Full GPU virtualization in mediated pass-through way

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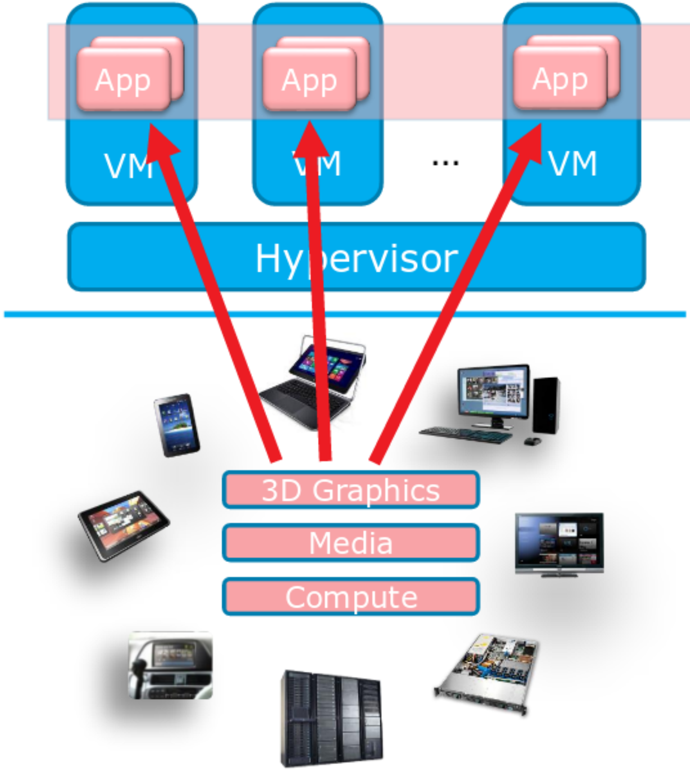
So…GPU virtualization



GPU Accelerated Tasks

Games

Video Playback/Edit

Web Experience

Office Productivity

User Interface

Computer Aided Design

Weather broadcast

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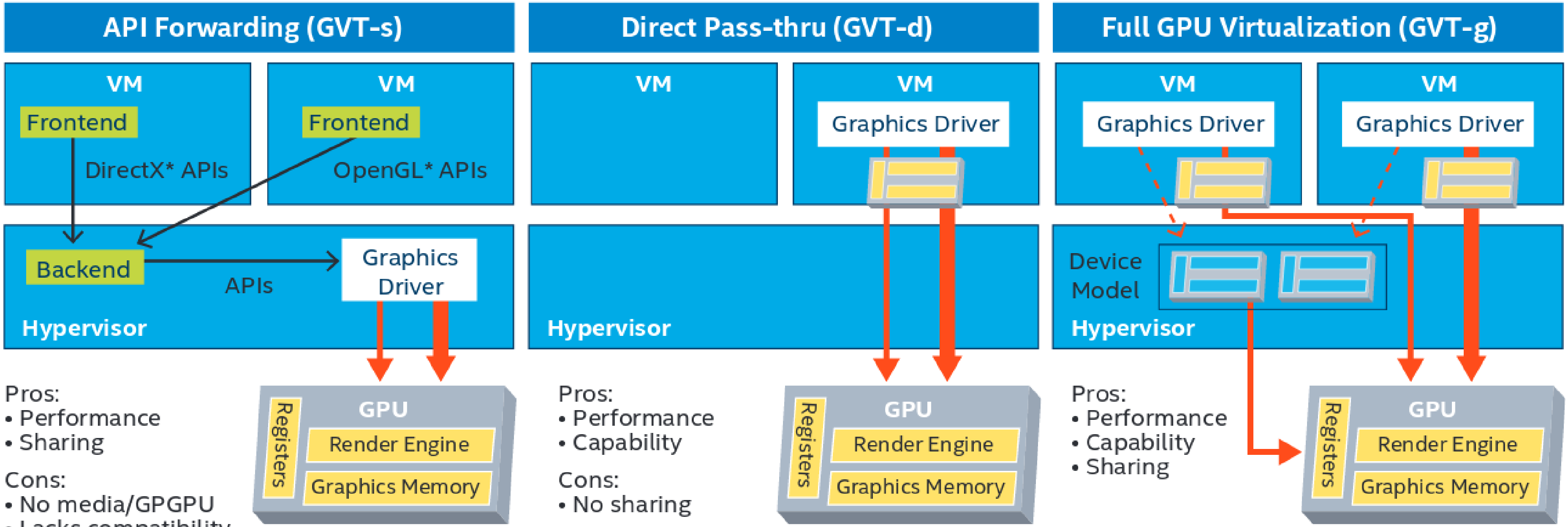
Topics

- Intel GPU virtualization approaches
- A little history of GVT-g project
- VFIO with mediated device
- GVT-g device model

Intel GPU virtualization approaches



Pros:
- Performance
- Sharing

Cons:
- No media/GPGPU
- Lacks compatibility

Pros:
- Performance
- Capability

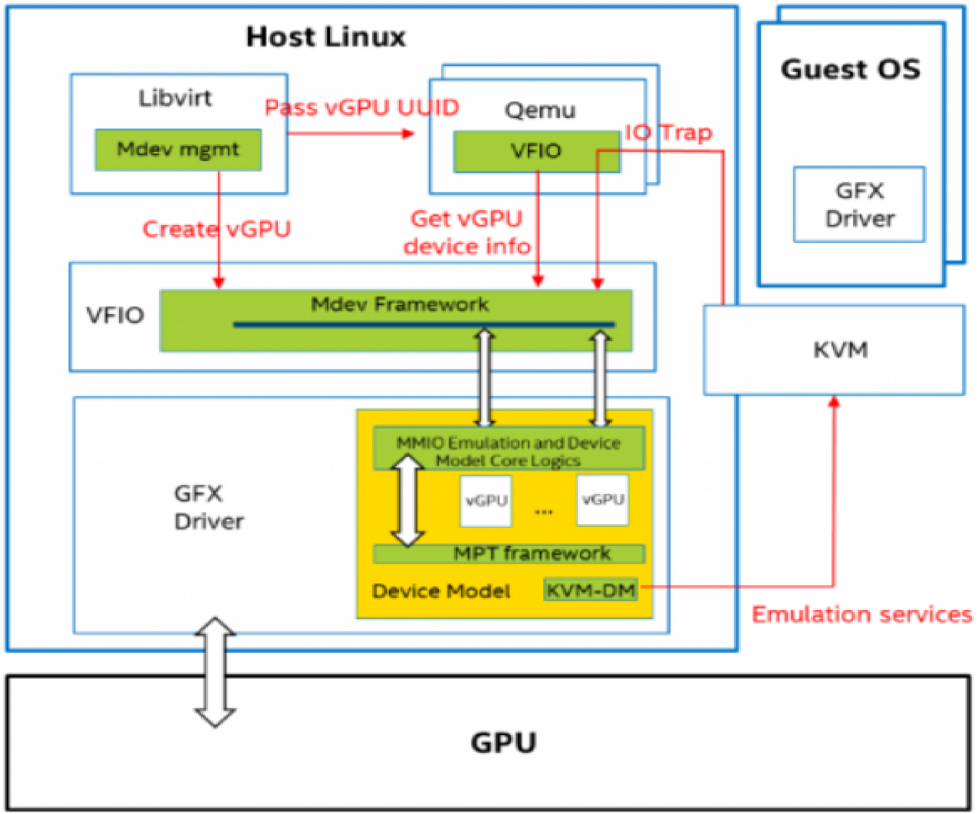
Cons:
- No sharing

Pros:
- Performance
- Capability
- Sharing

GVT-g history

2011-2012	Project Start: First XenGT POC done in 2012 on Sandybridge
2013	Work with Citrix for XenGT production, Haswell support
2014	Add KVMGT support, Broadwell support
2015	GVT device model rewrite for upstream i915, Skylake support
2016	Engage in VFIO/mdev model, KVMGT upstream merged at 4.10!
2017	Kabylake and more features support, XenGT upstream ongoing

GVT-g architecture overview



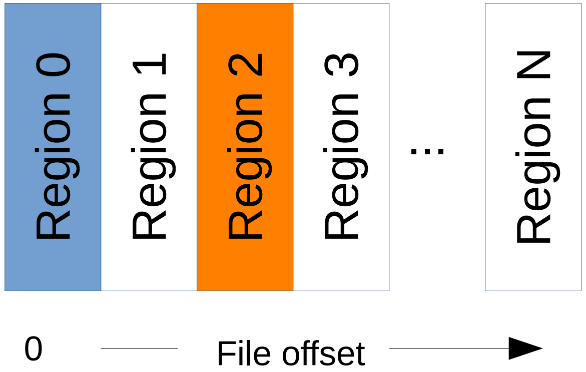
VFIO

- Original “Virtual Function I/O” → “Versatile Framework for userspace I/O”
  - VFIO is a secure, userspace driver framework
  - IOMMU-based DMA mapping and isolation (iommu_group)
  - Full device access (MMIO, I/O port, PCI config)
  - Used for physical device assign to VM
    - now for virtual device assignment
- Device assignment = userspace driver
  - Access to device resources
  - Isolation and secure DMA mapping through an IOMMU
  - Interrupt signaling support

VFIO resource access

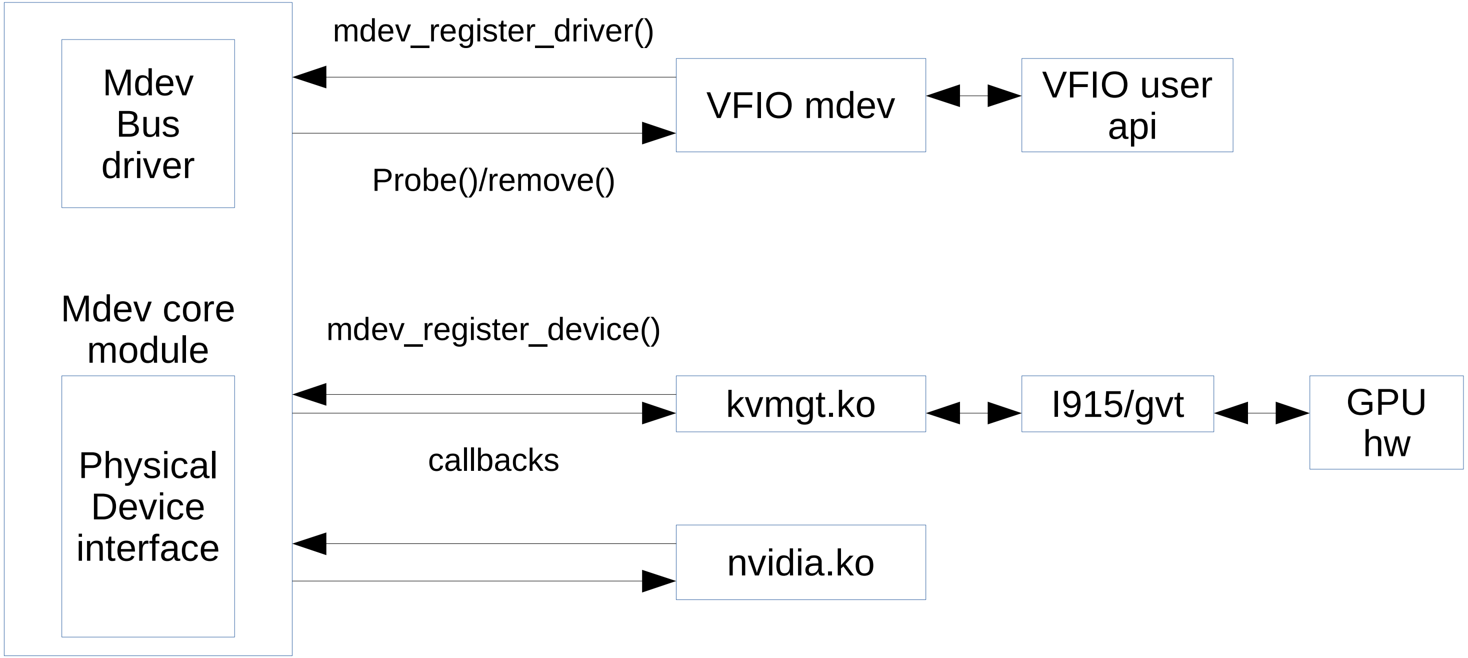
- Divided into regions with index
- Each region maps to a device resource
  - MMIO Bar, IO Bar, PCI config space
- Region count and info discovered through ioctl
  - VFIO_DEVICE_GET_REGION_INFO
- Fast “mmap”, slow “read/write”
- Access Path
  - Trapped by Hypervisor (QEMU/KVM)
  - MemoryRegion lookup performed
  - MemoryRegion.{read,write} accessors called
  - Read/write VFIO region offsets

```
00:04.0 VGA compatible controller: Intel Corporation Iris Graphics 540 (rev 0a)
(prog-if 00 [VGA controller])
        Subsystem: Intel Corporation Iris Graphics 540
        Physical Slot: 4
        Control: I/O+ Mem+ BusMaster+ SpecCycle- MemWINV- VGASnoop- ParErr- Step
ping- SERR+ FastB2B- DisINTx+
        Status: Cap+ 66MHz- UDF- FastB2B- ParErr- DEVSEL=fast >TAbort- <TAbort-
<MAbort- >SERR- <PERR- INTx-
        Latency: 0
        Interrupt: pin A routed to IRQ 26
        Region 0: Memory at fd000000 (64-bit, non-prefetchable) [size=16M]
        Region 2: Memory at 80000000 (64-bit, prefetchable) [size=1G]
        Expansion ROM at 000c0000 [disabled] [size=128K]
```



Mediated device framework

- Co-work from NVidia, Redhat, Intel, IBM
- Represent virtual device to userspace via VFIO interface
- Virtual device access is handled by vendor-specific driver to mediate resource sharing

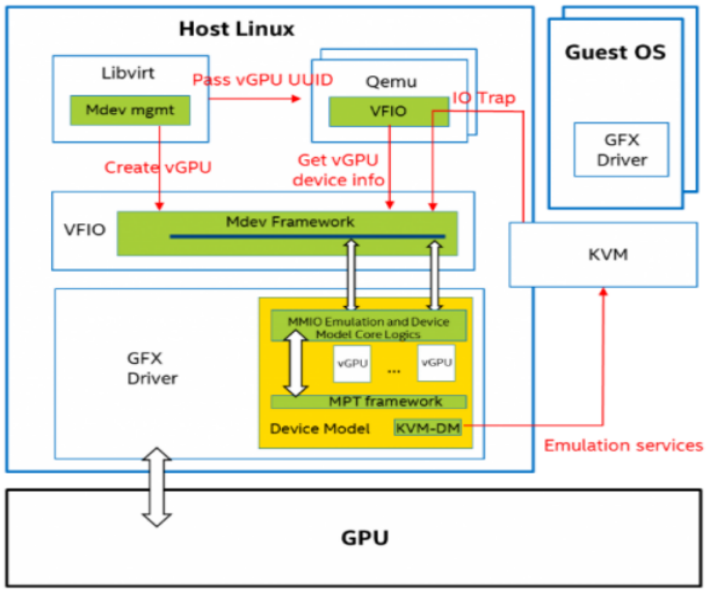


Mdev create & assignment

- Vendor driver register device
  - mdev_create: create virtual device
  - mdev_destroy
  - mdev_supported_types: typed mdev configuration
    - vGPU types base on memory/fence/resolution configs
- UUID based device node:
  - /sys/bus/mdev/devices/$UUID/
- Get VFIO device file descriptor and present to VM

MDev resource access

- Get region info via VFIO ioctl from vendor driver
- Guest MMIO access trapped by KVM
- KVM forward to QEMU VFIO driver
- Convert to R/W request on VFIO device regions
- Handled by mediated vendor driver in kernel



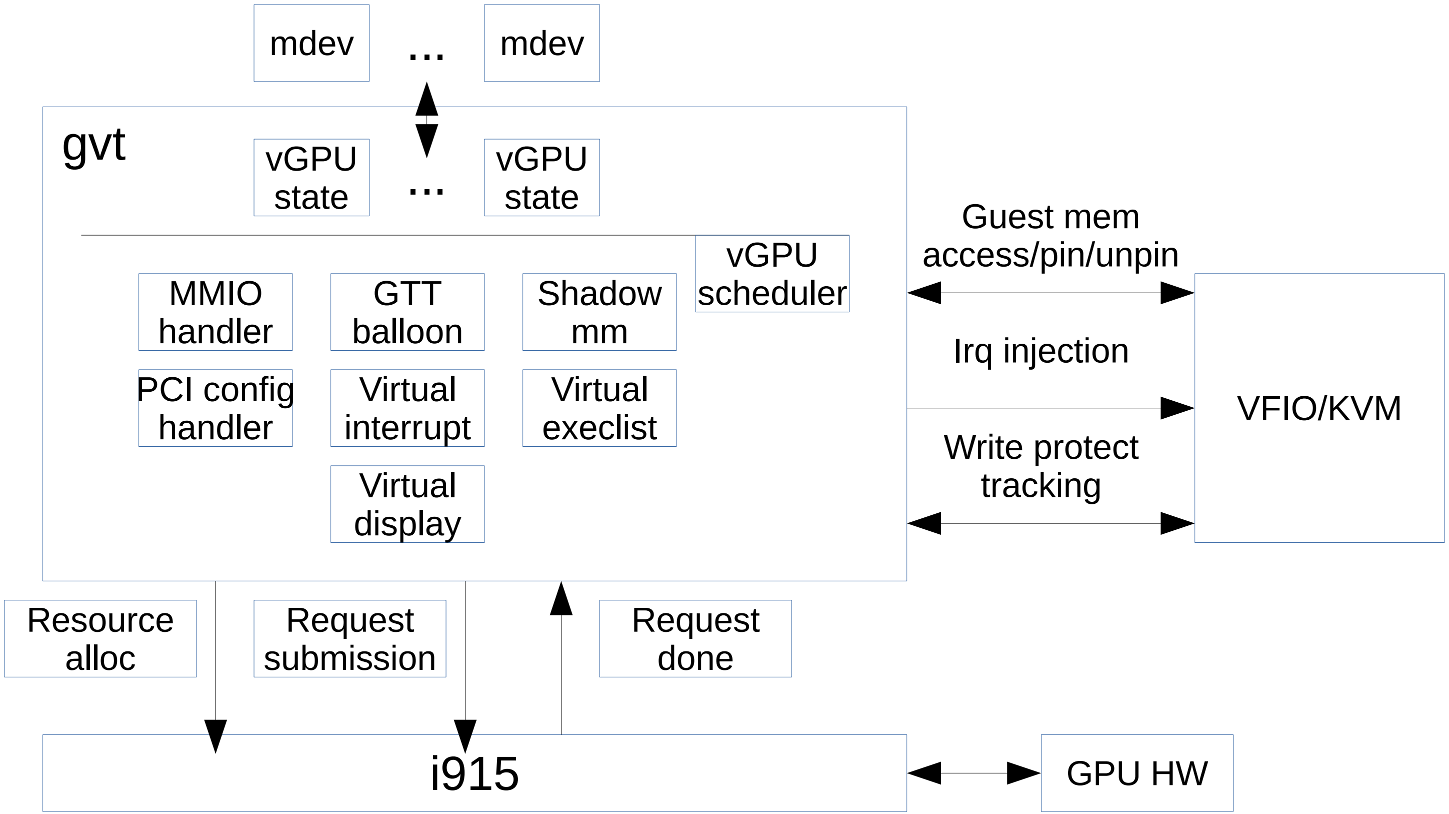
MDev DMA

- QEMU setup guests memory
- VFIO_MAP_DMA with {GFN, VA}
- Vendor driver call VFIO pin pages to get PFN
  - VFIO keep reference counted pinned <IOVA, PFN>
- Vendor driver call dma map API for pIOVA

MDev interrupt

- QEMU setup KVM irqfd
- QEMU notify vendor driver with irqfd via VFIO interface
  - VFIO_DEVICE_SET_IRQS
- Vendor driver inject interrupt by signaling on eventfd
  - Directly inject into VM

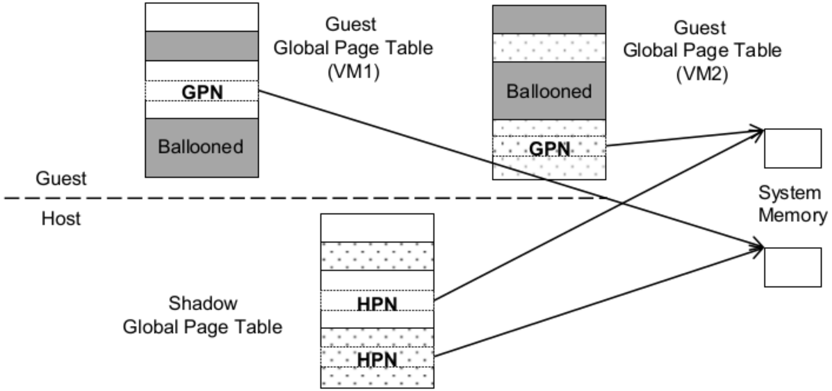
GVT-g device model



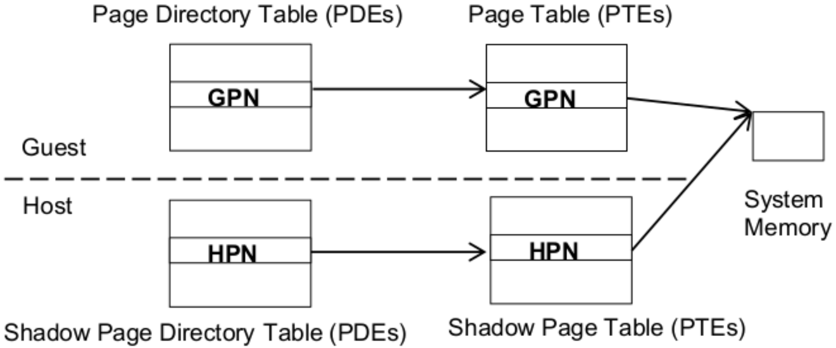
GVT-g device model

- where GPU virtualization logic actually lives
  - virtual GPU state maintenance for VM
  - MMIO handler to emulate HW access behavior for guest driver
  - GPU workload submission emulation and VM notification

vGPU memory manage



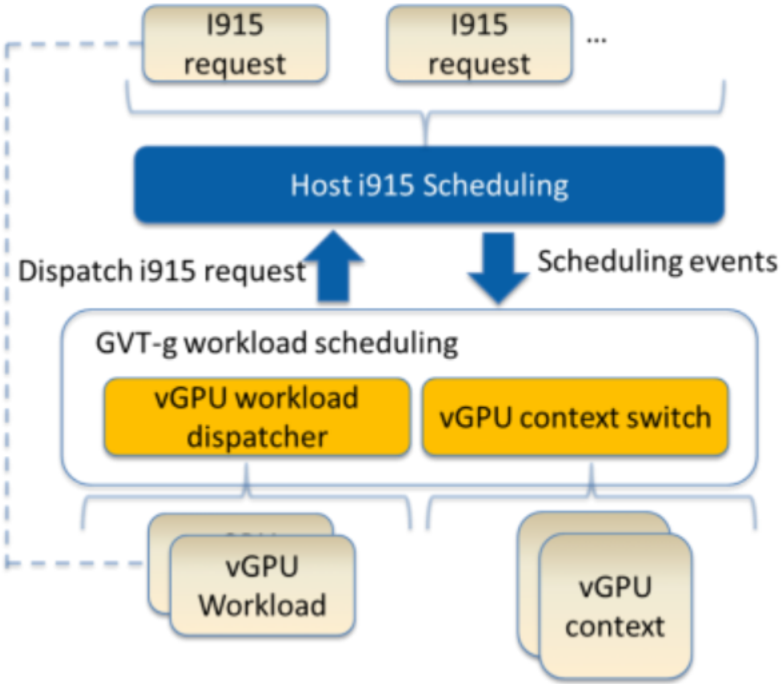
- Global graphics memory is partitioned
- Ballooned space
- Aperture access without trap



- Fully shadowed PPGTT
- Use KVM guest page write protect for page table update tracking

vGPU workload execution

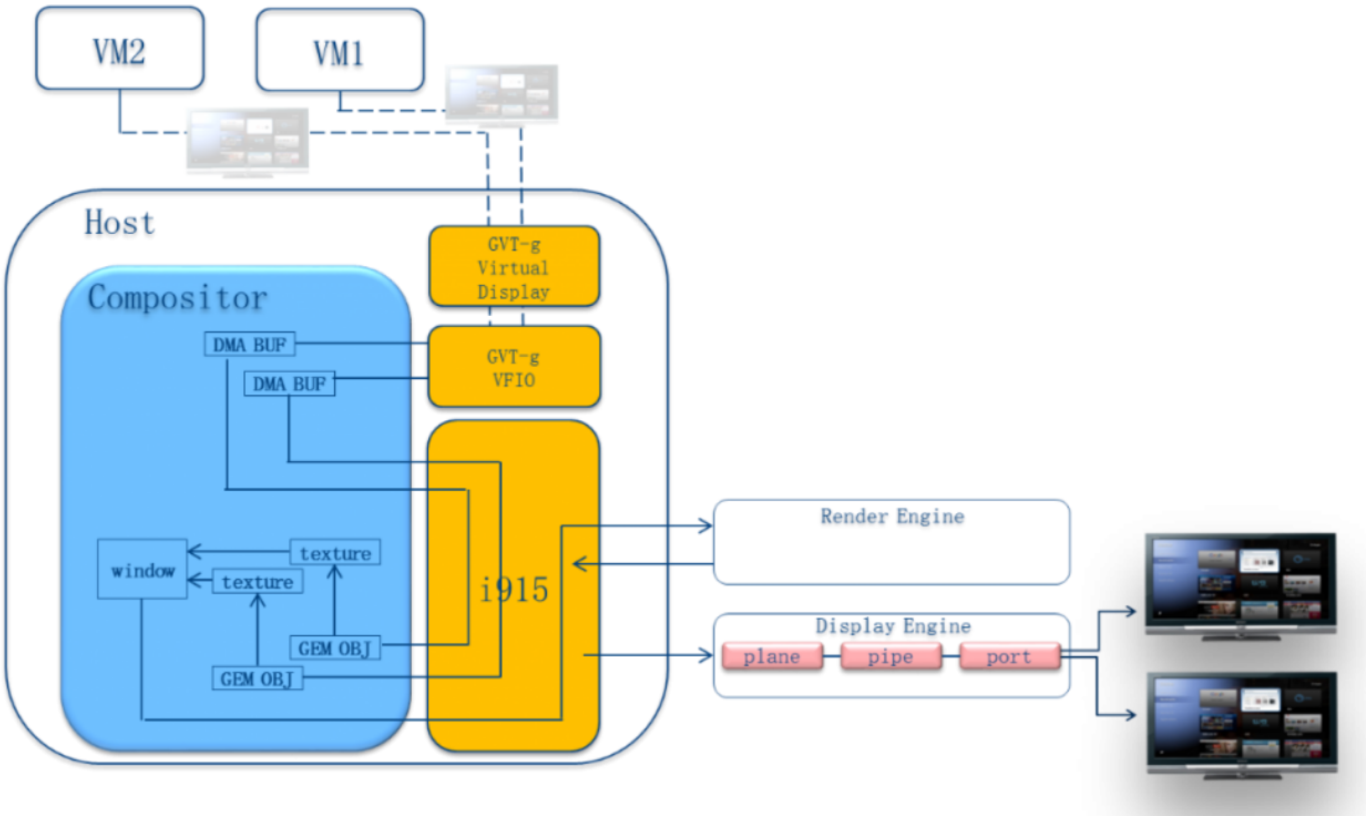
- vGPU shadow context
- Virtualized execlist interface
- Command parser on vGPU ring/privileged buffer
  - Emulated user interrupt



vGPU scheduling

- vGPU instance: time based scheduling
- Scheduled vGPU instance can submit requests to all engines
  - Per-engine work thread
- Scheduler policy based on vGPU weight

vGPU full virtualized display



HOWTO

- Kernel config (>= 4.10)
  - CONFIG_VFIO, CONFIG_VFIO_MDEV, CONFIG_VFIO_MDEV_DEVICE
  - CONFIG_DRM_I915_GVT, CONFIG_DRM_I915_GVT_KVMGT
  - i915.enable_gvt=1
- Create mdev (vGPU)
  - `“uuid > /sys/devices/pci0000:00/0000:00:02.0/mdev_supported_types/i915-GVTg_V5_4/create”`
- Start VM
  - `“qemu-system-x86_64 -m 1024 -enable-kvm -device vfio-pci,sysfsdev=/sys/bus/pci/devices/0000:00:02.0/$UUID...”`
- Detailed HOWTO
  - https://github.com/01org/gvt-linux/wiki

Current upstream status

- KVMGT fully support in upstream, kernel >=4.10, qemu
- Support Broadwell/Skylake/Kabylake for Linux (includes Android) guest (kernel >= 4.8) and Windows guest
- All kinds of GPU applications are supported in guest
  - Although some media features missed for GuC/HuC firmware support
- MTBF time (1 Windows VM): more than 1 week
- Performance (Media workload)
  - Peak perf 95% of native host (1VM)
  - Reach average over 85% performance of native (1 VM run)
- Links:
  - https://github.com/01org/gvt-linux.git
  - https://01.org/igvt-g

Q & A