Virtual Machines

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Roadmap

- CPU management
- Memory management
- Disk management
- Network and security
- **Virtual machine**

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Cloud Computing

Image Source: http://btstrategy.com/wp-new/2013/10/18/is-everything-really-going-to-the-cloud-advice-for-business-owners/

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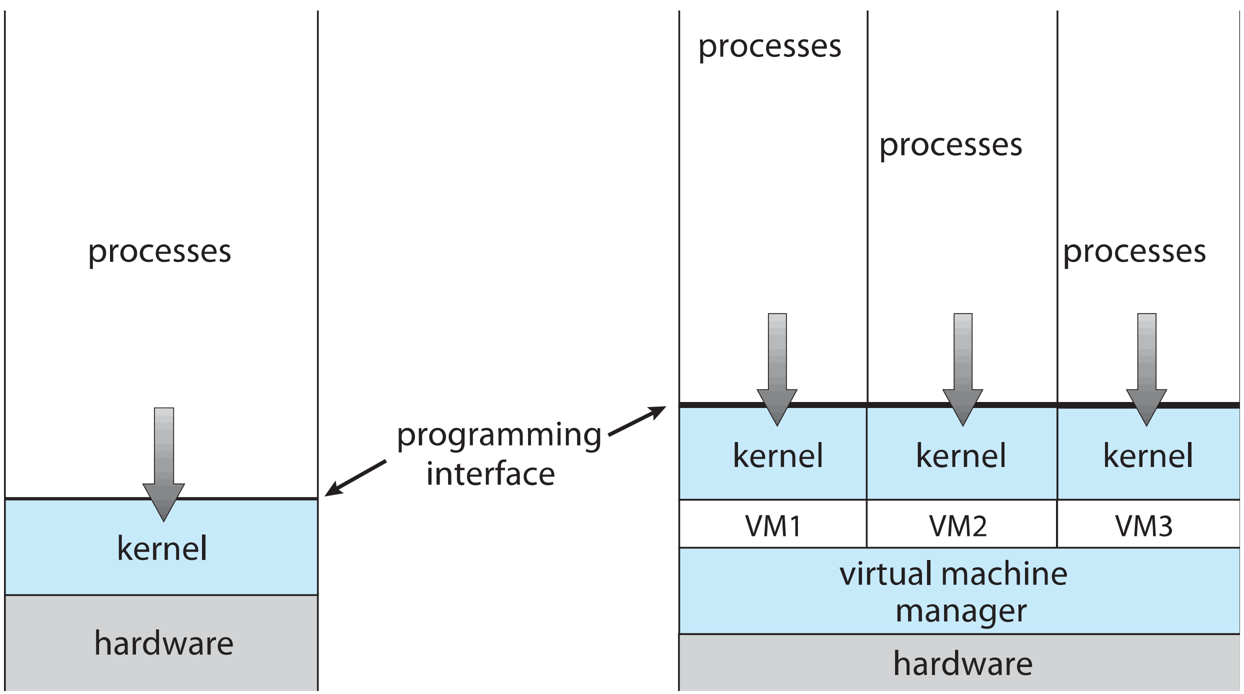
Cloud Computing

amazon web services™ | EC2

Microsoft Azure

Virtual Machines

- Enabling technology of cloud computing
- Basic idea: Provide **machine** abstractions



Virtual Machines

- Benefits
  - Can run **multiple OSes**, each in its own virtual machine
  - Can **copy** a VM image and run it on a different machine
  - Can create a **snapshot** of the state and restore it later
  - Can create a **customized** VM with specific OS version and libraries to avoid version dependency problems
  - More **efficient** resource utilization is possible
- Downsides?
  - Overhead
  - Interference

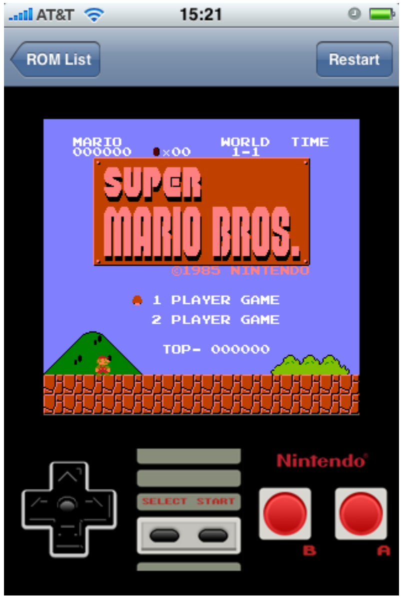
History

- Late 1960s
  - IBM introduced first full VMM on mainframes
- Late 1990s
  - **Xen** was developed for Intel PCs
- Mid 2000s
  - Hardware support was introduced (e.g.,Intel VT-x)
  - Widely adopted in data centers.

Today

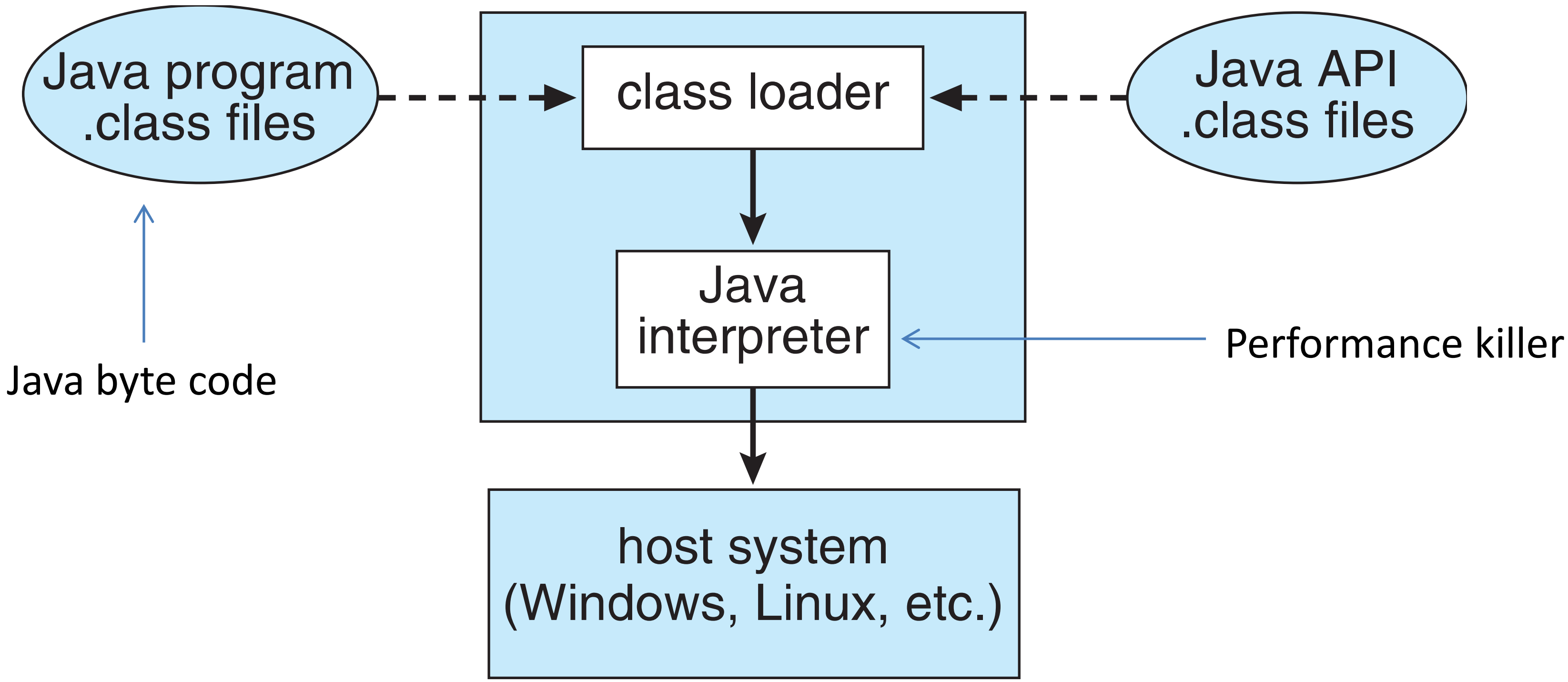
- How to implement VMMs?
- How to reduce overhead?

How to Implement a VMM?



- Emulators
  - Many game consoles are emulated
  - In theory, any h/w can be emulated (virtualized) via s/w
- Language based virtual machines
  - Instead of virtualizing real hardware, provide a specially designed virtual hardware for specific languages
  - JVM for Java, CLR for MS .Net
- Common issues: **performance**

Java Virtual Machine



How to Implement a VMM?

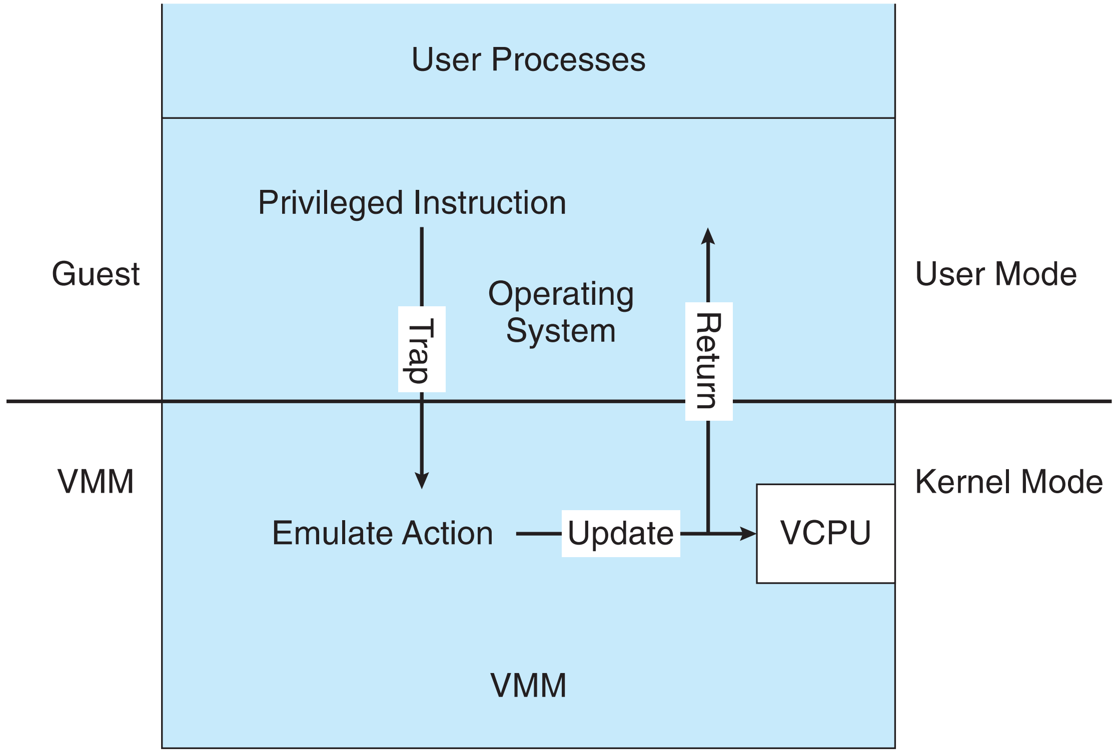
- Modern VMMs
  - Normal instructions are executed on the real CPU
    - In case of emulator, each instruction is executed in s/w
    - No performance loss for user-mode instructions
  - Any “unusual” instrs cause **traps** to the VMM
    - Privileged instructions (e.g., addr. space change)
    - Kernel calls in the guest OS

Instructions Types

- Normal instructions
  - add, sub, load/store, branch, …
  - Execute natively

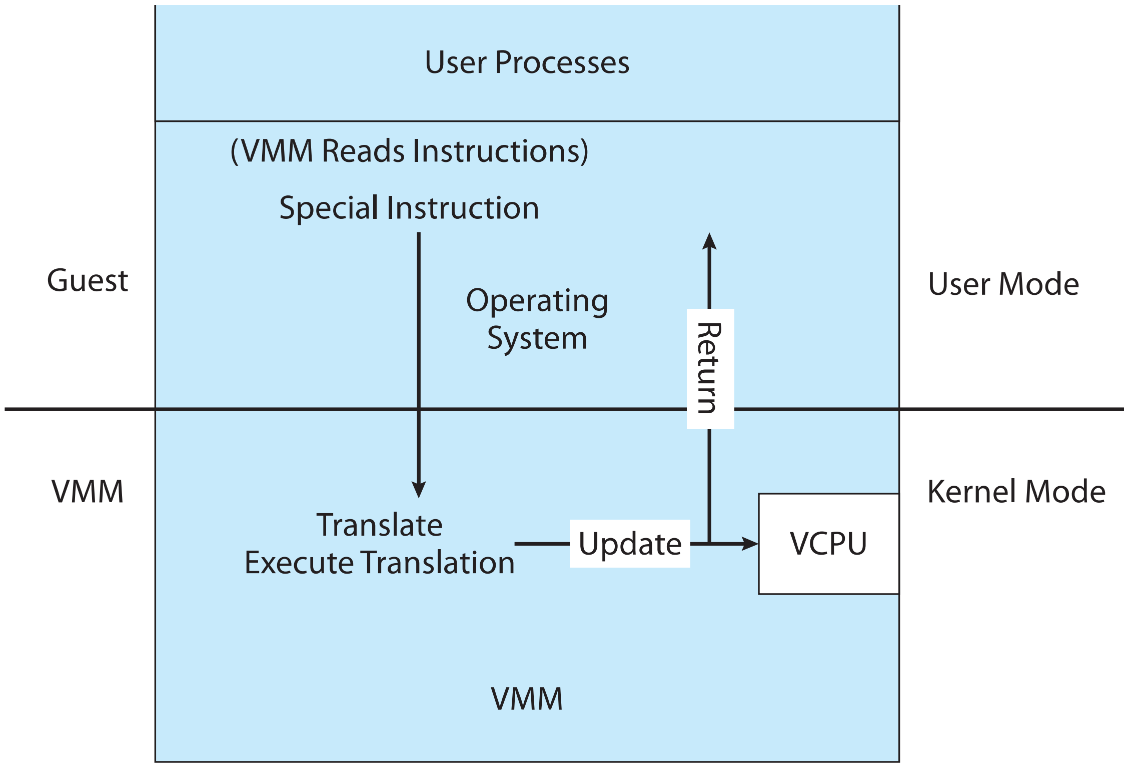
- Privileged instructions
  - Setup page tables, load/flush TLB and caches
    - LGDT, LLDT, LTR, MOV <Control Reg>, LMSW, …
  - Mode change, system state monitor
    - HLT, RDMSR, WRMSR, RDPMC

Trap and Emulation in VMM



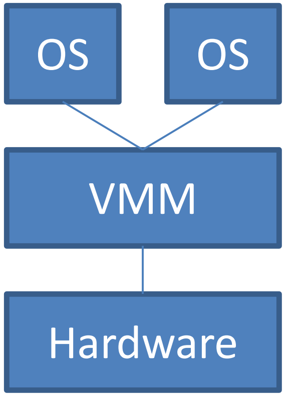
- Virtualize privileged instructions
  - Guests run in user-mode, generating exceptions

Binary Translation



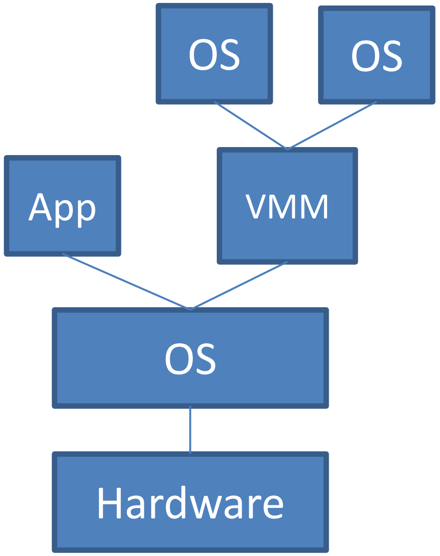
- Some instructions are not virtualizable
  - Execute in both user and kernel modes, but behave differently (e.g., popf)

Types of VMM

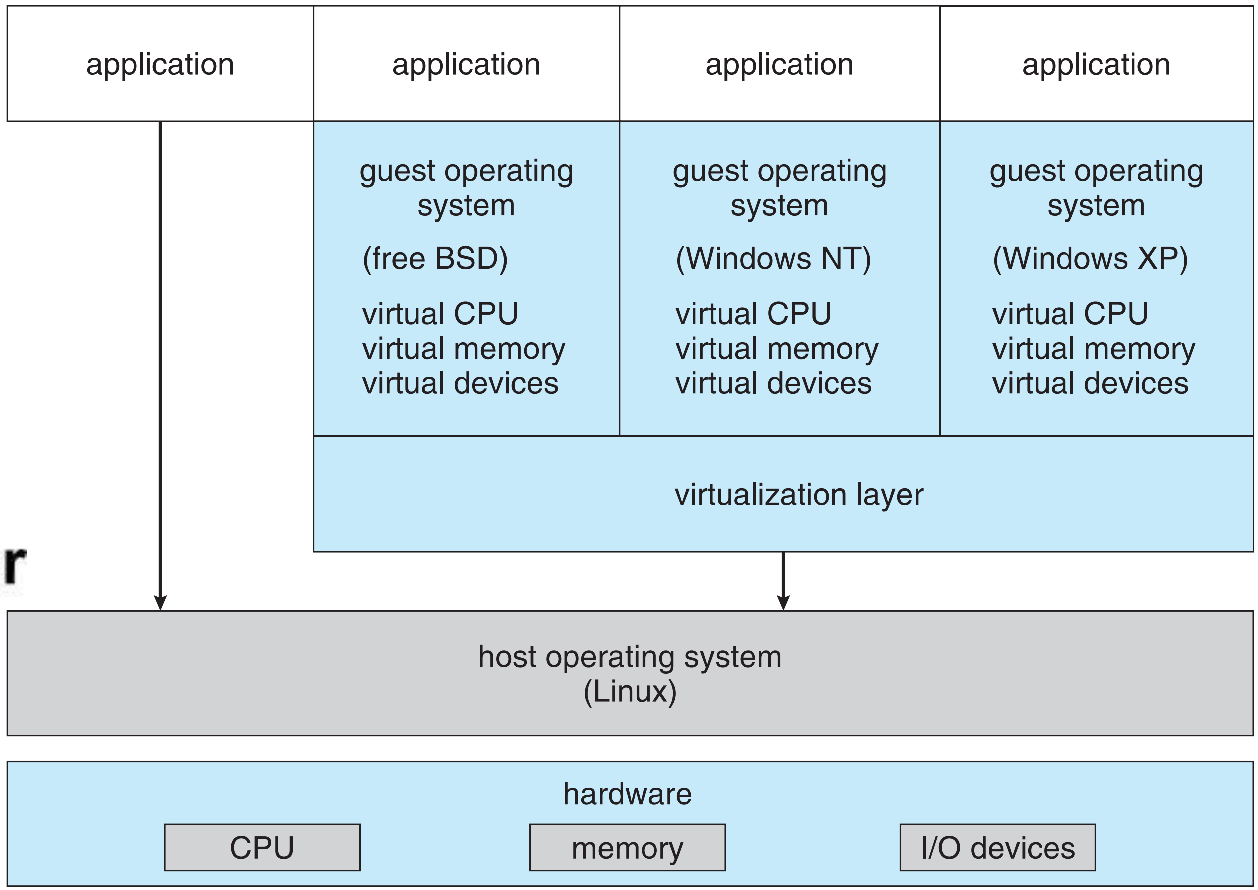


- Native (or Type 1) VMM
  - VMM runs directly on top of bare hardware
  - Vmware ESX, Microsoft Hyper-V
  - VMM is a kind of a OS on its own right

- Hosted (or Type 2) VMM
  - VMM runs within an OS
  - VirtualBox, VMWare Workstation
  - VMM relies on functionalities of the host OS



VMware WorkStation (Player)



How to Virtualize Hardware?

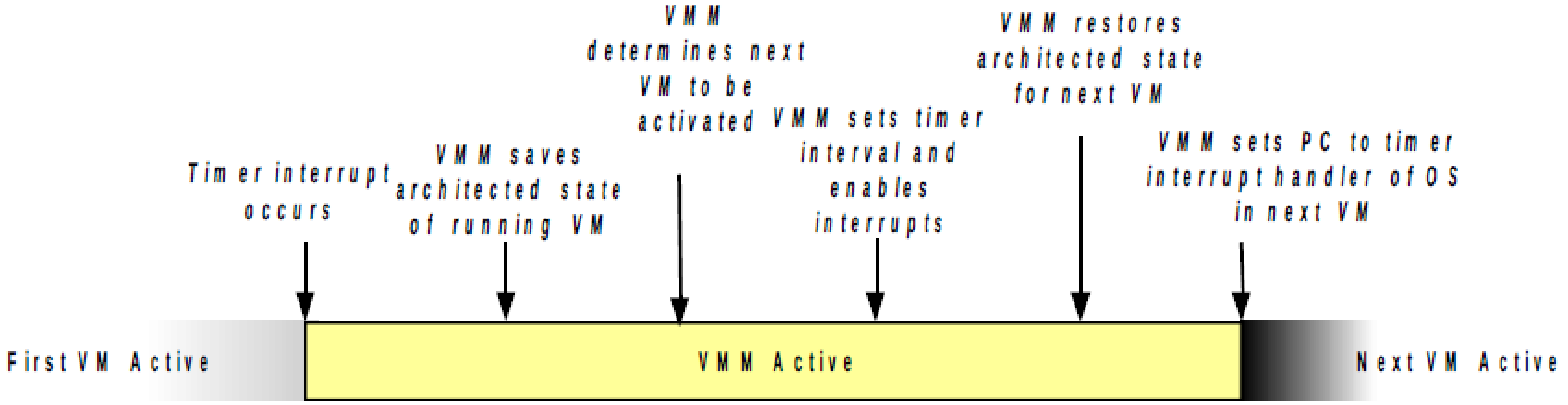
- CPU
- Memory
- Events
  - Exceptions, interrupts
- I/O devices
  - Disk, network

Virtualizing the CPU

- Virtual CPU (vCPU)
  - One or more vCPUs for every VM
  - Seen as physical CPU for the guest OS on the VM

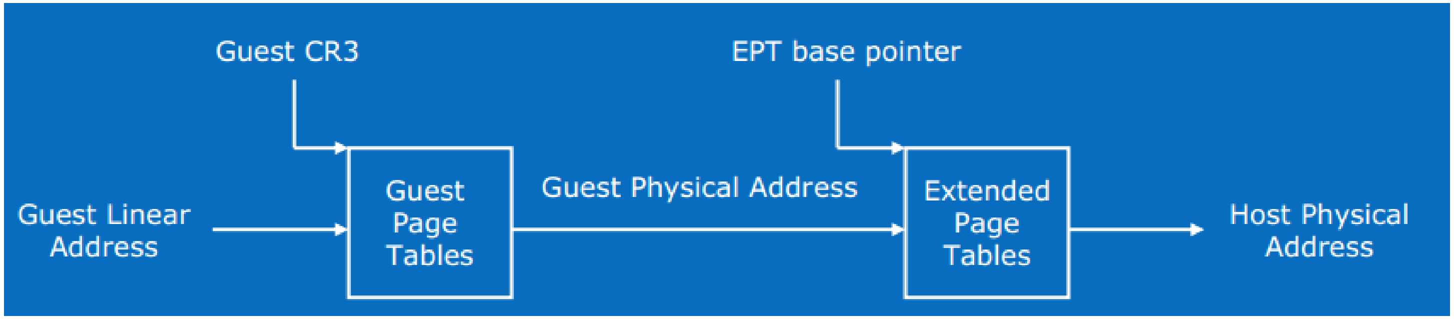
- How?
  - Timeslice the CPU
  - Just like CPU scheduling in OS
  - VMM uses CFS like scheduler(s)

VMM Timesharing



Virtualizing Memory

- OS view
  - Virtual address → physical address
- VMM view
  - Guest virtual → guest physical → VMM physical
  - Does MMU know about VMM physical???
  - Originally no, but now yes
    - Intel/AMD support nest page tables



[Intel EPT (extended page table)]

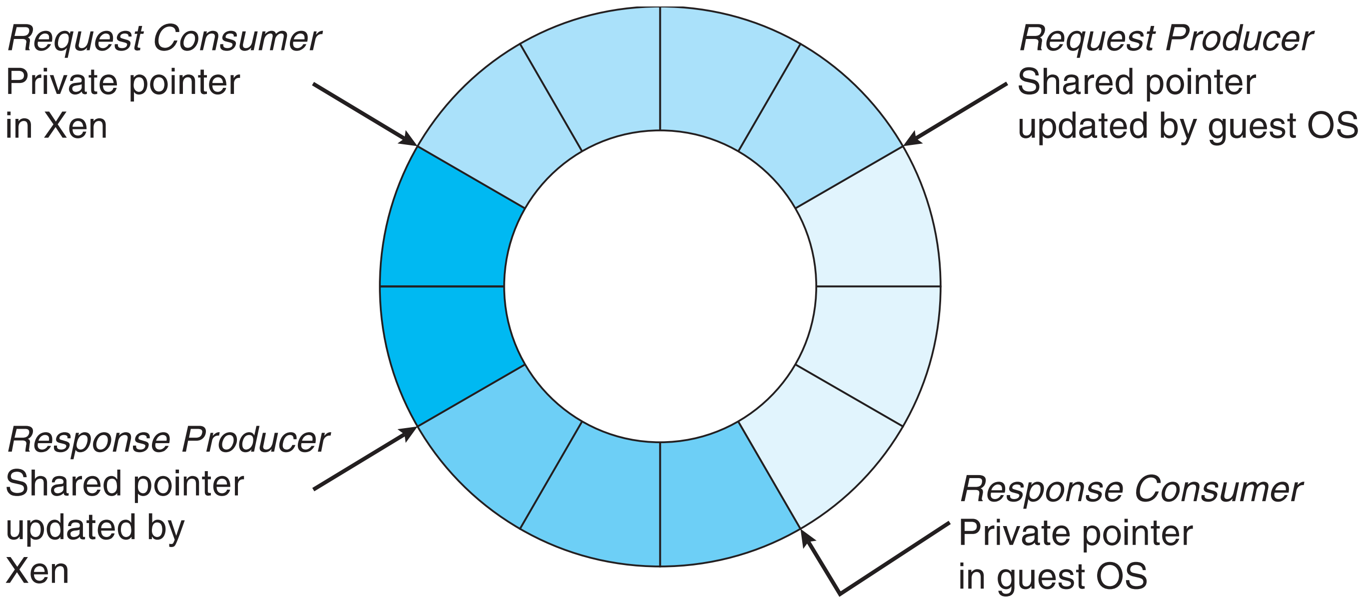
Virtualizing Interrupts & I/O

- VMM receives h/w interrupts
  - Determines which VM to receive
  - Emulate interrupt controller for the VM
- VMM emulate a specific h/w devices
  - Guest OS → VMM → devices
    - E.g., AMD Lance PCNet ethernet device
- Lots of I/O → performance killers

Para-virtualization

- Idea: provides simple/fast APIs to guests
  - Instead of emulating actual hardware (e.g., PCNet32 ethernet card)
  - Pros
    - can be a lot faster (more efficient I/O)
  - Cons
    - need to modify the guest OS

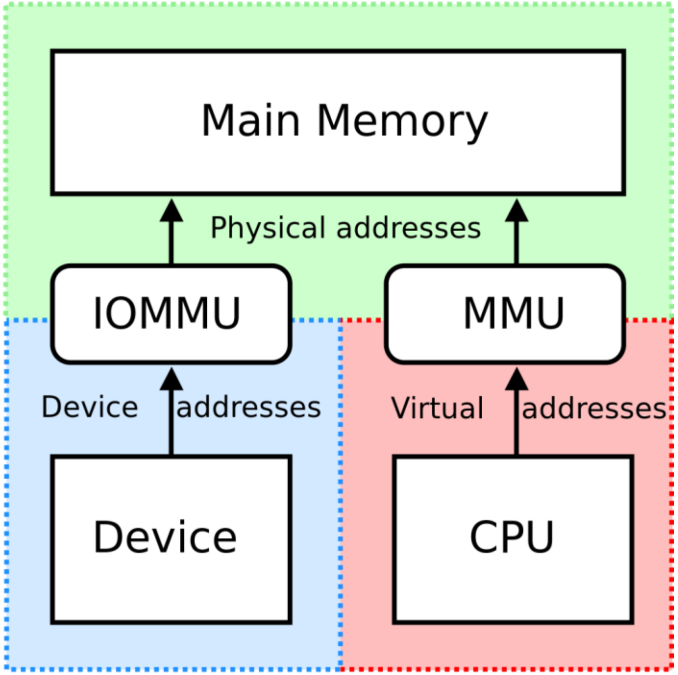
I/O in Xen via Shared Buffer



- **Request queue** - Descriptors queued by the VM but not yet accepted by Xen
- **Outstanding descriptors** - Descriptor slots awaiting a response from Xen
- **Response queue** - Descriptors returned by Xen in response to serviced requests
- **Unused descriptors**

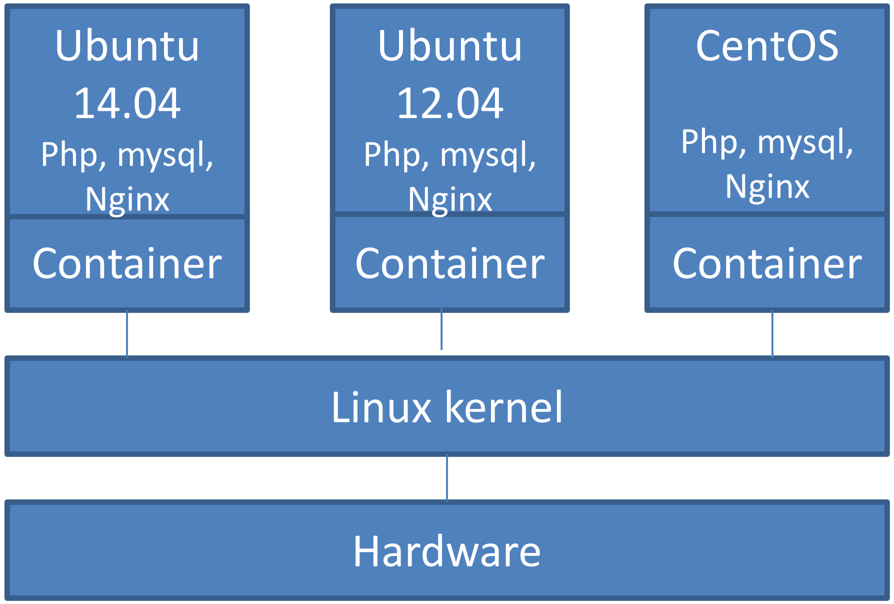
IOMMU

- Problem: How to do DMA in a VM?
  - DMA controller needs host physical address, not guest physical address
- IOMMU
  - MMU for IO devices
  - maps guest physical → host physical for the I/O devices



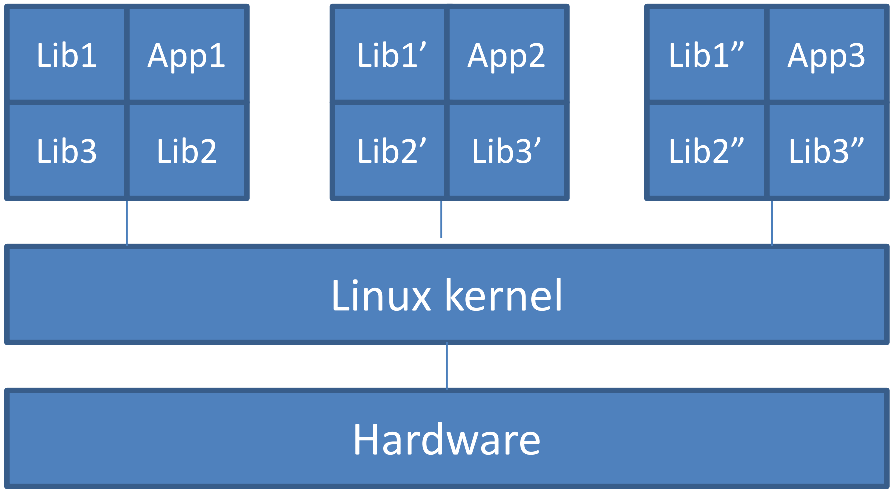
https://en.wikipedia.org/wiki/Input%E2%80%93output_memory_management_unit#/media/File:MMU_and_IOMMU.svg

LXC: OS (Linux) Container



- Same kernel, separate user-space
- Virtualize OS, not machine
- Low overhead, flexible

Docker: Application Container



- A container contain one application (process)
- Built on top of OS containers
- Even more flexible

Summary

- Virtual Machine (hardware virtualization)
  - Trap & emulate
  - Binary translation
  - Para-virtualization
  - Hardware support for virtualization
- Containers
  - OS container: same kernel, different user-space
  - App container: same kernel, per-process space