- **UNIT II: Cloud Enabling technology and Virtualization**
  - Cloud-Enabling Technology: Broadband Networks and Internet Architecture, Data Center Technology, Virtualization Technology, Web Technology, Multitenant Technology, Service Technology.
  - 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.

Virtualization Technology

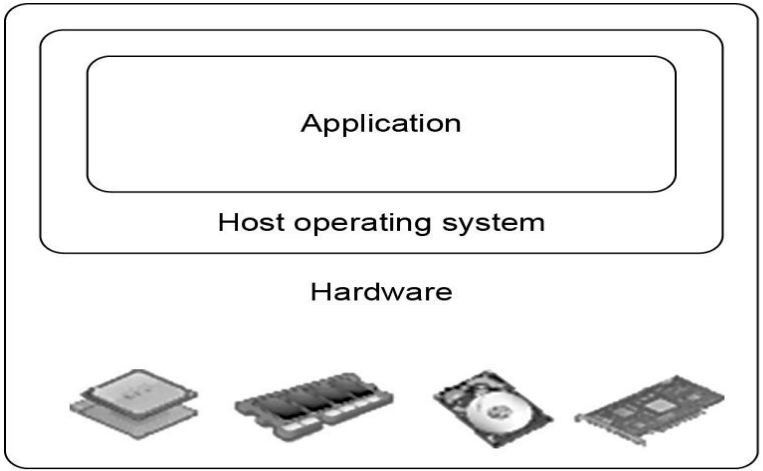
- Virtualization is a technique of how to separate a service from the underlying physical delivery of that service. It is the process of creating a virtual version of something like computer hardware.

- It involves using specialized software to create a virtual or software-created version of a computing resource rather than the actual version of the same resource.

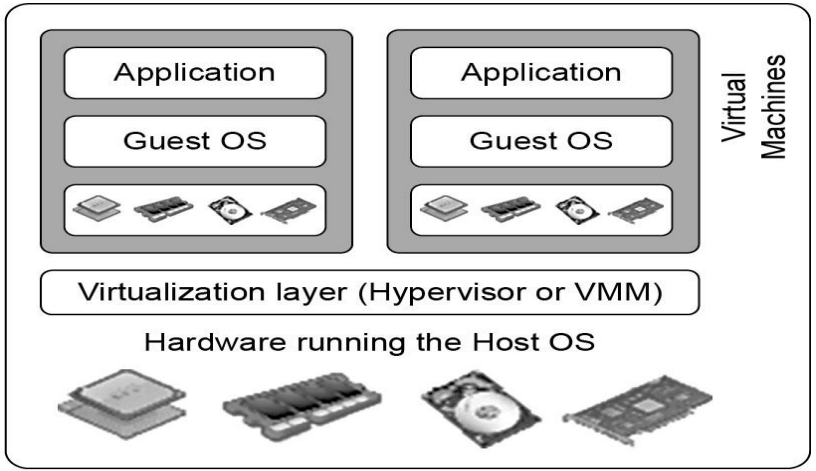
- With the help of Virtualization, multiple operating systems and applications can run **on same machine and its same hardware at the same time, increasing the utilization and flexibility of hardware.**

Virtualization

- Virtualization is a **technique of partitioning the resources of a single computing platform** into multiple segregated, virtualized, execution environments.
- Each environment runs independently of the other, thus allowing multiple operating systems to run on the same hardware.
- Virtualization basically allows one computer to do the job of multiple computers, by sharing the resources of a single hardware across multiple environments



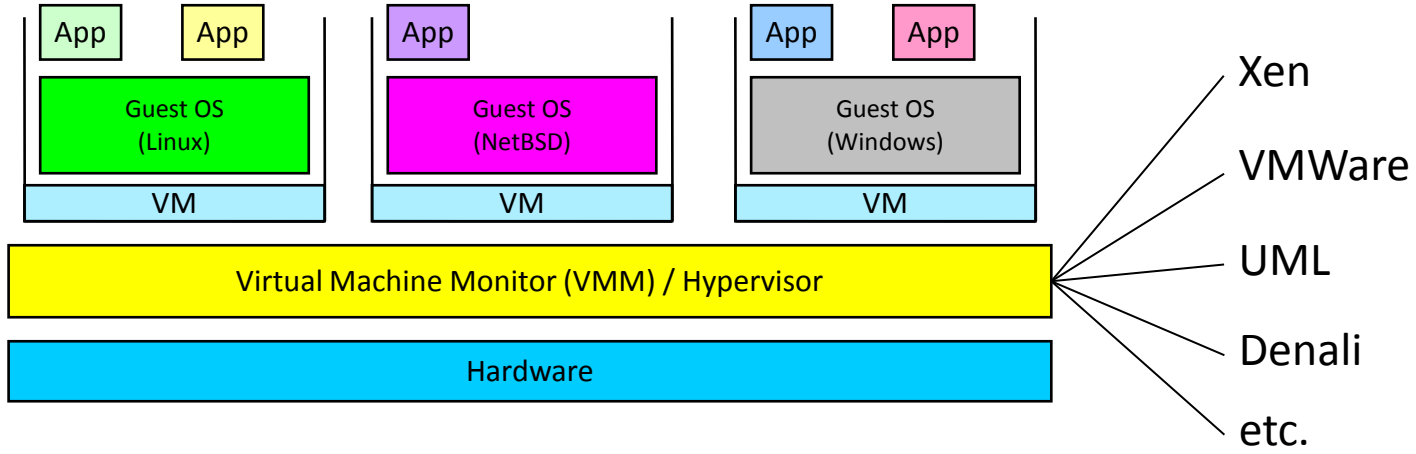
(a) Traditional computer



(b) After virtualization

Virtual Machines

- VM technology allows multiple virtual machines to run on a single physical machine.



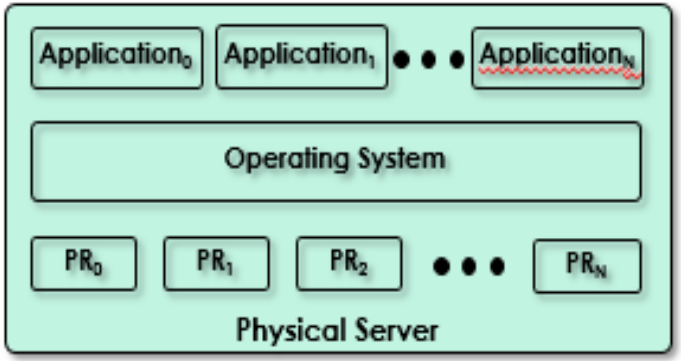
Performance: Para-virtualization (e.g. Xen) is very close to raw physical performance!

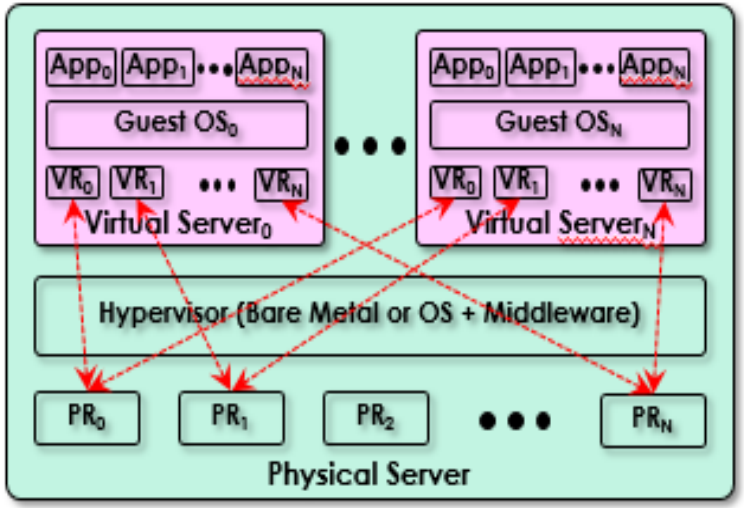
Virtualization

- Virtualization of the CPU: If a process tries to consume all of the CPU, the operating system will preempt it and allow other processes to execute;
- Virtualization of the memory: a running process has its own virtual address space that the operating system maps to physical memory to give the process the illusion that it is the only user of RAM.
- Virtualization of the CPU: If an OS tries to consume all of the CPU, the hypervisor will preempt it and allow other processes to execute;
- Virtualization of the memory: a running OS has its own virtual address space that the hypervisor maps to physical memory to give the process the illusion that it is the only user of RAM.

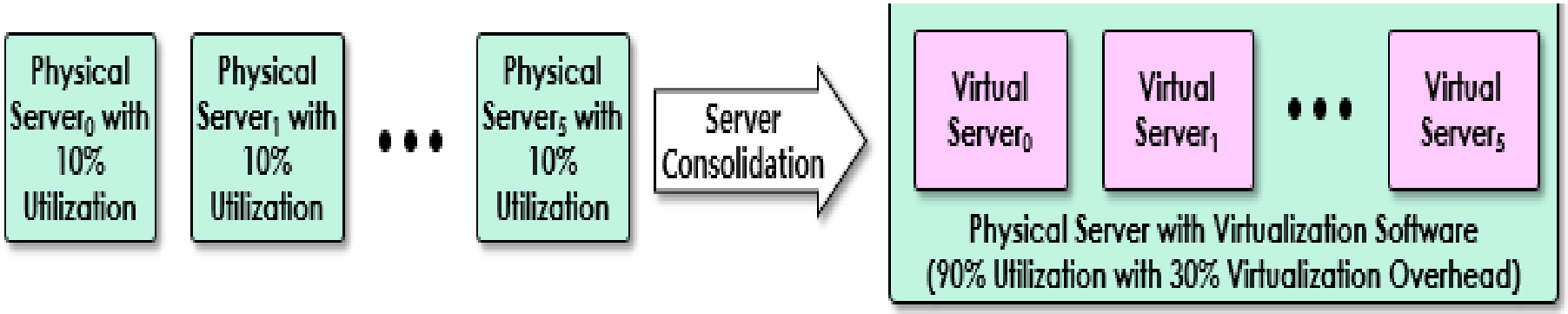
- **Virtualization** is the "**creation of a virtual (rather than actual) version of something, such as a server, a desktop, a storage device, an operating system or network resources".**
- In other words, Virtualization is a technique, which allows **to share a single physical instance of a resource or an application among multiple customers and organizations**. It does by assigning a logical name to a physical storage and providing a pointer to that physical resource when demanded.
- What is the concept behind the Virtualization?
- Creation of a virtual machine over existing operating system and hardware is known as Hardware Virtualization. A Virtual machine provides an environment that is logically separated from the underlying hardware.
- The machine on which the virtual machine is going to create is known as **Host Machine** and that virtual machine is referred as a **Guest Machine**
- This virtual machine is managed by a software or firmware, which is known as **hypervisor.**

Virtualization Technology

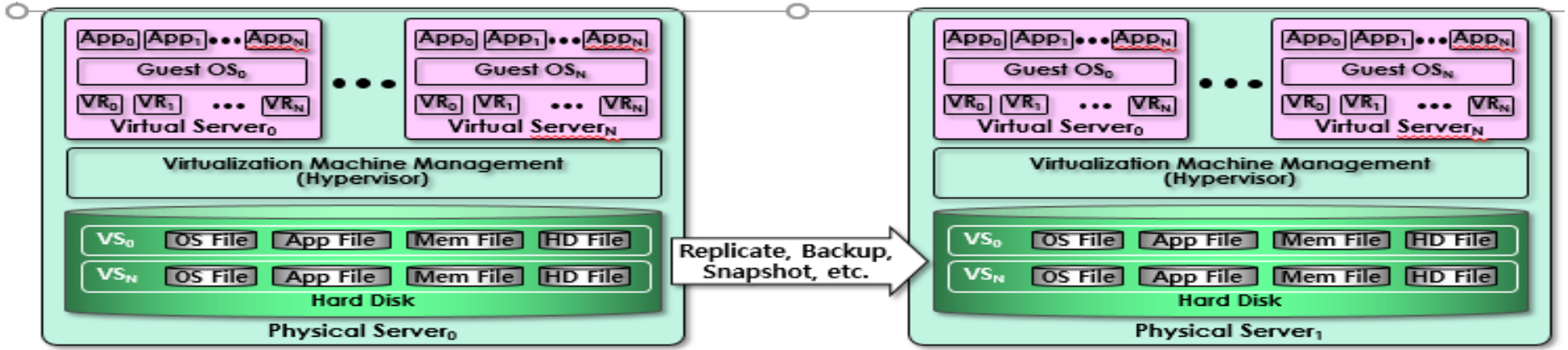




Virtualization Technology



Virtualization Technology



BENEFITS OF VIRTUALIZATION

1.More flexible and efficient allocation of resources.

2.Enhance development productivity.

3.It lowers the cost of IT infrastructure.

4.Remote access and rapid scalability.

5.High availability and disaster recovery.

6.Pay peruse of the IT infrastructure on demand.

7.Enables running multiple operating systems.

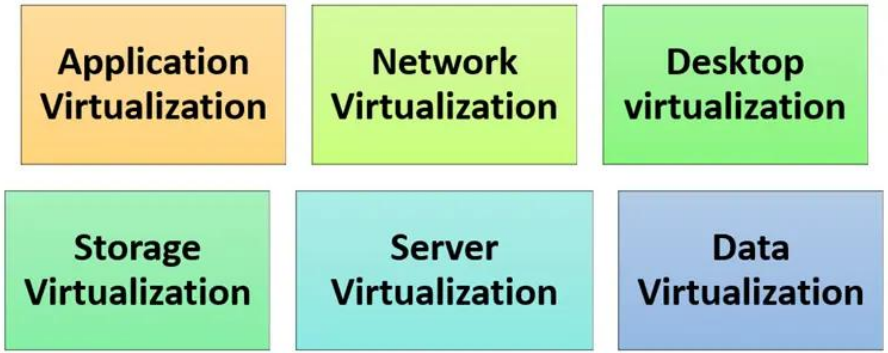
Features of Virtualization

1. **Partitioning**: Multiple virtual servers can run on a physical server at the same time.
2. **Encapsulation of data**: All data on the virtual server, including boot disks, is encapsulated in a file format.
3. **Isolation**: The Virtual server running on the physical server is safely separated and don't affect each other.
4. **Hardware Independence**: When the virtual server runs, it can migrate to a different hardware platform.

- **Distribution of resources:** Virtualization and Cloud Computing technology ensure end-users develop a unique computing environment. It is achieved through the creation of one host machine. Through this host machine, the end-user can restrict the number of active users. By doing so, it facilitates easy of control. They can also be used to bring down power consumption.
- **Accessibility of server resources:** Virtualization delivers several unique features that ensure no need for physical servers. Such features ensure a boost to uptime, and there is less fault tolerance and availability of resources.
- **Resource Isolation:** Virtualization provides isolated virtual machines. Each virtual machine can have many guest users, and guest users could be either operating systems, devices, or applications.
  The virtual machine provides such guest users with an isolated virtual environment. This ensures that the sensitive information remains protected, and, at the same time, guest users remain inter-connected with one another.
- **Security and authenticity:** The virtualization systems ensure continuous uptime of systems, and it does automatic load balancing and ensures there is less disruption of services.

- Types of Virtualization:

1. Data virtualization.
2. Hardware Virtualization.
3. Operating system Virtualization.
4. Server Virtualization.
5. Storage Virtualization.
6. Application virtualization
7. Desktop virtualization



Application Virtualization

- Application virtualization allows users to run applications from devices that don't possess the operating system the application requires.
- Another possible reason to use application virtualization is to run conflicting programs that can't coexist on the same device.
- *An example of this would be a user who needs to run two different versions of the same software.*
- Two of the main application virtualization technologies are hosted applications and packaged applications.
- Hosted solutions use servers to host applications and allow users to connect to the server from their device. The user sends keystrokes and mouse clicks to the server and the server sends screen changes to the user, while the server is actually running the applications. Many users can run applications on the server simultaneously so these servers must have a lot of resources. The user's device doesn't require a lot of resources since it's not doing the work – one of the many benefits of application virtualization
- Example: Microsoft Office 365 with App-V-

Desktop Virtualization

- Desktop Virtualization should be used if application virtualization can't deliver the required applications and desktops.
- Desktop virtualization separates the desktop environment from the physical device and configured as a "virtual desktop infrastructure" (VDI).
- One of the biggest advantages of desktop virtualization is that users are able to access all their personal files and applications on any PC, meaning they can work from anywhere without the need to bring their work computer.
- It also lowers the cost of software licensing and updates. Maintenance and patch management are simple, since all of the virtual desktops are hosted at the same location.
- Users that want specific operating systems other than Windows Server will need to have a virtual desktop.
- Some of the common benefits of desktop and application virtualization are user mobility, easy management of software installation, updates and patches.
- Ex- **Citrix Virtual Desktops**:

Data Virtualization

- Data virtualization is the process of retrieve data from various resources without knowing its type and physical location where it is stored.
- It collects heterogeneous data from different resources and allows data users across the organization to access this data according to their work requirements.
- This heterogeneous data can be accessed using any application such as web portals, web services, E-commerce, Software as a Service (SaaS), and mobile application.
- We can use Data Virtualization in the field of **data integration, business intelligence,** and **cloud computing**.

- **Advantages of Data Virtualization**
- It allows users to access the data without worrying about where it resides on the memory.
- It offers better customer satisfaction, retention, and revenue growth.
- It provides various security mechanism that allows users to safely store their personal and professional information.
- It reduces costs by removing data replication.
- It provides a user-friendly interface to develop customized views.
- It provides various simple and fast deployment resources.
- It increases business user efficiency by providing data in real-time.
- It is used to perform tasks such as data integration, business integration, Service-Oriented Architecture (SOA) data services, and enterprise search.
- **Disadvantages of Data Virtualization**
- It creates availability issues, because availability is maintained by third-party providers.
- It required a high implementation cost.
- It creates the availability and scalability issues.
- Although it saves time during the implementation phase of virtualization but it consumes more time to generate the appropriate result.

- Uses of Data Virtualization

1. Analyze performance

- Data virtualization is used to analyze the performance of the organization compared to previous years.

2. Search and discover interrelated data

- Data Virtualization (DV) provides a mechanism to easily search the data which is similar and internally related to each other.

3. Agile Business Intelligence

- It is one of the most common uses of Data Virtualization. It is used in agile reporting, real-time dashboards that require timely aggregation, analyze and present the relevant data from multiple resources. Both individuals and managers use this to monitor performance, which helps to make daily operational decision processes such as sales, support, finance, logistics, legal, and compliance.

4. Data Management

- Data virtualization provides a secure centralized layer to search, discover, and govern the unified data and its relationships.

- Data Virtualization Tools

Red Hat JBoss data virtualization

TIBCO data virtualization

Oracle data service integrator

SAS Federation Server

Denodo

- Industries that use Data Virtualization
- **Communication & Technology**
  In Communication & Technology industry, data virtualization is used to increase revenue per customer, create a real-time ODS for marketing, manage customers, improve customer insights, and optimize customer care, etc.
- **Finance**
  In the field of finance, DV is used to improve trade reconciliation, empowering data democracy, addressing data complexity, and managing fixed-risk income.
- **Government**
  In the government sector, DV is used for protecting the environment.
- **Healthcare**
  Data virtualization plays a very important role in the field of healthcare. In healthcare, DV helps to improve patient care, drive new product innovation, accelerating M&A synergies, and provide a more efficient claims analysis.
- **Manufacturing**
  In manufacturing industry, data virtualization is used to optimize a global supply chain, optimize factories, and improve IT assets utilization.

Hardware Virtualization:

- When the virtual machine software or virtual machine manager *(VMM) is directly installed on the hardware system* is known as hardware virtualization.
- The main job of hypervisor is to control and monitoring the processor, memory and other hardware resources.
- After virtualization of hardware system we can install different operating system on it and run different applications on those OS.
- Hardware Virtualization is nothing but creating a completely new system on the existing primary system via virtualization that acts as a real computer with an operating system it is also termed as a virtual machine.
- **Usage:**
- Hardware virtualization is mainly done for the server platforms, because controlling virtual machines is much easier than controlling a physical server.

- Advantages of Hardware Virtualization

1) More Efficient Resource Utilization:

- Physical resources can be shared among virtual machines. Although the unused resources can be allocated to a virtual machine and that can be used by other virtual machines if the need exists.

2) Lower Overall Costs Because Of Server Consolidation:

- Now it is possible for multiple operating systems can co-exist on a single hardware platform, so that the number of servers, rack space, and power consumption drops significantly.

3) Increased Uptime Because Of Advanced Hardware Virtualization Features:

- The modern hypervisors provide highly orchestrated operations that maximize the abstraction of the hardware and help to ensure the maximum uptime. These functions help to migrate a running virtual machine from one host to another dynamically, as well as maintain a running copy of virtual machine on another physical host in case the primary host fails.

4) Increased IT Flexibility:

- Hardware virtualization helps for quick deployment of server resources in a managed and consistent ways. That results in IT being able to adapt quickly and provide the business with resources needed in good time.

Operating System Virtualization

- When the virtual machine software or virtual machine manager *(VMM) is installed on the Host operating system* instead of directly on the hardware system is known as operating system virtualization.
- **Usage:**
- Operating System Virtualization is mainly used for testing the applications on different platforms of OS.

Server Virtualization

- When the virtual machine software or virtual machine manager *(VMM) is directly installed on the Server system* is known as server virtualization.
- the central-server(physical server) is divided into multiple different virtual servers by changing the identity number, processors. So, each system can operate its own operating systems in isolate manner. Where each sub-server knows the identity of the central server.
- **Usage:**
- Server virtualization is done because a single physical server can be divided into multiple servers on the demand basis and for balancing the load.
- The concept of Server Virtualization widely used in the IT infrastructure to minimizes the costs by increasing the utilization of existing resources.

- Types of Server Virtualization

1. Hypervisor
2. Full Virtualization
3. Para Virtualization

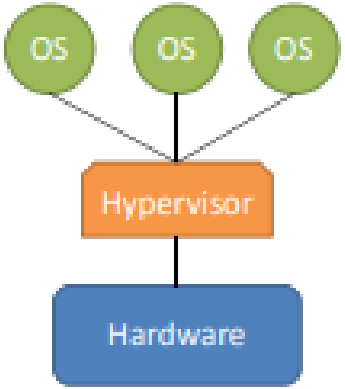
Hypervisor

- Hypervisor, also known as a virtual machine monitor, is a process that creates and runs virtual machines (VMs).
- It allows some of the multiple operating systems to share a single host and its hardware.
- This hypervisor manages requests by the virtual machines to access the hardware resources like RAM , CPU etc.
- Types of Hypervisor

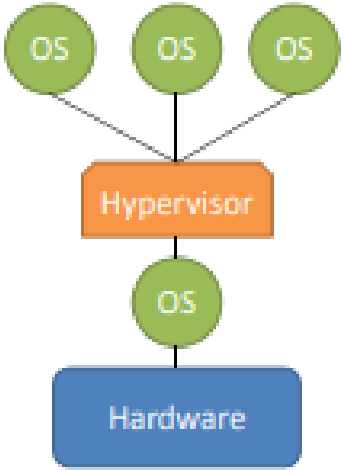
1) Type-1/Native/Bare Metal Hypervisor.
2) Type-2/Hosted Hypervisor.

- Type 1Hypervisor :
  - Type 1 hypervisor is installed directly on bare-metal hardware, it doesn't require an additional OS,
  - EX. Xen, Microsoft Hyper-V , VMWare ESXi
  - System is thin, the hypervisor has direct access to the HW.
- Type 2 Hypervisor :
  - Type-2 Hypervisor is also known as Hosted Hypervisor.
  - It runs on a host operating system that provides a virtualization service.
  - Type-2 Hypervisor is installed on an operating system and then it supports in other operating systems.
  - • EX. VirtualBox and Vmware Workstation

Hypervisor



Type-1
(*bare-metal*)



Type-2
(*hosted*)

- **Full Virtualization**
- Full Virtualization uses a **hypervisor** to directly communicate with the CPU and physical server. It provides the best isolation and security mechanism to the virtual machines.
- The biggest disadvantage of using hypervisor in full virtualization is that a hypervisor has its own processing needs, so it can slow down the application and server performance.
- **VMWare ESX server** is the best example of full virtualization.

- Para Virtualization
- Para Virtualization is quite similar to the Full Virtualization.
- The advantage of using this virtualization is that it is **easier to use**, **Enhanced performance**, and **does not require emulation overhead**. Xen primarily and UML use the Para Virtualization.
- The difference between full and pare virtualization is that, in para virtualization hypervisor does not need too much processing power to manage the OS.

Advantages of Server Virtualization

1. Independent Restart

- In Server Virtualization, each server can be restart independently and does not affect the working of other virtual servers.

2. Low Cost

- Server Virtualization can divide a single server into multiple virtual private servers, so it reduces the cost of hardware components.

3. Disaster Recovery

- Disaster Recovery is one of the best advantages of Server Virtualization. In Server Virtualization, data can easily and quickly move from one server to another and these data can be stored and retrieved from anywhere.

4. Faster deployment of resources

- Server virtualization allows us to deploy our resources in a simpler and faster way.

5. Security

- It allows users to store their sensitive data inside the data centers.

Disadvantages of Server Virtualization

1. The biggest disadvantage of server virtualization is that when the server goes offline, all the websites that are hosted by the server will also go down.
2. There is no way to measure the performance of virtualized environments.
3. It requires a huge amount of RAM consumption.
4. It is difficult to set up and maintain.
5. Some core applications and databases are not supported virtualization.
6. It requires extra hardware resources.

Uses of Server Virtualization

- Server Virtualization is used in the testing and development environment.
- It improves the availability of servers.
- It allows organizations to make efficient use of resources.
- It reduces redundancy without purchasing additional hardware components.

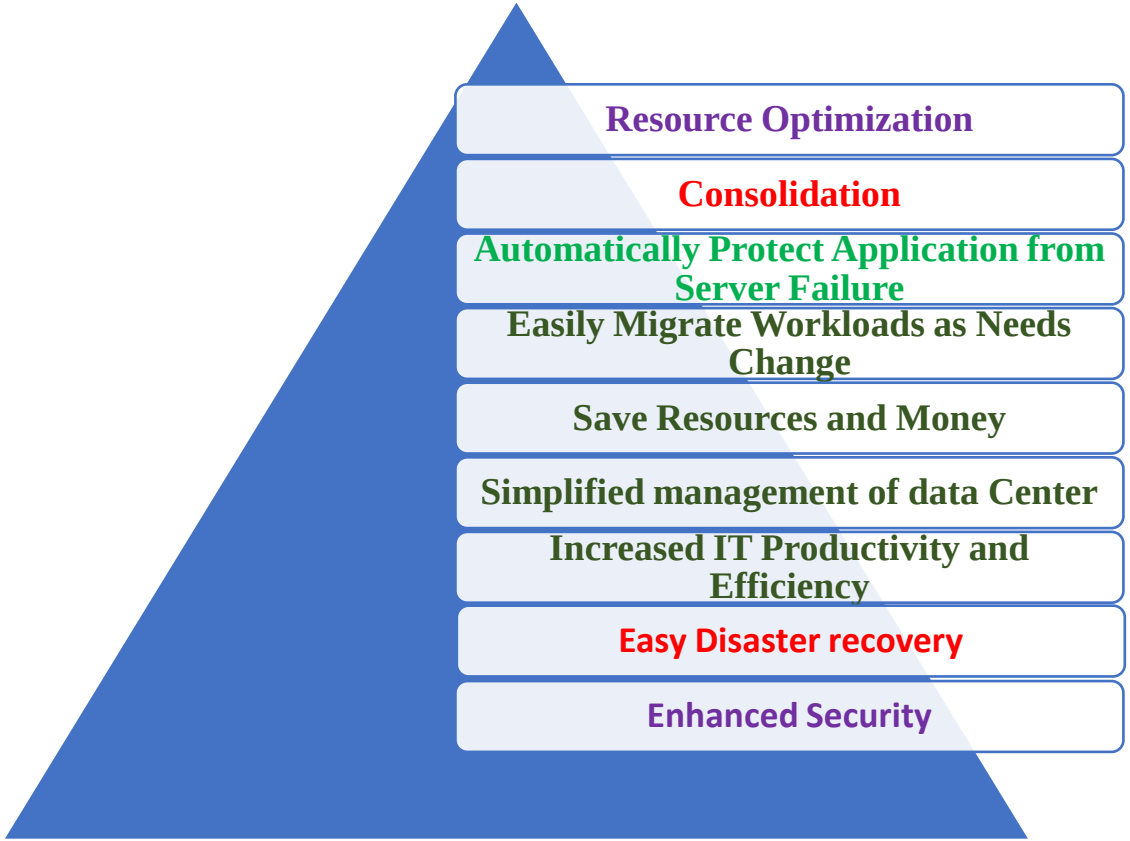
Storage Virtualization:

- Storage virtualization is the *process of grouping the physical storage from multiple network storage devices so that it looks like a single storage device*.
- Storage virtualization is also implemented by using software applications.
- Storage virtualization is a major component for storage servers, in the form of functional RAID levels and controllers. Operating systems and applications with device can access the disks directly by themselves for writing.
- **Usage:**
- Storage virtualization is mainly done for back-up and recovery purposes.

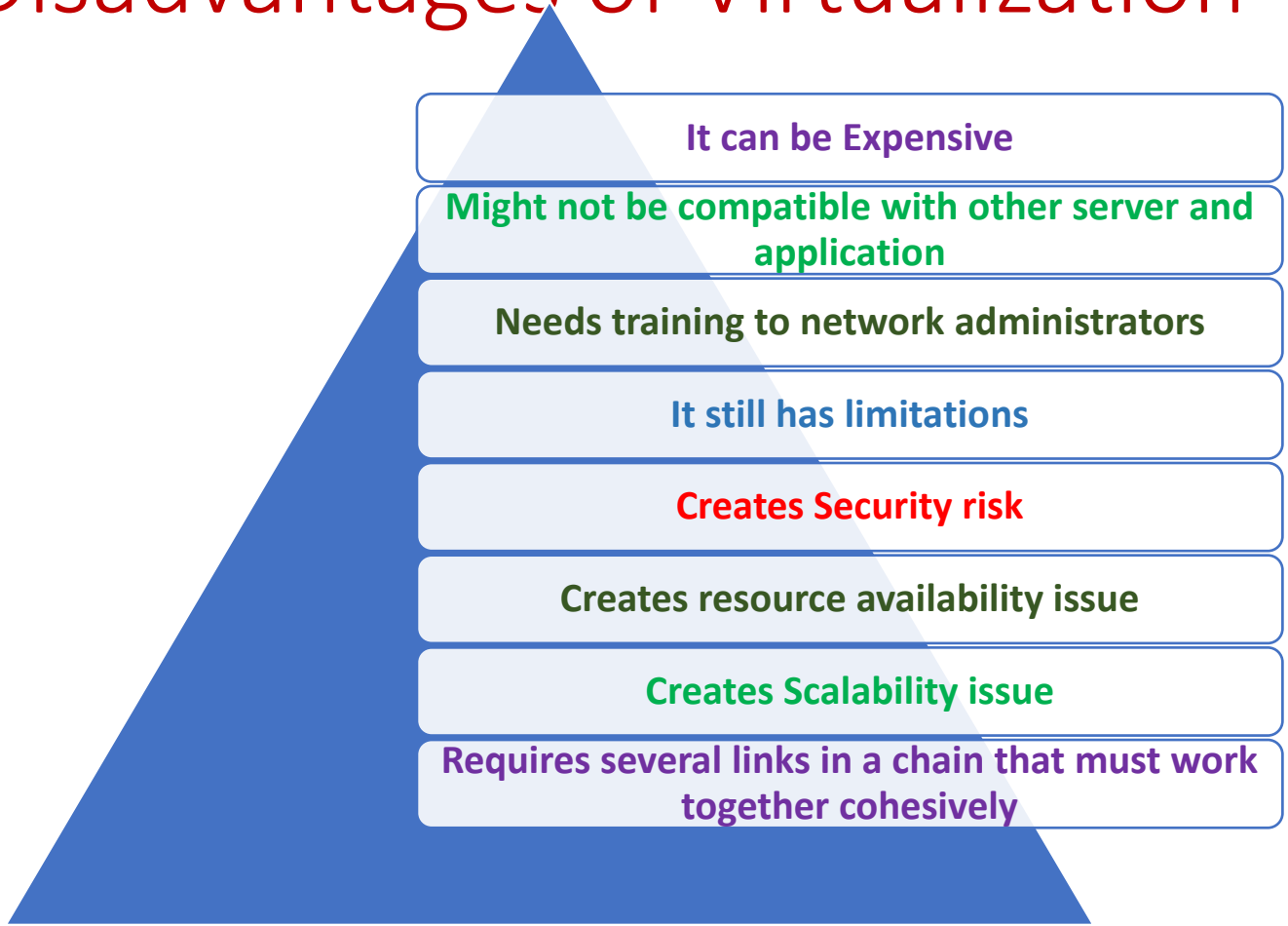
Advantages of Storage Virtualization

1. Data is stored in the more convenient locations away from the specific host. In the case of a host failure, the data is not compromised necessarily.
2. The storage devices can perform advanced functions like replication, reduplication, and disaster recovery functionality.
3. By doing abstraction of the storage level, IT operations become more flexible in how storage is provided, partitioned, and protected.

Need of Virtualization/Advantages of Virtualization



Disadvantages of Virtualization



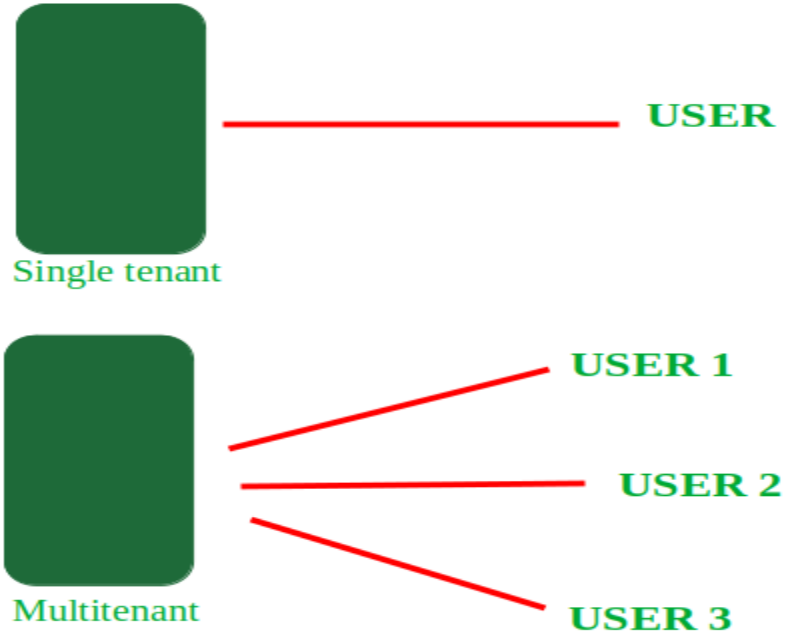
Multitenant Technology

- Multitenancy is a type of software architecture where a single software instance can serve multiple distinct user groups.
- It means that multiple customer’s of cloud vendor are using same computing resources .
- As they are sharing same computing resources but the data of each Cloud customer is kept totally separate and secure. It is very important concept of Cloud Computing.
- In cloud computing Multitenancy also refer as shared host where same resources are divided among different customer’s.

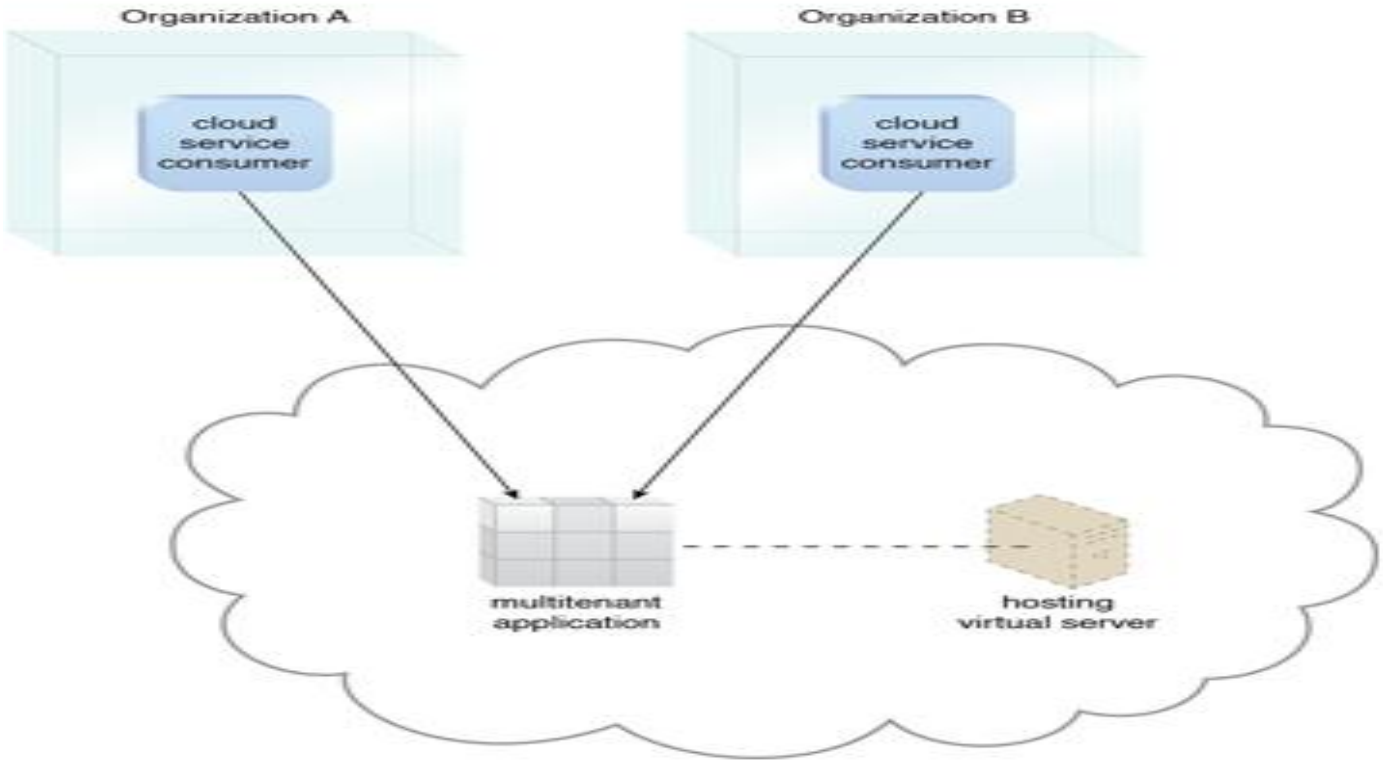
Multitenant Technology

- The multitenant application design was created to enable multiple users (tenants) to access the same application logic simultaneously.
- Each tenant has its own view of the application that it uses, administers, and customizes as a dedicated instance of the software while remaining unaware of other tenants that are using the same application.
- This architecture is commonly used in cloud computing and SaaS (Software as a Service) applications, enabling cost efficiency, scalability, and ease of maintenance while ensuring data security and privacy for each tenant.

Multitenant Technology



Multitenant Application



Advantages of Multitenant Technology

- Use of Available resources is maximized by sharing resources.
- Customer's Cost of Physical Hardware System is reduces.
- It reduce usage of physical devices and thus power consumption and cooling cost save.
- Save Vendor's cost as it become difficult for cloud vendor to provide separate Physical Services to each individual.

Disadvantages of Multitenant Technology

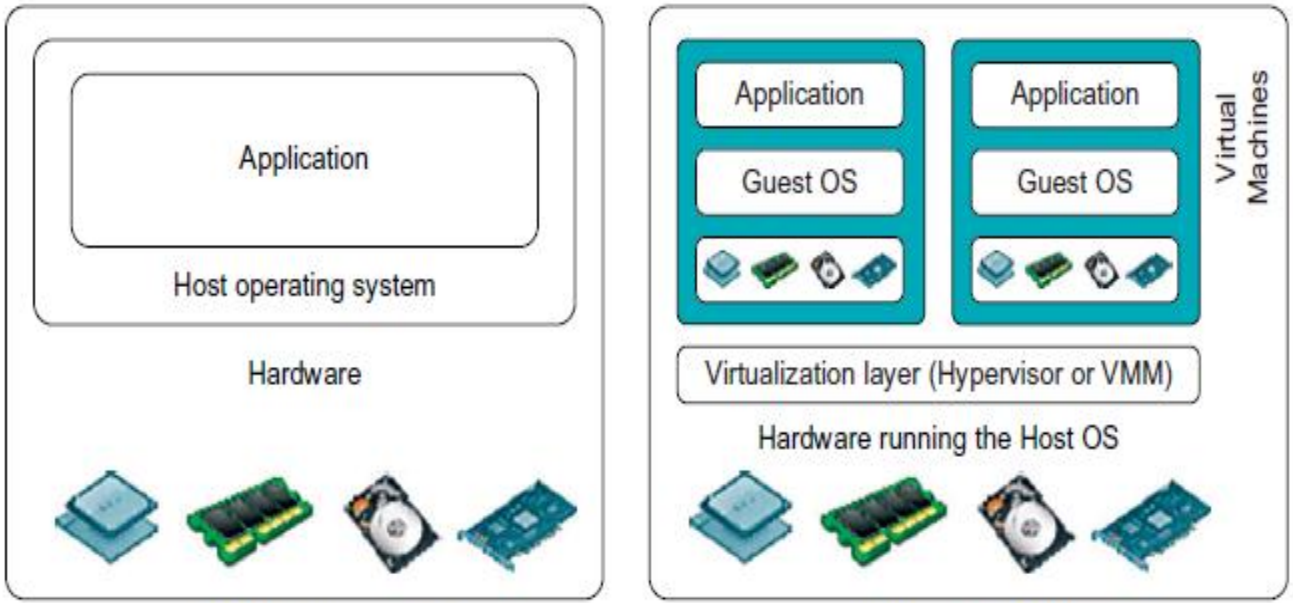
- As data is stored in third party services , this reduces security of our data and put it into vulnerable condition .

- Unauthorized access will cause damage of data.

Implementation Levels of Virtualization

- Traditional computer runs under the control of its operating system which basically tailored for its hardware architecture.
- After the implementation of virtualization, various user application which are handled by their own operating system can be executed on the same hardware, independent of the host OS
- This is usually implemented by introducing additional software called a virtualization layer or Hypervisor
- The improtant funcationality of the software layer in the process of virtualization is to virtualize the physical hardware owned by the host machine in the form of virtual resource to be utilized by the VMs

Implementation Levels of Virtualization



(a) Traditional computer

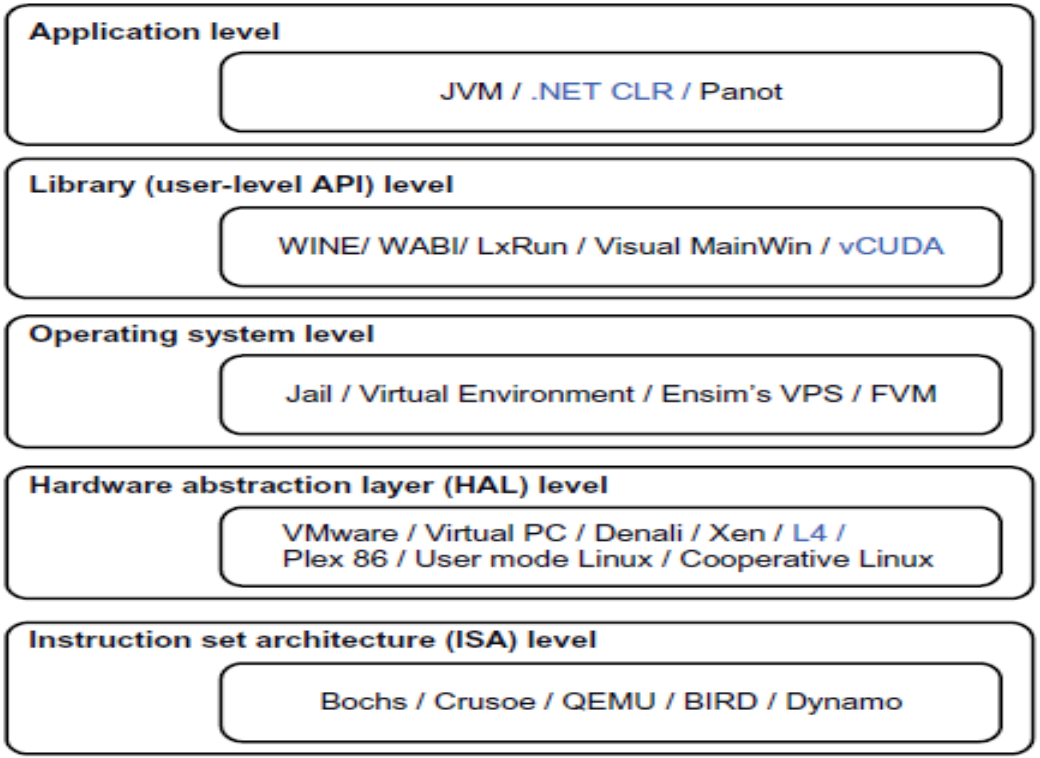
(b) After virtualization

Implementation Levels of Virtualization

- Functionality of software layer is implemented at different operational levels

- The virtualization layer includes following levels:
  - Instruction Set Architecture(ISA) level
  - Hardware level
  - Operating System Level
  - Library Support Level
  - Application Level

Implementation Levels of Virtualization



- **JVM:** A Java virtual machine is an abstract computing machine that enables a computer to run a Java program. There are three notions of the JVM: specification, implementation, and instance.
- **.NET CLR:** The Common Language Runtime, the virtual machine component of Microsoft's .NET framework, manages the execution of .NET programs.
- **WINE:** Wine (recursive backronym for Wine Is Not an Emulator) is a free and open-source compatibility ..... product that uses some Wine code for its DirectX handling. VirtualBox, a virtual machine that uses some Wine code for its Direct3D handling.
- **WABI**: Sun used Windows Application Binary Interface to make Solaris more appealing to those needing Windows applications. The WABI software sits between an application and the operating system, intercepts the applications Windows calls, and translates them to "equivalent" Unix calls. On x86, the guest instructions were run directly on the processor, while they were emulated and/or binary translated on SPARC. WABI can also use an optional DOS emulator to run DOS applications.

- **Lxrun** is software for executing Linux a.out and ELF binaries (x86 only) on x86 Unix systems such as SCO OpenServer, SCO UnixWare, and later, Solaris. This is achieved by "remapping" Linux system calls on the fly. You need the Linux shared libraries that the application requires, as well as the Linux dynamic loader. Lxrun is thus a system call emulator. There are various caveats as to what kind of applications will not run, etc.

- **MainWin:** Microsoft had versions of Internet Explorer and Outlook Express for Solaris (SPARC). This was achieved not by porting them to Solaris, but by using API emulation. Mainsoft, the software company behind that effort, now has a product called Visual MainWin that allows for applications developed on Windows using Visual Studio to be run on Solaris, Linux, HP-UX, and AIX. It recompiles the applications from source on the deployment platform, using the latter's compilers.

- vCuda: vCUDA is a general-purpose graphics processing unit (GPGPU) computing solution for virtual machines (VMs).

- Jail: The FreeBSD jail mechanism is an implementation of operating system-level virtualization that allows system administrators to partition a FreeBSD-based computer system into several independent mini-systems called jails.

- A **Virtual Environment,** put simply, is an isolated working copy of Python which allows you to work on a specific project without worry of affecting other projects It enables multiple side-by-side installations of Python, one for each project.

-

Ensim VPS solution virtualizes a server's native OS so it can be partitioned into isolated computing environments which operate independently of each other, just like a dedicated server.

- Featherweight Virtual Machine (FVM) is an OS-level virtual machine for Windows XP and Windows.

- VMware, Inc. is a subsidiary of Dell Technologies that provides cloud computing and platform virtualization.

- Windows Virtual PC is a virtualization program for Microsoft Windows. In July 2006 Microsoft released the Windows version as a free product.

- The Denali project seeks to enable an array of new networking and distributed middleware applications by designing and implementing lightweight protection domains, focusing in particular on the use of lightweight virtual machines and monitors. A virtual machine monitor (VMM) is a thin virtualization layer between hardware and ``guest'' operating systems, enabling hosts to safely execute untrusted applications and guest OS's inside a VM.

- Xen Project is a hypervisor using a microkernel design, providing services that allow multiple computer operating systems to execute on the same computer hardware concurrently. It was developed by the University of Cambridge and is now being developed by the Linux Foundation with support from Intel.

- The L4 Runtime Environment (L4Re) provides a basic set of services and abstractions, which are useful to implement and run user-level applications on top of the Fiasco.OC microkernel.

- Plex86 is a very lightweight Virtual Machine (VM) for running Linux/x86.
- User-Mode Linux is a safe, secure way of running Linux versions and Linux processes. Run buggy software, experiment with new Linux kernels or distributions, and poke around in the internals of Linux, all without risking your main Linux setup.
- Bochs is a portable x86 PC emulation software package that emulates enough of the x86 CPU, related AT hardware, and BIOS to run Windows, Linux, *BSD, Minix, and other OS's, all on your workstation.
- The Crusoe is a family of x86-compatible microprocessors developed by Transmeta and introduced in 2000. Crusoe was notable for its method of achieving x86 compatibility. Instead of the instruction set architecture being implemented in hardware, or translated by specialized hardware, the Crusoe runs a software abstraction layer, or a virtual machine, known as the Code Morphing Software (CMS). The CMS translates machine code instructions received from programs into native instructions for the microprocessor. In this way, the Crusoe can emulate other instruction set architectures (ISAs).
- QEMU is a hosted virtual machine monitor: it emulates CPUs through dynamic binary translation and provides a set of device models, enabling it to run a variety of unmodified guest operating systems. It also can be used with KVM to run virtual machines at near-native speed (requiring hardware virtualization extensions on x86 machines). QEMU can also do CPU emulation for user-level processes, allowing applications compiled for one architecture to run on another.
- Dynamo is an experimental web framework that runs on Elixir. It leverages the power of the Erlang VM to build highly performant and concurrent web applications. Dynamo's goals are performance, robustness and simplicity.
- http://www.kernelthread.com/publications/virtualization/

Virtualization at ISA (Instruction Set Architecture) level

- Emulating a given ISA by the ISA of the host machine.
- enabling a program designed for one instruction set architecture (e.g., x86, ARM) to run on a machine with a different ISA.
- e.g, MIPS binary code can run on an x-86-based host machine with the help of ISA emulation.
    - Typical systems: Bochs, Crusoe, Qemu, 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 instruction may require tens or hundreds of native target instructions to perform its function, which is relatively slow.
    - V-ISA requires adding a processor-specific software translation layer in the complier.

Virtualization at ISA level

- **Cross-Platform Compatibility:**
  - Running programs designed for one architecture on a machine with a different architecture.
  - Example: Running x86 programs on an ARM-based system.
- **Legacy System Support:**
  - Allowing outdated applications designed for older architectures to run on modern systems.
  - Example: Emulating older ISAs like MIPS or PowerPC on x86 machines.
- **Testing and Development:**
  - Software developers can test code for a specific ISA without needing hardware that supports it.
  - Example: Developing software for an embedded ARM device on a standard x86 machine.
- **Virtual Machines and Emulators:**
  - Tools like QEMU use ISA-level virtualization to enable emulation of different architectures.

Virtualization at Abstraction Level

- Hardware-level virtualization is performed right on top of the bare hardware.
- On the one hand, this approach generates a virtual hardware environment for a VM.
- On the other hand, the process manages the underlying hardware through virtualization.
- The idea is to virtualize a computer's resources, such as its processors, memory and I/O devices. The intention is to upgrade the hardware utilization rate by multiple users concurrently.

- Typical systems: VMware, Virtual PC, Denali, Xen

- Advantage:

- Has higher performance and good application isolation

- Shortcoming & limitation:

- Very expensive to implement (complexity)

Virtualization at OS Level

- It is an abstraction layer between traditional OS and user placations.
- This virtualization creates isolated containers on a single physical server and the OS-instance to utilize the hardware and software in datacenters.
- OS-level virtualization is commonly used in creating virtual hosting environments to allocate hardware resources among a large number of mutually distrusting users.
- Typical systems: Jail / Virtual Environment / Ensim's VPS / FVM
- Advantage:
- Has minimal startup/shutdown cost, low resource requirement, and high scalability; synchronize VM and host state changes.
- Shortcoming & limitation:
- All VMs at the operating system level must have the same kind of guest OS
- Poor application flexibility and isolation.

Virtualization at OS Level

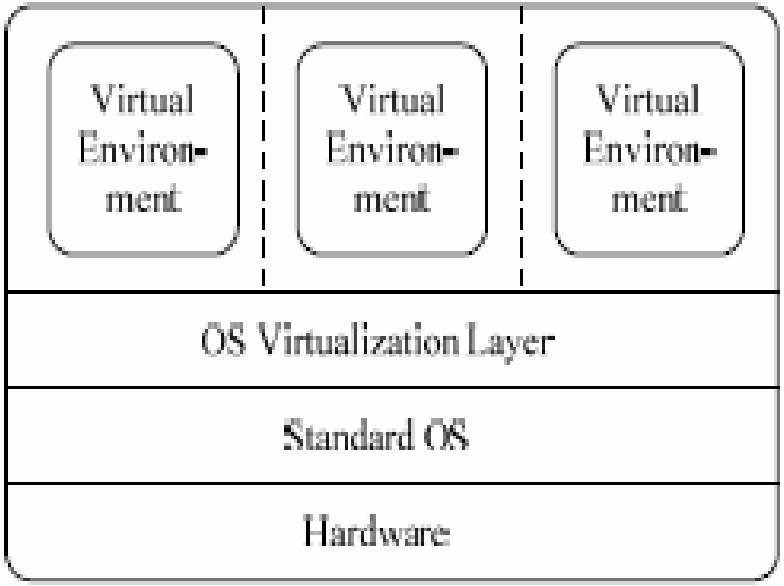
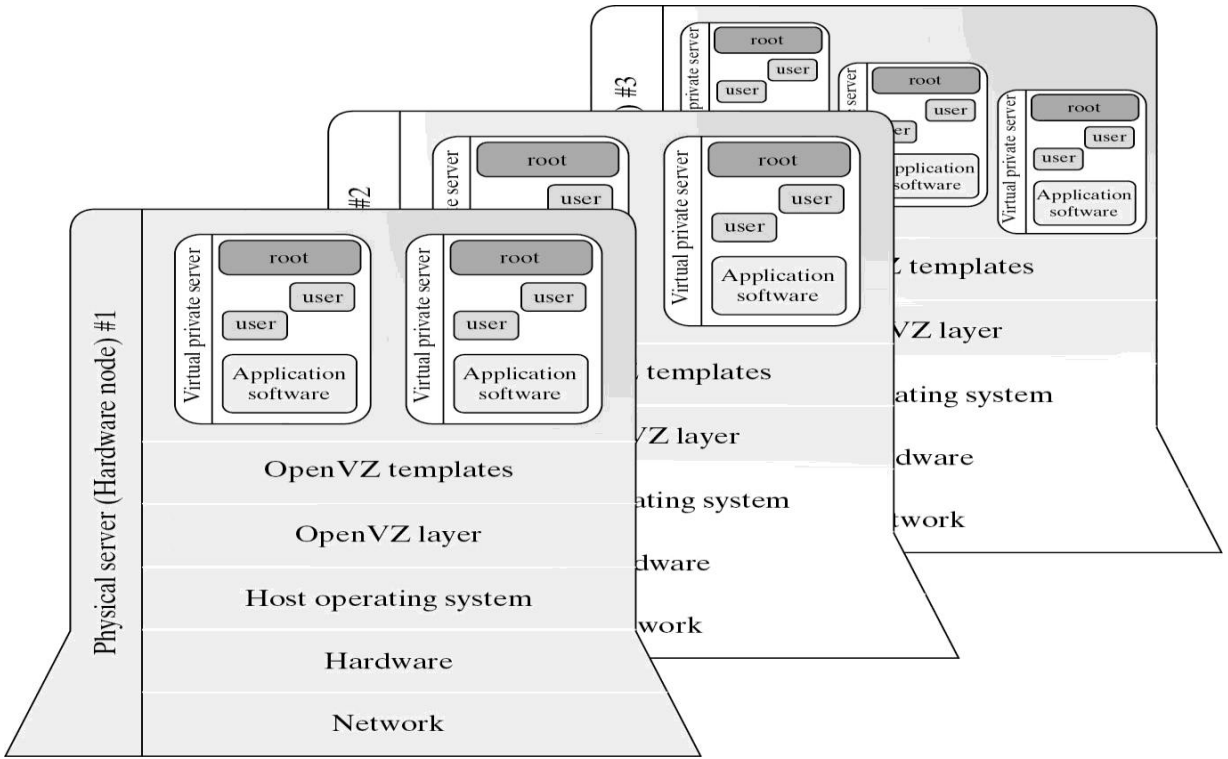


Figure 6.3 The virtualization layer is inserted inside an OS to partition the hardware resources for multiple VMs to run their applications in virtual environments

Virtualization for Linux



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

Disadvantage of OS Extension for Virtualization

- All VMs in the same OS container must have the same or similar guest OS, which restrict application flexibility of different VMs on the same physical machine.

Virtualization at Library Support Level

- Known as user-level Application Binary Interface (ABI) or API emulation
- It creates execution environments for running alien programs on a platform rather than creating VM to run the entire operating system.
- The software tool WINE has implemented this approach to support Windows applications on top of UNIX hosts.
- Example: Running Windows games or productivity applications on Linux.
- It is done by API call interception and remapping.
- **POSIX Compatibility Libraries:**
- Implement POSIX standards on non-POSIX operating systems, enabling cross-platform development.
- Example: **Cygwin** provides a Unix-like environment on Windows.
- Typical systems: Wine, WAB, LxRun , VisualMainWin
- Advantage:
- It has very low implementation effort
- Shortcoming & limitation:
- poor application flexibility and isolation
- Limited Scope:

Virtualization with Middleware Support

Table 3.4 Middleware and Library Support for Virtualization

Middleware or Runtime Library and References or Web Link	Brief Introduction and Application Platforms
WABI (http://docs.sun.com/app/docs/doc/802-6306)	Middleware that converts Windows system calls running on x86 PCs to Solaris system calls running on SPARC workstations
Lxrun (Linux Run) (http://www.ugcs.caltech.edu/~steven/lxrun/)	A system call emulator that enables Linux applications written for x86 hosts to run on UNIX systems such as the SCO OpenServer
WINE (http://www.winehq.org/)	A library support system for virtualizing x86 processors to run Windows applications under Linux, FreeBSD, and Solaris
Visual MainWin (http://www.mainsoft.com/)	A compiler support system to develop Windows applications using Visual Studio to run on Solaris, Linux, and AIX hosts
vCUDA (Example 3.2) (IEEE *IPDPS* 2009 [57])	Virtualization support for using general-purpose GPUs to run data-intensive applications under a special guest OS

The vCUBE for Virtualization of GPGPU

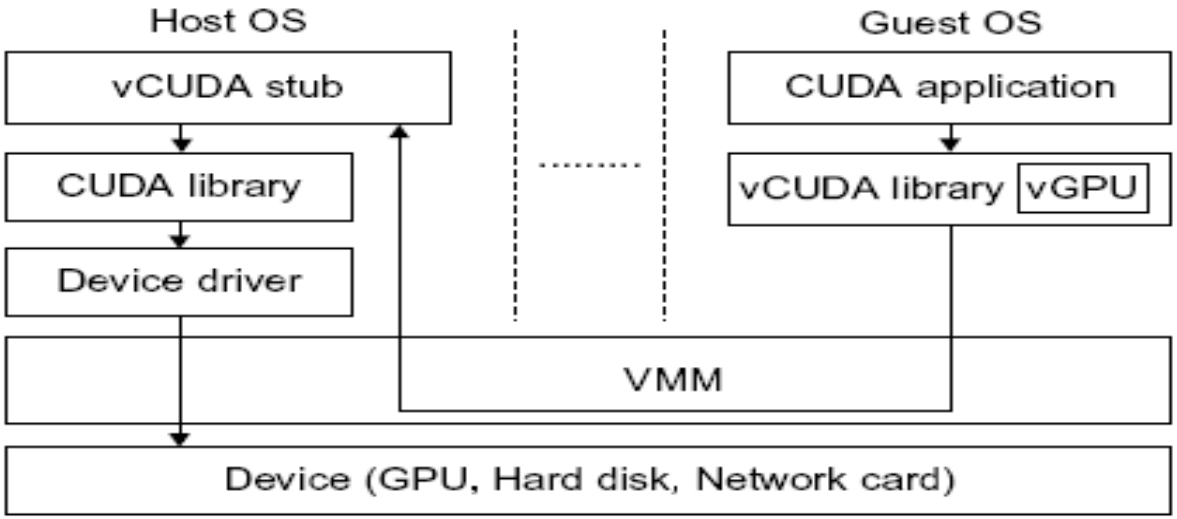


FIGURE 3.4

Basic concept of the vCUDA architecture.

(Courtesy of Lin Shi, et al. [57])

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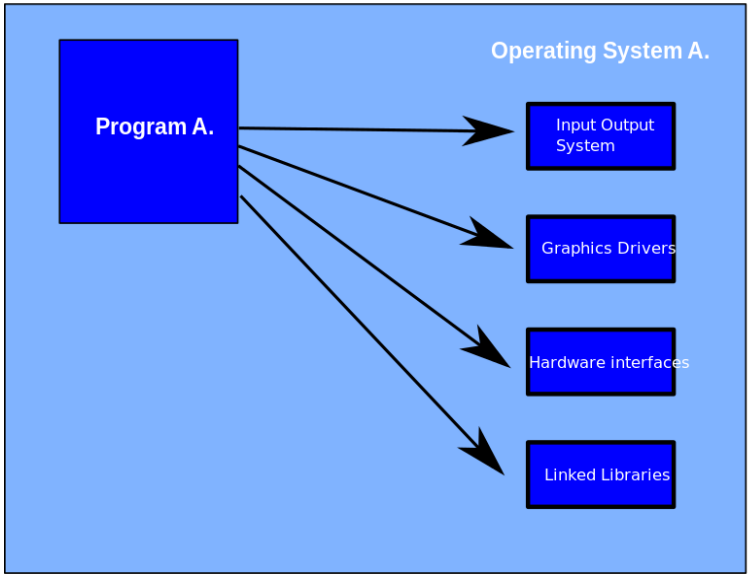
Virtualization at User Application Level

- It virtualizes an application as a virtual machine. On a traditional OS, an application often runs as a process.
- also known as process-level virtualization
- 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
- application isolation, application sandboxing, or application streaming. The process involves wrapping the application in a layer that is isolated from the host OS and other applications.
- Advantage:
- has the best application isolation

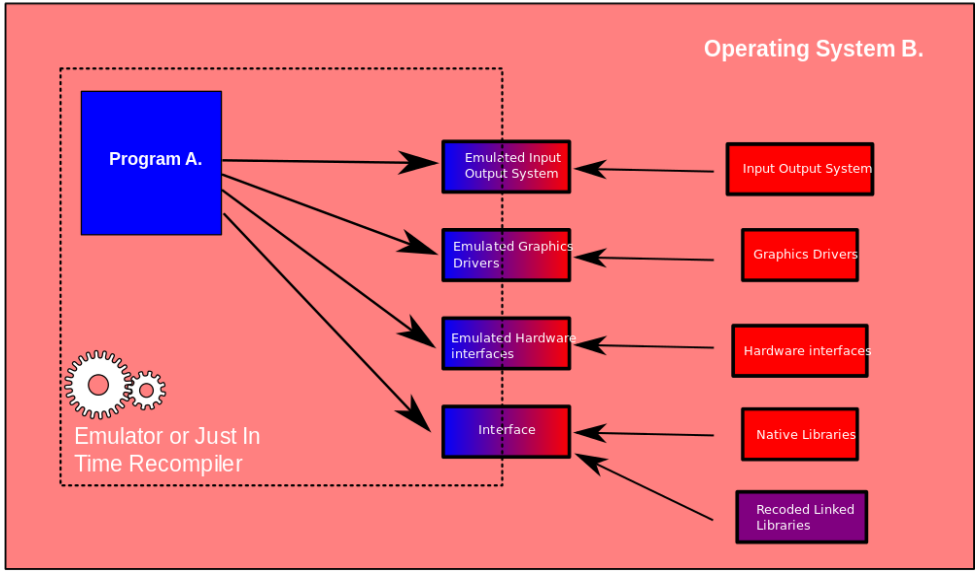
- Shortcoming & limitation:
- low performance, low application flexibility and high implementation complexity.

User-Application Level Virtualization

1. Application in Native Environment



2. Application in Non-Native Environment



Relative Merits of Different Approaches

- The column heading corresponds to four technical heading
- - Higher Performance
- - Application Flexibility
- - Implementation Complexity[implies the implementation cost of virtualization level]
- - Application Isolation[refers to the effort required to isolate resource committed to different VMs]

Level of Implementation	Higher Performance	Application Flexibility	Implementation Complexity	Application Isolation
ISA	X	XXXX	XXX	XXX
Hardware-level virtualization	XXXX	XXX	XXXX	XXX
OS-level virtualization	XXXX	XX	XXX	XX
Runtime library support	XXX	XX	XX	XX
User application level	XX	XX	XXXX	XXXX

VMM Design Requirements and Providers

- Hardware-level virtualization insert a layer between real hardware and traditional Operating systems call as Virtual Machine Monitor(VMM)
- It manages hardware resources of a computing system
- There are three requirements for VMM
  - VMM should provide an environment for program which is essentially Identical to original machine
  - Program run in this environment should show, at worst, only minor decrease in speed
  - VMM should be in complete control of system resources

Provider and References	Host CPU	Host OS	Guest OS	Architecture
VMware Workstation [71]	x86, x86-64	Windows, Linux	Windows, Linux, Solaris, FreeBSD, Netware, OS/2, SCO, BeOS, Darwin	Full Virtualization
VMware ESX Server [71]	x86, x86-64	No host OS	The same as VMware Workstation	Para-Virtualization
Xen [7,13,42]	x86, x86-64, IA-64	NetBSD, Linux, Solaris	FreeBSD, NetBSD, Linux, Solaris, Windows XP and 2003 Server	Hypervisor
KVM [31]	x86, x86-64, IA-64, S390, PowerPC	Linux	Linux, Windows, FreeBSD, Solaris	Para-Virtualization

Virtualization Structure/Tools and Mechanisms

- Before the implementation of virtualization, the hardware is managed by operating system
- After virtualization process, a virtualization layer is placed in between the hardware and the OS
- Converting the real hardware into virtual hardware is the responsibility of this virtualization layer
- There are several classes of VM architecture which depends on the position of the virtualization layer. These are mainly Hypervisor architecture, Para Virtualization, Full virtualization

Hypervisor architecture

- type of hardware-level virtualization on bare metal devices like CPU, memory, disk and network interfaces
- Known as VMM
- exactly placed between physical hardware and its operating system
- provides hypercalls for the guest OSes and applications.
- Depending on the functionality, a hypervisor can assume a micro-kernel architecture or a monolithic hypervisor architecture.
- A **micro-kernel hypervisor** includes only the basic and unchanging functions (such as physical memory management and processor scheduling).
- The device drivers and other changeable components are outside the hypervisor.
- A **monolithic hypervisor** implements all the aforementioned functions, including those of the device drivers.
- The size of the hypervisor code of a micro-kernel hypervisor is s**maller** than that of a monolithic hypervisor
- It is very important that the hypervisor should have capability to convert physical devices

Xen Architecture

- It is an open source hypervisor program which is developed by Cambridge University- microkernel hypervisor
- Separates the policy from the mechanism
- All the machine are implemented by Xen hypervisor, and policy handling is the responsibility of Domain 0

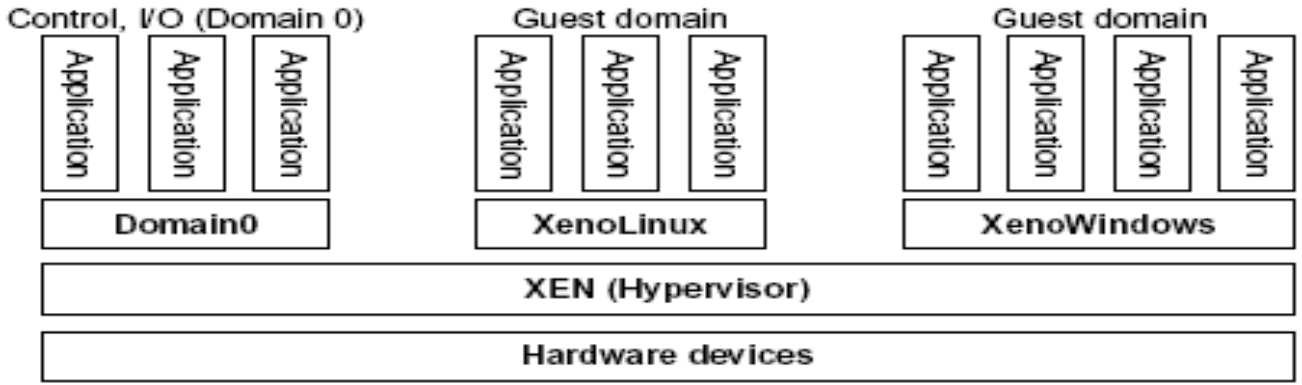


FIGURE 3.5

The Xen architecture's special domain 0 for control and I/O, and several guest domains for user applications.

- core components are the hypervisor, kernel, and applications
- In Xen, no device drivers are included natively, just a mechanism is provided by Xen with the help of which guest OS can have direct access to the physical device
- Like other virtualization, number of guest OS can be executed on top of hypervisor
- The guest OS, which can control other OS is known as Domain 0 while other are known as Domain U
- Domain 0 is considered as privilege guest OS of Xen
- Initially Domain 0 is loaded when Xen boots
- The basic aim behind design of Domain 0 is to access hardware directly as well as manage device
- Allocating and mapping hardware resources for the guest domain (Domain U) is responsibility of Domain 0

Full Virtualization

- Hardware virtualization can be classified into two categories based on the implementation technology:

Full Virtualization and Host-based virtualization

➢ Full Virtualization:

- Does not need to modify guest OS
- Non-critical instructions execute on hardware directly
- Critical instruction are trapped into VMM for binary translation
- VMware Workstation applies full virtualization, which uses binary translation to automatically modify x86 software on- the-fly to replace critical instructions.
-ISA of a guest OS is different from the ISA of the underlying hardware, binary translation must be adopted

➢ Advantage:

- no need to modify OS.

➢ Disadvantage:

- binary translation slows down the performance.

Binary Translation of Guest OS Request using VMM

- Host-Based Virtualization
- An alternative VM architecture is to install a virtualization layer on top of the host OS.

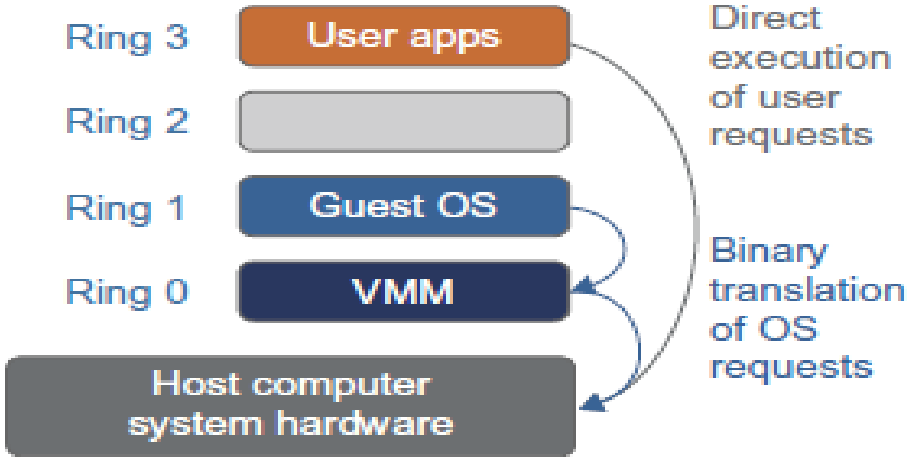
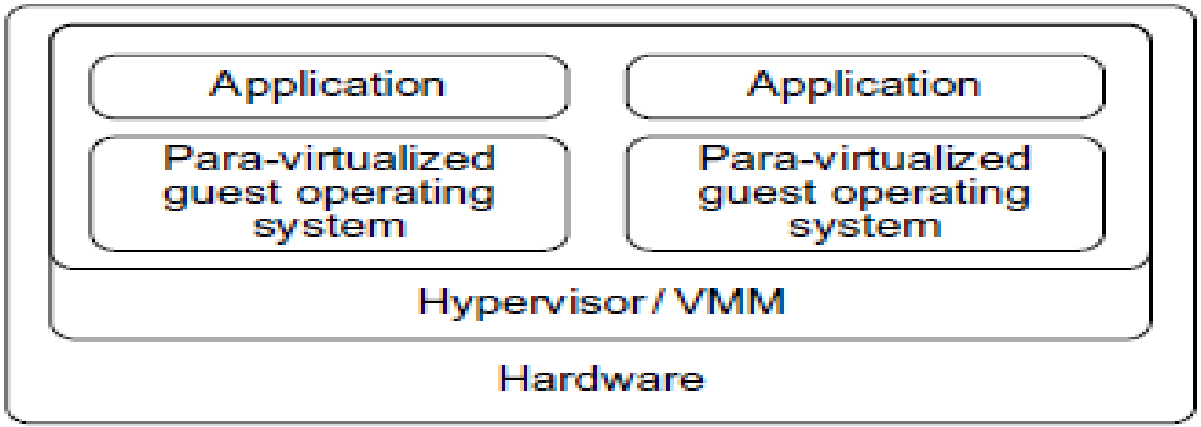


FIGURE 3.6

Indirect execution of complex instructions via binary translation of guest OS requests using the VMM plus direct execution of simple instructions on the same host.

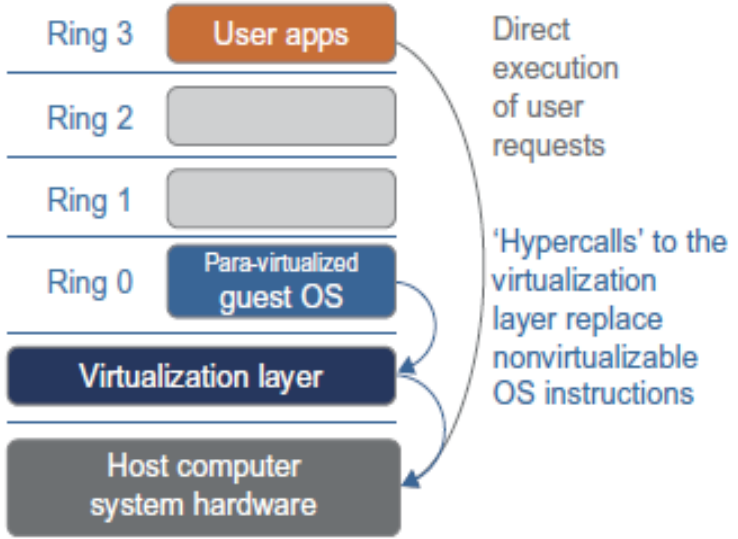
Para-Virtualization

- The guest OS are modified by the Para-Virtualization
- Special API is provided by the para-virtualized VM which requires substantial OS modification in the user application
- Following fig. illustrate the concept of para-virtualized VM architecture



Para-Virtualization

- In the traditional x86 processor, there are four instruction execution rings: Ring 0,1,2,3
- The lower the ring number, higher the privilege of instruction being executed
- The hardware management and execution of privileged instruction is done by the OS so implemented at Ring 0, while user-level application are executed at Ring 3
- example of para-virtualization is the KVM(Kernel-based Virtual Machine)



Para-Virtualization

- Para-virtualization reduces the overhead,
- it has incurred problems like compatibility and portability, high cost
- the performance advantage of para-virtualization varies
- Compared with full virtualization, para-virtualization is relatively easy and
- The main problem in full virtualization is its low performance in binary translation.-slow

Types of Hypervisor

A hypervisor is a hardware virtualization technique allowing multiple operating systems, called guests to run on a host machine. This is also called the Virtual Machine Monitor (VMM).

Type 1: Bare Metal Hypervisor

- sits on the bare metal computer hardware like the CPU, memory, etc.
- All guest operating systems are a layer above the hypervisor.
- The original CP/CMS hypervisor developed by IBM was of this kind.

Type 2: hosted hypervisor

- Run over a host operating system.
- Hypervisor is the second layer over the hardware.
- Guest operating systems run a layer over the hypervisor.
- The OS is usually unaware of the virtualization

Virtualization of CPU, Memory, and I/O Devices

- To support virtualization, processors such as the x86 employ a special running mode and instructions, known as hardware-assisted virtualization
- the VMM and guest OS run in different modes and all sensitive instructions of the guest OS and its applications are trapped in the VMM
- all processors have at least two modes, user mode and supervisor mode, to ensure controlled access of critical hardware.
- Instructions running in supervisor mode are called privileged instructions. Other instructions are unprivileged instructions.

Virtualization of CPU, Memory, and I/O Devices

CPU Virtualization

- A VM is a duplicate of an existing computer system in which a majority of the VM instructions are executed on the host processor in native mode. Thus, unprivileged instructions of VMs run directly on the host machine for higher efficiency. Other critical instructions should be handled carefully for correctness and stability.
- The critical instructions are divided into three categories: privileged instructions, control–sensitive instructions, and behavior-sensitive instructions.
- Privileged instructions execute in a **privileged mode and will be trapped** if executed outside this mode.
- Control-sensitive instructions attempt **to change the configuration** of resources used.
- Behavior-sensitive instructions have **different behaviors depending on the configuration of resources**, including the load and store operations over the virtual memory.

- A CPU architecture is virtualizable if it supports the ability to run the VM's **privileged and unprivileged instructions in the CPU's user mode** while the **VMM runs in supervisor mode.**
- When the privileged instructions including control- and behavior-sensitive instructions of a VM are executed, they are trapped in the VMM.
- In this case, the VMM acts as a unified mediator for hardware access from different VMs to guarantee the correctness and stability of the whole system. However, not all CPU architectures are virtualizable.
- **RISC CPU architectures** can be naturally virtualized because all control and behavior-sensitive instructions are privileged instructions.
- On the contrary, **x86 CPU architectures are not primarily designed** to support virtualization.

Memory Virtualization

- Virtual memory virtualization is similar to the **virtual memory support provided by modern operating systems**.
- In a traditional execution environment, the operating system maintains **mappings of virtual memory to machine memory using page tables**, which is a one-stage mapping from virtual memory to machine memory.
- All modern x86 CPUs include a memory management unit (MMU) and a translation lookaside buffer (TLB) to optimize virtual memory performance.
- However, in a virtual execution environment, virtual memory virtualization involves sharing the physical system memory in RAM and dynamically allocating it to the physical memory of the VMs.
- That means a **two-stage mapping** process should be maintained by the guest OS and the VMM, respectively: **virtual memory to physical memory** and **physical memory to machine memory.**

Memory Virtualization

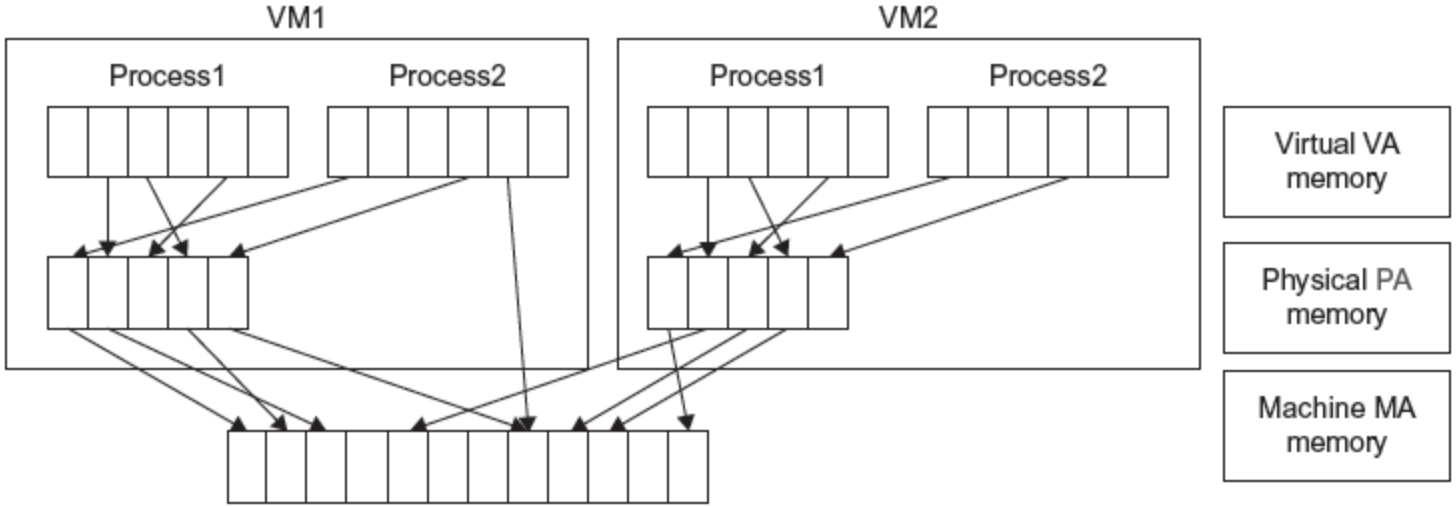


FIGURE 3.12

Two-level memory mapping procedure.

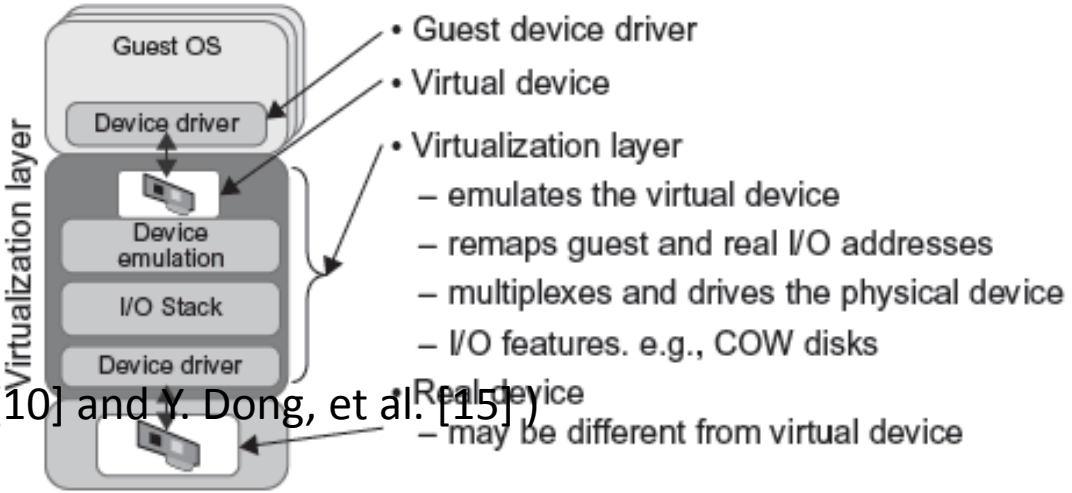
(*Courtesy of R. Rblig, et al. [68]*)

I/O Virtualization

- It involves managing the **routing of I/O requests between virtual devices and**
- **the shared physical hardware.**
- There are three ways to implement I/O virtualization: full device emulation, para-virtualization, and direct I/O.
- full device emulation:Generally, this approach emulates well-known, real-world devices. All the functions of a device or bus infrastructure, such as device enumeration, identification, interrupts, and DMA, are replicated in software. This software is located in the VMM and acts as a virtual device.

I/O Virtualization

The I/O access requests of the guest OS are trapped in the VMM which interacts with the I/O devices.
Software emulation runs much slower than the hardware it emulates



(Courtesy of V. Chadha, et al. [10] and Y. Dong, et al. [15])

I/O Virtualization

- The para-virtualization method of I/O virtualization is typically used in Xen.
- It is also known as the split driver model consisting of a frontend driver and a backend driver.
- The frontend driver is running in Domain U and the backend driver is running in Domain 0.
- They interact with each other via a block of shared memory.
- The frontend driver manages the I/O requests of the guest OSes and the backend driver is responsible for managing the real I/O devices and multiplexing the I/O data of different VMs.
- It achieves better device performance than full device emulation, it comes with a higher CPU overhead

I/O Virtualization

- Direct I/O virtualization lets the VM access devices directly.
- It can achieve close-to native performance without high CPU costs.

VIRTUAL CLUSTERS AND RESOURCE MANAGEMENT

- A physical cluster is a collection of servers (physical machines) interconnected by a physical network such as a LAN.
- When a traditional VM is initialized, the administrator needs to manually write configuration information or specify the configuration sources. When more VMs join a network, an inefficient configuration always causes problems with overloading or underutilization.
- Virtual clusters are built with VMs installed at distributed servers from one or more physical clusters.
- The VMs in a virtual cluster are interconnected logically by a virtual network across several physical networks.

VIRTUAL CLUSTERS AND RESOURCE MANAGEMENT

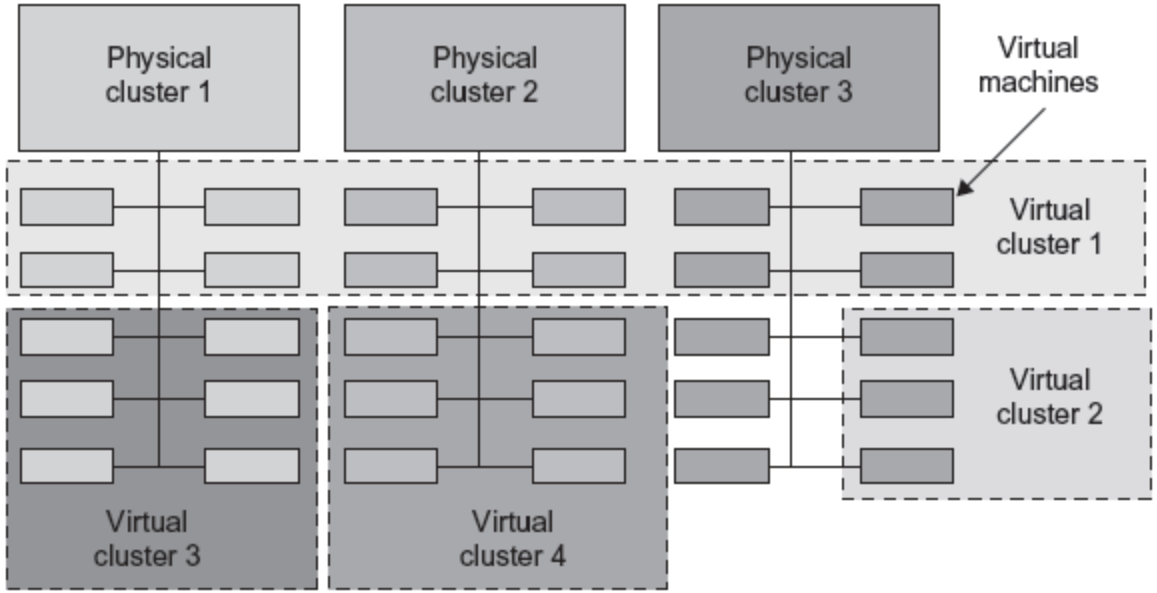


FIGURE 3.18

A cloud platform with four virtual clusters over three physical clusters shaded differently.

(*Courtesy of Fan Zhang, Tsinghua University*)

VIRTUAL CLUSTERS AND RESOURCE MANAGEMENT

- The virtual cluster nodes can be either physical or virtual machines. Multiple VMs running with different OSes can be deployed on the same physical node.
- A VM runs with a guest OS, which is often different from the host OS, that manages the resources in the physical machine, where the VM is implemented.
- The purpose of using VMs is to consolidate multiple functionalities on the same server. This will greatly enhance server utilization and application flexibility.
- VMs can be replicated in multiple servers for the purpose of promoting distributed parallelism, fault tolerance, and disaster recovery.
- The size (number of nodes) of a virtual cluster can grow or shrink dynamically
- The failure of any physical nodes may disable some VMs installed on the failing nodes. But the failure of VMs will not pull down the host system.

VIRTUAL CLUSTERS AND RESOURCE MANAGEMENT

- All major IT companies are pouring their resources into building new data centers.
- Google, Yahoo!, Amazon, Microsoft, HP,Apple, and IBM are all in the game.
- Investment of billions of dollars in datacenter construction and automation
- Data-center automation means that huge volumes of hardware, software, and database resources in these data centers can be allocated dynamically to millions of Internet users simultaneously, with guaranteed QoS and cost-effectiveness
- Server Consolidation in Data Centers
- Virtual Storage Management