Hardware-Assisted Mediated Pass-Through with VFIO

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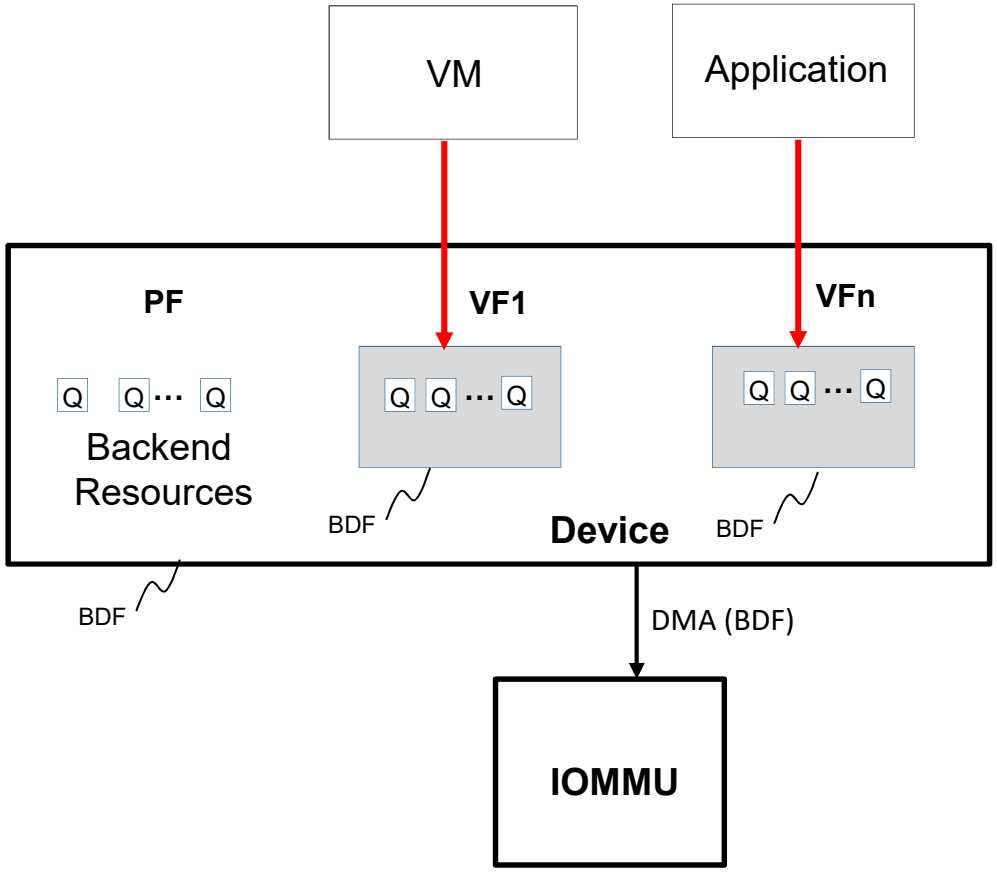
VFIO

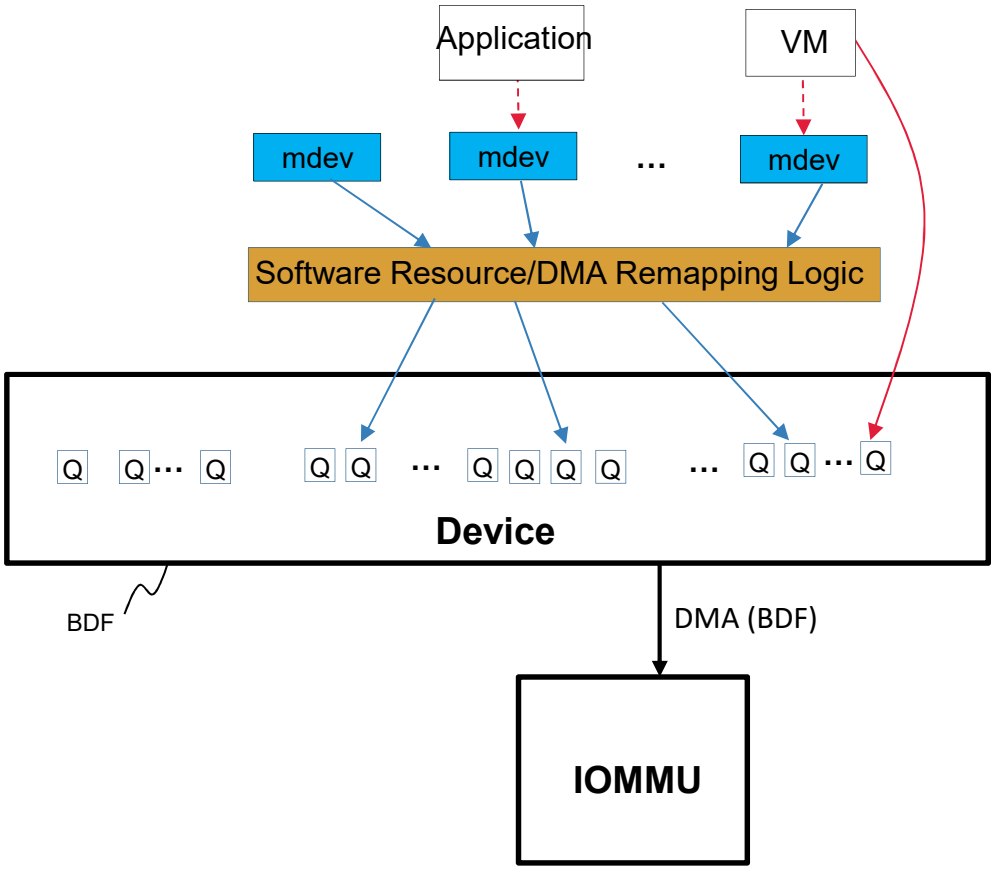
- A secure, userspace driver framework
- VFIO physical device
  - PCI endpoints, platform devices, etc.
  - PCI device sharing through PCIe® Single Root I/O Virtualization (SR-IOV)
- VFIO mediated device
  - vGPUs, channel I/O devices, crypto APs, etc.
  - Device sharing through vendor specific resource mediation policy

PCIe® SR-IOV



- Hardware-assisted I/O virtualization
  - Physical Function (PF)
  - Virtual Function (VF)
- Pros
  - Software simplicity
  - IOMMU-based DMA isolation
- Cons
  - Limited scalability
  - Fixed resource allocation
  - Lack of composability

Mediated Device

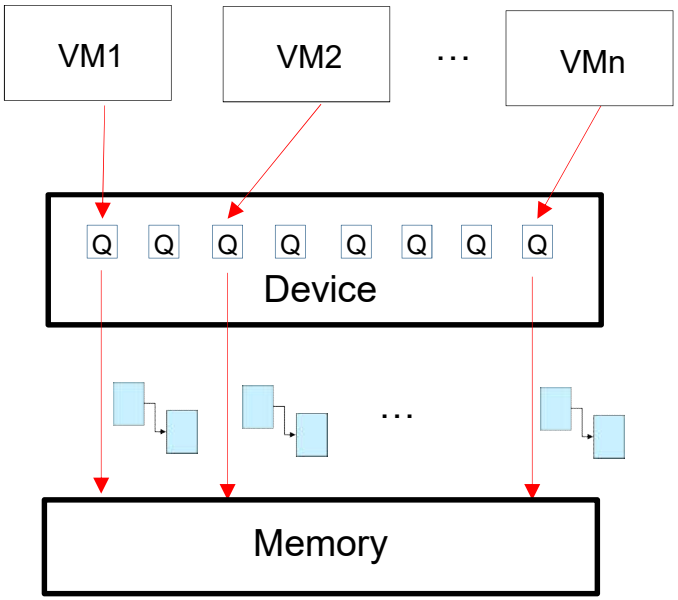


- Mediated pass-through architecture
  - Slow-path operations emulated by software
  - Fast-path operations passed through
- Pros
  - Flexible resource allocation
  - Composability
- Cons
  - Software-based DMA isolation (thus increases complexity and limits scalability)

Can we enjoy merits from both sides for hyper-scaled usage?

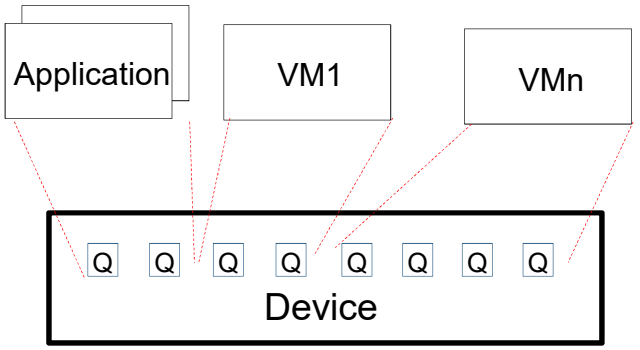
Goals

Finer-grained resource sharing

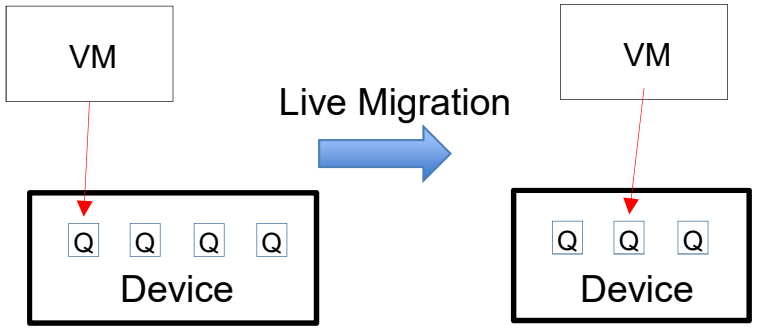


Hardware-enforced DMA Isolation

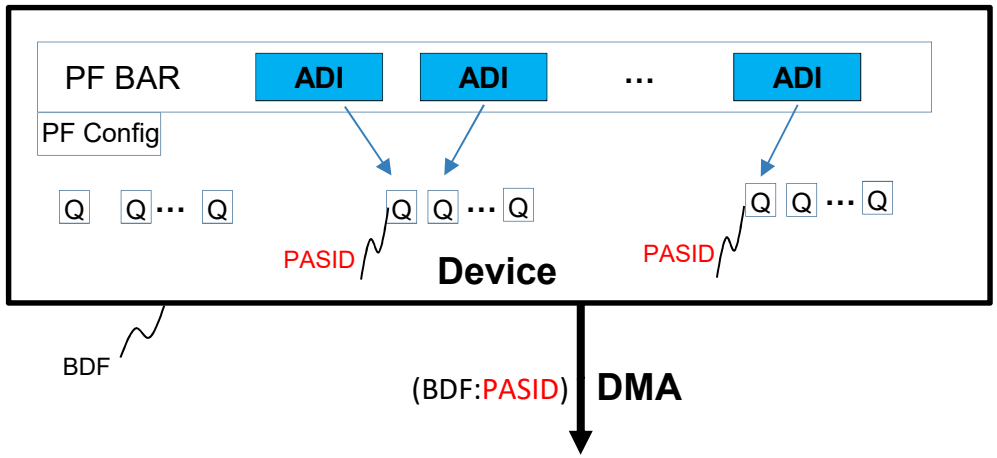
Flexible Resource Allocation



Composability



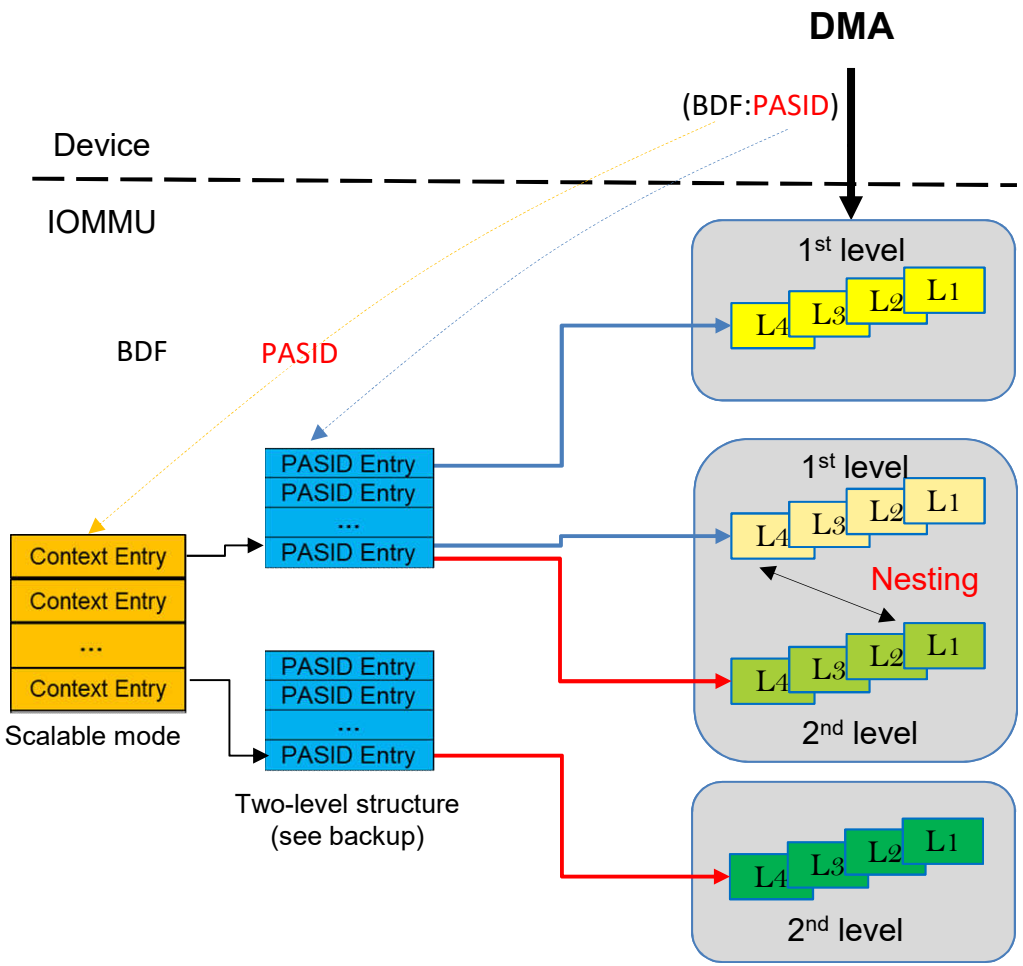
Assignable Device Interfaces (ADI)



- ADI - represents minimal sharable resource
  - Queues, queue pairs, contexts
  - Enumerated through DVSEC capability (see backup)
- Meets isolation criteria to be ‘assignable’
  - Functional isolation between ADIs
  - ADI MMIO in separate system page size regions
  - Independently resettable
  - Interrupt Message Storage (IMS)
  - …
- Tags DMA with unique PASIDs

Enable maximum possible scalability!

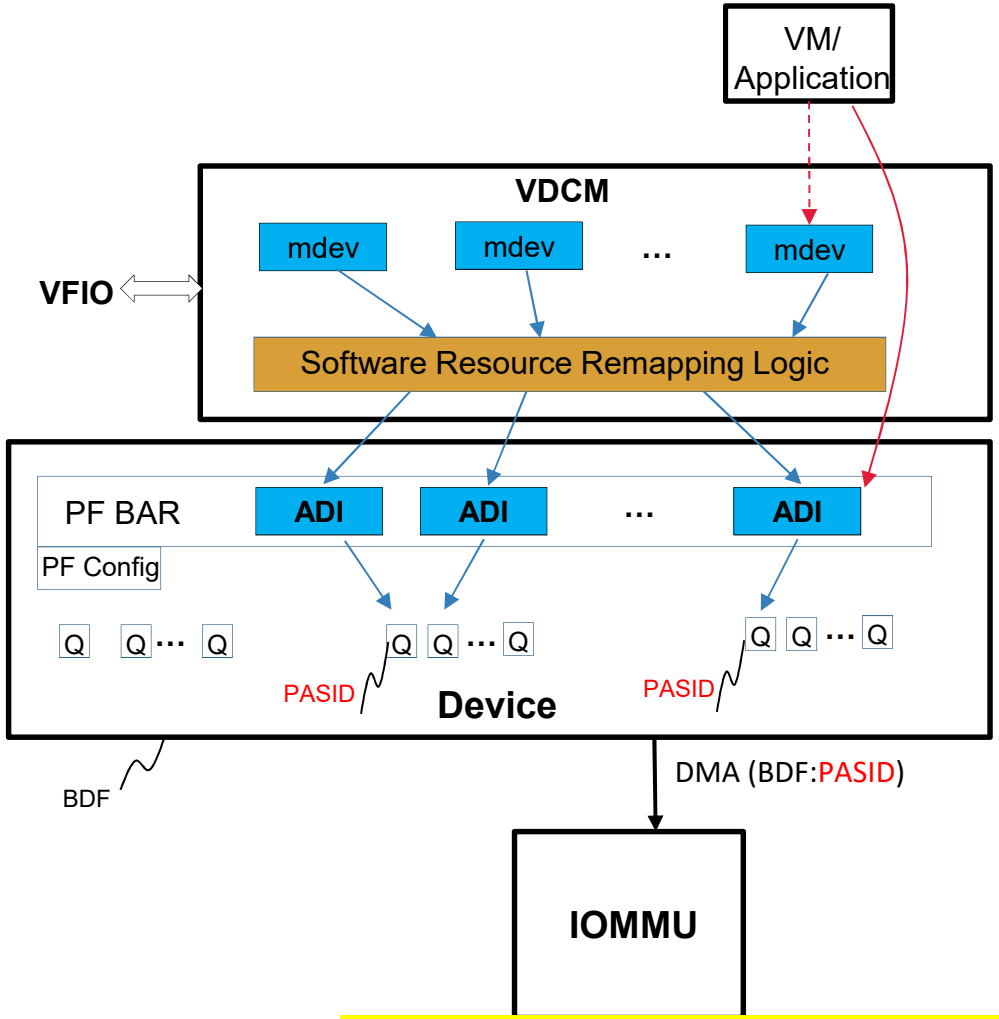
PASID-granular DMA Isolation



- Moves all IOMMU paging structures to per-PASID
  - 1st level translation
  - 2nd level translation
  - Nested translation
  - Pass-through translation
- Enables PASID-granular DMA isolation
- Supports all existing address translation usages
  - IOVA, VA, GPA, GIOVA and GVA

Enable hardware-enforced DMA isolation!

Software Composition



- Virtual Device Composition Module (VDCM)
  - Software managed resource remapping between mdev and ADI
  - Composes ADIs into mediated device (mdev)
- Leverage VFIO mdev framework for
  - Managing mdev life-cycle
  - Setting up access policy on mdev resources
  - Serving slow-path operations from guest

Enables great flexibility and composability!

Combining them together…

Intel® Scalable I/O Virtualization (Intel® Scalable IOV)

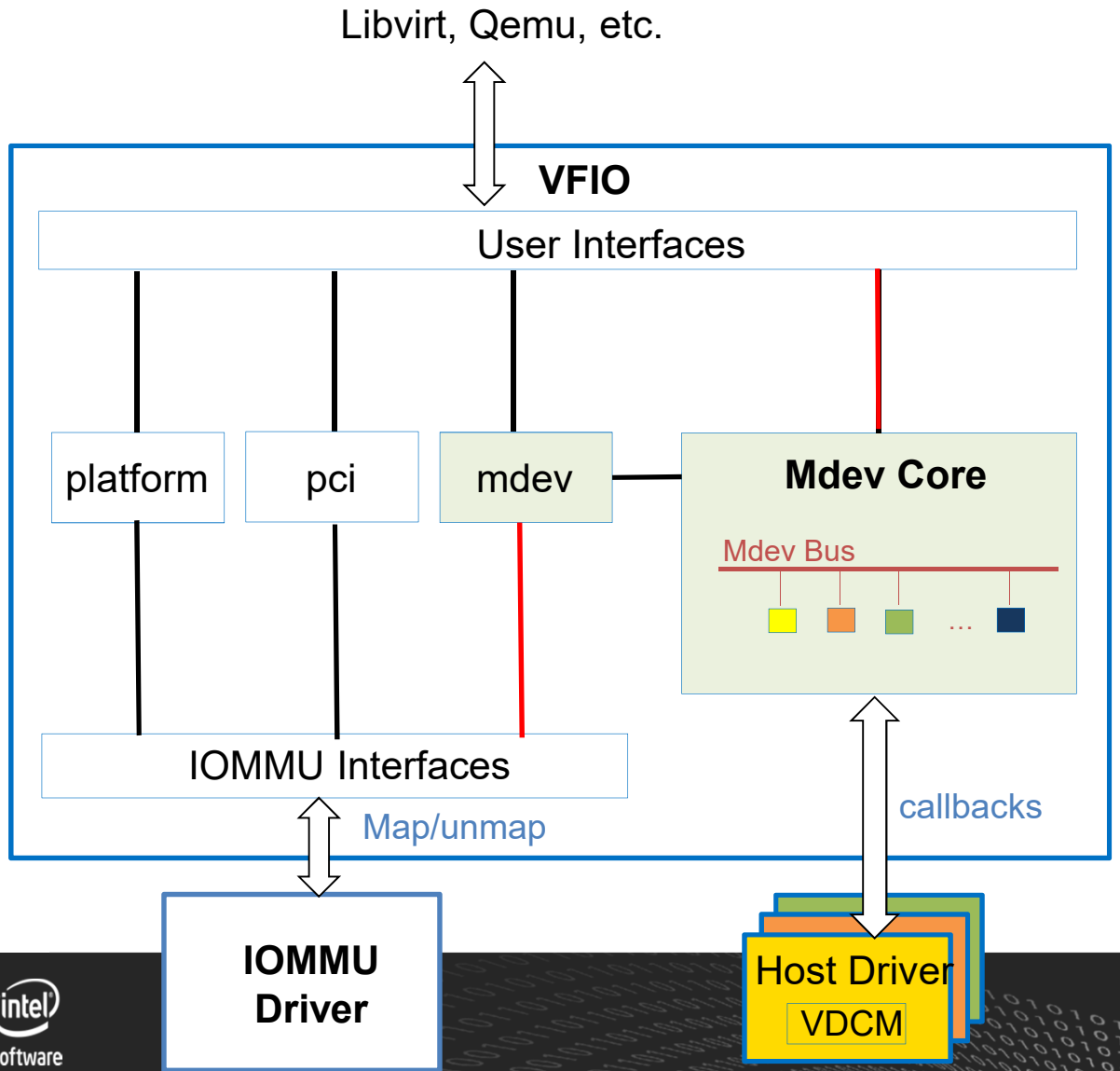
- A hardware-assisted mediated pass-through architecture
  - Device: supports Assignable Device Interfaces (ADIs)
  - Platform: extends Intel® VT-d with PASID-granular DMA isolation (*scalable mode*)
  - Software: moves infrequent (slow-path) accesses from device to software
- Supports any type of devices
  - e.g. NIC, storage, GPU, accelerators, … (integrated or discrete)
- Supports both VM and bare-metal usages

Documentation

- Intel® VT-d specification update (Rev 3.0)
  - Documents Intel® VT-d (IOMMU) support for PASID granular address translation
- Intel® Scalable I/O Virtualization Technical Specification (Rev 1.0)
  - Documents the Scalable IOV architecture blueprint and operation, including DVSEC
  - Addresses architecture requirements for devices and drivers
  - Agnostic of type of device or specific implementation
  - Openly published to enable broad device and software ecosystem
- https://software.intel.com/en-us/articles/intel-sdm

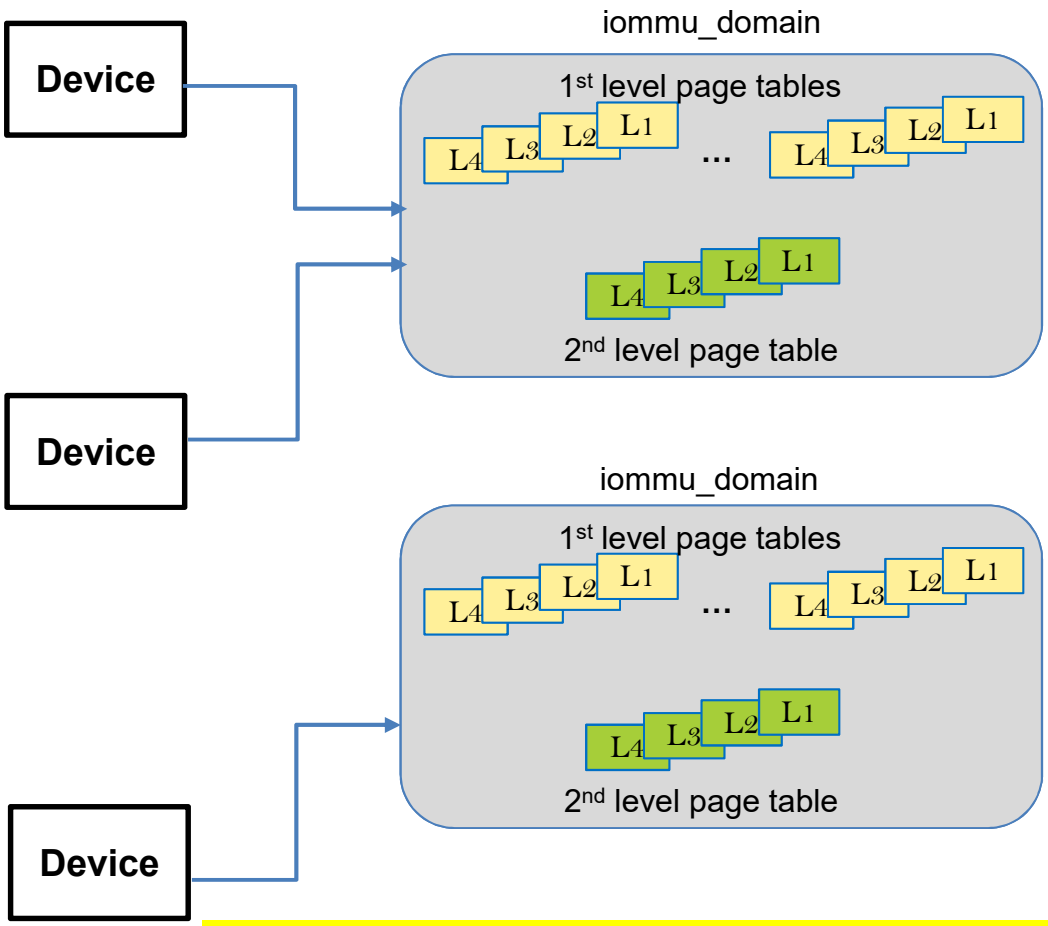
What does it mean to VFIO/IOMMU driver?

VFIO: IOMMU-capable Mdev



- IOMMU-capable mdev
  - Allow IOMMU operations on mdev
  - Opt-in by VDCM
- Finer-grained resource management
  - New aggregated type to compose any number of ADIs into a mdev

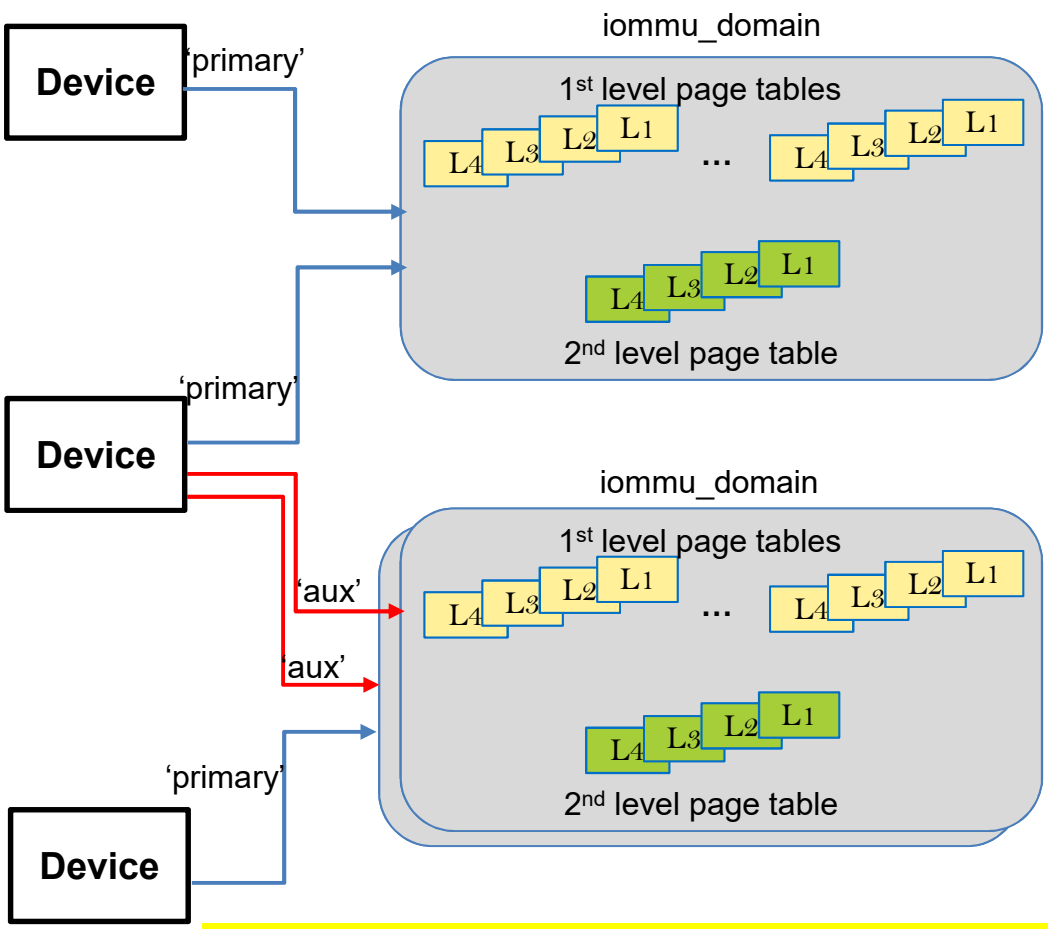
IOMMU Domains



- One device can attach to one domain, at any time
  - One domain can be attached to multiple devices
- Domain type describes IOMMU policy for device DMAs
  - DMA, UNMANAGED, IDENTITY, and BLOCKED
- Domain is switched when policy changes

"one domain" scheme doesn't work for IOMMU-capable mdev!

Auxiliary Domain



- One device can attach to multiple domains
  - A primary domain used for DMA-API
  - Multiple auxillary domains used for mdev instances
- 'aux' is a device attribute instead of domain attribute
  - Same domain may represent as 'primary' to deviceA and 'aux' to deviceB
  - 'primary' vs. 'aux' is decided at domain attach time
  - Device driver enables 'aux' capability on device before attaching domain
- No change to at(de)tach API
  - VFIO attaches domain to mdev's parent

Avoid mdev awareness in IOMMU layer!

Mdev with vIOMMU

- Ongoing effort to enable VFIO devices with vIOMMU
  - Shadow vIOMMU 2nd level usages (e.g. GIOVA)
  - Nesting vIOMMU 1st level usages (e.g. GIOVA/GVA)
    - Including system-wide PASID management
  - Cache invalidation forwarding (when nesting is in-use)
  - Page request/response handling (for guest SVA)
- Expect common user-space logic for vfio-pci and vfio-mdev
  - Just granularity difference handled within IOMMU driver
- Qemu: emulating new VT-d scalable mode emulation
- For more detail, join below session by Yi & Jacob!
  - "Shared Virtual Addressing in KVM"

Status

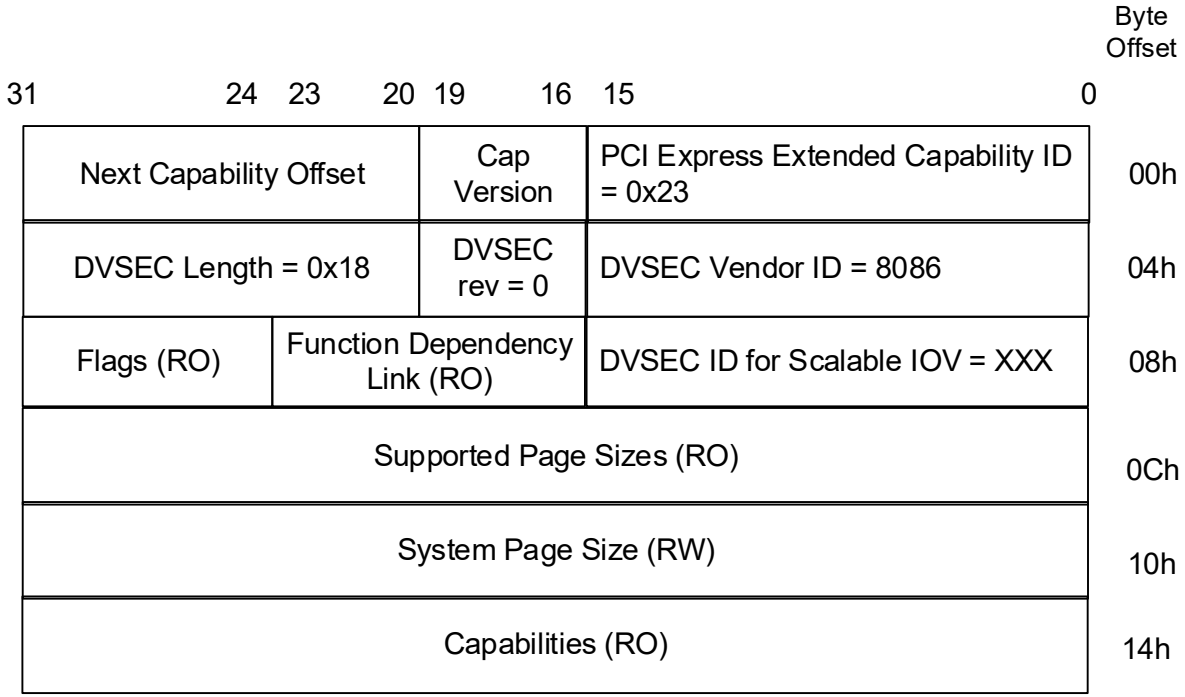
- Key developers
  - Baolu (Allen) Lu (baolu.lu@intel.com)
  - Yi Liu (yi.l.liu@intel.com)
  - Jacob Pan (jacob.jun.pan@intel.com)
- RFC patch progress
  - https://lkml.org/lkml/2018/10/7/54 for scalable mode support in intel-iommu driver in v3
  - https://lkml.org/lkml/2018/10/12/225 for aux_domain and IOMMU capable mdev in VFIO/IOMMU driver in v3
  - Continued hot discussion around vIOMMU/vSVM (in multiple threads)
    - Mdev requirement is being considered gradually
  - https://www.mail-archive.com/libvir-list@redhat.com/msg173811.html for aggregated mdev type in v3

Q/A

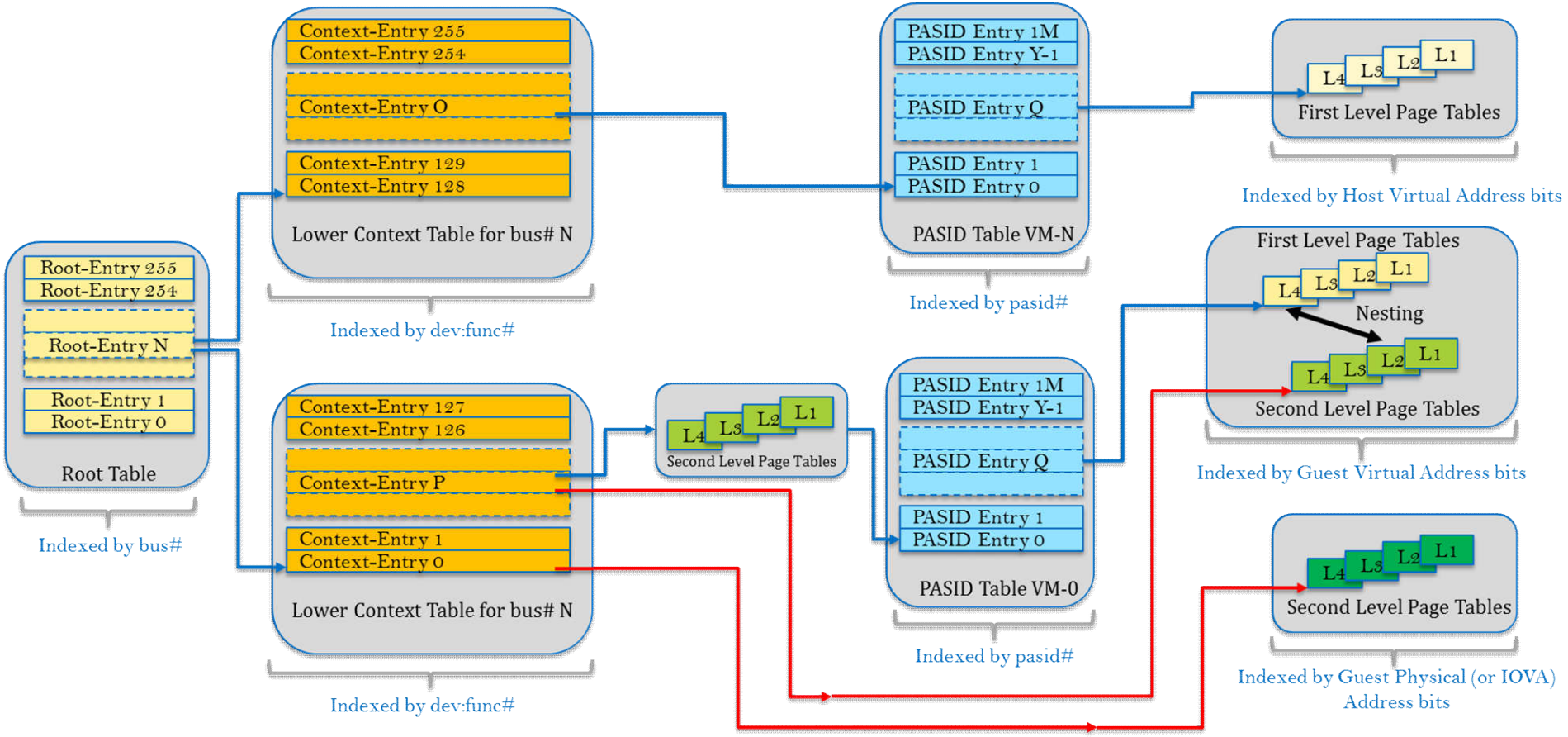
Backup

Enumeration of Intel® Scalable IOV Capability

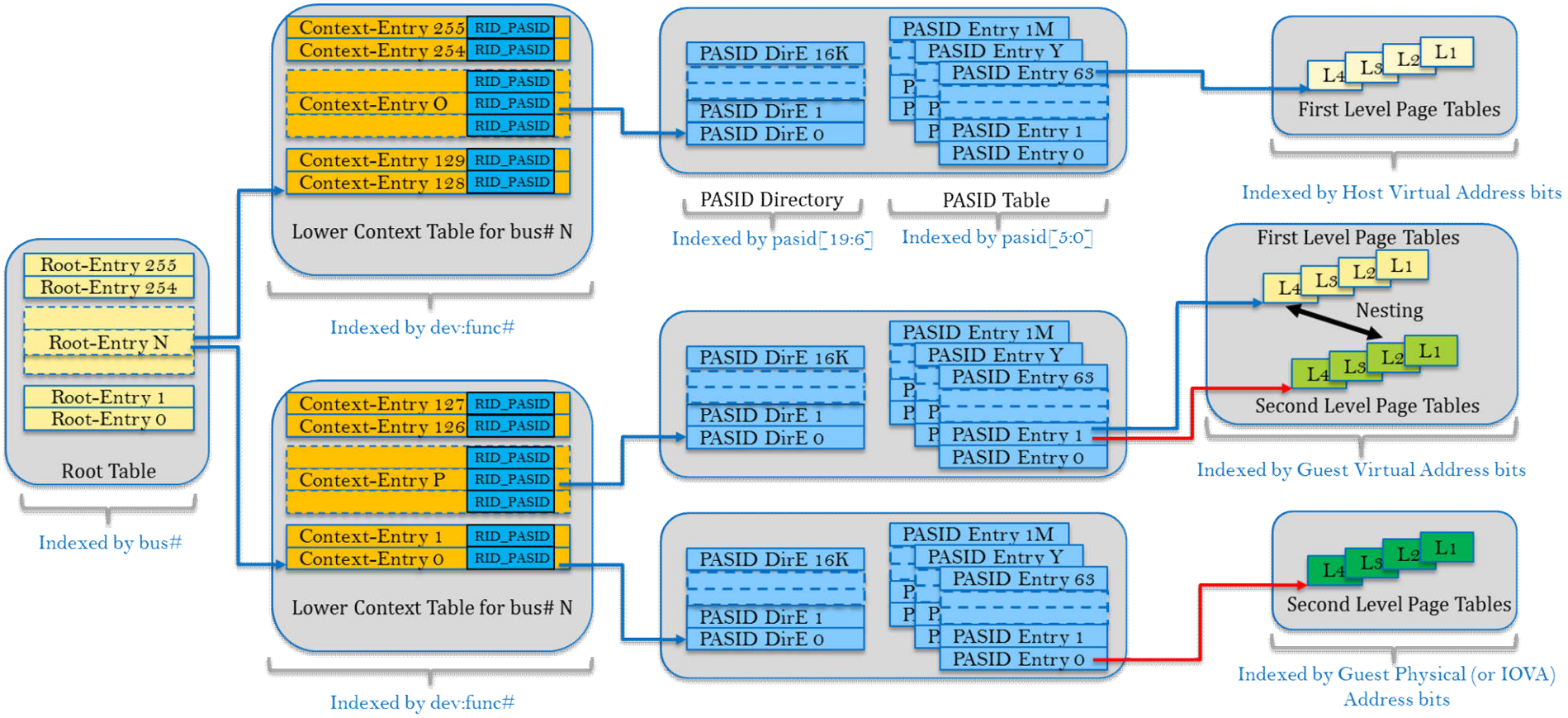
- Designated Vendor Specific Extended Capability (DVSEC) to discover Intel® Scalable IOV capability
  - A simplified subset of SR-IOV capability



VT-d Extended Context Mode (Deprecated)



VT-d Scalable Mode (New)



Key Difference: PASID is a global ID space shared by all VMs.

ALL page-table pointers moved to PASID Granular table