Virtualization

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Outline

- Part I
  - What is virtualization : a first definition
  - Why virtualizing?
  - The new features offered by virtualization
  - The various virtualization solutions
- Part II : Nuts and bolts
  - Refresher on computer architecture and the harware/OS/Application interfaces
  - Popek and Golberg criteria for virtualizing an ISA
  - Details on Vmware player
  - Hardware support: Intel-VT and AMD-V
- Part III : Networking in a virtualized environment
  - VXLAN
  - Open Vswitch design and performance

Part I: Introduction

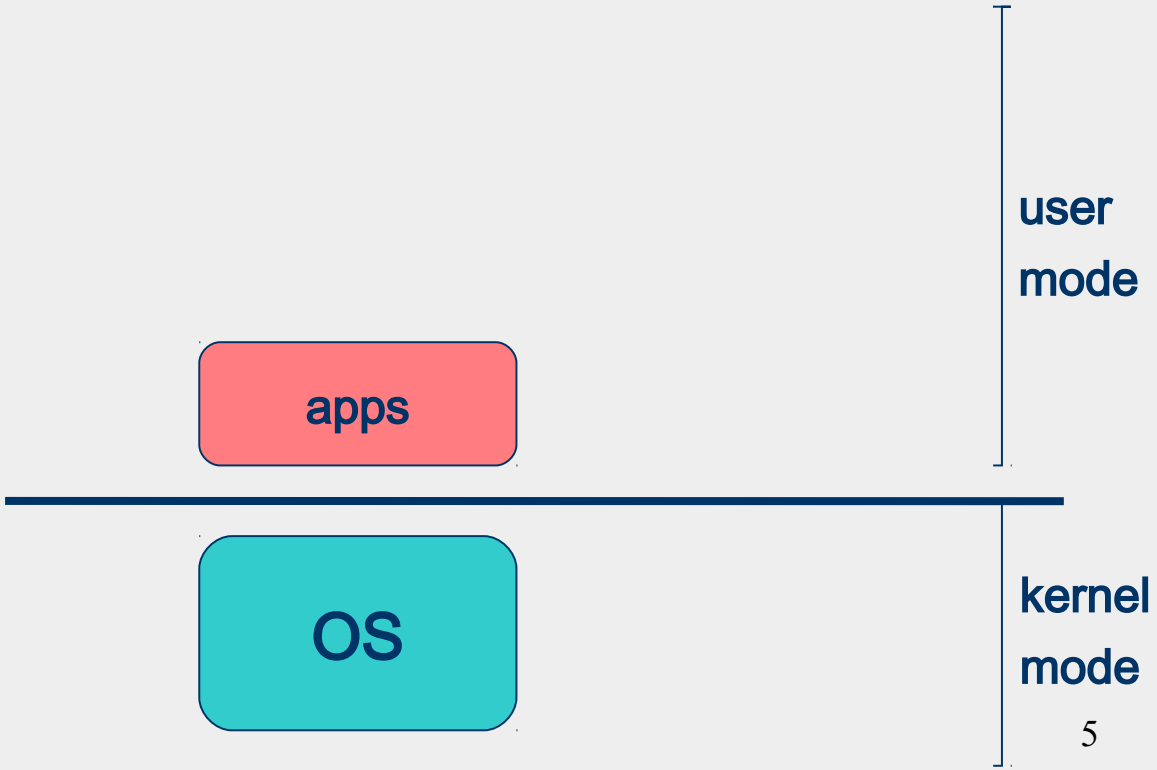
Introduction

- Set of techniques to enable several OS to run simultaneously on a physical machine/server (≠ **multi-boot)**

- **Virtualization entails a specific layer called a hypervisor, a.k.a, virtual machine monitor (VMM)**
  - **Mediator between physical resources and the OSes that are virtualized**

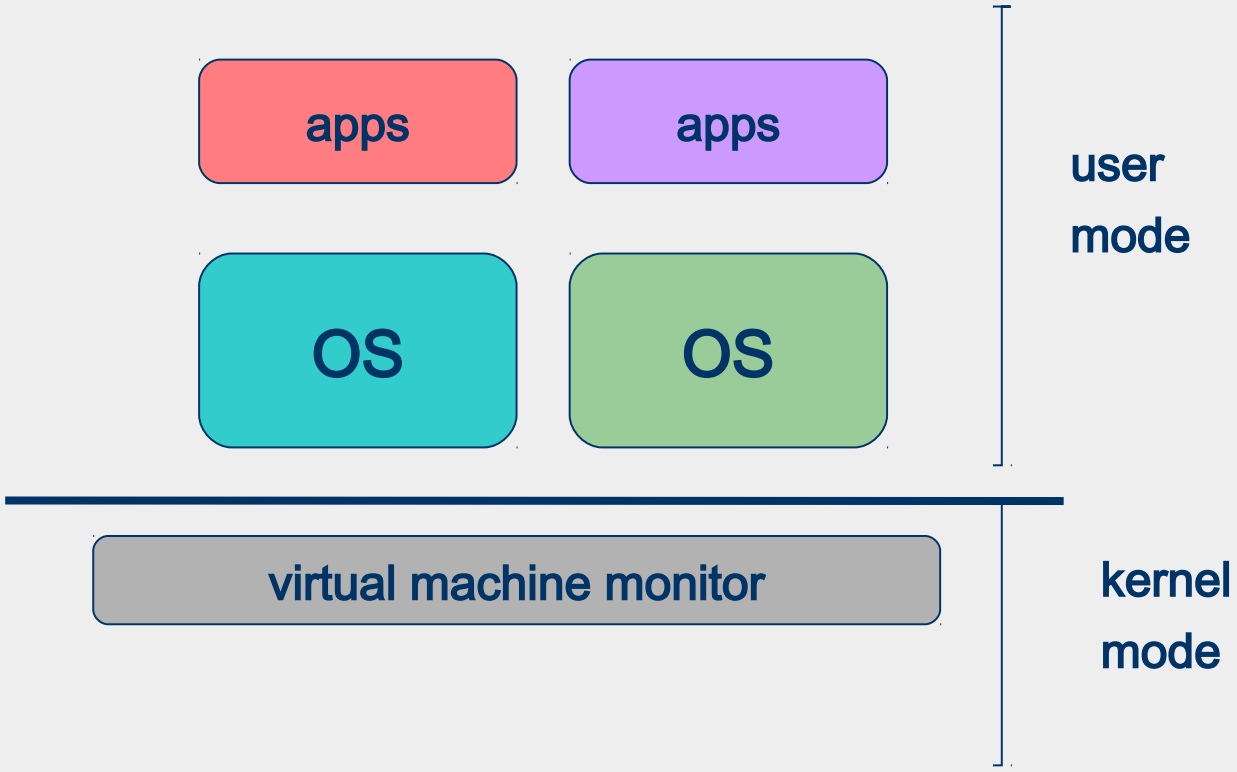
Virtualization = unpriviledging an OS

- Processors features two modes : user and kernel



Unpriviledging an OS

OS in user mode is called Guest OS



Hypervisors Zoo

- For servers :
  - VmWare Vsphere ~ 60% market share
  - Microsoft Hyper-V ~ 20%
  - Citrix XenServer ~ 4% - Amazon Web Services
  - QEMU/KVM – default openstack deployements
- For clients
  - Oracle Virtualbox
  - Vmware player
- Source : http://www.nasdaq.com/article/growing-competition-for-vmware-in-virtualization-market-cm316783

Why virtualizing?

- In the 90s, cost of servers decreased gradually
- Software editors (Microsoft, distribution Linux) advocate one application/service per server →
  - One DNS server
  - One mail server
  - One NFS server
- Each server with specific OS version and libraries
- Servers isolation

Why virtualizing

- Net result:
  - A host of servers in servers rooms (data centers)
  - 80% have an average utilization below 10%
  - Maintenance/operational costs increase with the number of servers
  - Server rooms are not infinitely extensible → lack of place
  - Non negligible electricity/air conditioning cost

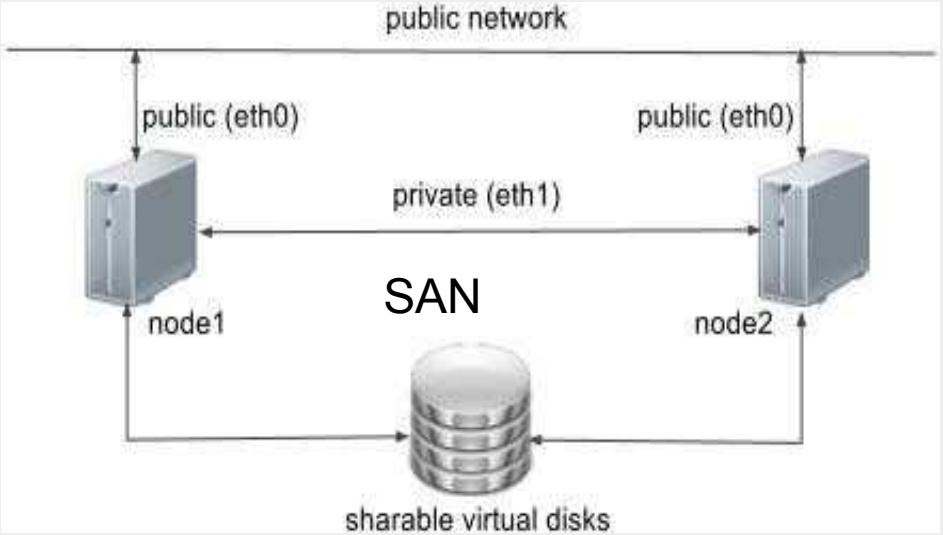
Why virtualizing

- Servers are less expensive but also more powerful
  - 64 bits multi-core with tons of RAMs are the norm
  - One server in 2009 is roughly estimated to be one order of magnitude more powerful than a server in 2004
- Replacing servers on a one to one basis is not an option any more
- Still, one wants to ensure service isolation

Advantages of virtualization

- Consider a company that has virtualized its IT
- Typical set-up for an SME:
  - Two high-end servers, a SAN (Storage Area Network) to share/consolidate storage between the servers
  - Licences, e.g., Vmware
  - Training cost for IT service

Source : http://oracle-base.com

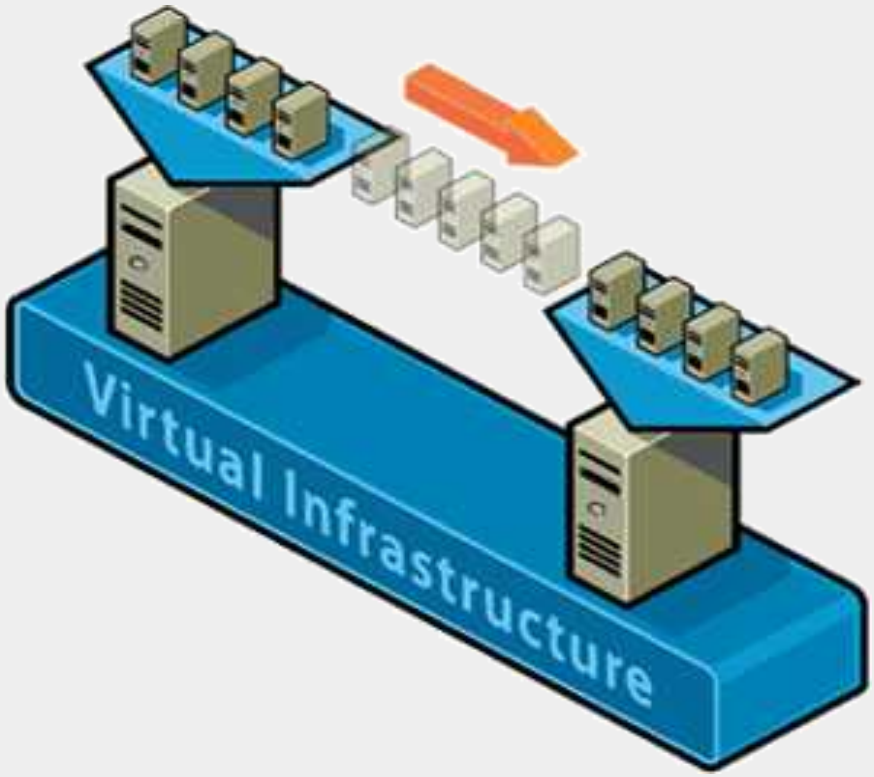


Advantages of virtualization

- Cost reduction
  - 20 to 40% (even if you had a a few tens of servers before and just 2 after)
- More space in the server room
- New functionalities

Virtualization: New features

- Migration of VM from one physical server to the other one
  - In case of failure (rare) → higher availability
  - Maintenance of physical servers (more often)



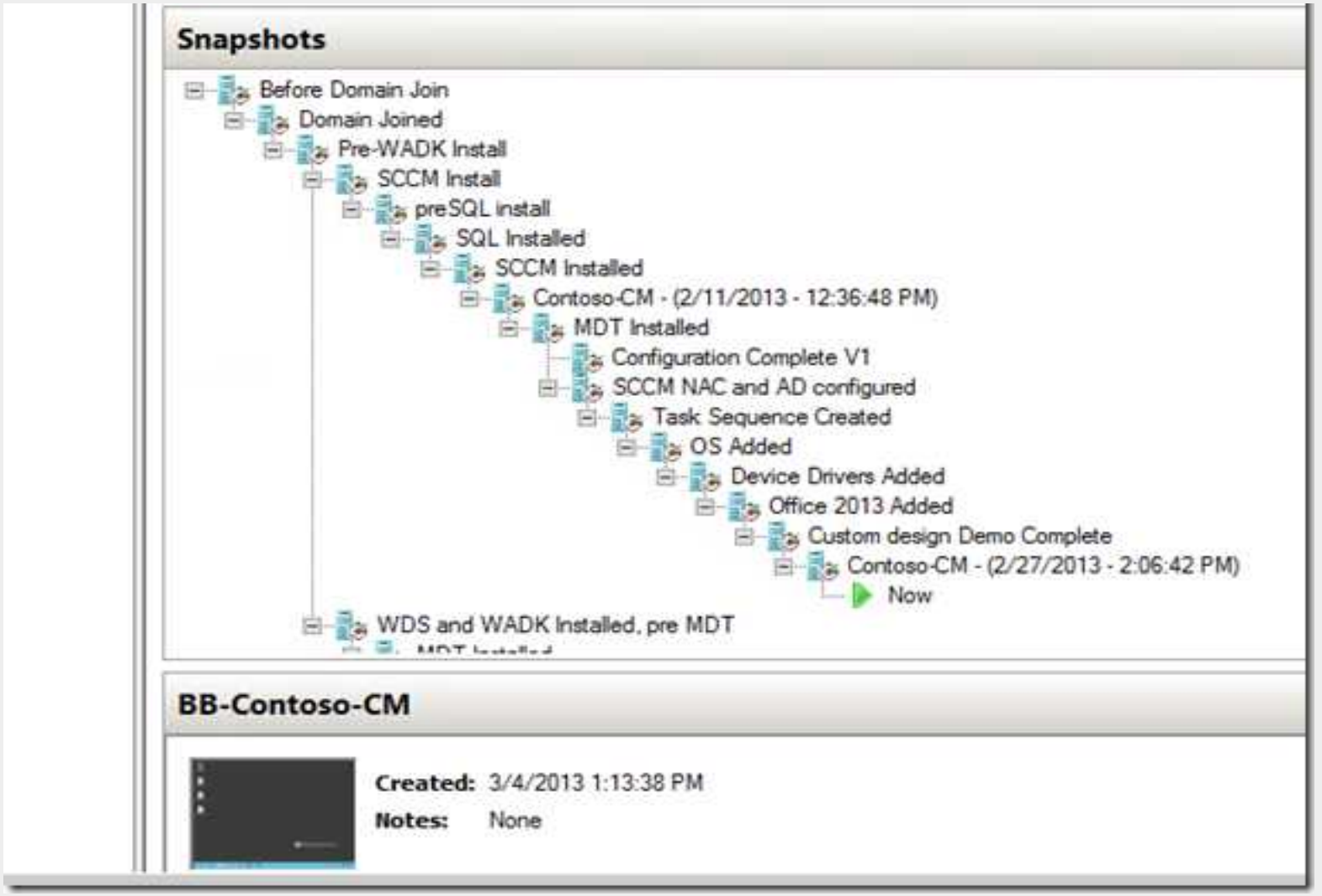
Virtualization: New features

- Fast start-up of new machines through a GUI:
  - Pick number of CPU, amount of memory, disk type and size, network access, OS
  - Indicate where the ISO image of OS
  - Start installation
- Using ISO takes time
  - Use of templates(one for Linux Debian, etc) that are duplicated (aka clone in the virtualization world) on the fly
  - Called images in Virtualization world
    - Vagrant images, AMI (Amazon Images), Docker images
- Current trend : automatic preparation of images out of ISO
  - See Packer https://packer.io/

Virtualization: New features

- Snapshots of VM stage
- Example :
  - You want to update a library/software but you are unaware of final outcome
  - You can :
    - Make a snapshot
    - Install the library/software
    - Roll-back time if it is not satisfactory
  - Also used by hypervisor when freezing (stopping/saving) a virtual machine

Snapshots



Source : blogs.technet.com

Virtualization: New features

- Isolation
  - Virtualization still enforces the one server per machine rule
  - If one VM is compromised, the other services remain safe
- On the fly reconfiguration of VMs → more CPU, more memory, new virtual disks
- Easier configuration of VM as hypervisor always displays the same interface to the VM
  - This is the hypervisor that handles the gory details, e.g., supports of SSD drive while VMs are exposed always an SCSI drive → no need to install driver in VMs!!!!

Various types of virtualization

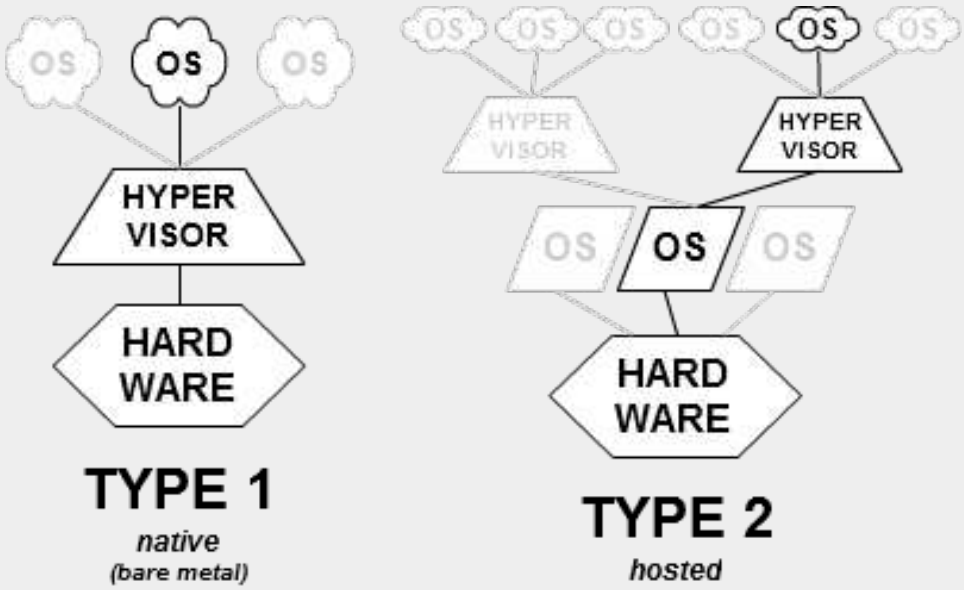
- Different types:
  - Bare-metal (native) versus host-based ..versus KVM/QEMU
  - Virtual versus para-virtual.. versus hardware assisted
  - Container-based versus hypervisor-based

Bare metal vs. host-based

- Bare-metal :
  - Layer 1
  - Production servers, data centers
  - Hypervisor seats directly on top of hardware
    - Machine boots on hypervisor directly
    - Installed as an OS
  - Examples :
    - VMware VSphere Hypervisor
    - Microsoft Hyper-V
    - Citrix XenServer

Bare metal vs. host-based

- Host-based
  - Hypervisor is an application running in an existing OS
  - Layer 2 virtualization
  - Typically deployed on end-user machines
    - VMware player
    - Virtualbox

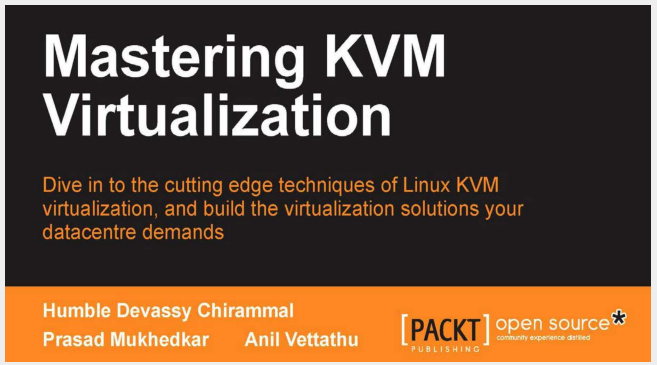


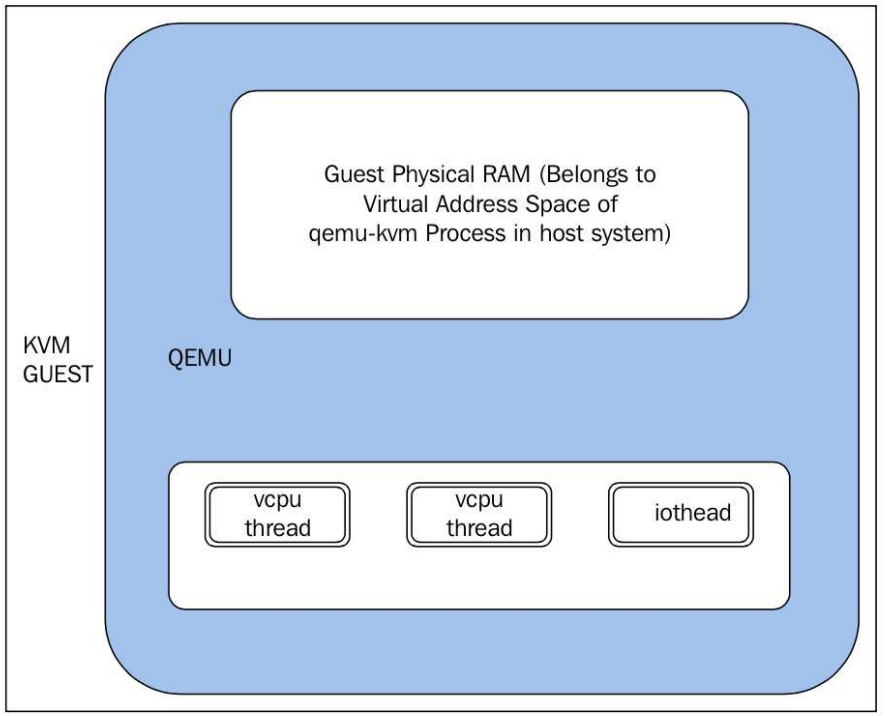
Source : wikipedia

Bare metal vs. host-based

- KVM – Kernel Virtual Machine
  - Support of virtualization in Linux kernel
  - Not an hypervisor per se
- Need QEMU – Quick emulator
- Layer 1 in terms of perf
- Layer 2 in style…
- Default in Openstack

Source :





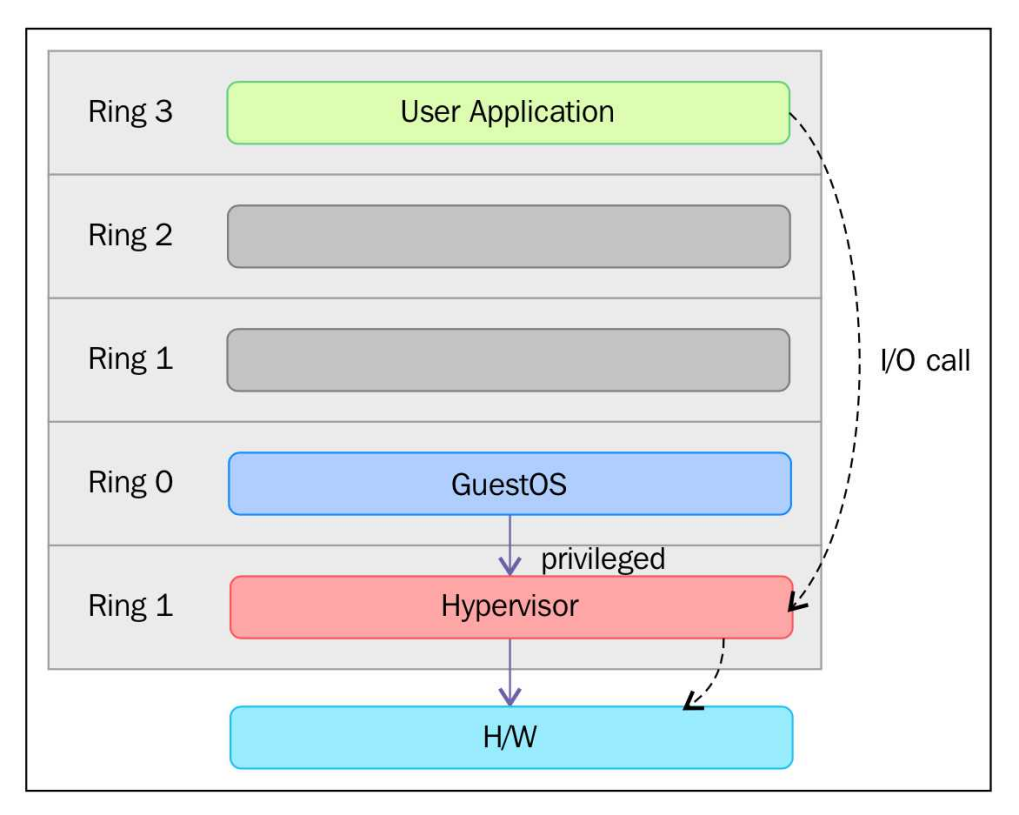
KVM Guest

Full vs. Para-virtulization

- Key question : is there a need to patch the guest OS?
  - No → full virtualization
    - Direct support by hypervisor
    - VMware approach
  - Yes → para-virtualization
    - A (typically small) part of the kernel is patched to interact with hypervisor
    - Better performance
    - Used by Xen initially
- Current trend : no patch but installation of guest additions inside OS

Hardware assisted Virtualization

- Intel and AMD propose various solutions to support virtualization at hardware level → ease of hypervisor task
- Intel VT-x, AMD-V
- Enable OS of virtual machines to do more actions natively → addition of a duplicated structures within processor and a new control level called (-1) for hypervisor



Container-based vs. Hypervisor-based

- Rather than using an hypervisor, the container approach shares kernel among VM
- On a typical server :
  - 10-100 virtual machines
  - 100-1000 containers
- A container is a group of processes on a Linux host, grouped together in an isolated environment.
  - Use of **namespaces** so as to assign to a set of processes : isolation, their own network stack (interfaces, sockets, routing), volumes
  - Use of **cgroups** to assign resources to processes, eg., CPU share, memory limit

Container-based vs. Hypervisor-based

- Inside the box, it looks like a VM.
- Outside the box, it looks like normal processes.
- A container might not contain a full VM, it might contain simply process, eg. Apache or MySQL server.

- Container engines:
  - LXC (LinuX Containers – August 2008)
  - Docker (started in March 2013)
  - Openvz (started in 2005)

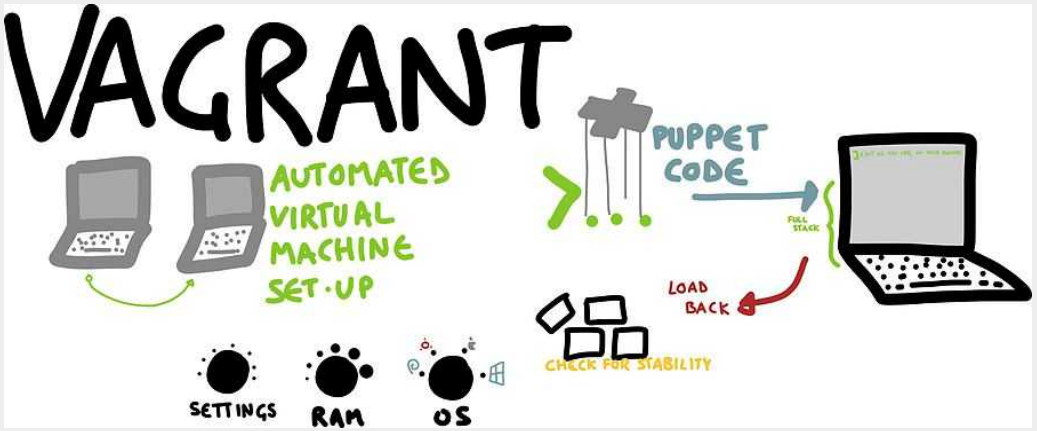
Container-based vs. Hypervisor-based

- Typical arguments for container approach
  - Source : **http://goo.gl/bFHSh**

	Ships within ...	Manual deployment takes ...	Automated deployment takes ...	Boots in ...
No virtualisation	days	hours	minutes	minutes
Virtualization	minutes	minutes	seconds	less than a minute
Lightweight Virtualization	seconds	minutes	seconds	seconds

Around virtualization: management of VMs, containers, virtual network

- Management of VMs
  - Vmware Vsphere, Citrix Xen are hypervisors and can offer management of a handful nodes of the same type (ESX servers only or Citrix Server only)
  - Vagrant: Management of VMs a hypervisor independent approach
    - Notion of images (boxes in Vagrant)
    - Provisioning of VM: Puppet, Chef, Ansible to configure automatically the VMs
    - A single file that includes everything

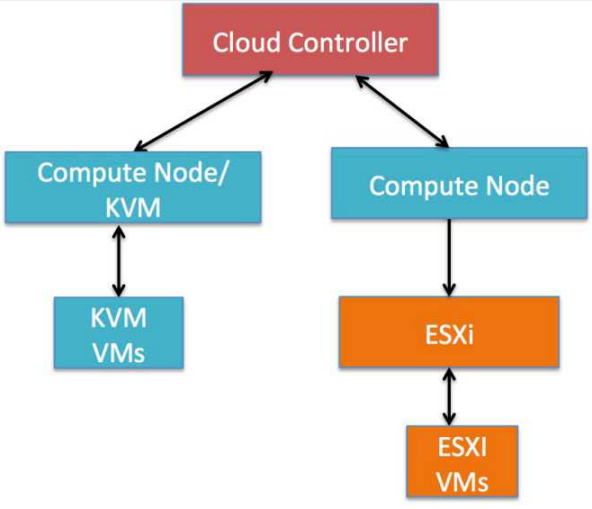


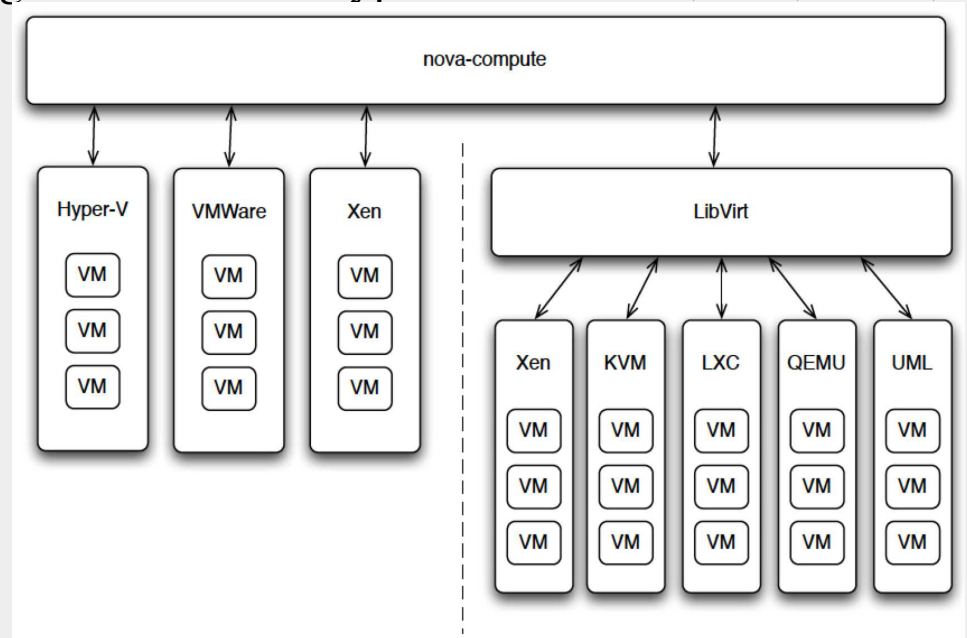
Vagrantfile (excerpt)

```
# -*- mode: ruby -*-
# vi: set ft=ruby :

# All Vagrant configuration is done below. The "2" in Vagrant.configure
# configures the configuration version (we support older styles for
# backwards compatibility). Please don't change it unless you know what
# you're doing.
Vagrant.configure(2) do |config|
  # The most common configuration options are documented and commented below.
  # For a complete reference, please see the online documentation at
  # https://docs.vagrantup.com.

  # Every Vagrant development environment requires a box. You can search for
  # boxes at https://atlas.hashicorp.com/search.
  config.vm.box = "ubuntu/vivid64"

  # Disable automatic box update checking. If you disable this, then
  # boxes will only be checked for updates when the user runs
  # `vagrant box outdated`. This is not recommended.
  # config.vm.box_check_update = false

  # Create a forwarded port mapping which allows access to a specific port
  # within the machine from a port on the host machine. In the example below,
  # accessing "localhost:8080" will access port 80 on the guest machine.
   config.vm.network "forwarded_port", guest: 5001, host: 5001

  # Create a private network, which allows host-only access to the machine
  # using a specific IP.
  # config.vm.network "private_network", ip: "192.168.33.10"

  # Create a public network, which generally matched to bridged network.
  # Bridged networks make the machine appear as another physical device on
  # your network.
   config.vm.network "public_network"
```

Around virtualization: management of VMs, containers, virtual network

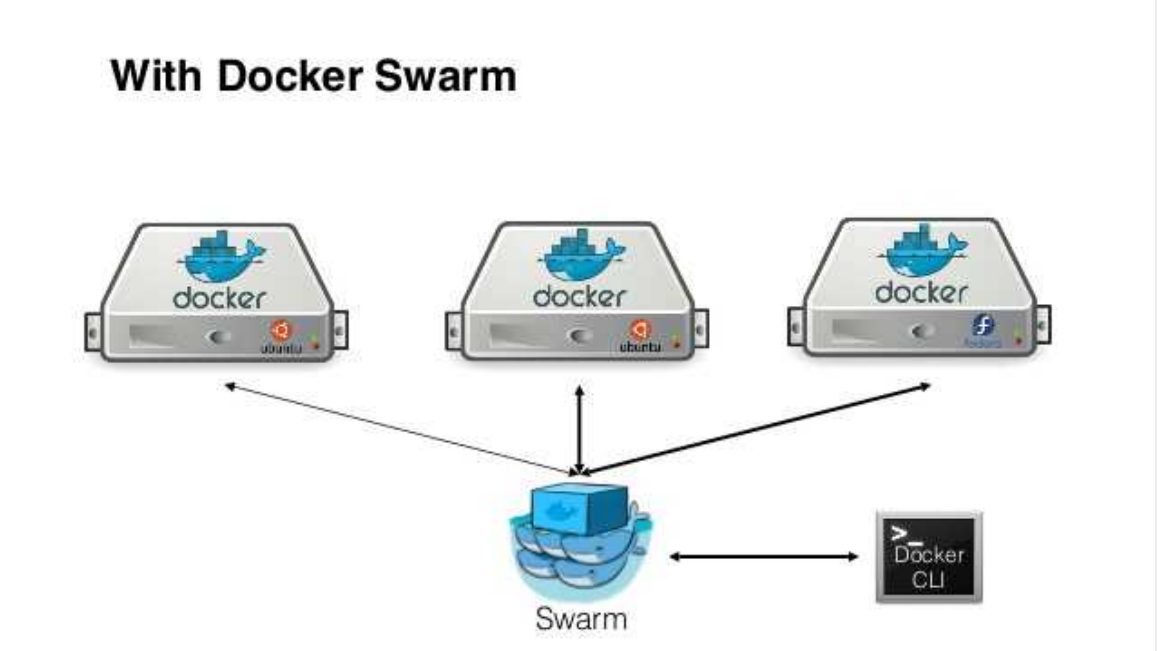
- Cloud platforms to orchestrate at a larger scale, with possibly different hypervisors
  - Openstack
    - Each function (management of VM, of network, of volumes, of identities) is a component
      - Nova: compute nodes (hypervisors)
      - Cinder : volumes
      - Neutron : network
    - Components interact through a REST API
    - Compute nodes (physical servers) might run different hypervisors: KVM, Xen, Citrix, etc





Around virtualization: management of VMs, containers, virtual network

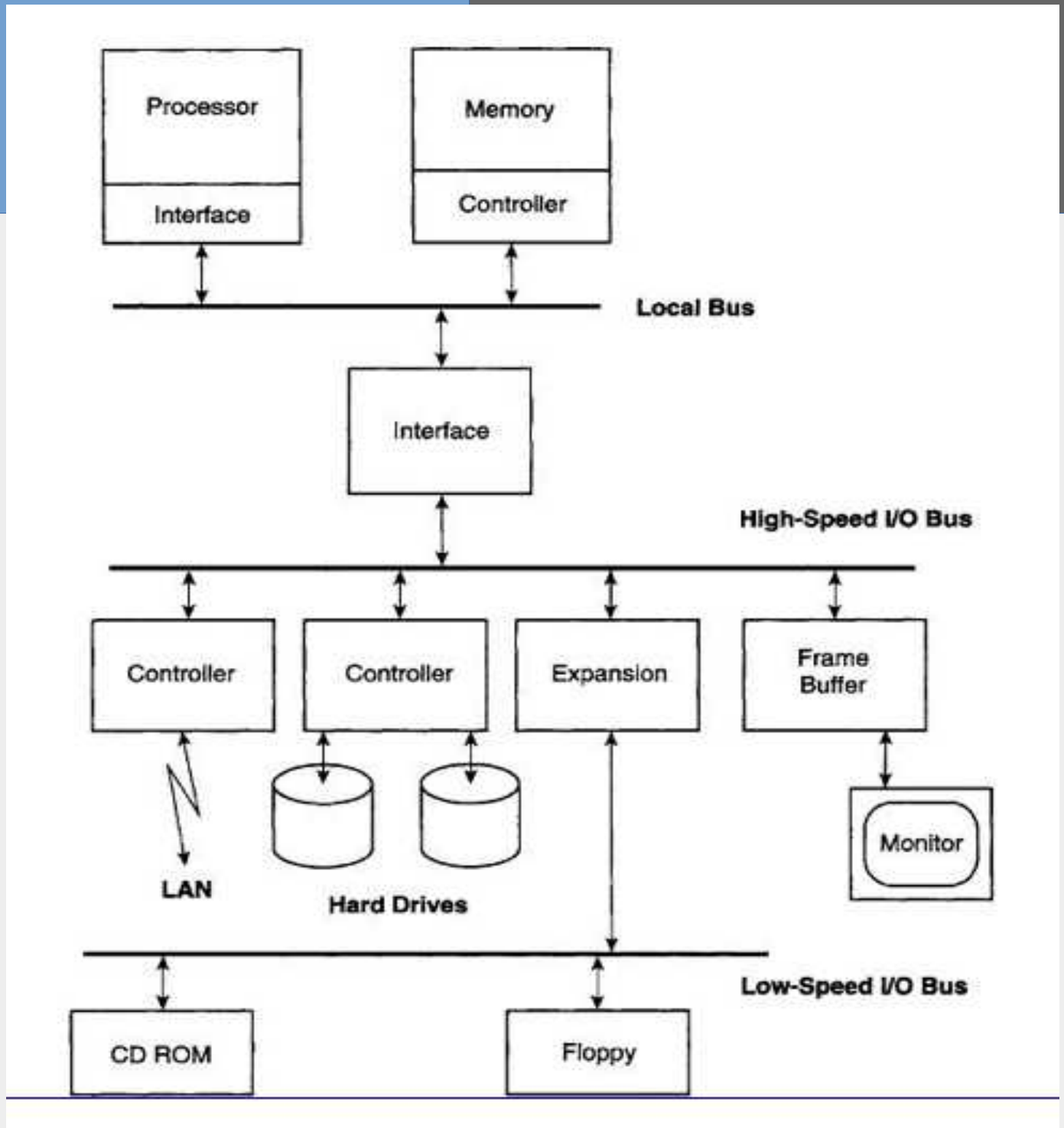
- Orchestration of containers
  - Single server level: Docker, LXC
  - Several servers level: Docker Swarm
- Advanced orchestration: Kubernetes, Swarm, Mesos



Part II: the nuts and bolts of (hypervisor-based) virtualization

Refresher on computer architecture and OS

- Computer Components
- ISA (Instruction Set Architecture)
- Operating System


Processor
Interface
Memory
Controller
Local Bus
Interface
High-Speed I/O Bus
Controller
Controller
Expansion
Frame Buffer
Monitor
LAN
Hard Drives
Low-Speed I/O Bus
CD ROM
Floppy

33

Processor

- Nowadays processors
  - Several cores
  - Multithreading → 2 processes sharing the same core
- Consequence: if you have p processors with c core and multithreading, VMware, Xen and others will expose 2 * p * c vCPU (virtual CPUs)
- We talk hereafter about processor by referring to a basic computation unit (a processor or a core or half a core..)
- Important : at a given time instant, a processor is servicing a single program:
  - Either a user program (processor in user mode)
  - Or the OS (processor in kernel mode)

ISA

- Architecture of a processor defines
  - A set of resources : memory, registers, ...
  - A set of instructions that operate on registers and memory
- Definition of storage resources + instructions → Instruction Set Architectures (ISA)
- One distinguishes :
  - User instructions for programs → computations
  - System instructions for OS → management of resources

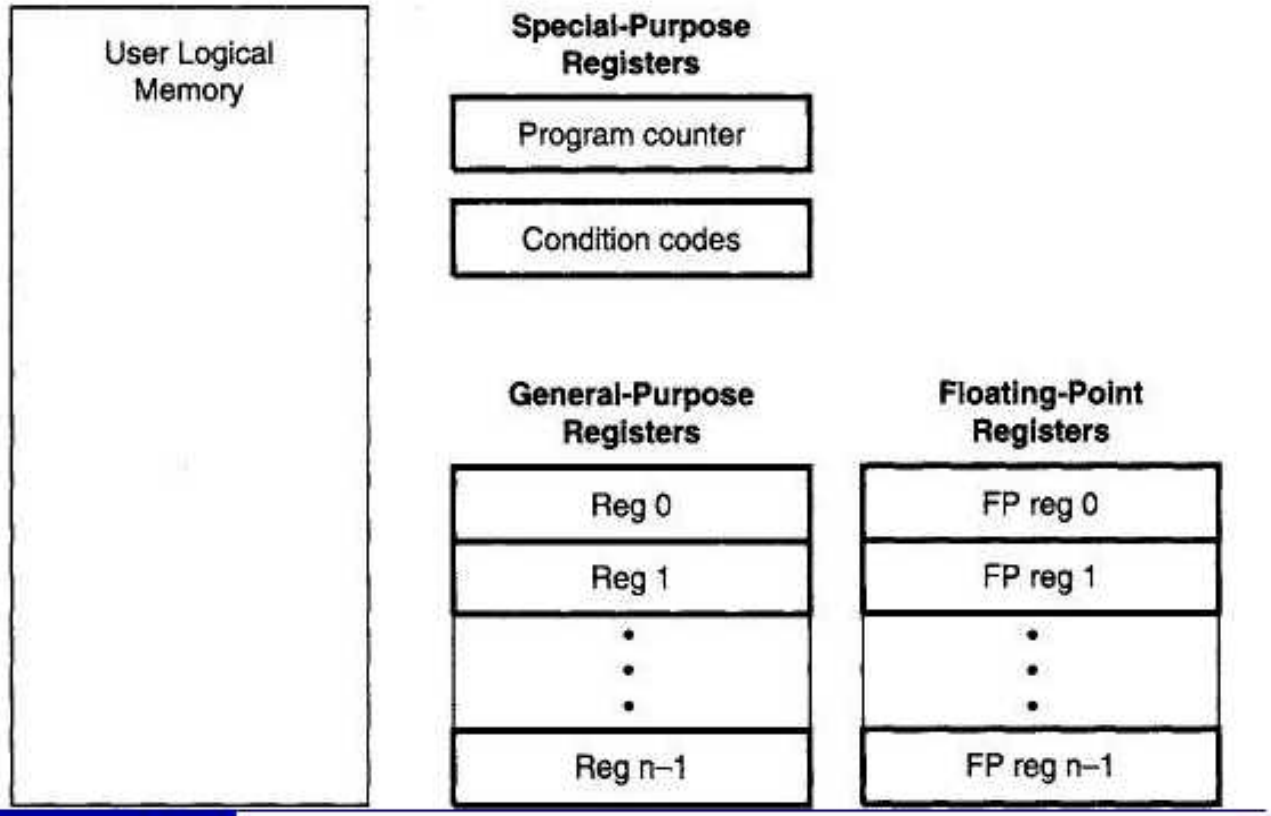


Figure A.6 Key Architected User State of a Typical ISA. *This includes a logical (virtual) memory space, a special-purpose register, general-purpose registers, and floating-point registers.*

Registers

- Generic(aka working) registers
  - Can host different types of values
- Typed registers: for specific operands
  - ISA dependent
  - ex: pointers towards memory segments in Intel IA-32 ISA
- Specific registers:
  - Program counters: index of current instuction
  - Condition

User ISA

- Four main categories
  - Load/store memory ↔ registers
  - Integral/logical operations and shifting
  - Floating point operations
  - Branching and jumps

System ISA

- Processors features several execution modes :
  - In general 4, from 0 to 3
  - Windows and Unix use levels 0 and 3
  - Level 0 : system mod for OS to control and share fairly resources among programs
  - Level 3 : user programs
- Execution mode is stored in a specific register

System registers

- Time Register
- Traps and interruptions registers
- Traps and interruptions masking registers
- Page table pointer
  - Mapping between logical and physical spaces. Kept in RAM
  - “Page table pointer” points to the memory location of this table

Traps and interruptions

- Traps and Interruptions lead to a transfer of control of processor to OS
- Interruption: request from an I/O device to the OS
- Trap:
  - An error during the execution of an instructions(page fault , division by 0, ..)

or

  - An explicit demand from a program

System ISA : management of processor

- OS must be able to hand over control of the processor to a user program
  - Jump to an instruction of a user program
  - Modification of execution state register
- … and must be able to gain control later again
  - Thanks to a timer that will generate an interruption

System ISA : I/O management

- Can be specific instructions
- Can be specific addresses translated as instructions to be executed by memory controller
- Wide variety of I/O devices → ISA offers in general only a few basic instructions
  - → OS in charge of communication with devices through the device driver

Refresher on Operating system

OS tasks

- Manage resources on behalf of user programs
  - Time multiplexing of processor
  - Management of physical memory via page table and TLB
    - When page error, OS takes over control of CPU
  - I/O management:
  - Processes perform requests to OS via system calls (that result in traps)
  - OS uses device drivers (that are added to OS) to control devices

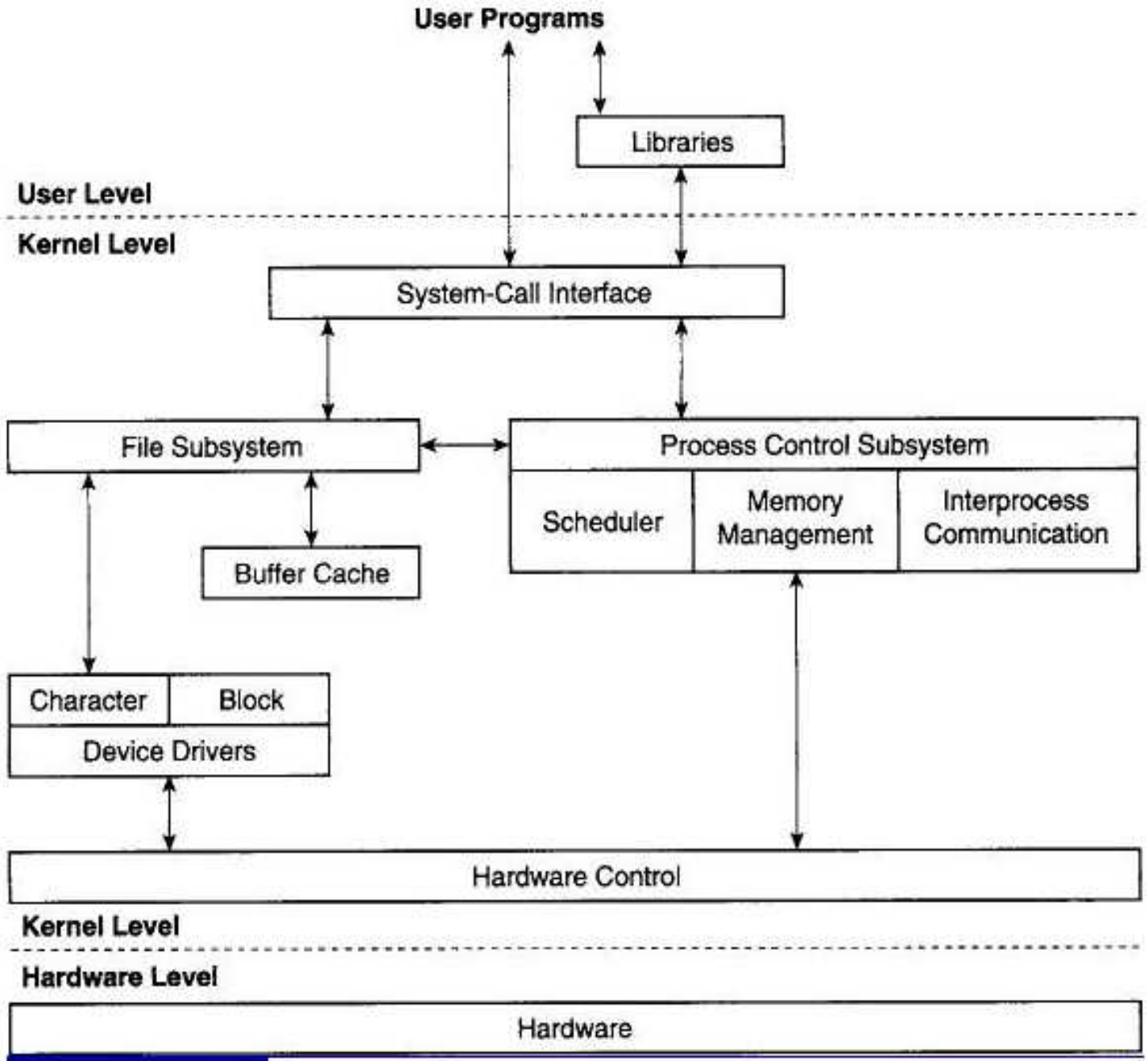


Figure A.12 Linux Architecture.

Interface with OS

- User mode ISA directly accessible to user programs
- ABI (Application Binary Interface) is the interface with OS
- API: high-level libraries (as compared to ABI)
- System calls:
  - Process management, ex : fork()
  - Memory management, ex : malloc()
  - I/O, ex : . read()
- Abstraction of traps and interruptions at ABI = signals

ISA, ABI, API

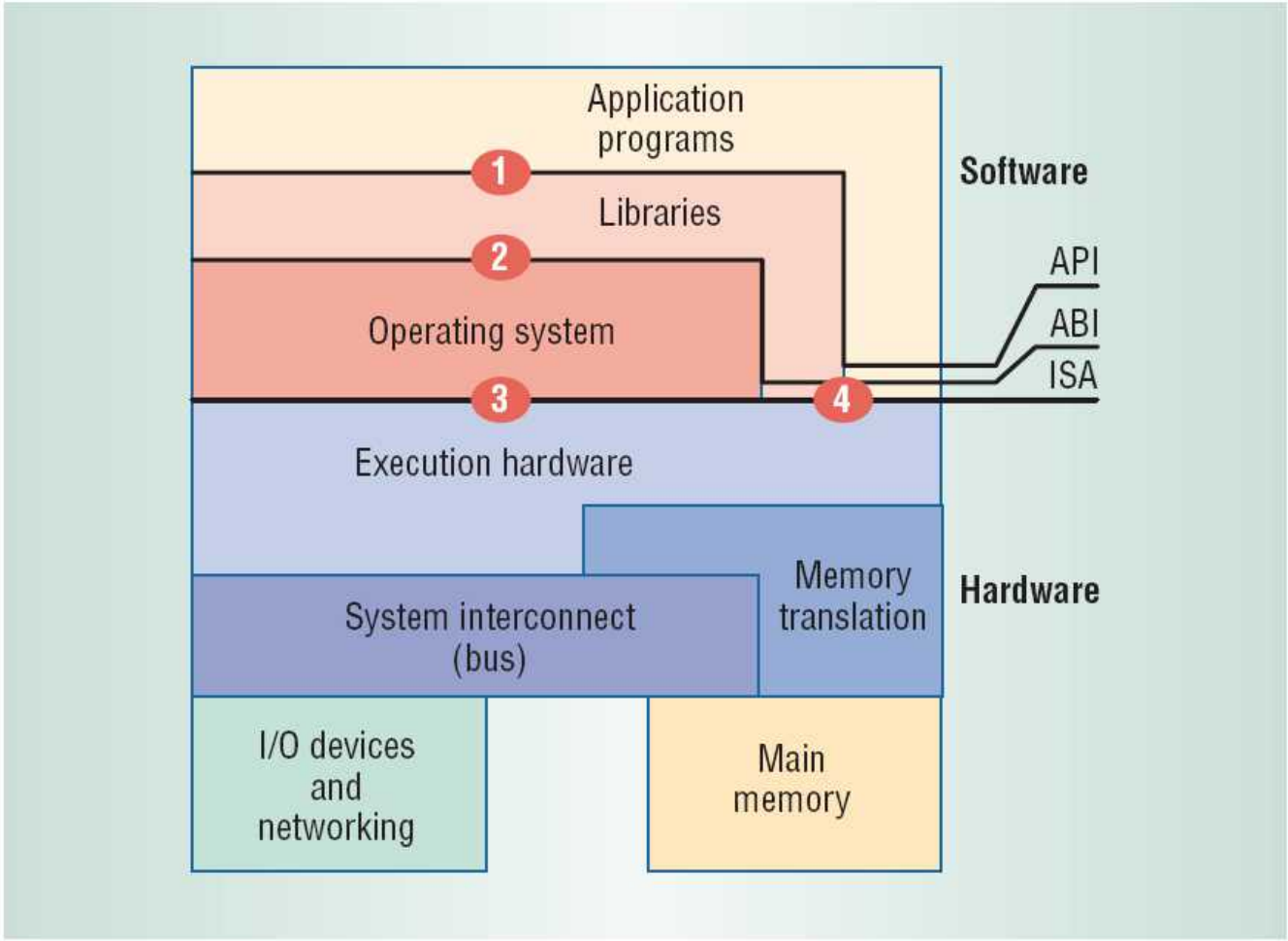
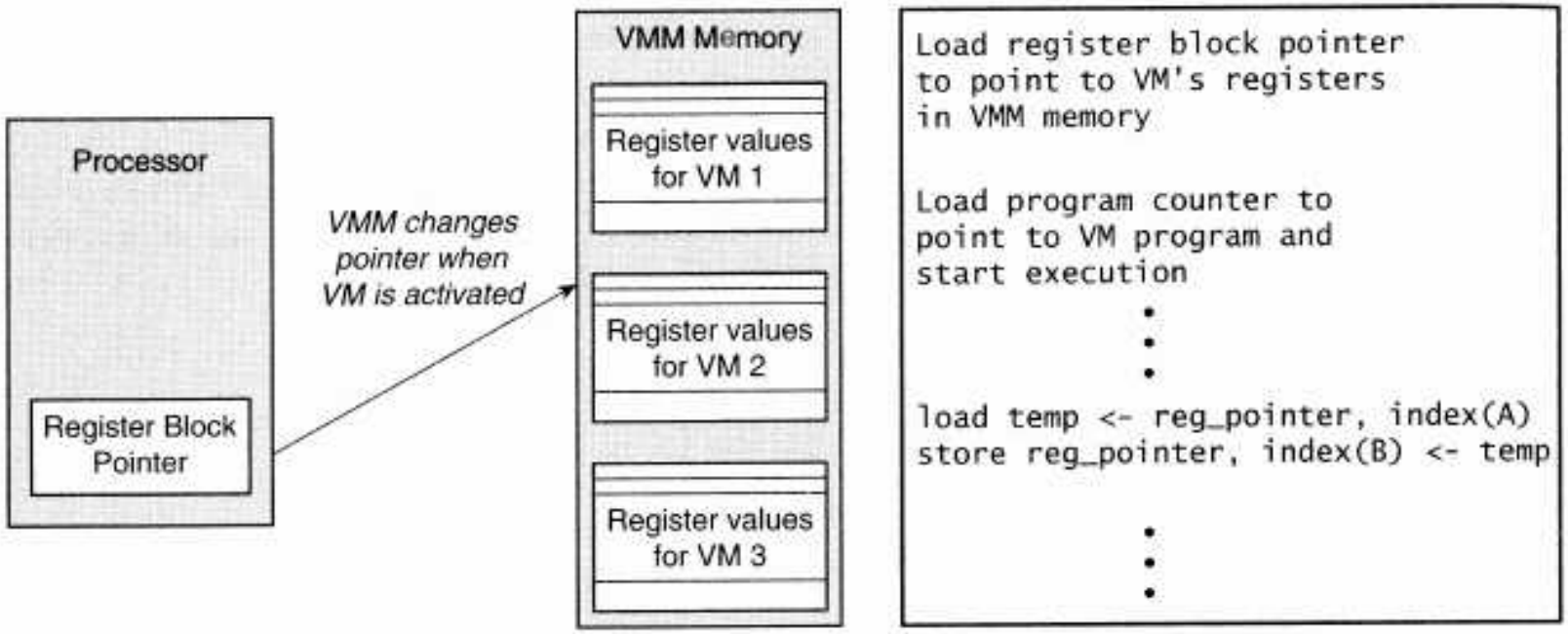


Figure 2. Computer system architecture. Key implementation layers communicate vertically via the instruction set architecture (ISA), application binary interface (ABI), and application programming interface (API).

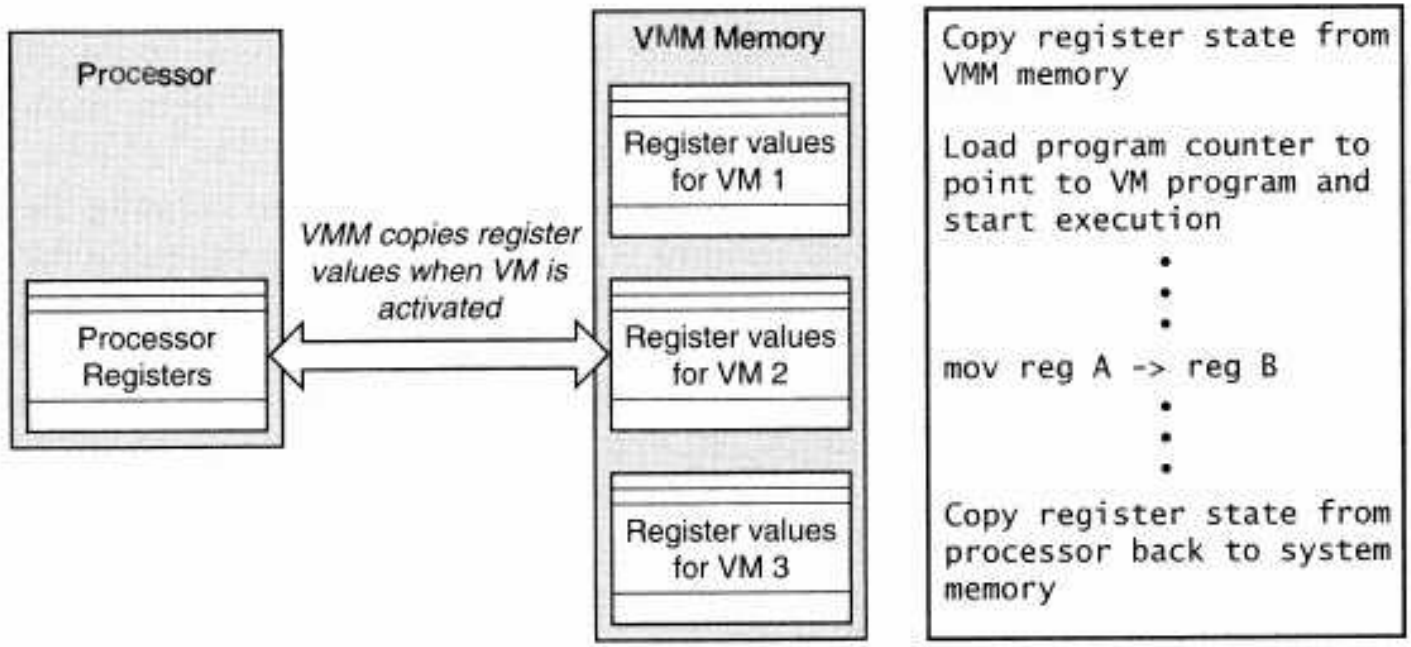
L1 and L2 hypervisors from the inside

Management of VM states

- Hypervisor must store complete VM state when switching from one VM to the next VM :
  - Registers
  - Page table (of guest OS)
  - I/O
- Two main options for context switching:
  - Indirection – inefficient because operation between register imposes several memory accesses
  - Copy – possible if same ISA between guest and host (the


Processor
Register Block Pointer
VMM changes pointer when VM is activated
VMM Memory
Register values for VM 1
Register values for VM 2
Register values for VM 3
Load register block pointer to point to VM's registers in VMM memory
Load program counter to point to VM program and start execution
load temp <- reg_pointer, index(A)
store reg_pointer, index(B) <- temp

(a)

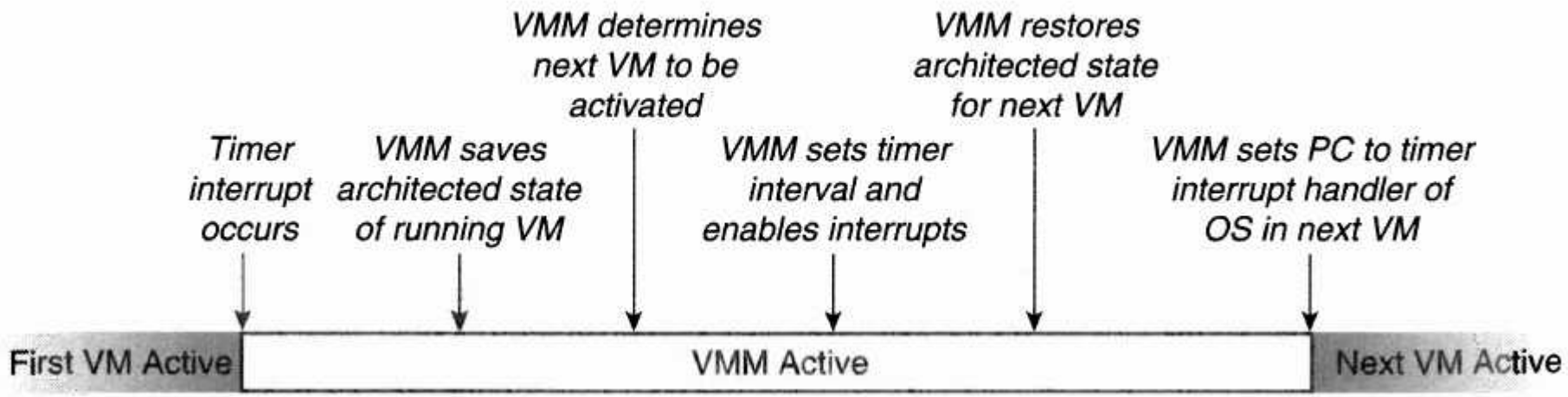

Processor
Processor Registers
VMM copies register values when VM is activated
VMM Memory
Register values for VM 1
Register values for VM 2
Register values for VM 3
Copy register state from VMM memory
Load program counter to point to VM program and start execution
mov reg A -> reg B
Copy register state from processor back to system memory

(b)

Global control by Hypervisor

- VMM (=hypervisor) must be able to get back control of processor when VMs
  - Equivalent to time multiplexing of OS (dealing with user programs)
  - Same objective: fairness
- How? VMM manages the time timer
- As guest OSes need also this timer, one needs emulate this timer for guest OSes

Global control by Hypervisor



Virtualization of resources – processor

- Two main approaches
- Emulation
  - Mandatory if guest and host (physical) ISA are different
    - Ex: you want to test an Android program on a different architecture
- Direct execution (same ISA) :
  - Faster than emulation
  - Some instruction must be emulated anyway:
    - Instructions sent by user program can be executed as is
    - Instruction sent by guest OS must often be emulated

Conditions for an ISA to be virtualizable

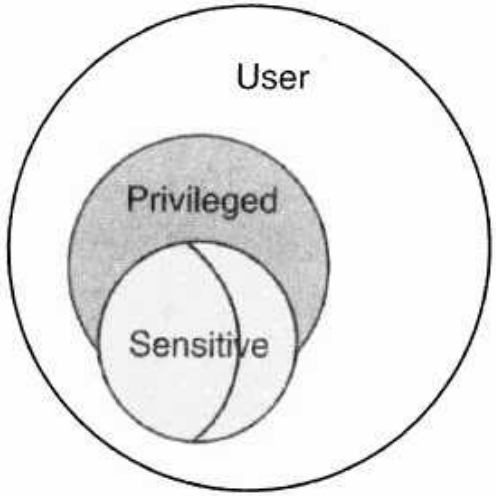
- Article Popek and Goldberg 1974
  - Virtualization dates back to the mainframe age
- Hypotheses (short version) :
  - Hardware = 1 (unique) processor
  - Processor has 2 modes : system and user
  - Some instructions can only be executed in kernel mode
- I/O non considered in article, but results can be extended to this case

Sensitive vs. non sensitive instructions

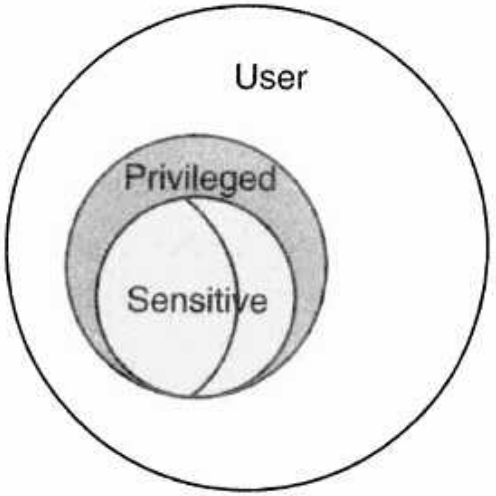
- Sensitive instructions:
  - Modify the configuration of resources, e.g. memory or execution mode (control type)
  - Ex : SPT - Set CPU timer (IBM/370)
  - Whose result depend on resource state (behavioral type)
  - Ex : Load Real Address (IBM/370)
  -
- Instructions that are neither of control nor behavioral type are called benign (non sensitive)

Popek and Goldberg

Property : sensitive instructions must form a subset of privileged instructions



(a) Does not satisfy condition



(b) Satisfies condition — efficiently virtualizable

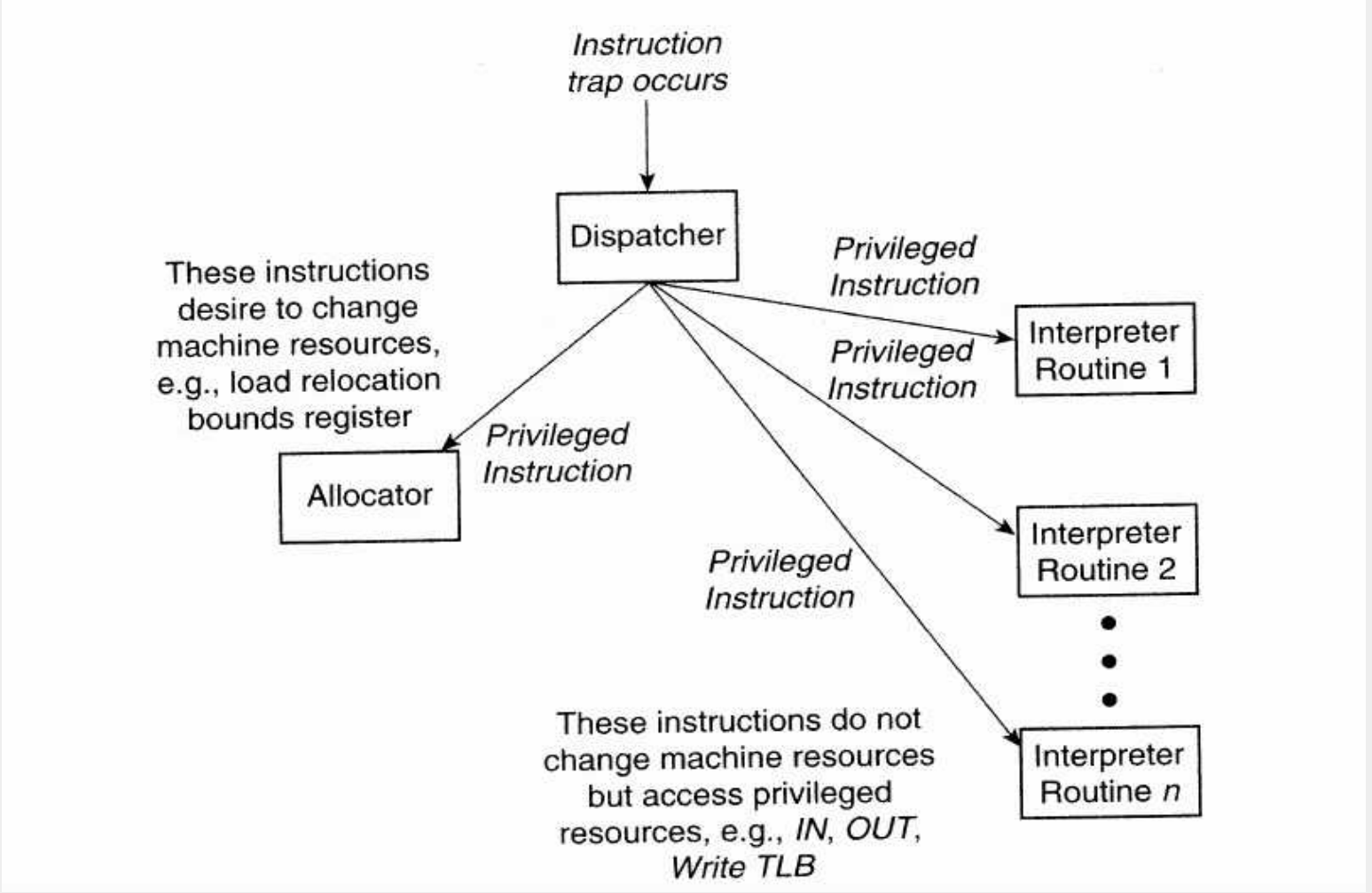
Job of hypervisor if Popek and Goldberg conditions are met

- Non sensitive instructions can be executed natively (no interference of hypervisor) → speed
- Hypervisor keeps control of resources : a user program or the guest OS cannot modify system resources (as processor has to be in kernel mode)

Job of hypervisor if Popek and Goldberg conditions are met

- If the set of sensitive instructions is a subset of privileged ones, the job of hypervisor is easy: wait for traps (errors from guest OS or guest programs) and patch:
  - If an error by guest OS, do the job and give back hand to the guest OS
  - If an error by guest program, give back hand to guest OS

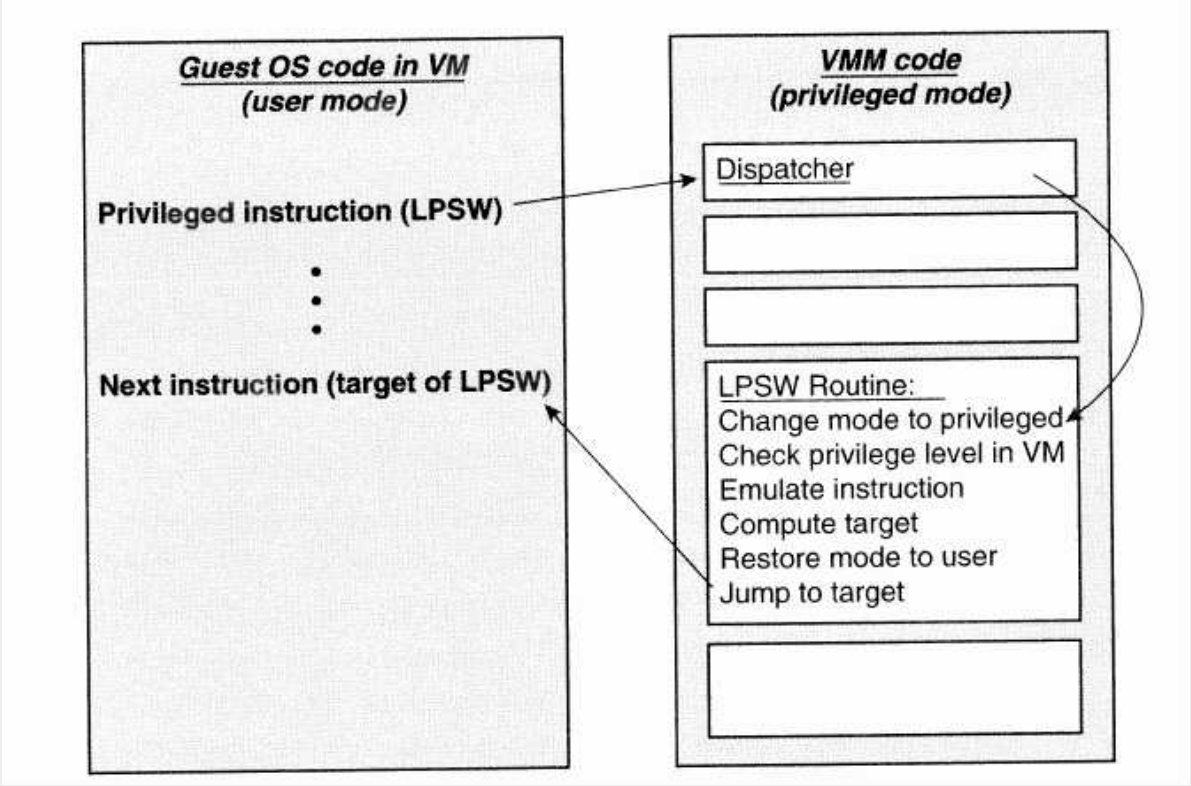
Job of hypervisor if Popek and Goldberg conditions are met: Wait for traps!!!



Intel ISA x86 case

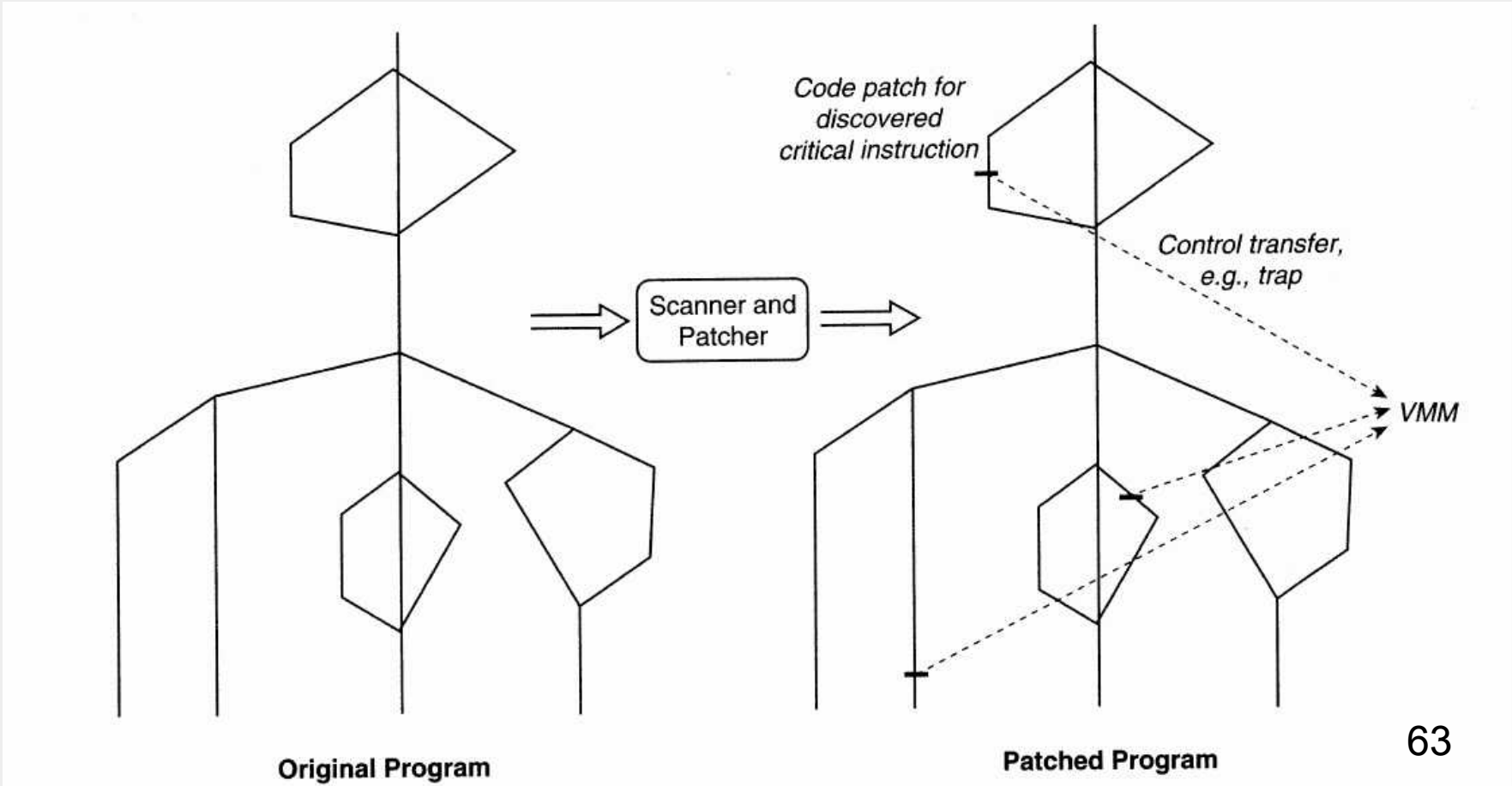
- "Analysis of the Intel Pentiums Ability to Support a Secure Virtual Machine Monitor" USENIX 2000, J. Robin, C. Irvine
- Over the 250 instructions, 17 are sensitive but not privileged (they are called critical)
  - Example: popf
    - Popf in user mode: change ALU flag
    - Popf en kernel mode: change ALU *and* system flag
    - No trap in user mode

- Consequence : if popf executed by guest OS, it will not trapped but system flag won't be modified → guest OS will be in inconsistent state!!!
- Similar problem in other ISAs.
- Solution: VMM intercepts and “patches”



Hypervisor job: track critical instructions

- Hypervisor must scan code and patch instructions before execution
- Challenge : code can branch and it is difficult to know which branch will be used in advance



Processor Virtualization: summary

- Popek and Goldberg conditions not met by ISA in general
- Hypervisor must scan code
  - Only when guest OS is in function
- It must patch
- Above operation is called Binary Translation
  - VMware is an expert in this area

I/O Virtualization

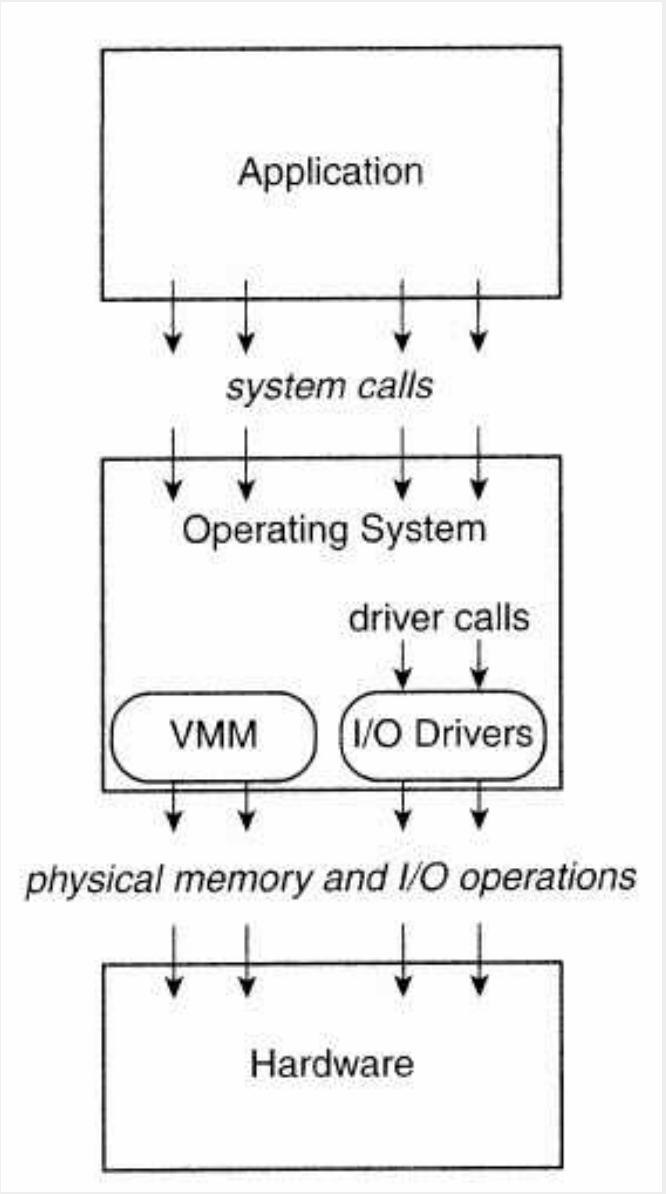
- One of the most complex tasks in virtualization because there is a LOT of I/O devices
- General approach: offer a clean interface to guest OS

I/O Virtualization

- Typology of devices:
  - Dedicated. Ex: screen, keyboard.
  - Partitioned. Ex : disks
  - Shared. Ex: NIC
  - Spooled. Ex : printer. Shared, but at a high level of granularity(files in spooler). In practice, printers often accessed through network
  - Non existing. Ex : virtual switch to interconnect VM in the same physical machine

Where can we virtualize I/O?

- Options:
  - System calls?
  - Drivers?
  - I/O operations?
- Solution used: driver level

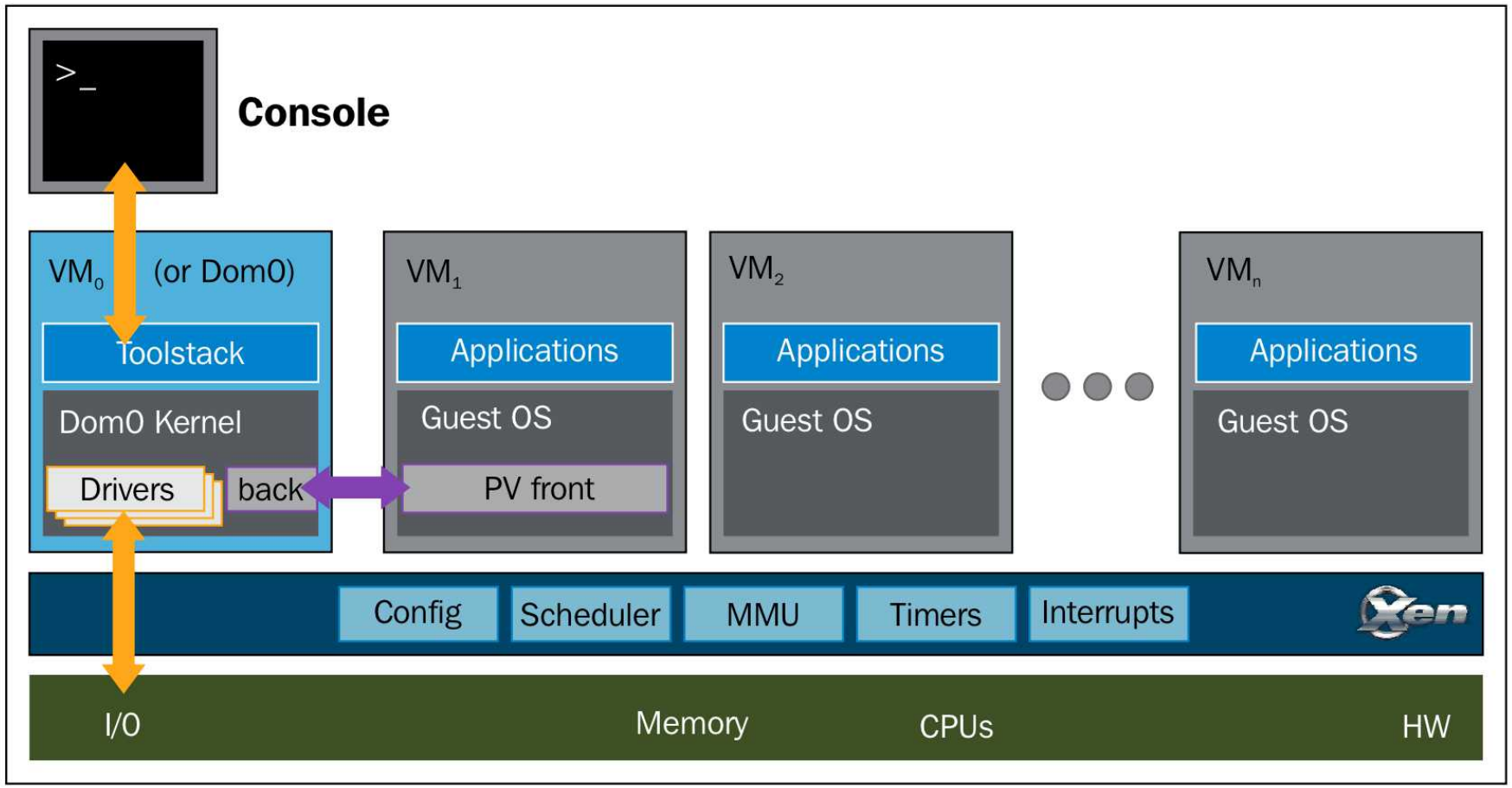


Driver level

- Call to driver via system call
- For hypervisor to intercept this call, it must know details of the guest OS and of driver → too complex
- Alternative approach: offer a normalized interface to device(e.g., always the same Intel Ethernet card, irrespectively of physical one) and provide a specific driver to guest OS to intercept and translate requests.
- This entails that hypervisor has drivers for real device

Virtualization at driver level : the case of Xen

- Dom U: VMs
- Dom 0 : drivers



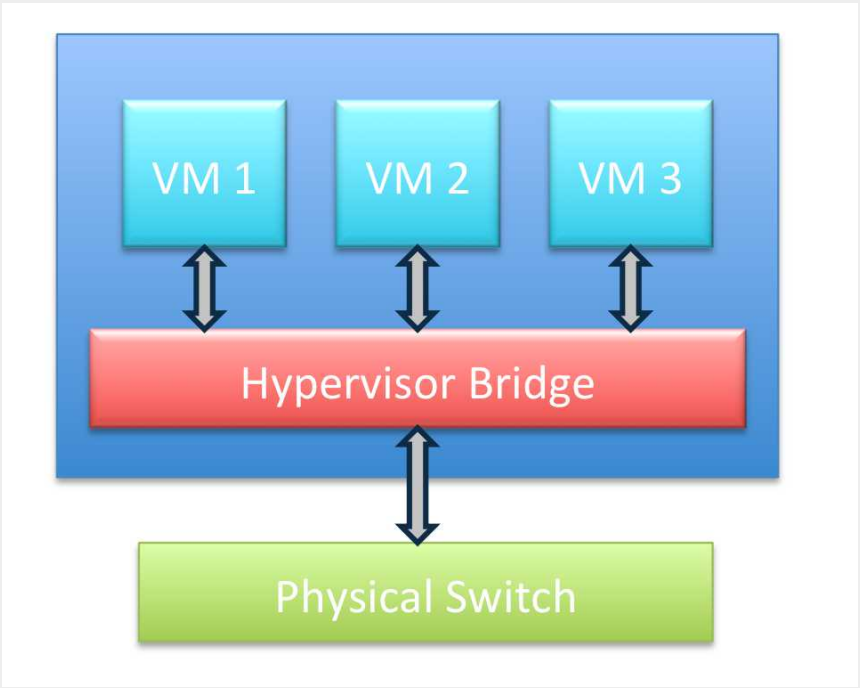
Source: http://www.xenproject.org/

Part III: Networking in virtual environments

sources :
http://openvswitch.org/slides/LinuxSummit-2011.pdf
http://openvswitch.org/slides/OpenStack-131107.pdf

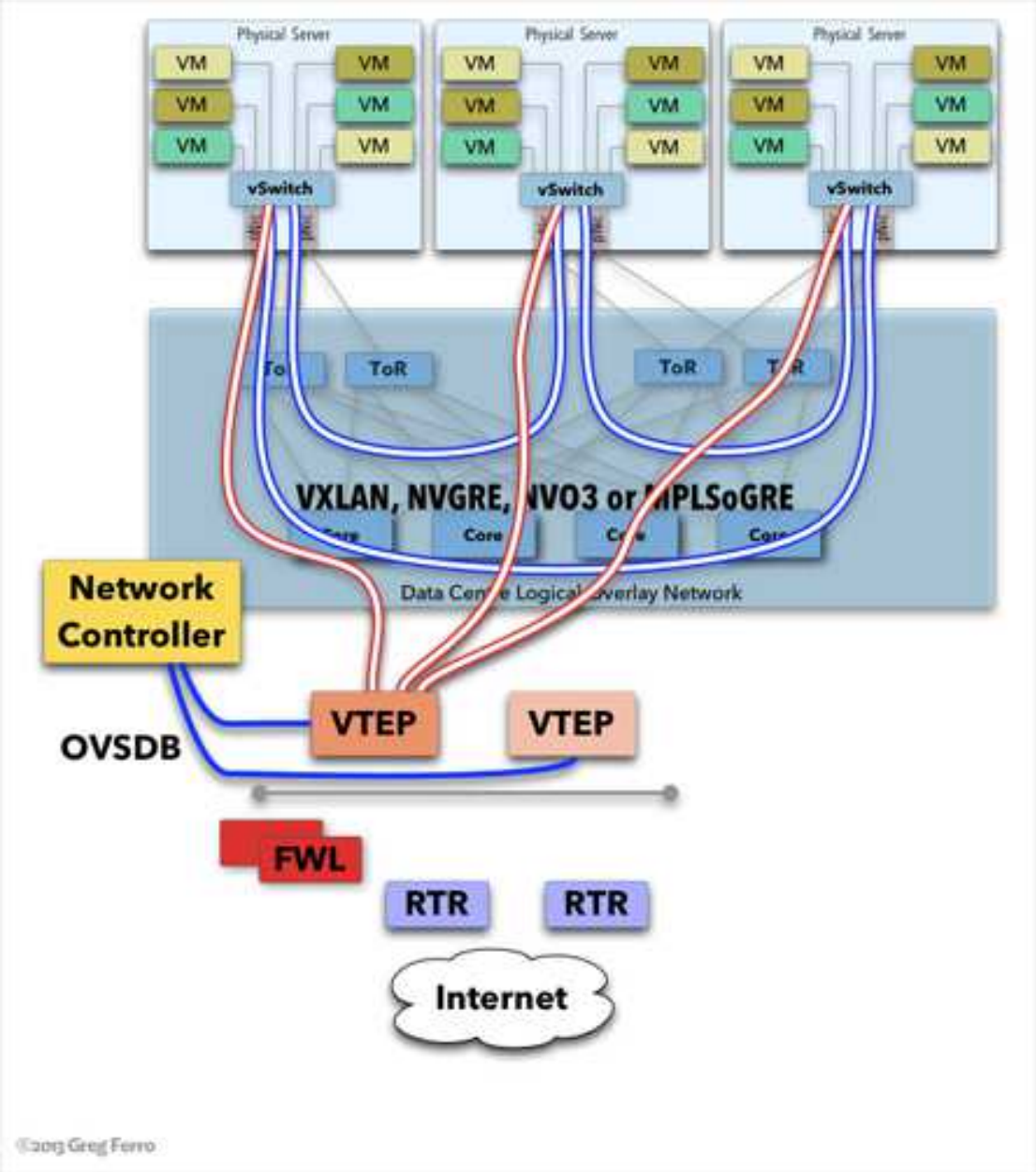
Introduction

- Multiple VMs on same host
  - Sharing of physical interfaces
- Works on Linux-based hypervisors: Xen, KVM, VirtualBox
- Open source, started in 2009

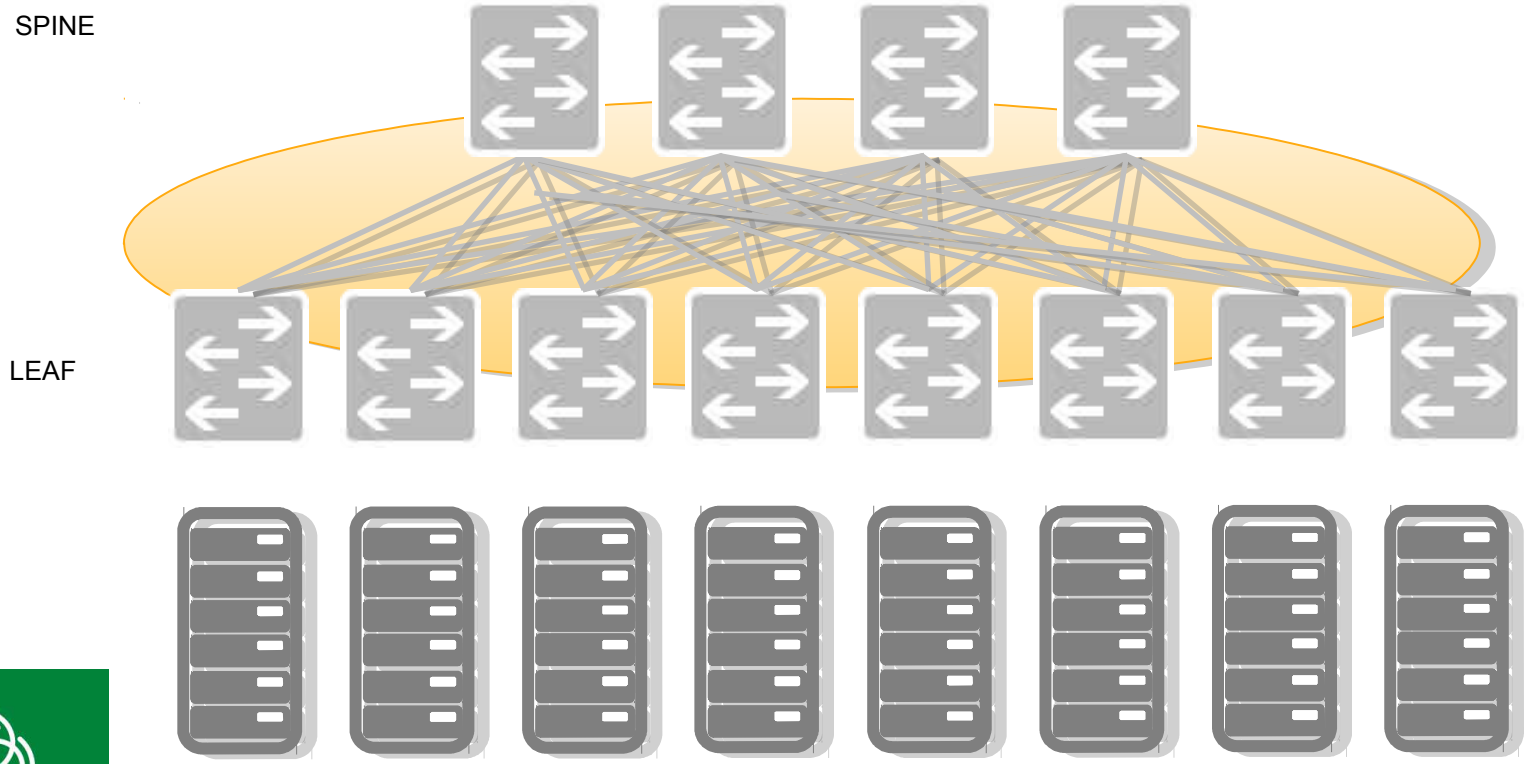


Need also network to interconnect multiple vitualized servers

- Tunnels (VXLAN, GRE) between virtual switches
- Centralized management of switches
- VTEP : virtual tunnel endpoint
- Minimal support of physical switches that simply interconnect OVS switches
- Other options with clever physical switches possible



L3: A better design



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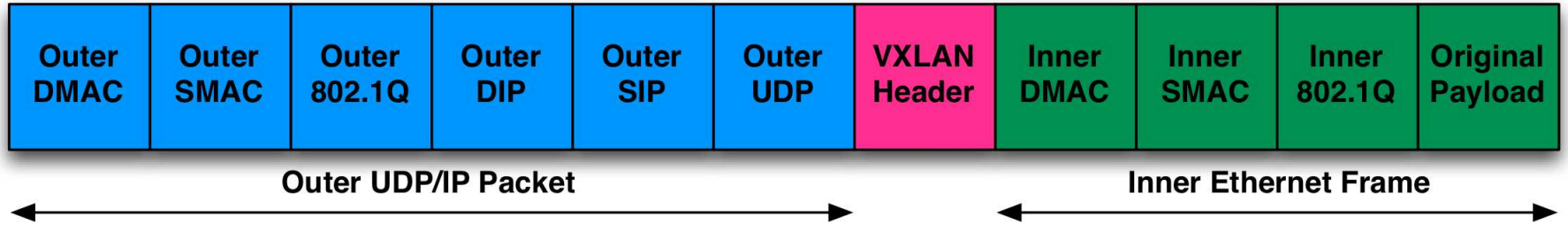
Pure L3 is great for maximizing connectivity, but what about segregation of projects?

VXLAN: Virtual eXtensible LAN

- RFC 7348
- A type of network overlay technology that encapsulates L2 frames as UDP packets

VXLAN: Virtual eXtensible LAN



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VXLAN: Virtual eXtensible LAN

- VNI – VXLAN Network Identifier
  - 24 bit number (16M+ unique identifiers)
  - Part of the VXLAN Header
  - Similar to VLAN ID
  - Limits broadcast domain
- VTEP – VXLAN Tunnel End Point
  - Originator and/or terminator of VXLAN tunnel for a specific VNI
  - Outer DIP/Outer SIP

VXLAN: Virtual eXtensible LAN

- Sending a packet
  - ARP table is checked for IP/MAC/Interface mapping
  - L2 FDB is checked to determine IP of destination VTEP for destination MAC on source VTEP

```
root@mcpl.dev4.mc:~$ ip addr show dev vxlan12345
140: vxlan12345: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UNKNOWN
 group default
    link/ether 4e:3c:82:2e:09:0e brd ff:ff:ff:ff:ff:ff
    inet 10.9.8.1/24 scope global vxlan12345
       valid_lft forever preferred_lft forever
root@mcpl.dev4.mc:~$ arp -an | grep 10.9.8.2
? (10.9.8.2) at 7a:79:96:de:2c:a2 [ether] on vxlan12345
root@mcpl.dev4.mc:~$ bridge fdb show dev vxlan12345
7a:79:96:de:2c:a2 dst 172.16.3.102 self
4e:3c:82:2e:09:0e dst 127.0.0.1 self
```

VXLAN: Virtual eXtensible LAN

- Sending a packet
  - Packet is encapsulated for destination VTEP with configured VNI and sent to destination
  - Destination VTEP un-encapsulates the packet and the inner packet is then processed by the receiver

How do VTEPs handle BUM (Broadcast, Unknown Unicast, Multicast)?

BUM

- All BUM type packets (ex. ARP, DHCP, multicast) are flooded to all VTEPs associated with the same VNI.
- Flooding can be handled 2 ways
  - Packets are sent to a multicast address that all VTEPs are subscribers of
  - Packets are sent to a central service node that then floods the packets to all VTEPs found in its local DB for the matching VNI

VXLAN: Virtual eXtensible LAN

- Well supported in most modern Linux Distros
  - Linux Kernel 3.10+
    - Linux uses UDP port 8472 instead of IANA issued 4789
  - iproute2 3.7+
- Configured using ip link command

```
root@mcpl.dev4.mc:~$ ip link add vxlanl2345 type vxlan id l2345 remote 172.16.3.100
root@mcpl.dev4.mc:~$ ip link set dev vxlanl2345 up
root@mcpl.dev4.mc:~$ ip -d link show dev vxlanl2345
140: vxlanl2345: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UNKNOWN
 mode DEFAULT group default
    link/ether 4e:3c:82:2e:09:0e brd ff:ff:ff:ff:ff:ff promiscuity 0
    vxlan id l2345 remote 172.16.3.100 port 32768 61000 ageing 300
```

OpenVswitch

- Works on Linux-based hypervisors: Xen, KVM, VirtualBox
- Open source, started in 2009

List of contributors

Packaging

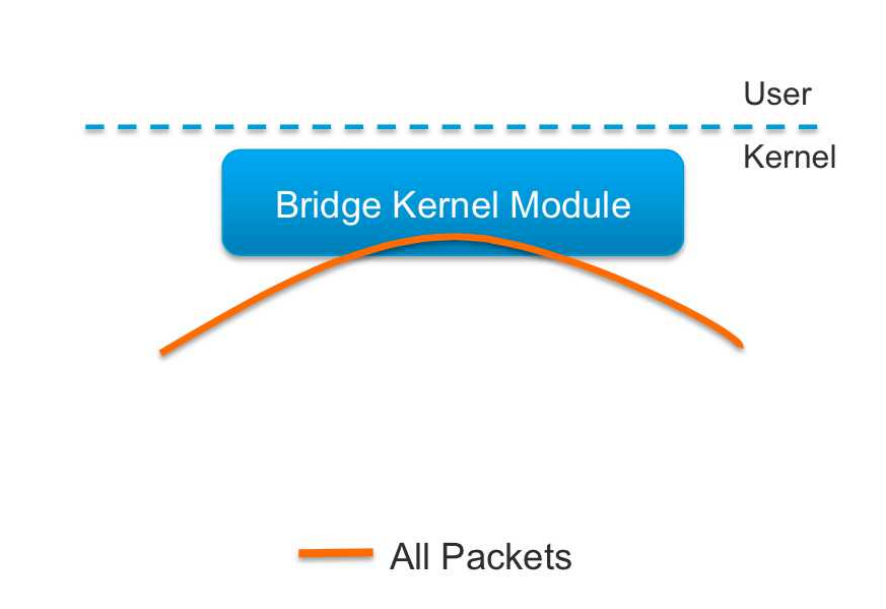
- Default networking stack for Xen Cloud Plaborm (XCP)
- Ships with Citrix XenServer and basis for their Distributed Virtual Switch (DVS)
- Distribution packaging
  - Debian
  - Ubuntu
  - SUSE
  - Red Hat

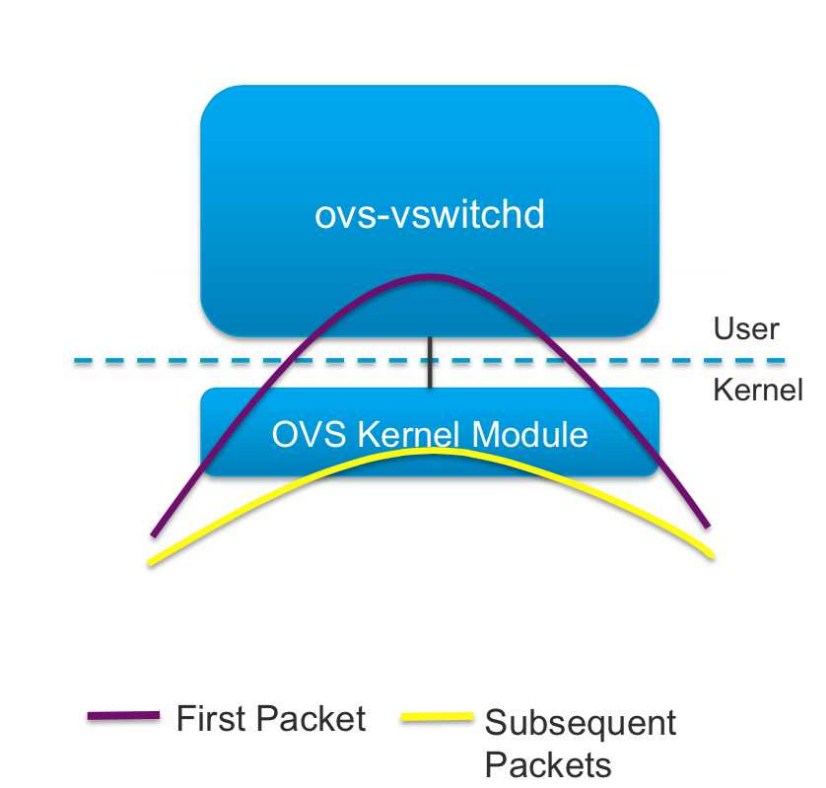
Functionalities

- Network protocols:
  - Openflow: centralized controller that controls several switches and installs flow rules (matching L2 to L4 fields)
  - Alternatively can work as normal L2 switch
  - Tunneling with GRE and VXLAN:
    - Interconnect openvswitches over the network
- Reporting:
  - Netflow
    - Wireshark at router level: a summary line per flow (TCP, UDP connection) with duration and volumes. Fits into memory as routers/switches have no disk
    - sFlow (sampled netflow)
  - Port mirroring
- ACL and QoS
- In fact, we have here what any CISCO/Juniper switch would feature (+ openflow which is less common)

L2 vs Openflow

- L2 legacy forwarding

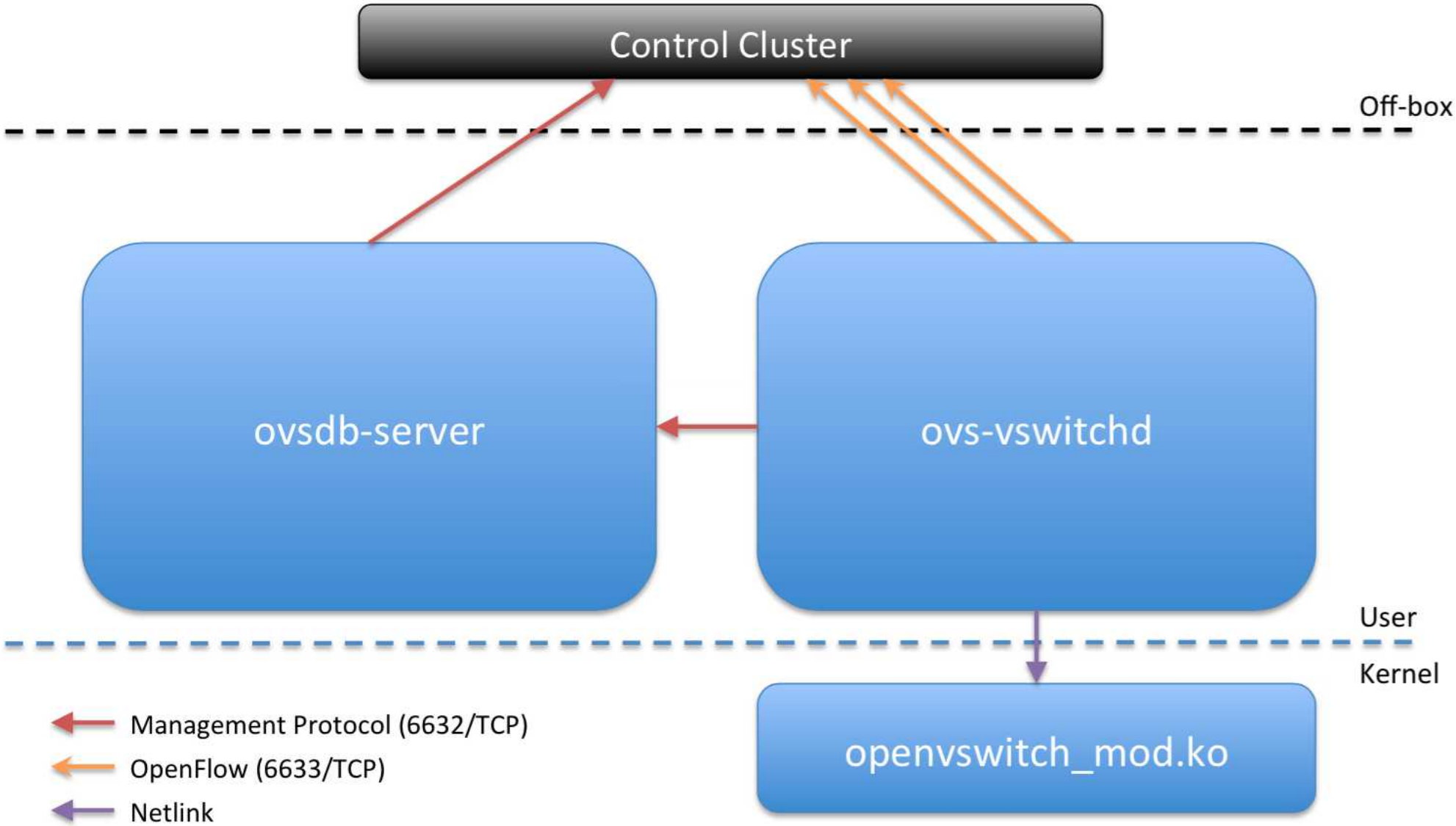




OpenFlow :

- first packet need to install rules → contact controller.
- Subsequent in fast path

Main components



Forwarding components

- Ovs-vswitchd (Slow Path)
  - Forwarding logic (learning, mirroring, VLANs, and bonding)
  - Remote configuration and visibility
- Openvswitch_mod.ko (Fast Path)
  - Linux kernel module
  - Packet lookup, modification, and forwarding
  - Tunnel encapsulation/decapsulation

Control plane

- Database that holds switch-level configuration: Bridge, interface, tunnel definitions
- OVSDB and OpenFlow controller addresses
- Configuration is stored on disk and survives a reboot

Performance

- A key factor in production environments

Accepted at 2014 IEEE 3rd International Conference on Cloud Networking (CloudNet)

Performance Characteristics of Virtual Switching

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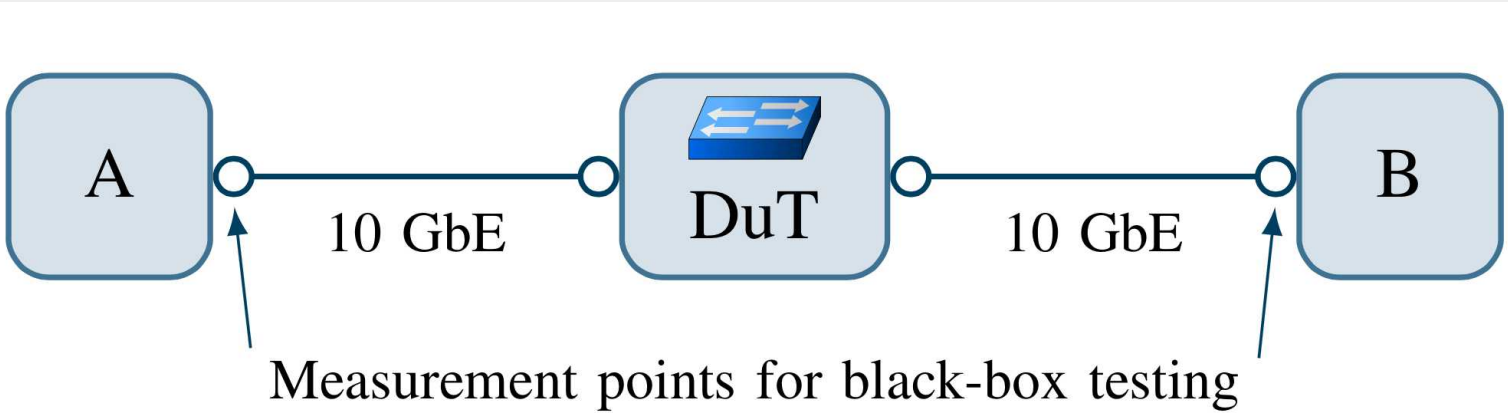
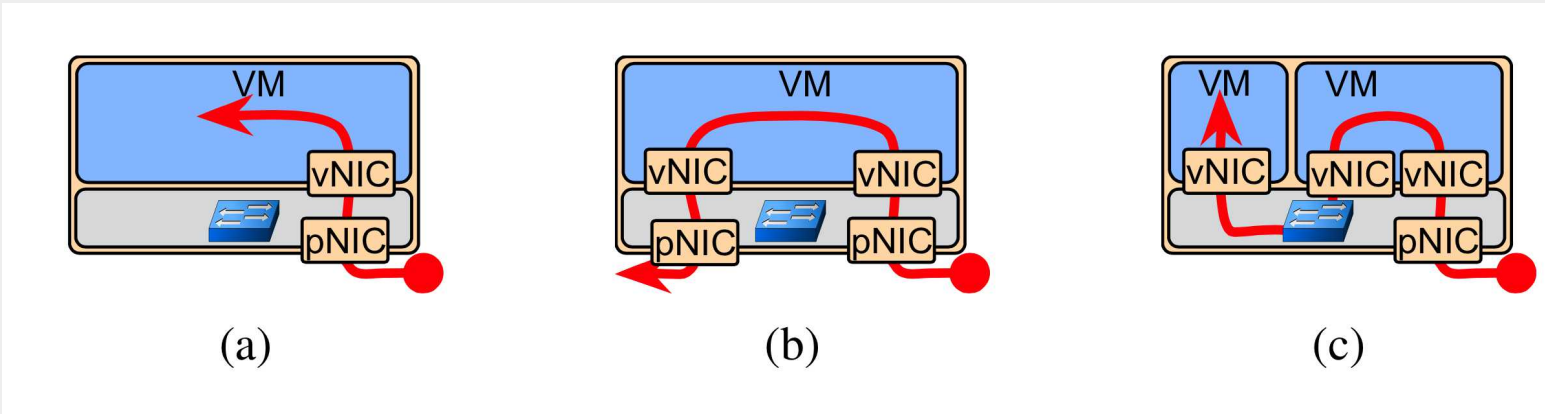
Performance

- Test set up: DUT = Device Under Test
- p/vNIC = physical/virtual NIC





Performance

- Switches: Linux bridge, OVS, IP forwarding (routing between IP by kernel)
- Results in pps (packet per s): this is what matters. Small packets → stress on I/O

TABLE I. SINGLE CORE DATA PLANE PERFORMANCE COMPARISON

Application	pNIC-pNIC [Mpps]	pNIC-vNIC [Mpps]	pNIC-vNIC-pNIC [Mpps]	pNIC-vNIC-vNIC [Mpps]
Open vSwitch	1.88	0.85	0.3	0.27
IP forwarding	1.58	0.78	0.19	0.16
Linux bridge	1.11	0.74	0.2	0.19

Performance

- Switch sends packets over different CPU: scale until reaching the maximum number of cores
- Visible when close to saturation → when the packet size becomes small

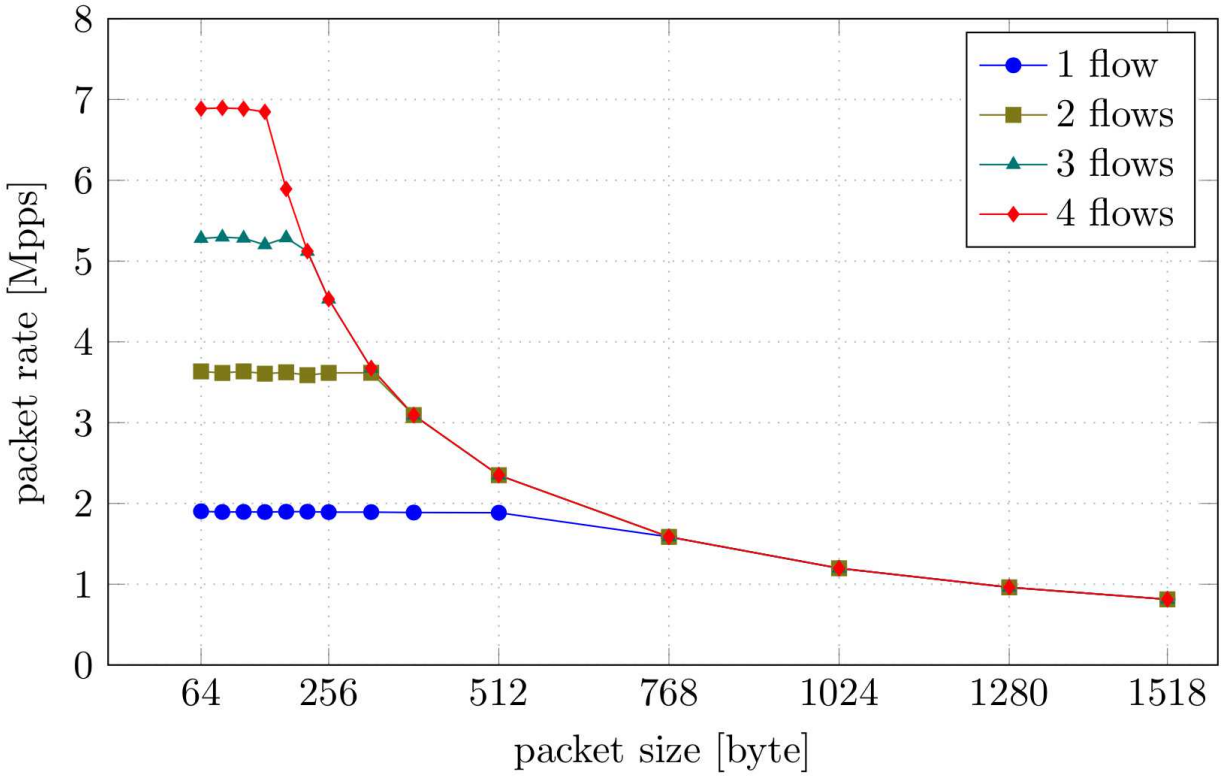


Fig. 5. Throughput with various packet sizes and flows

Performance

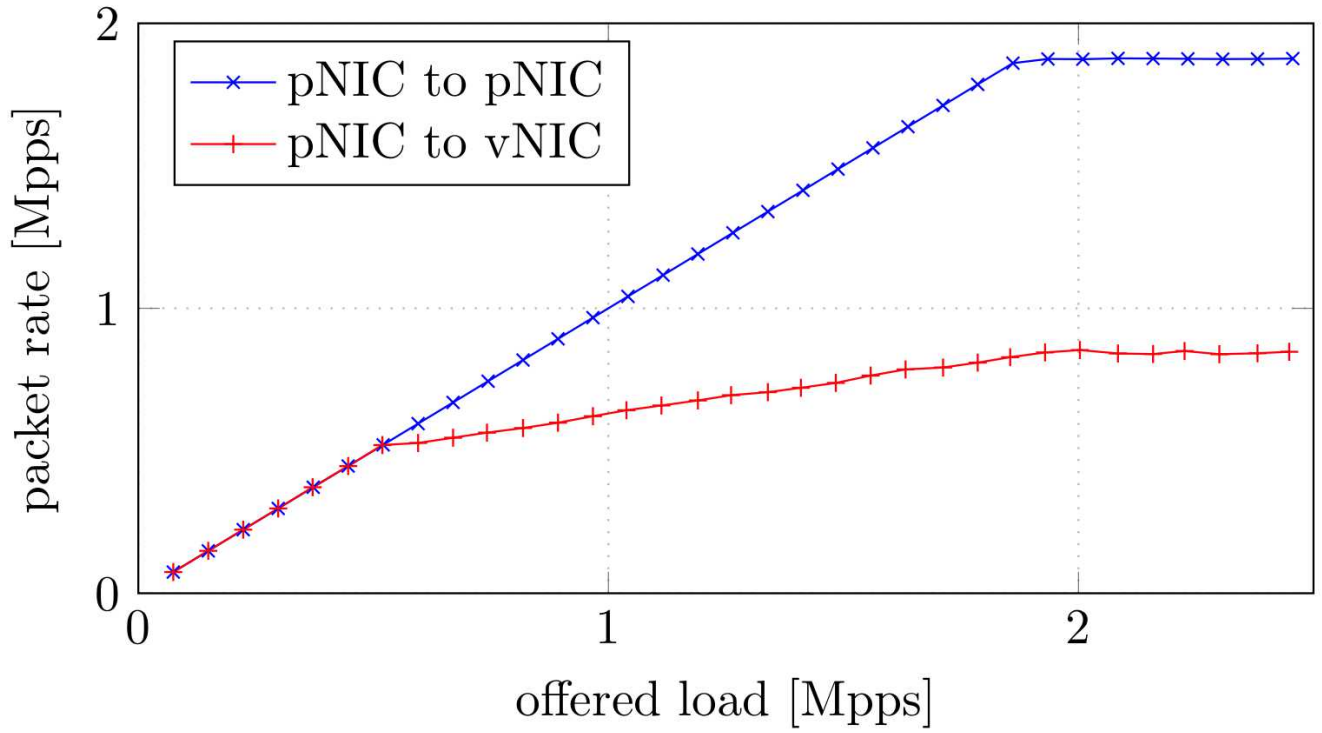


Fig. 9. Offered load vs. throughput with pNICs and vNICs

Performance

- Moving from pNIC to vNIC means moving to a different VM → context switching from ovs process to the VM process by the hypervisor

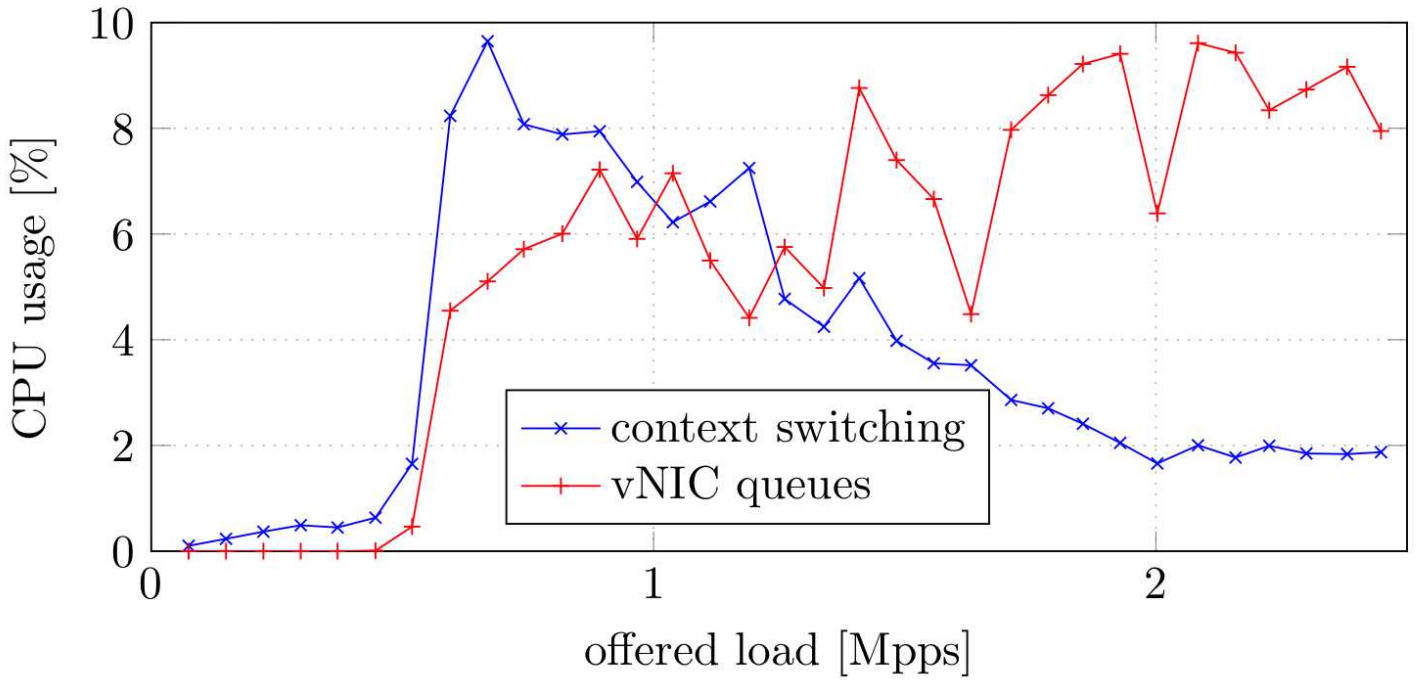


Fig. 10. CPU load of context switching and vNIC queuing

References

- Smith and Nair - Elsevier

References

The Architecture of Virtual Machines

A virtual machine can support individual processes or a complete system depending on the abstraction level where virtualization occurs. Some VMs support flexible hardware usage and software isolation, while others translate from one instruction set to another.

James E. Smith
University of Wisconsin-Madison

Ravi Nair
IBM T.J. Watson Research Center

Virtualization has become an important tool in computer system design, and virtual machines are used in a number of subdisciplines ranging from operating systems to programming languages to processor architectures. By freeing developers and users from traditional interface and resource constraints, VMs enhance software interoperability,

A computer's instruction set architecture (ISA) clearly exemplifies the advantages of well-defined interfaces. Well-defined interfaces permit development of interacting computer subsystems not only in different organizations but also at different times, sometimes years apart. For example, Intel and AMD designers develop microprocessors that implement the Intel IA-32 (x86) instruction set,