KVM Architecture Overview

2015 Edition

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Introducing KVM virtualization

KVM hypervisor runs virtual machines on Linux hosts

- Mature on x86, recent progress on ARM and ppc

Most popular and best supported hypervisor on OpenStack

- https://wiki.openstack.org/wiki/HypervisorSupportMatrix

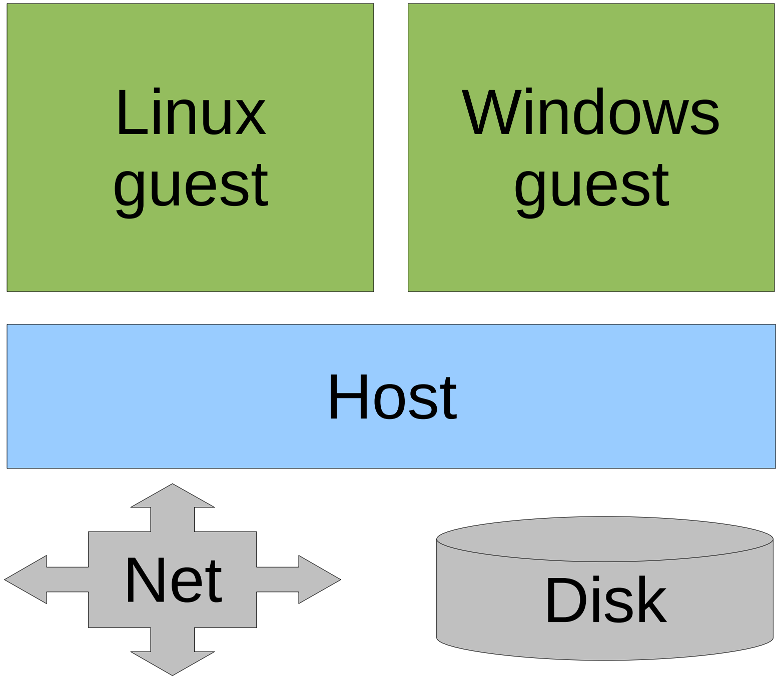
Built in to Red Hat Enterprise Linux

- Qumranet startup created KVM, joined Red Hat in 2008

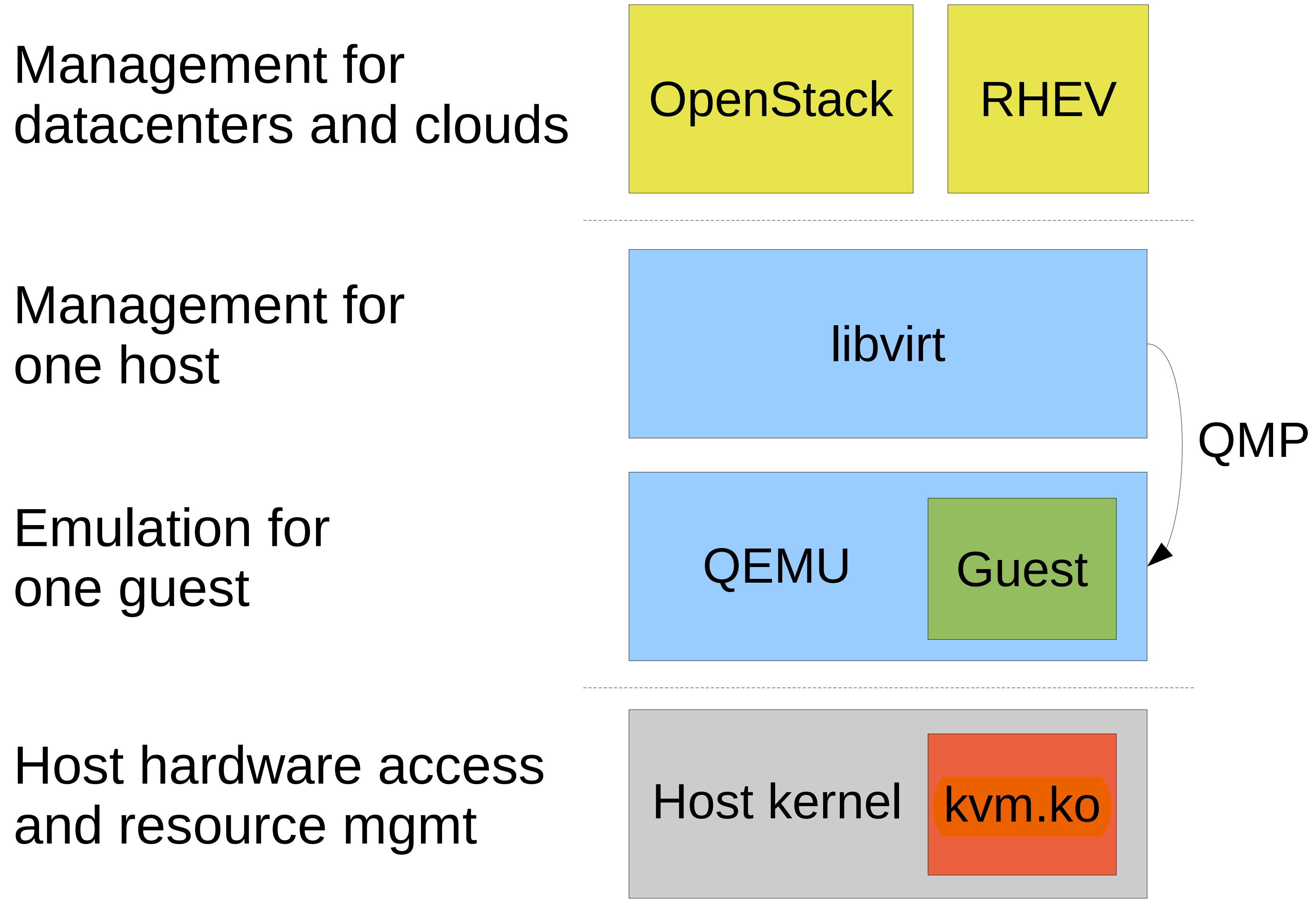
Virtualization goals

Efficiently and securely running virtual machines on a Linux host

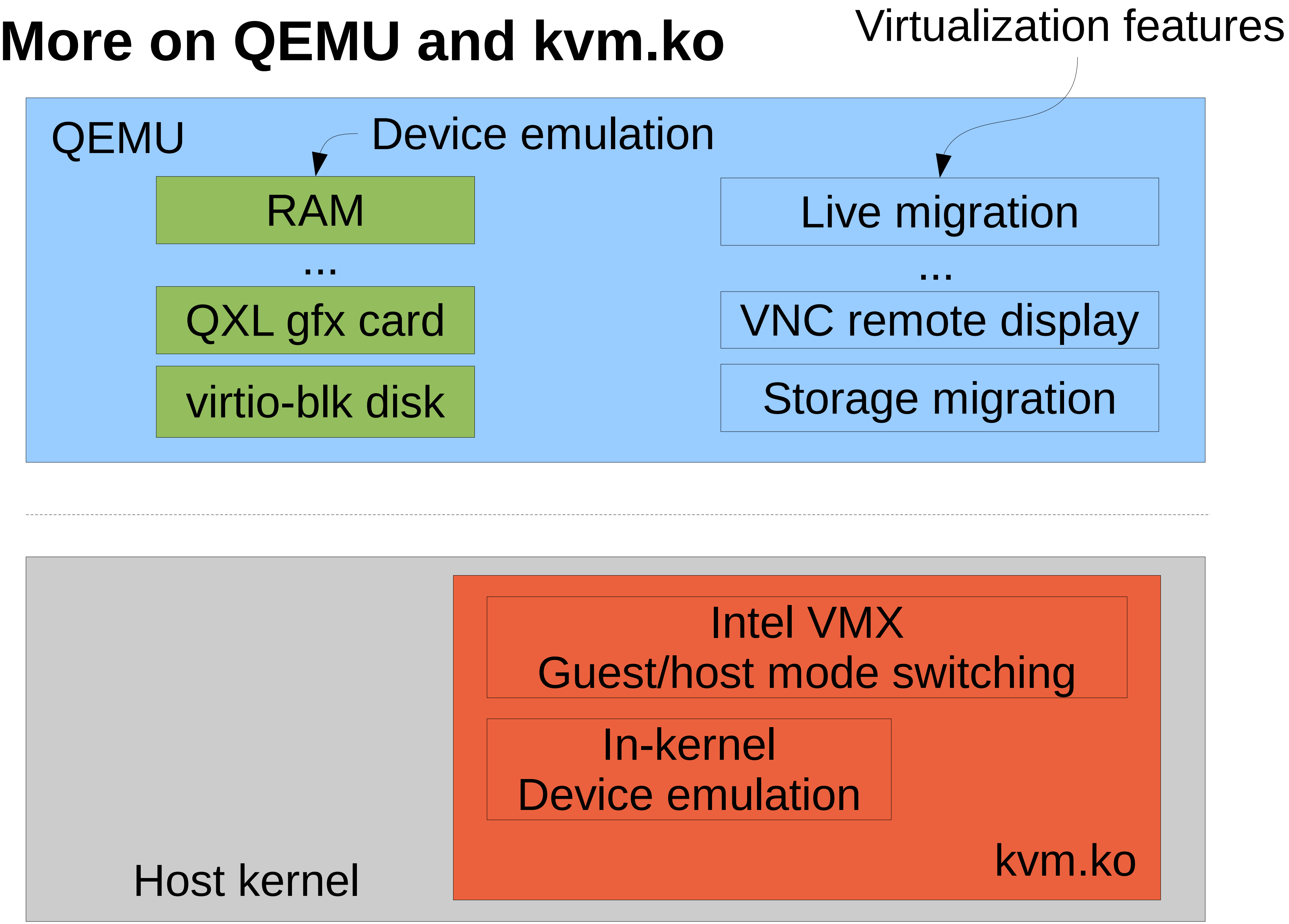
- Linux, Windows, etc guest operating systems
- Access to networking and storage in a controlled fashion



Where does KVM fit into the stack?



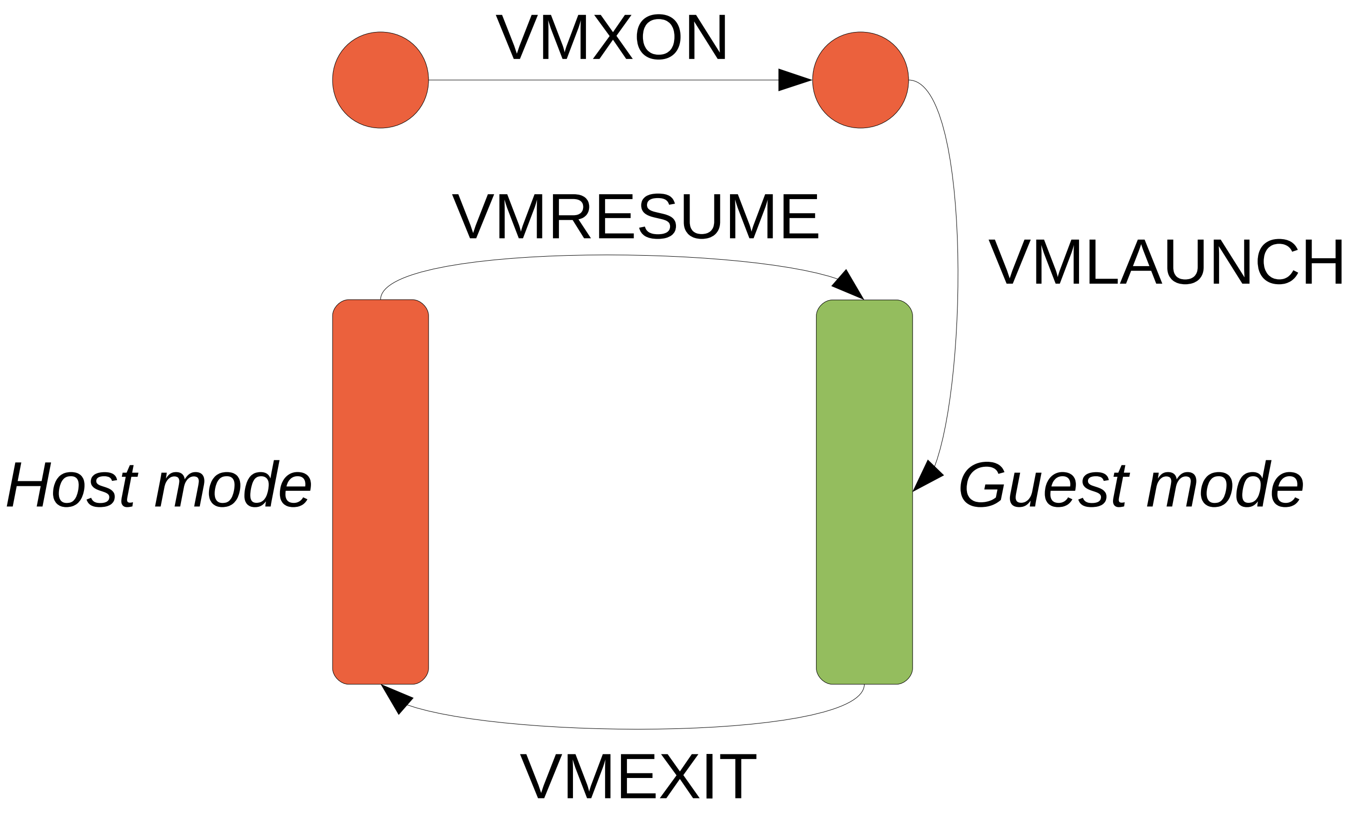
More on QEMU and kvm.ko



Hardware virtualization support with Intel VMX

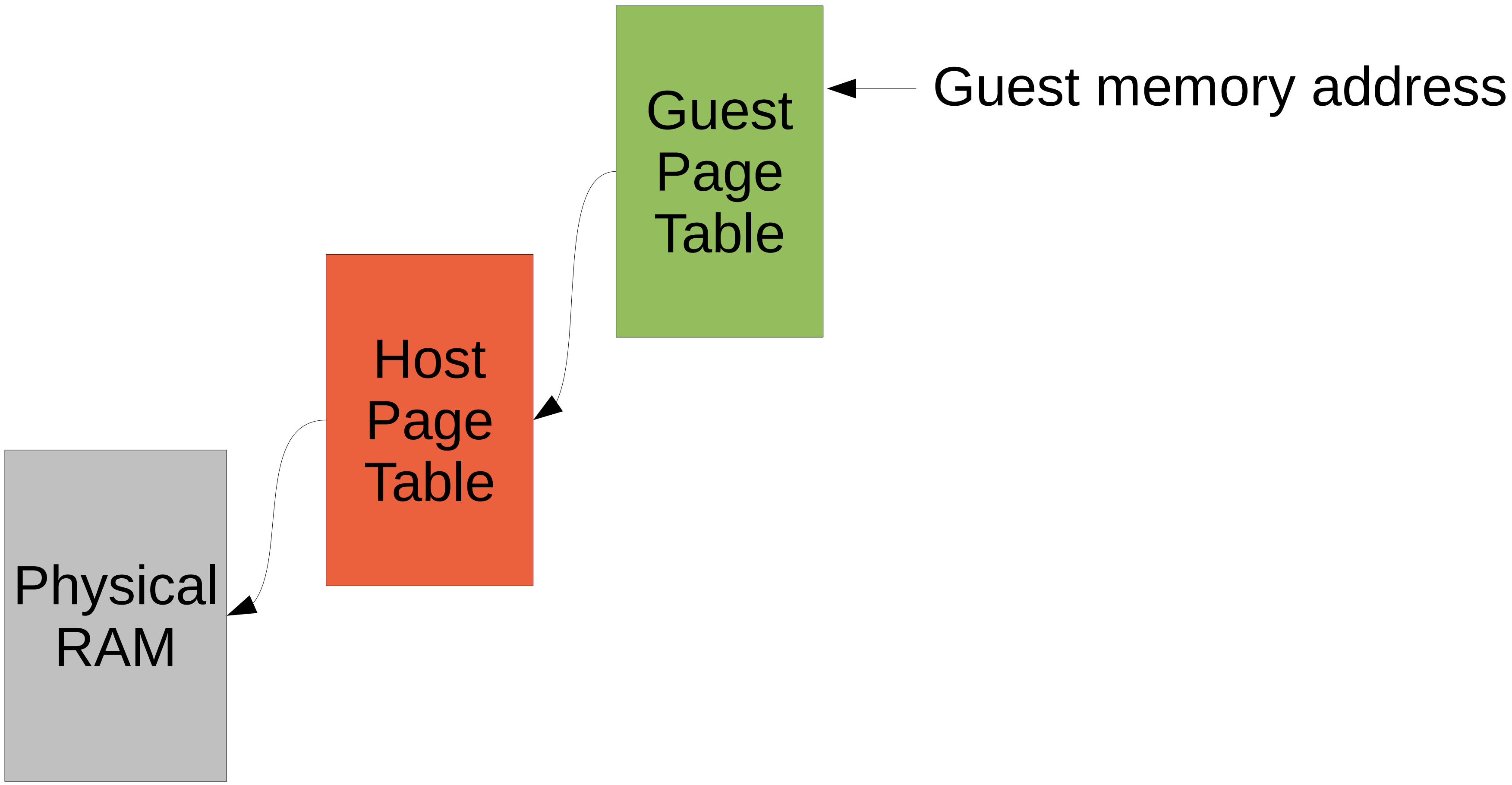
Allows safe guest code execution at native speed

- Certain operations trap out to the hypervisor



Memory virtualization with Intel EPT

Extended Page Tables (EPT) add a level of address translation for guest physical memory.

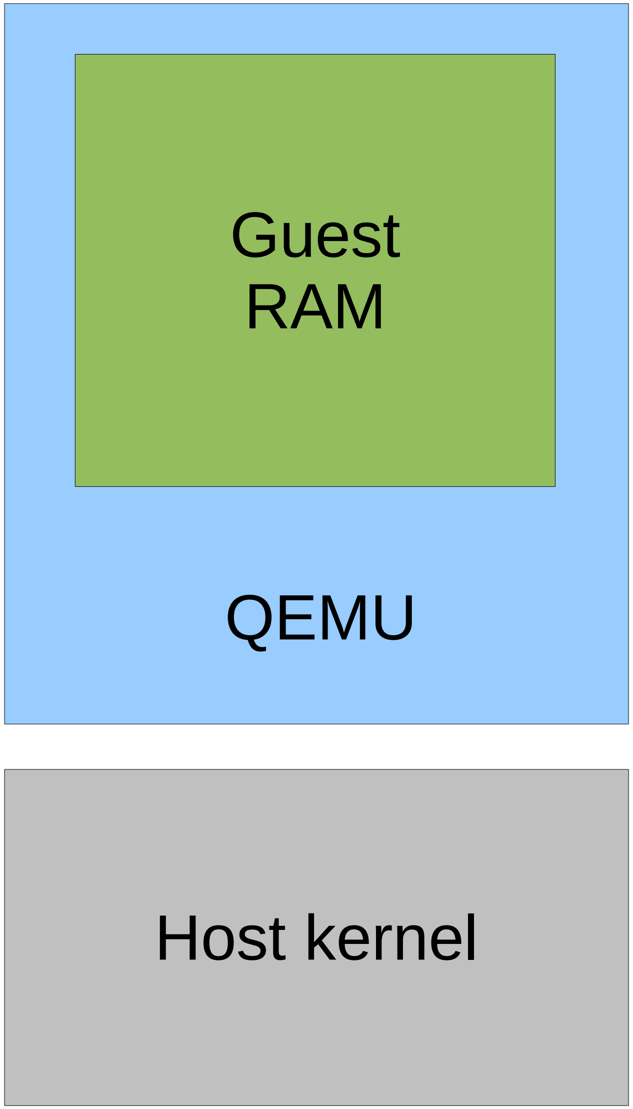


How QEMU uses kvm.ko

QEMU userspace process uses kvm.ko driver to execute guest code:

```
open("/dev/kvm")
ioctl(KVM_CREATE_VM)
ioctl(KVM_CREATE_VCPU)
for (;;) {
     ioctl(KVM_RUN)
     switch (exit_reason) {
     case KVM_EXIT_IO:  /* ... */
     case KVM_EXIT_HLT: /* ... */
     }
}
```

QEMU process model



QEMU is a userspace process

Unprivileged and isolated using SELinux for security

Each KVM vCPU is a thread

Host kernel scheduler decides when vCPUs run

Linux concepts apply to QEMU/KVM

Since QEMU is a userspace process, the usual Linux tools work:

ps(1), top(1), etc see QEMU processes and threads

tcpdump(8) sees tap network traffic

blktrace(8) sees disk I/O requests

SystemTap and perf see QEMU activity

etc

Architecture: Event-driven multi-threaded

Event loops are used for timers, file descriptor monitoring, etc

- Non-blocking I/O
- Callbacks or coroutines

Multi-threaded architecture but with big lock

- VCPU threads execute in parallel
- Specific tasks that would block event loop are done in threads, e.g. remote display encoding, RAM live migration work, virtio-blk dataplane, etc
- Rest of QEMU code runs under global mutex

Architecture: Emulated and pass-through devices

Guest sees CPU, RAM, disk, etc like on real machines

- Unmodified operating systems can run
- Paravirtualized devices for better performance

Most devices are emulated and not real

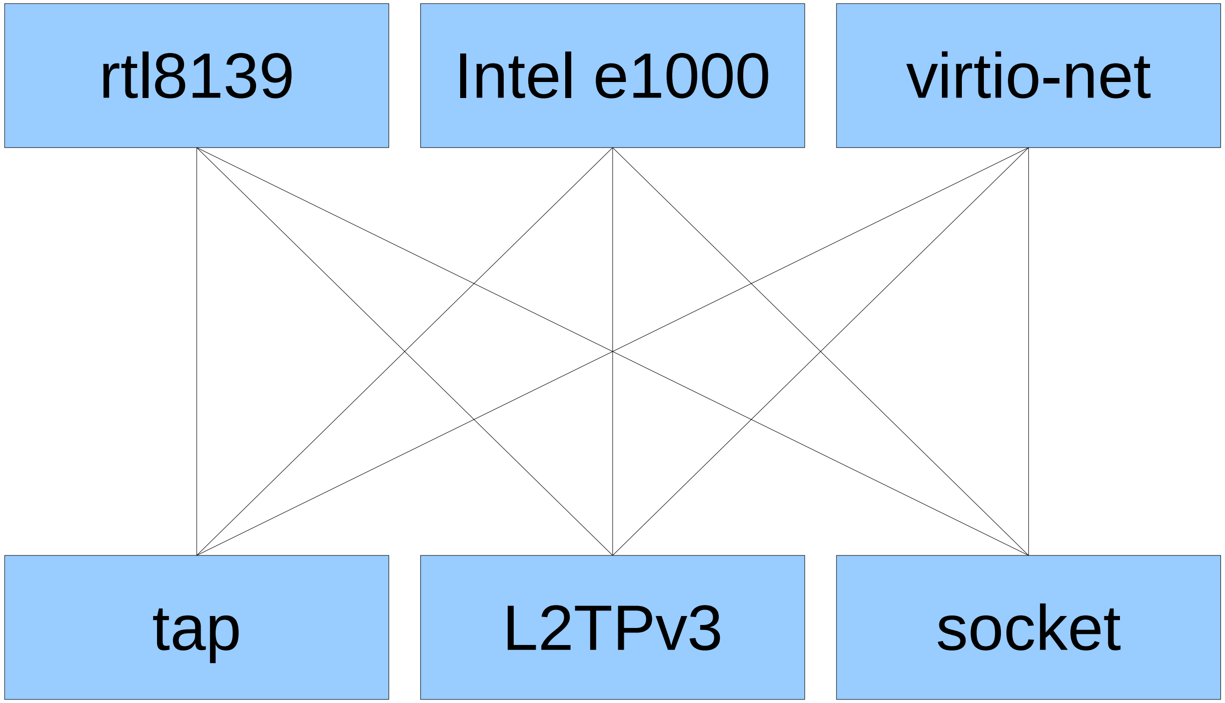
- Isolation from host for security
- Sharing of resources between guests

Pass-through PCI adapters, disks, etc also possible

- Dedicated hardware

Architecture: Host/guest device emulation split

Guest device – device model visible to guest



Decouples hardware emulation from I/O mechanism

Host device – performs I/O on behalf of guest

Architecture: virtio devices

KVM implements virtio device models

- net, blk, scsi, serial, rng, balloon
- See http://docs.oasis-open.org/virtio/ for specs

Open standard for paravirtualized I/O devices

Red Hat contributes to Linux and Windows guest drivers

Architectural exception: vhost in-kernel devices

Most device emulation is best done in userspace

- Some APIs or performance features only available in host kernel

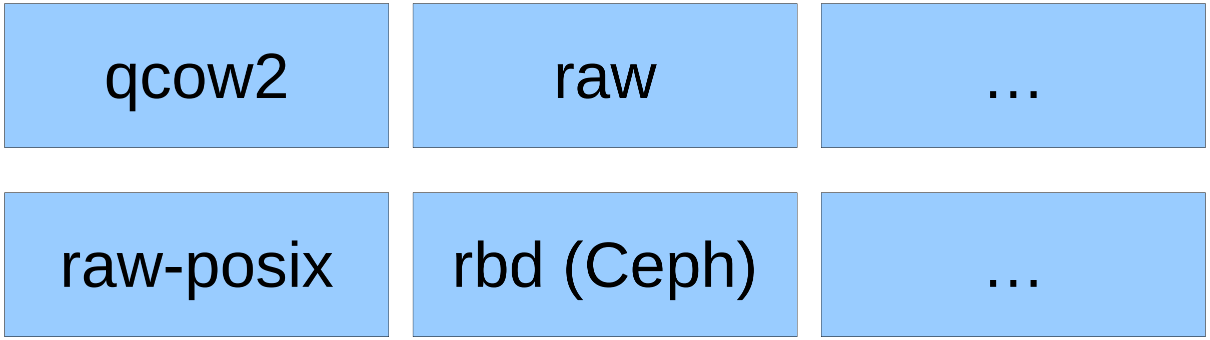
vhost drivers emulate virtio devices in host kernel

- vhost_net.ko high-performance virtio-net emulation takes advantage of kernel-only zero-copy and interrupt handling features
- Other devices could be developed in theory, but usually userspace is a better choice

Storage in QEMU

Block drivers fall in two categories:

Formats – image file formats (qcow2, vmdk, etc)



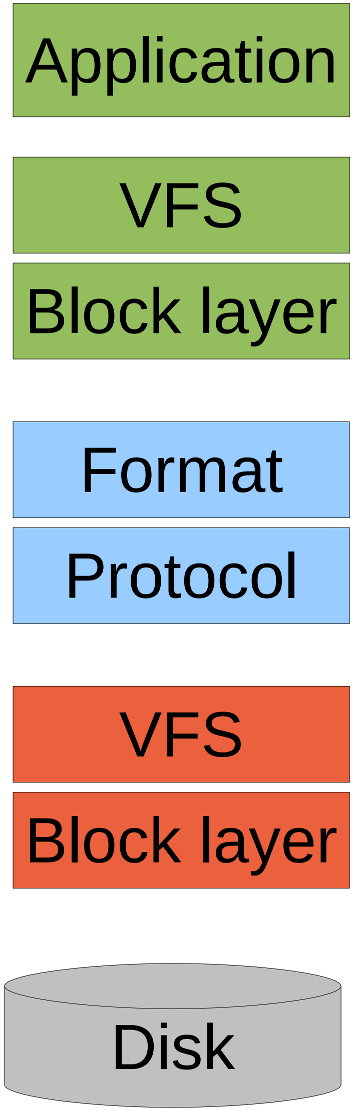
qcow2 | raw | …

raw-posix | rbd (Ceph) | …

Protocols – I/O transports (POSIX file, rbd/Ceph, etc)

Plus additional block drivers that interpose like quorum, blkdebug, blkverify

Storage stack



Application

VFS

Block layer

Format

Protocol

VFS

Block layer

Disk

Guest – application plus full file system and block layer

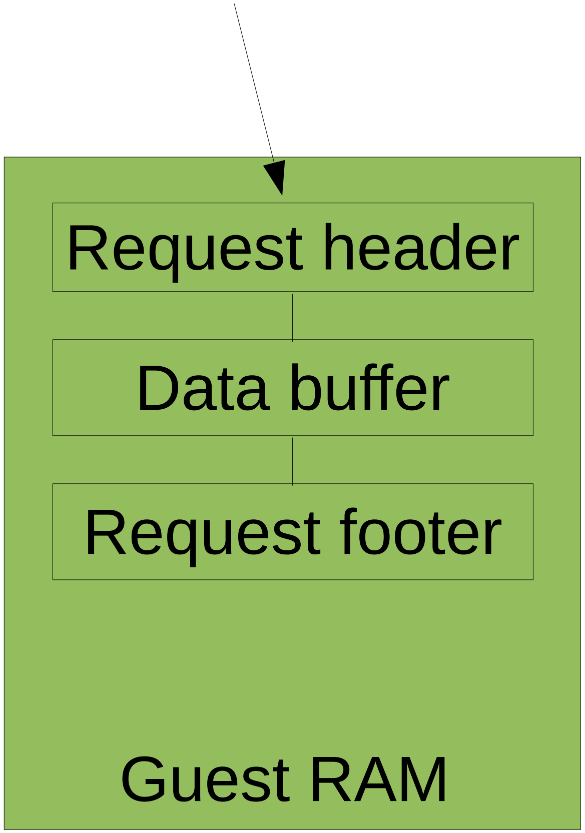
QEMU – image format, storage migration, I/O throttling

Host – full file system and block layer

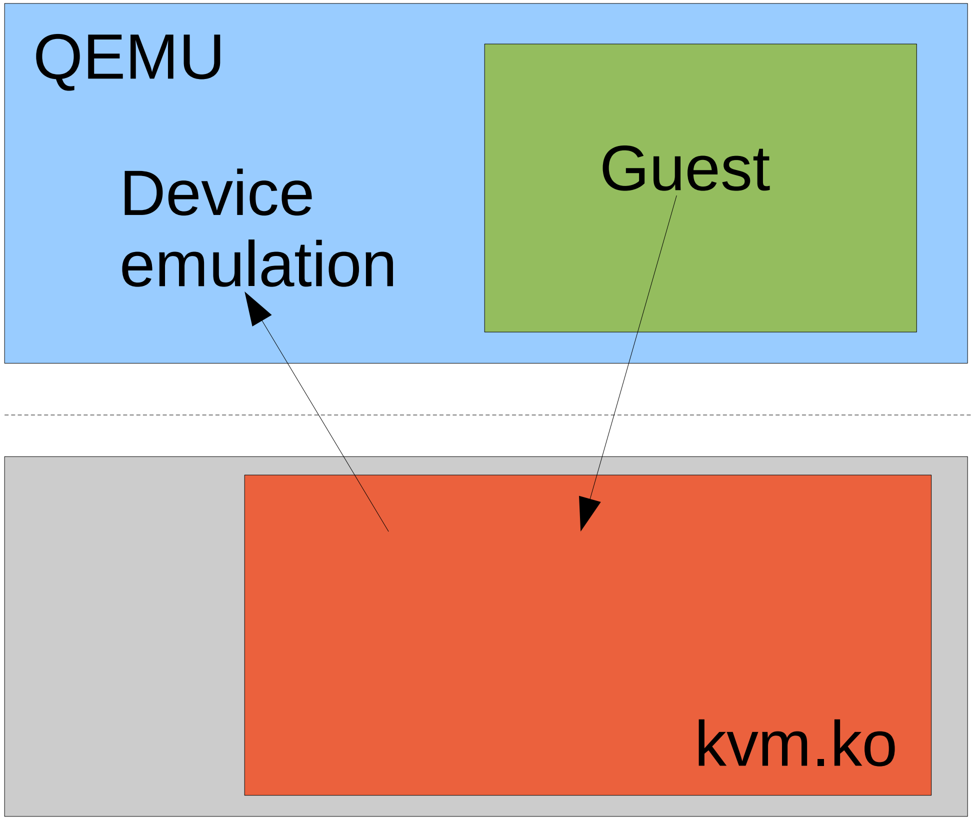
Beware double caching and anticipatory scheduling delays!

Walkthrough: virtio-blk disk read request (Part 1)

1. Guest fills in request descriptors

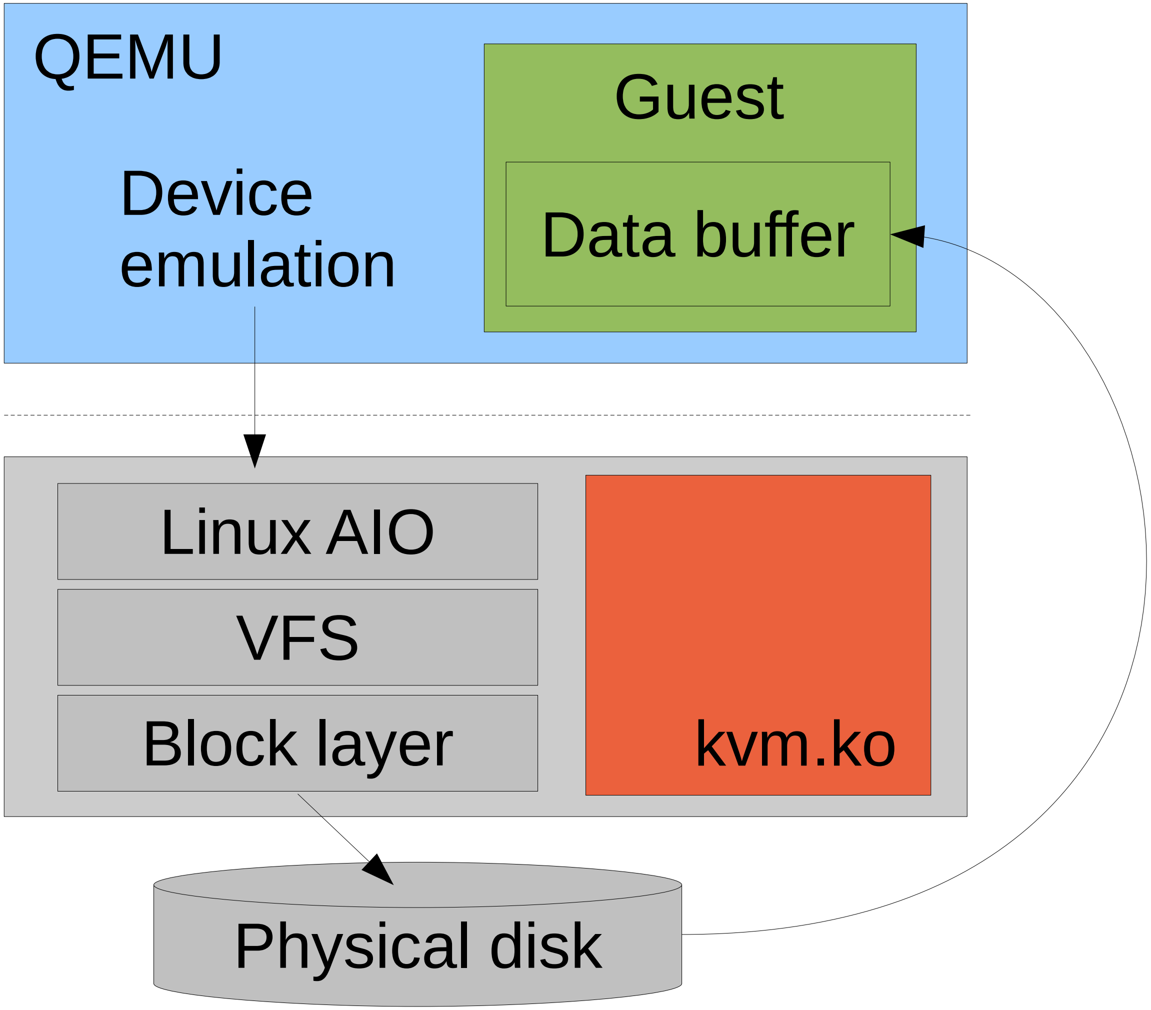


2. Guest writes to virtio-blk virtqueue notify register



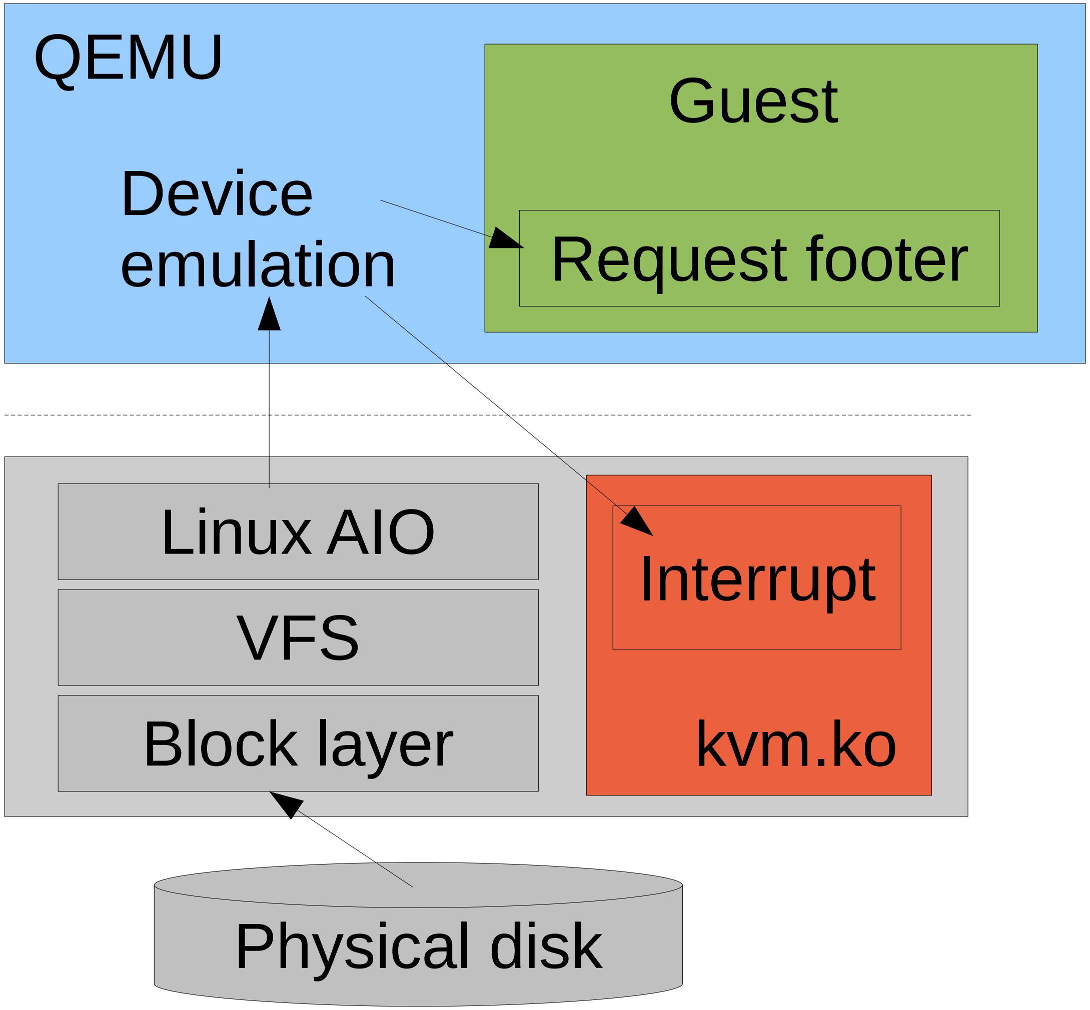
Walkthrough: virtio-blk disk read request (Part 2)

3. QEMU issues I/O request on behalf of guest



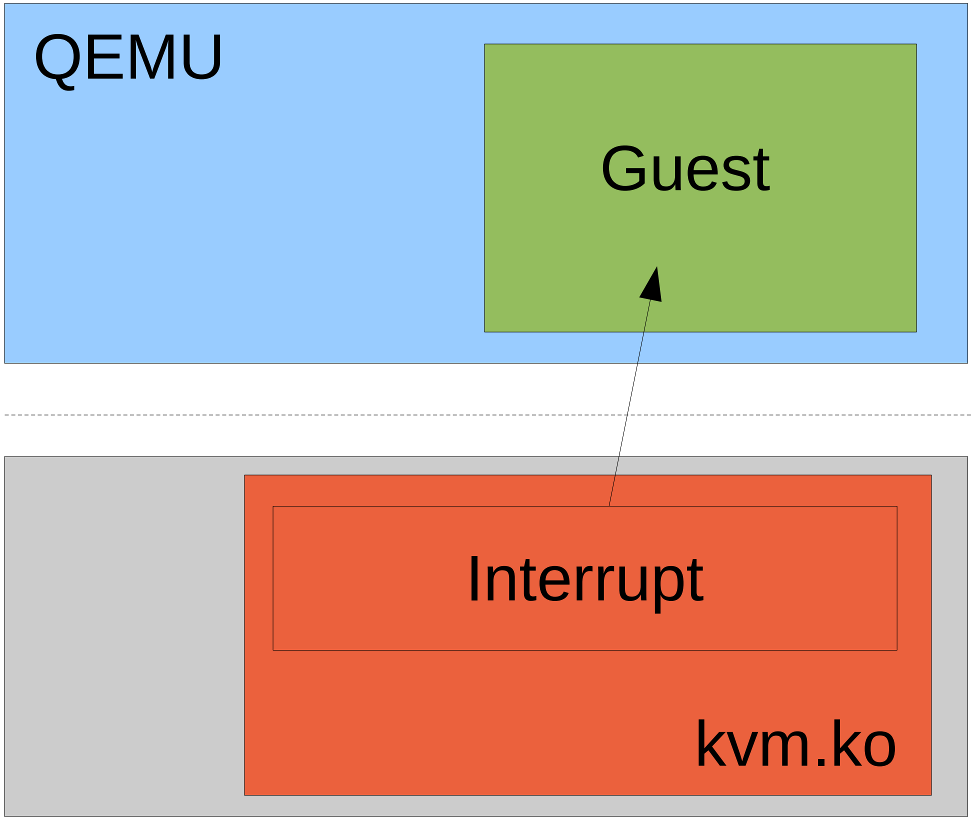
Walkthrough: virtio-blk disk read request (Part 3)

4. QEMU fills in request footer and injects completion interrupt

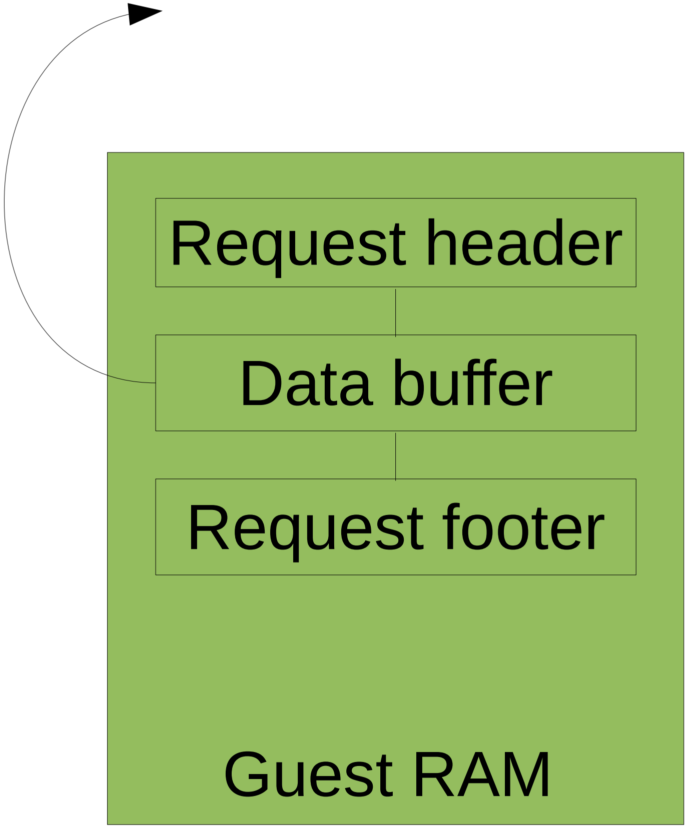


Walkthrough: virtio-blk disk read request (Part 4)

5. Guest receives interrupt and executes handler



6. Guest reads data from buffer



Thank you!

Technical discussion: qemu-devel@nongnu.org

IRC

- #qemu on irc.oftc.net
- #kvm on chat.freenode.net

http://qemu-project.org/

http://linux-kvm.org/

More on my blog: http://blog.vmsplice.net/