Real-time in a virtual system?! Comparing real-time capabilities of various types of Linux hypervisors and containers, Basic lecture

Technical concepts of Linux hypervisors and containers

Alexander Bähr
Open Source Automation Development Lab (OSADL) eG

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Main topics

- Virtualization: Definition and overview
  - Hardware virtualization
  - System virtualization
- Hardware virtualization example: kvm
- System virtualization examples: chroot, docker
- Conclusion

Virtualization: Definition and overview

Virtualization: Provision of resources **simulated** by software

- Hardware:
  - Particular **hardware**, *e.g.* interfaces (network, serial, ...)
  - **Platform** virtualization , incl. CPU, memory, devices

- Software:
  - Operating system emulation
  - Services, *e.g.* OpenGL
  - Application

Origin of virtualization: hardware time sharing

- **Shared usage** of computer resources among a large group of users
- **Increase** the **efficiency** of both users and expensive computer resources **by sharing**
- Costs for providing computing capability **dropped considerably** -> use a computer without actually owning one

Advantages of virtualization technologies

- Resource optimization: Assign each VM precisely the **amount of computing power** it needs for its jobs or tasks
- Increase the uptime of services over the network/Internet – 99.999 % (five nines) or better through **live migration**
- **Back up**, **copy**, and **clone** VMs
- Reduced hardware requirements also **reduces power consumption** -> minimizing the carbon footprint (**green IT**)

Reasons for the wide popularity of virtualization

- Hardware isolation
  - Running legacy OS in safe environment
  - Maintenance, manageability (i.e. installation of server)
  - Security and/or performance isolation
- Testing
  - Development of i.e. a driver without hardware
  - Wide range of test scenarios
- Power savings
  - Fewer machines = easier maintenance
  - Reduced energy costs

Virtualization: chronological overview

- 1968 CP/CMS from IBM with **Virtual Machines** (VM), community and growing interest provide a strong development
- Publication of **various hypervisors** and **virtualization technologies** over the years (i.e. chroot, XEN, VM-Ware, Hyper-V)
- 23 Oct 2006, **kvm patch set** for Linux 2.6.20 to run virtual machines on Linux **without** using a full hypervisor like XEN

Hypervisor definition (Popek and Goldberg)

- Equivalence / Fidelity

  A program running under the VMM should exhibit a behavior **essentially identical** to that demonstrated when running on an **equivalent machine** directly.

- Resource control / Safety

  The VMM must be in **complete control** of the virtualized resources.

- Efficiency / Performance

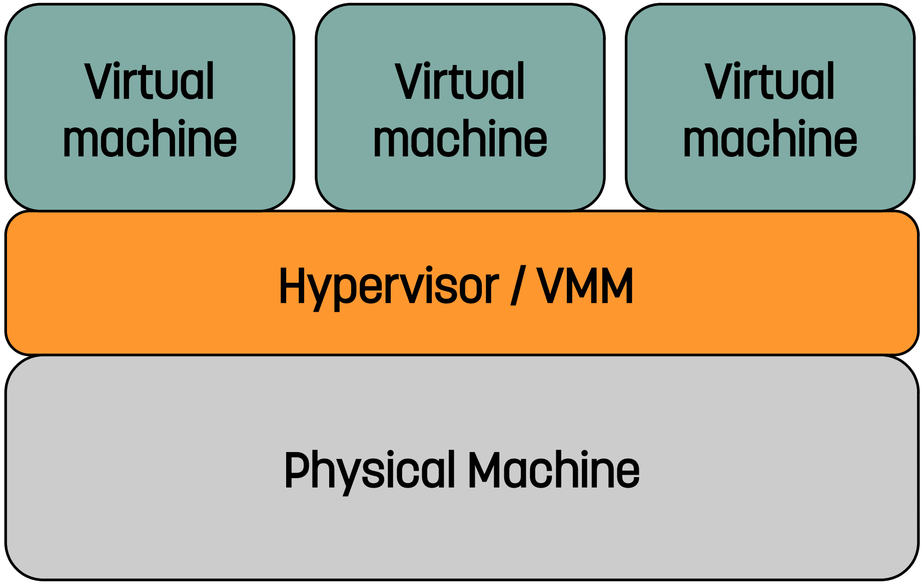
  A statistically dominant fraction of machine instructions must be executed **without VMM intervention**.

Hardware (full) virtualization

- Physical virtualization
- The **hypervisor** separates the guest systems from the host.
- It provides **simulated hardware** to the guest systems at instruction level.
- The guest systems are **completely independent** from each other and not aware that they are virtualized (except by inspecting the configuration).
- Examples: kvm

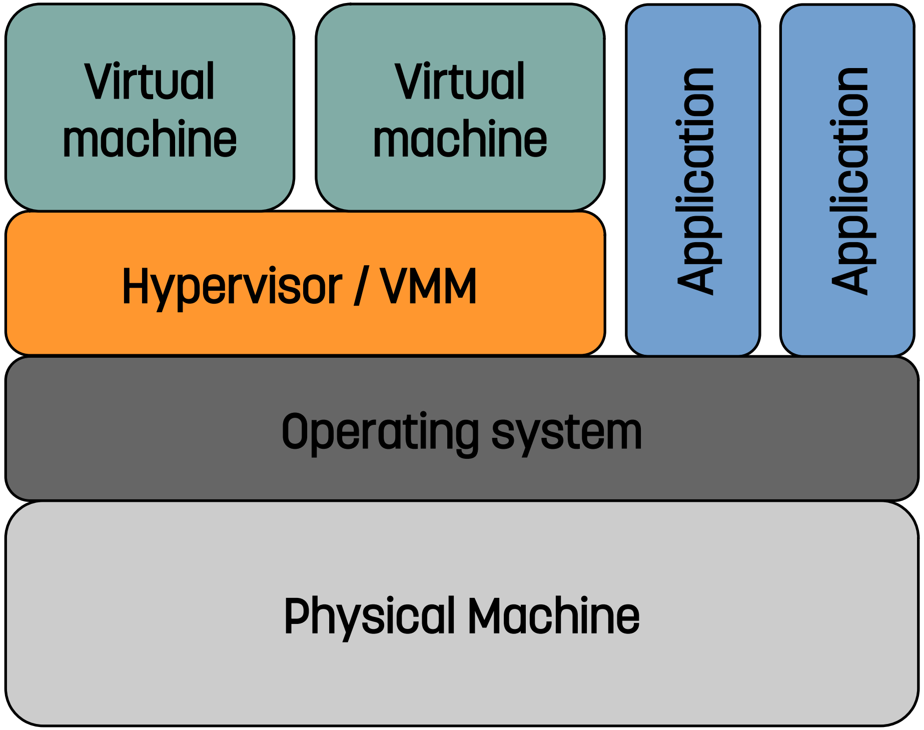
Hardware virtualization – Type-1 hypervisor

- runs directly on the underlying computer's physical hardware
- interacting directly with its CPU, memory, and physical storage
- takes the place of the host operating system
- Examples: kvm, XEN, jailhouse



Hardware virtualization – Type-2 hypervisor

- runs as an application in an OS
- accesses computing, memory, and network resources via the host OS
- can cause latency issues, affecting performance
- Security risk: compromised host OS could manipulate a guest OS
- Examples: QEMU



Hypervisor example: kvm

- Kernel module **kvm.ko** → add type-1 hypervisor to Linux
- **Open Source project** (GPL-2.0-only)
- Full functionality merged into Linux 2.6.20 on 5. Feb. 2007
- Initially provides CPUs from **Intel** with the **vmx** (**v**irtual **m**achine e**x**tension) and **AMD** with **svm** (**s**ecure **v**irtual **m**achine)
- Up to now full visualization on **x86, x86-64, s390, PowerPC, ARM**
- Use of the **same hardware,** so guest CPU same as host

Hypervisor example: kvm

Date Thu, 19 Oct 2006 15:45:49 +0200
From Avi Kivity <>
Subject [PATCH 0/7] KVM: Kernel-based Virtual Machine

share 0

```
The following patchset adds a driver for Intel's hardware virtualization
extensions to the x86 architecture.  The driver adds a character device
(/dev/kvm) that exposes the virtualization capabilities to userspace.  Using
this driver, a process can run a virtual machine (a "guest") in a fully
virtualized PC containing its own virtual hard disks, network adapters, and
display.
```

“It was the right project at the right time,” Kivity said. “Virtualization was very hot at the time, and the only open-source alternative at the time was Xen, which was outside of the Linux kernel.”

Prerequisits for virtualization on x86

- CPU-extensions (Intel, AMD)
  - Guest operating mode
  - Hardware state switch
  - Exit reason reporting
- Kvm architecture
  - Character device in `/dev/kvm`
  - Kvm API: `ioctl()` to control vm (type: system, vm, or vcpu)

Setup kernel and system for use of kvm

- Config and build kernel with:

```
-General setup
    [*]Control Group support
            [*]CPU controller
            [*]Cpuset controller
            [*]Freezer controller
            [*]Device controller

-Virtualization
    [*] Kernel Based Virtual Machine (KVM) support
            → (select the hardware dependent options)
```

- Install on system:

```
libvirt-bin
libvirt-daemon
```

Management of kvm-systems

Several tools available to manage kvm virtual machines, different emphasis for particular use cases, i.e.:

- QEMU/kvm (straight from the command line)
- virsh (cli)
- kvm-admin (python-scripts)
- Proxmox VE (server virtualization management, web,cli, API)
- kimchi (web, python)

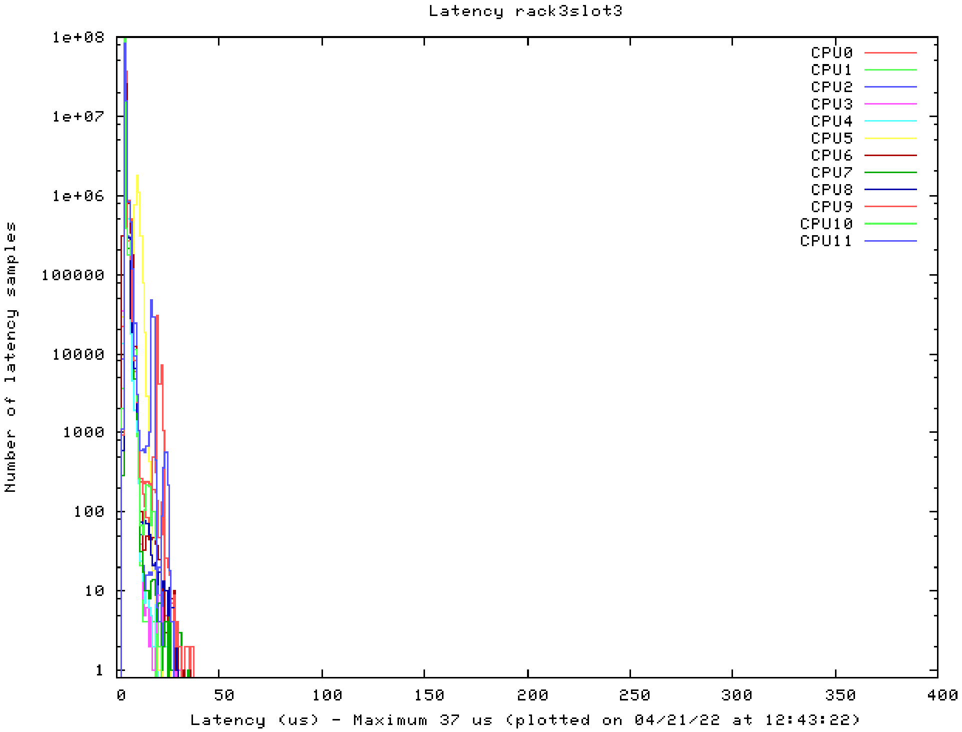
Management of kvm-systems - QEMU

QEMU (Quick Emulator) can work in two modes:

- **Full system emulation** mode, is to provide virtualization of an entire machine (CPU, memory, IO devices) to run a guest OS
  - CPU may be fully emulated using DBT (Dynamic Binary Translation)
  - Use a hypervisor such as KVM to gain better performance
- **User mode emulation**, where only a binary compiled for one CPU is executed on another CPU
  - To ease cross-compilation and cross-debugging
  - Running the Wine Windows API emulator

Scenario: Realtime and kvm (rack 3 slot 3)

Host



Guest

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Realtime with kvm?

- Priority and lock holders are not visible for the host, therefore no priority inheritance.
- To achieve realtime in kvm:

CPU

1	2
3	4
5	6
7	8

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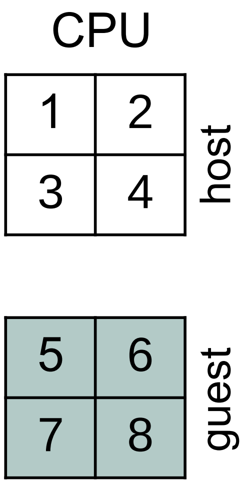

- **Partition** between CPUs running system tasks and **isolated CPUs** running **realtime guests** (`isolcpu` and `nohz` in the kernel command line).

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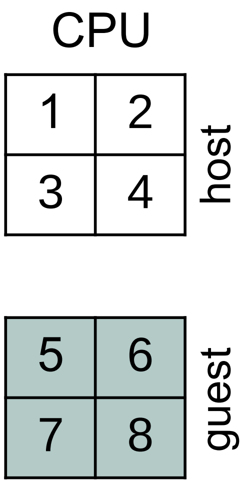

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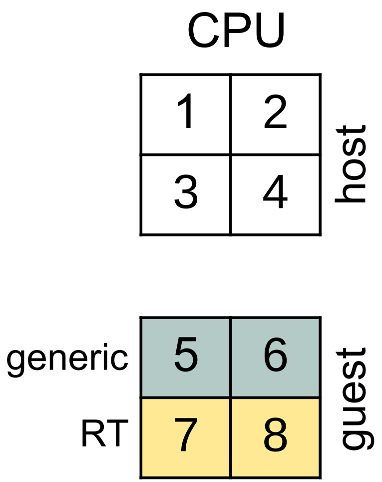

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- Run virtual CPUs (VCPUs) of the guest with **very high priority**, only interfered by ksoftirqd.
- On the guest **partition** between **realtime** VCPUs and **generic task** VCPUs.

Realtime with kvm?

Additional configurations to improve realtime capabilities of the guest systems:

- Disable **hyperthreading** (in BIOS) or via Kernel command line:

  `nr_cpus=<x>` (x=physical number of CPUs)

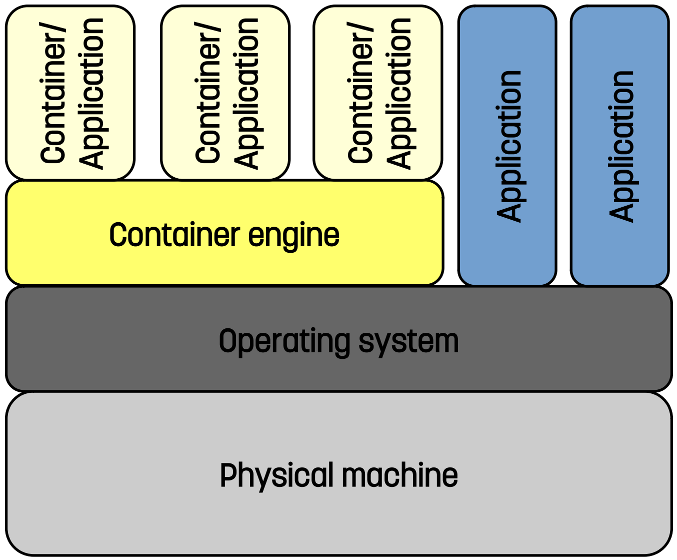
- Disable **interrupt balancing:**

```
# systemctl disable irqbalance
# reboot
```

System-level virtualization: containers

Main properties:

- multiple isolated user space instances, called containers
- includes all the code, its dependencies and even the operating system itself
- Ease of use
- Examples: Docker, proxmox, chroot



Container virtualization - docker

- "Docker" is the trademark of the company Docker®, Inc.
- Docker provides **isolation** between the workload and reproducible environment.
- Virtualization takes place at **operating system level.**
- The separation of guest systems is based on **partitioning** of resources.
- The guest systems use the host system's **kernel** and **virtual filesystems**.

Container virtualization - docker

- Docker is a tool to **distribute applications.**
- Docker uses a technology called **namespaces** to provide the isolated workspace called the container.
- **Docker Hub** provides the infrastructure for storing and sharing their code in containers.
- Personal use of **Docker Hub** is free of charge, incl. public repositories, other business plans available.
- Most containers include Free and Open Source software (FOSS) → **license obligations have to be fulfilled**

System level virtualization with chroot

- Introduced 1979 during development of Version 7 UNIX
- Create and host a **separated** virtualized copy of a root file system **(chroot jail)**
- Useful for
  - **Recovery** of damaged environment after bootstrapping from an alternate root file system.
  - **Test** of unstable/risky software in a safe environment
  - **Run and develop** software with the expected dependencies without the need to install it on the host

System level virtualization with chroot

- Change to the new root filesystem

```
# cd [NEW ROOT FS]
```

- Mount system fs:

```
# mount -t proc proc ./proc
# mount -t sysfs nodev ./sys
# mount -t devtmpfs nodev ./dev
# mount -t devpts devpts ./dev/pts
# mount -t debugfs nodev ./sys/kernel/debug
```

- Chroot to [NEW ROOT FS]

```
# chroot [NEW ROOT FS] /bin/bash
```

Summary

- In general, **virtual systems** do not inherit their host's deterministic behavior due to various separation methods.
- **Real-time capabilities** can be improved with additional configurations of host and guest systems.
- **System virtualization** (chroot, Docker, etc.) shows superior real-time performance compared to **physical virtualization**. However, it does not offer the same **degree of separation** between host and guest systems.