Multi-process QEMU

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Presented with

redhat

Slim down QEMU

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Program Agenda

1. QEMU in virtualization
2. Xen usage of QEMU
3. KVM usage of QEMU
4. Security!

QEMU usage

- Both KVM and Xen use QEMU emulation (IDE, e1000)
- None use the binary translation in QEMU.
  - Xen and KVM in the hypervisor code base deal with opcodes:
    - movdqa m128,xmm
    - (traped on MMIO access)
- KVM uses QEMU as control stack (launch/destroy guest) as in privileged operations (access to /dev/kvm).
- Xen uses **only** QEMU emulation (which is why you can't launch guests with QEMU parameters and need to use libvirt or xl).

Evil guest attack vectors

- Cloud provides have to deal with risk of customers becoming evil.
- The “customers” have usually four primary attack vectors:
  - Emulation (VENOM – CVE-2015-3456) of floppy driver, VGA, NICs, etc in QEMU.
  - MSRs (x2APIC range gap – CVE-2014-7188) of x2APIC emulation in hypervisor.
  - VMCALL (hypercalls to hypervisor – CVE-2012-3497).
  - Opcode emulations (INVEPT instructions – CVE-2015-0418).
- This talk is about the first: **QEMU** and ways to lessen the impact if it is exploited, or alternatively erect more “jails” around QEMU.

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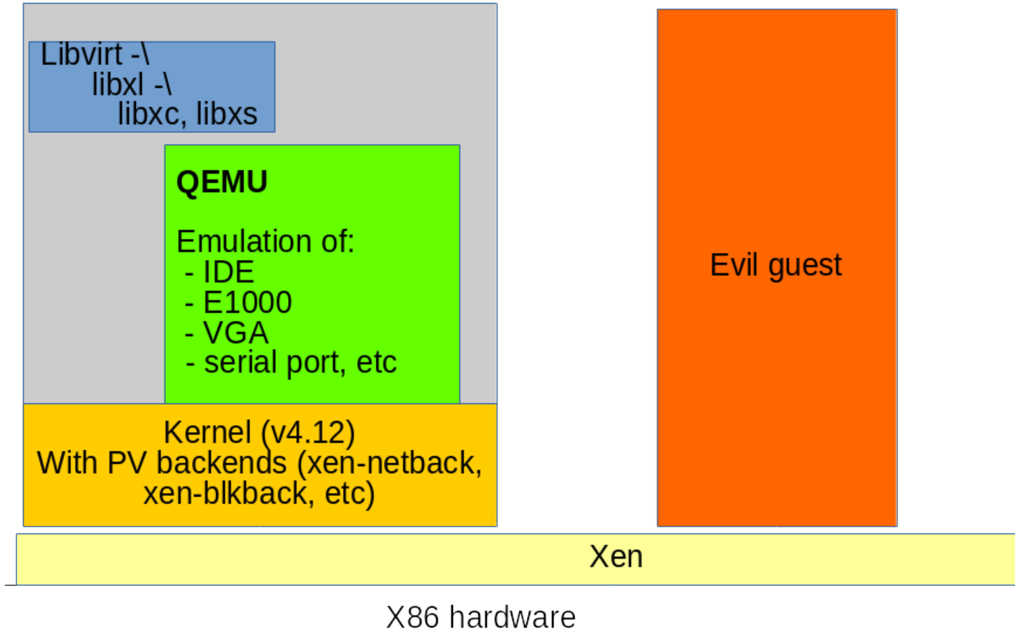
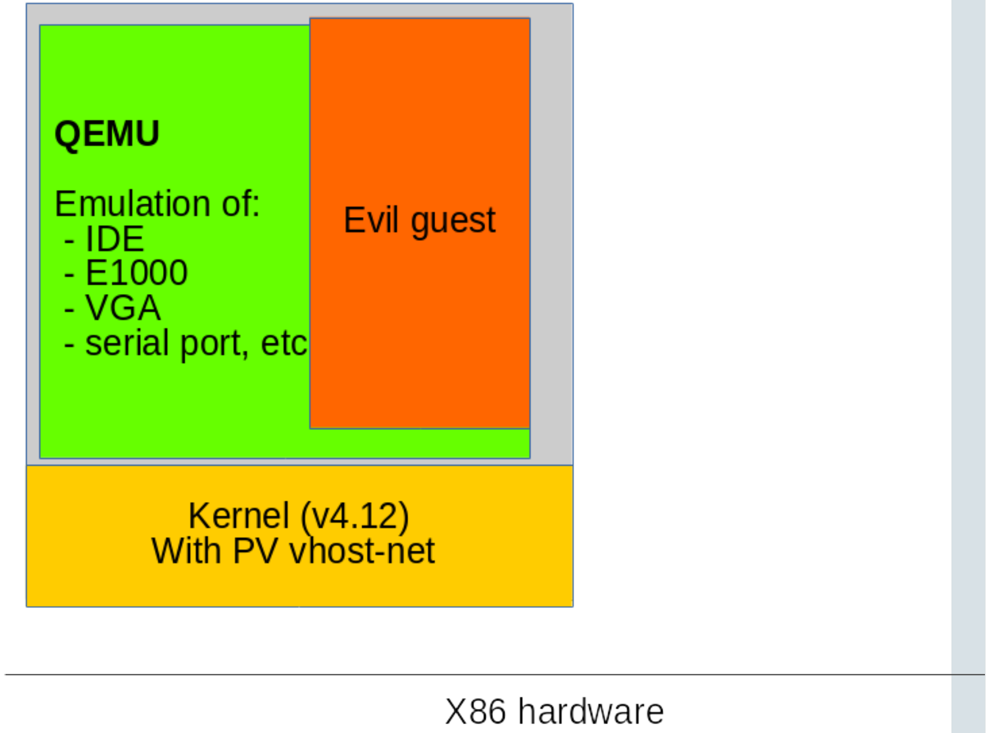
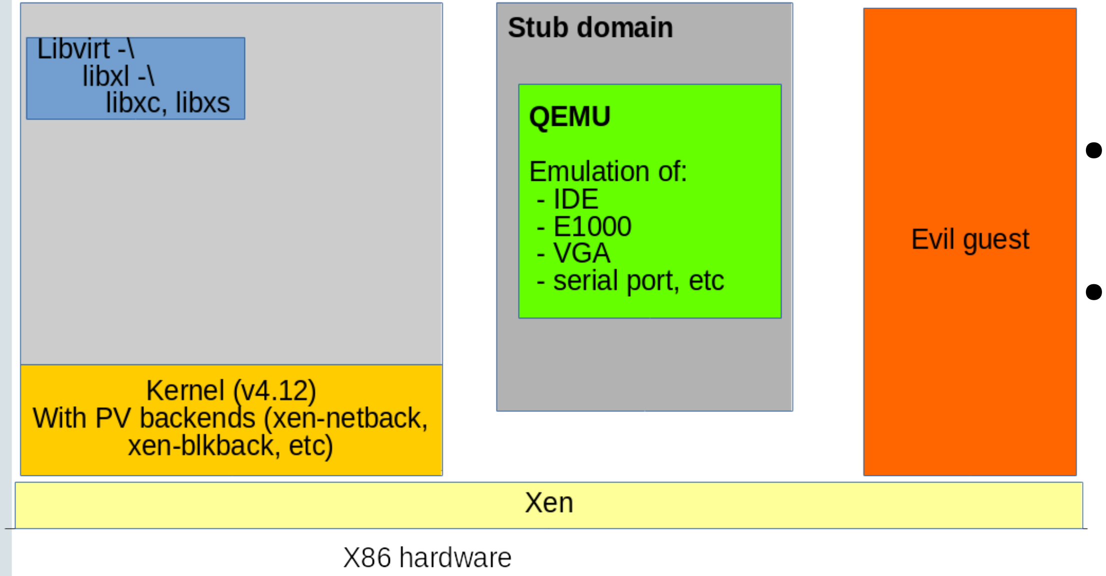
Xen and KVM architecture (usual)



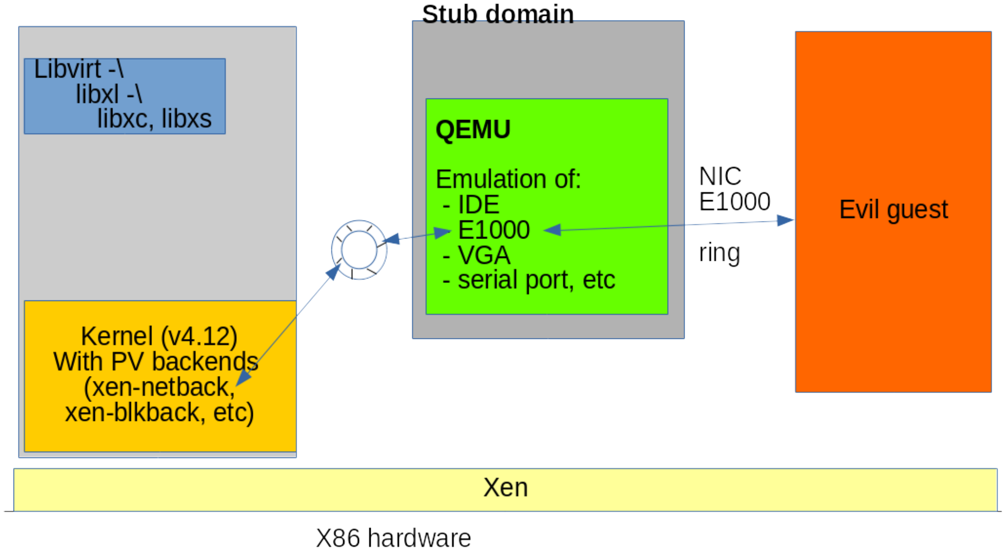


Xen disaggregated architecture



- Move QEMU to be a standalone guest running in ring0 (32MB guest).
- Each stubdomain serves **one** guest.
- Evil guest has to subvert stub domain emulation first, then from there jump to control domain.

Xen disaggregated architecture (network)



- Evil guest uses e1000 for attack.
- QEMU uses PV frontend driver to send packets to **real** backend
- If evil guest subverts stub domain the next attack is the PV protocol
- CVE-2015-8550: double fetch:

  "Specifically the shared memory between the frontend and backend can be fetched twice (during which time the frontend can alter the contents) possibly leading to arbitrary code execution in backend.
- But protocol **MUCH simpler** than emulated devices.

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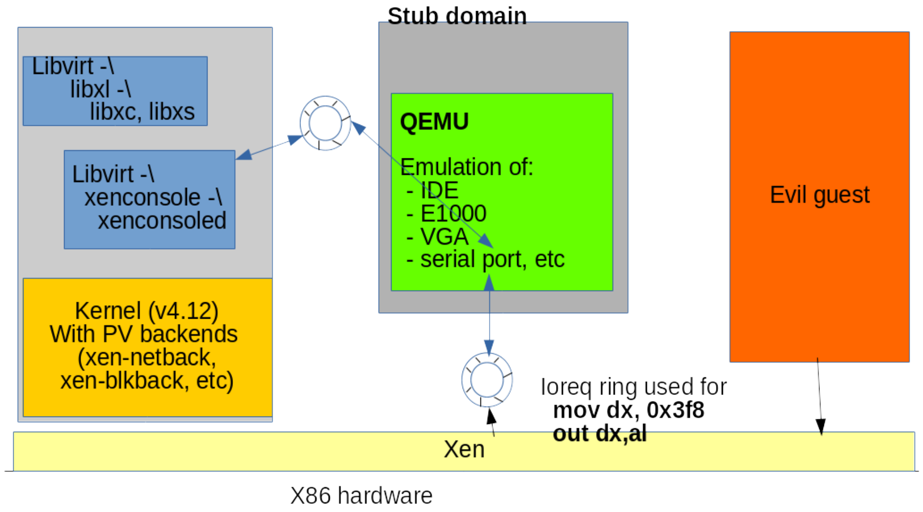
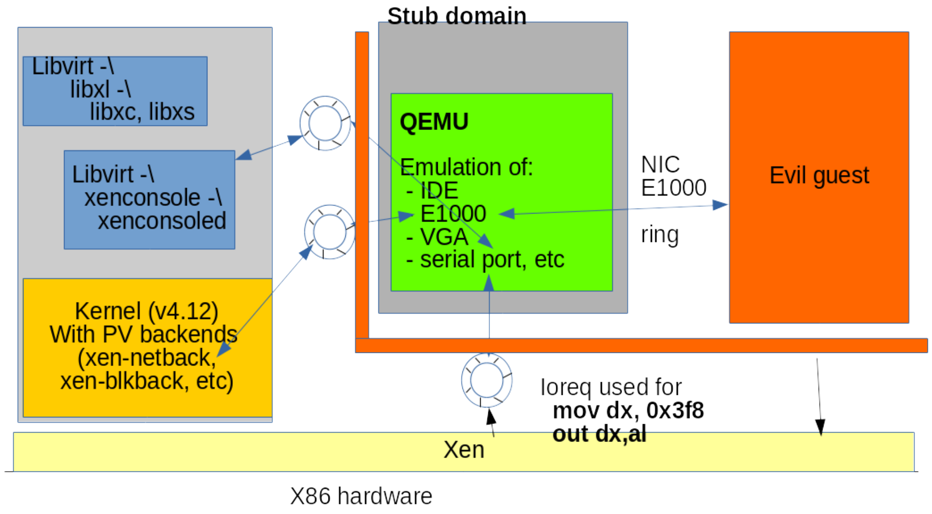
Xen disaggregated architecture (serial)



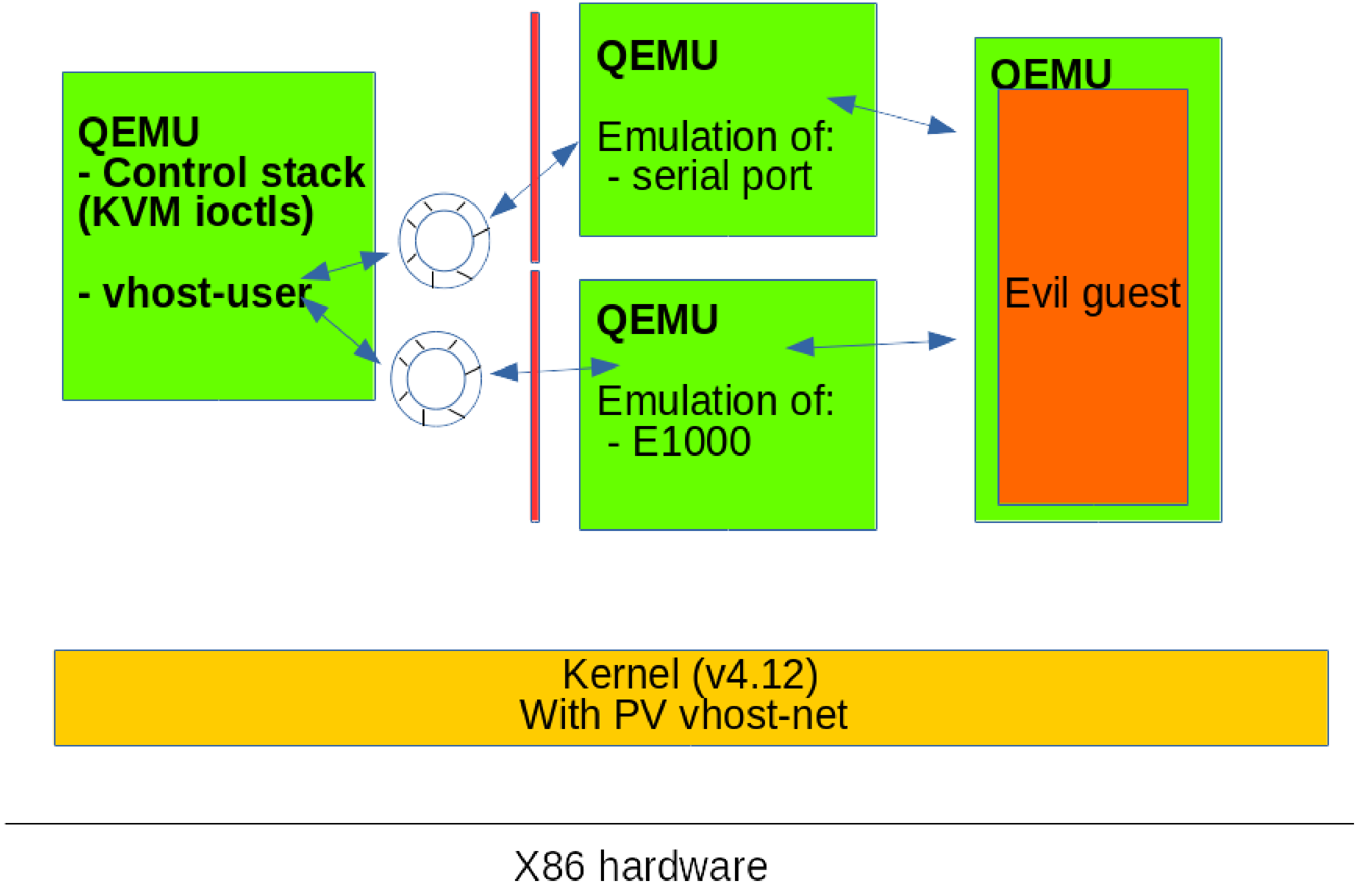
- Privilege opcodes (out/in) always end up in hypervisor.
- A ring between hypervisor and QEMU for device model to process.
- QEMU and xenstored have a PV ring to copy data back/forth.

Xen disaggregated architecture: jail around QEMU



- In effect the barrier between QEMU and control stack is via the PV ring.
- If evil guest exploits stub domain they are the same place as before.
- Attacks left then are via:
  - MSRs
  - Hypervisor hypercalls
  - Opcode emulation
  - (But this presentation is not about those attacks).

Can we do something similar in KVM?



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Can we do something similar in KVM? Is it needed?

- QEMU is used for emulation **and** control stack.
  - If we disaggregate QEMU we can move each component in its own process.
- We have security measures in place:
  - secomp & ebpf (filter the ioctls to /dev/kvm)
  - Containers (chroot jails)
  - Continuing work on improving QEMU security
- Sure, but separating components apart (each running in its own jail) means we can focus security audit on the high-stake parts
- OK, how do we do this?

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Multi-process QEMU

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Multi-threading QEMU

or Ingo might be right.. sort of

Anthony Liguori – aliguori@us.ibm.com

IBM Linux Technology Center

Aug 2010

- **Motivations for QEMU**
- **Requirements for devices**
  - KVM features
- **Various QEMU solutions**
- **Conclusion & QA**

A big binary

```
elmarco@boraha:~$ ls -lhS /bin/ | head -n20
-rwxr-xr-x.   1 root root       33M Aug 16 16:00 dockerd-current
-rwxr-xr-x.   1 root root       17M Sep 15 00:46 emacs-25.3
-rwxr-xr-x.   1 root root       16M Sep  7 16:32 node
-rwxr-xr-x.   1 root root       15M Jun 26 11:51 ocamlopt.byte
-rwxr-xr-x.   1 root root       15M Jul  4 15:33 doxygen
-rwxr-xr-x.   1 root root       13M Aug 16 16:00 docker-current
-rwxr-xr-x.   1 root root       12M Sep  8 21:59 qemu-system-aarch64
-rwxr-xr-x.   1 root root       12M Sep  8 21:59 qemu-system-arm
-rwxr-xr-x.   1 root root       12M Jun 26 11:51 ocaml
-rwxr-xr-x.   1 root root       11M Sep  8 21:59 qemu-system-x86_64
-rwxr-xr-x.   1 root root       11M Sep  8 21:59 qemu-system-i386
-rwxr-xr-x.   1 root root       11M Jun 26 11:51 ocamlc.byte
-rwxr-xr-x.   1 root root       11M Sep  8 21:59 qemu-system-mips64el
-rwxr-xr-x.   1 root root       11M Sep  8 21:59 qemu-system-mips64
-rwxr-xr-x.   1 root root       11M Sep  8 21:59 qemu-system-mipsel
-rwxr-xr-x.   1 root root       11M Sep  8 21:59 qemu-system-mips
-rwxr-xr-x.   1 root root      7.1M Apr 25 17:44 crash
-rwxr-xr-x.   1 root root      6.9M Jun 26 11:51 ocamldoc.opt
-rwxr-xr-x.   1 root root      6.4M Jun 26 11:51 ocamlopt.opt
```

A big project

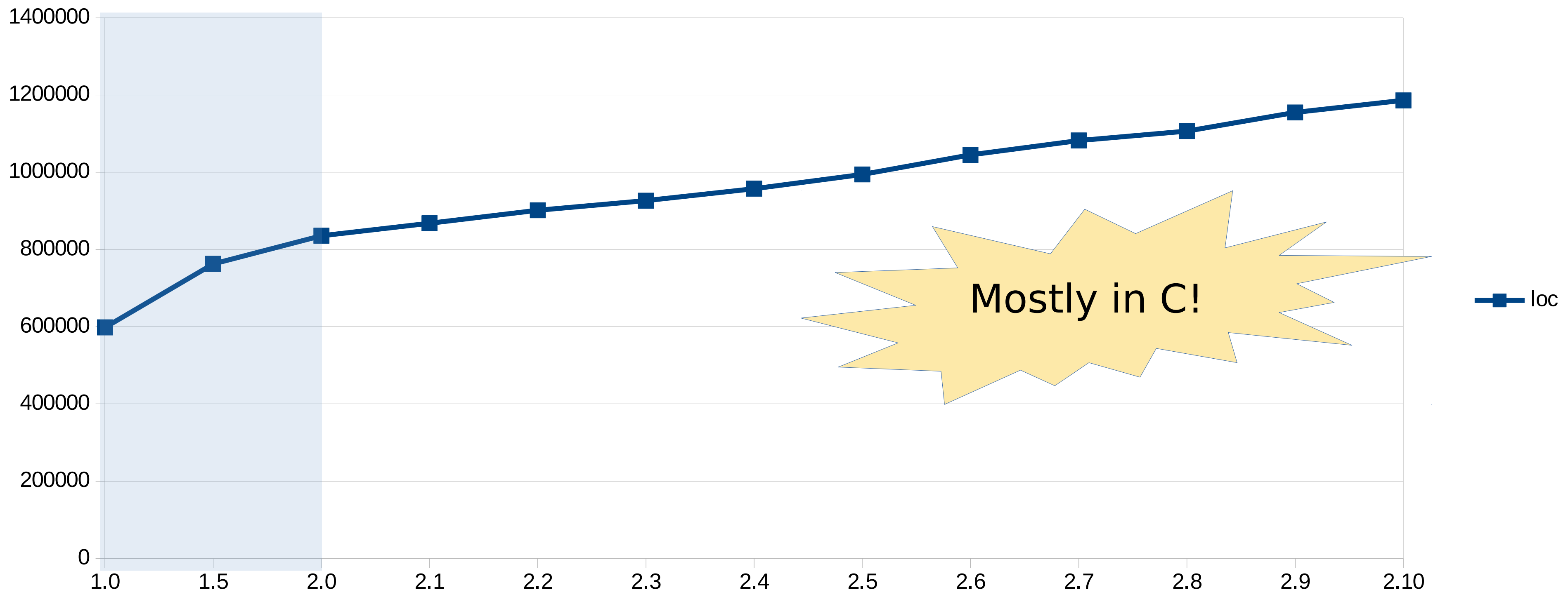
```
$ cloc qemu-2.10
- files: 4 280
- comment: 172 425
- code: 1 186 140

$ cloc kvmtool
- files: 275
- comment: 3 728
- code: 27 844
$ cloc crosvm
- code: 32 159
```

```
$ cloc linux
- files: 49 744
- code: 16 834 046
```

How much with all dependencies?

Still growing



Many dependencies

- Fedora 26: qemu 2.9.0-5.fc26.x86_64

```
$ readelf -d /usr/bin/qemu-system-x86_64  | grep NEEDED | wc -l
60

$ ldd /usr/bin/qemu-system-x86_64 | wc -l
158
```

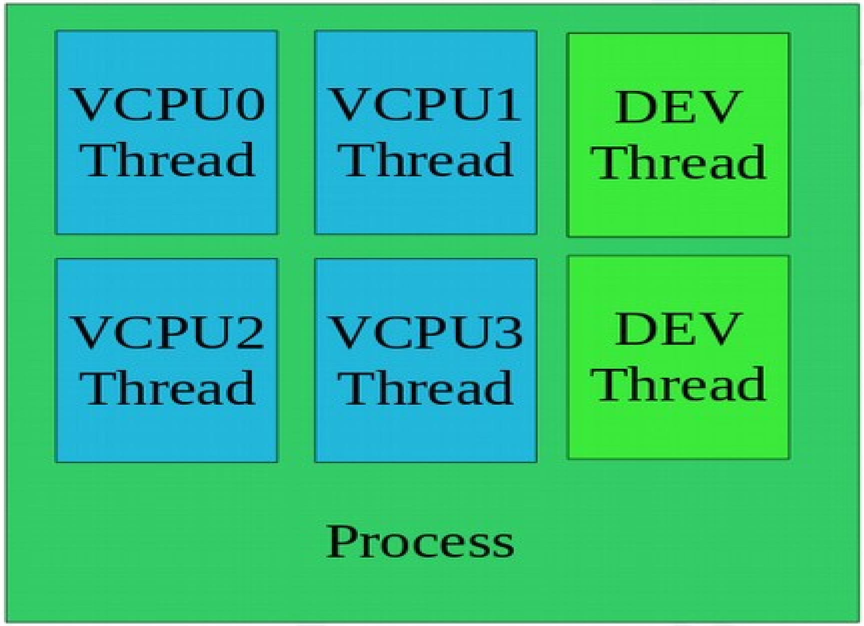
- Kvmtool (with all optional dependencies, gtk3, SDL, vncserver...)

```
$ readelf -d lkvm | grep NEEDED | wc -l
19

$ ldd lkvm | wc -l
83
```


Too big to fail

Ideal KVM Architecture



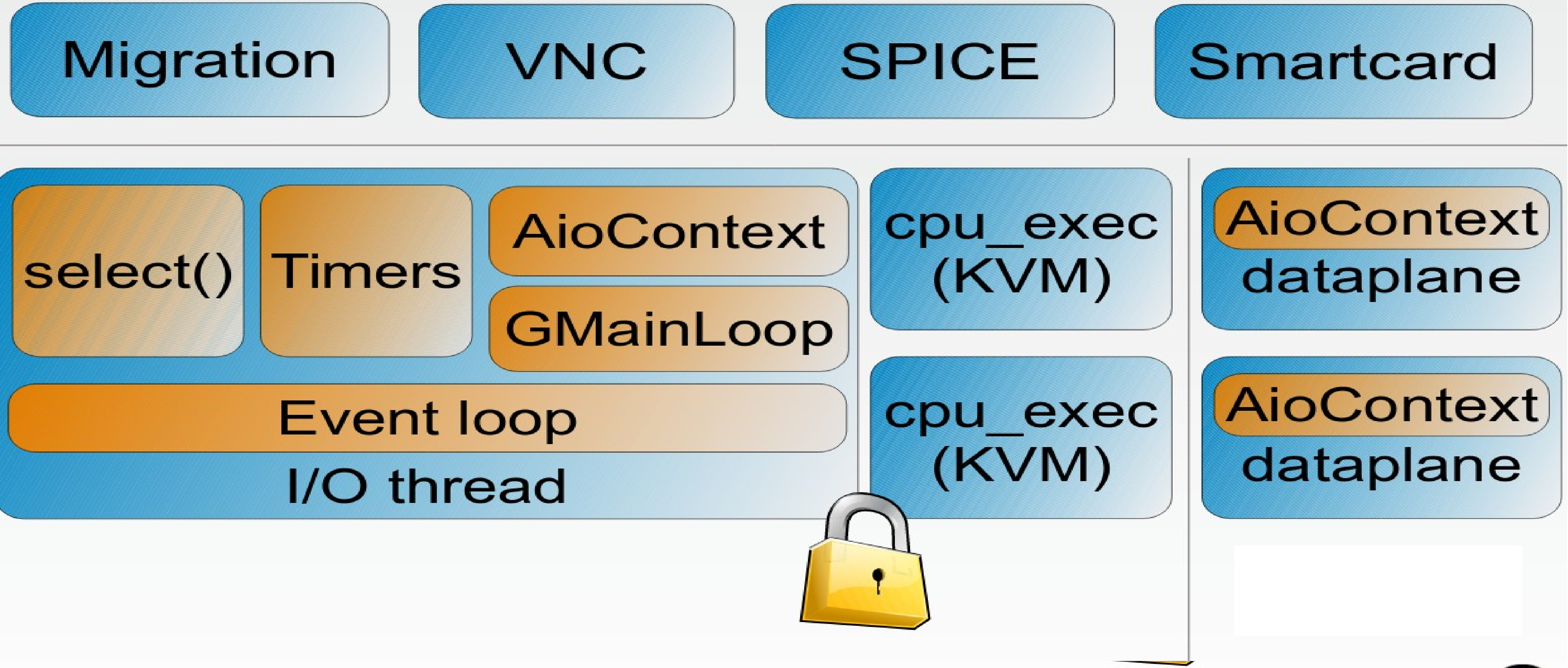
Design

- One thread per-VCPU
- Device models run concurrent in VCPU thread
- Long running operations run in additional device thread

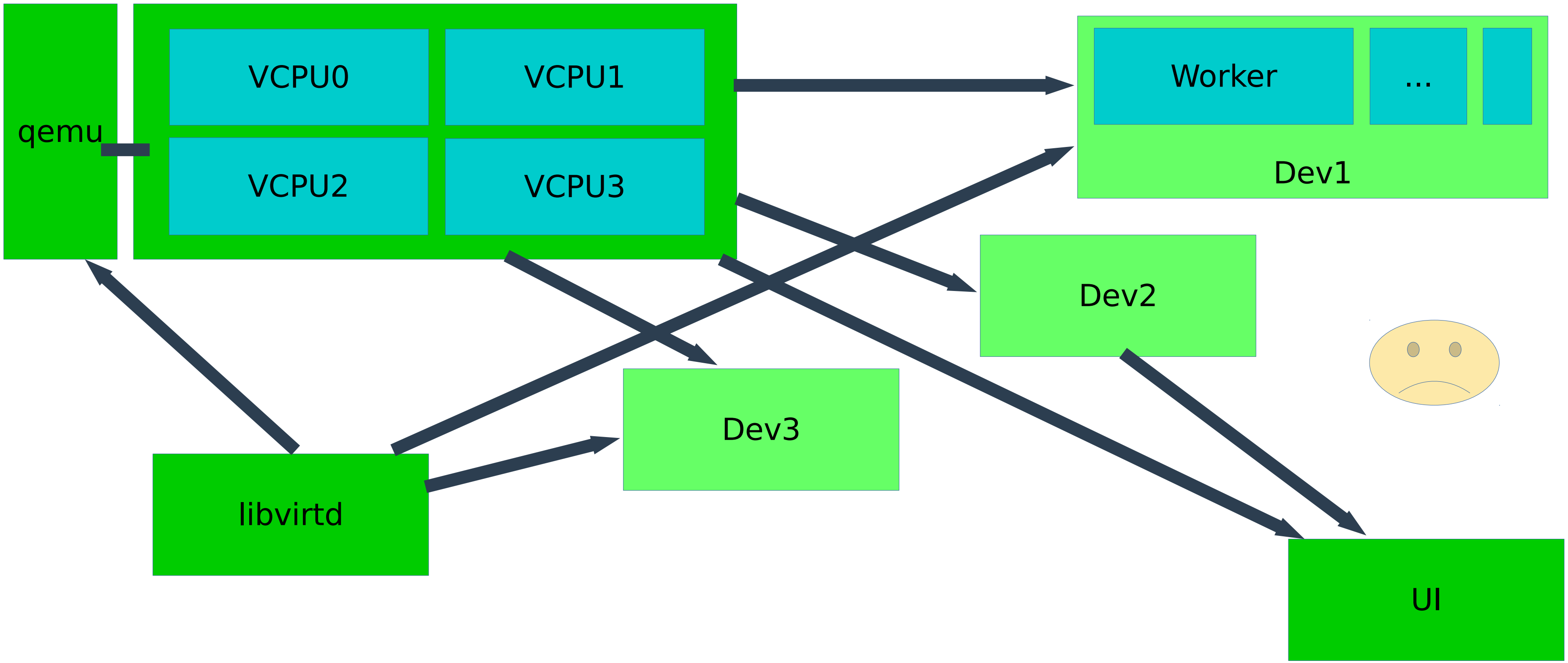
Goals

- Maximize CPU affinity
- Minimize PIO/MMIO latency

QEMU architecture (now)



Ideal architecture ?



Why not?

- The monolithic vs microkernel/services debate
- Difficult to manage
- Difficult to debug
- Difficult to test (test matrix)
- Performance?

Why seperate processes?

- **Modularity**
  - clear interface separation = less conflicts/bql concerns
  - smaller qemu, less dependencies
  - allowing alternative implementations, “crazy” ideas
  - separate projects, different release cycles…
- **Isolation (+iommu) & crash robustness**
- **Better sandboxing (seccomp/ns)**
- **Easier monitoring/tweaking (memory, cpu etc)**

Sandboxing for dummies

Change user id

Regular DAC/MAC check

Add/drop capabilites(7)

Subset of root privileges (if needed)

Namespaces(7)

Own view/access of the system (uid/pid/ns/net/ipc..)

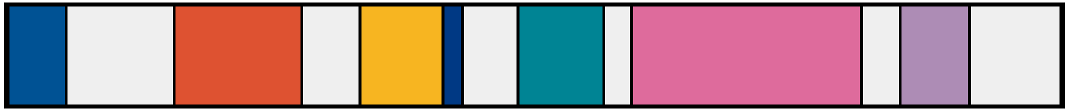
Seccomp()/bpf

Filter syscalls

Libvirt, minijail, systemd, flatpack...

A word about memory fragmentation

All devices & workloads in a single process can lead to more fragmentation.



Using subprocesses may help to partition the load and more easily reclaim the space.

How? various strategies

- **Fork-only strategy (crosvm)**
  - Code in same binary
  - No version combinations, less modularity
  - Device setup and teardown can be hardcoded in parent

- **Exec a helper or device process**
  - Can allow arbitrary implementations
  - IPC require greater level of stability
  - Nicer if IPC allows various kind of devices

Managing the processes

- **Qemu**
  - Not a great idea to fork from qemu (VM space, safety)
  - Slirp & migration can do it…
  - Could exec() from an helper process instead?

- **Outside, libvirt or other:**
  - Not suitable for command line users
  - Natural fit for libvirt etc

How? various device needs

- **HW description & bus registration**
- **Communication mechanism:**
  - Io / Mmio regions & rw events, Irqs
  - Memory map (& iommu)
  - Or at higher level of abstraction (USB etc)
- **acpi / device-tree manipulation (& fw_cfg)**
- **Device state & migration**
- **Dirty regions tracking, post-copy...**
- **Object hierarchy / introspection**

KVM <-> device emulation

Direct memory access

Or VM exit:

```
run = mmap(cpufd,..)
ioctl(cpufd, KVM_RUN)
run→exit_reason == KVM_EXIT_IO/MMIO
run→io/mmio_addr mapping
BQL!
MemoryRegionOps.read/write()
```

← ioctl(vmfd, KVM_IRQ_LINE, irq_level)

KVM nifty ioctl

KVM_IOEVENTFD

This ioctl attaches or detaches an ioeventfd to a legal pio/mmio address within the guest. A guest write in the registered address will signal the provided event instead of triggering an exit.

KVM_IRQFD

Allows setting an eventfd to directly trigger a guest interrupt.

Ioeventfd vs MemoryRegionOps

```
struct kvm_ioeventfd {
        __u64 datamatch;
        __u64 addr;        /* legal pio/mmio address */
        __u32 len;         /* 0, 1, 2, 4, or 8 bytes    */
        __s32 fd;
        __u32 flags;
        __u8  pad[36];
};
```

Write only, coalesced events, not a range API

Extend it to support ranges - IOEVENTFD_FLAG_RANGE?

Then KVM_GET_IOEVENTS (similarity with AIO)

For traditional sync devices

IPC qemu → helper (necessary for TCG)

Introduce a KVM user device?

```
devfd = ioctl(vmfd, KVM_CREATE_DEVICE_USER)
reg = {
  .group = KVM_DEV_USER_GROUP,
  .attr = KVM_DEV_USER_SET_MEMORY_REGION,
  .addr = (struct) { .slot = 0,
                     .addr = 0x3f8,
                     .flags = PIO,
                     .eventfd = efd }
}
ioctl(devfd, KVM_SET_DEVICE_ATTR, &reg)
poll(efd)
ioctl(devfd, KVM_GET_DEVICE_CPU_EXITS, &exits)
ioctl(devfd, KVM_SET_DEVICE_CPU_EXITS, &exits)
```

Migration

In qemu stream vs out of stream

- Handled by qemu or not
- Security aspect

Share VMState infrastructure with helper?

- Instead of blobs
- Make it a library, IPC hook for saving/loading to/from stream
- Unlikely to be accepted as standard in external projects

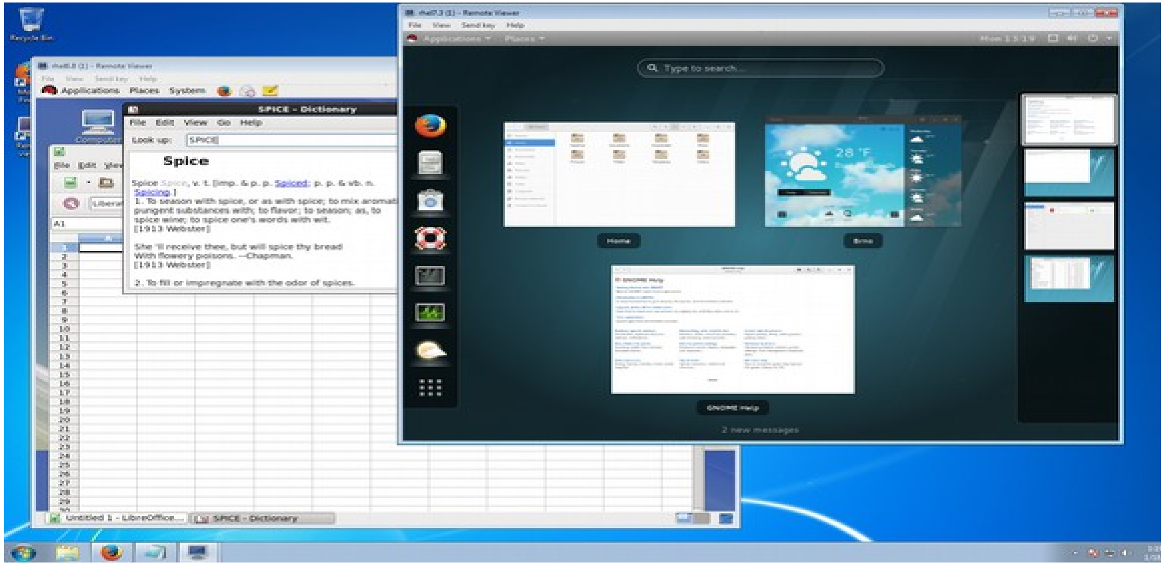
Mostly non-existent today, with rare exceptions

And today?

- VNC / Spice
- Block devices
- usbredir / cacard
- ipmi-bmc-extern
- TPM emulation
- ~~ivshmem~~ device
- vhost, vhost-user
- VFIO/mdev

VNC & Spice

- UI in remote process
- Resume session
- Migration
- VT & monitor?



What about?

QEMU to start a graphical client instead?

Remove GTK/SDL/VTE/audio code from qemu?

Block devices

```
$ qemu-nbd -k nbd.sock vm.qcow2
$ qemu -drive driver=nbd,
  server.path=nbd.sock,server.type=unix
```

(other protocols exist: iSCSI, NBD, SSH, Sheepdog, gluster, http/ftp..)

Block devices

Would performance be good enough for general case?

Could use shared memory, to avoid extra copy, opportunistic polling…

Usbredir

```
$ usbredirserver -p 2001 <vendorid>:<prodid>

$ qemu <ehci-uhci> …
-chardev socket,port=2001,id=chr
-device usb-redir,chardev=chr
```

✓migrate

✗**migrate**

USB Devices

QEMU emulation of USB devices in standalone process using usbredir API?

Cacard

```
$ qemu … -device usb-ccid
-chardev socket,server,port=2001,id=chr
-device ccid-card-passthru,chardev=chr

$ vscclient <host> 2001
```

✓migrate ✗**migrate**

Ipmi-bmc-extern

```
$ ipmilan -c conf-file -f cmd-file -s statedir

$ qemu … -device ipmi-bmc-extern,chardev=chr
-chardev socket,id=chr,host=localhost,port=…
-device isa-ipmi-bt,bmc=bmc0,irq=0
```

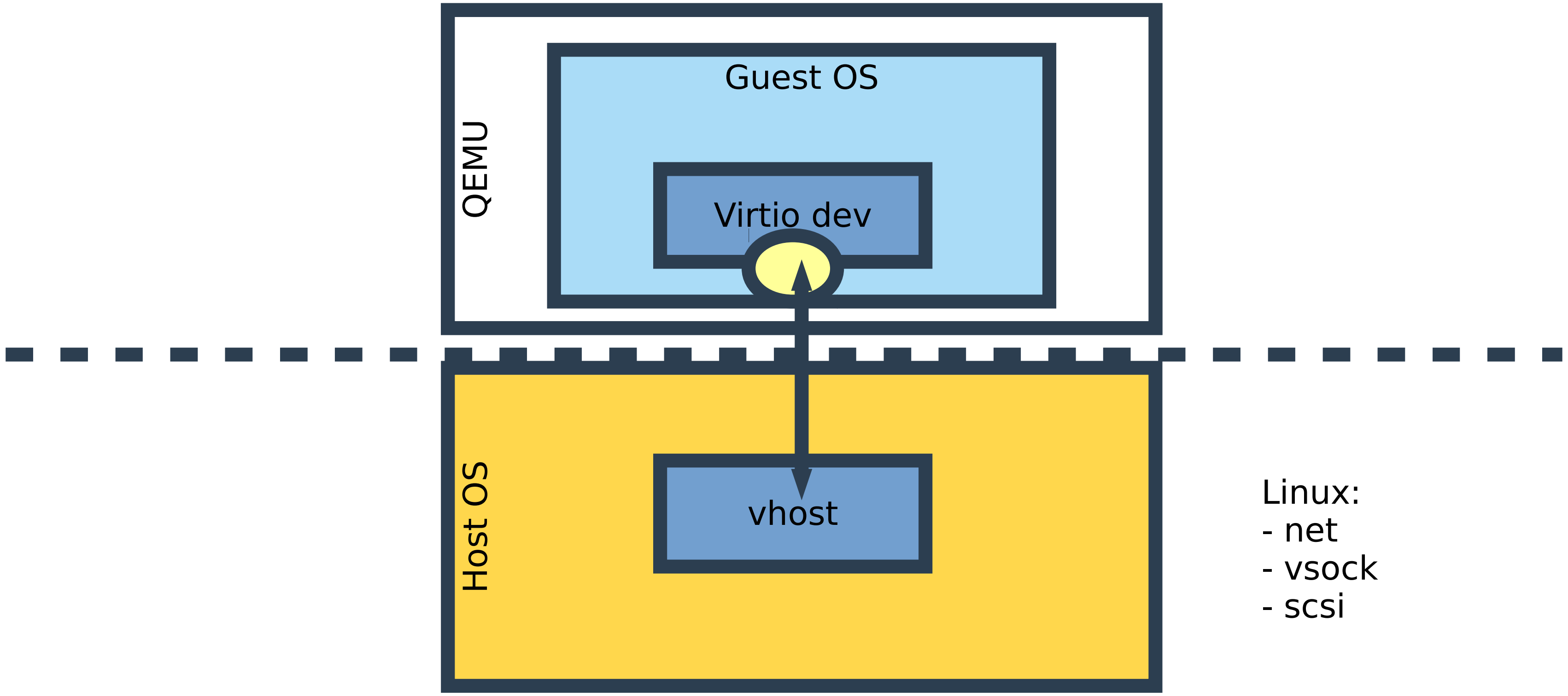
TPM emulator

```
$ swtpm socket --tpmstate dir=/tmp/myvtpm --ctrl
type=unixio,path=/tmp/ctrl
```

```
$ qemu … -tpmdev emulator,id=tpm0,chardev=chr
-chardev socket,id=chr,path=/tmp/ctrl
-device tpm-tis,tpmdev=tpm-tpm0,id=tpm0
```

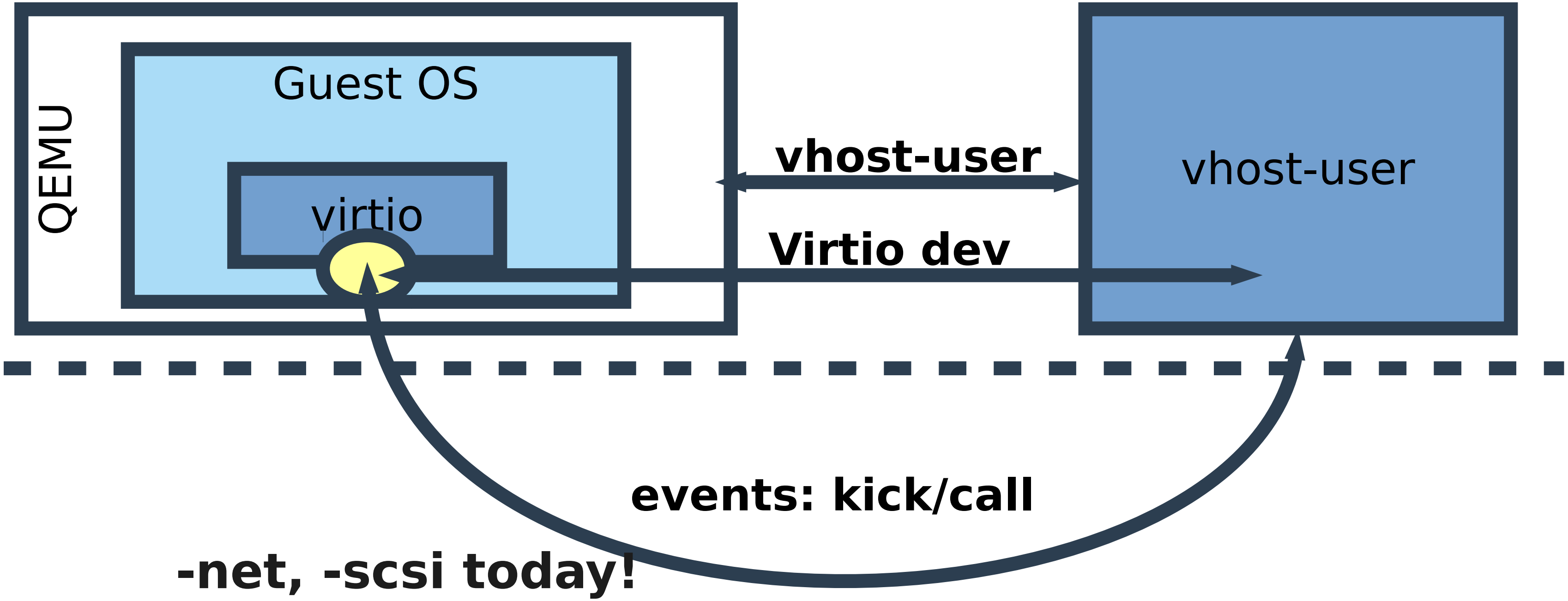
✓ migrate soon

Vhost overview



Linux:
- net
- vsock
- scsi

vhost-user



-net, -scsi today!

-blk, -gpu, -input, -crypto coming!

Vhost(-user) in a nutshell

Memory listener to have RAM flat view

SET_MEM_TABLE

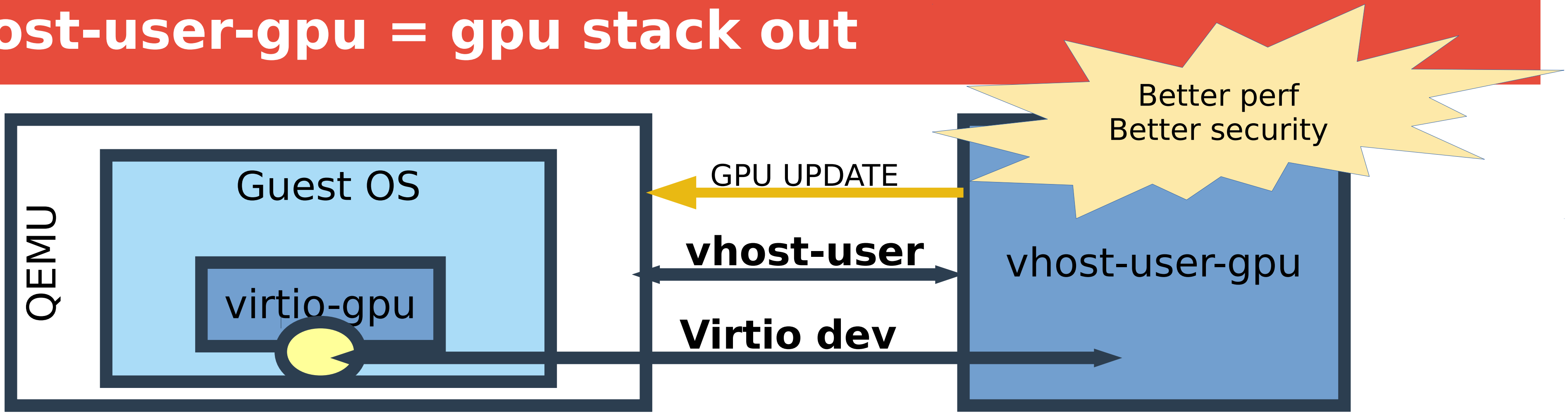
(Fd)	Guest Address	User Address	Size
34	0xA000	0xf2bc0000	0x40000000
...			

SET_VRING_ADDR, SET_VRING_NUM

Index	Desc Address	Used Address	Avail Address
0	0xf2bc1000	0xf2bc2000	0xf2bc3000

SET_VRING_KICK(fd), SET_VRING_CALL(fd)

vhost-user-gpu = gpu stack out




```
-object vhost-user-backend,id=vug,cmd="./vhost-user-gpu"
-device virtio-vga,virgl=true,vhost-user=vug
```

GPU socket commands:
- SCANOUT
- UPDATE
- GL SCANOUT
- GL UPDATE (+)
- CURSOR UPDATE

Could be handled outside of QEMU
(spice or client)

Benefits of virgl out of process?

- avoids blocking qemu main loop

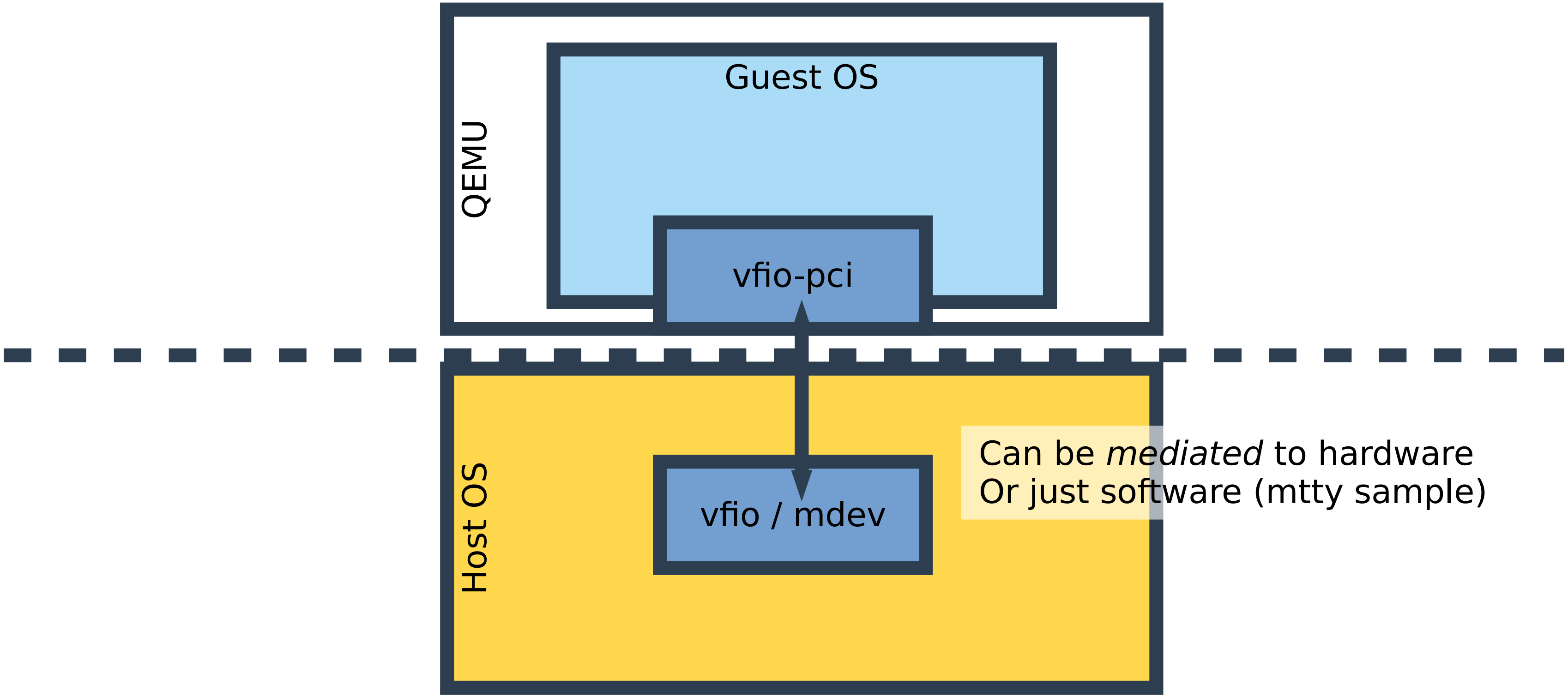
Shaders may take long to compile

- virgl needs to do polling (GL queries & fences)

- virgl crash (various crash/leaks fixed)

- GL isn’t a very safe API (size/buffer mismatch – ARB_robustness is an extension)

Mdev / vfio overview



Can be *mediated* to hardware
Or just software (mtty sample)

VFIO in userspace?

Implement PCI devices in userspace with a VFIO-user?

Conclusion

- Qemu is mostly monolithic & big today
- Strategies to run separate processes exist, but provide different interfaces & integration levels
- Use vhost-user for virtio devices
- Many ideas for a multi-process future

Questions

QEMU

STOP STOP STOP STOP STOP STOP STOP

STOP
STOP
✓ **migrate**

✗ **migrate**

Virtio device → vhost-user device

Check ioeventfd support

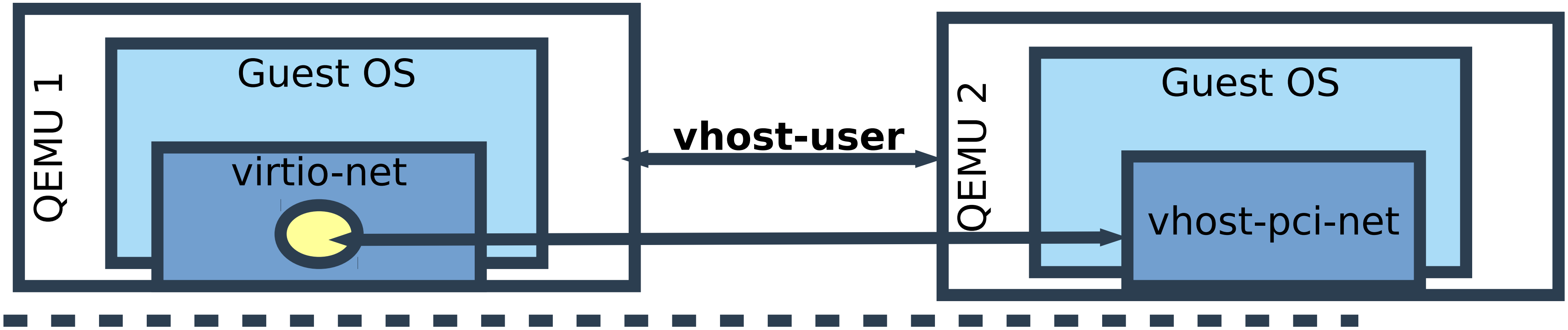
vhost_dev.vqs = g_new(vhost_queues, N)

vhost_dev_init(vhost, chr, TYPE_USER, timeout)

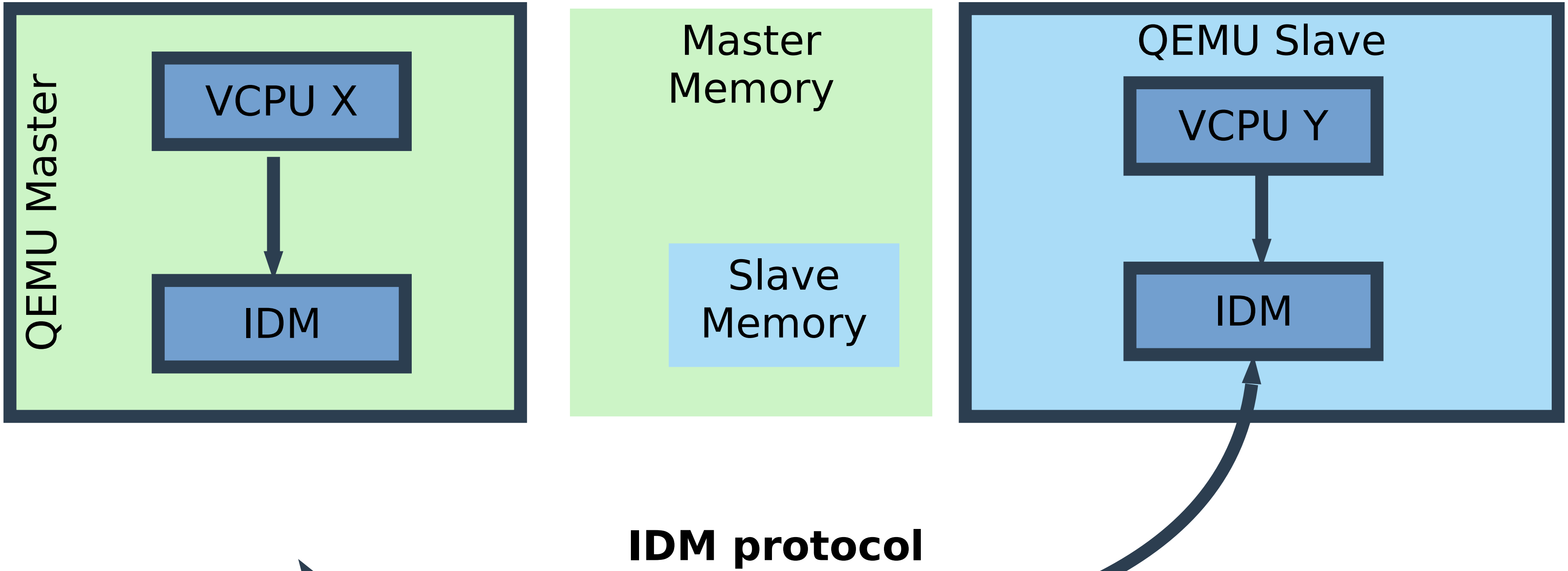
VirtioDeviceClass.set_status() & reset():

- vhost_dev_enable_notifiers()
- VirtioBus parent: set_guest_notifiers()
- Set dev.acked_features = virtio.guest_features
- vhost_dev_start()
- vhost_virtqueue_mask() forall queues

Vhost-pci WIP
(Inter-VM communication)



Heterogeneous QEMU



"[RFC PATCH 0/8] Towards an Heterogeneous QEMU" C. Pinto Sept 2015
& virtio-sdm & also xilinx remote-proc