KVM: Virtual vs. Physical Machines

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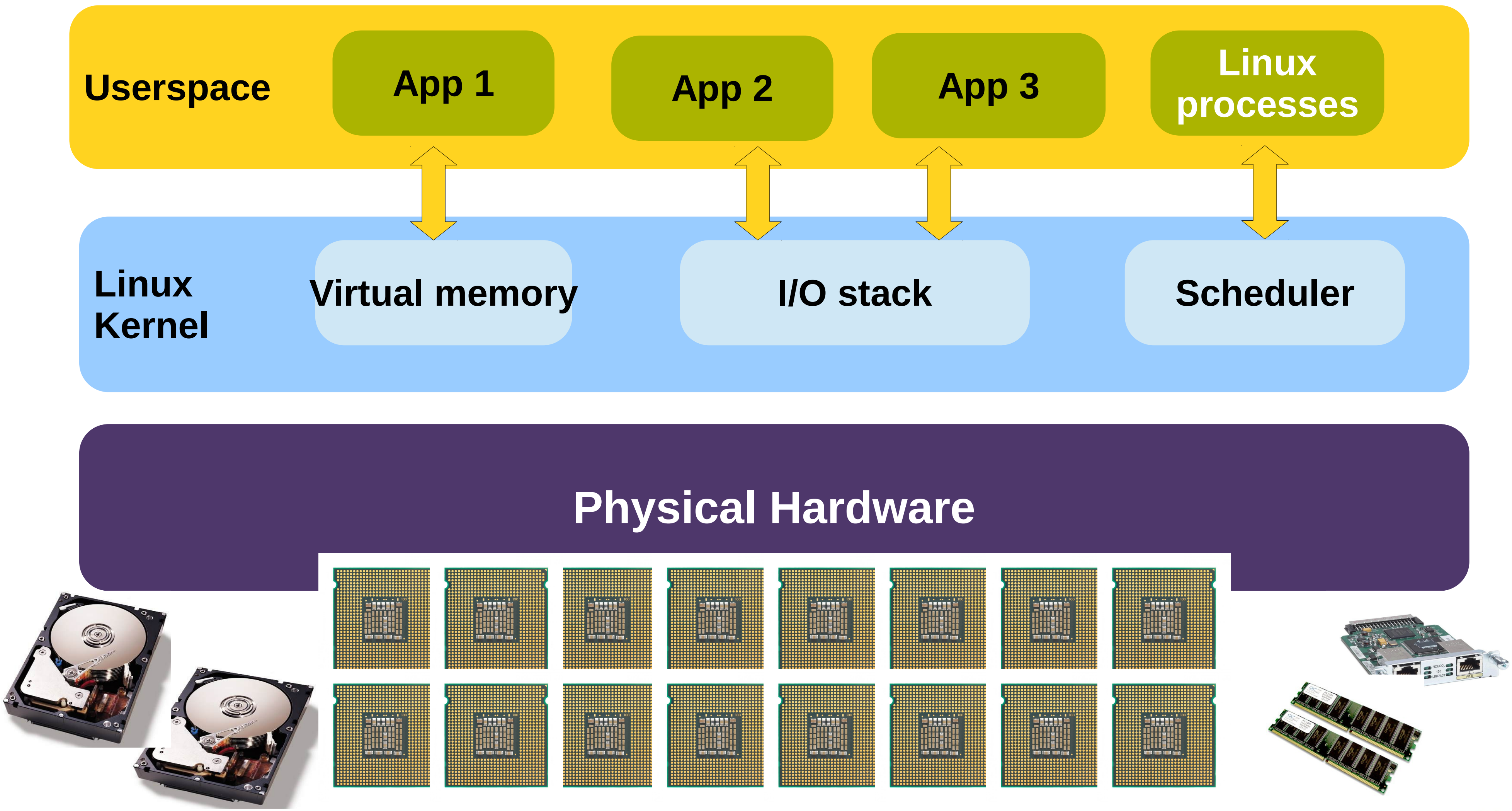
DevConf.cz Feb 2014

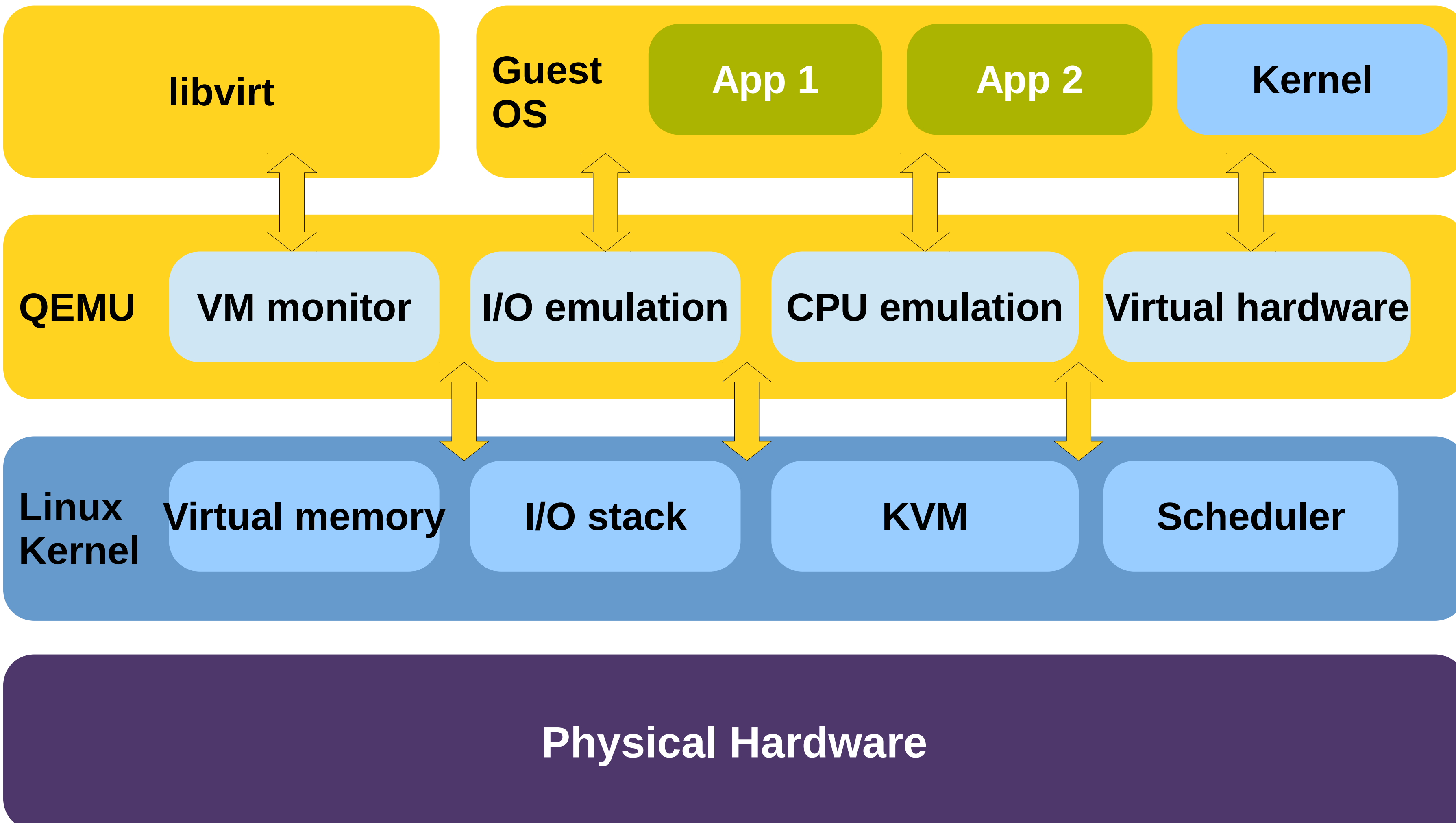
Agenda

- Virtual vs. Physical Machines
- CPU and Memory Hot-plug
- Live Migration
- Timers and Clocks
- Performance Monitoring
- Testing your application in both worlds

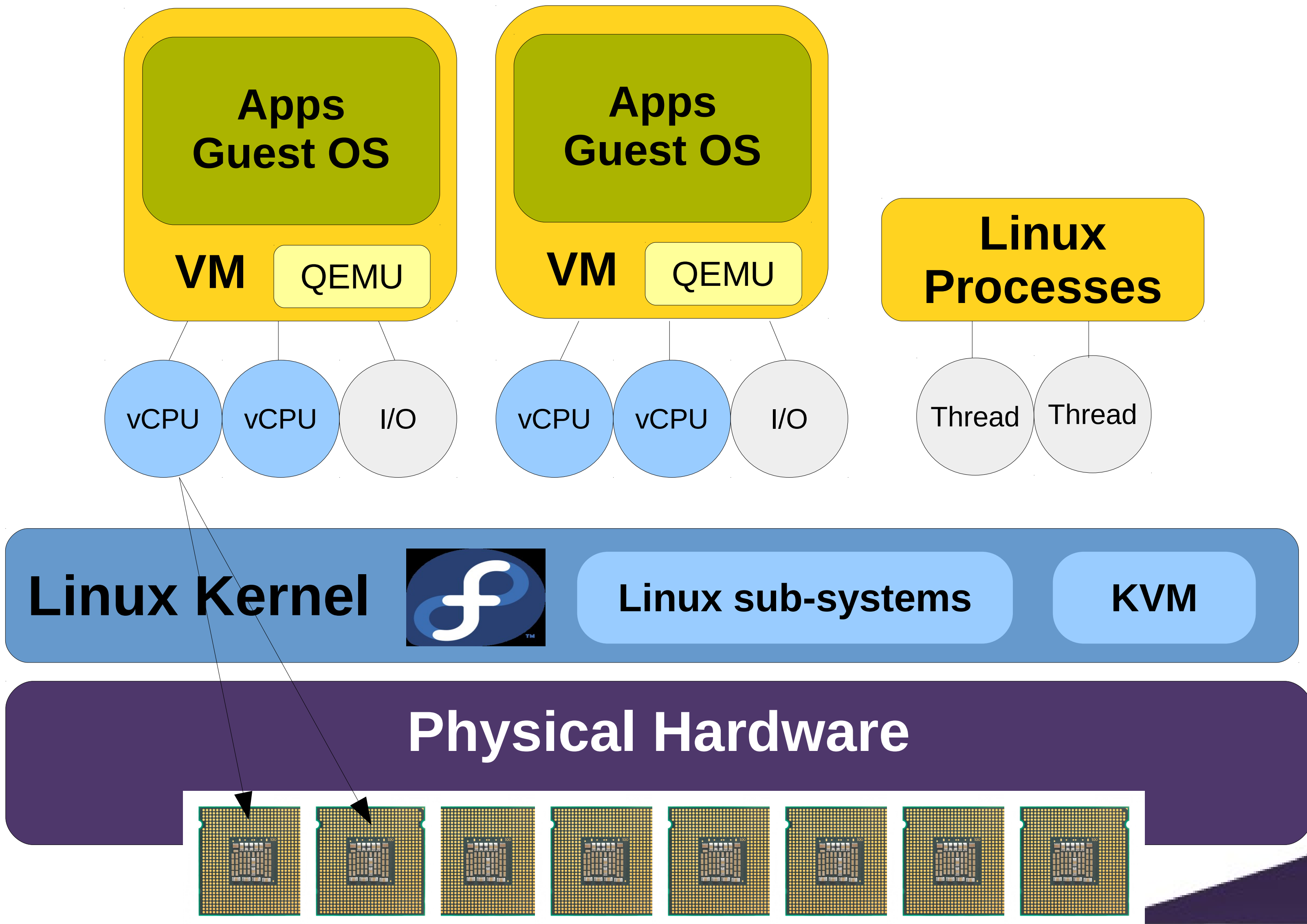
Linux on Physical Systems



KVM Architecture



KVM: Virtual Machines



QEMU running on a Linux host

```
# ps -ef | grep -i qemu
qemu     26705     1  1 Mar27 ?  00:45:11 /usr/bin/qemu-system-x86_64
-machine accel=kvm -name knoel1 -S -machine pc-q35-1.6,accel=kvm,
usb=off -cpu host -m 1024 -realtime mlock=off -smp 1,maxcpus=4,
sockets=4,cores=1,threads=1 -uuid f8023c16-22b1-4163-a7b5-df2452241fed
-no-user-config -nodefaults -chardev
...


# ps -mo pid,tid,fname,user,psr -p 26705
  PID   TID COMMAND  USER     PSR
26705     - qemu-sys qemu       -
    - 26705 -        qemu       2
    - 26737 -        qemu       2
    - 26756 -        qemu       0
    - 26802 -        qemu       0
    - 26808 -        qemu       3
```

Why do people use Virtual Machines?

- Consolidation of HW resources – save money/power
- Hardware abstraction
- Fast provisioning
- Flexibility
- Cloud – Infrastructure as a Service (IaaS)
- And others
- It's important to understand the differences...

Hot-plug:
CPUs and Memory

CPU Hot-plug – physical hardware

- ACPI hot-plug – supported by high-end systems
- In-plug:
  - Operator inserts new CPU
  - ACPI sends event to OS
  - OS onlines CPU
- Un-plug:
  - OS offlines CPU
  - Calls ACPI eject method
  - Operator removes CPU

CPU Hot-plug – OS commands

- To online a CPU
  - echo 1 > /sys/devices/system/cpu/**cpu#**/online
- To offline a CPU
  - echo 0 > /sys/devices/system/cpu/**cpu#**/online

vCPU Hot-plug – virtual machine

- Leverages ACPI hot-plug support
- In-plug: initiated on host
  - QEMU creates new vCPU thread and structures
  - ACPI sends event to OS
  - libvirt calls guest agent to online CPU
- Un-plug: initiated on host
  - libvirt calls guest agent on offline CPU
  - Calls ACPI eject method – coming soon
  - QEMU removes vCPU thread and structures – coming soon

vCPU Hot-plug: uses guest agent

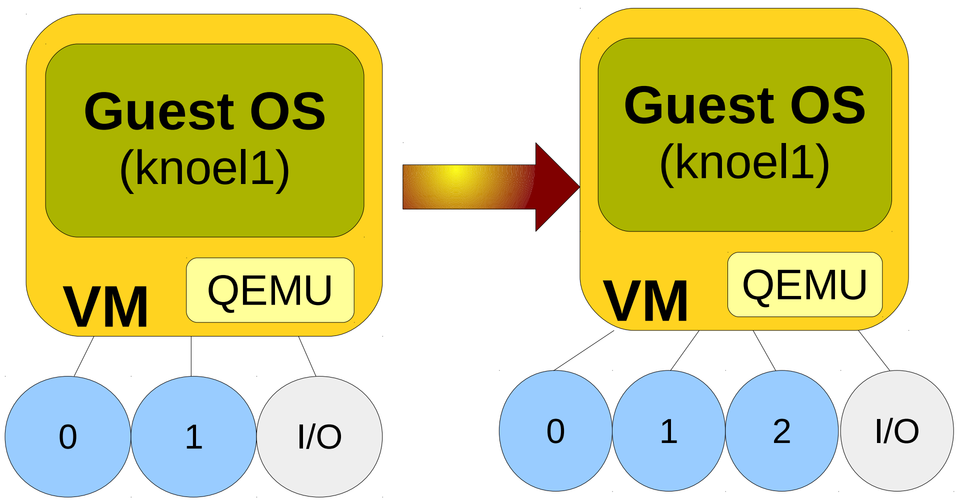
```
<channel type='unix'>
  <source mode='bind'path='/var/lib/libvirt/qemu/channel/
target/knoel1.org.qemu.guest_agent.0'/>
  <target type='virtio' name='org.qemu.guest_agent.0'/>
  <address type='virtio-serial' controller='0' bus='0' port='1'/>
</channel>

# virsh qemu-agent-command knoel1 '{"execute":"guest-ping"}'
# virsh qemu-agent-command knoel1 '{"execute":"guest-info"}'
```

- Commands:
  - guest-get-vcpus
  - guest-set-vcpus
  - etc.

vCPU In-Plug using virsh commands

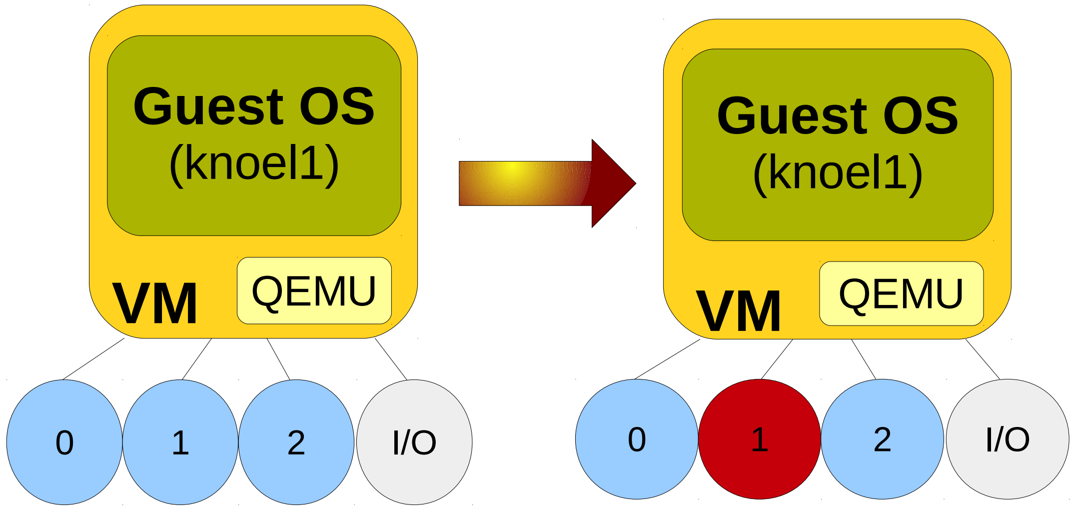
```
# virsh qemu-agent-command knoel1 '{"execute":"guest-get-vcpus"}'
{
  "return": [
      {
        "online": true,
        "can-offline": false,
        "logical-id": 0
      },
      {
        "online": true,
        "can-offline": true,
        "logical-id": 1
      }
  ]
}
```




```
# virsh setvcpus knoel1 3
# virsh setvcpus knoel1 3 --guest
```

vCPU Un-Plug using virsh commands

```
# virsh setvcpus knoel1 2 --guest
# virsh qemu-agent-command knoel1 '{"execute":"guest-get-vcpus"}'
{
  "return": [
    {
      "online": true,
      "can-offline": false,
      "logical-id": 0
    },
    {
      "online": false,
      "can-offline": true,
      "logical-id": 1
    },
    {
      "online": true,
      "can-offline": true,
      "logical-id": 2
    }
  ]
}
```



Watch out for vCPU hot-plug

- Number of CPUs can change at any time
- Examples:
  - Daemons with # of threads = # of CPUs
  - Licensing based on # of CPUs

Memory Ballooning

- Host over-commits memory for Virtual Machines
  - Without swapping in the host
- Balloon driver runs in guest kernel
  - Inflate the balloon
    - Allocate memory from guest kernel
    - Return memory to host kernel
  - Deflate the balloon - opposite
- Stay tuned for automatic ballooning
- Stay tuned for memory hot-plug

Processor Emulation

CPU info – on host (SandyBridge)

```
# grep "model name" /proc/cpuinfo
model name : Intel(R) Core(TM) i7-2620M CPU @ 2.70GHz
model name : Intel(R) Core(TM) i7-2620M CPU @ 2.70GHz
model name : Intel(R) Core(TM) i7-2620M CPU @ 2.70GHz
model name : Intel(R) Core(TM) i7-2620M CPU @ 2.70GHz

# grep flags /proc/cpuinfo
flags: fpu vme de pse tse msr... constant_tsc
arch_perfmon pebs... vmx... xsave avx... tpr_shadow
vnmi flexpriority ept vpid
```

CPU info – in guest (host-passthrough)

libvirt XML (on the host):

```
<cpu mode='host-passthrough'>
</cpu>
```

In the guest:

```
# grep "model name" /proc/cpuinfo
model name : Intel(R) Core(TM) i7-2620M CPU @ 2.70GHz
# cat /proc/cpuinfo
flags: fpu vme de pse tsc msr... constant_tsc
arch_perfmon... xsave avx hypervisor lafh_lm xsaveopt
tsc_adjust
```

- CPUID feature flags do not match host!
  - Note: arch_perfmon set in both
  - Missing: vmx, tpr_shadow, vnmi, ept, vpid, others
  - Added: hypervisor

CPU info – in guest (SandyBridge)

libvirt XML (on the host):

```
<cpu mode='custom' match='exact'>
    <model fallback='allow'>SandyBridge</model>
    ...
```

In the guest:

```
# grep "model name" /proc/cpuinfo
model name : Intel Xeon E312xx (Sandy Bridge)
# cat /proc/cpuinfo
flags: fpu vme de pse tsc msr... constant_tsc...
xsave avx hypervisor lafh_lm xsaveopt
```

- CPUID feature flags do not match host!
  - Missing: arch_perfmon
  - Missing: vmx, tpr_shadow, vnmi, ept, vpid, others
  - Added: hypervisor

CPU info – in guest (Nehalem)

libvirt XML (on the host):

```
<cpu mode='custom' match='exact'>
  <model fallback='allow'>Nehalem</model>
  ...
```

In the guest:

```
# grep "model name" /proc/cpuinfo
model name: Intel Core i7 9xx (Nehalem Class Core i7)
# cat /proc/cpuinfo
flags: fpu vme de pse tsc msr... constant_tsc...
hypervisor lafh_lm
```

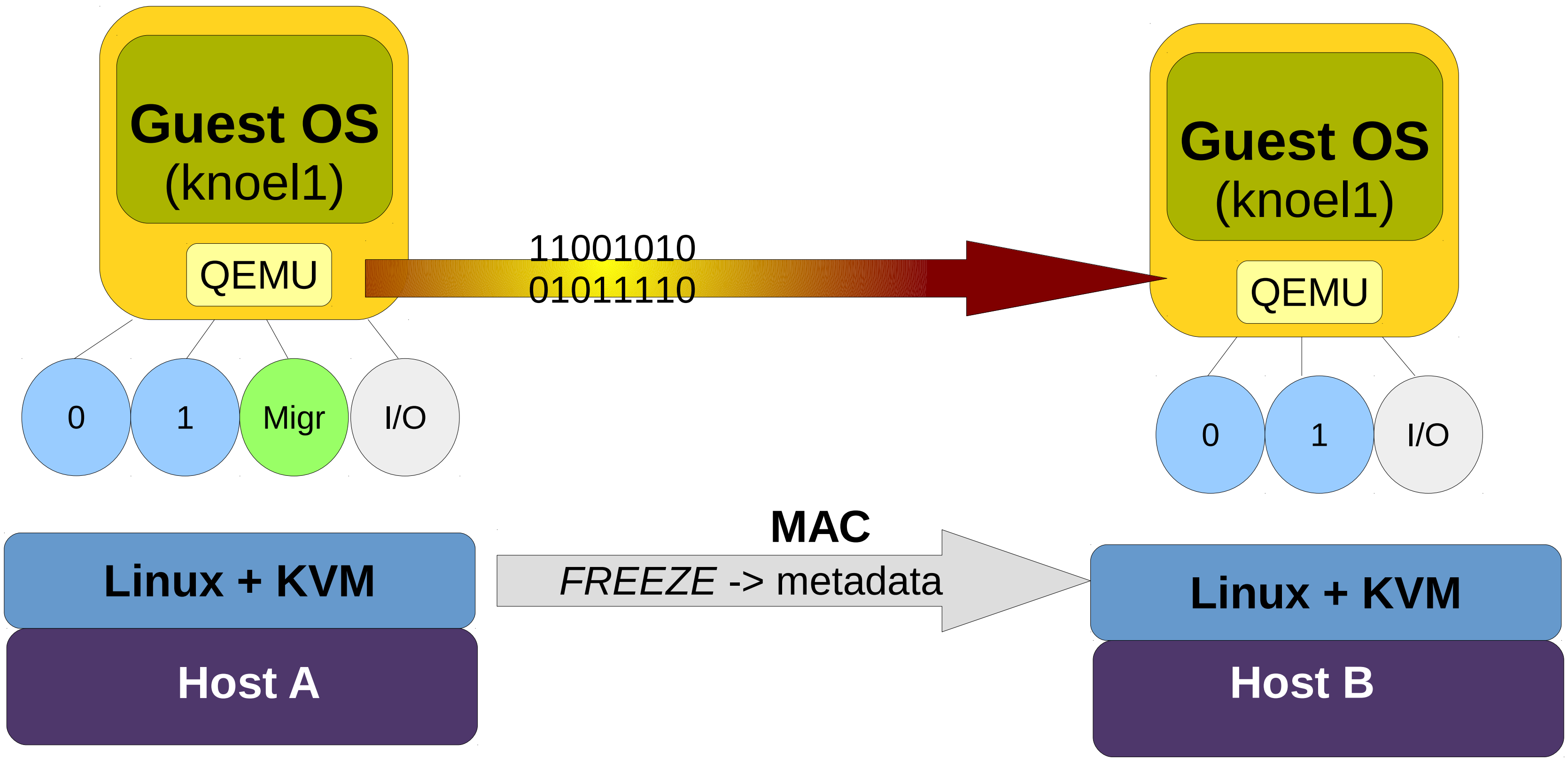
- Do CPUID flags match Nehalem exactly?
  - Missing: arch_perfmon
  - Missing: vmx, ept, others
  - Added: hypervisor

Use /proc/cpuinfo flags

- Processor model - same on host and guest
  - With different features
- Processor model – different on host and guest
  - Hypervisor might emulate features, might not
- Example:
  - PMU features based on processor model

Live Migration

Live Migration: move running VM to another host



Live migration: downtime - internal

- Downtime = time that vCPUs are not running
- vCPUs freeze in between instructions
- No disruption of kernel or applications

```
(qemu) info migrate
capabilities: xbzrle: off x-rdma-pin-all: off auto-converge: on
zero-blocks: off
Migration status: completed
total time: 172293 milliseconds
downtime: 3008 milliseconds
setup: 688 milliseconds
transferred ram: 22699191 kbytes
throughput: 5365.96 mbps
remaining ram: 0 kbytes
total ram: 268444380 kbytes
duplicate: 64939287 pages
skipped: 0 pages
normal: 5521319 pages
```

Live migration downtime - external

- Downtime = time that guest is not on network
- Ping from external system

```
...
64 bytes from 10.8.8.248: icmp_req=10 ttl=63 time=0.400 ms
64 bytes from 10.8.8.248: icmp_req=11 ttl=63 time=0.366 ms
64 bytes from 10.8.8.248: icmp_req=12 ttl=63 time=0.451 ms
64 bytes from 10.8.8.248: icmp_req=13 ttl=63 time=0.484 ms
64 bytes from 10.8.8.248: icmp_req=14 ttl=63 time=0.464 ms
64 bytes from 10.8.8.248: icmp_req=15 ttl=63 time=0.399 ms
...
64 bytes from 10.8.8.248: icmp_req=69 ttl=63 time=3091 ms *
64 bytes from 10.8.8.248: icmp_req=74 ttl=63 time=0.426 ms
64 bytes from 10.8.8.248: icmp_req=75 ttl=63 time=0.440 ms
64 bytes from 10.8.8.248: icmp_req=76 ttl=63 time=0.450 ms
64 bytes from 10.8.8.248: icmp_req=77 ttl=63 time=0.425 ms
...
```

normal

downtime

normal

Live migration – auto-convergence

- QEMU “throttles” the vCPUs
- Helps the live migration converge

```
64 bytes from 10.8.8.248: icmp_req=40 ttl=63 time=0.400 ms
64 bytes from 10.8.8.248: icmp_req=41 ttl=63 time=0.366 ms
64 bytes from 10.8.8.248: icmp_req=42 ttl=63 time=0.451 ms
64 bytes from 10.8.8.248: icmp_req=43 ttl=63 time=0.484 ms
64 bytes from 10.8.8.248: icmp_req=44 ttl=63 time=0.464 ms
64 bytes from 10.8.8.248: icmp_req=45 ttl=63 time=0.399 ms
...
64 bytes from 10.8.8.248: icmp_req=81 ttl=63 time=21.4 ms
64 bytes from 10.8.8.248: icmp_req=82 ttl=63 time=0.540 ms
64 bytes from 10.8.8.248: icmp_req=83 ttl=63 time=5.88 ms
64 bytes from 10.8.8.248: icmp_req=84 ttl=63 time=1.95 ms
64 bytes from 10.8.8.248: icmp_req=85 ttl=63 time=16.1 ms
64 bytes from 10.8.8.248: icmp_req=86 ttl=63 time=4.68 ms
64 bytes from 10.8.8.248: icmp_req=87 ttl=63 time=0.434 ms
64 bytes from 10.8.8.248: icmp_req=88 ttl=63 time=3.63 ms
64 bytes from 10.8.8.248: icmp_req=89 ttl=63 time=2983 ms *
64 bytes from 10.8.8.248: icmp_req=94 ttl=63 time=0.426 ms
64 bytes from 10.8.8.248: icmp_req=95 ttl=63 time=0.440 ms
64 bytes from 10.8.8.248: icmp_req=96 ttl=63 time=0.450 ms
64 bytes from 10.8.8.248: icmp_req=97 ttl=63 time=0.425 ms
```

normal (icmp_req=40–45)

throttle (icmp_req=81–88)

downtime (icmp_req=89)

normal (icmp_req=94–97)

Timers and Clocks

Hardware Timers/Clocks

- RTC - Real Time Clock
- LAPIC Timer - periodic, one-shot or TSC-deadline (recent)
- ACPI Timer, Power Management (PM) Timer - low resolution, not programmable
- TSC - Time Stamp Counter
- HPET - High Precision Event Timer

Virtual Machine Timers and Clocks

- RTC works – used by Windows
- LAPIC one-shot timer – fine in VM
- ACPI Timer, (PM) Timer – fine in VM, also used by Windows
- TSC – not reliable due to live migration even if iTSC
- HPET – no compensation for missed ticks (slow)

http://www.vmware.com/files/pdf/Timekeeping-In-VirtualMachines.pdf

http://www.linux-kvm.org/wiki/images/6/6a/2010-forum-time-keeping.pdf

Timers and Clocks – para-virtualized

- kvm-clock – para-virtualized clock
- Hyper-V reference time counter – for Windows – MSR (emulated in host kernel)
- Hyper-V iTSC – for Windows

Timers and Clocks: Watch out for...

- Do not read TSC directly
  - TSC frequency may change on live migration!
  - Destination host may not have iTSC
  - TSC Frequency in MSR_PLATFORM_INFO – not emulated on KVM!
- Use standard clock functions for timing
  - Example: clock_gettime(CLOCK_MONOTONIC, &ts)
- Use NTP within the guest
  - Adjust for live migration downtime
  - Compensate for clock drift – even with kvm-clock!
  - Leapseconds

Para-virtualized Clock – kvm-clock

cat /sys/devices/system/clocksource/clocksource0/
current_clocksource
kvm-clock

- struct pvclock_vcpu_time_info { ... }
- Fields to calculate accurate system time (ns accuracy)
  - Offset from host TSC timestamp
  - Shift & multiply to adjust from host frequency
  - Migration count (version field)
    - To different host pCPUs
    - To different pCPUs on different hosts

Para-virtualized Clock – new vsyscall

- Very efficient vsyscall for gettimeofday() and clock_gettime()
  - Introduced in 3.7 kernel
- Page with pvclock_vcpu_time_info structure
  - Mapped in userspace for each vCPU
  - Written by KVM in the host
  - Read by guest userspace and kernel

Performance Monitoring

Performance Monitoring - PMU

- Traditionally...
  - Each processor model = different PMU design
- On recent Intel x86_64 processors:
  - Subset of performance events are “architectural”
  - Same on all - arch_perfmon feature
- QEMU sets arch_perfmon with “-cpu host”
- libvirt XML = <cpu mode='host-passthrough'>

Performance Monitoring – architectural events

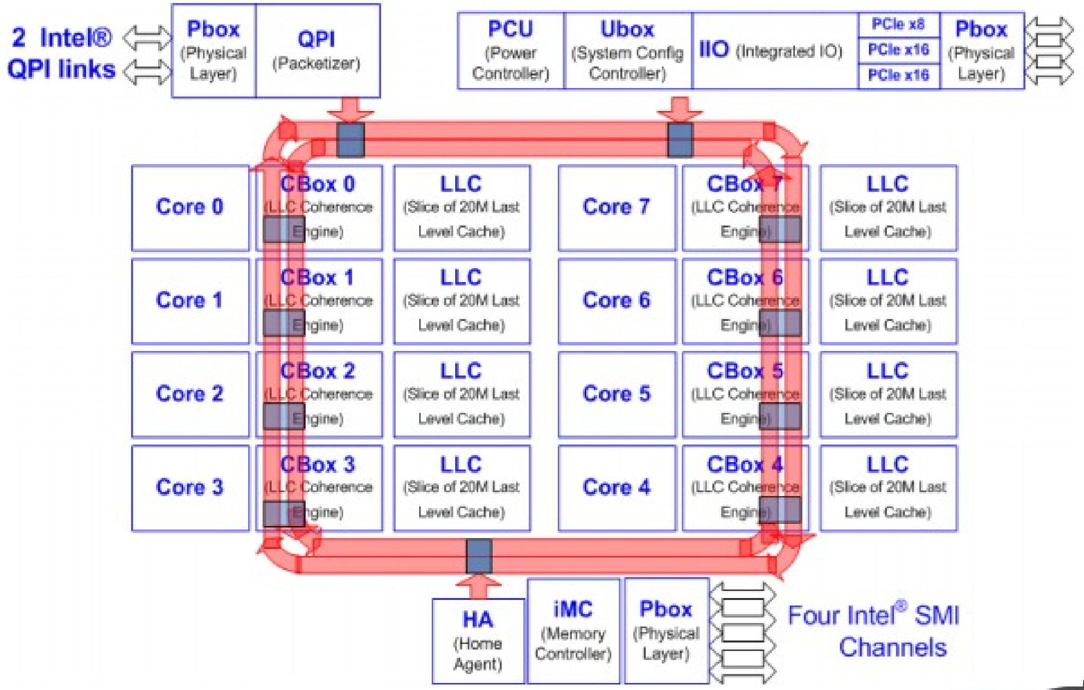
```
# perf list

List of pre-defined events (to be used in -e):
  cpu-cycles OR cycles                       [Hardware event]
  instructions                               [Hardware event]
  cache-references                           [Hardware event]
  cache-misses                               [Hardware event]
  branch-instructions OR branches            [Hardware event]
  branch-misses                              [Hardware event]
  bus-cycles                                 [Hardware event]
  idle-cycles-frontend                       [Hardware event]
  idle-cycles-backend                        [Hardware event]
  ref-cycles                                 [Hardware event]
```

Performance Monitoring – non-arch events

- All other hardware events are non-architectural
  - Execution unit usage counts, ...
  - Events that rely on other MSRs to be set first
  - Uncore events – cannot be multiplexed by KVM

http://www.intel.com/content/dam/www/public/us/en/documents/design-guides/xeon-e5-2600-uncore-guide.pdf



Performance Monitoring – live migration

- Issues with live migration and non-arch PMU
  - Events may not exist on another model
  - May be programmed differently on another model
  - Live migration to another model host --> bad results

Current QEMU and libvirt Support

- QEMU - arch_perfmon CPUID feature flag for -cpu host
- libvirt – disallow live migration with cpu host-passthrough unless same model on destination
- Future, for emulated processor models
  - QEMU – provide arch_perfmon?
  - KVM – disallow use of non-architectural PMU?

Conclusion: Testing!

Test on Physical Systems

- For testing hardware specific things
- Ensure application does not make Virtual Machine specific assumptions

Test on Virtual Machines

- Configuration flexiblity!
- 1 to 160 vCPUs (recommend up to host CPUs)
  - Don't assume uni-processor systems are gone!
- 512M up to 4TiB (do not over-commit too much)
  - When over-committing, use ballooning or large swap file
- Test on many emulated processor models
- Test with live migration
  - Know the max_downtime for your application

Questions?