Presentation Topic

Cloud Computing

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(An Autonomous Institute affiliated to Savitribai Phule Pune University)
(NBA and NAAC accredited, ISO 9001:2015 certified)

UNIT 2:

Virtualization

UNIT 2:

Virtualization

Contents

- Implementation Levels of Virtualization, Virtualization Structures/Tools and Mechanisms,
- Types of Hypervisors,
- Virtualization of CPU, Memory, and I/O Devices, Virtual Clusters and Resource Management, Virtualization for Data-Center Automation.
- Common Standards: The Open Cloud Consortium, Open Virtualization Format. Standards for Security.
- Case study : VirtualBox, Docker.

CO Achieved in First Lecture

- To study supporting technologies of cloud

Course Outcomes:-

At the end of the unit you will be able to:

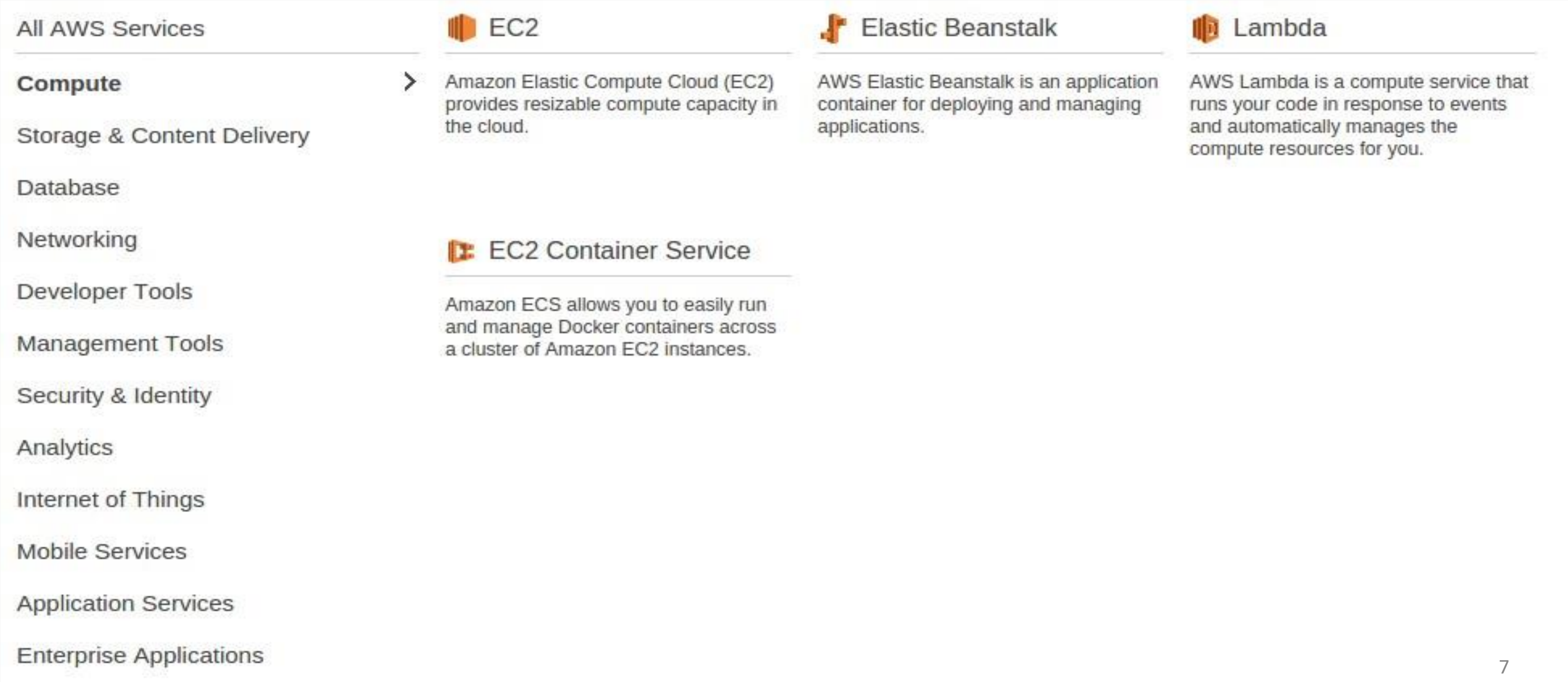
- Explore the supporting technologies of cloud computing (Understand)

Introduction

- Virtualization technology plays crucial role in IaaS.
- Virtualization allows the creation of a secure, customizable, and isolated execution environment for running applications, even if they are untrusted, without affecting other users' applications.

Introduction

- Virtualization technologies provide a virtual environment for not only executing applications but also for storage, database, and networking.



Introduction

- Several phenomena helped Virtualization to gain popularity:
  - Increased performance and computing capacity.
  - Underutilized hardware and software resources.
  - Lack of space.
  - Greening initiatives.
  - Rise of administrative costs.
- In 1995 Sun released Java(virtual machine-based programming language), which soon became popular among developers.
  - The ability to integrate small Java applications, called applets, made Java a very successful platform.
- In 2006, two of the three offiĐial laŶguages used for development at Google are Java and Python

Characteristics of virtualized environments

- Virtualization is a broad concept that refers to the creation of a virtual version of something, whether *hardware, a software environment, storage, or a network*.

- The main common characteristic of all these different implementations is the fact that the virtual environment is created by means of a **software program**.

Characteristics of virtualized environments

- In a virtualized environment there are three major components: guest, host, and virtualization layer.
  - The guest represents the system component that interacts with the virtualization layer rather than with the host, as would normally happen.
  - The host represents the original environment where the guest is supposed to be managed.
  - The virtualization layer is responsible for recreating the same or a different environment where the guest will operate

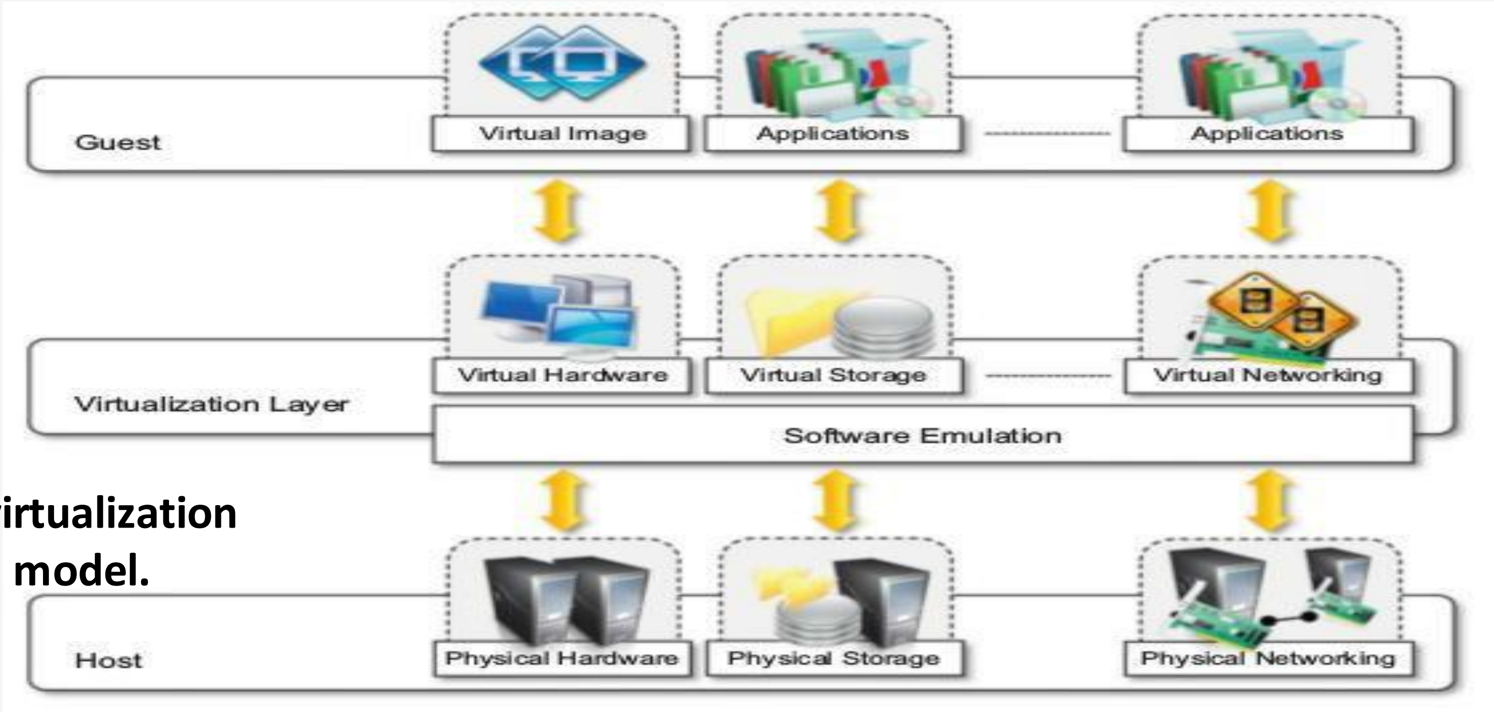


Fig. The virtualization reference model.

Characteristics of virtualized environments

Three main characteristics:

1. Increased security
2. Managed execution
3. Portability

Characteristics of virtualized environments

Three main characteristics:

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3. Portability

Characteristics of virtualized environments: **Increased security**

- The ability to control the execution of a guest in a controlled execution environment.
- The virtual machine represents an emulated environment in which the guest is executed.
- All the operations of the guest are generally performed against the virtual machine, which then translates and applies them to the host.
- This level of indirection allows the virtual machine manager to *control and filter the activity of the guest*, thus preventing some harmful operations from being performed.
- Sensitive information that is contained in the host can be naturally hidden without the need to install complex security policies.

Characteristics of virtualized environments: **Increased security**

- Increased security is a requirement when dealing with untrusted code.
- For example, applets downloaded from the Internet run in a sandboxed version of the Java Virtual Machine (JVM), which provides them with limited access to the hosting operating system resources.
- Both the JVM and the .NET runtime provide extensive security policies for customizing the execution environment of applications.
- Hardware virtualization solutions such as Vmware Desktop, VirtualBox, and Parallels provide the ability to create a virtual computer with customized virtual hardware on top of which a new operating system can be installed.

Characteristics of virtualized environments

Three main characteristics:

1. Increased security
2. Managed execution
3. Portability

Characteristics of virtualized environments: **Managed execution**

- Virtualization of the execution environment also allows sharing, aggregation, emulation, and isolation features.

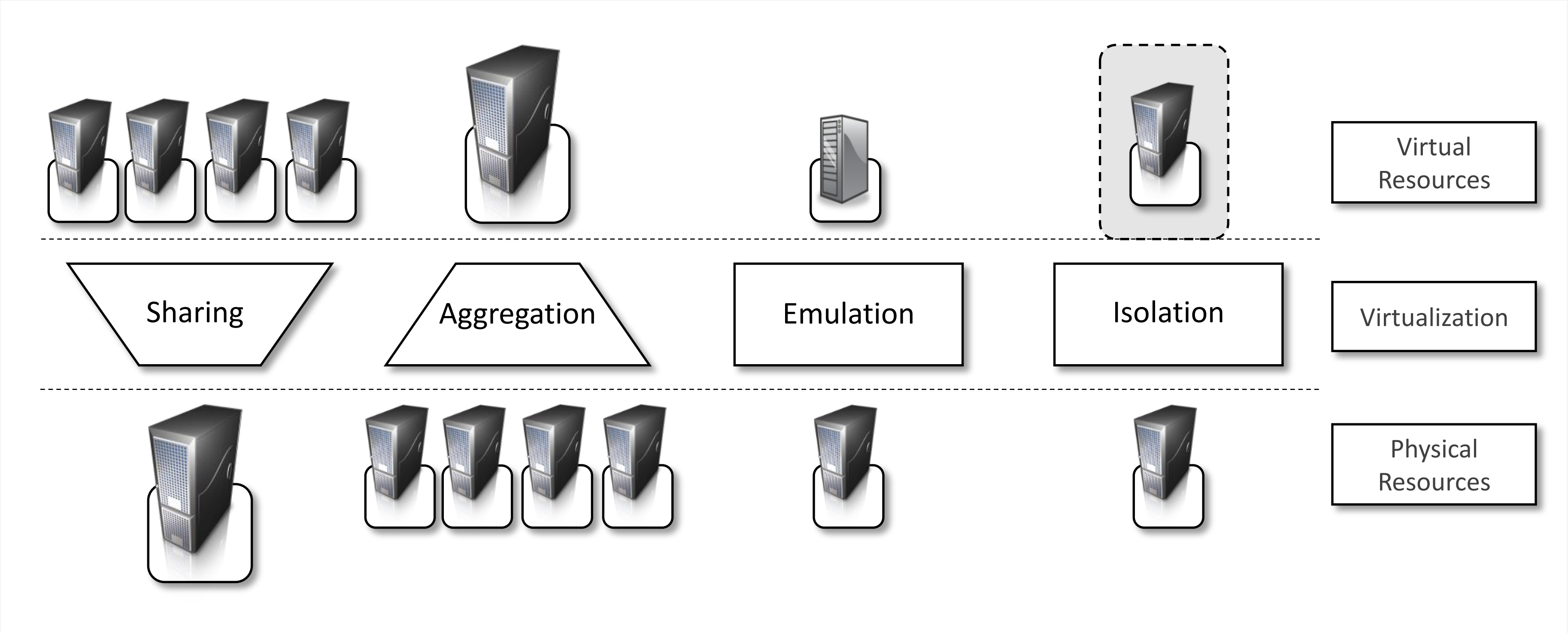

Figure: Functions enabled by managed execution.

Characteristics of virtualized environments: **Managed execution**

- **Sharing**
  - Virtualization allows the creation of a separate computing environments within the same host.
    - Allows fully exploit the capabilities of a powerful guest, which would otherwise be underutilized.

Characteristics of virtualized environments: **Managed execution**

- **Aggregation**
  - It is opposite process of sharing physical resource among several guests
  - A group of separate hosts can be tied together and represented to guests as a single virtual host.
  - Example
    - **Cluster management software**, which harnesses the physical resources of a homogeneous group of machines and represents them as a single resource.

Characteristics of virtualized environments: **Managed execution**

- **Emulation**
  - Guest programs are executed within an environment that is controlled by the virtualization layer, which ultimately is a program.
  - A completely different environment with respect to the host can be emulated.
    - Very *useful for testing purposes*, where a specific guest has to be validated against different platforms or architectures and the wide range of options is not easily accessible during development.
- Hardware virtualization solutions are able to provide virtual hardware and emulate a particular kind of device such as Small Computer System Interface (SCSI) devices for file I/O, without the hosting machine having such hardware installed.

Characteristics of virtualized environments: **Managed execution**

- **Isolation**

– Virtualization allows providing guests—whether they are operating systems, applications, or other entities— with a completely separate environment, in which they are executed.

1. It allows multiple guests to run on the same host without interfering with each other.

2. It provides a separation between the host and the guest.

  - The virtual machine can filter the activity of the guest and prevent harmful operations against the host

Characteristics of virtualized environments: **Managed execution**

- **Performance tuning**
  - Control the performance of the guest by finely tuning the properties of the resources exposed through the virtual environment.
  - For instance,
    - software-implementing hardware virtualization solutions can expose to a guest operating system only a fraction of the memory of the host machine or set the maximum frequency of the processor of the virtual machine.

Characteristics of virtualized environments: **Managed execution**

- **Virtual machine migration**
  - it allows easy capturing of the state of the guest program, persisting it, and resuming its execution.
  - For example,
    - allows virtual machine managers such as Xen Hypervisor to stop the execution of a guest operating system, move its virtual image into another machine, and resume its execution in a completely transparent manner.

Characteristics of virtualized environments

Three main characteristics:

1. Increased security
2. Managed execution
3. Portability

Characteristics of virtualized environments: **Portability**

- In *hardware virtualization solution*, the guest is packaged into a virtual image that, in most cases, can be **safely moved and executed** on top of different virtual machines.

Taxonomy of virtualization techniques

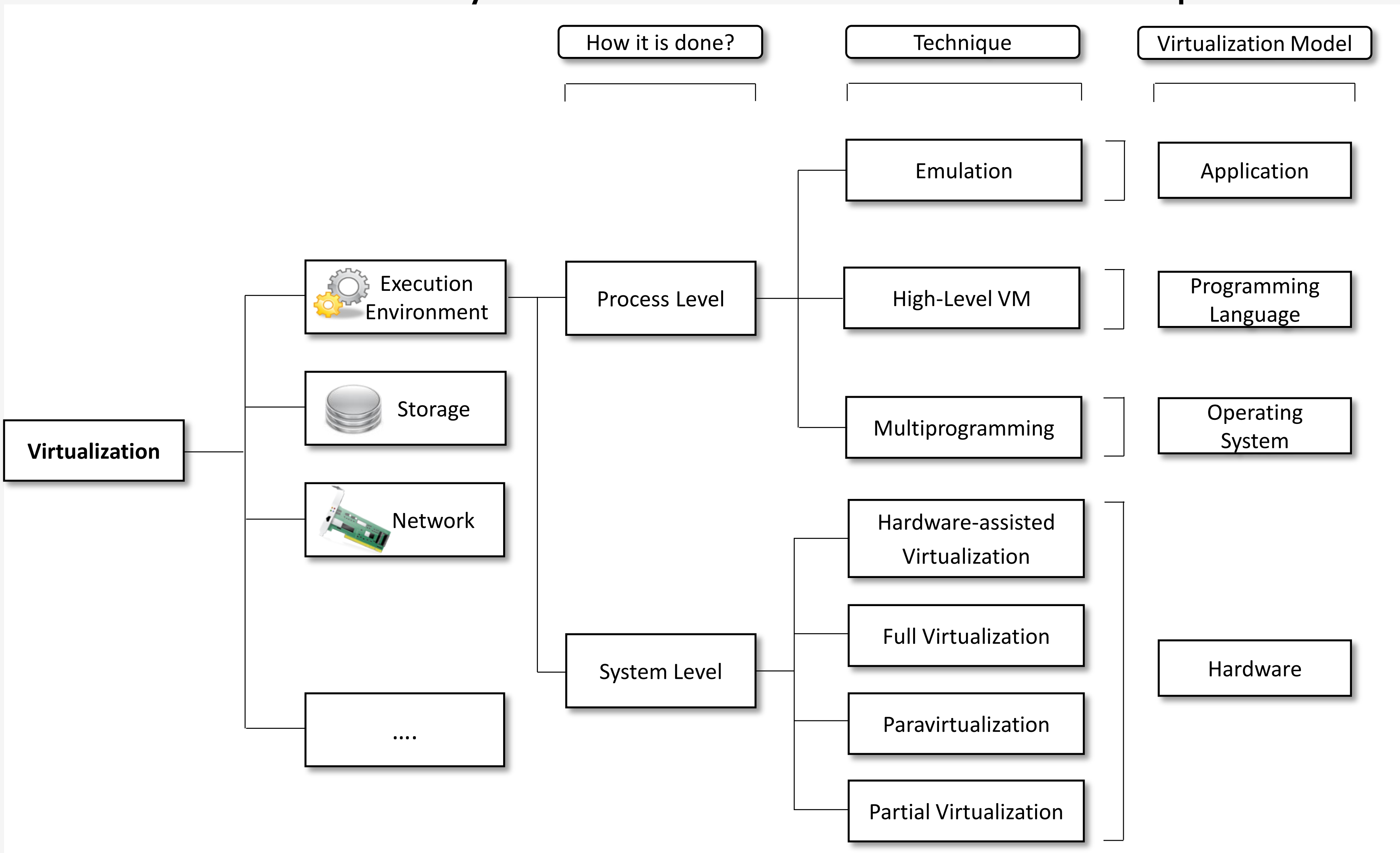

Figure: A taxonomy of virtualization techniques.

Taxonomy of virtualization techniques

1. Execution virtualization
   A. Machine reference model
   B. Hardware-level virtualization
   C. Programming language-level virtualization
   D. Application-level virtualization
2. Other types of virtualization
   A. Storage virtualization
   B. Network virtualization
   C. Desktop virtualization
   D. Application server virtualization

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Taxonomy of virtualization techniques: **Execution virtualization**

- Providing support for the execution of programs, whether these are the operating system, a binary specification of a program compiled against an abstract machine model, or an application.

- Execution virtualization can be implemented directly on top of the hardware by the operating system, an application, or libraries dynamically or statically linked to an application image.

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Taxonomy of virtualization techniques: **Machine reference model**

- It defines the ***interfaces between the levels*** of abstractions, which ***hide implementation details***.
- Virtualization techniques actually ***replace one of the layers*** and intercept the calls that are directed towards it.

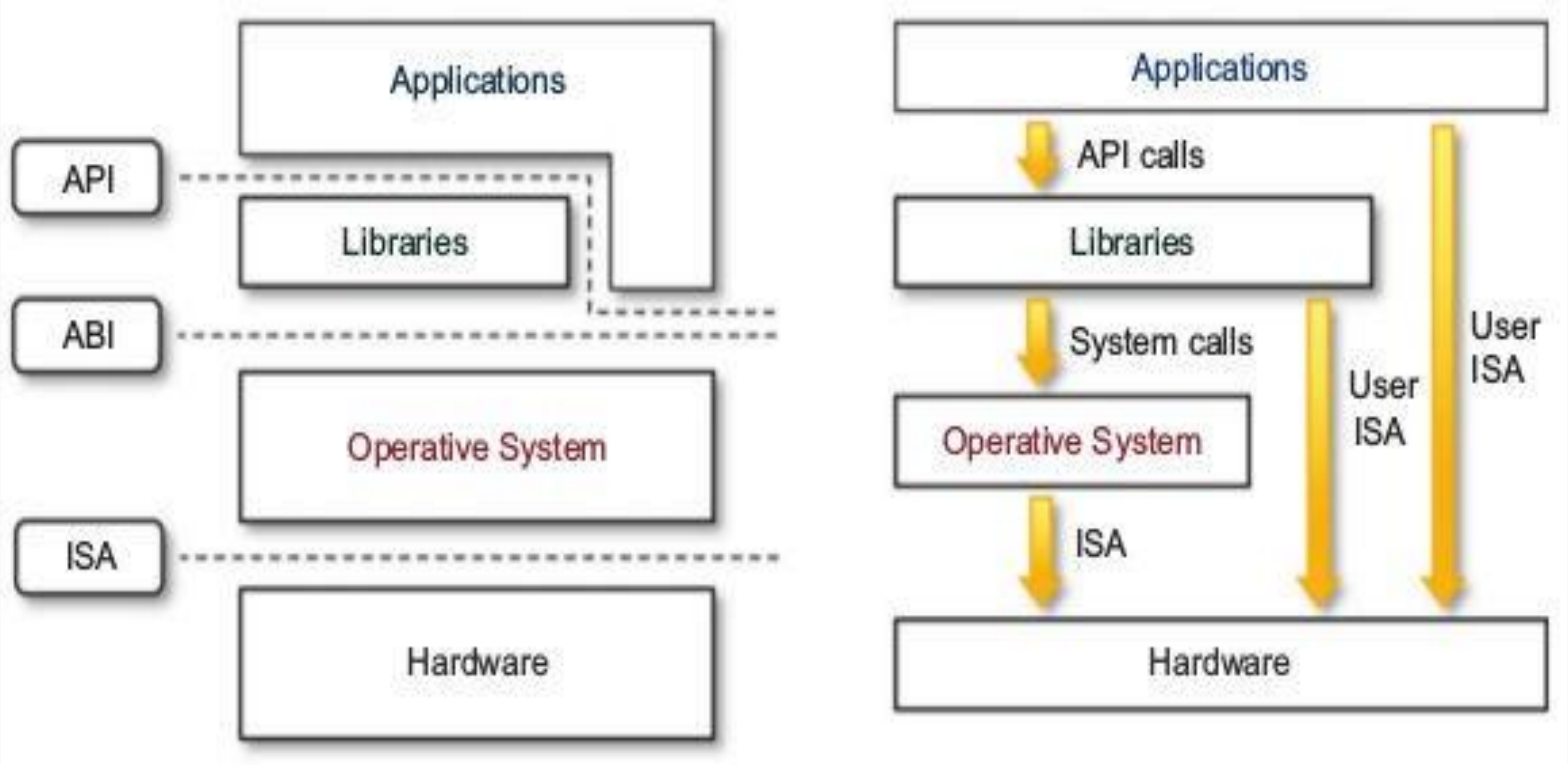


Figure: A machine reference model.

Non-privileged instructions

That can be used without interfering with other tasks because they ***do not access shared resources***.

Ex. Arithmetic , floating & fixed point.

Privileged instructions

That are executed under ***specific restrictions*** and are mostly used for ***sensitive operations***, which expose (*behaviour-sensitive*) or modify (*control-sensitive*) the privileged state.

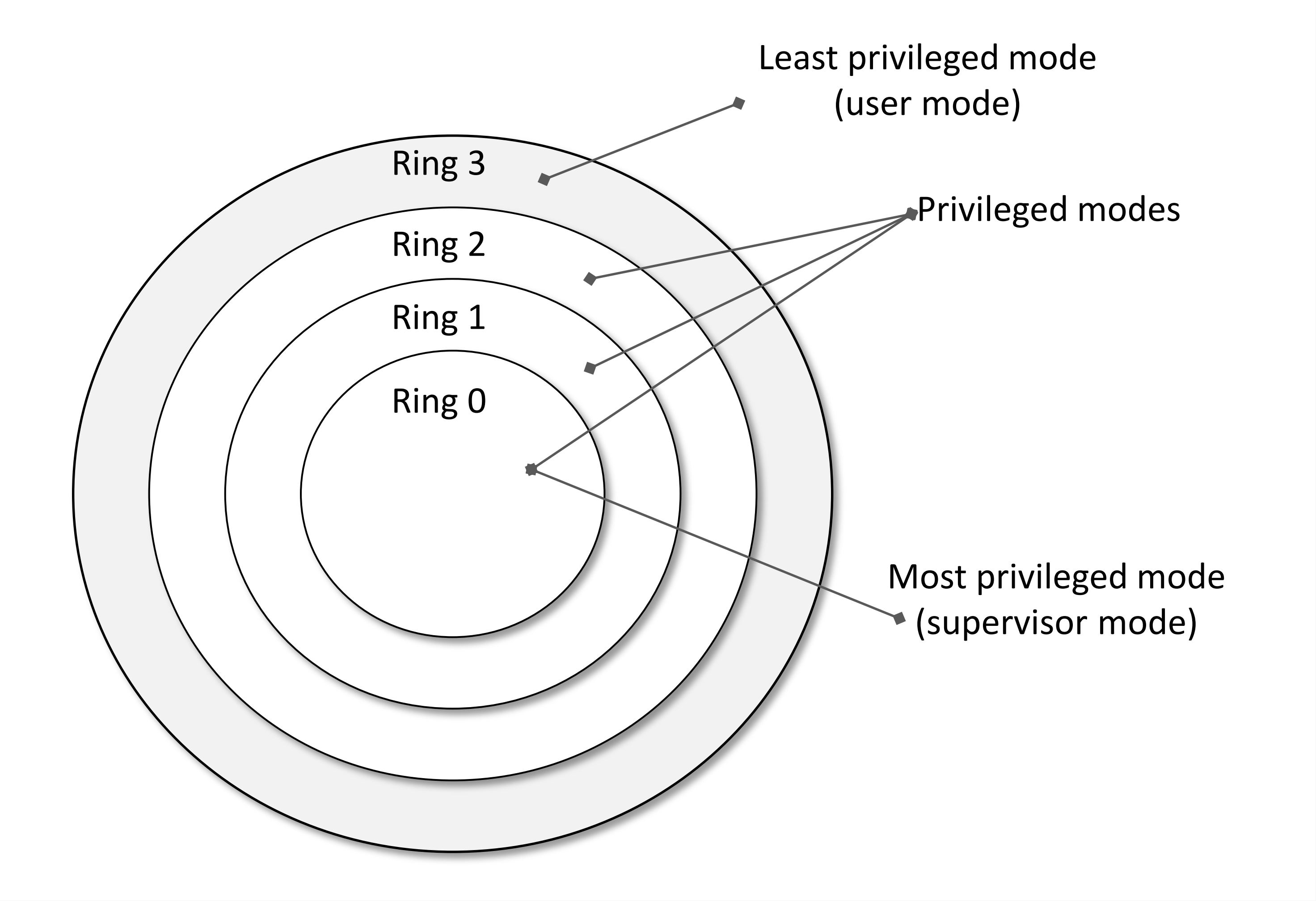
Behavior-sensitive – operate on the I/O

Control-sensitive – alter the state of the CPU register.

Types of Execution Modes

- All the current systems support at least two different execution modes: supervisor mode and user mode.
- The Supervisor mode denotes an execution mode in which all the instructions (privileged and non-privileged) can be executed without any restriction.
  - This mode, also called master mode or kernel mode, is generally used by the operating system (or the hypervisor) to perform sensitive operations on hardware-level resources.
- In user mode, there are restrictions to control the machine-level resources.
  - If code running in user mode invokes the privileged instructions, hardware interrupts occur and trap the potentially harmful execution of the instruction.
- Conceptually, the hypervisor runs above the supervisor mode
  - In reality, **hypervisors** are run in **supervisor mode**

Security rings and Privileged mode



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Taxonomy of virtualization techniques: **Hardware-level virtualization**

- It provides an abstract execution environment in terms of computer hardware on top of which a guest operating system can be run.

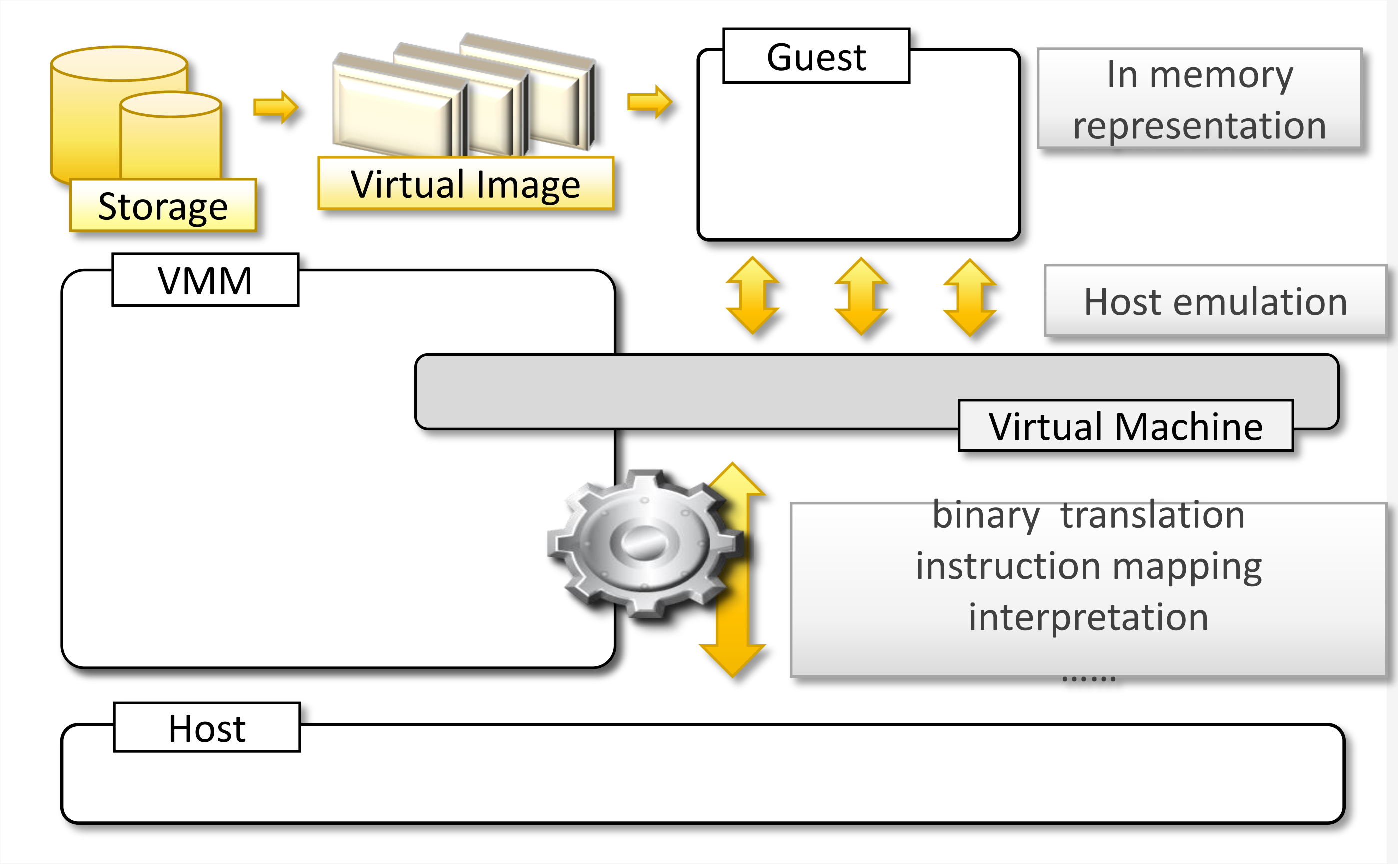


Figure: A hardware virtualization reference model.

Taxonomy of virtualization techniques: **Hardware-level virtualization**

- **Hypervisors or Virtual machine manager (VMM)**
  – A fundamental element of hardware virtualization.
  – It recreates a hardware environment in which guest operating systems are installed.
  – Two major types of hypervisor: Type I and Type II

Taxonomy of virtualization techniques: **Hardware-level virtualization**

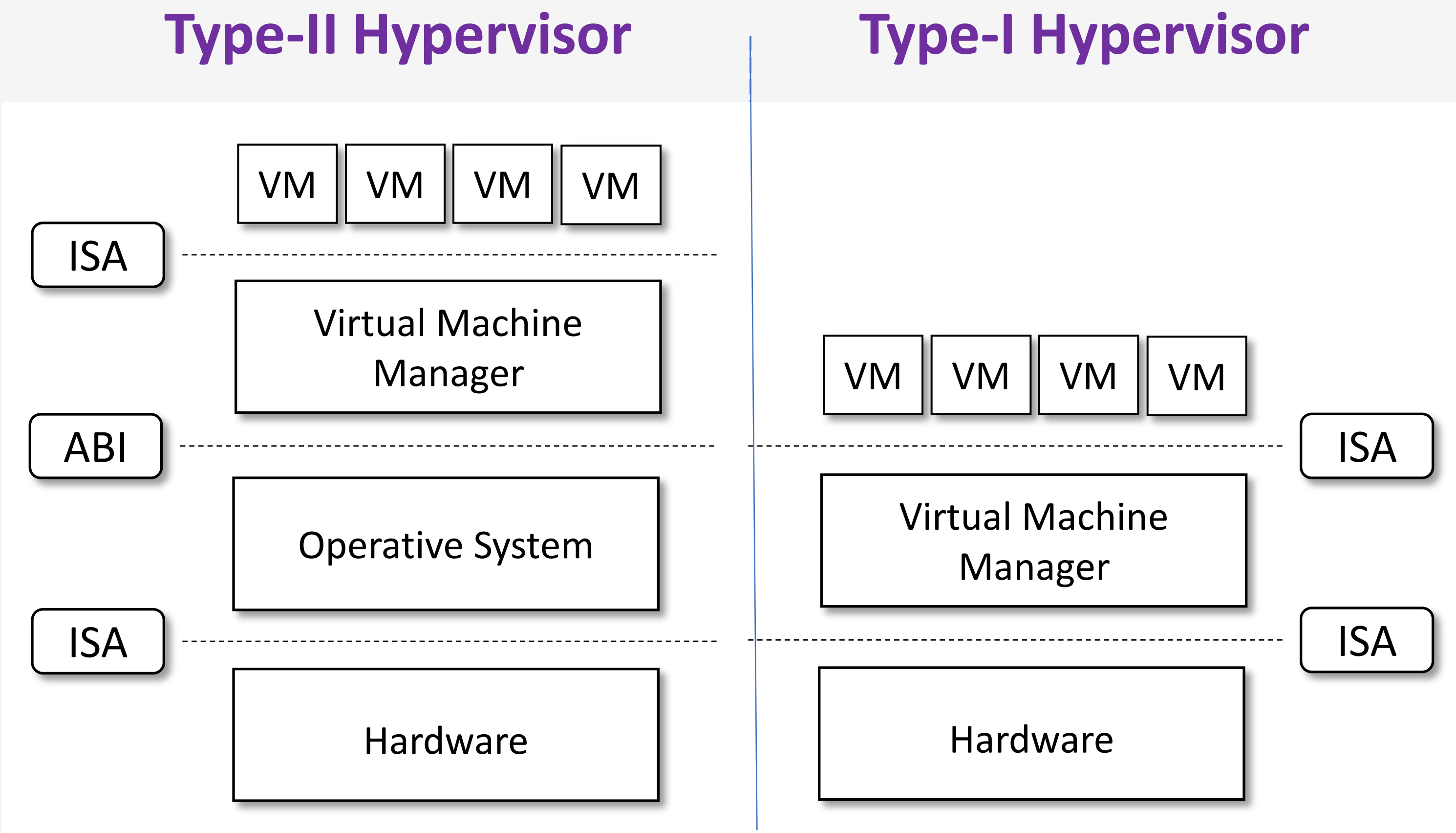


Figure: types of hypervisors

Taxonomy of virtualization techniques: **Hardware-level virtualization**

- **Type-I Hypervisor:**
  - **Steps to install Hypervisor Type-I**
    1. **Choose rack/Harware**
    2. **Install Hypervisor(**any vendor like **Citrix, Vmware)**
    3. **Go to console management(U.I.)**
    4. **Setup IP address i.e. configure hypervisor via U.I**

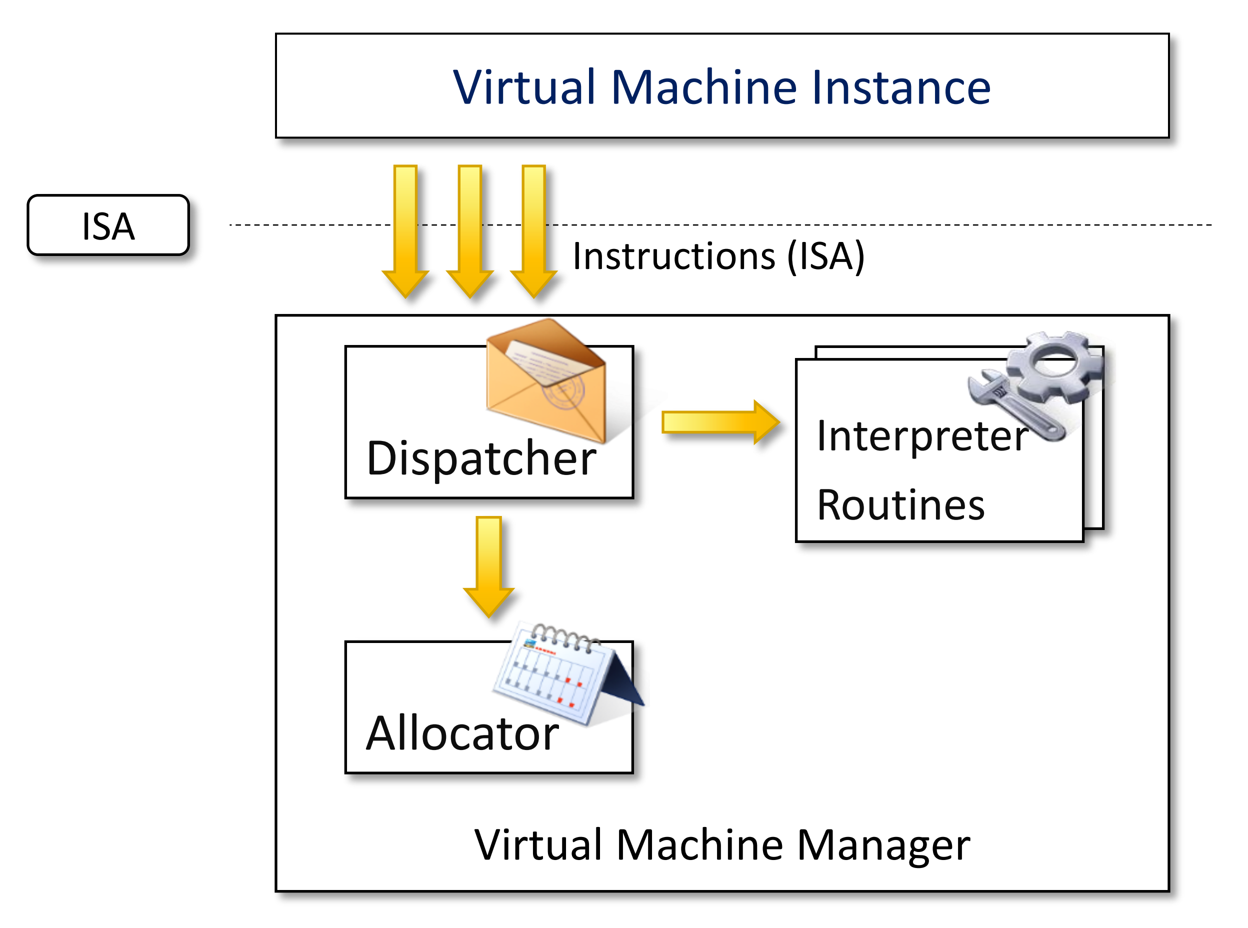
- Management console is imp as this *manages and does all configuration task* of OS instance, Overallocation and OS instance management.
- **Hypervisor Type-I are free** but charges for management S/W(console)

Taxonomy of virtualization techniques: **Hardware-level virtualization**

- **Type-II Hypervisor:**
  - **Installed inside on/onto OS**
  - **Easy and most preferred**
    - **No need of management console**
    - **Are free eg. Virtual box**

Taxonomy of virtualization techniques: **Hardware-level virtualization**

- A hypervisor reference architecture:



Taxonomy of virtualization techniques: **Hardware-level virtualization**

- A hypervisor reference architecture:

Main Modules :-

<u>Dispatcher</u>

- Entry Point of VMM
- Reroutes the instructions issued by VM instance.

<u>Allocator</u>

- Deciding the system resources to be provided to the VM.
- Invoked by dispatcher

<u>Interpreter</u>

- Consists of interpreter routines
- Executed whenever a VM executes a privileged instruction.
- Trap is triggered and the corresponding routine is executed.

Taxonomy of virtualization techniques: **Hardware-level virtualization**

- **Three properties* have to be satisfied by a virtual machine manager (VMM) to efficiently support virtualization.**

1. Equivalence.
   - A guest running under the control of a virtual machine manager should exhibit the same behavior as when it is executed directly on the physical host.
2. Resource control.
   - The virtual machine manager should be in complete control of virtualized resources.
3. Efficiency.
   - A statistically dominant fraction of the machine instructions should be executed without intervention from the virtual machine manager.

** criterias are established by Goldberg and Popek in 1974*

Taxonomy of virtualization techniques: **Hardware-level virtualization**

- **Hardware virtualization techniques**
  1. Hardware-assisted virtualization
  2. Full virtualization
  3. Paravirtualization
  4. Partial virtualization

Taxonomy of virtualization techniques: **Hardware-level virtualization**

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Taxonomy of virtualization techniques: **Hardware-level virtualization**

1. **Hardware-assisted virtualization**
   - hardware provides architectural support to a virtual machine manager (VMM) to run a guest operating system in complete isolation.
   - This technique was originally introduced in the IBM System/370.
   - Current examples are the extensions to the x86- 64 bit architecture introduced with Intel VT (formerly known as Vanderpool) and AMD V (formerly known as Pacifica).

Taxonomy of virtualization techniques: **Hardware-level virtualization**

- **Hardware virtualization techniques**
  1. Hardware-assisted virtualization
  2. Full virtualization
  3. Paravirtualization
  4. Partial virtualization

Taxonomy of virtualization techniques: **Hardware-level virtualization**

2. Full virtualization

- The ability to run a program, **most likely an operating system**, directly on top of a virtual machine and without any modification, as though it were run on the raw hardware.
- Virtual machine managers are required to provide a complete emulation of the entire underlying hardware.
- The principal **advantage** of full virtualization is **complete isolation**, which leads to enhanced security, ease of emulation of different architectures, and coexistence of different systems on the same platform.

Taxonomy of virtualization techniques: **Hardware-level virtualization**

- **Hardware virtualization techniques**
  1. Hardware-assisted virtualization
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Taxonomy of virtualization techniques: **Hardware-level virtualization**

3. Paravirtualization

- This is a not-transparent virtualization solution.
- It exposes a software interface to the virtual machine that is slightly **modified from the host** and, as a consequence, **guests need to be modified**.
- The **aim** of paravirtualization is *to provide the capability to demand* the execution of performance-critical operations directly on the host, thus preventing performance losses that would otherwise be experienced in managed execution.
- Guest source code is required for modification. ***So applicable to open source OS only.***

Taxonomy of virtualization techniques: **Hardware-level virtualization**

- **Hardware virtualization techniques**
  1. Hardware-assisted virtualization
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Taxonomy of virtualization techniques: **Hardware-level virtualization**

4. Partial virtualization

- Provides a **partial emulation of the underlying hardware,** thus not allowing the complete execution of the guest operating system in complete isolation.
- Allows many applications to run transparently, but not all the features of the operating system can be supported, as happens with full virtualization.
- An example of partial virtualization is address space virtualization used in time-sharing systems; this allows multiple applications and users to run concurrently in a separate memory space, but they still share the same hardware resources (disk, processor, and network).

Taxonomy of virtualization techniques:
Operating system-level virtualization

- **Operating system-level virtualization**
  - Differently from hardware virtualization, there is no virtual machine manager or hypervisor.
  - the **virtualization is done within a single operating system**, where the OS kernel allows for multiple isolated user space instances.
  - The kernel is also responsible for sharing the system resources among instances and for limiting the impact of instances on each other.

Taxonomy of virtualization techniques:
Operating system-level virtualization

- **Operating system-level virtualization**
  - It aims to provide separated and multiple execution containers for running applications.
  - Compared to hardware virtualization, this strategy imposes little or no overhead because applications directly use OS system calls and there is no need for emulation.

Examples: *chroot , Jails, OpenVZ etc.*

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Programming language-level virtualization

- It is mostly used to achieve ***ease of deployment*** of application, ***managed execution*** and ***portability across*** different platform and OS.
- It consists of a virtual machine ***executing the byte code of a program***, which is the result of the ***compilation process***.
- Produce a binary format representing the machine code for an abstract architecture.
- Example
  - Java platform – Java virtual machine (JVM)
  - .NET provides Common Language Infrastructure (CLI)
- They are stack-based virtual machines

Advantage of programming/process-level VM

- Provide ***uniform execution environment*** across different platforms.
- This ***simplifies*** the development and deployment efforts.
- Allow more ***control over the execution*** of programs.
- Security; by filtering the I/O operations
- Easy support for sandboxing

Application-level virtualization

- It is a technique allowing applications to run in ***runtime environments*** that do not ***natively support*** all the features required by such applications.
- In this, applications are not installed in the ***expected runtime environmen***t.
- This technique is most concerned with :-
  - Partial file system
  - Libraries
  - Operating System component emulation

Strategies for Implementation Application-Level Virtualization

- Two techniques:-
  - Interpretation -
    - In this every source instruction is ***interpreted*** by an emulator for executing ***native ISA instructions***,
    - ***Minimal*** start up cost but ***huge overhead***.
  - Binary translation -
    - In this every source insruction is ***converted to native*** instructions with equivalent functions.
    - Block of instructions ***translated*** , ***cached*** and ***reused***.
    - Large ***overhead cost*** , but over time it is subject to ***better performance***.

Different from H/w Virtualization

- In h/w virtualization , it allows the execution of a program ***compiled against a different h/w***.
- In Application level emulation , complete ***h/w environment***.
- Ex:-
  - Wine
  - CrossOver
  - and , many more

Storage Virtualization

- It allows decoupling the physical organization of the h/w from its logical representation.
- Using Network based virtualization known as ***storage area network*** (SAN).
- SAN – ***Self Study***

Network Virtualization

- It combines h/w appliances and specific software for the creation and management of a virtual n/w.
- It can aggregate ***different physical networks*** into a single logical network.
- VLAN – ***Self Study***

Pros & Cons of Virtualization

- Plays an important role in cloud computing.
- Primarily used to offer configurable computing environments and storage.
- H/w virtualization enabling solution in IaaS
- Programming language virtualization in PaaS.
- Virtualization provides :-
  - Consolidating
  - Isolation
  - Controlled environments

Pros & Cons of Virtualization

- Disadvantages
  - Performance degradation -
    - As it interposes and abstraction layer between guest & host.
  - Inefficiency and degraded user experience -
    - Some of specific features of the host is unexposed.
  - Security holes and new threats
    - *Case 1* – emulating a host in a completely transparent manner.
    - *Case 2* - H/w virtualization , malicious programs can preload themselves before the OS and act as a thin VMM.

What's the meaning of virtual?

- If you can see it and it is there
  It's **real**
- If you can't see it but it is there
  It's **transparent**
- If you can see it and it is not there
  It's **virtual**
- If you can not see it and it is not there
  It's **gone !**

Virtualized Data Center (VDC)

Agenda Datacenter Virtualization

- Physical Topology of the VMware Infrastructure Data Center
- Virtual Data Center Architecture
- Hosts, Clusters and Resource Pools
- VMware VMotion, VMware DRS and VMware HA
- Networking Architecture
- Storage Architecture
- VMware Consolidated Backup
- ESX Server External Interfacing Components
- VirtualCenter Management Server Architecture

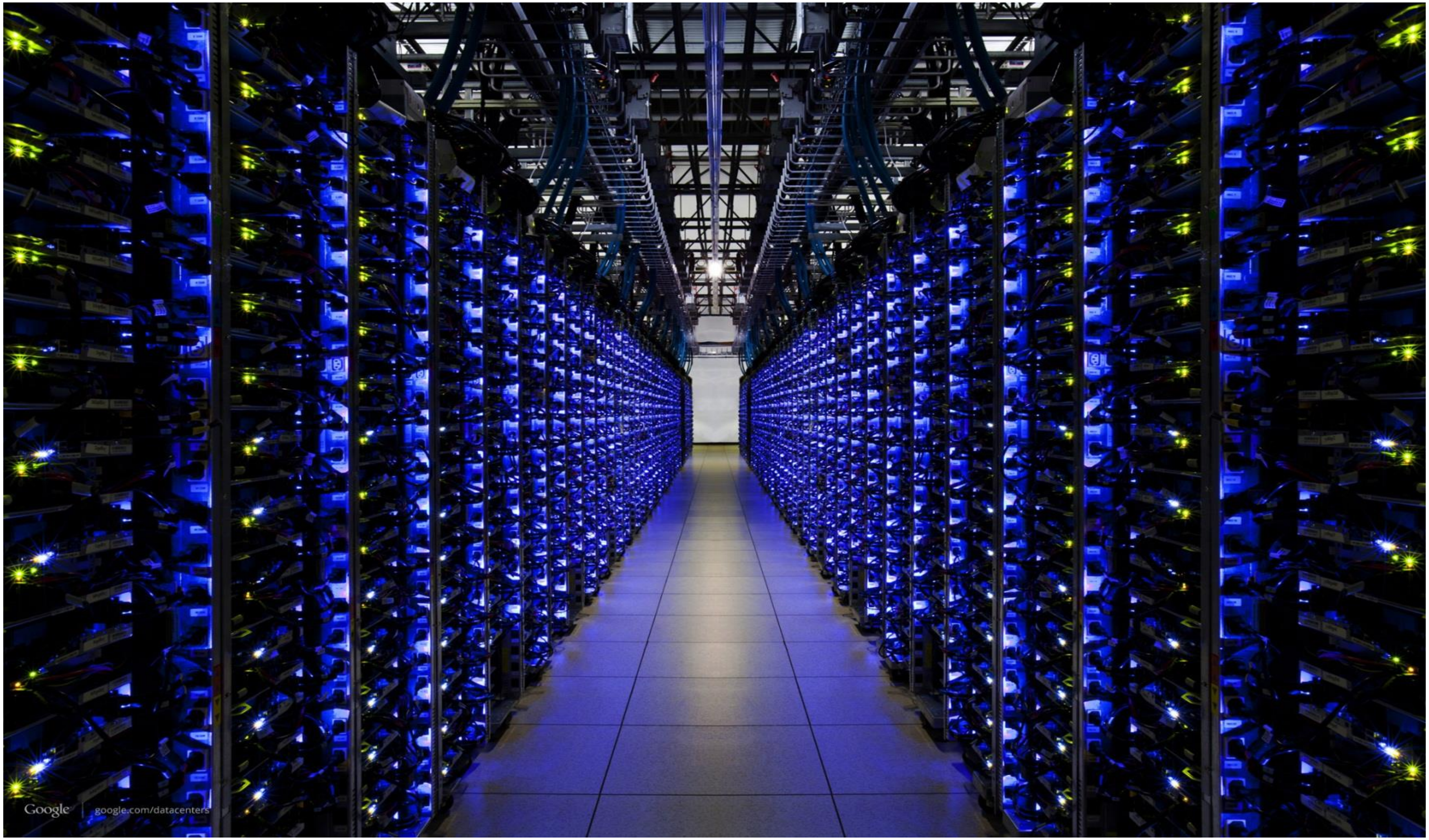
Data Center Buildings

Data Center Buildings

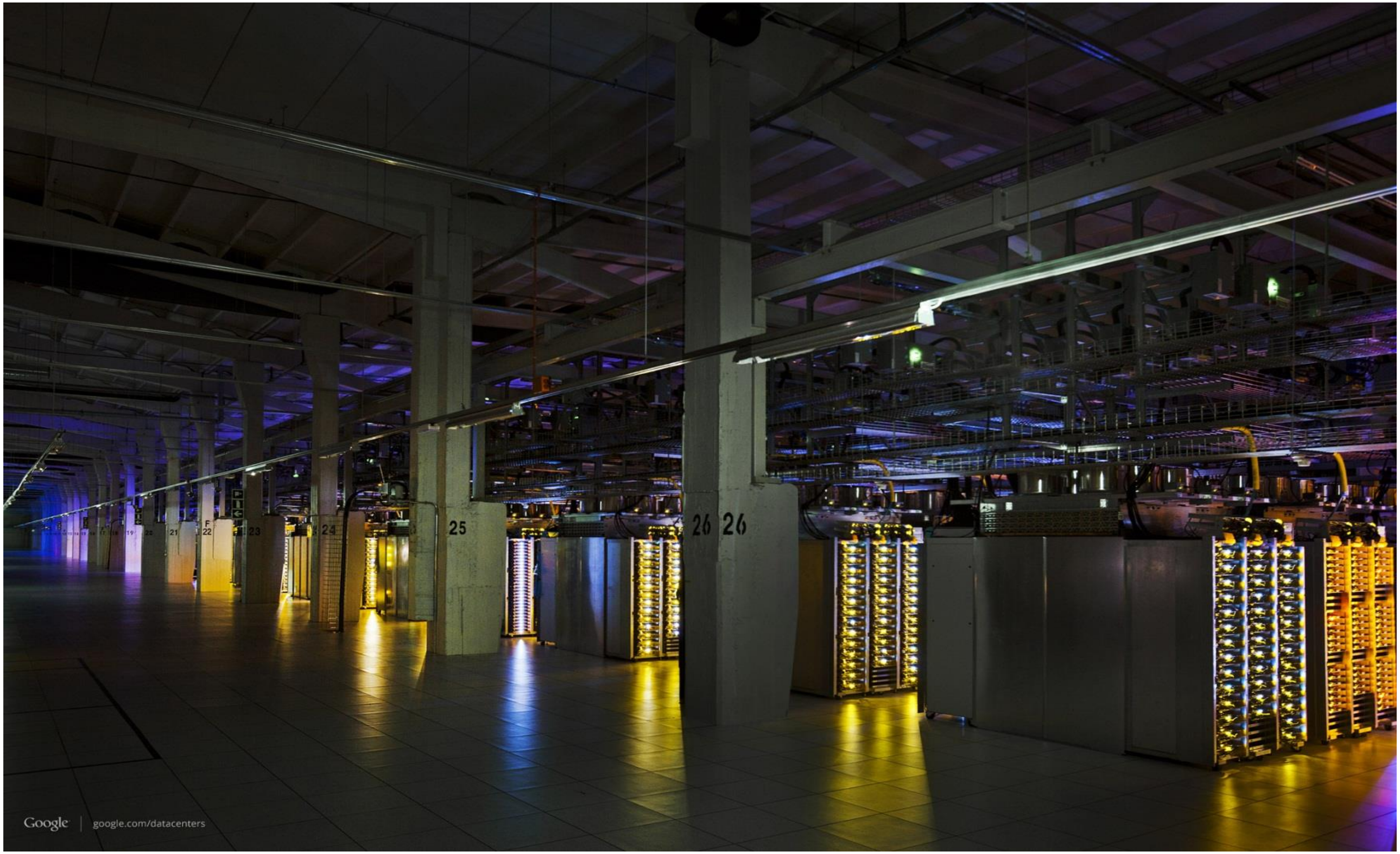
Data Center Buildings

Data Center Buildings

Racks



Racks



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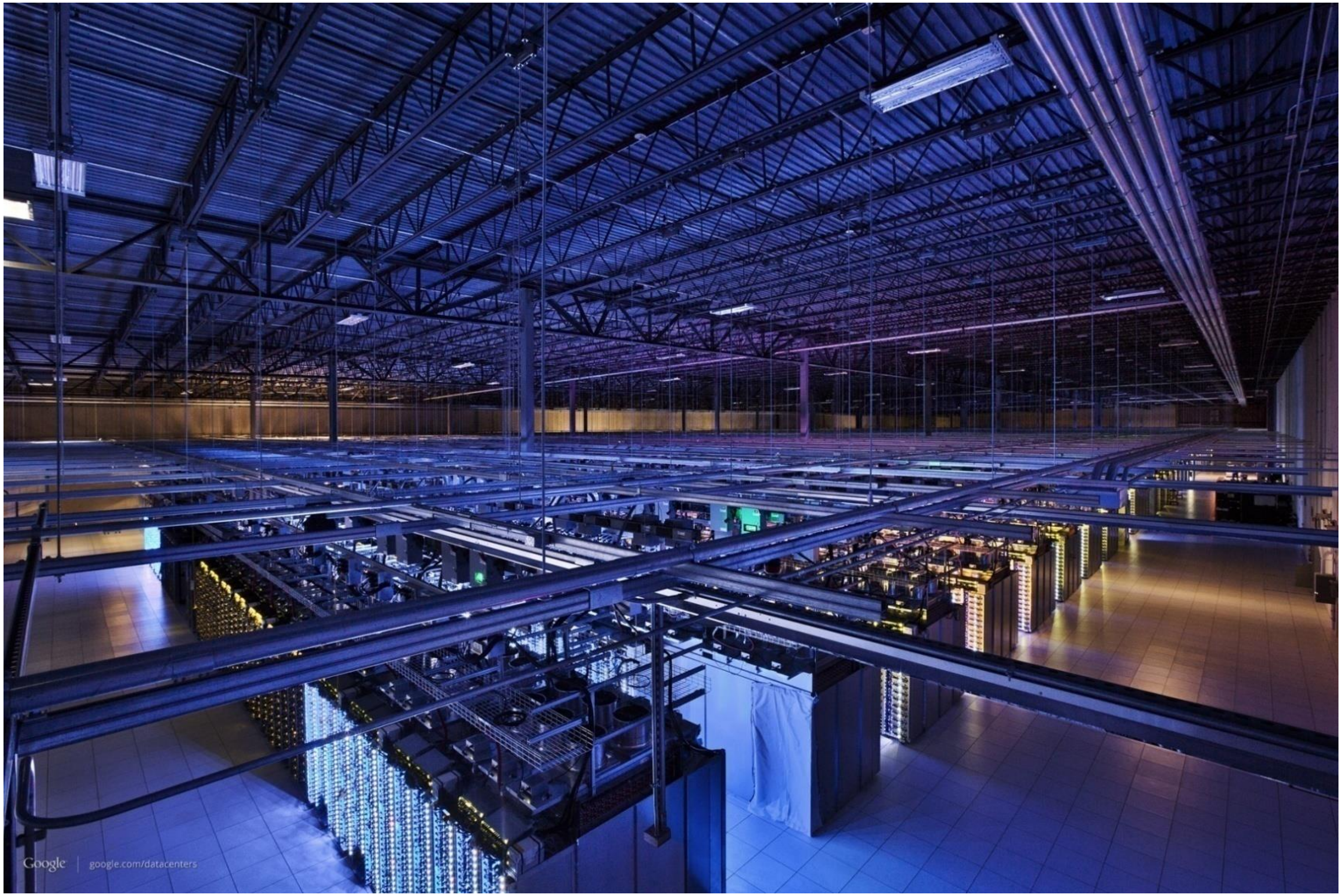
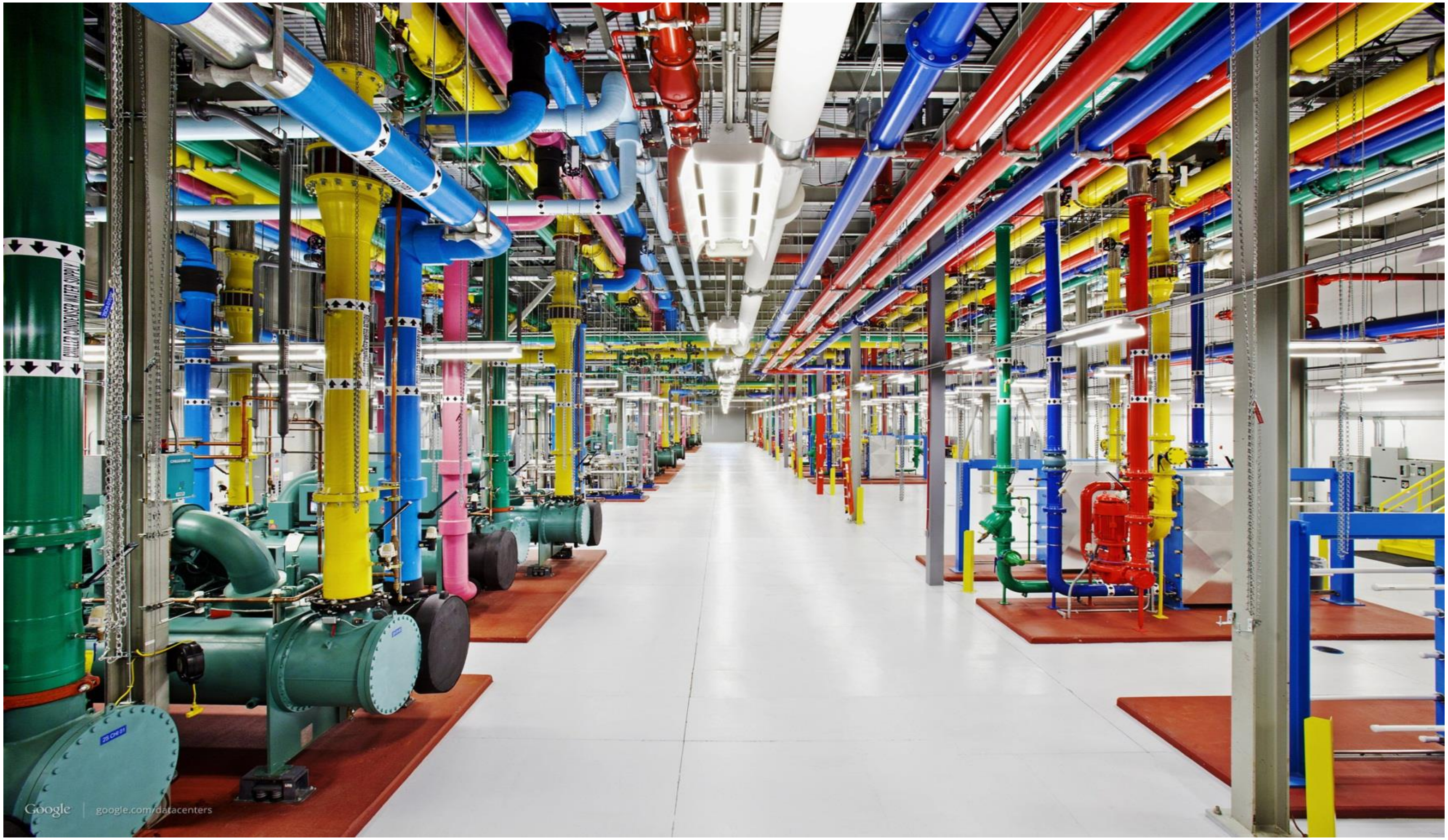


Cabling

Cooling

Cooling



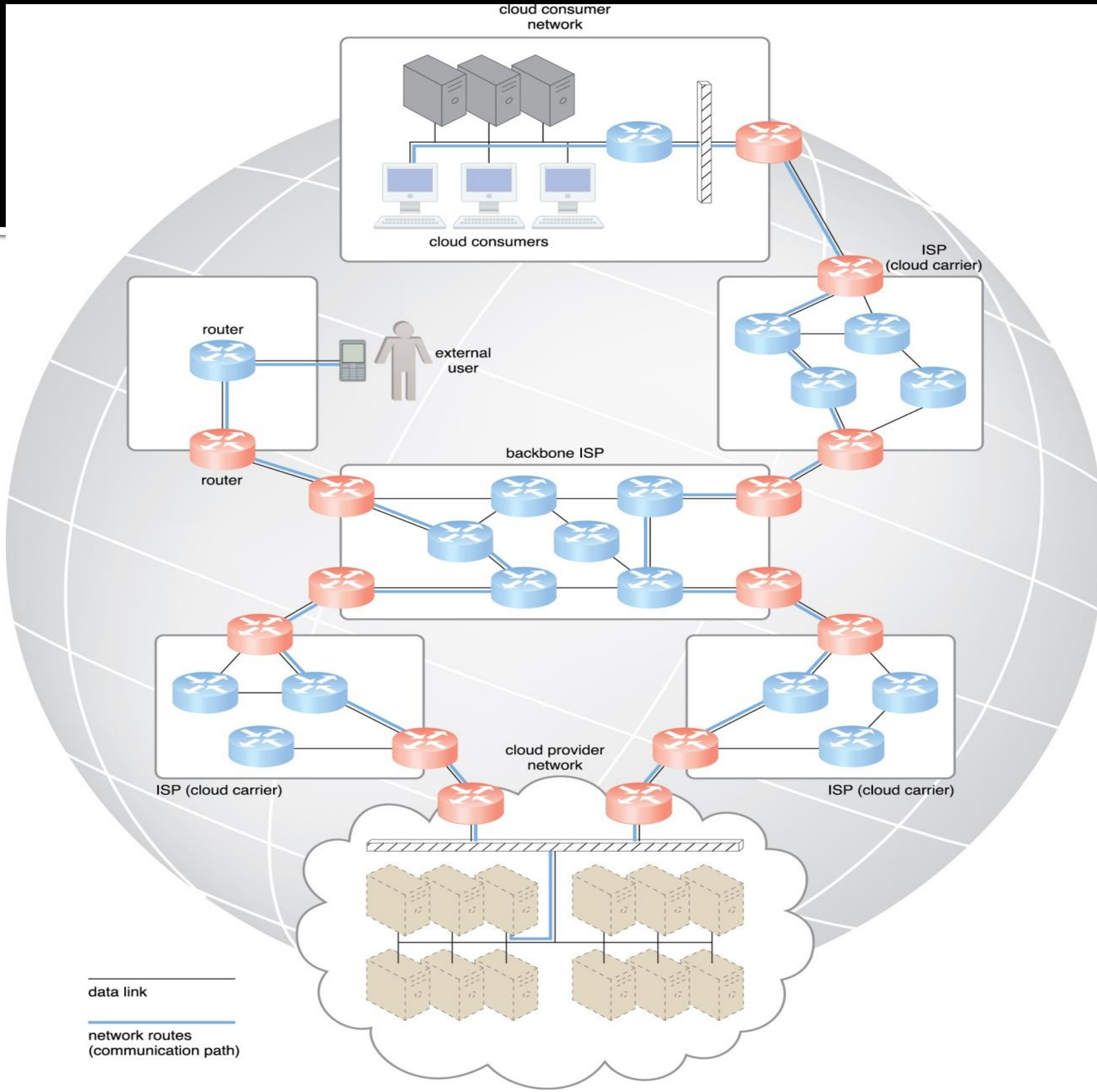

cloud consumer
network
cloud consumers
ISP
(cloud carrier)
router
external
user
router
backbone ISP
ISP (cloud carrier)
cloud provider
network
ISP (cloud carrier)
data link
network routes
(communication path)

Figure 1-2: VMware Infrastructure Data Center Physical Building Blocks

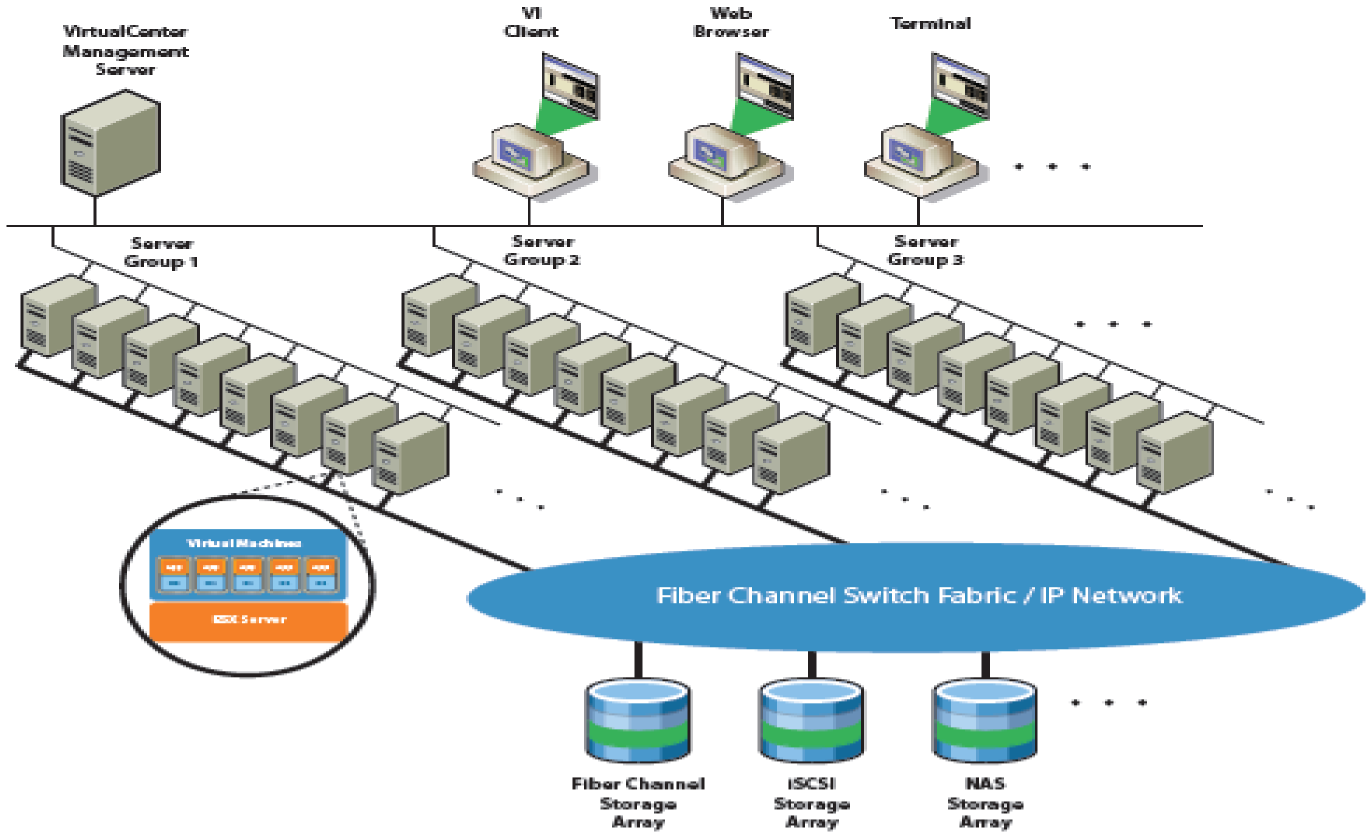
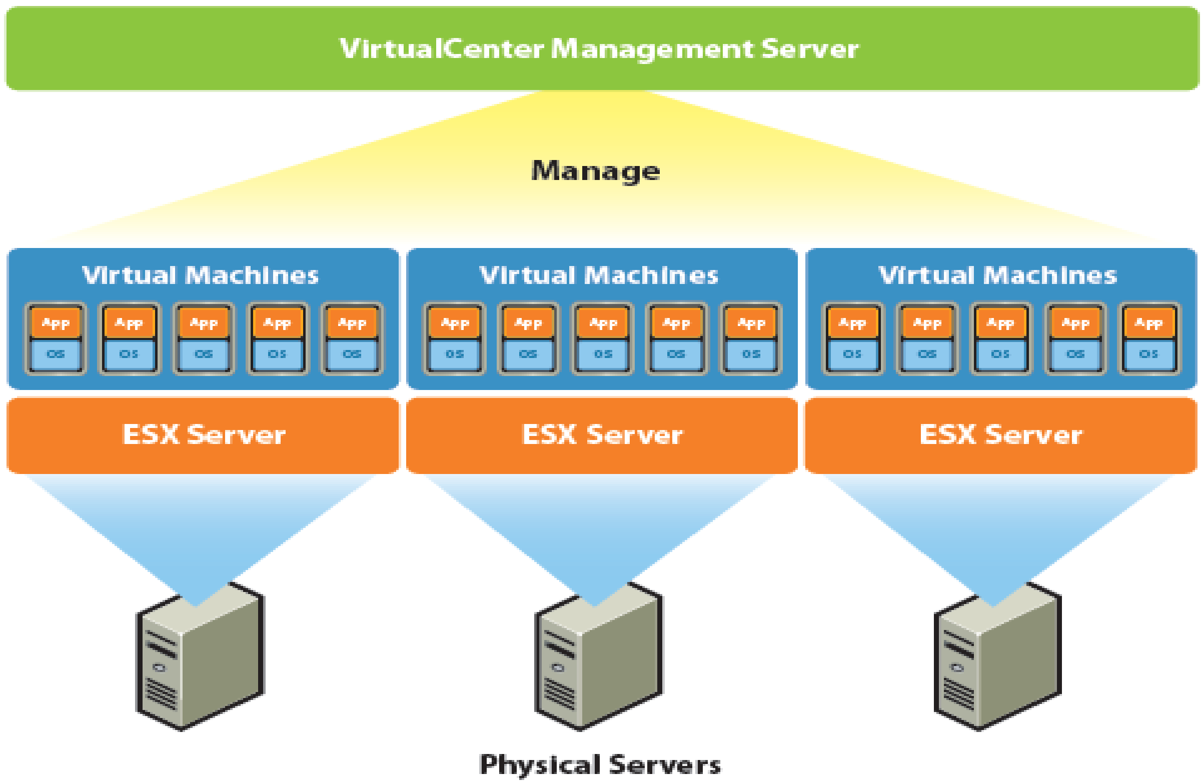


Figure 1-3: VirtualCenter Management Server centrally manages the assignment of virtual machines to physical servers



Virtual Data Center Architecture

- VMware Infrastructure virtualizes the entire IT infrastructure including servers, storage and networks.
- It aggregates these heterogeneous resources and presents a simple and uniform set of elements in the virtual environment.
- ***With Vmware Infrastructure, IT resources can be managed like a shared utility and dynamically provisioned to different business units and projects without worrying about the underlying hardware differences and limitations.***

Virtual Data Center Architecture

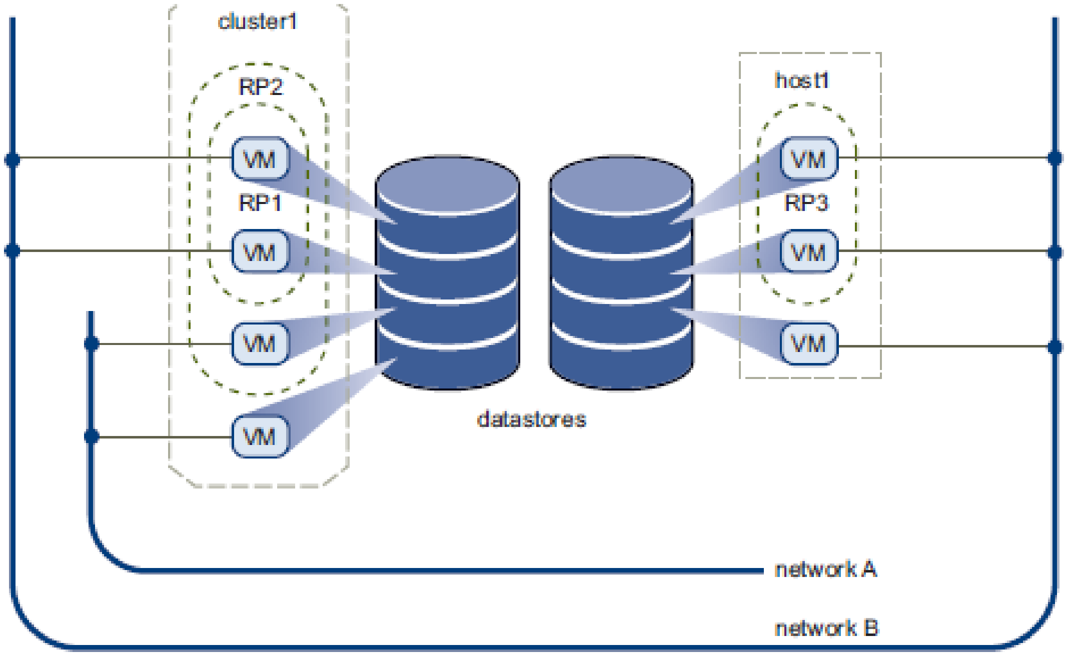


Figure 1-4: Virtual Data Center Architecture

Virtual Data Center Architecture

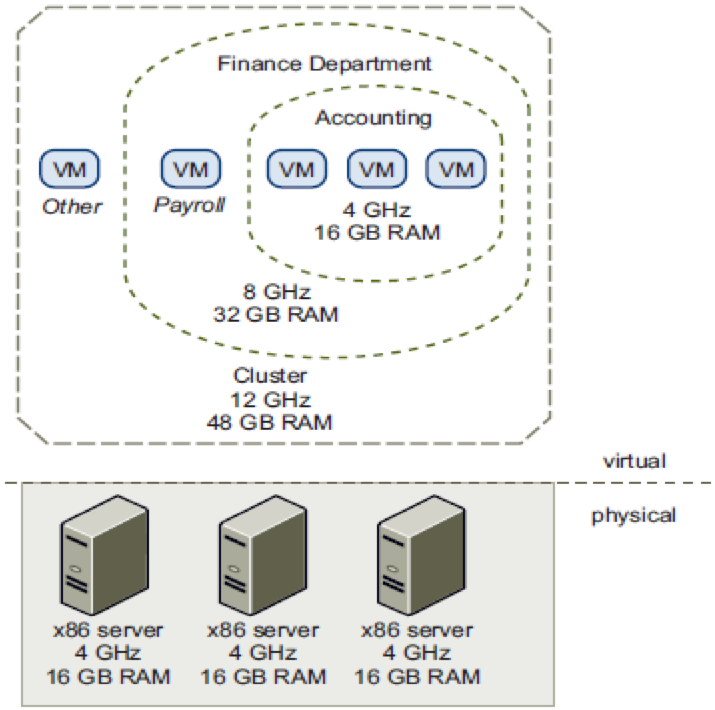
- Provisioning of virtual machines is much faster and easier than physical machines.

- Resources are provisioned to virtual machines based on the policies set by the system administrator who owns the resources.

Hosts, Clusters and Resource Pools

- Hosts, Clusters and Resources Pools provide flexible and dynamic ways to organize the aggregated computing and memory resources in the virtual environment and link them back to the underlying physical resources.

Figure 1-5: Hosts, Clusters and Resource Pools

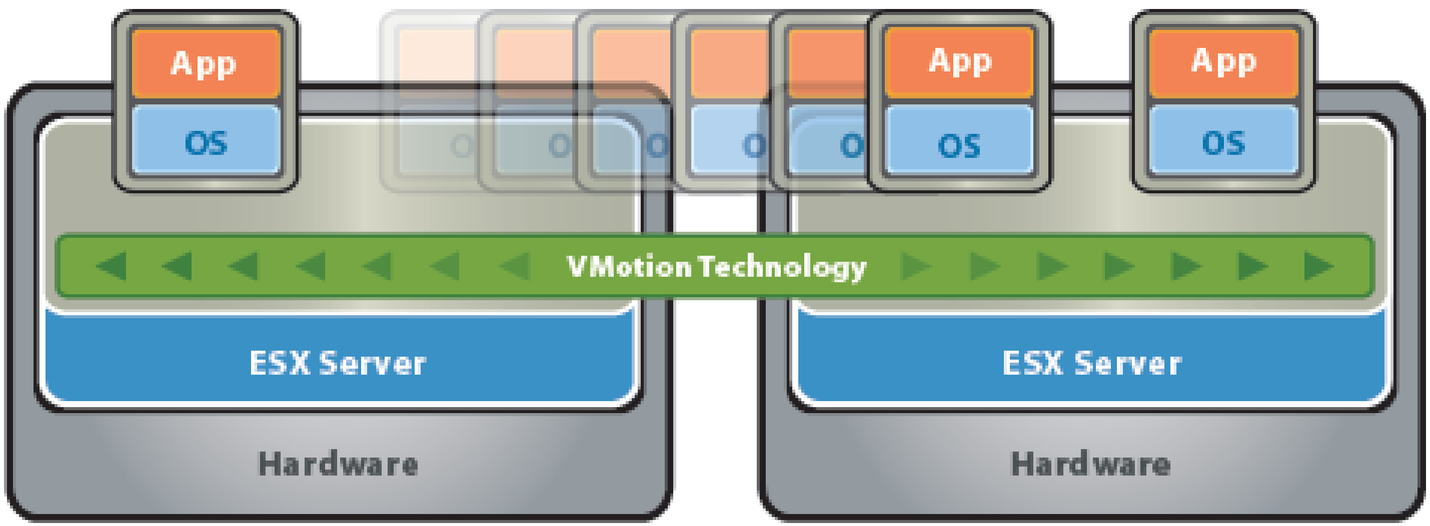


VMware VMotion, VMware DRS and VMware HA

- VMware VMotion, VMware DRS (Distributed Resource Scheduler) and VMware HA (High Availabilty) are distributed services that enable efficient and automated resource management and high virtual machine availability.

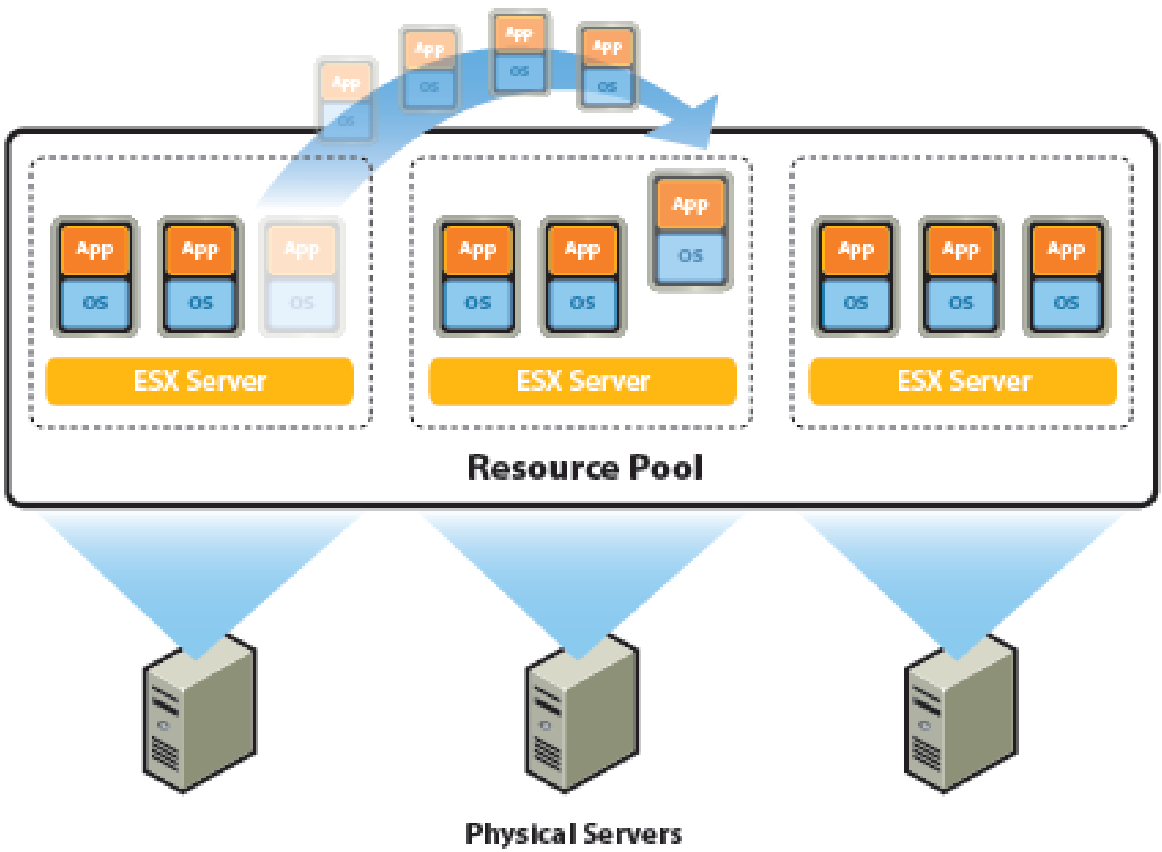
VMware VMotion

Figure 1-6: VMware VMotion



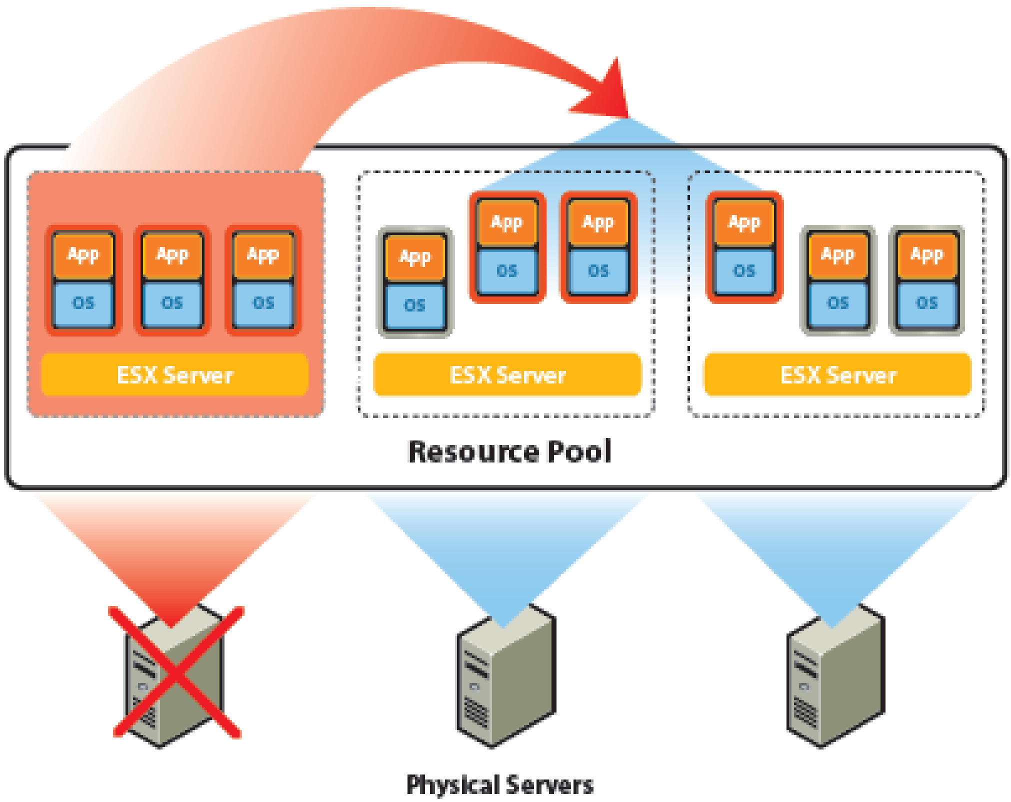
VMware DRS

Figure 1-7: VMware DRS



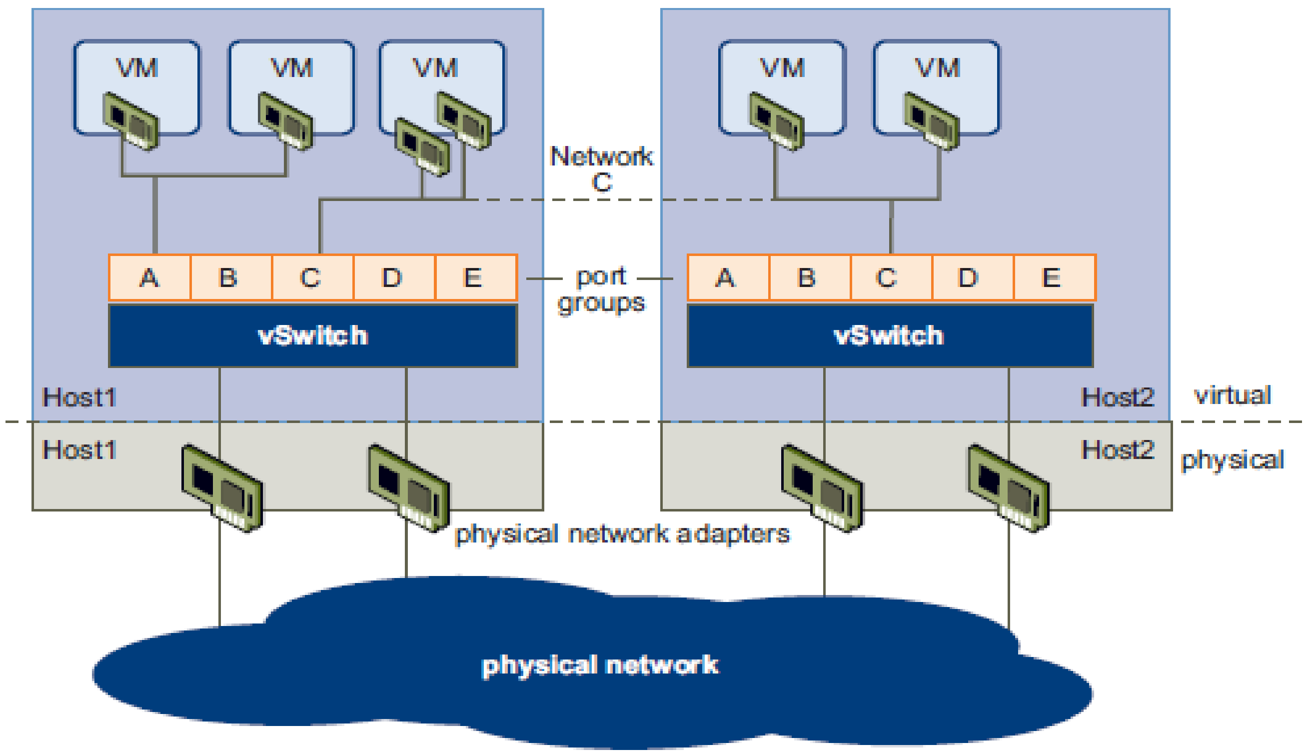
VMware HA

Figure 1-8. VMware HA



Networking Architecture

Figure 1-9: Networking Architecture



DMTF (Distributed Management Task Force) OVF (latest release2.0)

- **Open Virtualization Format** (**OVF**) is an open standard for packaging and distributing virtual appliances or, more generally, software to be run in virtual machines.

- The standard describes an "open, secure, portable, efficient and extensible format for the packaging and distribution of software to be run in virtual machines".

- The OVF standard is not tied to any particular hypervisor or instruction set architecture. The unit of packaging and distribution is a so-called *OVF Package* which may contain one or more *virtual systems* each of which can be deployed to a virtual machine.

What are the benefits of OVF? Why is it important?

- OVF describes an open, secure, portable, efficient and extensible format for the packaging and distribution of virtual appliances. The key features and benefits of the format are:
  1. Portable VM packaging
  2. Optimized for secure distribution
  3. Simplified installation and deployment
  4. Supports both VM and multi-VM configurations
  5. Vendor and platform independent
  6. Extensible
  7. Localizable

Open Commons Consortium

- The **Open Commons Consortium** (*aka* **OCC** - formerly the **Open Cloud Consortium**) is a 501(c)(3) non-profit venture which provides cloud computing and data commons resources to support "scientific, environmental, medical and health care research."
- OCC manages and operates resources including the Open Science Data Cloud (*aka* OSDC), which is a multi-petabyte scientific data sharing resource.
- The consortium is based in Chicago, Illinois, and is managed by the 501(c)3 Center for Computational Science Research.

The OCC is divided into Working Groups which include:

- **The Open Science Data Cloud** - This is a working group that manages and operates the Open Science Data Cloud (OSDC), which is a petabyte scale science cloud for researchers to manage, analyze and share their data.

- **Project Matsu** - Project Matsu is a collaboration between the NASA Goddard Space Flight Center and the Open Commons Consortium to develop open source technology for cloud-based processing of satellite imagery to support the earth science research community as well as human assisted disaster relief.

The OCC is divided into Working Groups which include:

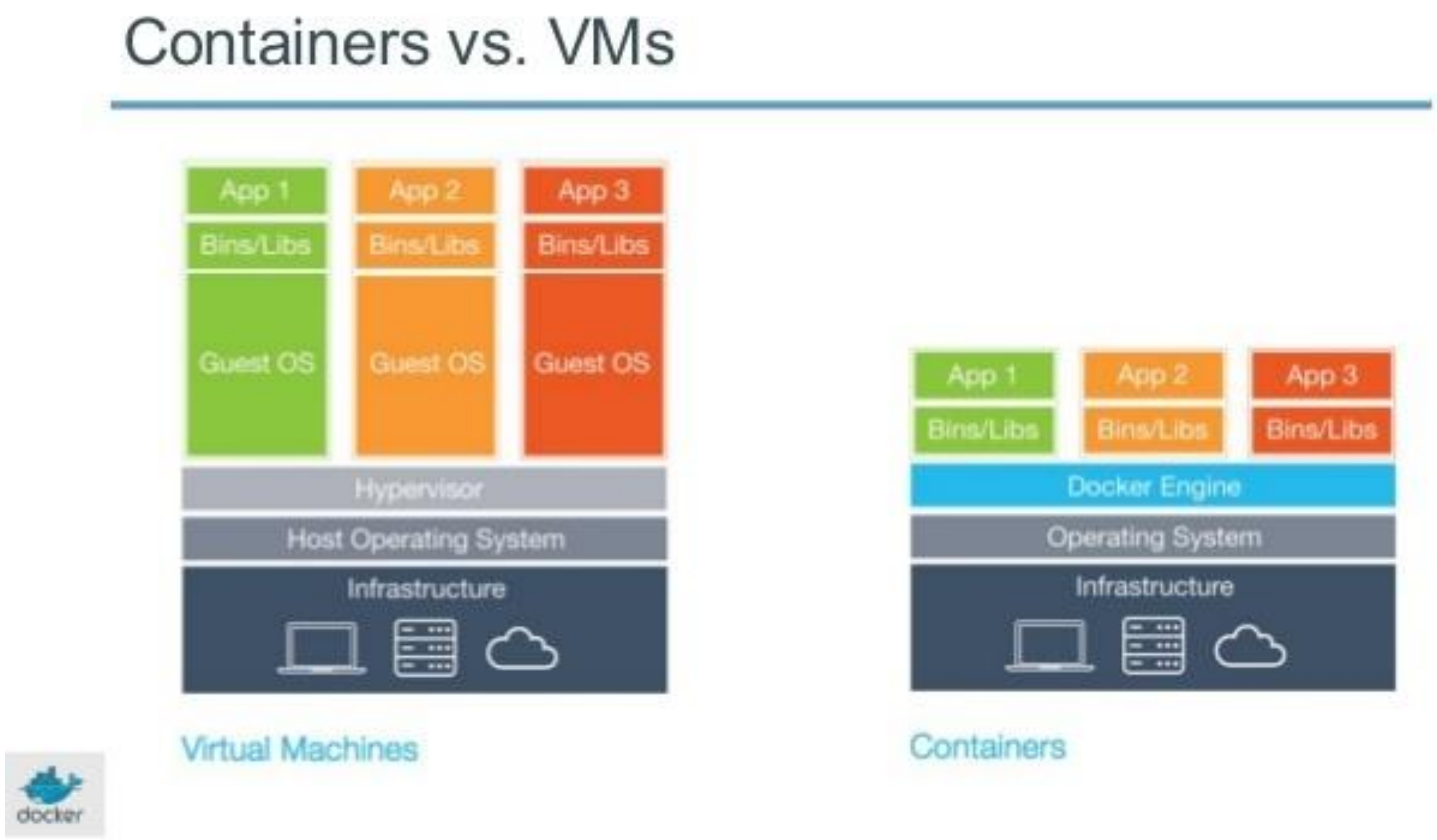
- **The Open Cloud Testbed** - This working group manages and operates the Open Cloud Testbed. The Open Cloud Testbed (OCT) is a geographically distributed cloud testbed spanning four data centers and connected with 10G and 100G network connections. The OCT is used to develop new cloud computing software and infrastructure.

- **The Biomedical Data Commons** - The Biomedical Data Commons (BDC) is cloud-based infrastructure that provides secure, compliant cloud services for managing and analyzing genomic data, electronic medical records (EMR), medical images, and other PHI data. It provides resources to researchers so that they can more easily make discoveries from large complex controlled access datasets.

The OCC is divided into Working Groups which include:

- **NOAA Data Alliance Working Group** - The OCC National Oceanographic and Atmospheric Administration (NOAA) Data Alliance Working Group supports and manages the NOAA data commons and the surrounding community interested in the open redistribution of NOAA datasets.

Difference between VM and container



Questions

1. What is virtualization and what are its benefits?
2. What are the characteristics of virtualized environments?
3. Discuss classification or taxonomy of virtualization at different levels.
4. Discuss the machine reference model of execution virtualization.
5. What are hardware virtualization techniques?
6. List and discuss different types of virtualization.
7. What are the benefits of virtualization in the context of cloud computing?

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