Chapter Three

Virtualization In Cloud Computing

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Hand-Book of Cloud: Chapters 1- 8
CLOUD COMPUTING Principles and Paradigms: Chapter 1

Virtualization

Virtualization

- It is a technology to **run multiple same or different OSs on a single physical system** which are **completely isolated from each other** to.
  - Share underlying hardware resources*
    - **Ex:** Run both Windows and Linux on the same machine
- It is defined as **the abstraction over computing resources, such as**
  - storage, processing power, memory, and network, I/O, etc..
- It is the **process** by which **one computer behaves as many computers.**
- Virtualization used to improve ***IT throughput*** and ***costs*** by using physical resources as ***a pool*** from which ***virtual resources*** can be allocated.

- VMWare white paper, *Virtualization Overview*

Virtualization

A technology to run multiple same or different isolated OSs on a single physical system by abstracting and partitioning its physical resource (storage, processing power, memory, and network or I/O) into multiple **V**irtual **M**achines (**VM**s) with different workloads to improve ***IT throughput*** and ***cost*** .

Dual Boot , Emulation and Virtualization

Dual Boot System

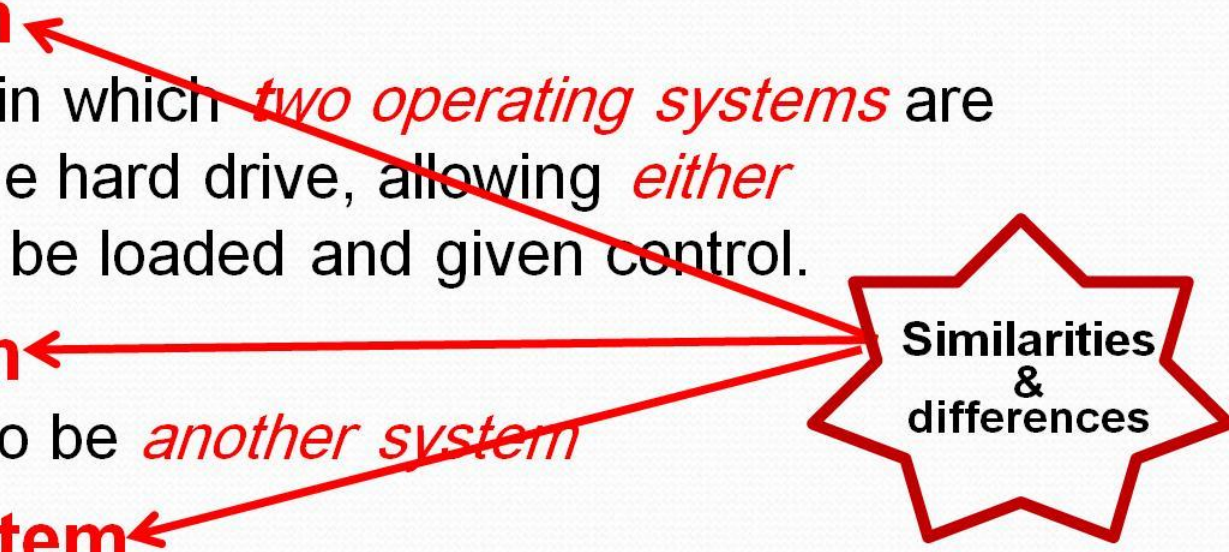
- A computer system in which *two operating systems* are *installed* on the same hard drive, allowing *either operating system* to be loaded and given control.

Emulation System

- A system *pretends* to be *another system*

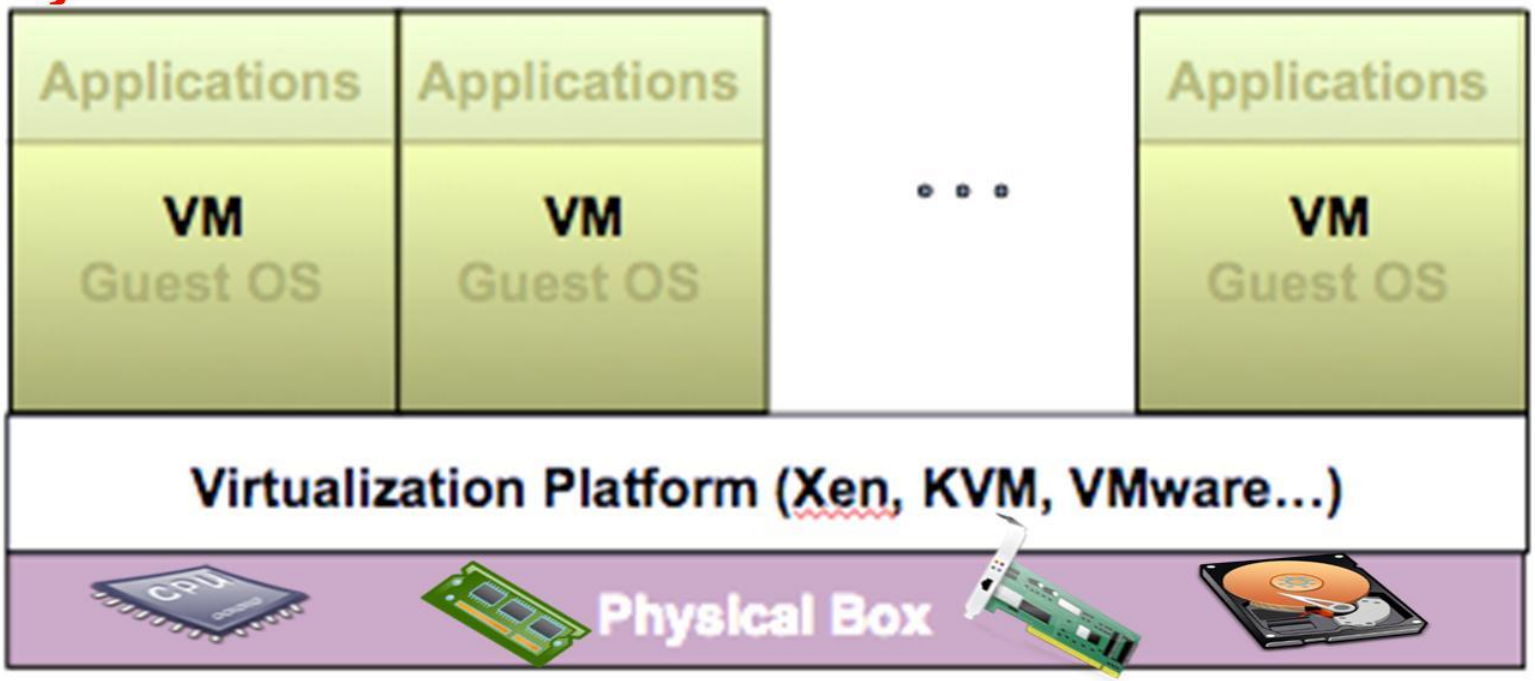
Virtualization System

- A system *pretends* to be *two or more of the same system*.
- *Virtualization layer* partitions *physical resource* of the *underlying physical server* into multiple *Virtual Machines (VMs) with different workloads*.



Virtualization Architecture

- A *Virtual Machine (VM)* is an *isolated runtime environment* (***guest OS*** and ***applications***)
- ***Multiple VMs*** can ***run*** on a ***single physical system***



Virtualization Overview

- VMs can be scaled ***up*** and ***down*** on demand with a high level of resources' abstraction.

- Virtualization enables:
  - ***High reliable***, and ***agile deployment mechanisms***, and ***management*** of ***services***

- Virtualization provides on-demand ***cloning*** and ***live migration*** services which improve ***reliability***.

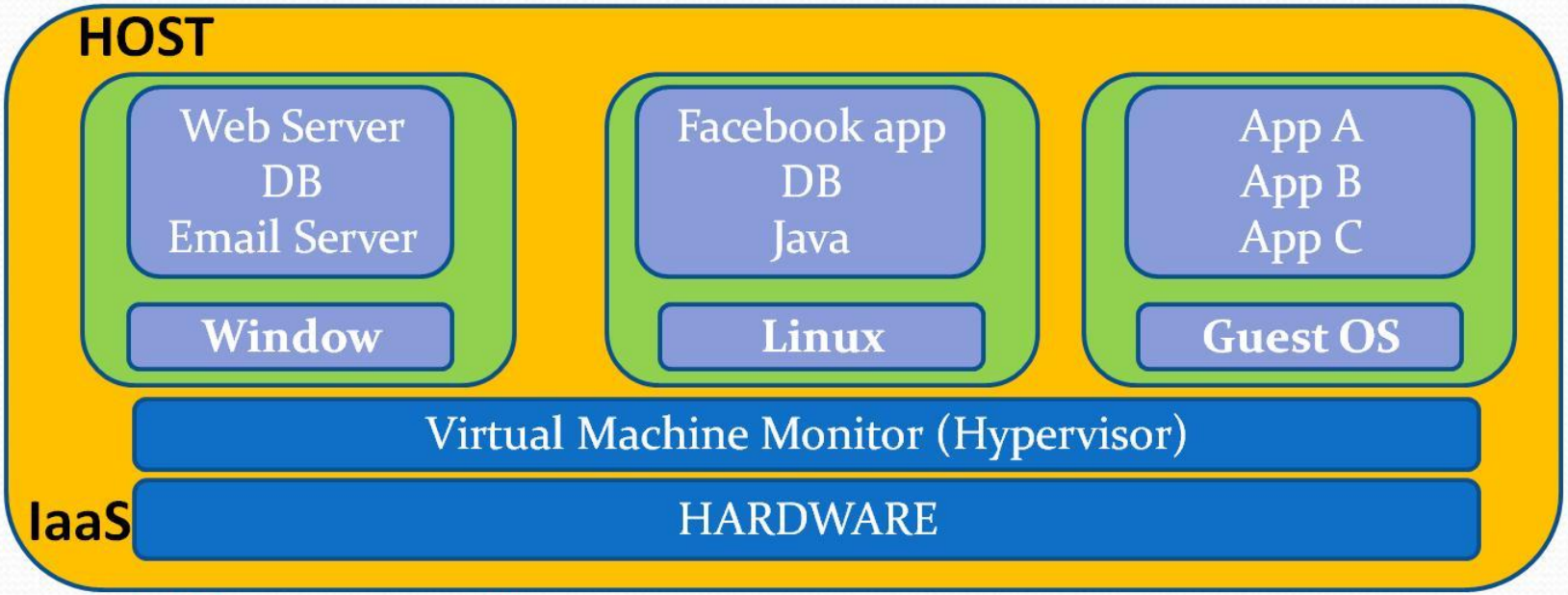
Virtualization Overview

Fundamental Idea :

- Abstract hardware of a single computer into several different execution environments by
  - Creating virtual system (**virtual machine**, or **VM**) on which operating systems and/or applications can run
    - (i.e., Virtualization creates VMs , and a VM can run both OS and application)
- Single physical machine can run ***multiple operating systems concurrently***, each in its ***own virtual machine***

Virtualization

VIM: Virtualization Infrastructure Management



- **Several Components**
  - **Host** – underlying hardware system
  - **Virtual Machine Manager (VMM)** or **hypervisor** – creates and runs virtual machines by providing interface that is ***identical*** to the host
  - **Guest** – process provided with virtual copy of the Host
    - Usually an operating system

Virtual Machine, Guest Operating System & VMM (Virtual Machine Monitor)

Virtual Machine (VM)

- A representation of a real machine using software that provides an operating environment which can run **Host** or **Guest OS**
- A VM provides interface identical to underlying **bare hardware**
  - ✓ i.e. all devices, interrupts, memory, page tables etc.

Guest Operating System

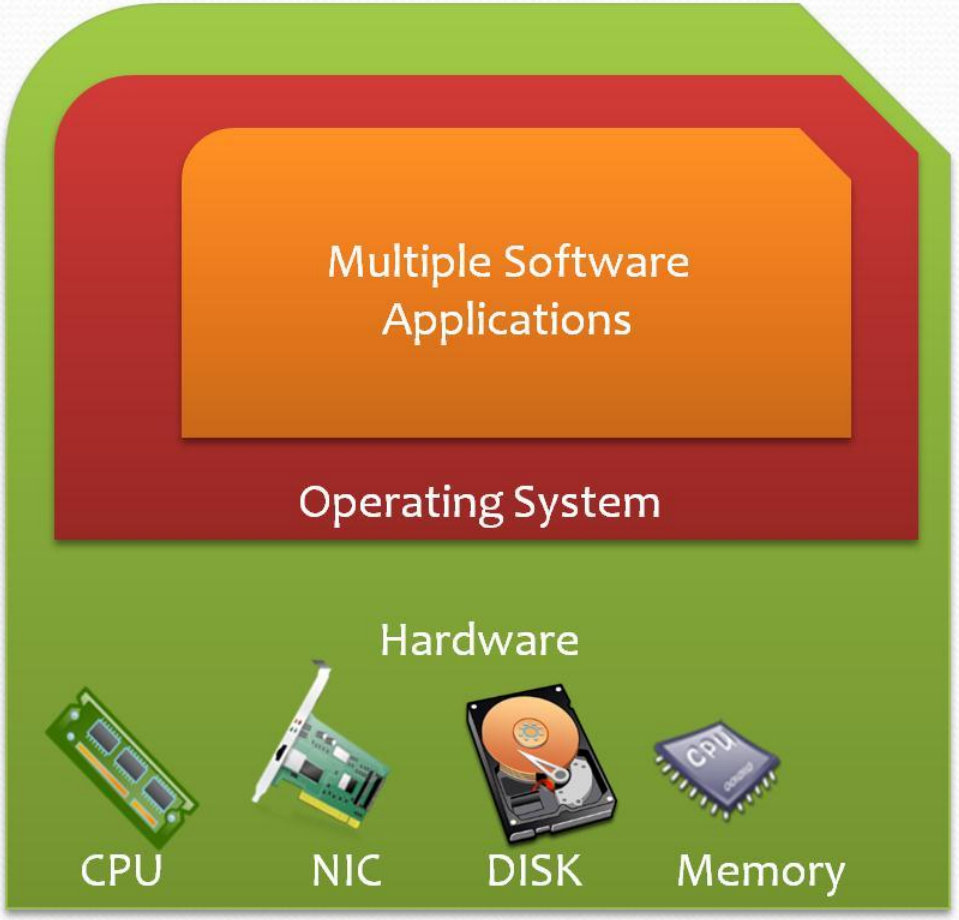
An operating system running in a virtual machine environment that would otherwise run directly on a separate physical system.

Virtualization Layer

Middleware between the underlying hardware and virtual machines represented in the system, also known as ***Vrtual Machine Monitor*** **(VMM)** or ***hypervisor***.

Server Without Virtualization

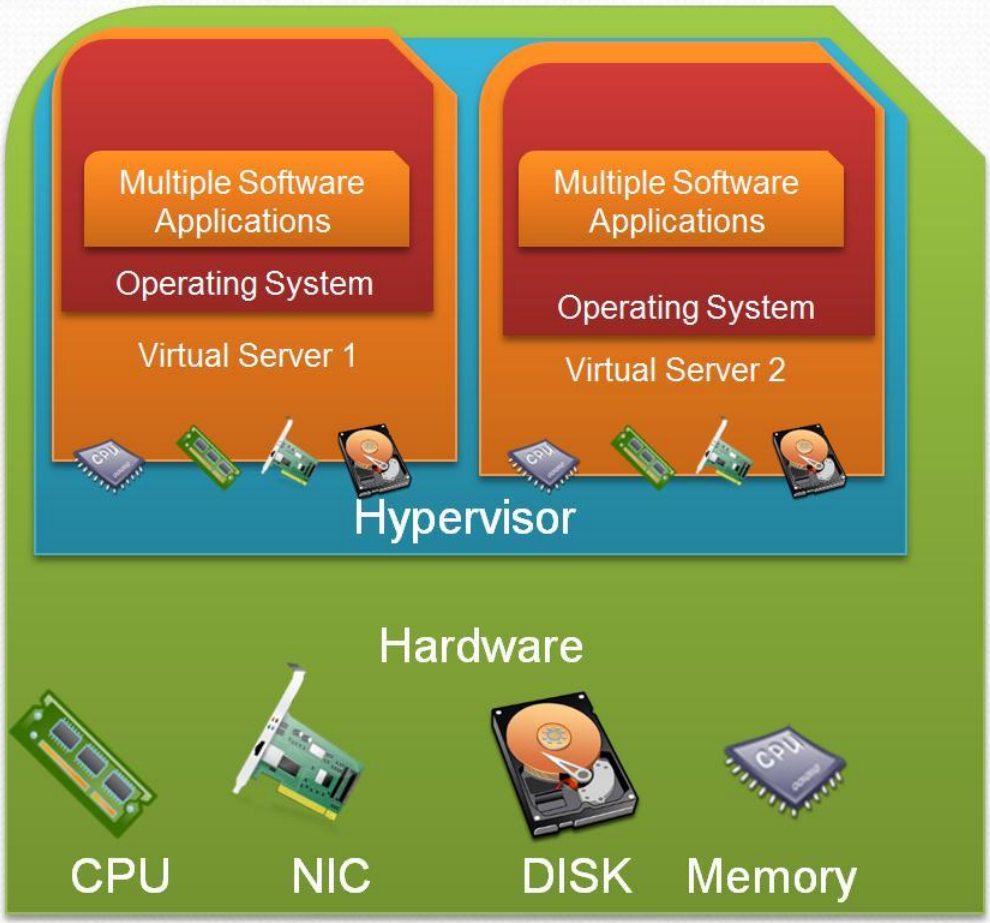
- ***Single OS*** can run at a time within a server.
- Software and hardware tightly coupled
  - *Running* multiple applications on same machine creates conflict
  - *Under* utilization of resources.
  - *Inflexible* and *costly* infrastructure.
  - Hardware changes require manual effort and access to the physical server.



(Courtesy of VMWare, 2008)

Server With Virtualization

- Hardware-***independence*** of OS and applications
- Can run *multiple OSs simultaneously*.
- *Each OS* can have *different hardware configuration*.
  - *Efficient utilization* of hardware resources.
  - Each virtual machine is independent and can be ***provisioned*** any time .
  - *Save electricity*, initial *cost* to buy servers, *space* etc.
  - *Easy* to manage and monitor virtual machines centrally.



(Courtesy of VMWare, 2008)

Hypervisor

A hypervisor

- Virtual Machine Manager/Monitor (VMM), or virtualization manager,
- A software that allows multiple ***OSs*** (guest) to share ***a single hardware host***.
- Each guest OS appears to have the host's processor, memory, and other resources all to itself.
- However, the hypervisor is actually

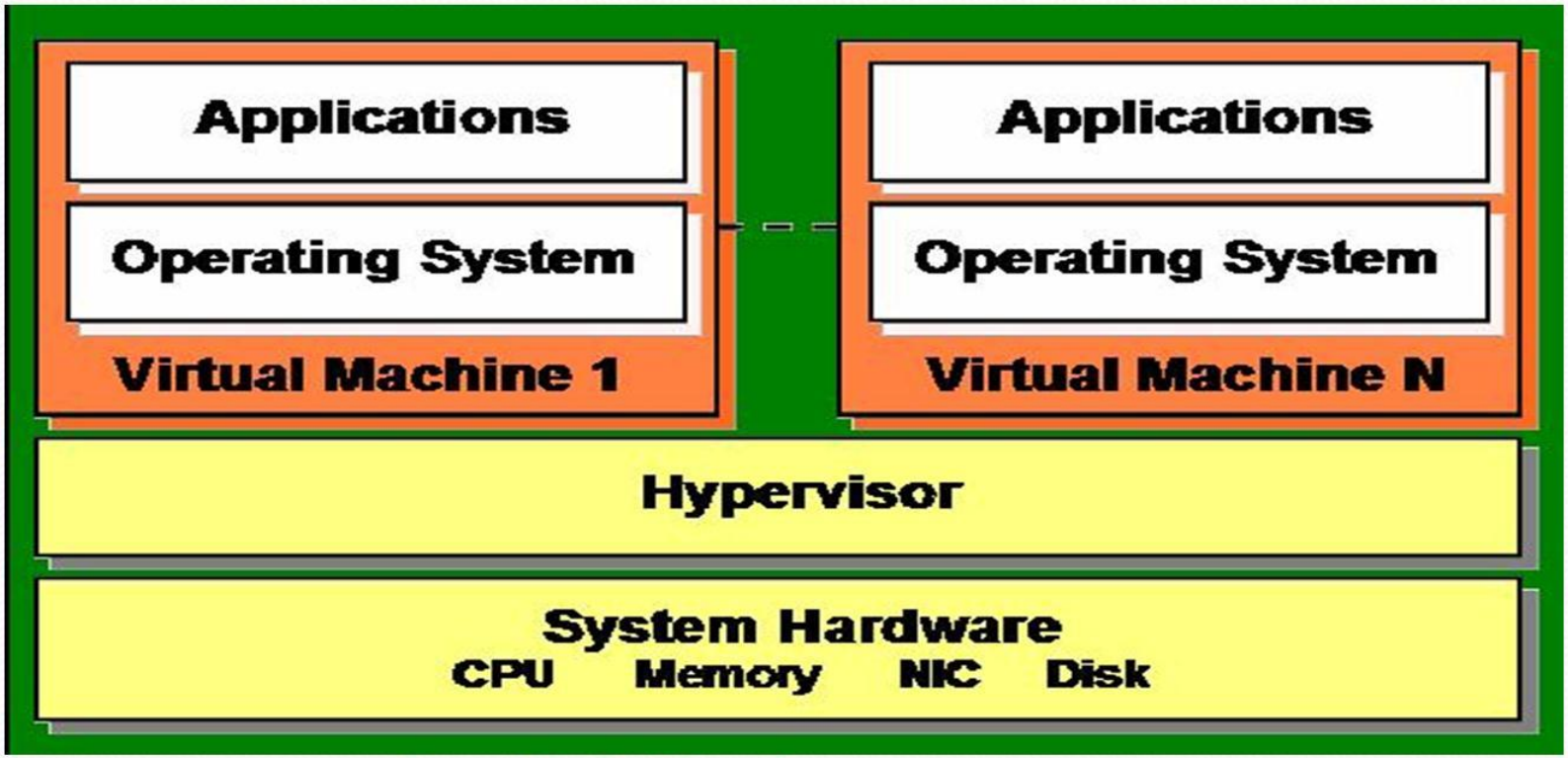
By

- ✓ ***Controlling*** the host processor and resources,
- ✓ ***Allocating*** what is needed to each operating system in turn, and
- ✓ ***Making sure*** that the guest operating systems (called Virtual Machines(VMs)) cannot disrupt each other.

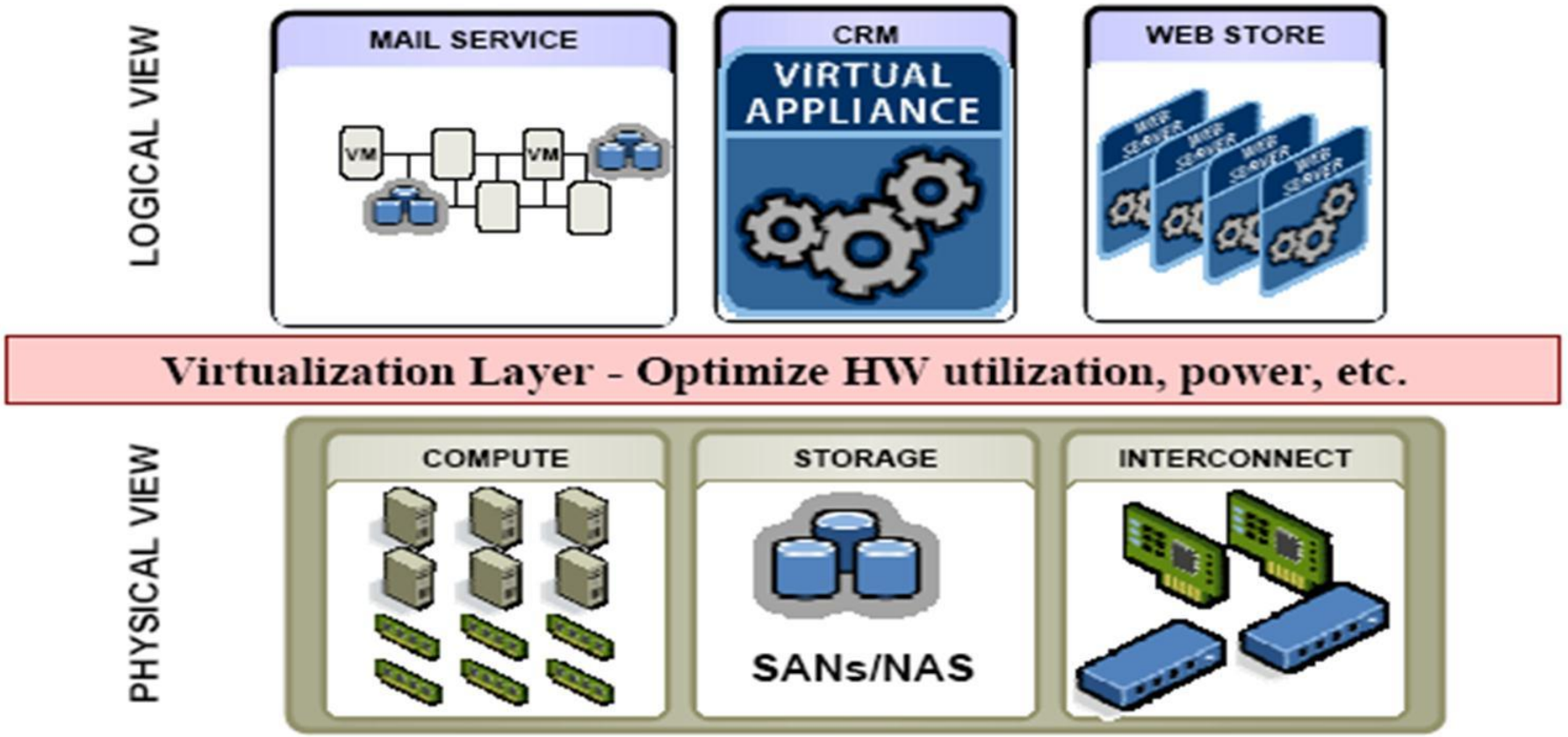
Hypervisor

- Virtualization Software
  - ✓ VMWare, KVM, Xen, QEMU

The term ***hypervisor*** is a variant of ***supervisor***, a traditional term for the kernel of an operating system: the ***hypervisor*** is the ***supervisor*** of the ***supervisor***, with ***hyper-*** used as a stronger variant of ***super***



User's view of virtualization



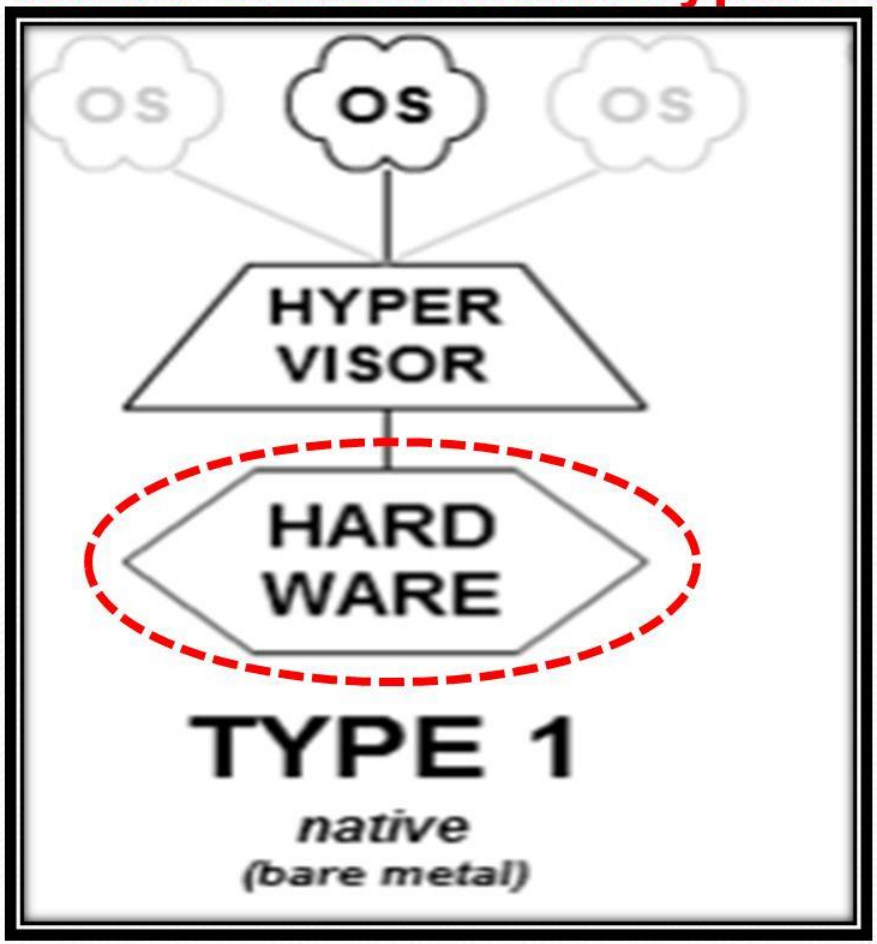
(Courtesy of VMWare, 2008)

Hypervisor Types

Hypervisor Types

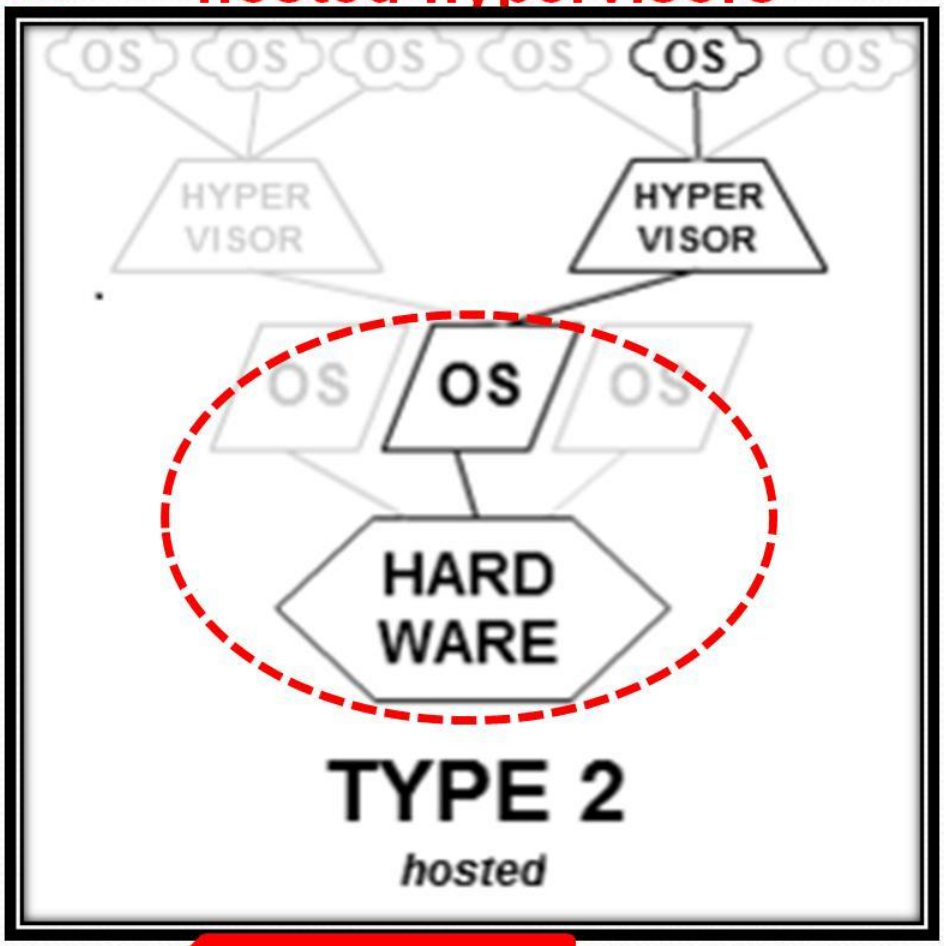
Type-1 (Full Virtualization)

native or bare-metal hypervisors



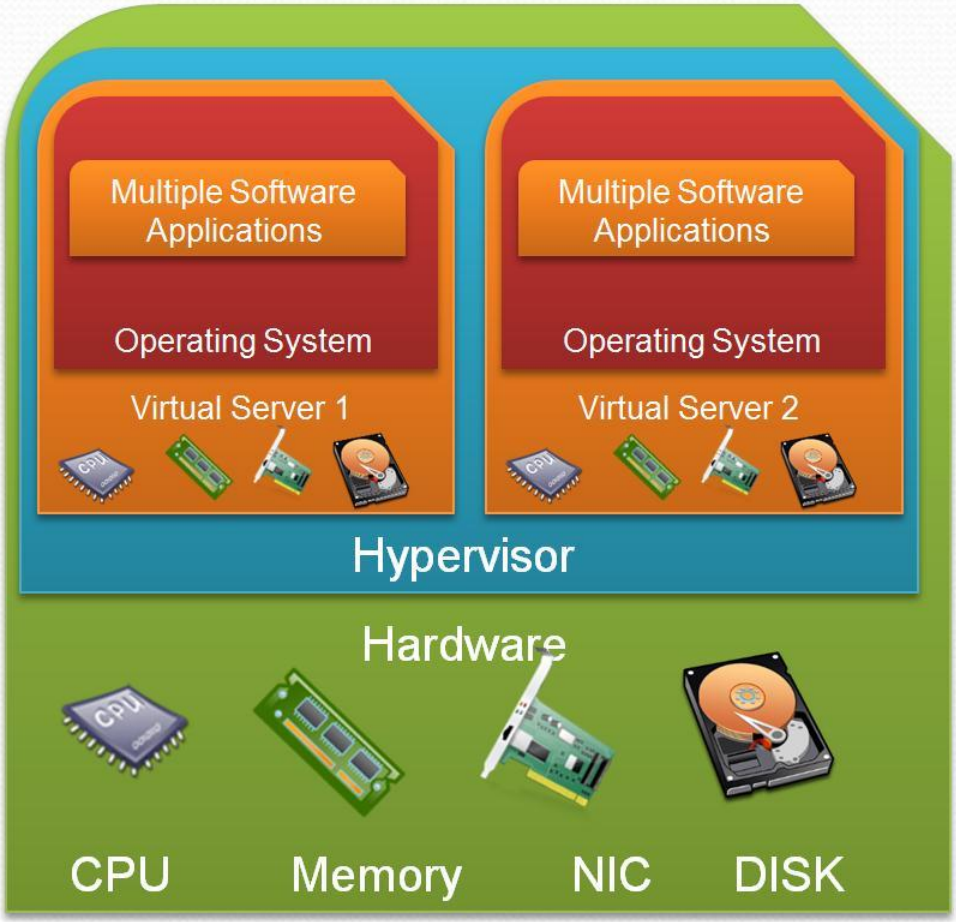
Type-2 (Para Virtualization)

hosted hypervisors



Full Virtualization

- It is called "***native or bare-metal hypervisors***"
- It directly sitting on top of the **bare hardware** devices
- Hypervisors Enable to run multi- unmodified ***guest operating system***
- Guest OS is not aware that it is being virtualized.
- **Note:** No ***host OS*** is used here



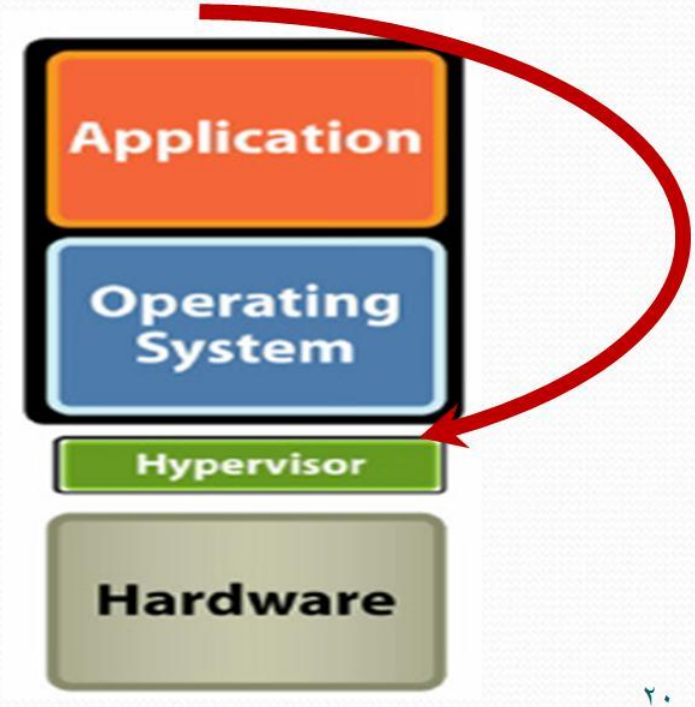
e.g.: **VMware** uses a combination of direct execution and binary translation techniques to achieve full virtualization of server systems.

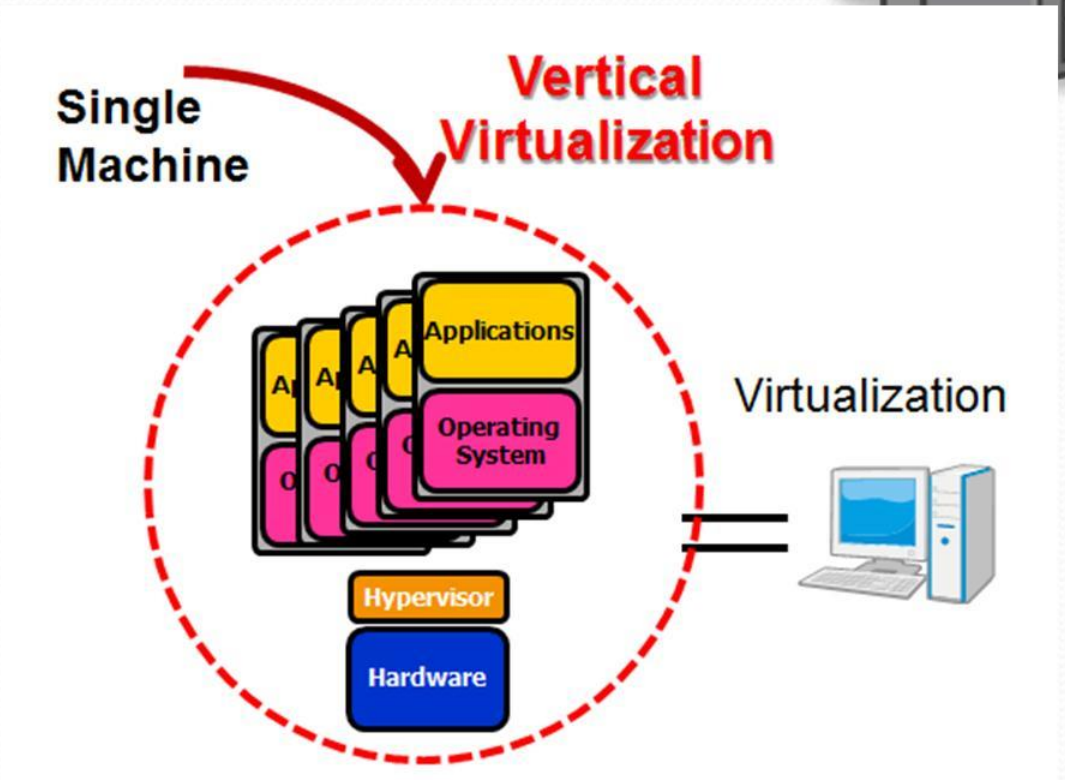
Full Virtualization Concepts

- A ***hypervisor*** is ***a software virtualization technique*** allowing multiple operating systems, called ***guests*** to run on a host machine.
- It is called the ***Virtual Machine Monitor*** (***VMM***).

The Existing Role of the Operating System

*Virtualization is Based on Insertion a **Hypervisor** on Top of Hardware*




Single Machine
Vertical Virtualization
Applications
Operating System
Hypervisor
Hardware
Virtualization

Full Virtualization

- A certain kind of virtual machine environment that ***provides a complete simulation of the underlying hardware.***
- The result is a system in which ***all software (including all OS's) capable of executing on the raw (bare) hardware***

Full virtualization has proven highly successful

- **Sharing a computer system among multiple users**
- **Isolating users from each other (and from the control program) and**
- **Emulating new hardware to achieve:**
  - ✓ **Improve reliability,**
  - ✓ **Security, and**
  - ✓ **Productivity.**

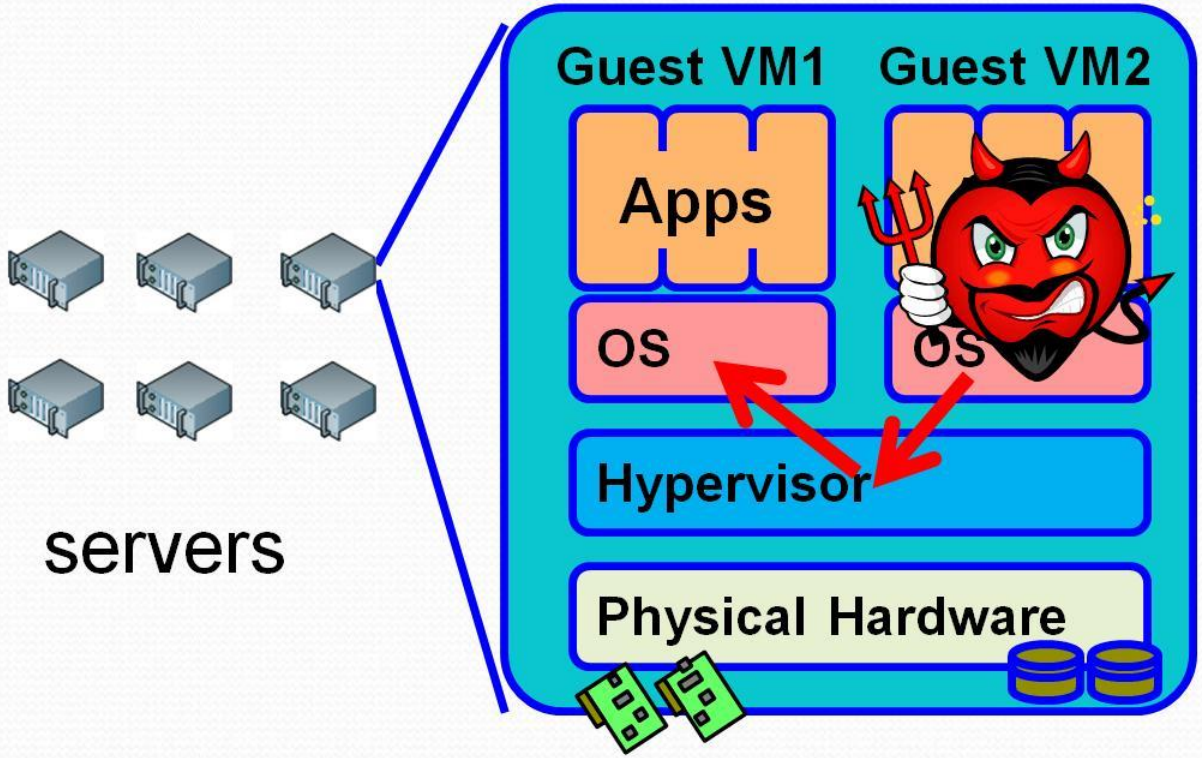
Full Virtualization -- Challenges

1) Security issues -- Interception
2) Simulation of privileged operations -- I/O instructions
3) The effects of every operation performed within a given virtual machine must be kept within that virtual machine – virtual operations cannot be allowed to alter the state of any other virtual machine, the control program, or the hardware (Encapsulation).
4) Some machine instructions of guest virtual machine can be executed directly by the hardware,
   - E.g., memory locations and arithmetic registers.
5) Some instructions of guest virtual machine cannot be allowed to execute directly; instead they must be trapped and simulated.
   - Such instructions either access or affect state information that is outside the virtual machine.
6) Some hardware is not easy to be used for full virtualization, **e.g.**, x86

Hypervisor Vulnerabilities

Malicious software can run on the same server:

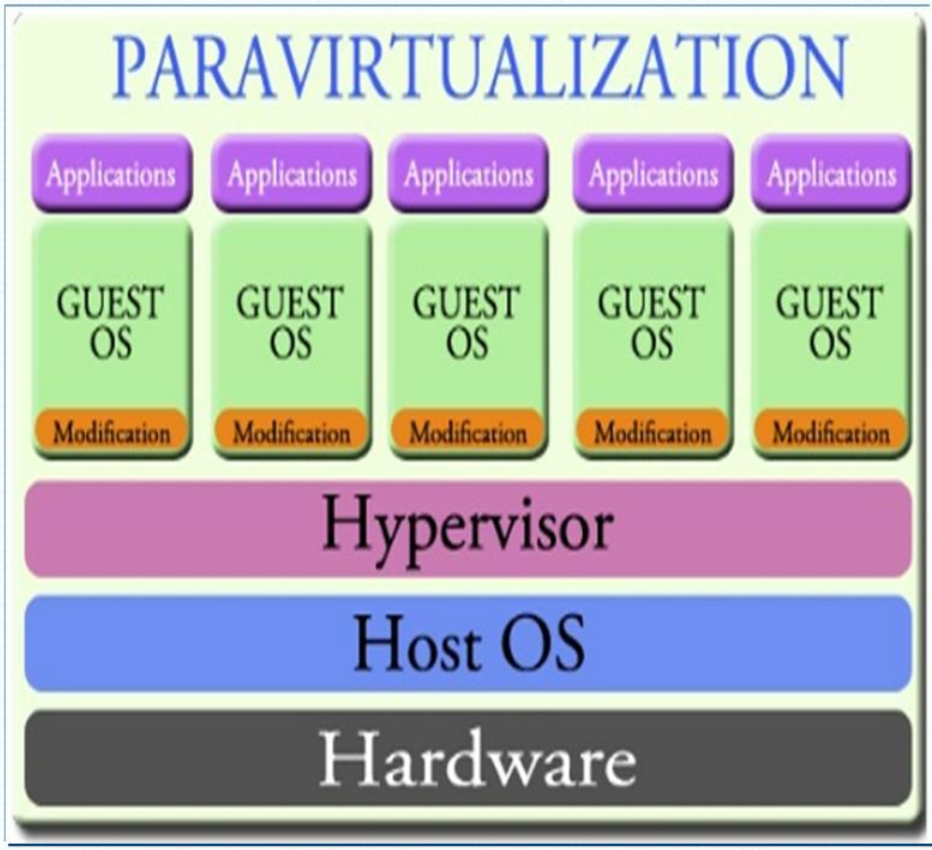
- Attack hypervisor
- Access/Obstruct other VMs



Para Virtualization

Full Vrs. Para

- These hypervisors run on a conventional operating system (**Host OS**) just as other computer programs do.
- A **Guest OS** runs as a process on the **Host OS**.
- Para hypervisors abstract **Guest OSs** from the **Host OS**.
  - By explicitly ***modifying*** **Guest OS.** So that it is aware of being virtualized to allow near native performance.
- Improves performance.
- Lower overhead.

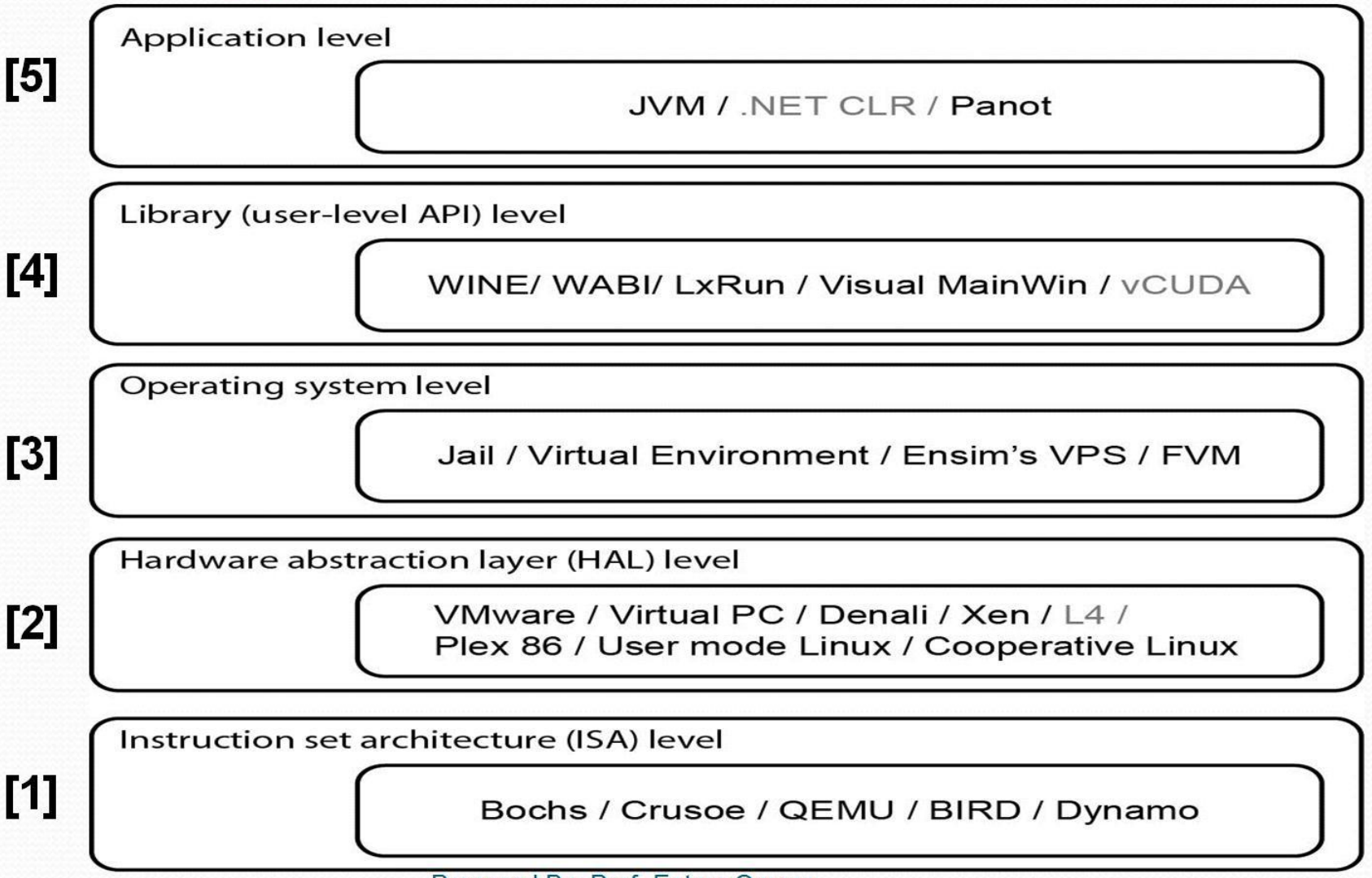


Ex: **Xen** -- modified Linux kernel and a version of Windows XP

Benefits of Virtualization

- ***Consolidation:*** Operate different OS's and applications on one single server
- ***Sharing of resources:*** helps cost reduction
- ***Isolation***: Virtual machines are isolated from each other as if they are physically separated
- ***Encapsulation:*** Virtual machines encapsulate a complete computing environment
- ***Hardware Independence:*** Virtual machines run independently of underlying hardware
- ***Portability:*** Virtual machines can be migrated between different hosts.

Virtualization Ranging from *Hardware* to *Applications* in Five Abstraction Levels



[1] *Virtualization at Instruction Set Architecture (ISA) Level:*

Emulating a given ISA by the ISA of the host machine.

- e.g., MIPS binary code can run on an x-86-based host machine with the help of ISA emulation.
  - Typical systems: Bochs, Crusoe, Quemu, BIRD, Dynamo

Advantage:

- It can **run** a large amount of **legacy binary codes** written for ***various processors*** on any given new ***hardware host machines***
- Best application flexibility

Shortcoming & limitation:

- One source ISA instruction may require ***tens*** or ***hundreds*** of native target ISA instructions to perform its function, which is relatively **slow**.
- **V-ISA** requires adding a processor-specific software translation layer in the complier.

[2] *Virtualization at Hardware Abstraction Level:*

Virtualization is performed on top of the hardware (*full Virtualization*).

- It generates virtual hardware environments for VMs, and manages the underlying hardware through virtualization.
- **Typical systems:** VMware, Virtual PC, Denali

Advantage:

- Has higher performance and good application isolation

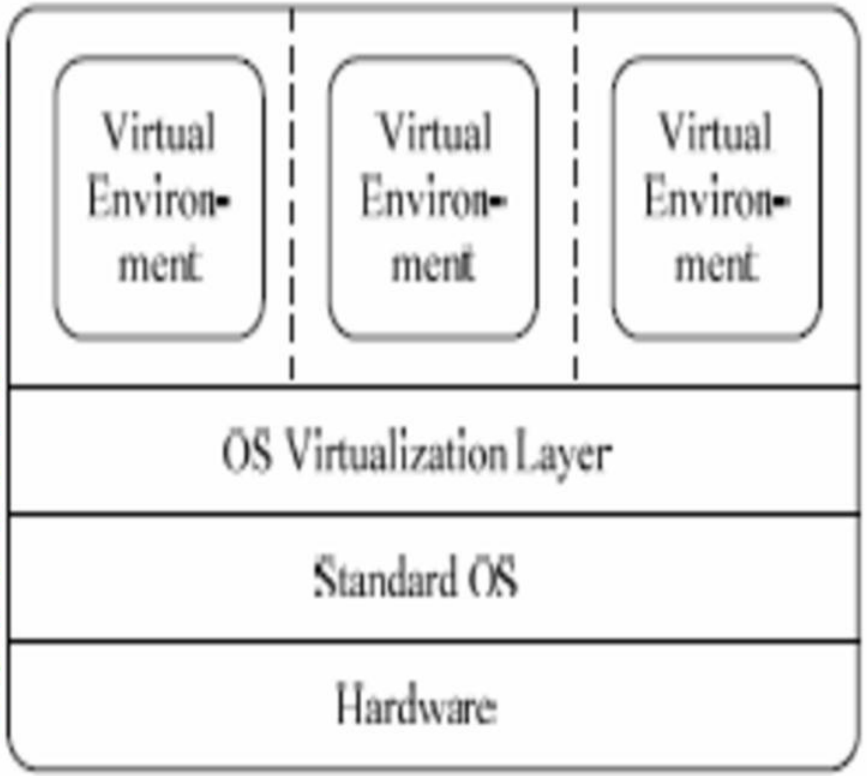
Shortcoming & limitation:

- Very expensive to implement (complexity)

[3] Virtualization at OS Level:

It is an abstraction layer between *traditional OS* and *user applications*

This virtualization layer creates ***isolated containers*** from a ***single physical server*** and the OS-instance to utilize the hardware and software in datacenters.



Advantages of OS Extension for Virtualization

1. VMs at **OS-level** has minimum startup/shutdown costs
2. **OS-level** VM can easily synchronize with its environment

Shortcoming & limitation:

1. All VMs at the **OS-level** must have ***the same kind of Host OS***
   - restrict ***application flexibility*** of different VMs on the same physical machine.
2. Poor application ***flexibility*** and ***isolation***.

[5] User-Application Level: (SaaS)

It virtualizes an application

- This layer sits as an application program ***on top of an operating system*** and exports an abstraction of a VM that can run programs written and compiled to a particular abstract machine definition.
- Typical systems: JVM , NET CLI , Panot

Advantage:

- It has the best ***application isolation***
- ***Support code portability***

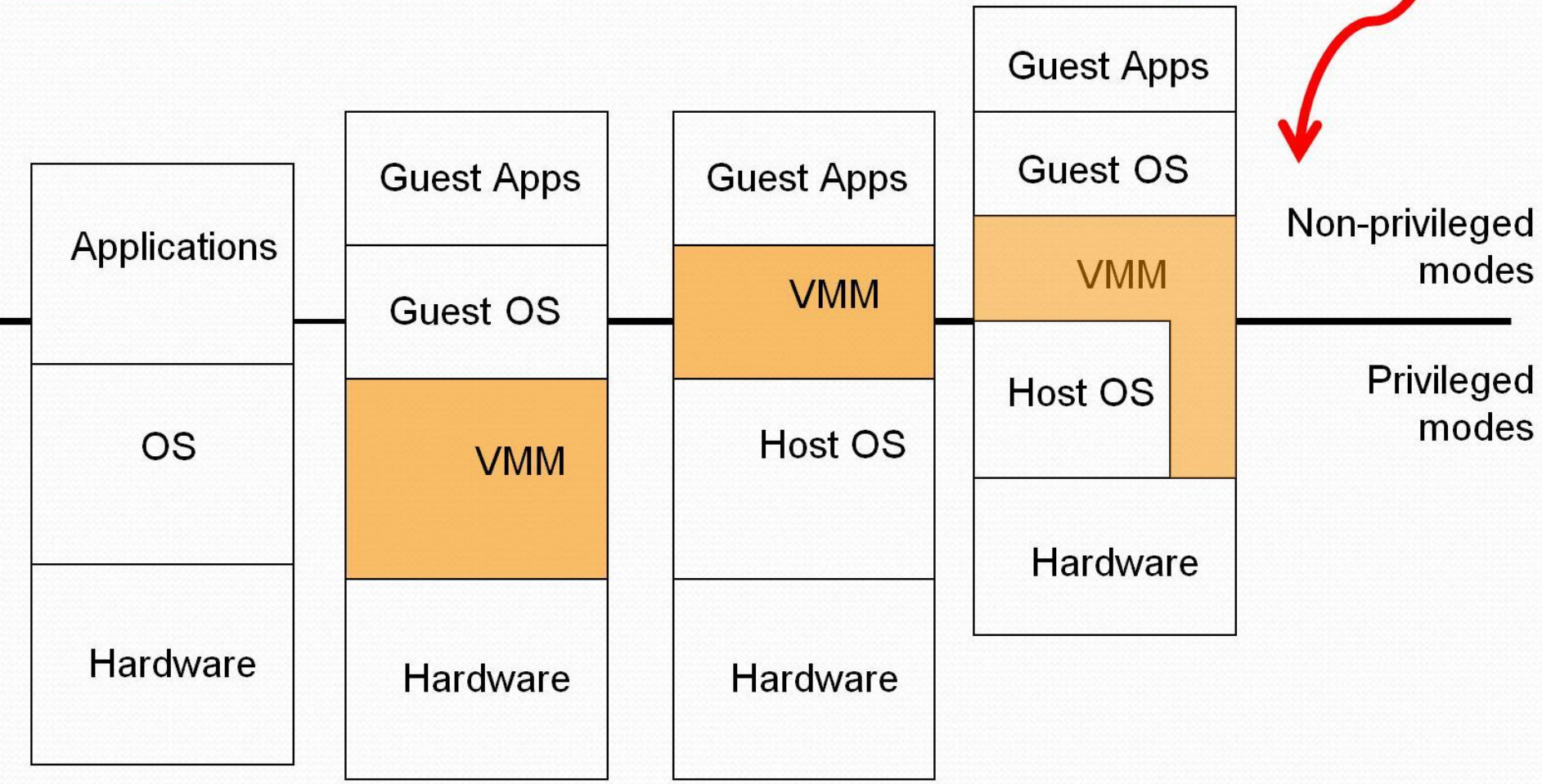
Shortcoming & limitation:

- low performance, low application flexibility and high implementation complexity.

Generally; Virtualization

- It is the enabling technology which creates virtual machines that allows a single machine to act as if it were many machines ***(OS-Level Virtualization)***.
- Sharing the resources of a single hardware across multiple environments ***(Full Virtualization)***
- ***Host OS*** provides an abstraction layer for running virtual ***guest OSs*** ***(Para Virtualization)***
  - Enable portability (migration) of virtual servers between physical servers
    - Increase utilization of physical servers

Native and Hosted VM Systems



Confusion…

Full, Para, and OS-Level virtualization

OS-Level Virtualization

- A type of server virtualization technology which works at the OS layer. The *physical server and single instance of the operating system is virtualized into multiple isolated partitions, where each partition replicates a real server*.
- The OS kernel will run a single operating system and provide that operating system functionality to each of the partitions.

Para Virtualization

- Refers to the use of ***software*** to ***allow system hardware to run multiple instances of different operating systems concurrently***, allowing you to run different applications requiring different operating systems on one computer system. The ***operating systems do not interfere with each other or the various applications.***

Terminology

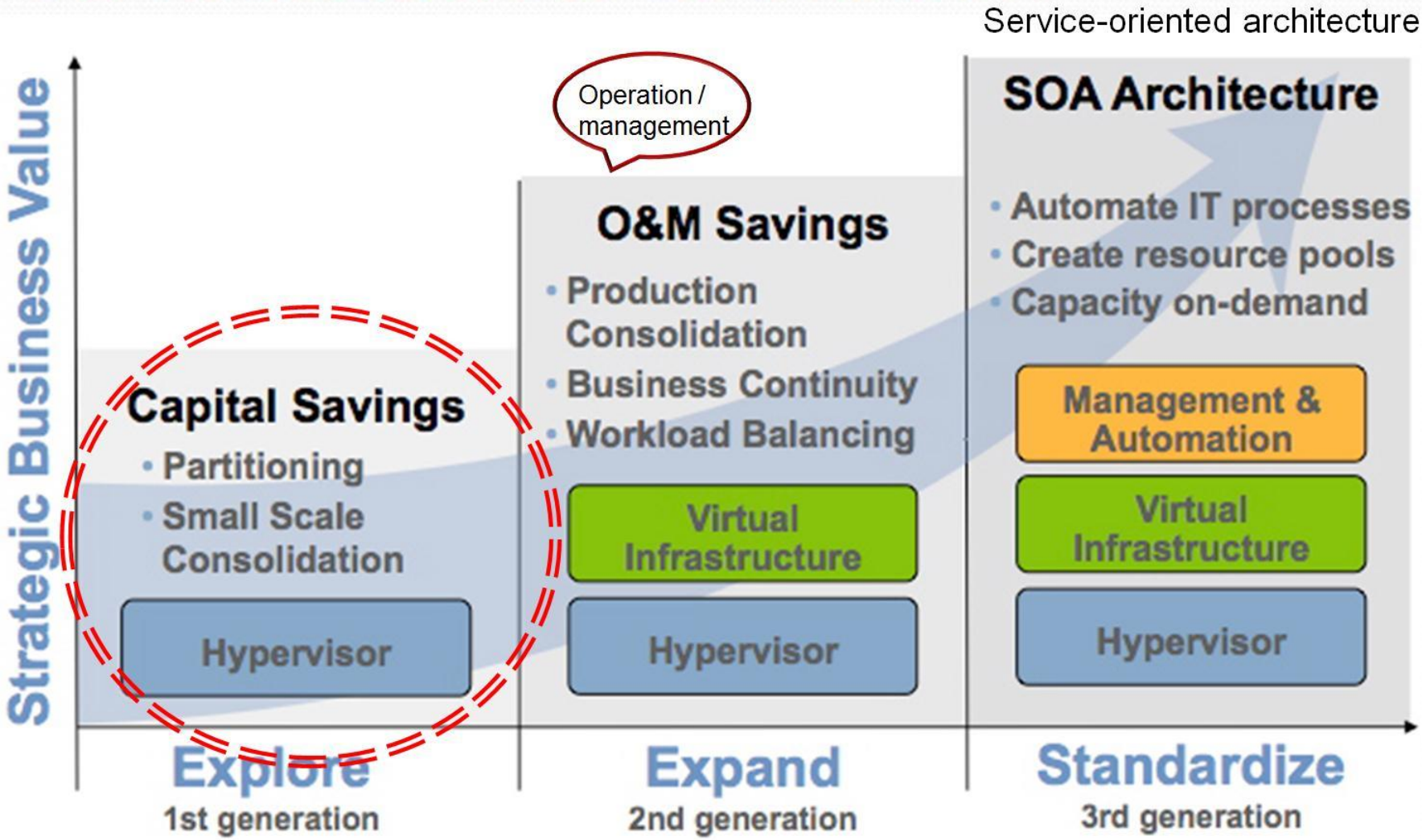
Small Scale Consolidation:

- Operate different OS's and applications ***on one single server***

Production Consolidation:

- A company can achieve ***greater efficiency*** and ***increase profitability*** by ***selling all or part*** of its manufacturing operations.
  - The end result - ***higher profitability*** for the company.

Virtualization Evolution

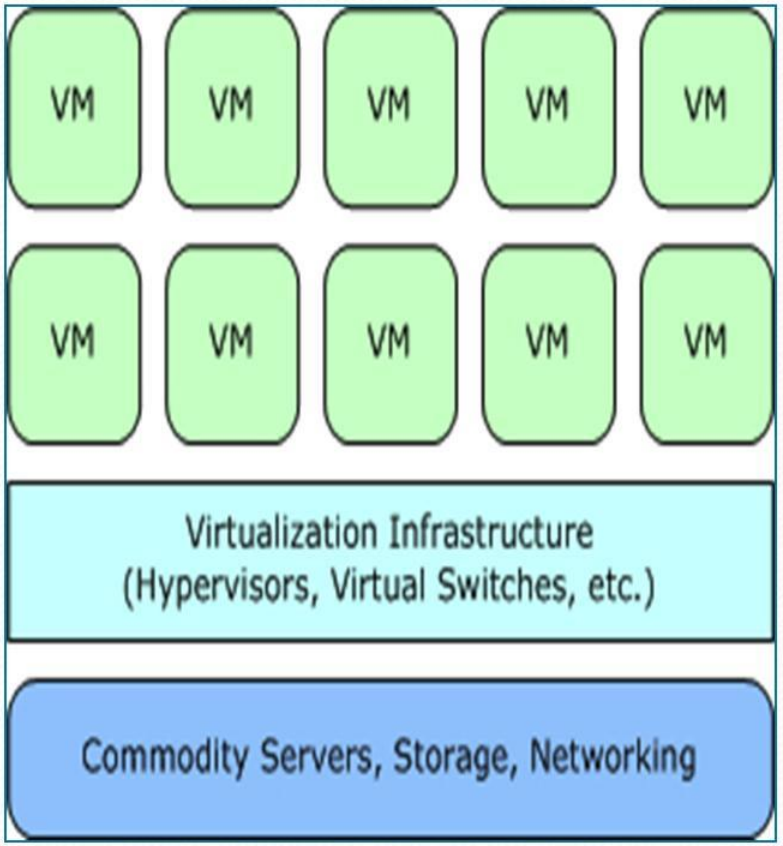


Virtualization in Cloud Computing

Virtualization in Cloud Computing

Cloud computing takes virtualization one step further:

- You don't **need** to **own hardware**
- Resources are **rented** as needed from a cloud
- Various providers allow creating virtual servers:
  - Choose the OS and software each instance will have
  - The chosen OS will run on a large server farm
  - Can instantiate more virtual servers or shut down existing ones within minutes
- You get **billed** only for what you used

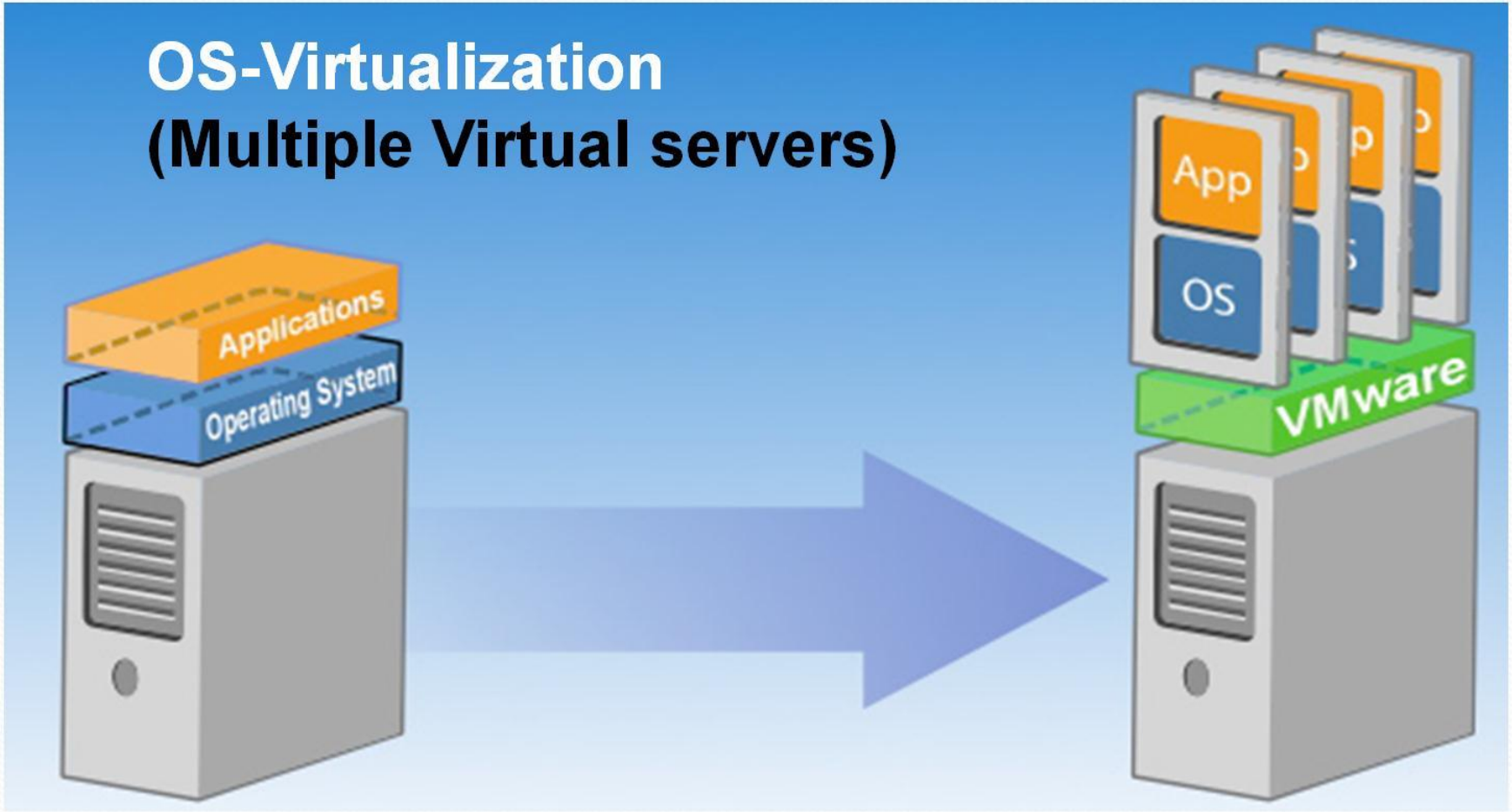


Virtualization Over Cloud Computing

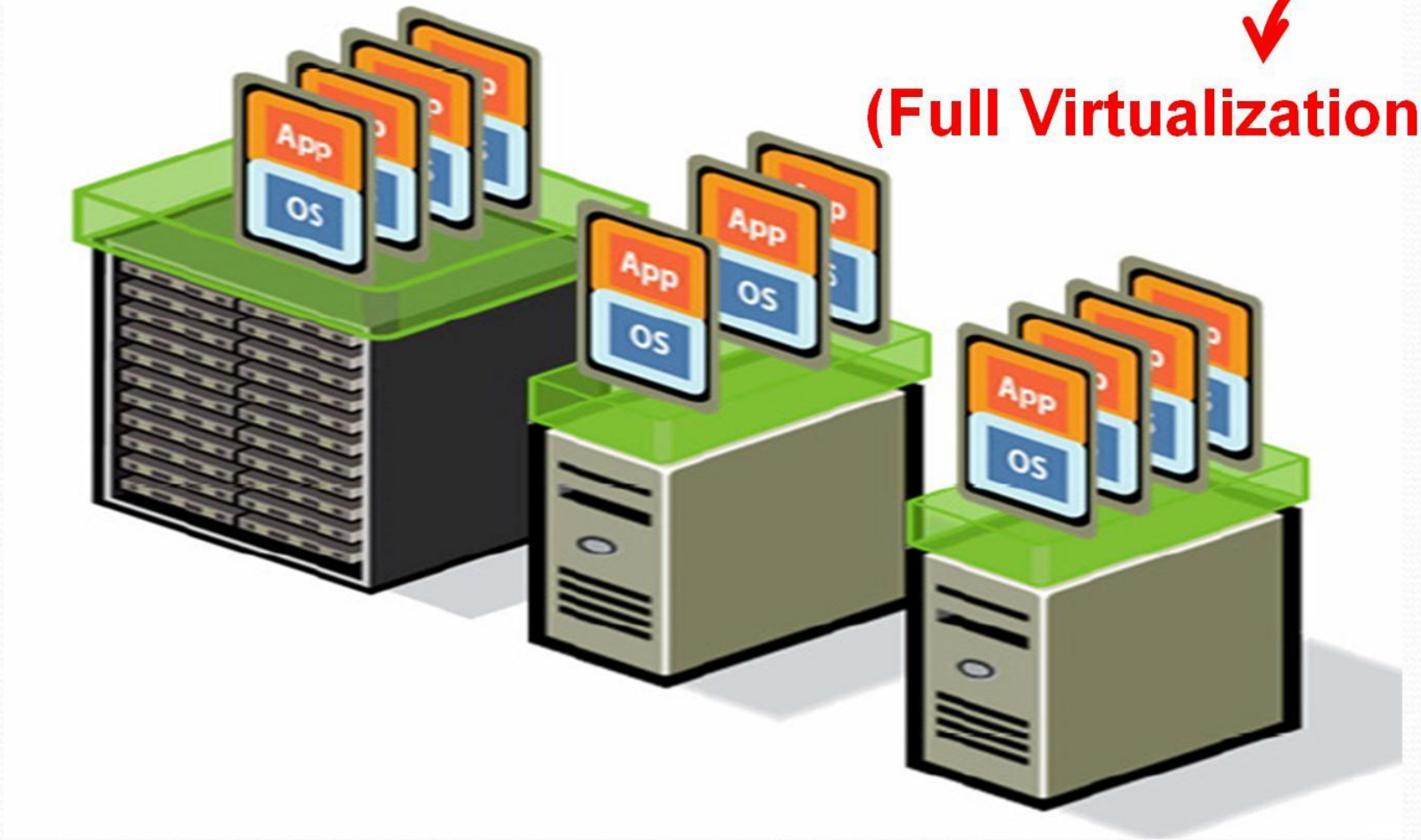
- Benefits of virtualization over cloud computing:
  - ✓ Reduce capital expenses (CAP-EX), and
  - ✓ Reduce maintenance and operation expenses (OP-EX) through server consolidation,
  - ✓ Reduce physical space needed in data centers.
  - ✓ Resource Management, Migration, Maintainability, High availability and Fault tolerance are other benefits.
- Virtualization is implemented using ***hypervisors***.

(cOmmon)Virtualization Allows Transformation a Server for Multiple Applications/OS

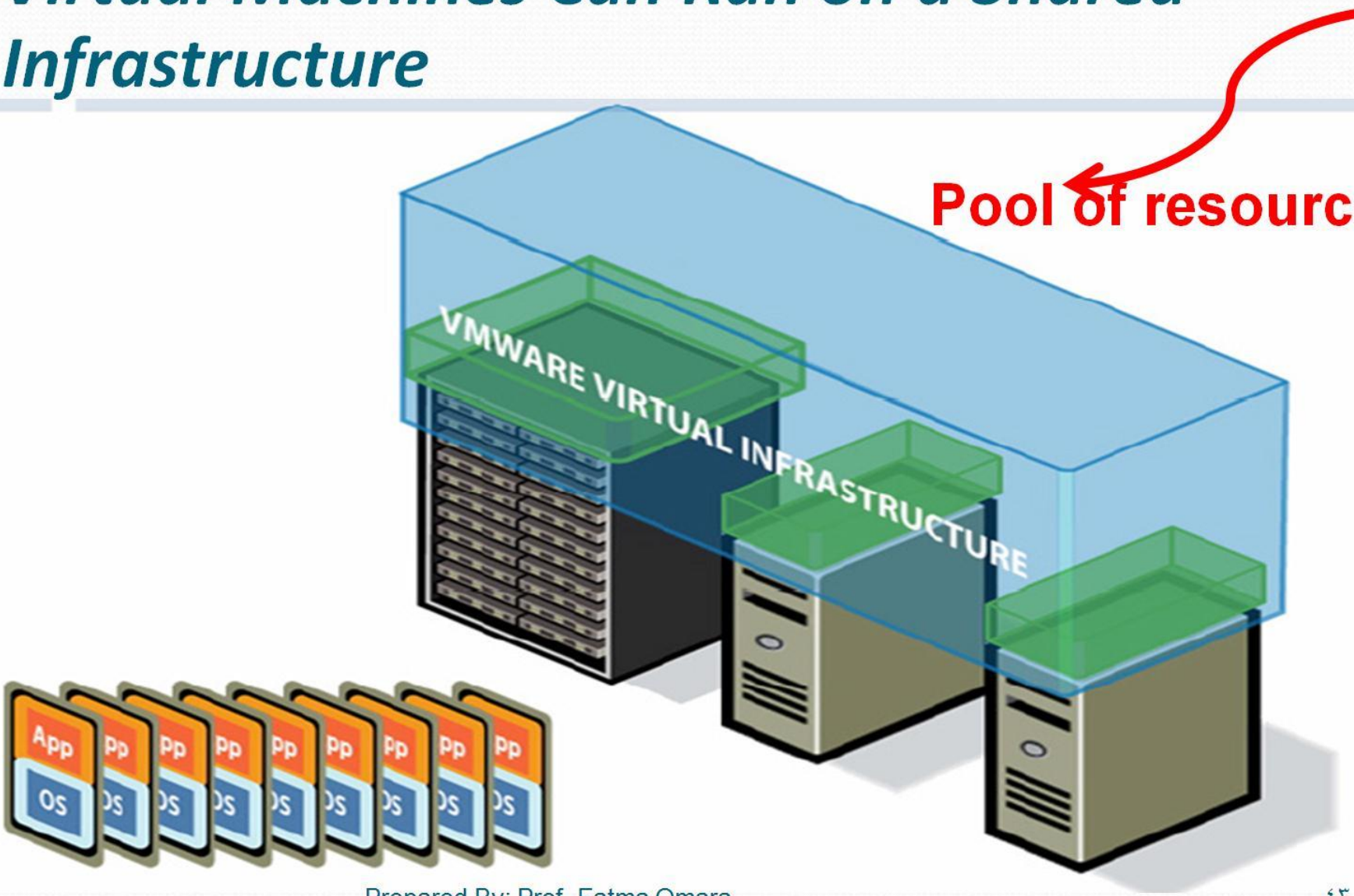
(Vertical Virtualization)



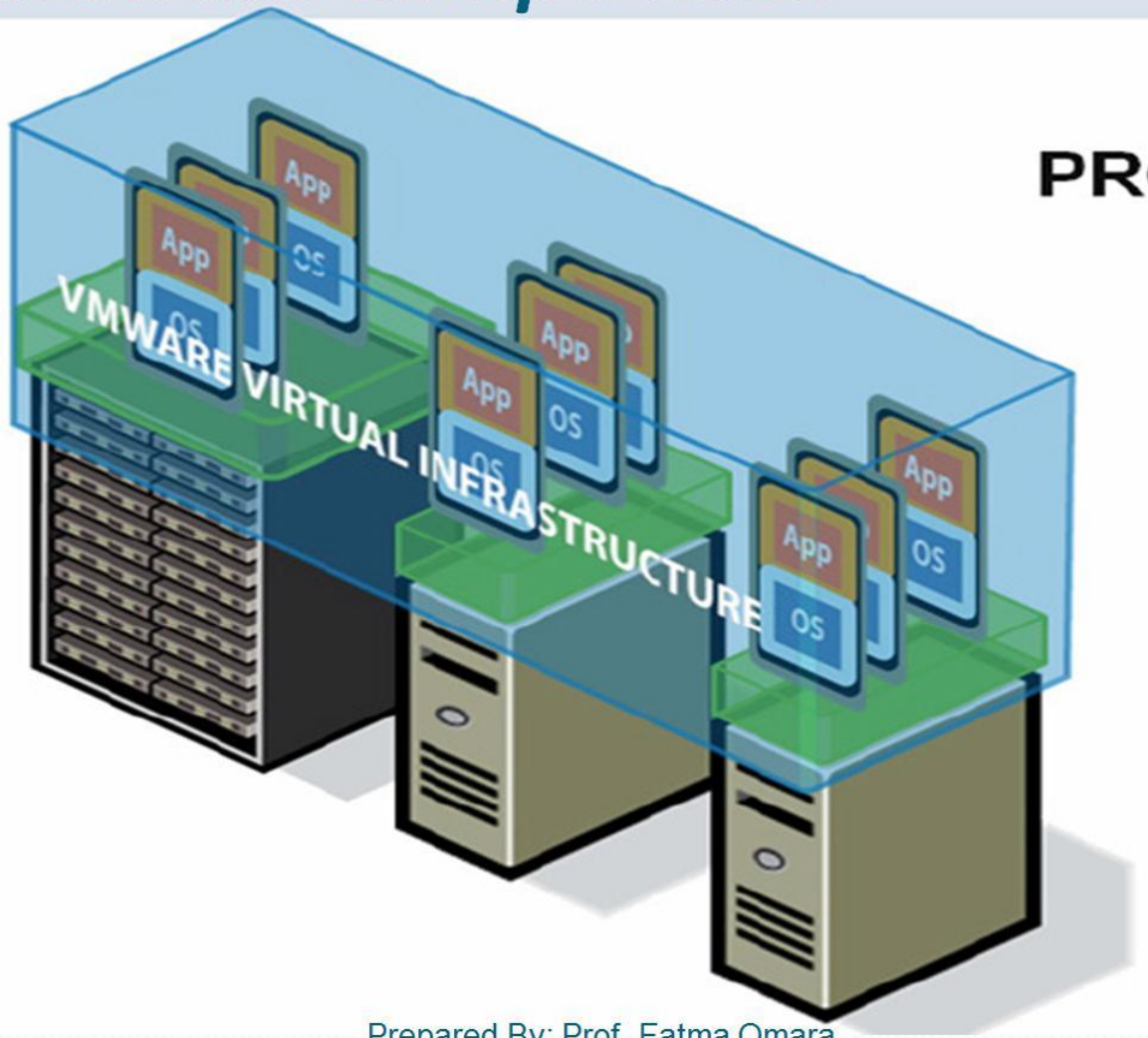
Virtual Machines Run on Any Hardware Configuration



Virtual Machines Can Run on a Shared Infrastructure

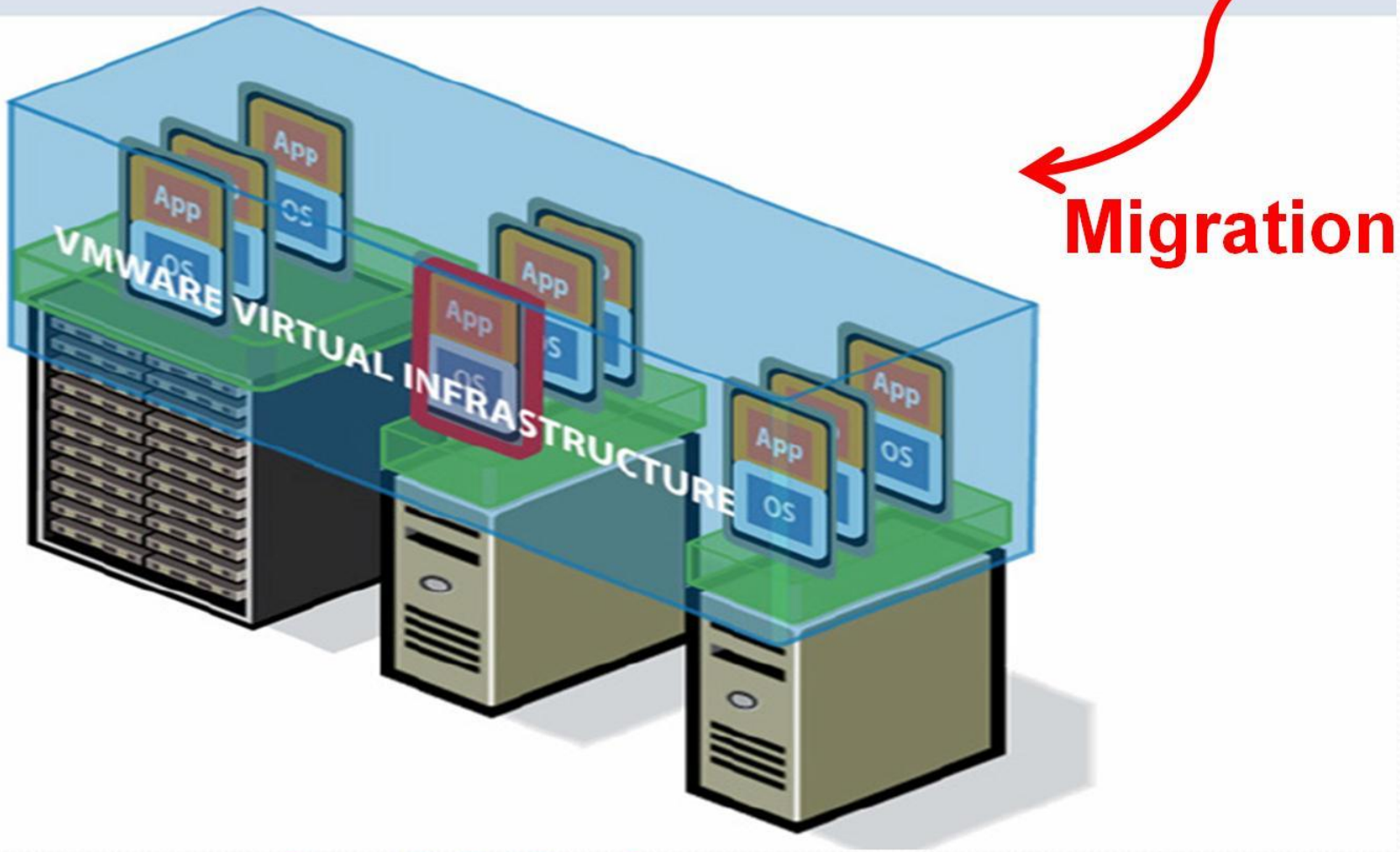


A Single Software Can Span Different Hardware Components

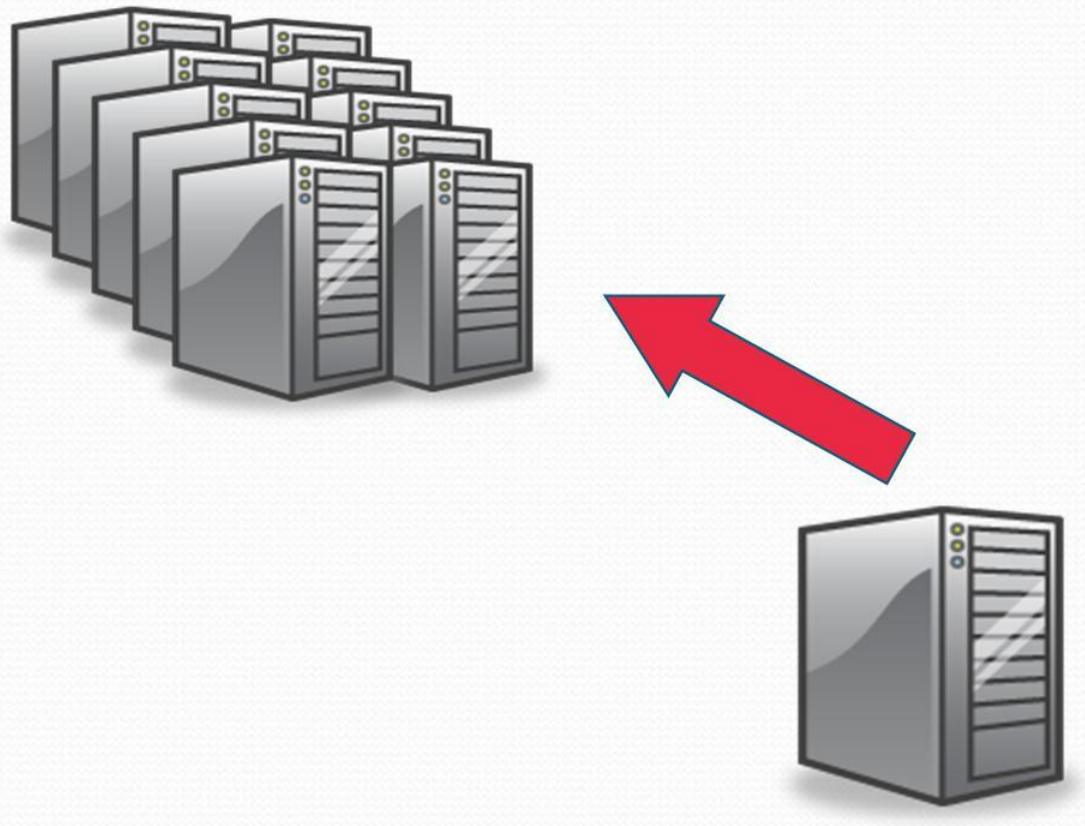


PROVISIONING

Virtualization Allows Moving Applications Without Service Interruption



Data Center Consolidation



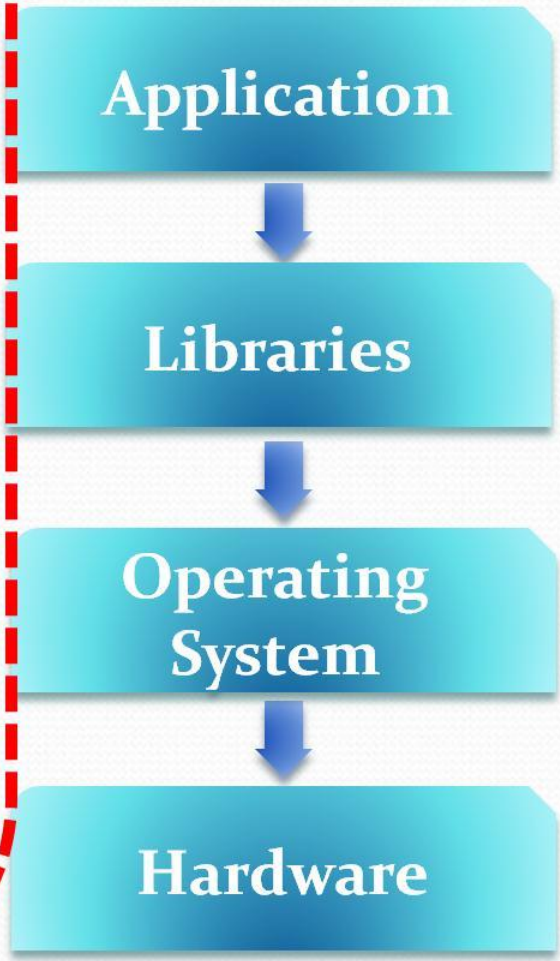
Virtualization

- Creation of a virtual version of hardware using software.
- Runs several applications at the same time on a single physical server by hosting each of them inside their own virtual machine.
  - A physical server can be utilized efficiently.

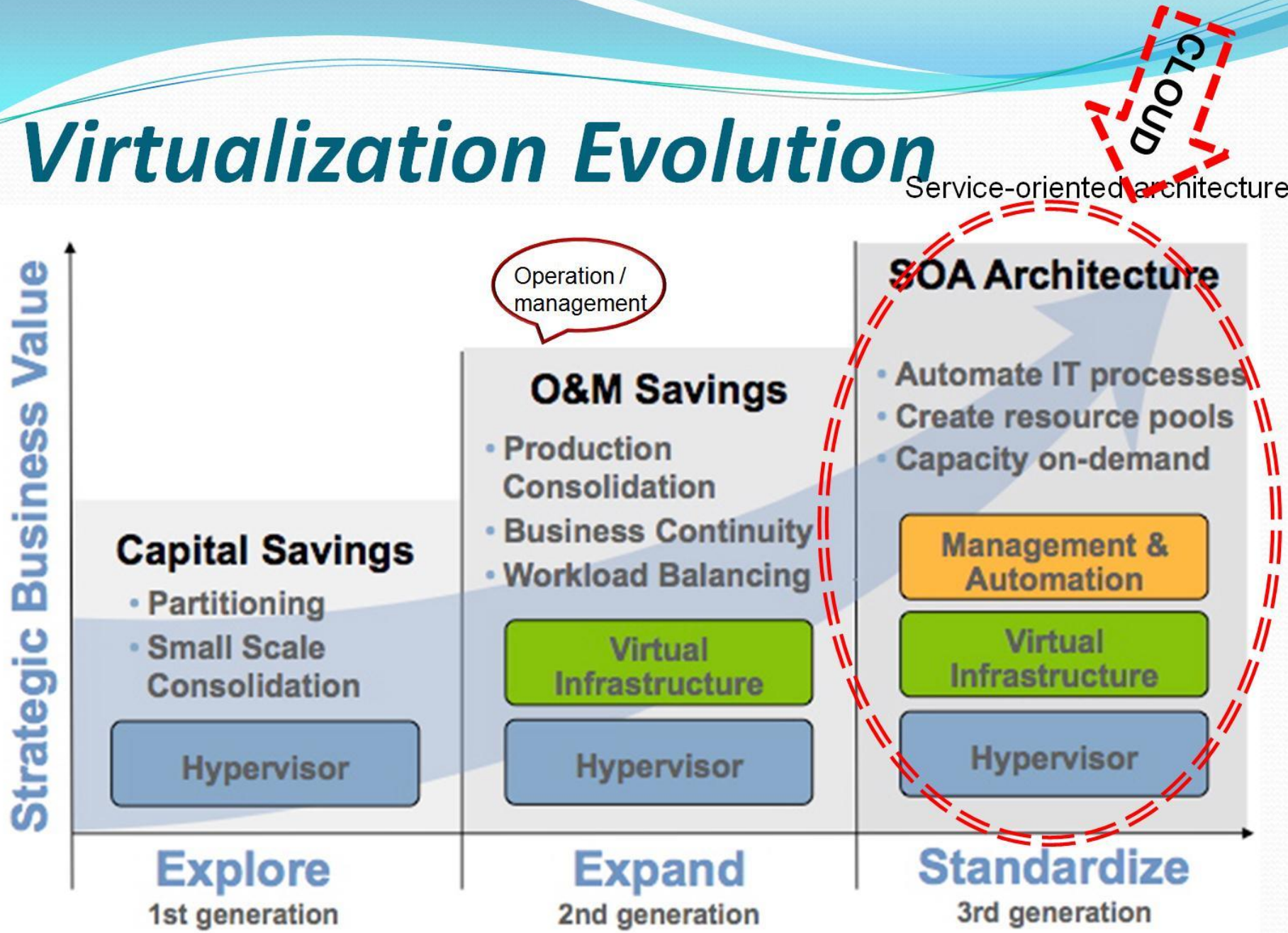
Primary approaches to virtualization

- **Platform virtualization** Ex : Server
- **Resources virtualization**
  - Ex : Storage, Network

Machine Stack showing virtualization opportunities



Virtualization Evolution



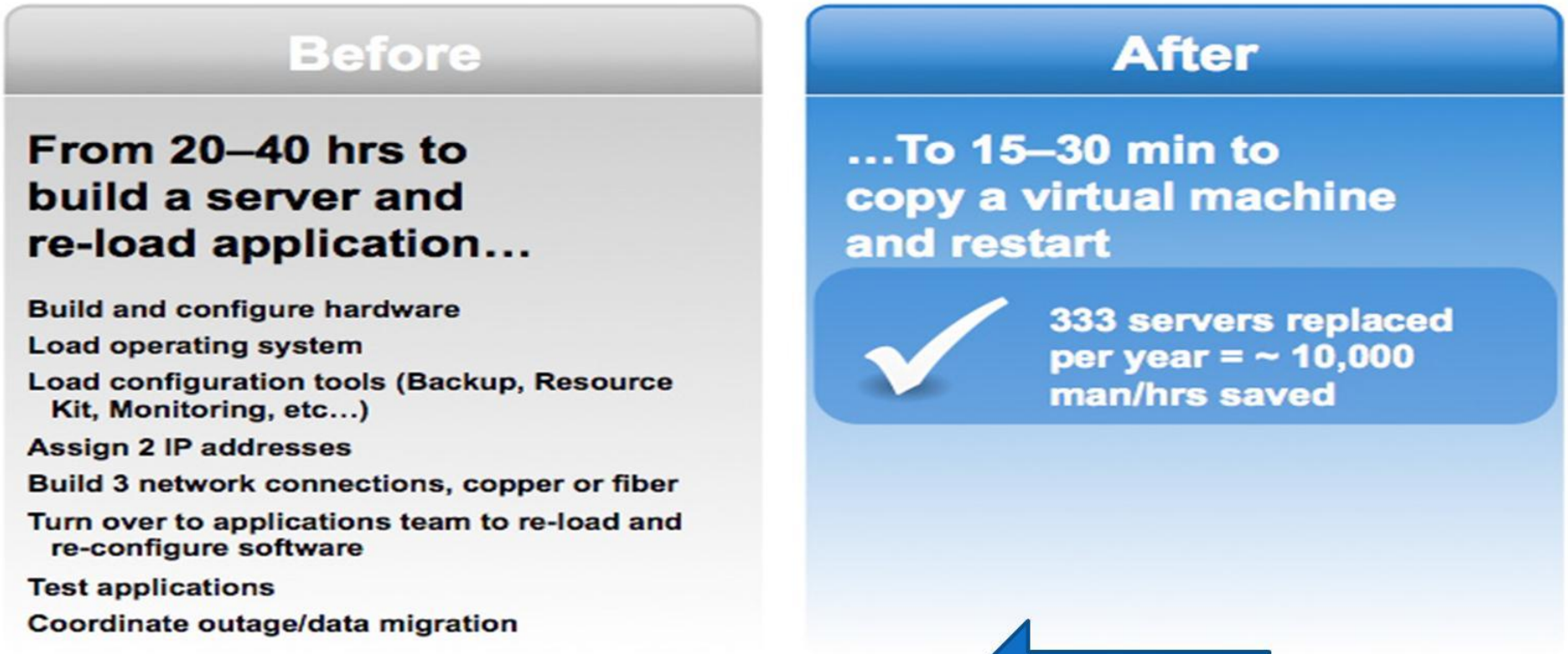
Advantages of Virtualization Over Cloud Computing

- Zero downtime maintenance
- Freedom from vendor-imposed upgrade cycles
- Instant provisioning
- Pooling hardware resource
- Virtual hardware supports legacy operating systems efficiently
- Dynamic resource sharing
- Security and fault isolation
- Business continuity, backups, and automated restoration

Impact of Virtualization Over Man Hours

Operations Require One Staff per 200-400 Virtual Machines

Note: Without virtualization one staff can handle up to **30 VMs**



Impact of Virtualization

Hard cost savings

- 70-80% reduction in data center space, power infrastructure
- $8M cumulative savings since 2003

Operational efficiency

- Server rebuild and application load went from 20-40 hrs =>15-30 min
- 10,000 man hours saved per year

System Virtual Machines Applications

- Implementing Multiprogramming (HPC)
- Multiple single-application virtual machines (SPMD)
- Multiple secure environments
- Managed application environments
- Mixed-OS environments
- Legacy applications
- Multiplatform application development
- New system transition

System Virtual Machines Applications (cont.)

- Management simplification
  - Dynamic provisioning
  - Workload management/isolation
  - Virtual machine migration
  - Reconfiguration
- Virtualization protects IT investment
- Virtualization is a true scalable multi-core work load

Virtualization - Green ICT

The Reality:

- Most servers only use **5-15%** of their capabilities on average, while consuming **60-90%** of their peak power.

The Solution - Virtualization:

- Use one server to host multiple applications.
- Reduce energy consumption
- Reduce CO_2 emissions

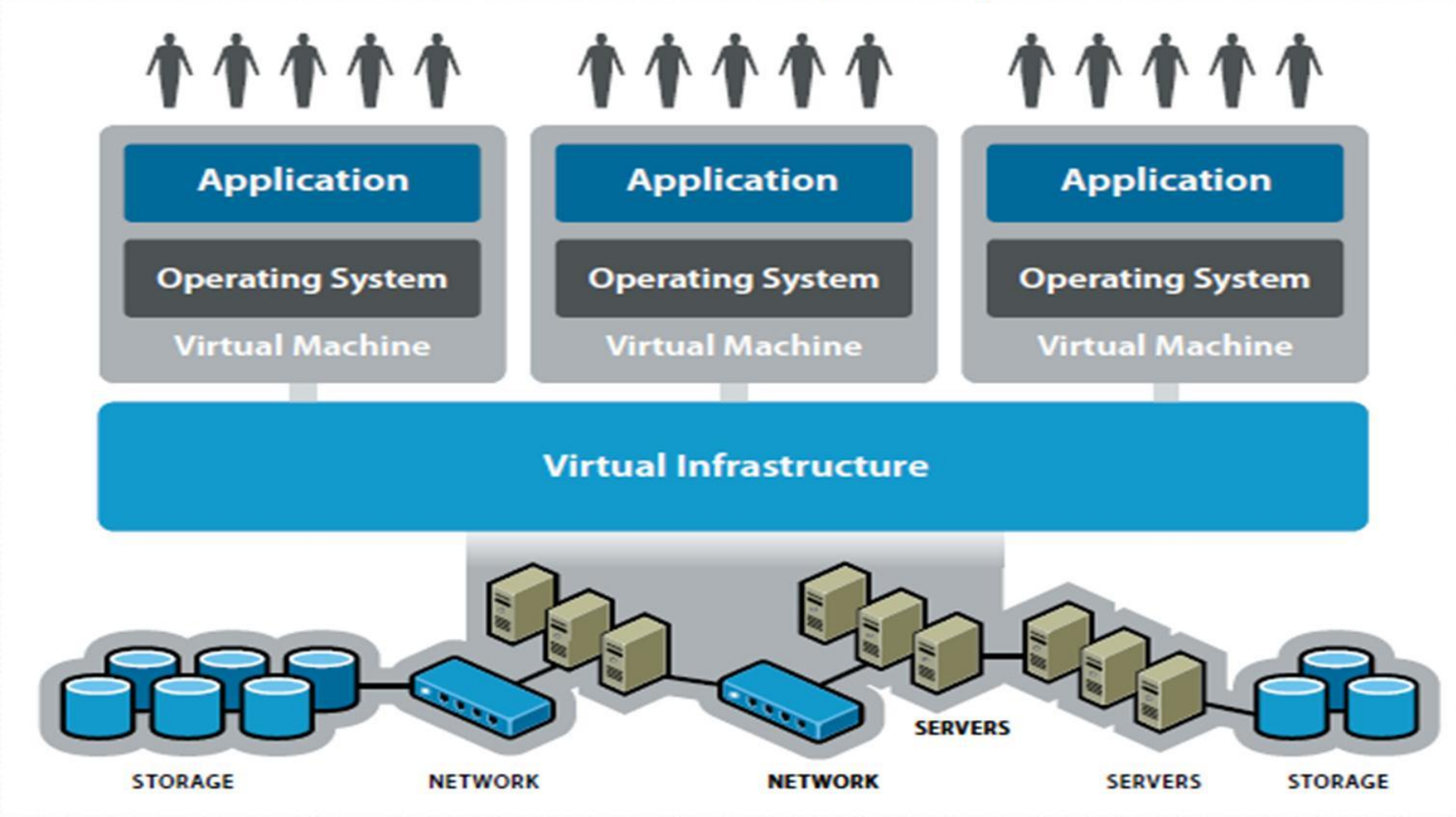
Green ICT

Running fewer, highly utilized servers:

- Free up space and Reduce power.
- Less space and power is better for ***Environment*** and saves money.

Massively Virtualized Model - Cloud

Infrastructure as Service (IaaS) Model



IaaS Model

- Cloud Computing offers ***infrastructure as a service*** which is based on:
  - Pay-as-you-use model
  - On-demand computing model
- To provide ***infrastructure as service (IaaS)***
  - ***Provisioning*** of the cloud infrastructure in data centers is a prerequisite
- However, provisioning for *systems and applications* on a large number of physical machines is traditionally a ***time consuming process***
- There are ***two core services*** enable the users to get the best out of the ***IaaS model***:
  - **Virtual machine provisioning**
  - **Migration services**

IaaS Model- Cont..

Virtualization Services:

Historically

- When it needs to install a ***new server*** for a certain workload to provide a particular service for a client
  - ***lots of effort*** needed by ***IT administrator***, and ***much time*** was spent to install and provision a new server because:
    - The administrator has to follow specific checklist and procedures to perform this task on hand

Now

- By emerging of virtualization technology and the cloud computing IaaS model,
  - it is just ***a matter of minutes (15-30 min)*** to achieve the same task

IaaS Model- Cont…

Resource Provisioning

- The virtualization layer will partition the physical resource of the underlying physical server into multiple *virtual machines* with *different workloads*
- The *main issue about* ***this virtualization layer*** is that:
  - ***Schedules***, ***allocates*** physical resource, and
  - Make each virtual machine think that it totally owns the whole underlying hardware's physical resource
    - E.g., processor, disks, RAMs, etc.

Virtualization Security Requirements

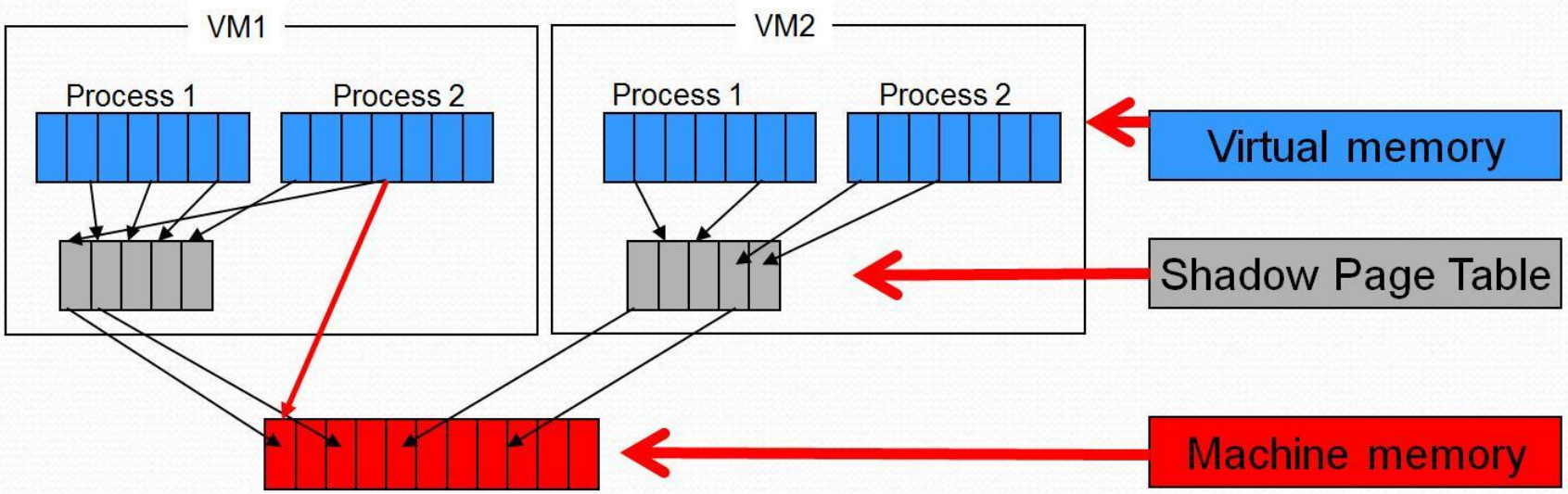
- **Scenario:** A client uses the service of a cloud computing company to **build a remote VM**, need:
  - A secure network interface
    - **T**ransport **l**ayer **S**ecurity (TLS)
  - A secure secondary storage
    - **N**etwork **F**ile **S**ystem (NFS)
  - A secure run-time environment

√ All cryptographic algorithms and security protocols reside in the run-time environment

√ Build, save, restore, destroy

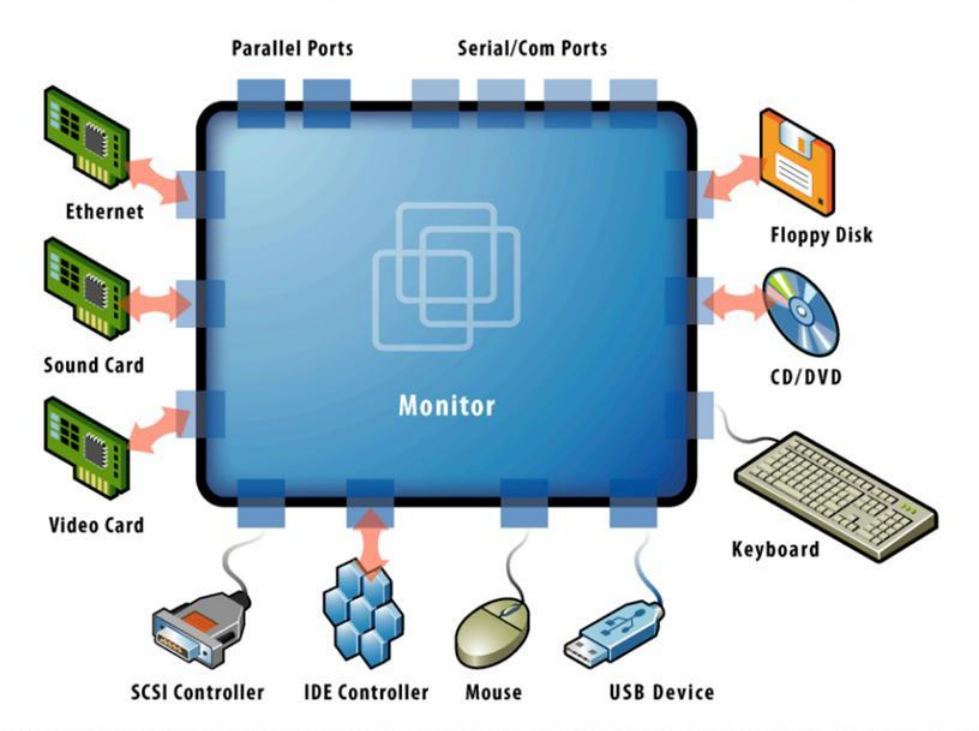
Memory Virtualization

- To run multiple VMs on ***a single system***, another level of ***memory virtualization*** is required.
- The VMM is responsible for ***mapping guest Virtual memory to the actual host machine memory, and it uses shadow page tables to accelerate the mappings.***



Device and I/O Virtualization

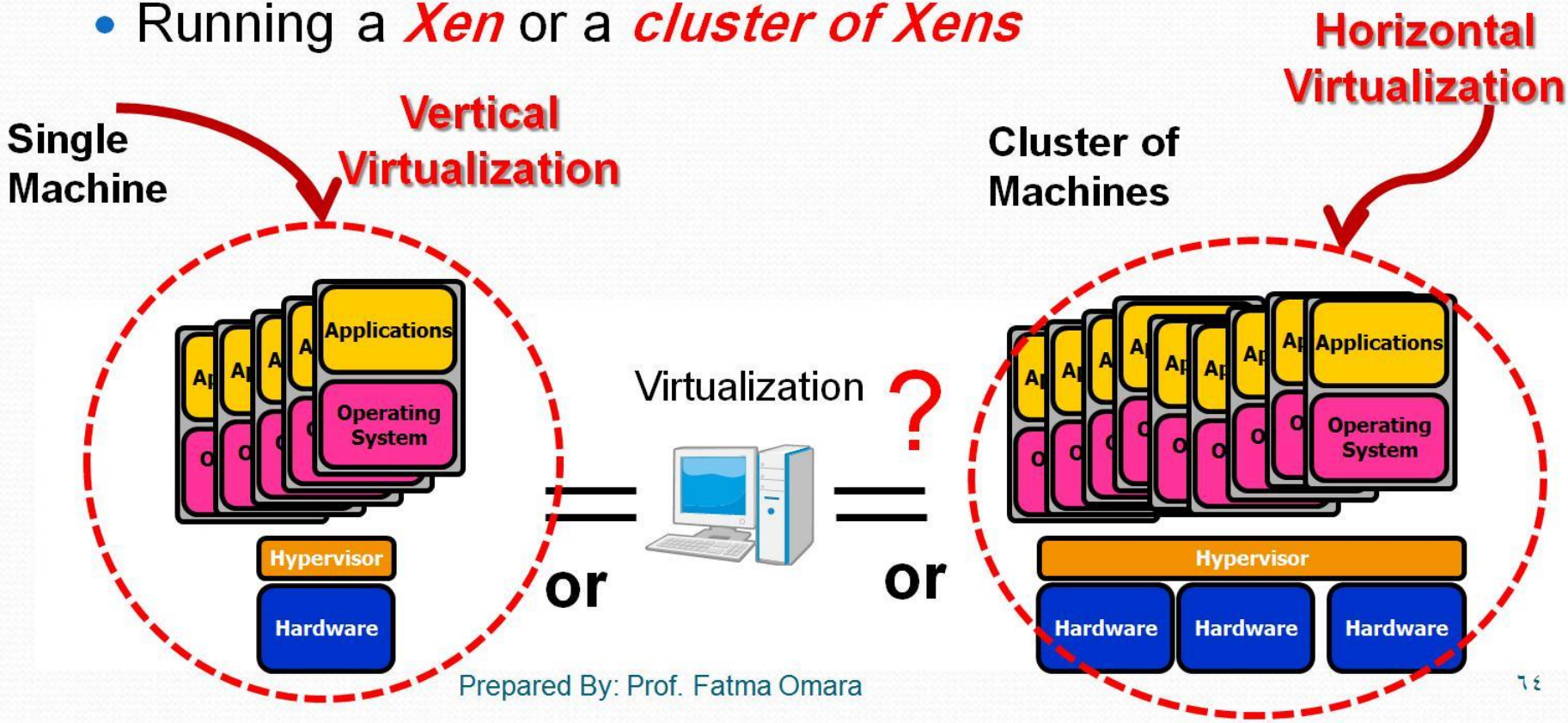
- VMM supports all device I/O drivers
- Physically/virtually existed



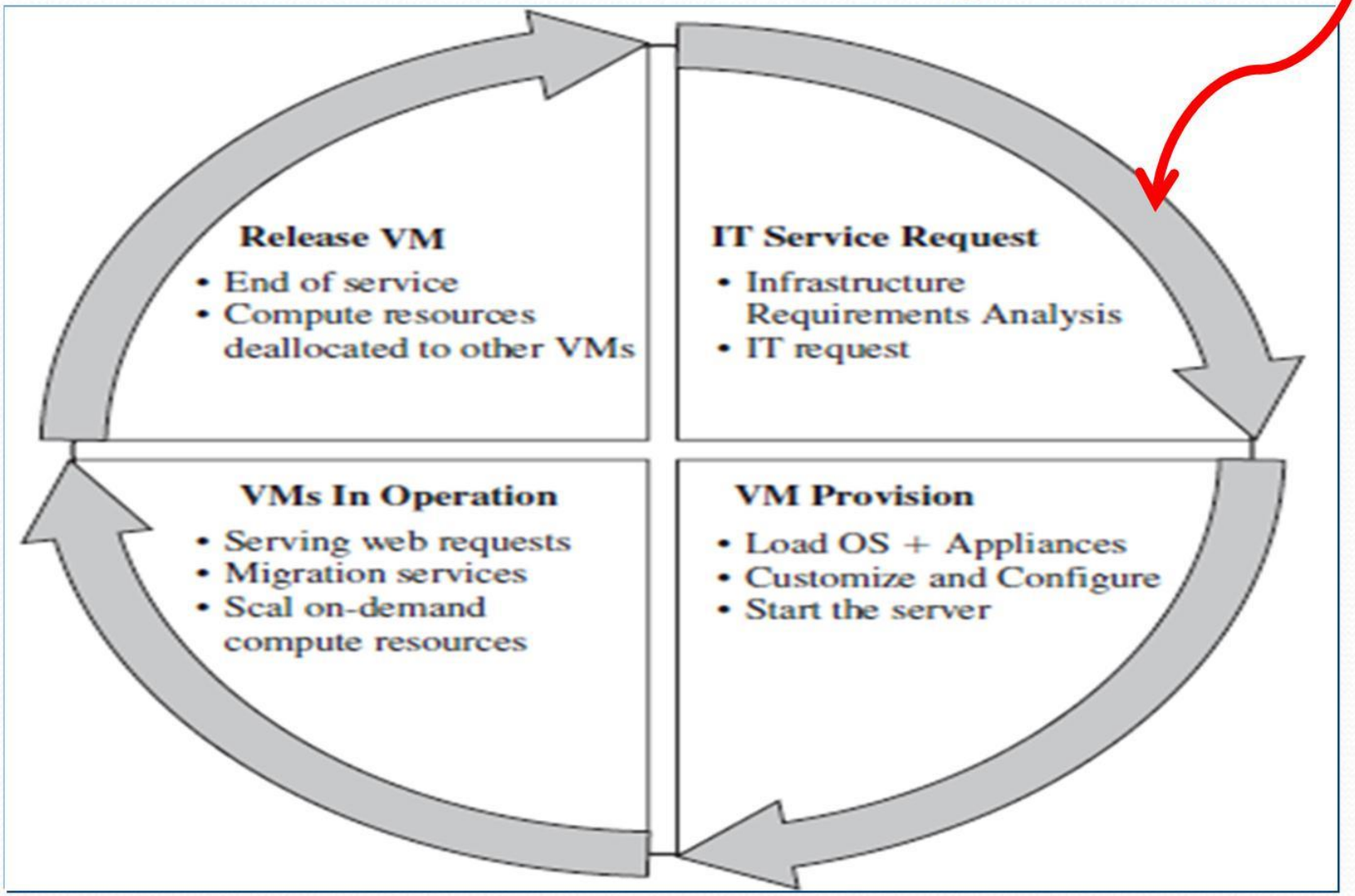
Source: VMware white paper, "Understanding Full Virtualization, Paravirtualization, and Hardware Assist"

Issues in Virtualization for Cloud-Computing

- Virtualization implemented on
  - A single machine (with multi-core CPUs)
  - a cluster of machines (with multi-core CPUs)
- The state-of-the-art
  - Running a *Xen* or a *cluster of Xens*



Virtual Machines Provisioning Life Cycle



Provisioning in Public Cloud

- Resources are dynamically provisioned via publicly accessible Web applications/Web services (SOAP or RESTful interfaces) ***from an off-site third-party provider***, who ***shares resources*** and ***bills*** on a fine-grained utility computing basis

Public Cloud Providers:

- Amazon EC2
- GoGrid
- RackSpace
- AppNexus
- FlexiScal
- …

Provisioning in Private Cloud

- Providing public cloud functionality on private resources, while maintaining control over an organization's data and resources to meet security and governance's requirements in an organization.
- Private cloud exhibits a highly virtualized cloud data center located inside your organization's firewall.
- Private Cloud Frameworks:
  - Eucalyptus
  - OpenNebula