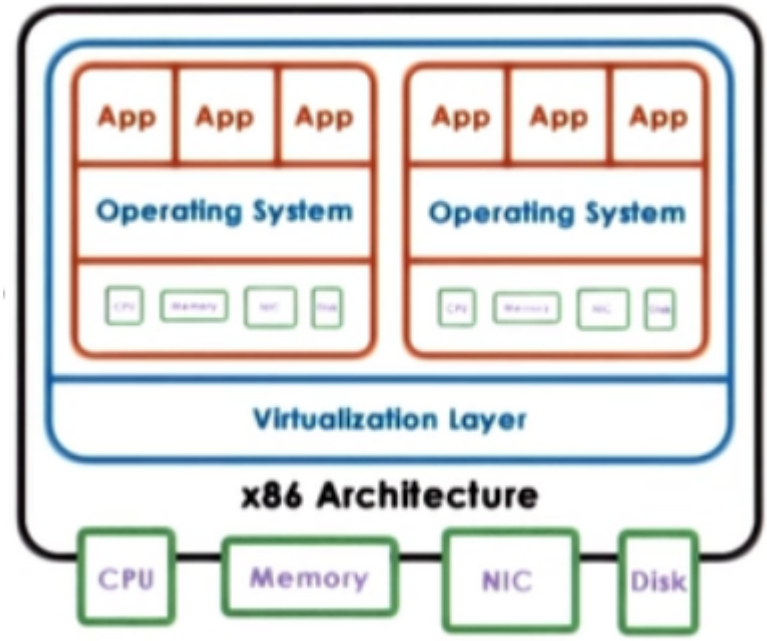
Virtualization

Virtualization allows concurrent execution of multiple OSs and their applications on the same physical machine.



- Virtual resources : each OS thinks that ot "owns" hardware resources
- Virtual machine (VM) : OS + applications + virtual resources (guest domain)
- Virtualization layer : management of physical hardware (virtual machine monitor, hypervisor)

Defining Virtual Machine

A Virtual Machine is an efficient, isolated duplicate of the real machine.

- Supported by a Virtual Machine Monitor (VMM):
  i. provides environment essentially identical with the original machine
  ii. programs show only minor decrease in speed at worst
  iii. VMM is in complete control of the system resources

VMM goals

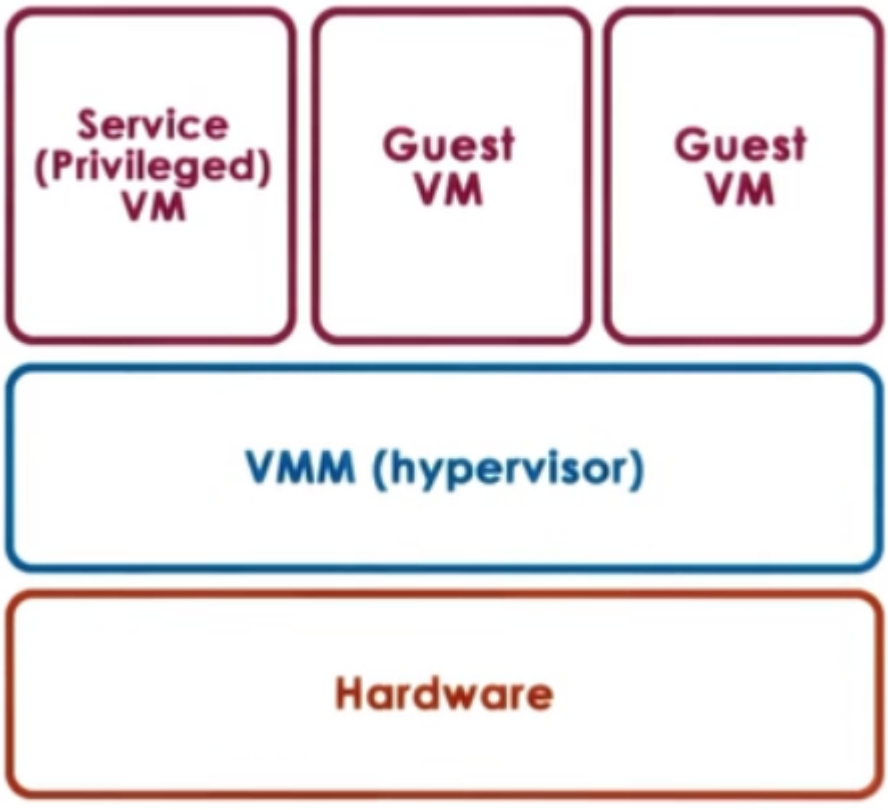
- Fidelity
- Performance
- Safety and Isolation

Virtualization advantages

- consolidation
  - decrease cost, improve manageability
- migration
  - availibility, reliability
- security, debugging, support for legacy OS

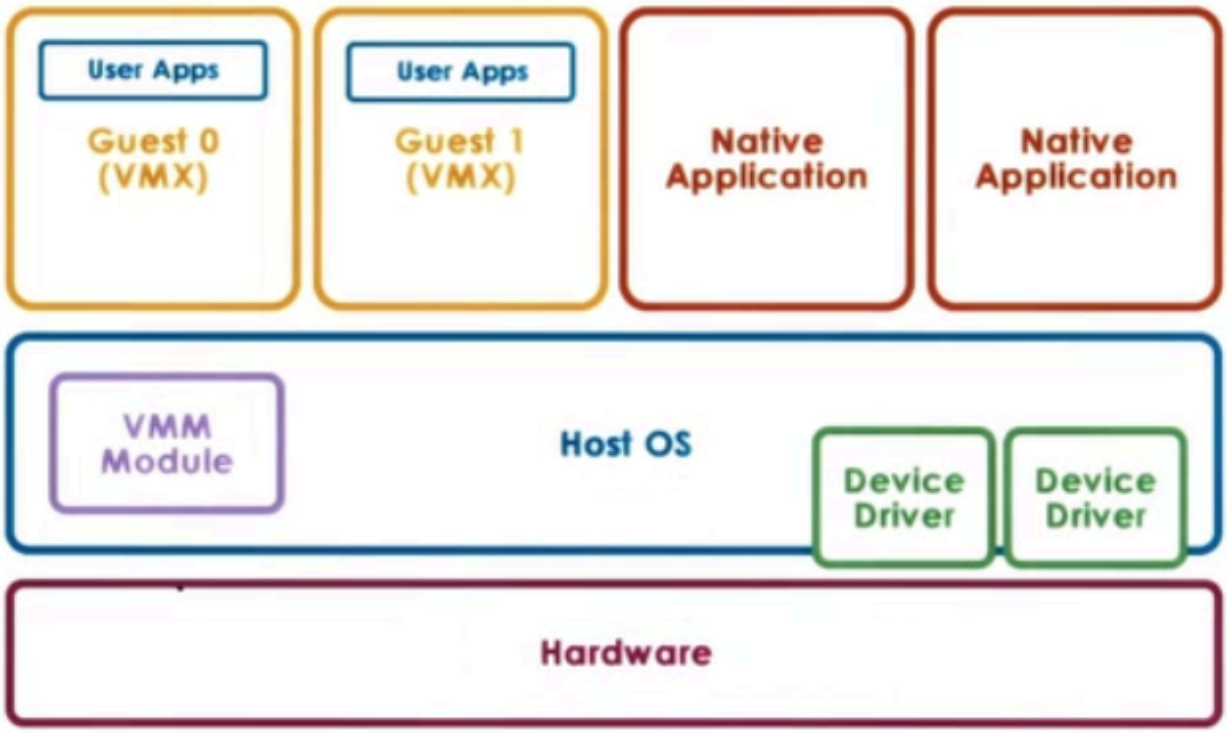
Two main Virtualization Models:

1. Bare-metal or Hypervisor based (Type 1)



- VMM (hypervisor) manages all hardware resources abd supports execution of VMs
- privileged, secure VM to deal with devices (and other configuration and management tasks)
- Adopted by Xen(Opensource or Citriol Xen Server) and ESX (VMware)

1. Hosted (Type 2)



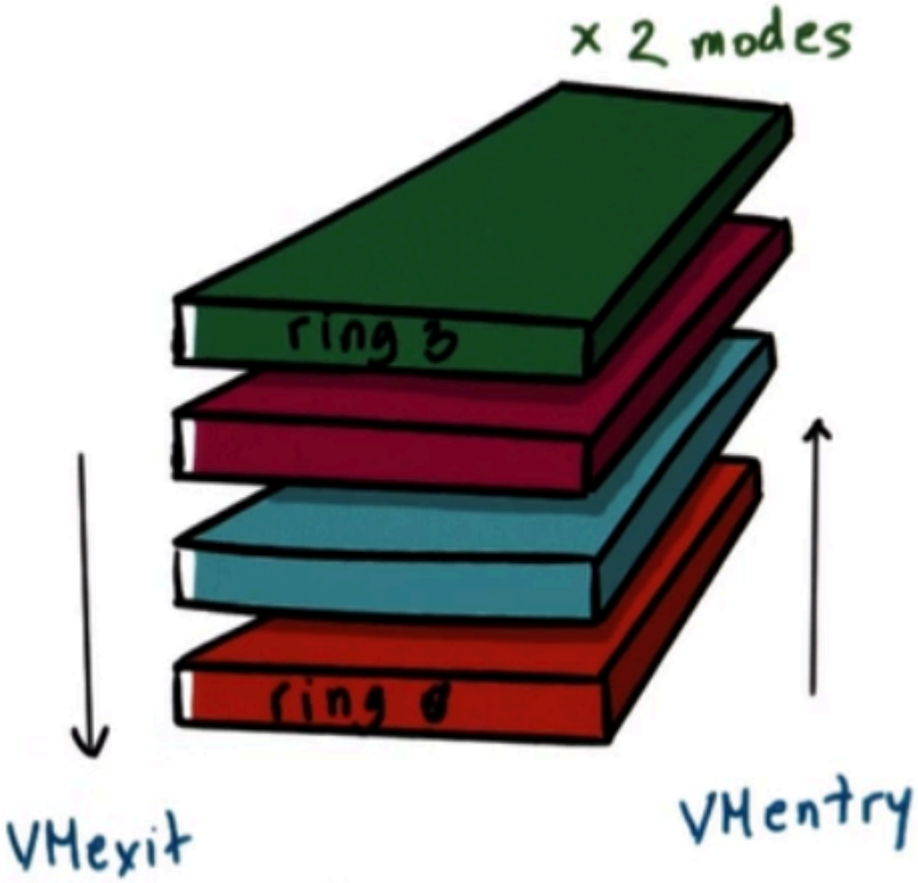
- Host owns all hardware
- Special VMM modle provides hardware interfaces to VMs and deals with VM context switching

Virtualization requirements

- Present virtual platform interface to VMs
  - virtualize CPU, memory, devices
- Provide isolation across VMs
  - preemption, MMU for address translation and validation
- Protect guest OS from applications
  - can't run guest OS and applications at same protection level
- Protect VMs from guest OS
  - can't run guest OS and VMMs at same protection level

Hardware protection levels

Commodity hardware has more than two protection levels



- x86 has 4 protection levels (rings)
  - ring 3 : lowest privilege (applications)
  - ring 1 : OS
  - ring 0 : highest privilege (hypervisor)
- and 2 protection modes
  - non root : VMs
    - ring 3 : apps
    - ring 0 : OS
  - root :
    - ring 0 : hypervisor

Process Virtualization (Trap-and-Emulate)

- Guest instruments
  - executed directly by hardware
  - for non-privileged operations : hardware speeds => efficiency
  - for privileged operations : trap to hypervisor
- Hypervisor determines what needs to be done:
  - if illegal operation : terminate VM
  - if legal operation : emulate the behaviour the guest OS was expecting from the hardware

Problems with Trap-and-Emulate

- 17 privileged information do not trao but fail silently
- Hypervisor doesn't know, so it doesn't try to change settings
- OS doesn't know, so assumes change was successful

Binary Translation

Goal : Full Virtualization i.e. guest OS is not modified

Approach : Dynamic Binary Translation

1. Inspect code blocks to be executed
2. If needed, translate to alternate instruction sequence
    - e.g. to emulate desired behaviour, possibly avoid traps
3. Otherwise run at hardware speeds
    - cache translated blocks to ammortize translation costs

Paravirtualization

Goal : Performance; give up on modified guest OSs

Approach : Paravirtualization : modify guest OSs so that

- it knows it is running virtualized
- it makes explicit calls to hyperisor (hypercalls)
- hypercalls (~ system calls)
    - package context information
    - specify desired hypercall
    - trap to VMM
- Xen : opensource hypervisor

Memory virtualization

- Full virtualization
    - all guests expect contiguous physical memory starting at 0
    - virtual vs physical vs machine addresses and page frame numbers
    - still leverages hardware (MMU, TLB..)
- Option 1
    - guest page table : VA => PA
    - hypervisor : PA => MA

    - too expensive!
- Option 2
    - guest page tables : VA => PA
    - hypervisor shadow PT : VA => MA
    - hypervisor maintains consistence
        - e.g. invalidate on context switch, write protect guest PT to track new mappings
- Paravirtualized
    - guest aware of virtualization
    - no longer strict requirement on contiguous physical memory starting at 0
    - explicitly registers page tables with hypervisor
    - can "batch" page tables updates to reduce VM exits
    - other optimazations

Overheads eliminated or reduced on newer platforms

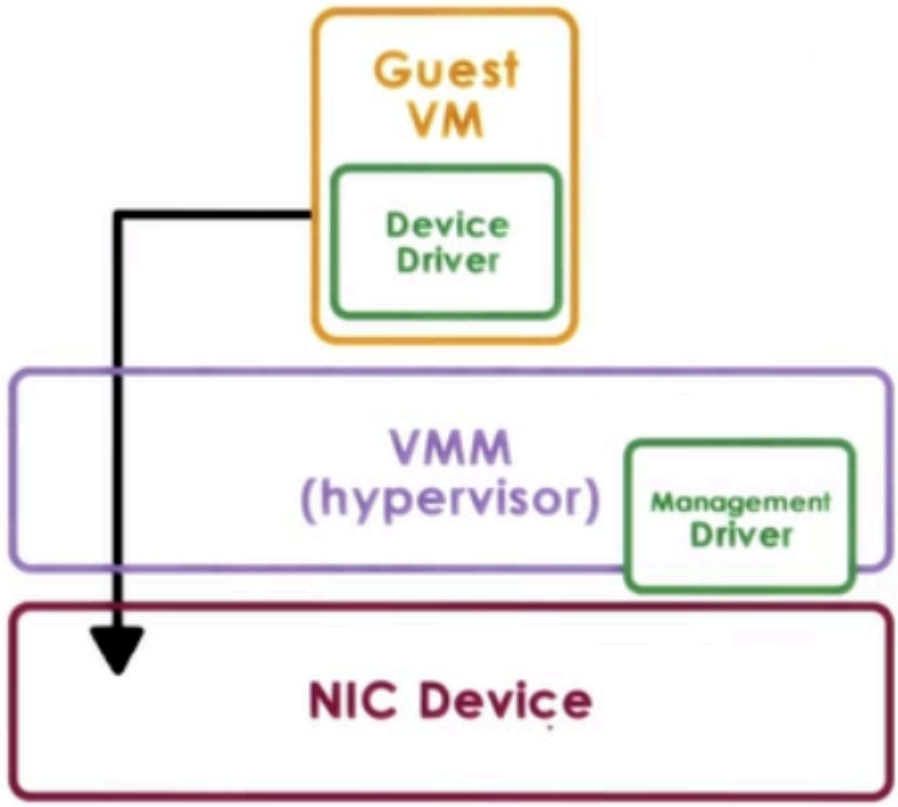
Device Virtualization

- For CPUs and Memory
    - less diversity, Intruction-Set-Architecture(ISA) level
    - Standardization of interface
- For Devices
    - high diversity
    - lack of standard specification of device interface and behaviour

3 key models for Device Virtualization:

1. Pass through model

Approach: VMM-level-driver configures device access permissions



Advantages

- VM provided with exclusive and direct (VMM bypass) access to the device

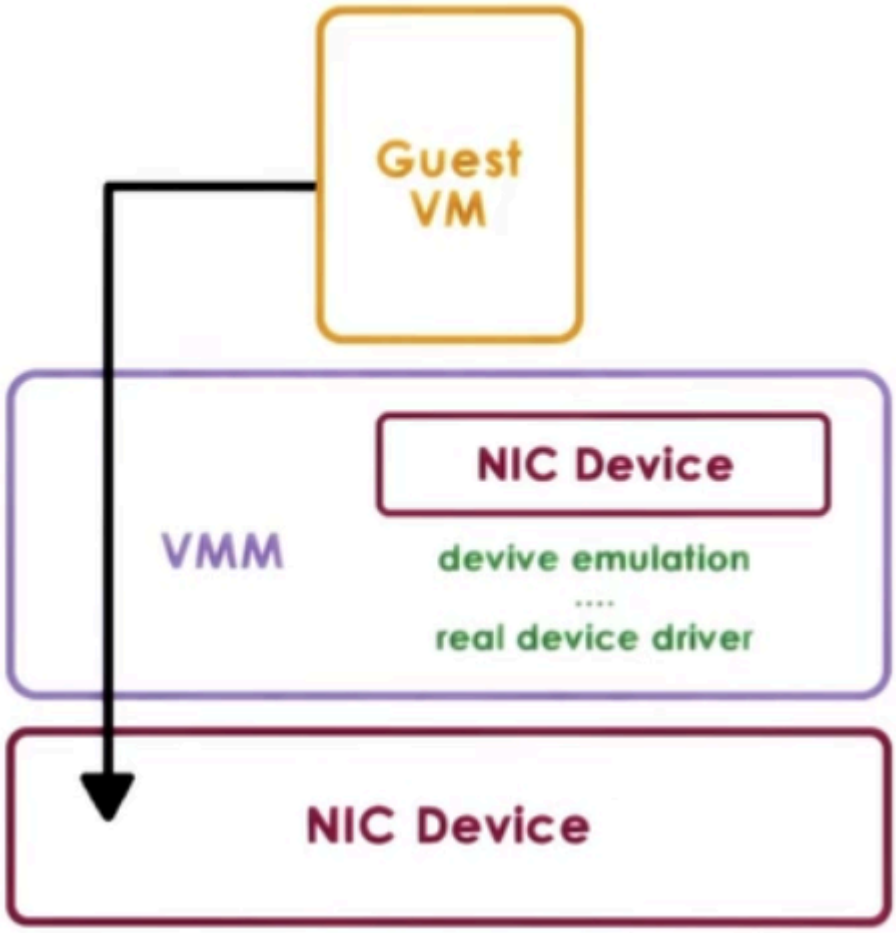
Disadvantages

- Device sharing difficult
- VMM must have exact type of device as what VM expects
- VM migration tricky

2. Hypervisor - Direct model

Approach:

- VMM interrupts all device accesses
- Emulate device operations
  - translate to generic I/O operations
  - traverse VMM-resident I/O stack
  - invoke VMM-resident driver



Advantages

- VM decoupled from physical device
- Sharing, migration, dealing with device specifics

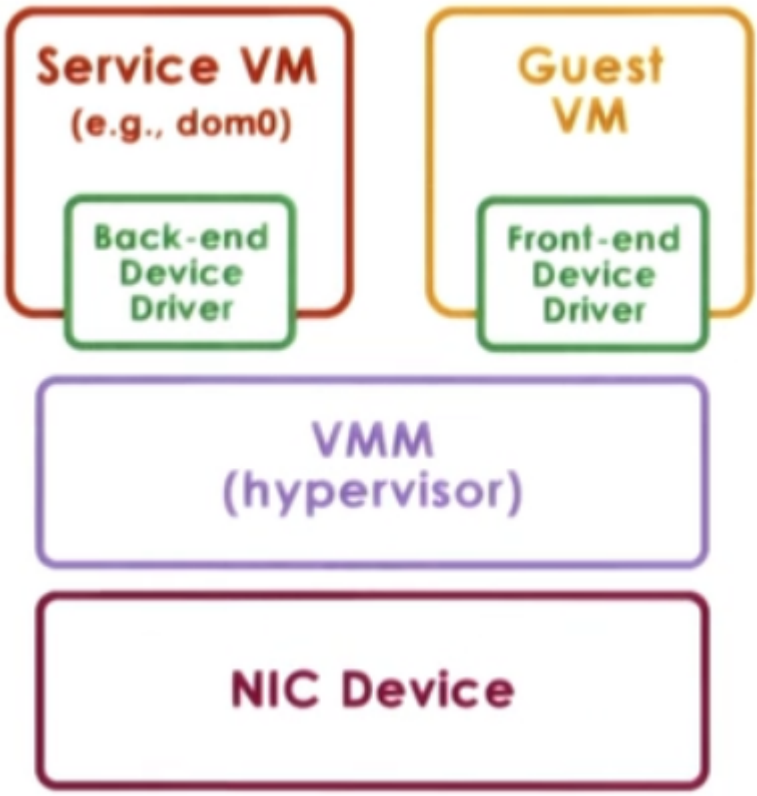
Disadvantages

- Latency of device operations
- Device driver ecosystem complexities in Hypervisor

3. Split Device-Driver model

Approach:

- Device access control split between
- Emulate device operations
  - front-end driver in guest VM (device API)
  - back-end driver in service VM (or Host)
  - modified guest drivers
    - i.e. limited to paravirtualized guests



Advantages

- Eliminate emulation overhead
- Allow for better management of shared devices