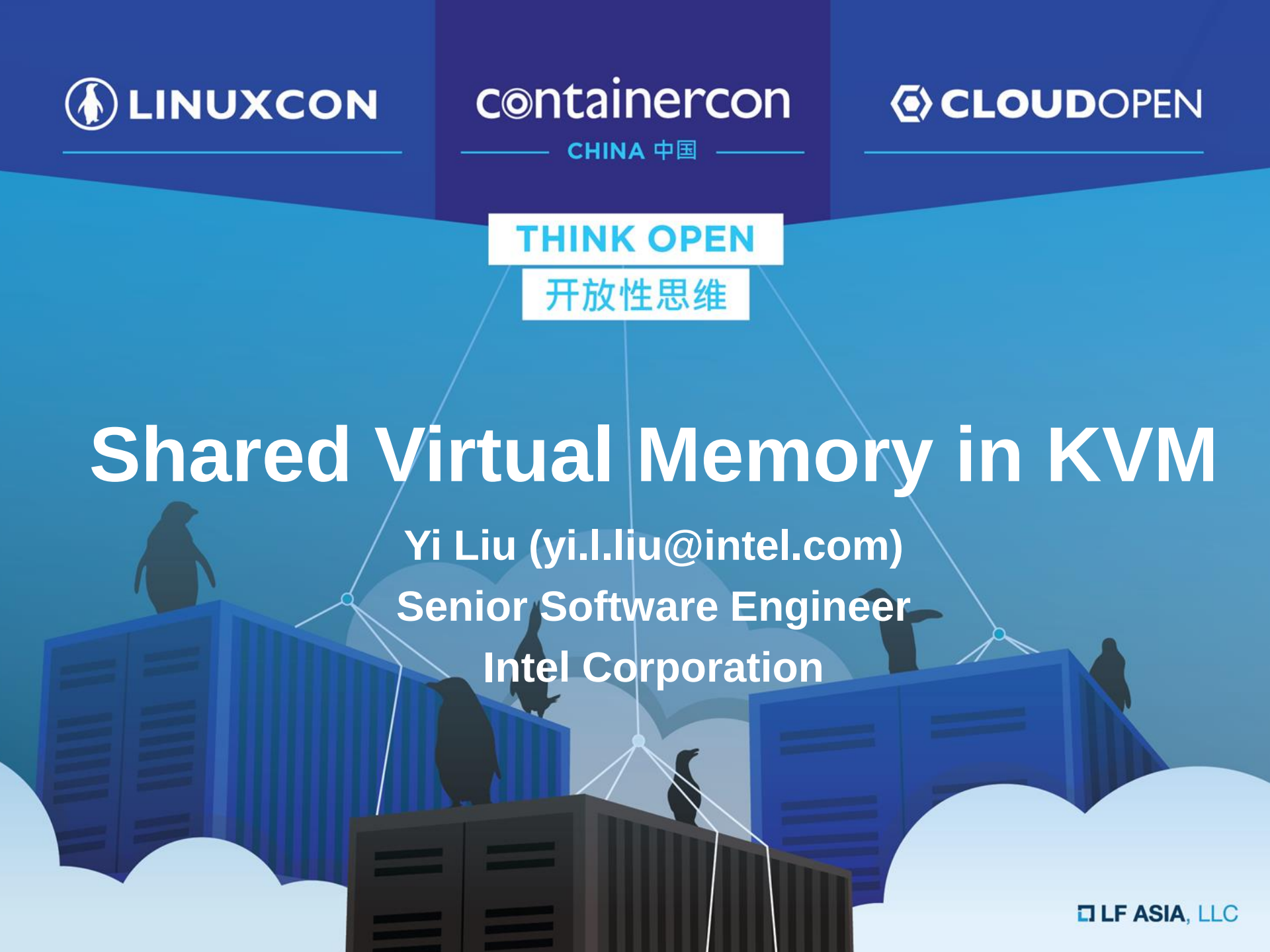

Shared Virtual Memory in KVM

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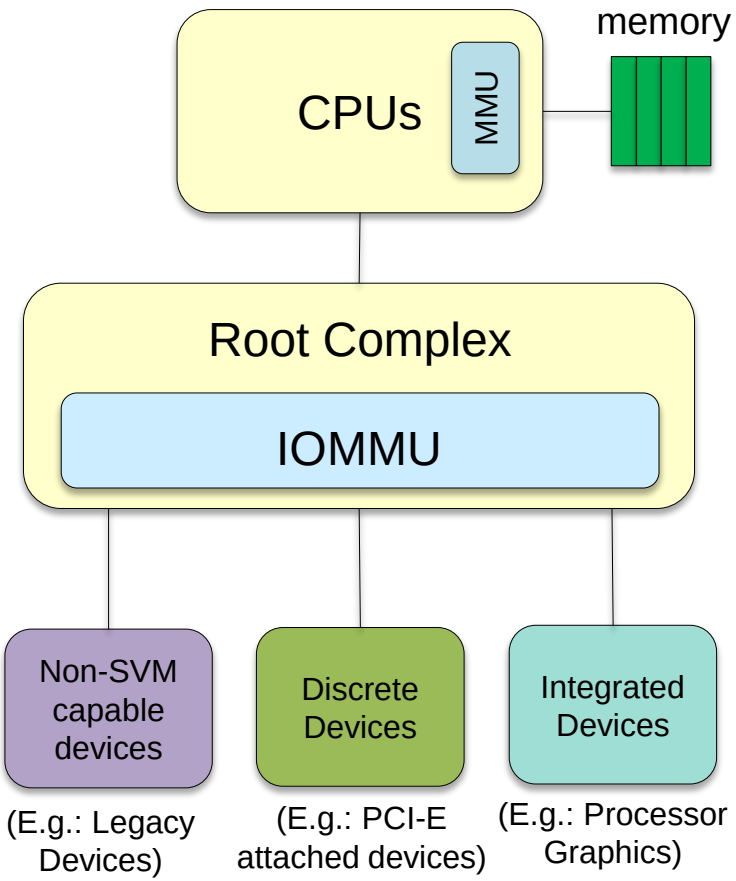
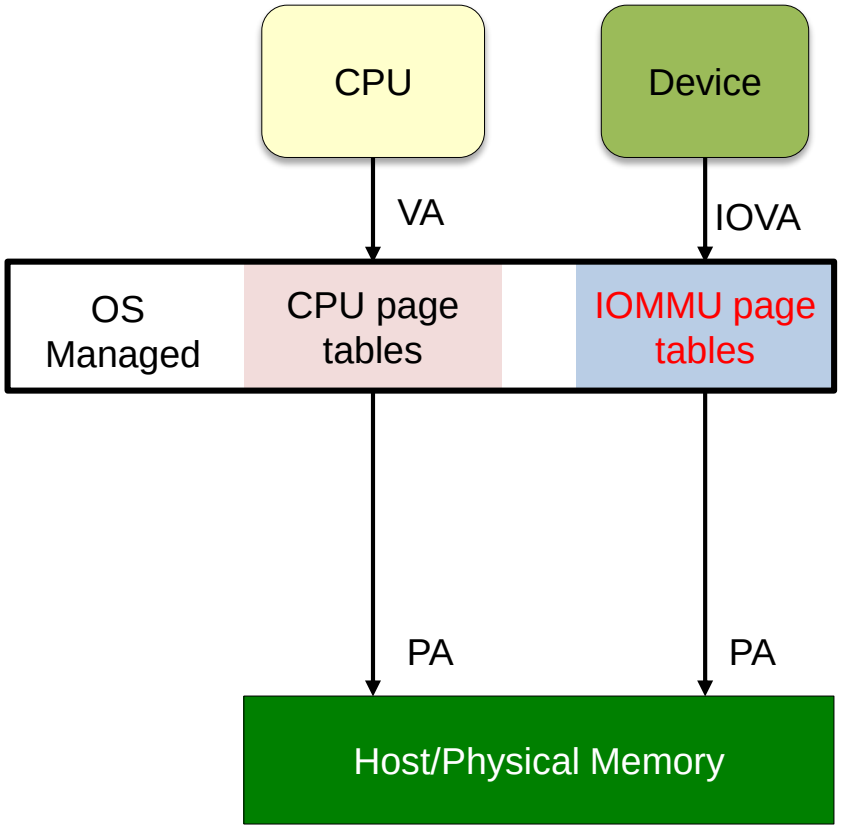
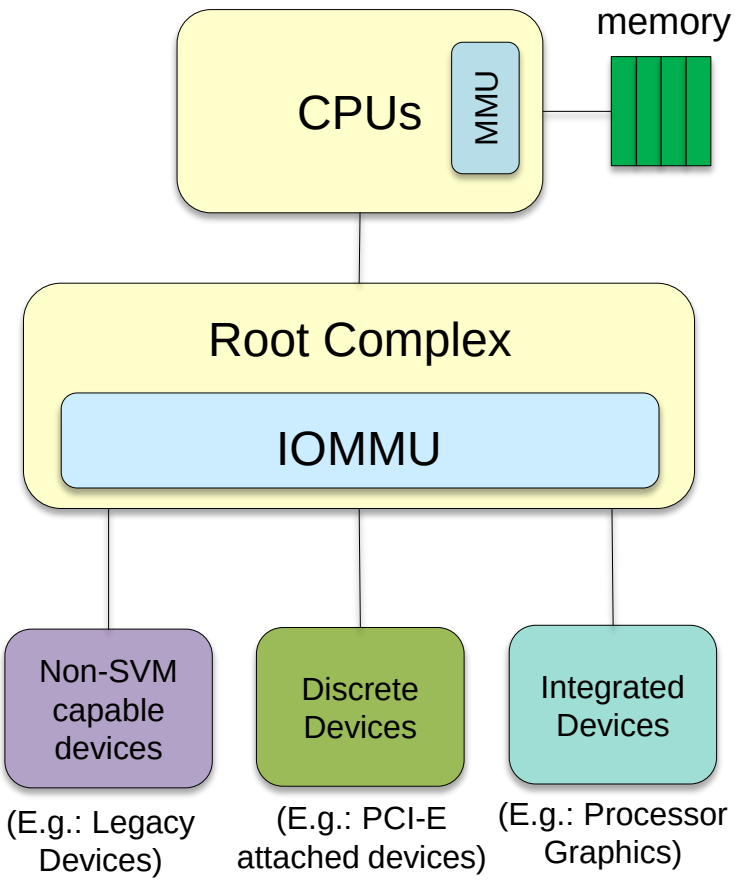
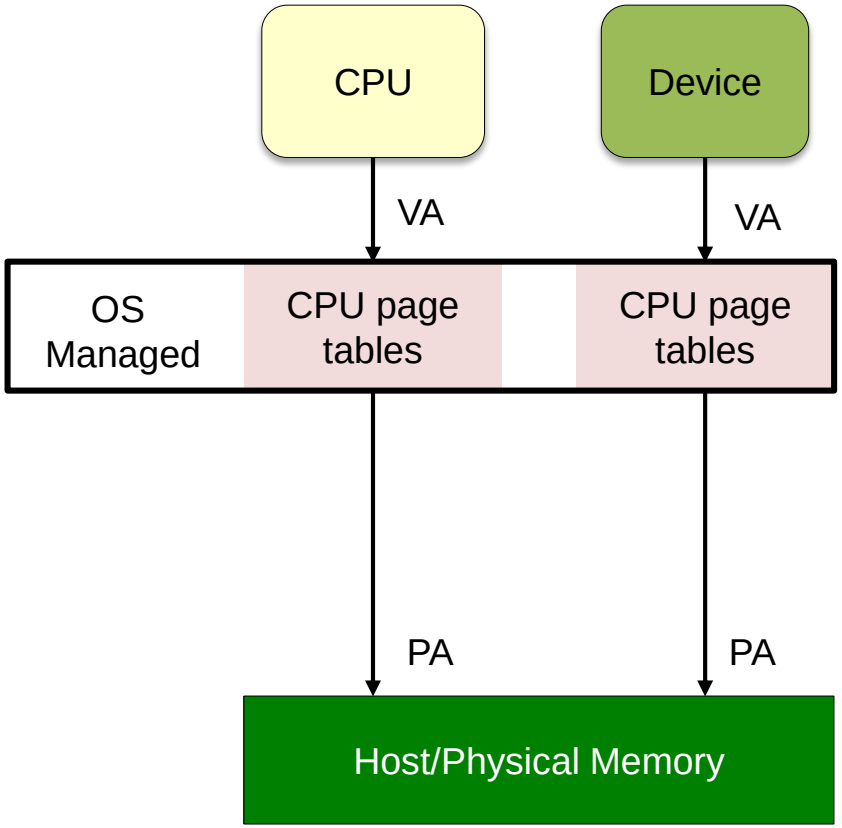
Shared Virtual Memory (SVM)





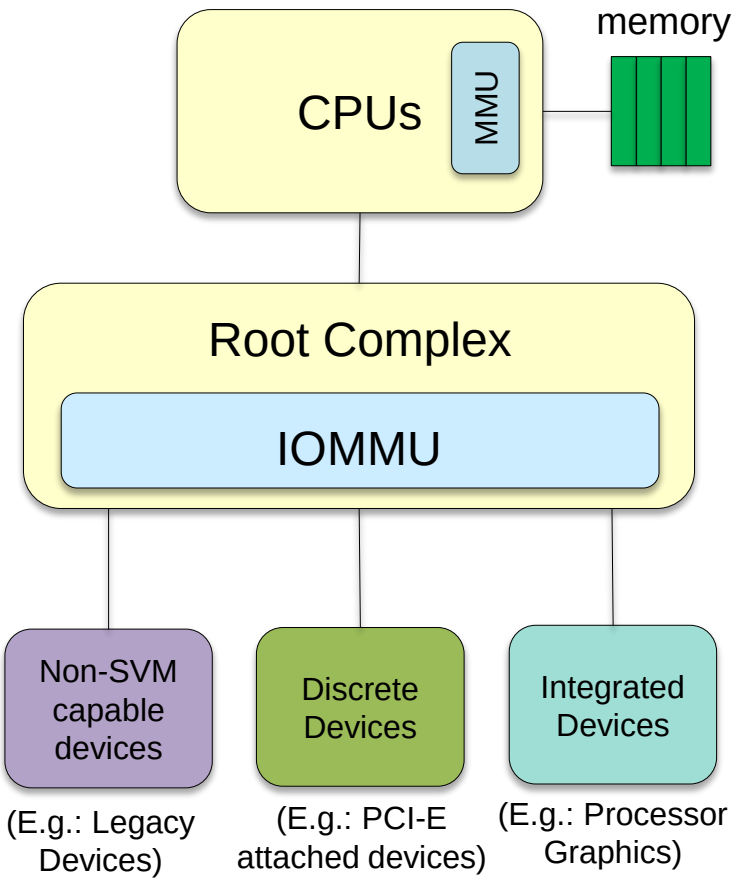
Shared Virtual Memory (SVM)

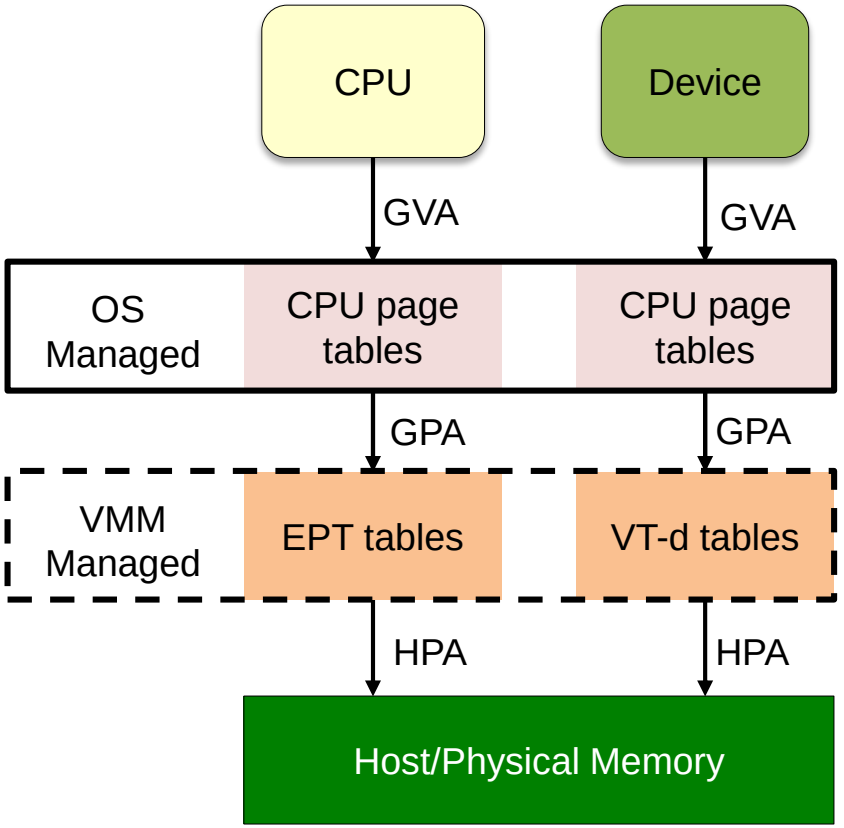




Called Shared Virtual Addressing in Linux Community

Shared Virtual Memory (SVM)



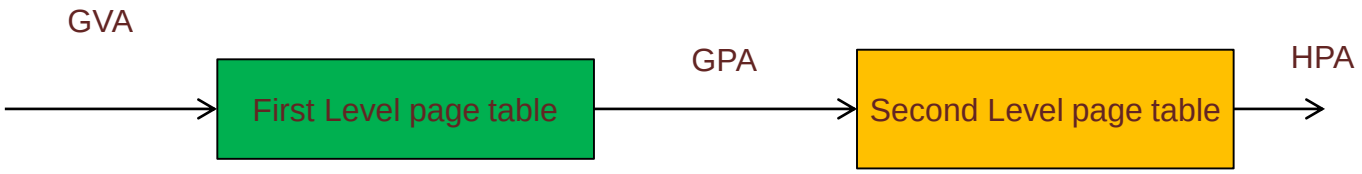


SVM on Intel® VT-d

- Process Address Space ID (PASID)
  - Identify process address space
- First-level translation
  - DMA requests with PASID
  - For SVM transaction from endpoint device
- Second-level translation
  - DMA requests without PASID
  - For normal DMA transaction from endpoint device
- Translation Types
  - First-Level translation
  - Second-Level translation
  - Nested translation
  - Pass-Through (address translation bypassed)
- Intel® VT-d 3.0 introduced Scalable Mode
  - SVM can be used together with Intel® Scalable I/O Virtualization

SVM on Intel® VT-d (Cont.)

- Nested Translation
  - Use both first-level and second-level for address translation
  - Enable SVM in virtualization environment
    - First-level: GVA->GPA
    - Second-level: GPA->HPA

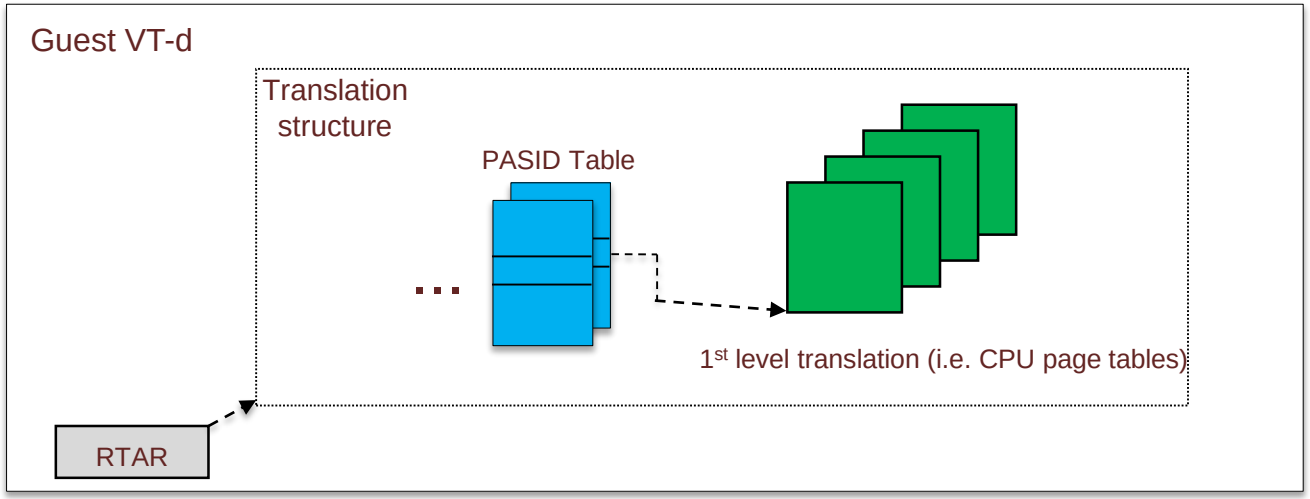


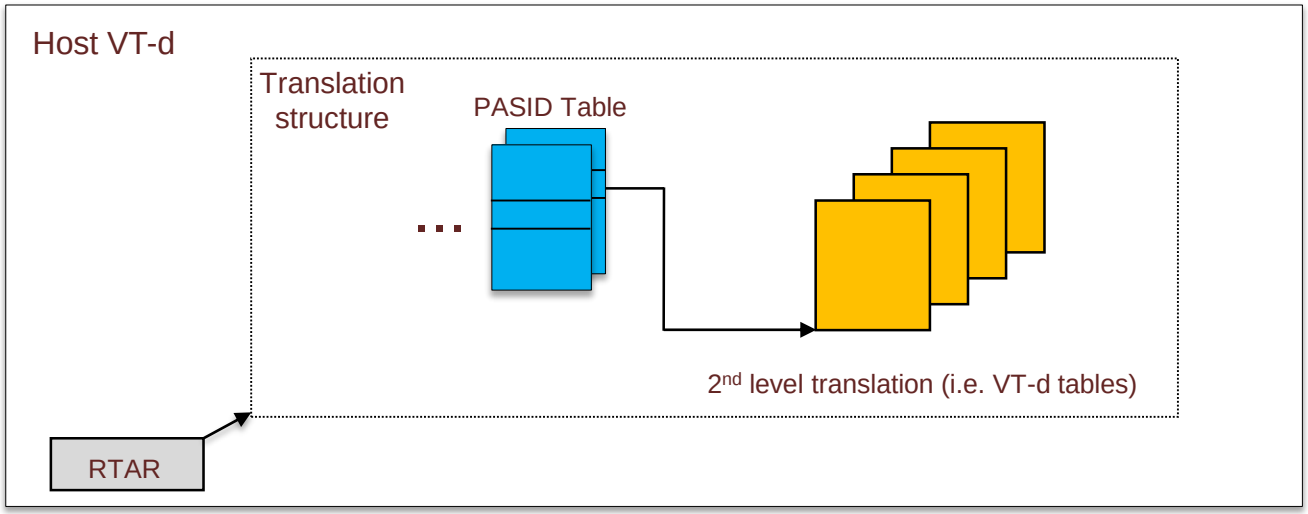
- Most vendor supports nested translation for SVM usage in Virtual Machine

Enable SVM in VM

- Need a virtual IOMMU with SVM capability
  - Proper emulation according to IOMMU spec (e.g. Intel® VT-d specification)
    - either fully-emulated or virtio-based IOMMU
- Notification for guest translation structure changes
  - Notification mechanism is vendor specific
  - For Intel® VT-d
    - “caching-mode”: explicit cache invalidation is required for any translation structure change in software
- Enable nested translation on physical IOMMU for given PASID

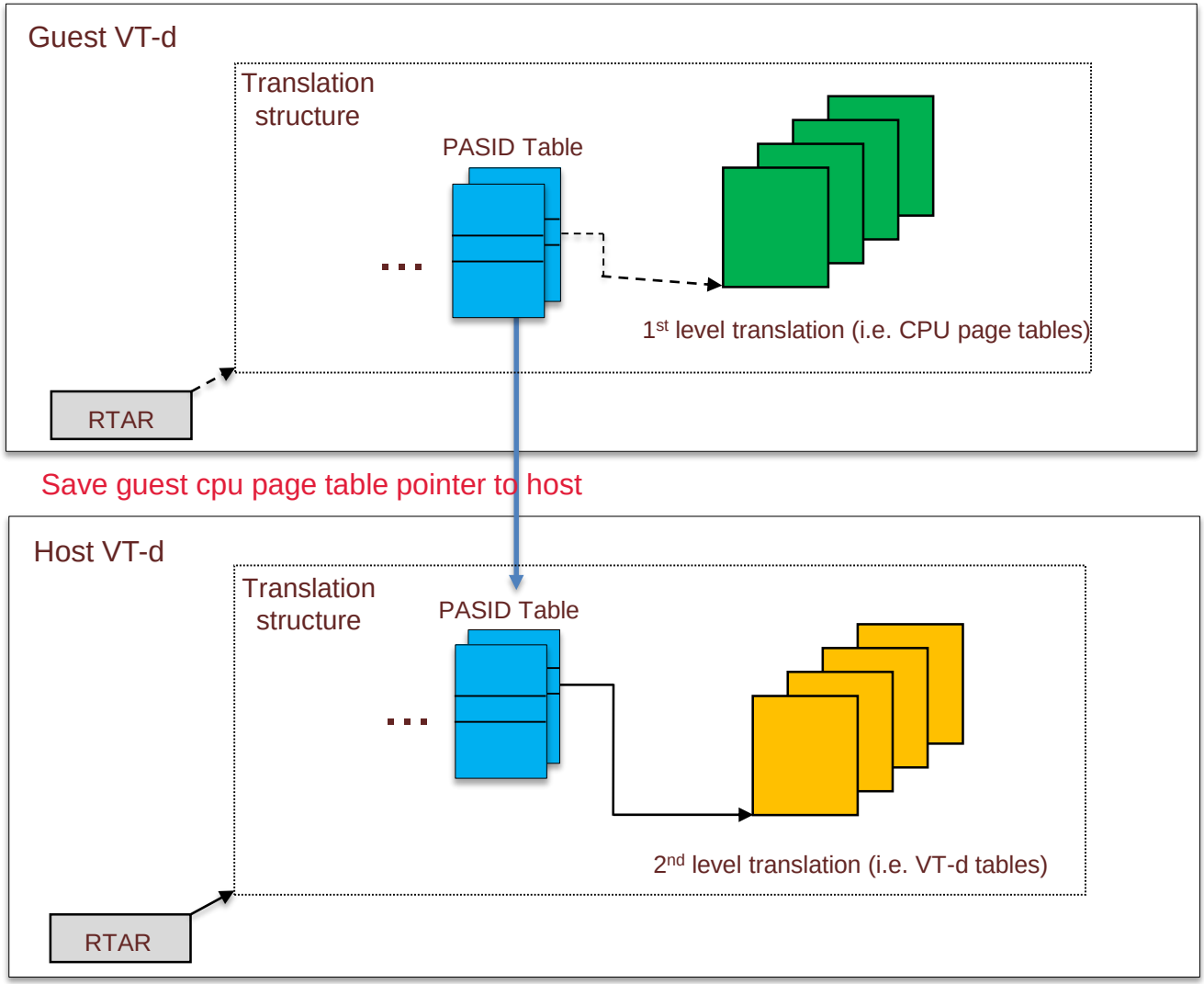
Enable SVM in VM (Cont.)





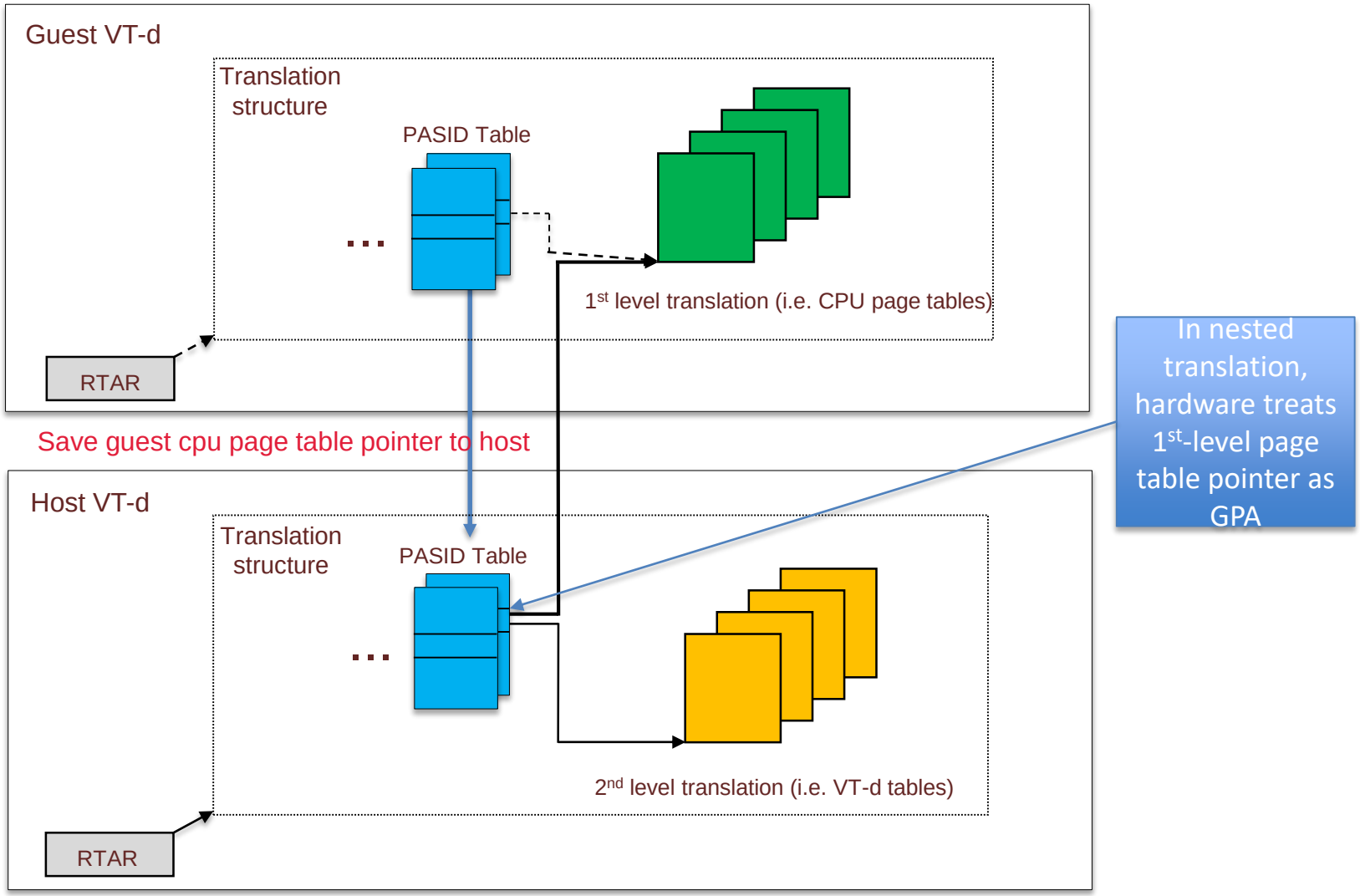
SVM in VM based on Intel® VT-d

Enable SVM in VM (Cont.)



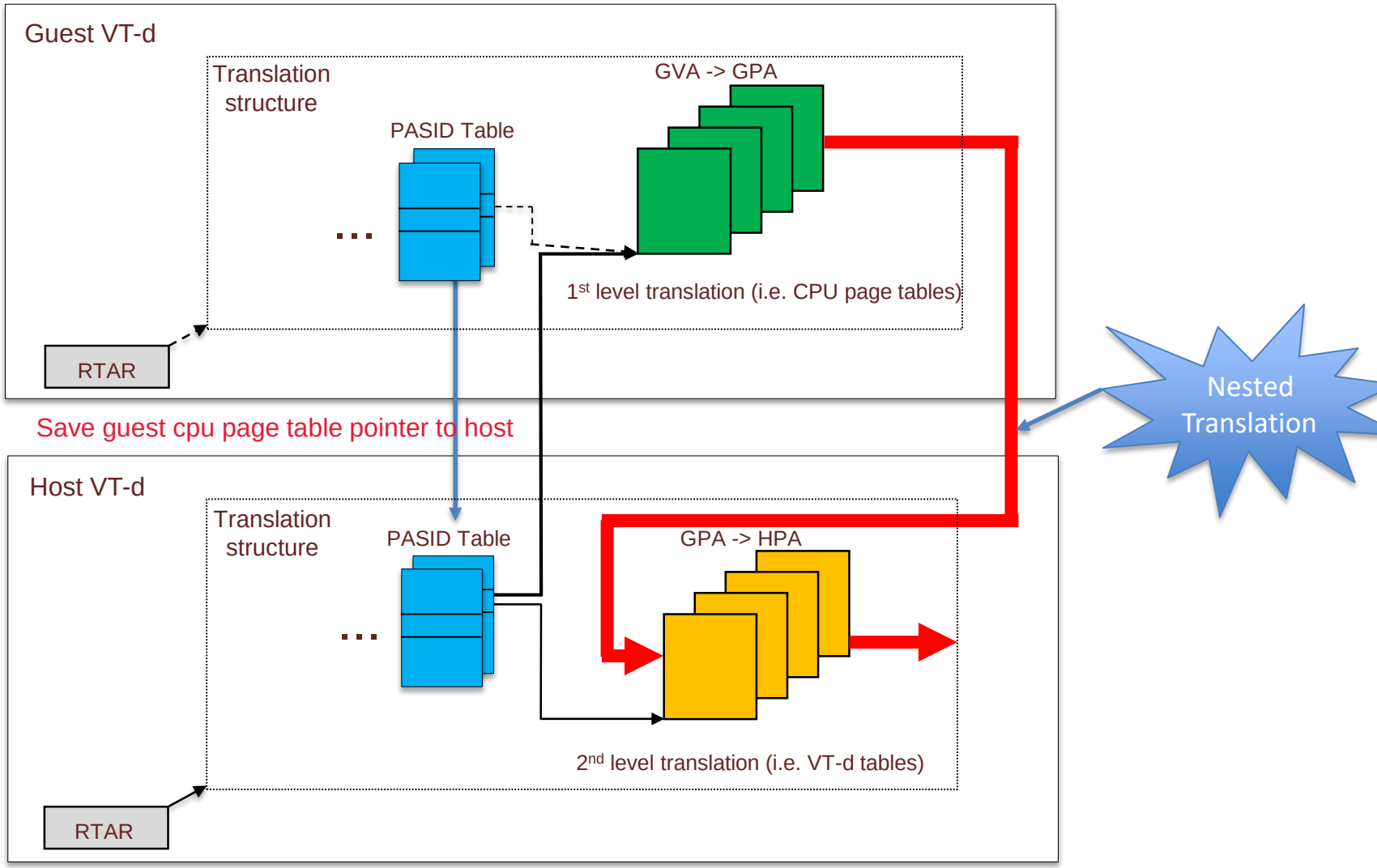
SVM in VM based on Intel® VT-d

Enable SVM in VM (Cont.)



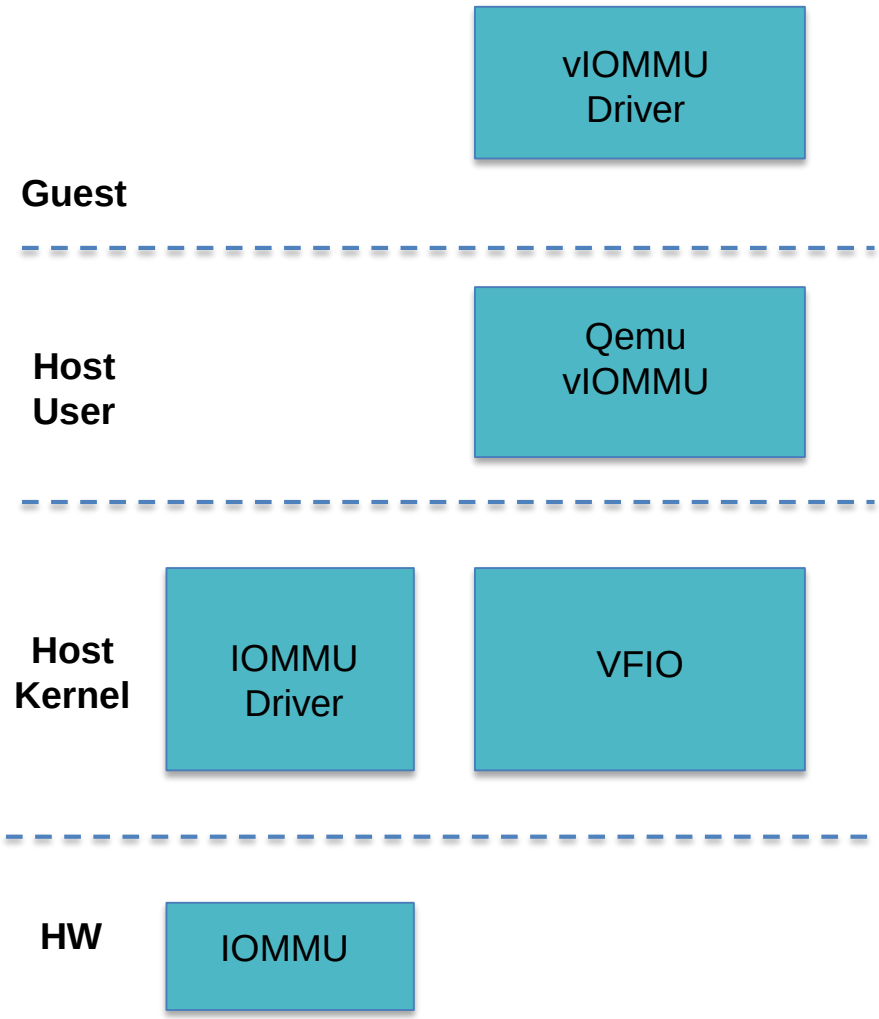
SVM in VM based on Intel® VT-d

Enable SVM in VM (Cont.)



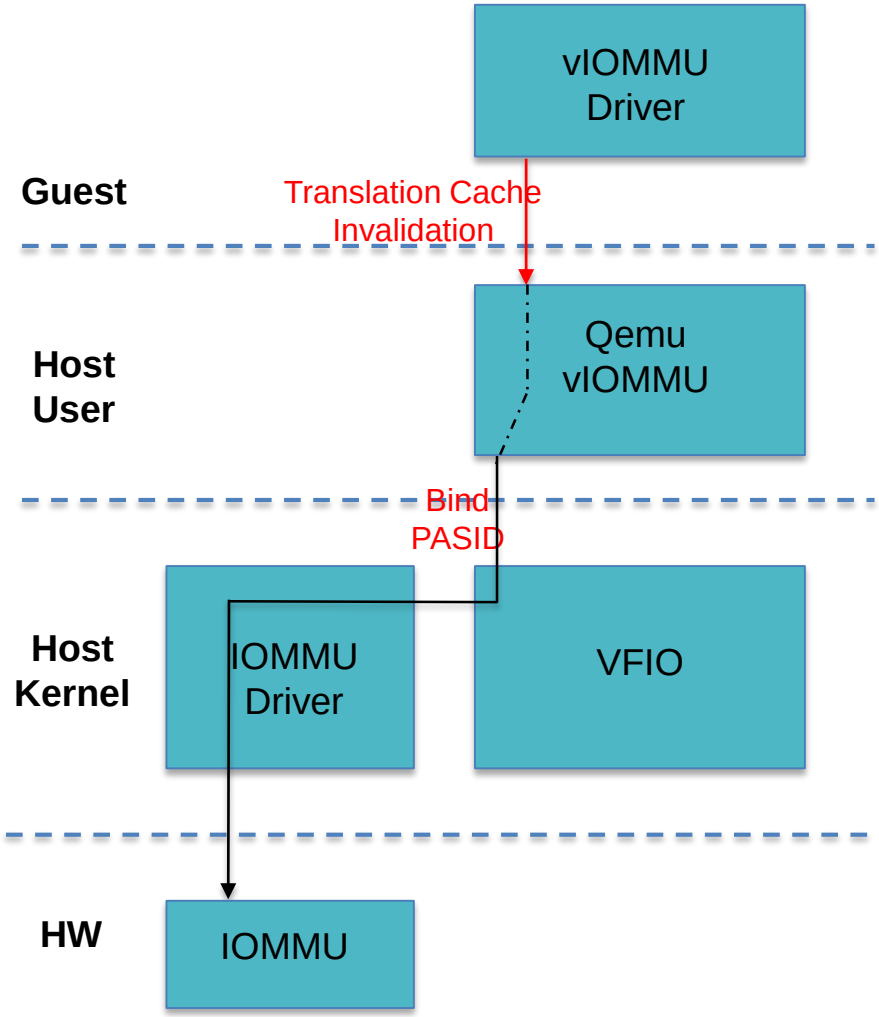
SVM in VM based on Intel® VT-d

Shared Virtual Memory in KVM



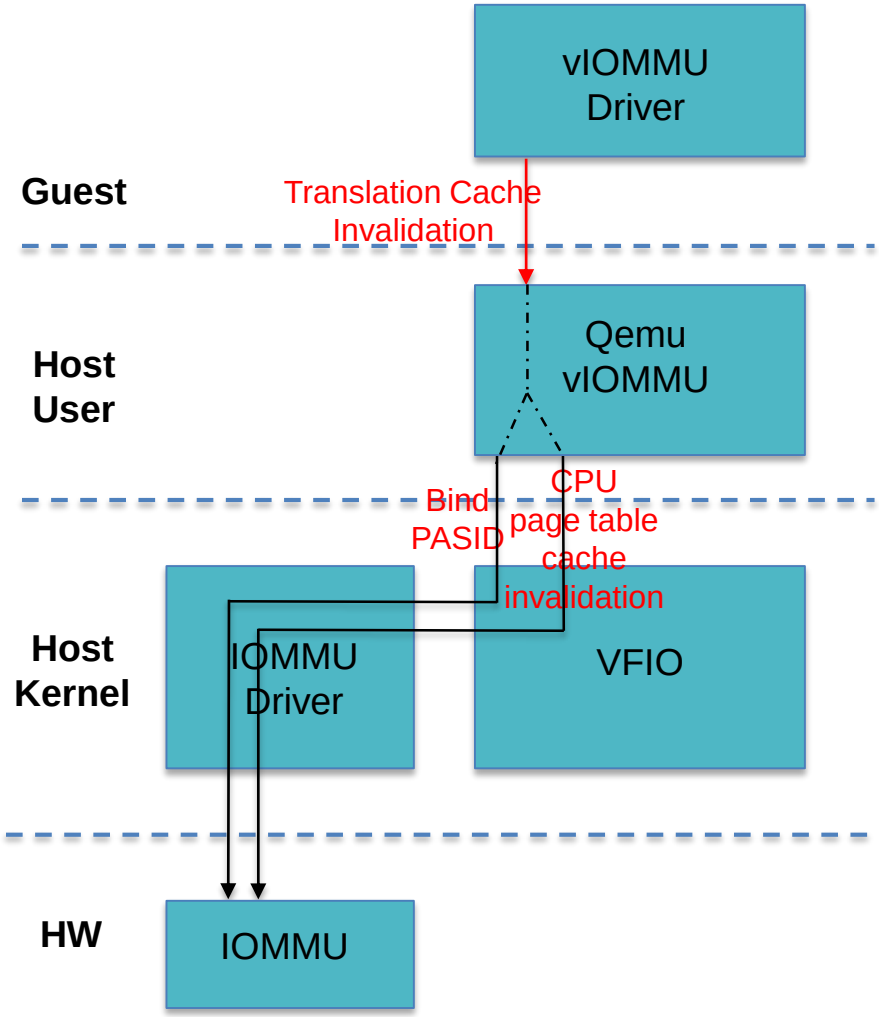
- Qemu
  - vIOMMU emulation is in Qemu
- VFIO: Virtual Function I/O
  - Program host IOMMU via VFIO
- IOMMU driver
  - New APIs exposed to VFIO for guest SVM

Shared Virtual Memory in KVM



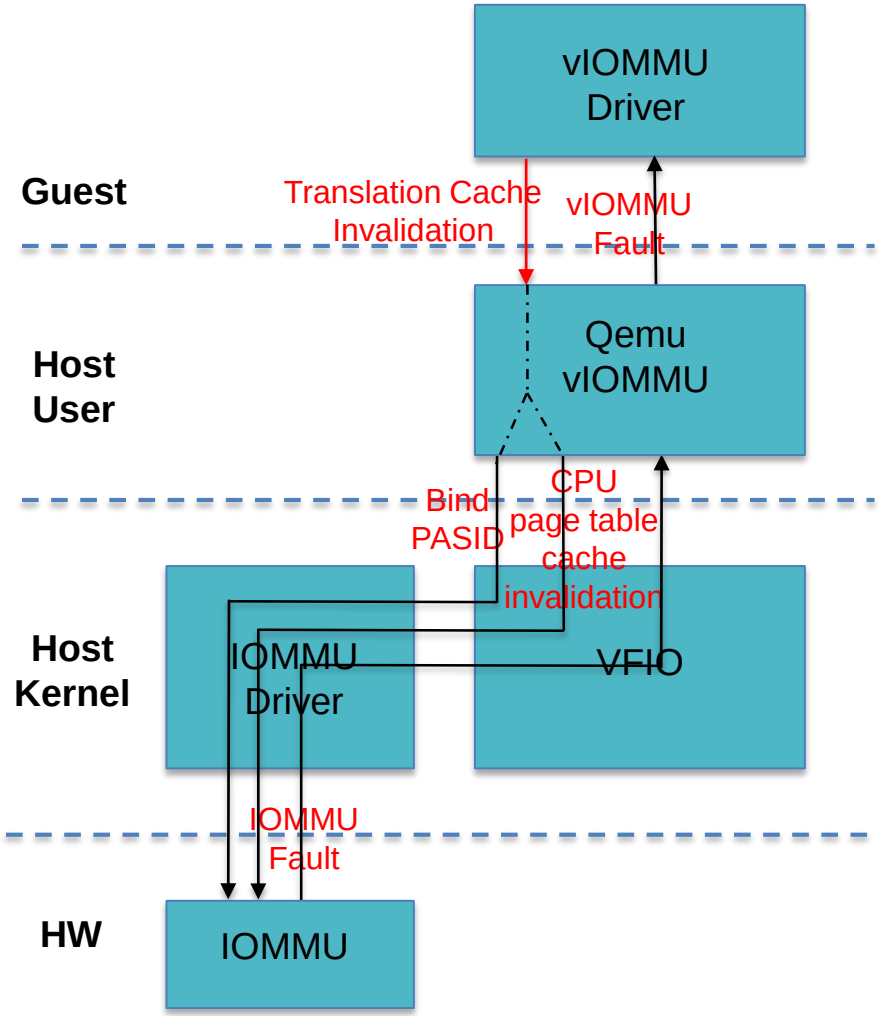
- Bind PASID to guest CPU page table

Shared Virtual Memory in KVM



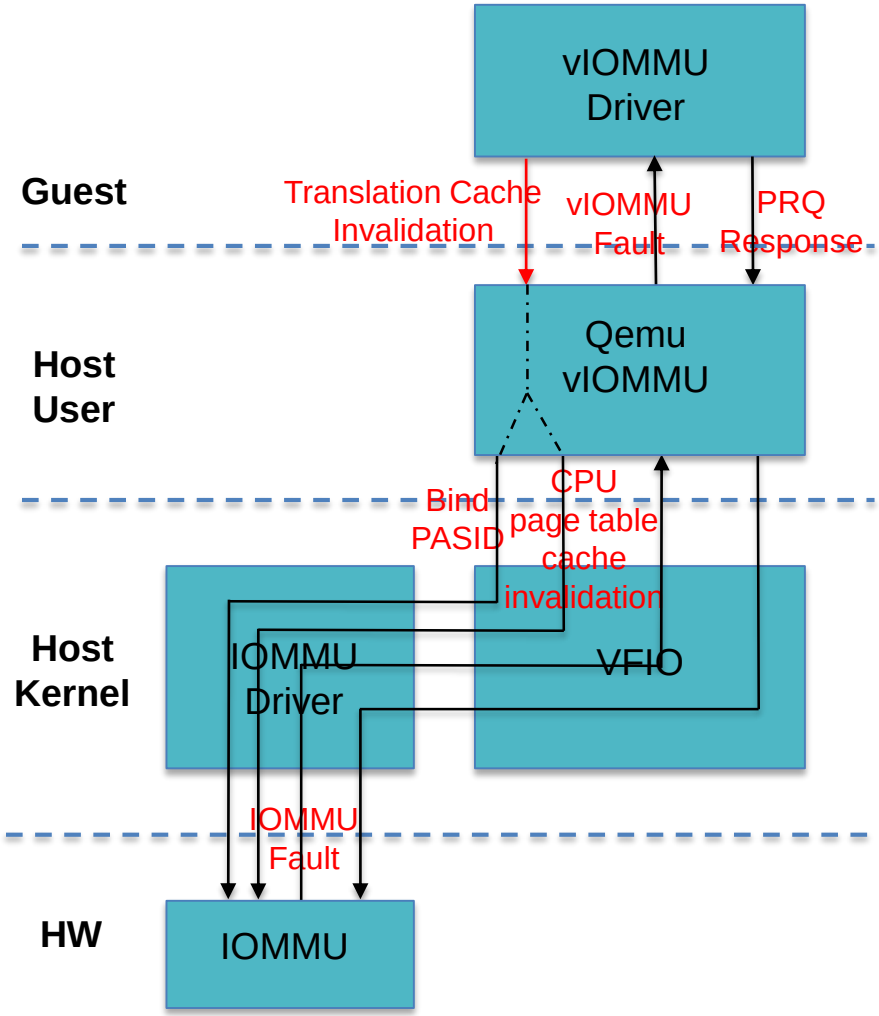
- Bind PASID to guest CPU page table
- Forward guest CPU page table cache invalidation to host

Shared Virtual Memory in KVM



- Bind PASID to guest CPU page table
- Forward guest CPU page table cache invalidation to host
- Page fault reporting and servicing

Shared Virtual Memory in KVM



- Bind PASID to guest CPU page table
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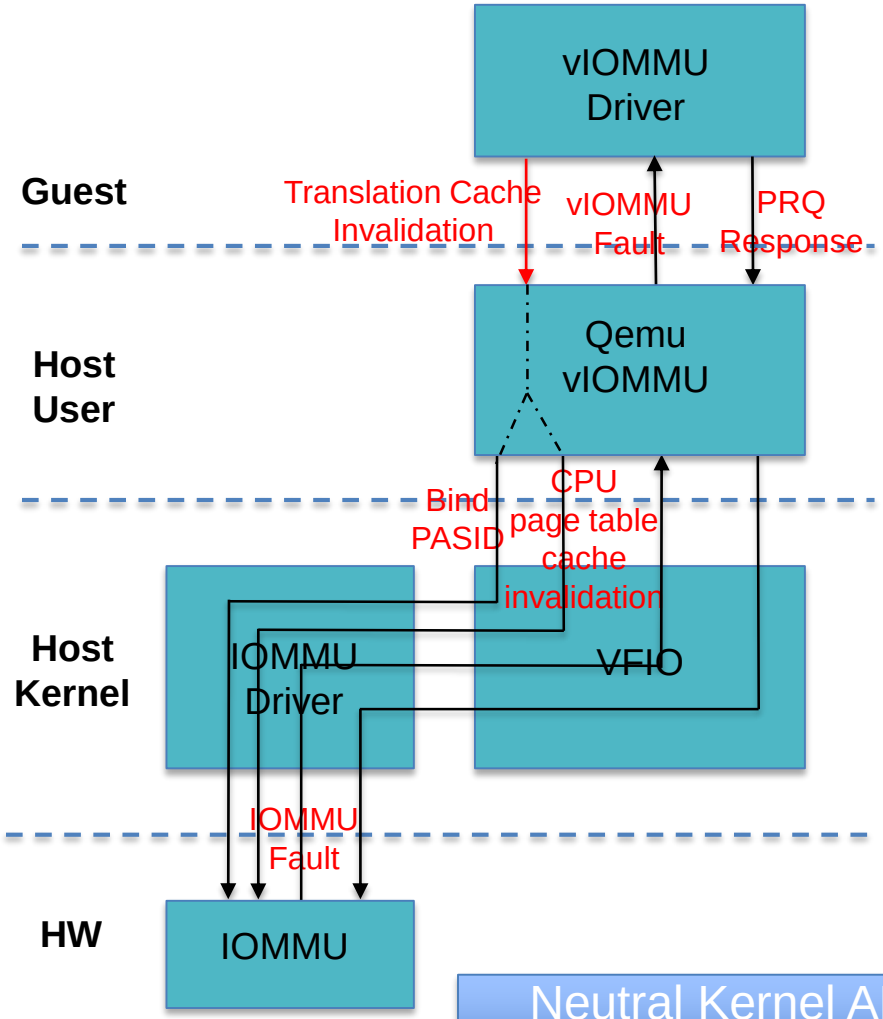
Shared Virtual Memory in KVM

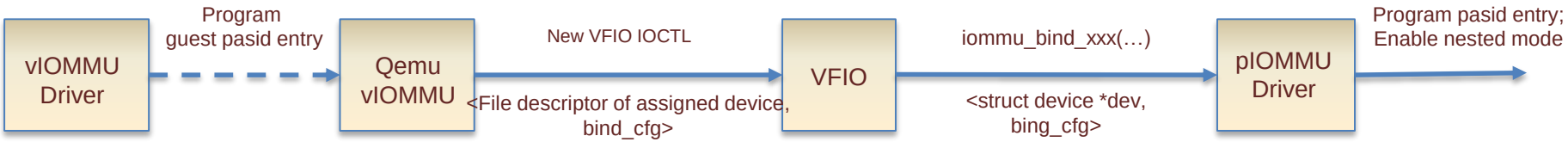


- Bind PASID to guest CPU page table
- Forward guest CPU page table cache invalidation to host
- Page fault reporting and servicing

Neutral Kernel APIs for both emulated and virtio-based vIOMMUs

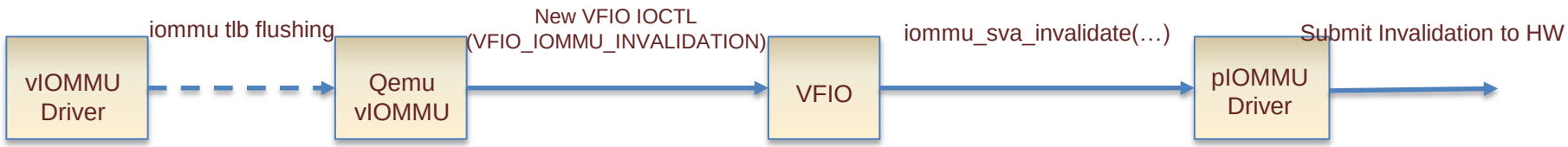
Bind PASID

- New VFIO IOCTL supporting multiple binding types:
  - VFIO_IOMMU_BIND_PROCESS
    - Binding to host CPU page table
  - VFIO_IOMMU_BIND_PGTBL
    - Binding to guest CPU page table
  - VFIO_IOMMU_BIND_PASID_TBL
    - Binding to guest PASID Table
- New IOMMU API to configure physical IOMMU
  - Need compatibility check of the table format



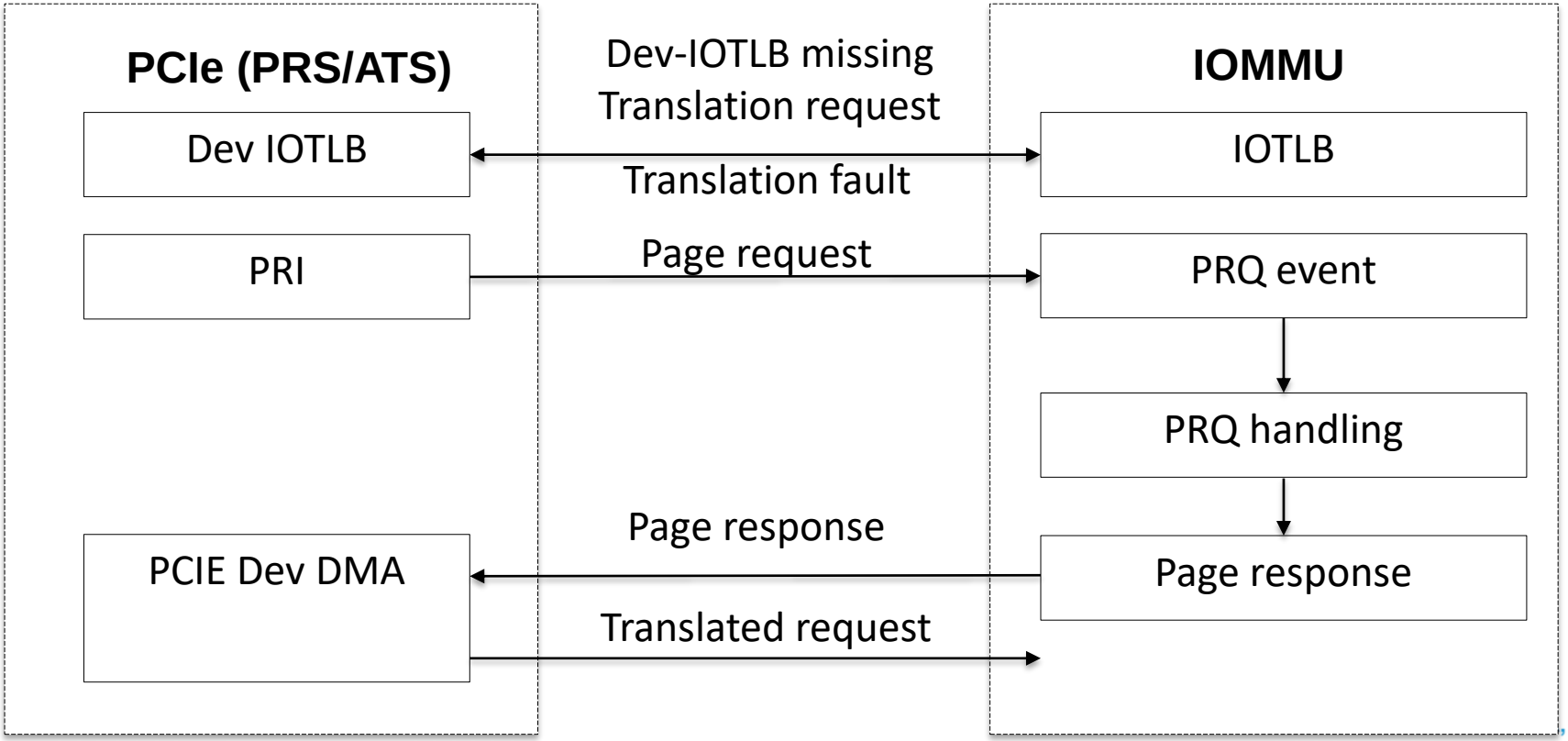
Forward Cache Invalidation to Host

- Invalidation types
  - IOMMU_INV_TYPE_TLB
    - IOTLB and paging structure-caches
- Granularity conversion
  - Supported granularities
    - Domain selective flush
    - PASID selective flush
    - Page selective flush
  - Avoid unnecessary flush
    - Guest global flush -> either domain/pasid selective flush in host
- Use host Identities
  - RID, Domain ID, PASID



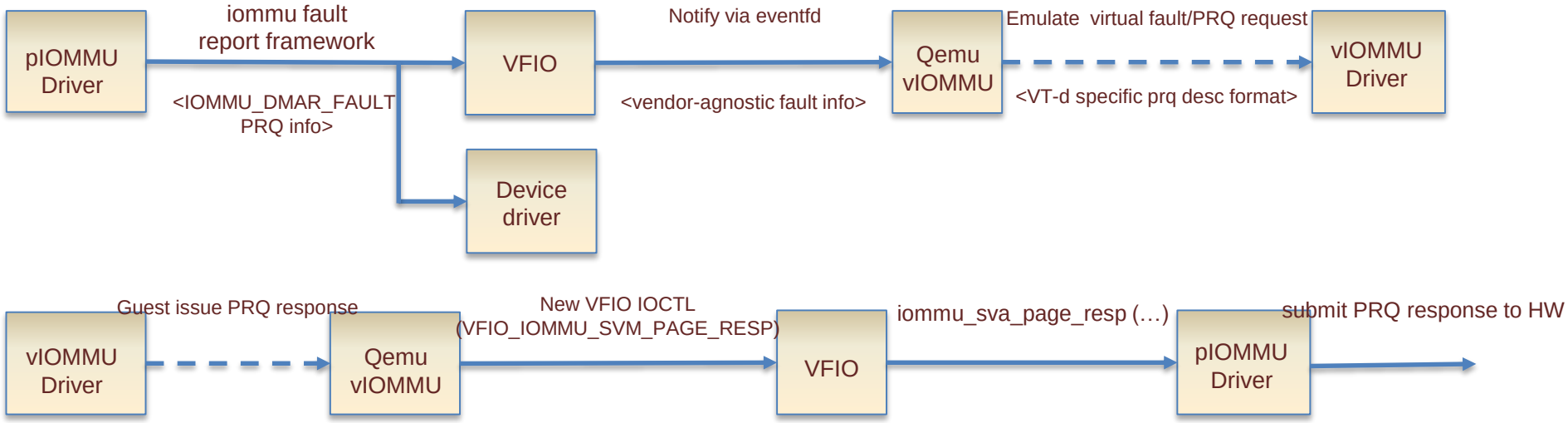
Page Fault Handling

- PCI Express® Address Translation Service
  - PRI: page request interface
  - Page Response (PRS)



Page Fault Handling (Cont.)

- Report PRQ to Guest
  - Page Request Capability in vIOMMU
- Forward guest page response to host



IOMMU Fault Reporting Framework

- Newly defined “struct iommu_fault_param”, added to “struct device”

```
/**
 * struct iommu_fault_param - Per device generic IOMMU runtime data
 * @dev_fault_handler: Callback function to handle IOMMU faults at device level
 * @data: handler private data
 * @faults: holds the pending faults which needs response, e.g. page response.
 * @timer: track page request pending time limit
 * @lock: protect pending PRQ event list
 */
struct iommu_fault_param {
        iommu_dev_fault_handler_t handler;
        struct list_head faults;
        struct timer_list timer;
        struct mutex lock;
        void *data;
};
```

IOMMU Fault Reporting Framework

- IOMMU fault handler registration
  - iommu_register_device_fault_handler()
  - iommu_unregister_device_fault_handler()
- In-kernel device driver and vfio driver registers its own fault handler
  - Vfio fault handler should further notify Qemu or other user-space application
- The original idea was brought up by David Woodhouse
  - May refer to more detail https://lwn.net/Articles/608914/

Upstream Status (Kernel)

- IOMMU/VFIO extension for virtual SVA support (Jacob Pan/Yi Liu, Intel)
  - Earliest RFC patch for vSVA support
  - current kernel API in v5 (https://lkml.org/lkml/2018/5/11/605)
- SVA native enabling on ARM platform (Jean-Philippe Brucker, ARM)
- Shared requirements in the two tracks
  - binding PASID, fault reporting

SVA stands for Shared Virtual Addressing in Linux community

Upstream Status (Qemu)

- Qemu vSVA enabling has two parts (Yi Liu, Intel)
  - vIOMMU emulation
    - Earliest RFC patch for vSVA back to 2017-April
  - Notification framework between vIOMMU emulator and VFIO within Qemu
    - Notifier framework in v3, with community comments addressed

Summary

- Shared Virtual Memory (SVM) enables efficient workload submission by directly programming CPU virtual addresses on the device
- Intel® VT-d 3.0 specification extends SVM usage together with Intel® Scalable I/O Virtualization
- Holistic enhancements are introduced cross multiple kernel/user space components, to enable SVM virtualization in KVM
- New kernel APIs are kept neutral to support all kinds of virtual IOMMUs (either emulated or para-virtualized)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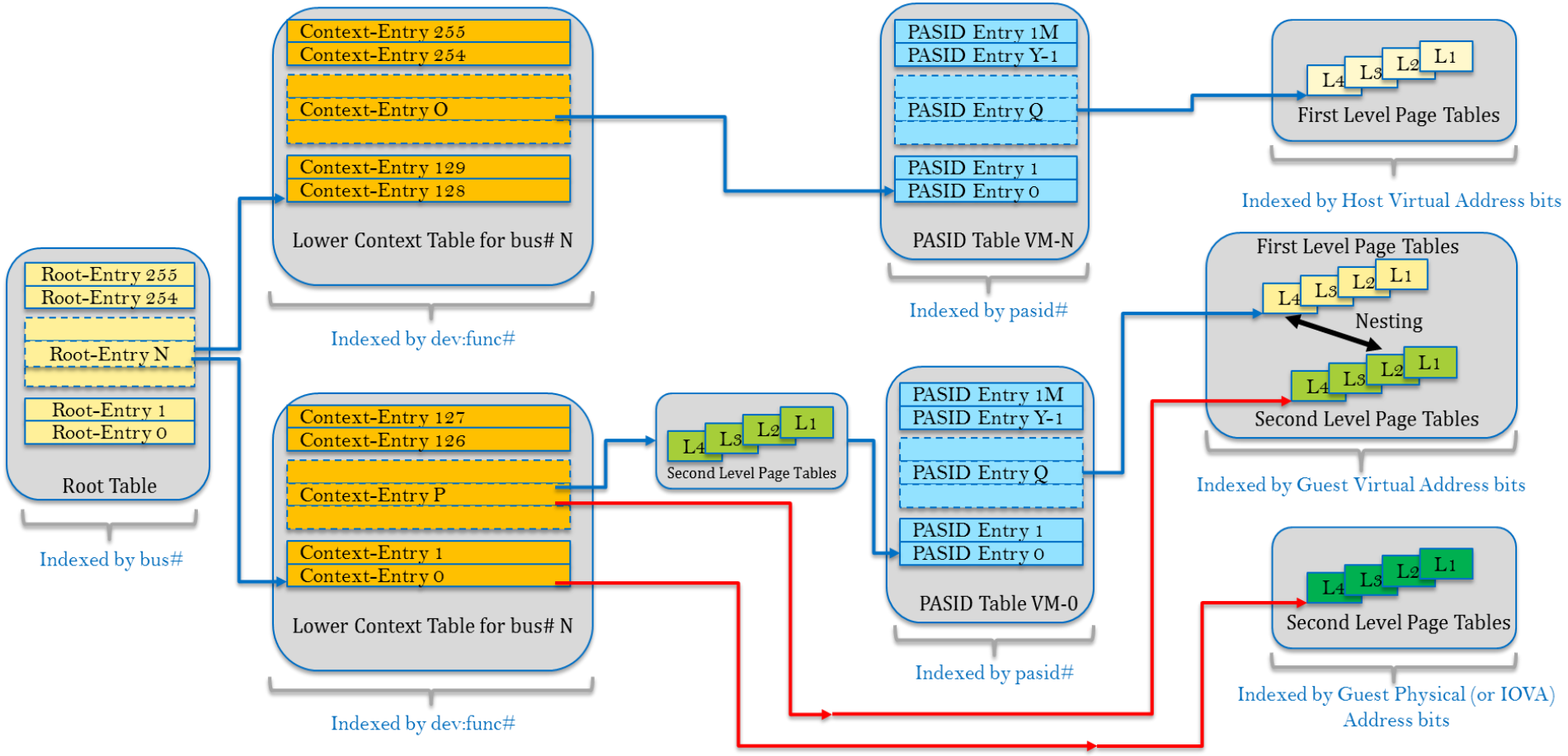
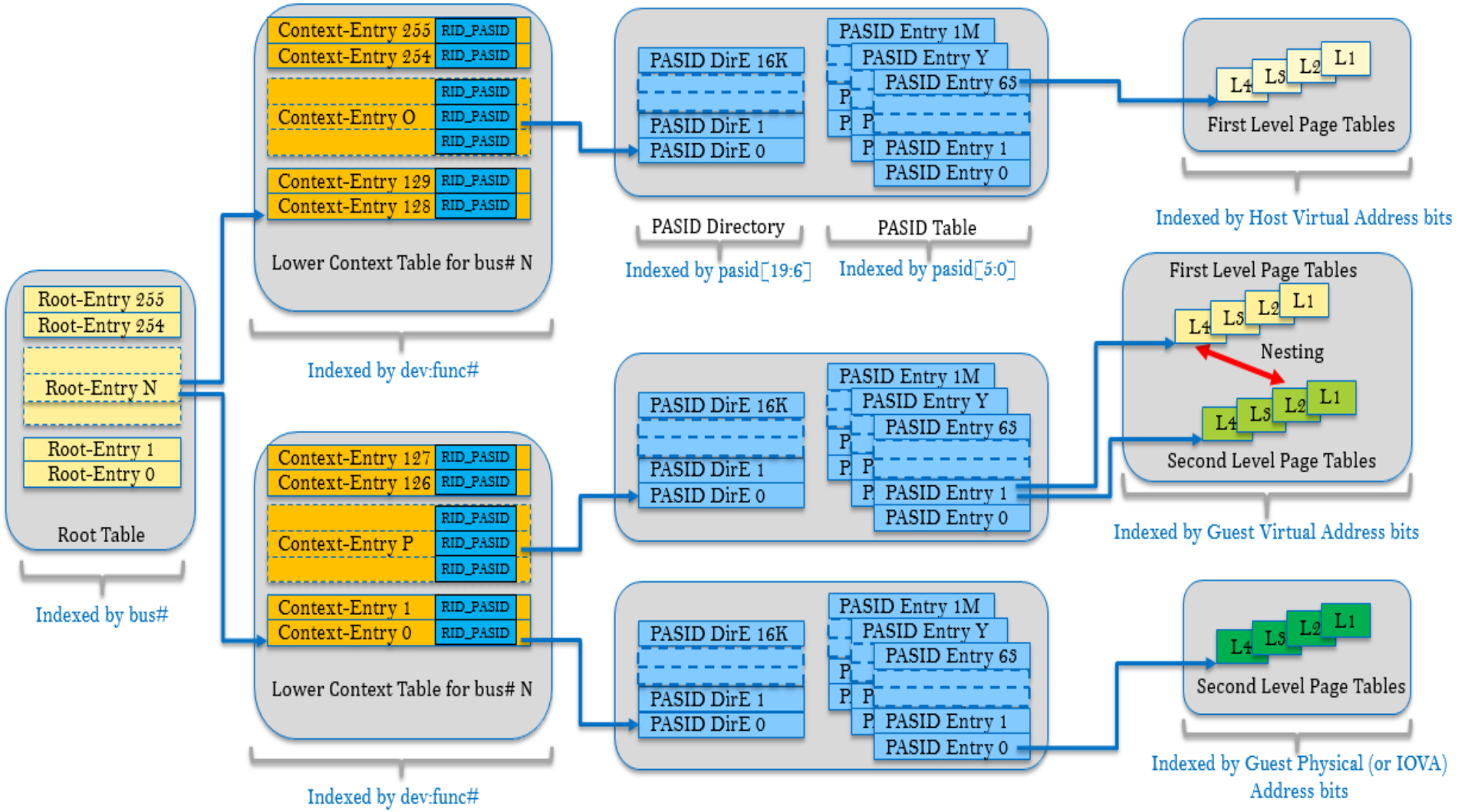
Intel® VT-d ECS (deprecated)



Intel® VT-d Scalable Mode Translation



Key Difference: PASID is a global ID space shared by all VMs.
ALL page-table pointers moved to PASID Granular table