Cloud Computing [131P15C302]

~ Asst. Prof. Shivkumar Chandey
M.Sc. Computer Science

Objectives

At the end of Cloud Computing course, the students will:

1. Have an insight into the basics of cloud computing along with virtualization.
2. Have a conceptual understanding of cloud computing and will be in the position to assess their application objectives and decide how to deploy their application in the cloud with ease.
3. Understand the security aspects in cloud.

Unit I Syllabus

Unit I	**Fundamentals of Cloud Computing:** Fundamentals of Cloud Computing, Origins and Influences, Basic Concepts and Terminology, Goals and Benefits, Risks and Challenges. Cloud Models: Roles and Boundaries, Cloud Characteristics, Cloud Delivery Models, Cloud Deployment Models Principles of Parallel and Distributed Computing: Parallel and Distributed Computing. Technologies for Distributed Computing. Introduction to Virtualization: Characteristics of virtualized environments, Taxonomy of virtualization techniques, Virtualization, and cloud computing

Text Books and References

- **Textbooks:**

1. Cloud Computing Black Book, Dreamtech Press, 2014
2. Mastering Cloud Computing - Technologies and Applications Programming, 2014

- **Reference Books:**

1. Cloud Computing: Concepts, Technology & Architecture, Pearson, 2013
2. Cloud and Distributed Computing: Algorithms and Systems, Wiley

Course Learning Outcomes

1. Student will have basic understanding about cloud and virtualization along with it how one can migrate over it.
2. Students can identify the various levels of services that can be achieved by cloud
3. Student can understand the issues related to Cloud Computing.
4. Students will recognize the administrative challenges in Cloud Computing.

List of Practicals

1. Implementation of Bare-metal and hosted virtualization
2. Implementation of containerization using docker
3. Demonstration of IaaS cloud
4. Demonstration of PaaS cloud
5. Demonstration of SaaS cloud
6. Implementation of Cloud services on Open stack cloud platform
7. Implementation of Cloud services on Amazon web services
8. Demonstration of data analytics in Cloud

Introduction to Cloud Computing

- Cloud Computing provides us means of accessing the applications as utilities over the Internet.
- It allows us to create, configure, and customize the applications online.

What is Cloud?

- The term Cloud refers to a Network or Internet. In other words, we can say that Cloud is something, which is present at remote location.
- Cloud can provide services over public and private networks, i.e., WAN, LAN or VPN.
- Applications such as e-mail, web conferencing, customer relationship management (CRM) execute on cloud.

What is Cloud Computing?

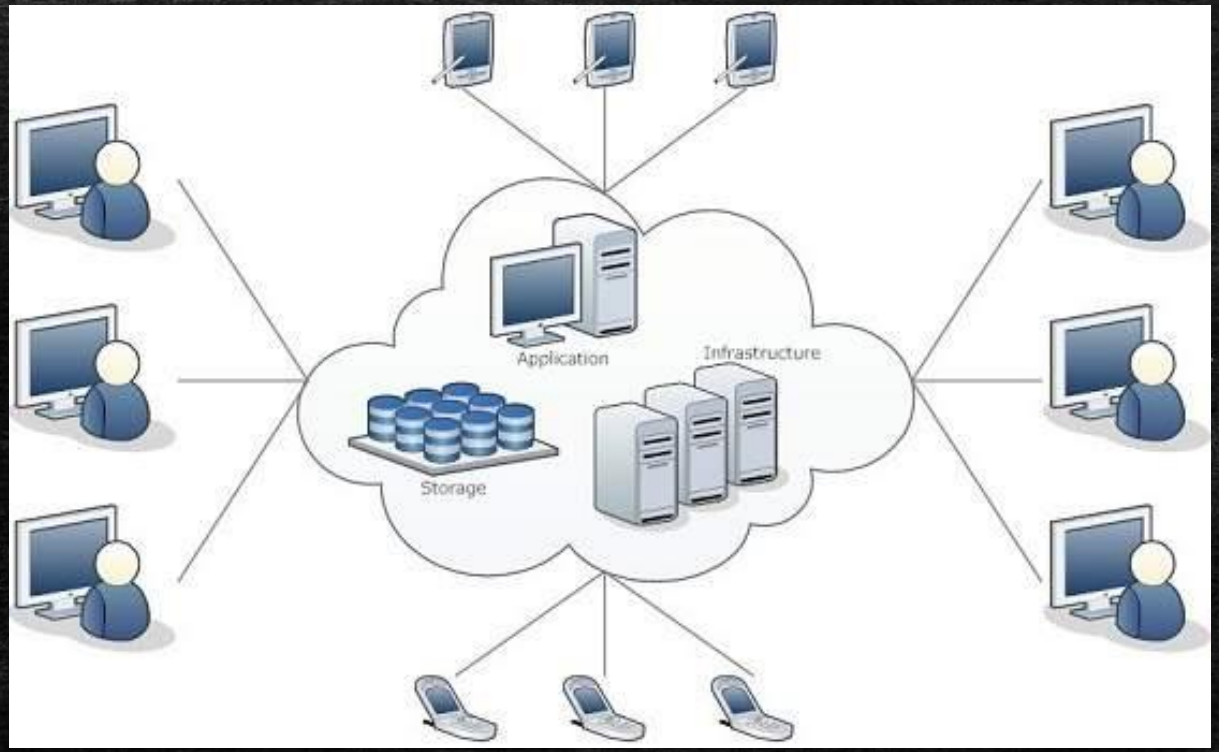
- Cloud Computing refers to manipulating, configuring, and accessing the hardware and software resources remotely. It offers online data storage, infrastructure, and application.

Operations on Cloud Computing

- There are the following operations that we can do using cloud computing:
  - Developing new applications and services
  - Storage, back up, and recovery of data
  - Hosting blogs and websites
  - Delivery of software on demand
  - Analysis of data
  - Streaming videos and audios

Cloud Computing

- Cloud computing offers platform independency, as the software is not required to be installed locally on the PC. Hence, the Cloud Computing is making our business applications mobile and collaborative.



Defining Cloud Computing

- I don't care where my servers are, who manages them, where my documents are stored, or where my applications are hosted. I just want them always available and access them from any device connected through Internet. And I am willing to pay for this service for as a long as I need it.

U.S. National Institute of Standards and Technology (NIST)

- Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.

Characteristics of Cloud Computing

1) Agility
   - The cloud works in a distributed computing environment. It shares resources among users and works very fast.

2) High availability and reliability
   - The availability of servers is high and more reliable because the chances of infrastructure failure are minimum.

Characteristics of Cloud Computing

3) High Scalability

- Cloud offers "on-demand" provisioning of resources on a large scale, without having engineers for peak loads.

4) Multi-Sharing

- With the help of cloud computing, multiple users and applications can work more efficiently with cost reductions by sharing common infrastructure.

Characteristics of Cloud Computing

5) Device and Location Independence

- Cloud computing enables the users to access systems using a web browser regardless of their location or what device they use e.g. PC, mobile phone, etc. As infrastructure is off-site (typically provided by a third-party) and accessed via the Internet, users can connect from anywhere.

6) Maintenance

- Maintenance of cloud computing applications is easier, since they do not need to be installed on each user's computer and can be accessed from different places. So, it reduces the cost also.

Characteristics of Cloud Computing

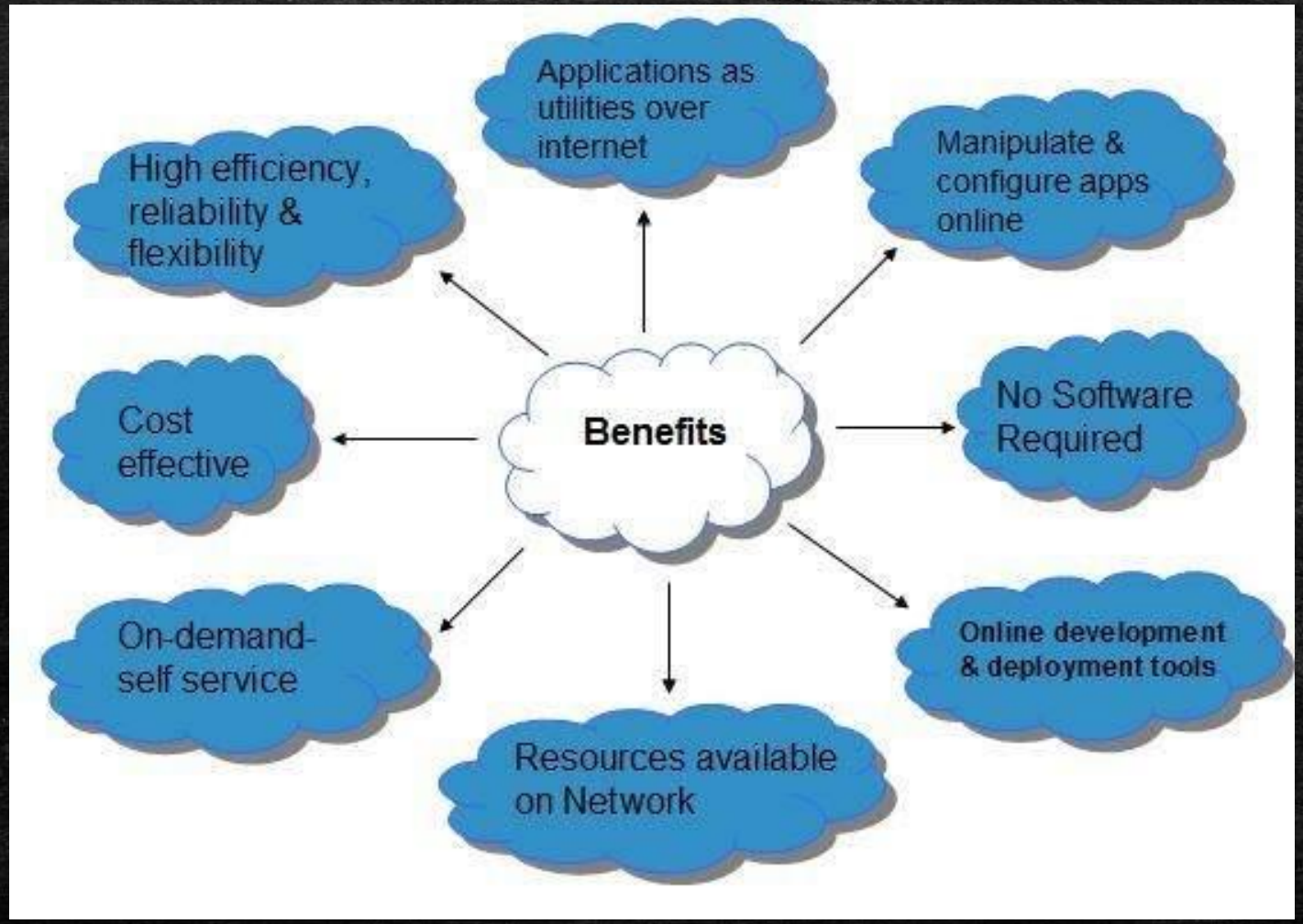
7) Low Cost

- By using cloud computing, the cost will be reduced because to take the services of cloud computing, IT company need not to set its own infrastructure and pay-as-per usage of resources.

8) Services in the pay-per-use mode

- Application Programming Interfaces (APIs) are provided to the users so that they can access services on the cloud by using these APIs and pay the charges as per the usage of services.

Benefits of CC



Benefits of CC

Cloud Computing has numerous advantages. Some of them are listed below -

- One can access applications as utilities, over the Internet.
- One can manipulate and configure the applications online at any time.
- It does not require to install a software to access or manipulate cloud application.
- Cloud Computing offers online development and deployment tools, programming runtime environment through PaaS model.

Benefits of CC

- Cloud resources are available over the network in a manner that provide platform independent access to any type of clients.
- Cloud Computing offers on-demand self-service. The resources can be used without interaction with cloud service provider.
- Cloud Computing is highly cost effective because it operates at high efficiency with optimum utilization. It just requires an Internet connection
- Cloud Computing offers load balancing that makes it more reliable.

Risks related to Cloud Computing

- Although cloud Computing is a promising innovation with various benefits in the world of computing, it comes with risks. Some of them are discussed below:
- Security and Privacy
  - It is the biggest concern about cloud computing. Since data management and infrastructure management in cloud is provided by third-party, it is always a risk to handover the sensitive information to cloud service providers.
  - Although the cloud computing vendors ensure highly secured password protected accounts, any sign of security breach may result in loss of customers and businesses.
- Lock In
  - It is very difficult for the customers to switch from one Cloud Service Provider (CSP) to another. It results in dependency on a particular CSP for service.

Risks related to Cloud Computing

- Isolation Failure
  - This risk involves the failure of isolation mechanism that separates storage, memory, and routing between the different tenants.
- Management Interface Compromise
  - In case of public cloud provider, the customer management interfaces are accessible through the Internet.

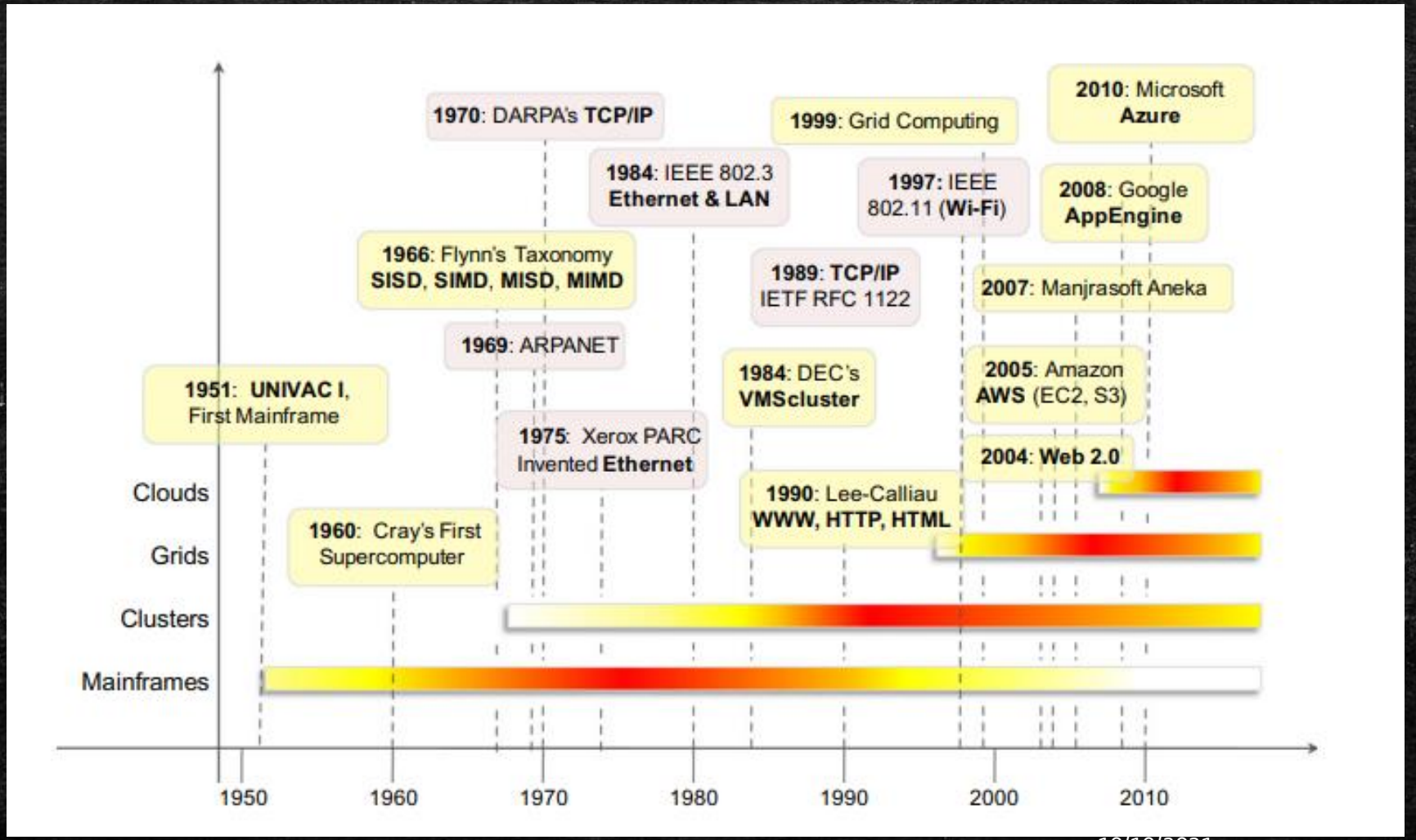
Historical developments

- The idea of renting computing services by leveraging large distributed computing facilities has been around for long time.
- It dates back to the days of the mainframes in the early 1950s. From there on, technology has evolved and been refined. This process has created a series of favorable conditions for the realization of cloud computing.

Historical developments

- Following figure provides an overview of the evolution of the distributed computing technologies that have influenced cloud computing.
- In tracking the historical evolution, we briefly review five core technologies that played an important role in the realization of cloud computing.
- These technologies are:
  - Distributed Systems,
  - Virtualization,
  - Web 2.0,
  - Service Orientation, and
  - Utility Computing.

The evolution of Distributed Computing Technologies, 1950s - 2010s.



Distributed systems

- Clouds are essentially large distributed computing facilities that make available their services to third parties on demand.
- A distributed system is a collection of independent computers that appears to its users as a single coherent system.
- Three major milestones have led to cloud computing:
  - Mainframe Computing,
  - Cluster Computing, and
  - Grid Computing.
- The primary purpose of distributed systems is to share resources and utilize them better.

Mainframes

- Mainframes were the first examples of large computational facilities leveraging multiple processing units.
- Mainframes were powerful, highly reliable computers specialized for large data movement and massive input/output (I/O) operations.
- They were mostly used by large organizations for bulk data processing tasks such as online transactions, enterprise resource planning, and other operations involving the processing of significant amounts of data.
- One of the most attractive features of mainframes was the ability to be highly reliable computers that were “always on” and capable of tolerating failures transparently.

Mainframe Computer

Clusters

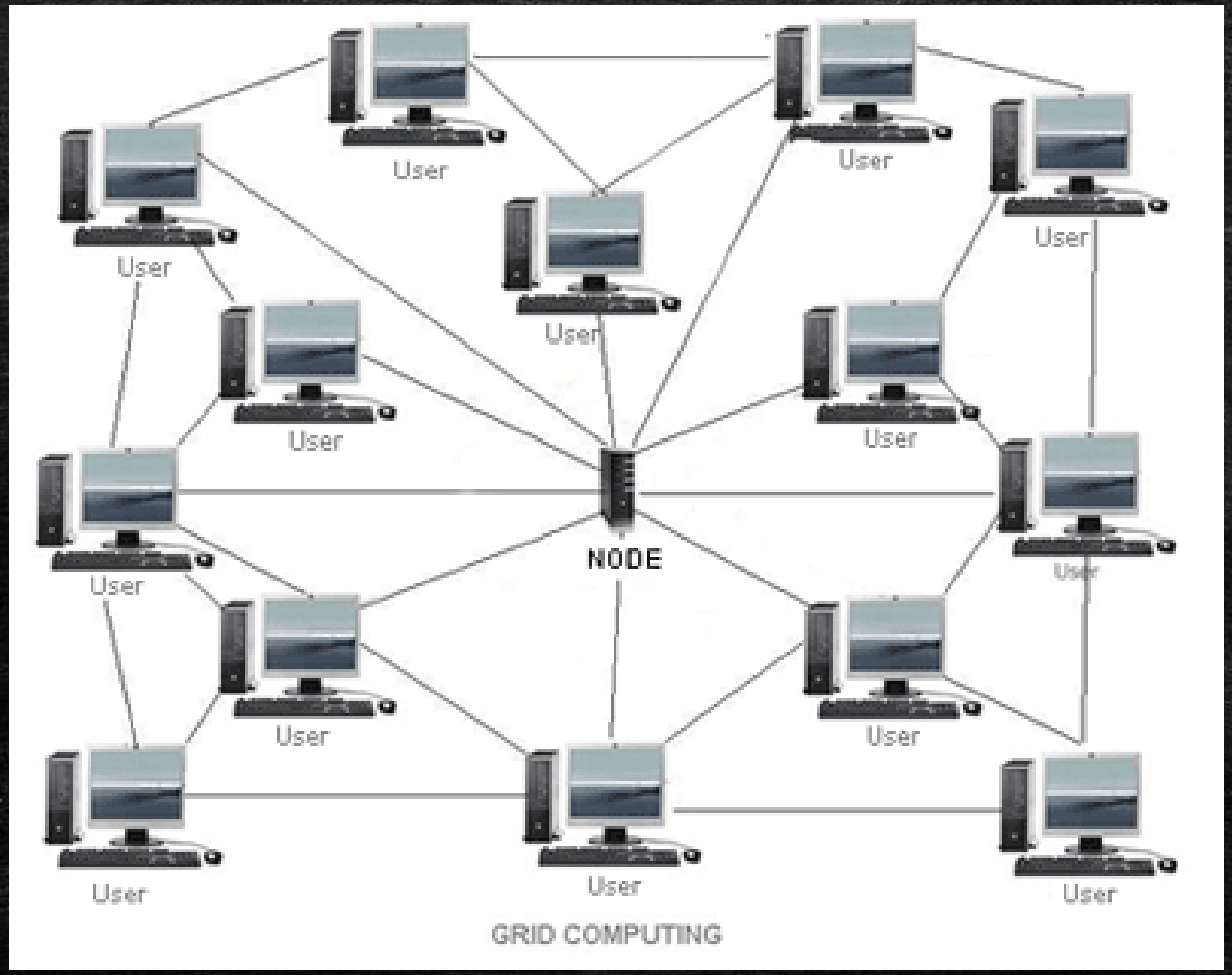
- Cluster computing started as a low-cost alternative to the use of mainframes and supercomputers. The technology advancement that created faster and more powerful mainframes and supercomputers eventually generated an increased availability of cheap commodity machines as a side effect.
- These machines could then be connected by a high-bandwidth network and controlled by specific software tools that manage them as a single system. Starting in the 1980s, clusters become the standard technology for parallel and high-performance computing.
- Built by commodity machines, they were cheaper than mainframes and made high-performance computing available to a large number of groups, including universities and small research labs.

Cluster Computers

Grids

- Grid computing appeared in the early 1990's as an evolution of cluster computing.
- In an analogy to the power grid, grid computing proposed a new approach to access large computational power, huge storage facilities, and a variety of services.
- Users can "consume" resources in the same way as they use other utilities such as power, gas, and water.

Grid Computing Architecture



Cloud Computing	Grid Computing
Cloud computing works more as a service provider for utilizing computer resource	Grid computing uses the available resource and interconnected computer systems to accomplish a common goal
Cloud computing is a centralized model	Grid computing is a decentralized model, where the computation could occur over many administrative model
Cloud is a collection of computers usually owned by a single party.	A grid is a collection of computers which is owned by a multiple parties in multiple locations and connected together so that users can share the combined power of resources
Cloud offers more services all most all the services like web hosting, DB (Data Base) support and much more	Grid provides limited services
Cloud computing is typically provided within a single organization (eg : Amazon)	Grid computing federates the resources located within different organization.

The evolution of distributed computing technologies.

- Cloud computing is often considered the successor of grid computing. In reality, it embodies aspects of all these three major technologies.
- Computing clouds are deployed in large datacenters hosted by a single organization that provides services to others.
- Clouds are characterized by the fact of having virtually infinite capacity, being tolerant to failures, and being always on, as in the case of mainframes.
- In many cases, the computing nodes that form the infrastructure of computing clouds are commodity machines, as in the case of clusters. The services made available by a cloud vendor are consumed on a pay-per-use basis, and clouds fully implement the utility vision introduced by grid computing.

Virtualization

- Virtualization is another core technology for cloud computing. It encompasses a collection of solutions allowing the abstraction of some of the fundamental elements for computing, such as hardware, runtime environments, storage, and networking.
- Virtualization is essentially a technology that allows creation of different computing environments. These environments are called virtual because they simulate the interface that is expected by a guest.
- The most common example of virtualization is hardware virtualization.

Web 2.0

- The Web is the primary interface through which cloud computing delivers its services.
- At present, the Web encompasses a set of technologies and services that facilitate interactive information sharing, collaboration, user-centered design, and application composition.
- This evolution has transformed the Web into a rich platform for application development and is known as Web 2.0. This term captures a new way in which developers architect applications and deliver services through the Internet and provides new experience for users of these applications and services.

Web 2.0

- Web 2.0 brings interactivity and flexibility into Web pages, providing enhanced user experience by gaining Web-based access to all the functions that are normally found in desktop applications.
- These capabilities are obtained by integrating a collection of standards and technologies such as XML, Asynchronous JavaScript and XML (AJAX), Web Services, and others.

Web 2.0

- Examples of Web 2.0 applications are Google Documents, Google Maps, Flickr, Facebook, Twitter, YouTube, de.li.cious, Blogger, and Wikipedia. In particular, social networking Websites take the biggest advantage of Web 2.0.
- The level of interaction in Websites such as Facebook or Flickr would not have been possible without the support of AJAX, Really Simple Syndication (RSS), and other tools that make the user experience incredibly interactive.
- Web 2.0 applications are extremely dynamic: they improve continuously, and new updates and features are integrated at a constant rate by following the usage trend of the community.

Service-oriented computing

- Service orientation is the core reference model for cloud computing systems. This approach adopts the concept of services as the main building blocks of application and system development.
- Service-oriented computing (SOC) supports the development of rapid, low-cost, flexible, interoperable, and evolvable applications and systems.
- Virtually any piece of code that performs a task can be turned into a service and expose its functionalities through a network-accessible protocol.
- A service is supposed to be loosely coupled, reusable, programming language independent, and location transparent.

Service-oriented computing

- Service-oriented computing introduces and diffuses two important concepts, which are also fundamental to cloud computing: quality of service (QoS) and Software-as-a-Service (SaaS).
- Quality of service (QoS) identifies a set of functional and nonfunctional attributes that can be used to evaluate the behavior of a service from different perspectives.
- These could be performance metrics such as response time, or security attributes, transactional integrity, reliability, scalability, and availability.
- QoS requirements are established between the client and the provider via an SLA that identifies the minimum values (or an acceptable range) for the QoS attributes that need to be satisfied upon the service call.

SOC

- One of the most popular expressions of service orientation is represented by Web Services.
- These introduce the concepts of SOC into the World Wide Web, by making it consumable by applications and not only humans.
- Web services are software components that expose functionalities accessible using a method invocation pattern that goes over the HyperText Transfer Protocol (HTTP).

SOC

- The interface of a Web service can be programmatically inferred by metadata expressed through the Web Service Description Language (WSDL).
- This is an XML language that defines the characteristics of the service and all the methods, together with parameters, descriptions, and return type, exposed by the service.
- The interaction with Web services happens through Simple Object Access Protocol (SOAP).

Utility-oriented computing

- Utility computing is a vision of computing that defines a service-provisioning model for compute services in which resources such as storage, compute power, applications, and infrastructure are packaged and offered on a pay-per-use basis.
- The idea of providing computing as a utility like natural gas, water, power, and telephone connection has a long history but has become a reality today with the advent of cloud computing.

Utility-oriented computing

- The first traces of this service-provisioning model can be found in the mainframe era.
- IBM and other mainframe providers offered mainframe power to organizations such as banks and government agencies throughout their datacenters.

Utility Computing	Cloud Computing
Utility computing refers to the ability to charge the offered services, and charge customers for exact usage	Cloud Computing also works like utility computing, you pay only for what you use but Cloud Computing might be cheaper, as such, Cloud based app can be up and running in days or weeks.
Utility computing users want to be in control of the geographical location of the infrastructure	In cloud computing, provider is in complete control of cloud computing services and infrastructure
Utility computing is more favorable when performance and selection infrastructure is critical	Cloud computing is great and easy to use when the selection infrastructure and performance is not critical
Utility computing is a good choice for less resource demanding	Cloud computing is a good choice for high resource demanding
Utility computing refers to a business model	Cloud computing refers to the underlying IT architecture

Basic Concepts and Terminology

- Please refer the following document for knowing more about basic terminologies used in Cloud Computing.
- Cloud Computing Terminologies.pdf

Risks and Challenges of Cloud Computing

Cloud Migration

- Cloud migration is the process of moving data, applications, and other important information of an organization from its on-premises either desktops or servers to the cloud infrastructure, and this can also involve in moving data between different cloud setups.
- Cloud migration enables all the computing capabilities those were performed earlier by devices installed on-premises.
- Cloud migration is a big challenge as many companies when they require to migrate from on-premises to cloud or from one cloud to another, they partner with experienced cloud service provider.

Incompatibility

- During moving workloads from on-premises to the cloud, the common issue the incompatibility between on-premises infrastructure and the services which are companies going to buy from the public cloud providers.
- In last current years, most CSPs tried to create “connectors of sort” to make practices more standardize and homogenous.

Data security

- CSPs are responsible to provide clouds' security, but they're not responsible for your apps, servers, and security of data.
- As per CDW 2013 State of the Cloud Report, "46 percent of respondents face security of data or applications as a significant challenge."
- When your CSP ensure you about the complete compliance and regulation, don't consider it as 100% compliant and yielding.
- You still require to encrypt and secure your own data and should invest in buying suite of tools from your CSP to protect your data from cyber-attacks.

Data security

Following questions may be asked before engaging with your cloud service provider.

- Can you ensure protection of my data?
- How will you protect my data from corruption?
- Do you have experts and professionals on board if something happens wrong?

Lack of expertise

- With the quick advancements and improvements in cloud technologies, more and more organizations are clouds to place their workloads. However, they face difficulties to keep up with the tools which require particular expertise.
- Organizations can deal with this challenge by providing cloud technologies training to their system admins along with development staff.
- By adding cloud specialists to IT teams may be costly too for small and medium businesses (SMBs).
- Luckily, various routine activities that specialists perform can be automated using automated tools.

Downtime

- Businesses suppose complete data accessibility and availability when their data is stored on cloud anytime from anywhere.
- The main challenge most organizations face is they can access their data from cloud only through internet connection. So, poor internet connection can disrupt cloud services and higher risks of data accessibility.

Bandwidth Cost

- Though organizations and businesses can save money on hardware using cloud, but they have to pay extra for the bandwidth they use to access their workloads.
- However, it doesn't charge much for smaller apps, but data-intensive apps need more bandwidth which can costs higher.

Roles and Boundaries

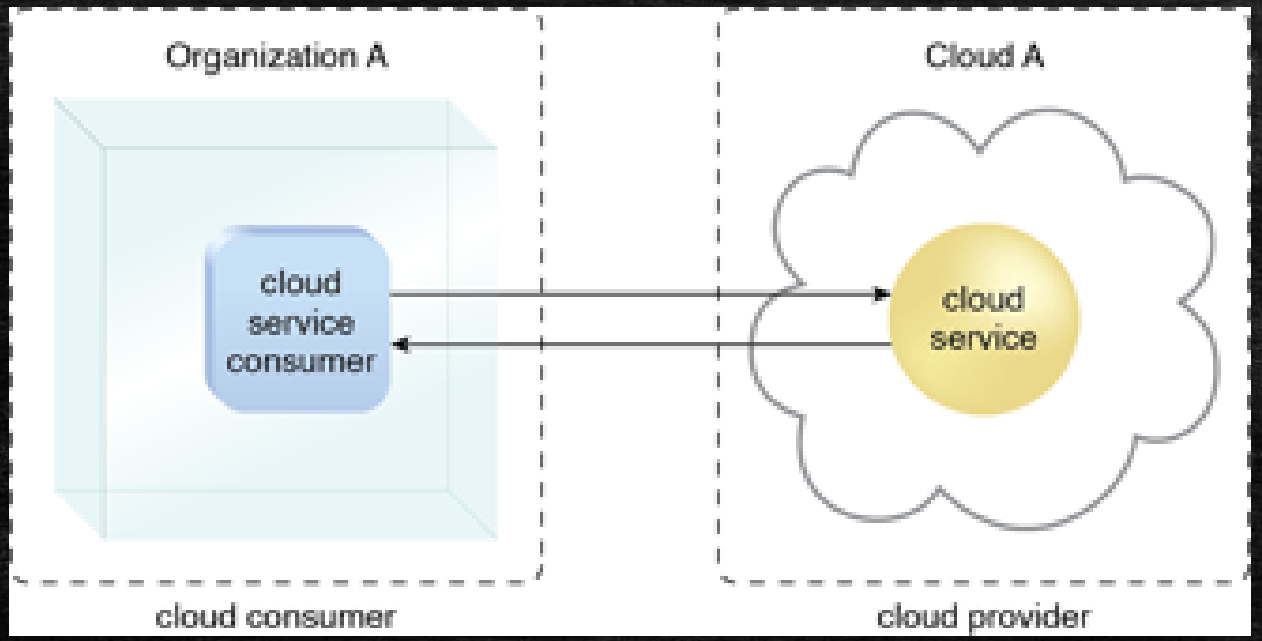
- Organizations and humans can assume different types of pre-defined roles depending on how they relate to and/or interact with a cloud and its hosted IT resources.
- Each of the upcoming roles participates and carries out responsibilities in relation to cloud-based activity.

Cloud Provider

- The organization that provides cloud-based IT resources is the cloud provider.
- When assuming the role of cloud provider, an organization is responsible for making cloud services available to cloud consumers, as per agreed upon SLA guarantees.
- The cloud provider is further tasked with any required management and administrative duties to ensure the on-going operation of the overall cloud infrastructure.
- Cloud providers normally own the IT resources that are made available for lease by cloud consumers; however, some cloud providers also "resell" IT resources leased from other cloud providers.

Cloud Consumer

- A cloud consumer is an organization (or a human) that has a formal contract or arrangement with a cloud provider to use IT resources made available by the cloud provider.
- Specifically, the cloud consumer uses a cloud service consumer to access a cloud service.



Cloud Service Owner

- The person or organization that legally owns a cloud service is called a cloud service owner. The cloud service owner can be the cloud consumer, or the cloud provider that owns the cloud within which the cloud service resides.
- For example, either the cloud consumer of Cloud X or the cloud provider of Cloud X could own Cloud Service A (Figures 1 and 2).

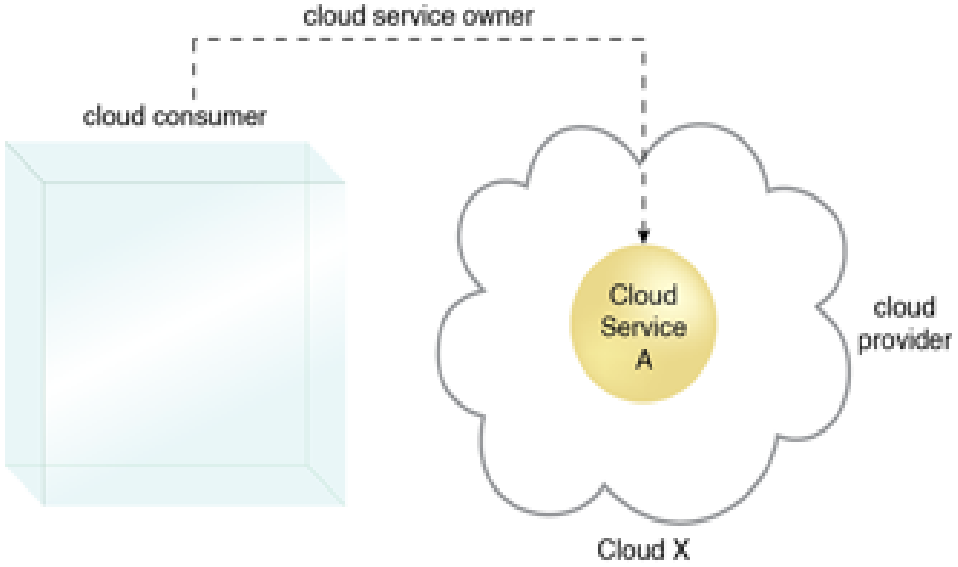


Figure 1 – A cloud consumer can be a cloud service owner when it deploys its own service in a cloud.

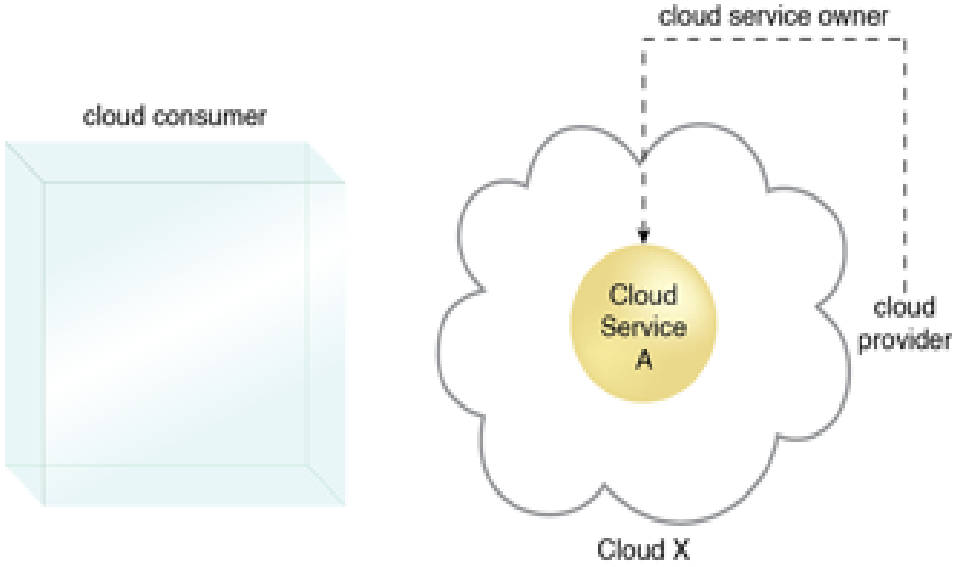


Figure 2 – A cloud provider becomes a cloud service owner if it deploys its own cloud service, typically for other cloud consumers to use.

Note

- Note that a cloud consumer that owns a cloud service hosted by a third-party cloud does not necessarily need to be the user (or consumer) of the cloud service.
- Several cloud consumer organizations develop and deploy cloud services in clouds owned by other parties for the purpose of making the cloud services available to the general public.
- The reason a cloud service owner is not called a cloud resource owner is because the cloud service owner role only applies to cloud services.

Cloud Resource Administrator

- A cloud resource administrator is the person or organization responsible for administering a cloud-based IT resource (including cloud services).
- The cloud resource administrator can be (or belong to) the cloud consumer or cloud provider of the cloud within which the cloud service resides. Alternatively, it can be (or belong to) a third-party organization contracted to administer the cloud-based IT resource.
- For example, a cloud service owner can contract a cloud resource administrator to administer a cloud service (Figures 1 and 2).

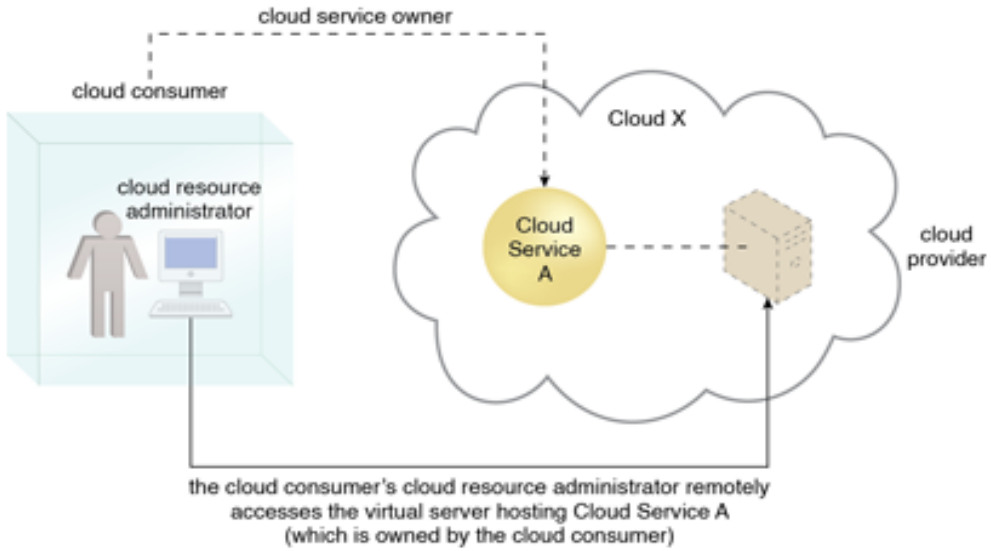


Figure 1 – A cloud resource administrator can be with a cloud consumer organization and administer remotely accessible IT resources that belong to the cloud consumer.

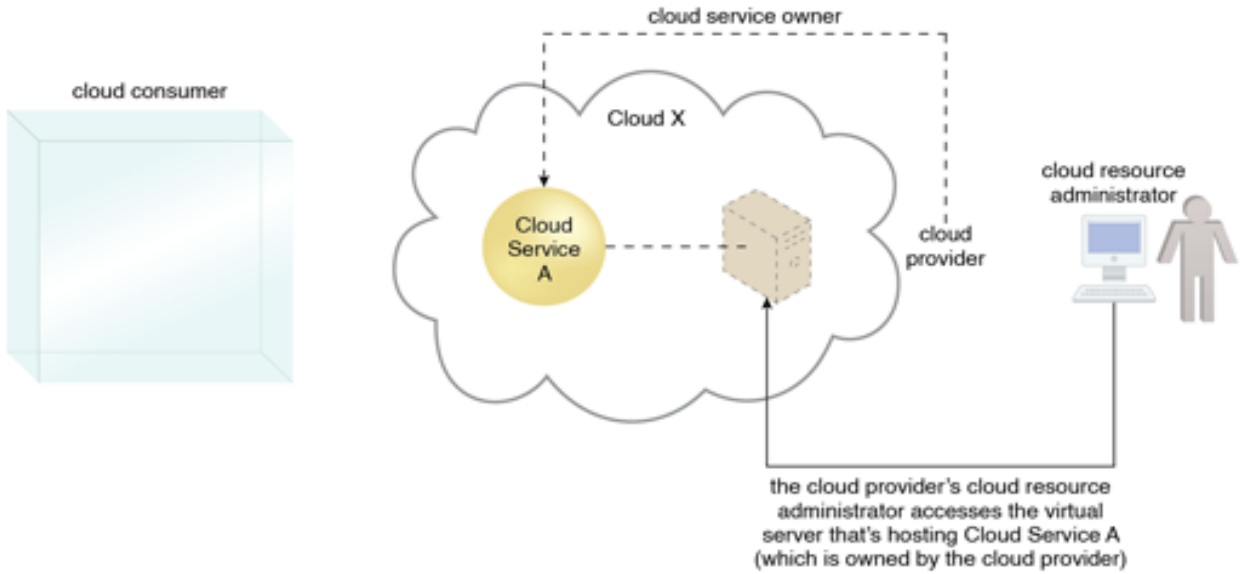


Figure 2 – A cloud resource administrator can be with a cloud provider organization for which it can administer the cloud provider's internally and externally available IT resources.

Additional Roles

- The NIST Cloud Computing Reference Architecture defines the following supplementary roles:
  - Cloud Auditor
  - Cloud Broker
  - Cloud Carrier

Cloud Auditor

- A third-party (often accredited) that conducts independent assessments of cloud environments assumes the role of the cloud auditor.
- The typical responsibilities associated with this role include the evaluation of security controls, privacy impacts, and performance.
- The main purpose of the cloud auditor role is to provide an unbiased assessment (and possible endorsement) of a cloud environment to help strengthen the trust relationship between cloud consumers and cloud providers.

Cloud Broker

- This role is assumed by a party that assumes the responsibility of managing and negotiating the usage of cloud services between cloud consumers and cloud providers.
- Mediation services provided by cloud brokers include service intermediation, aggregation, and arbitrage.

Cloud Carrier

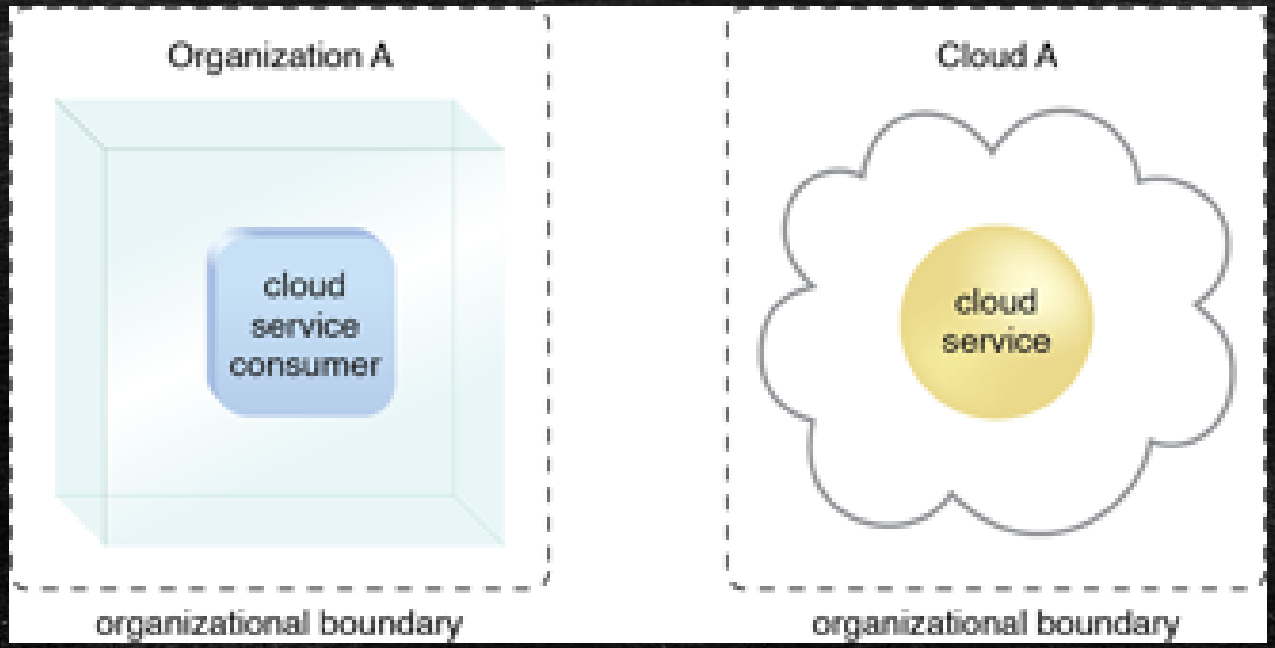
- The party responsible for providing the wire-level connectivity between cloud consumers and cloud providers assumes the role of the cloud carrier.
- This role is often assumed by network and telecommunication providers.

Organizational Boundary

- An organizational boundary represents the physical perimeter that surrounds a set of IT resources that are owned and governed by an organization.
- The organizational boundary does not represent the boundary of an actual organization, only an organizational set of IT assets and IT resources. Similarly, clouds have an organizational boundary.

Organizational Boundary

- Organizational boundaries of a cloud consumer (left), and a cloud provider (right), represented by a broken line notation.

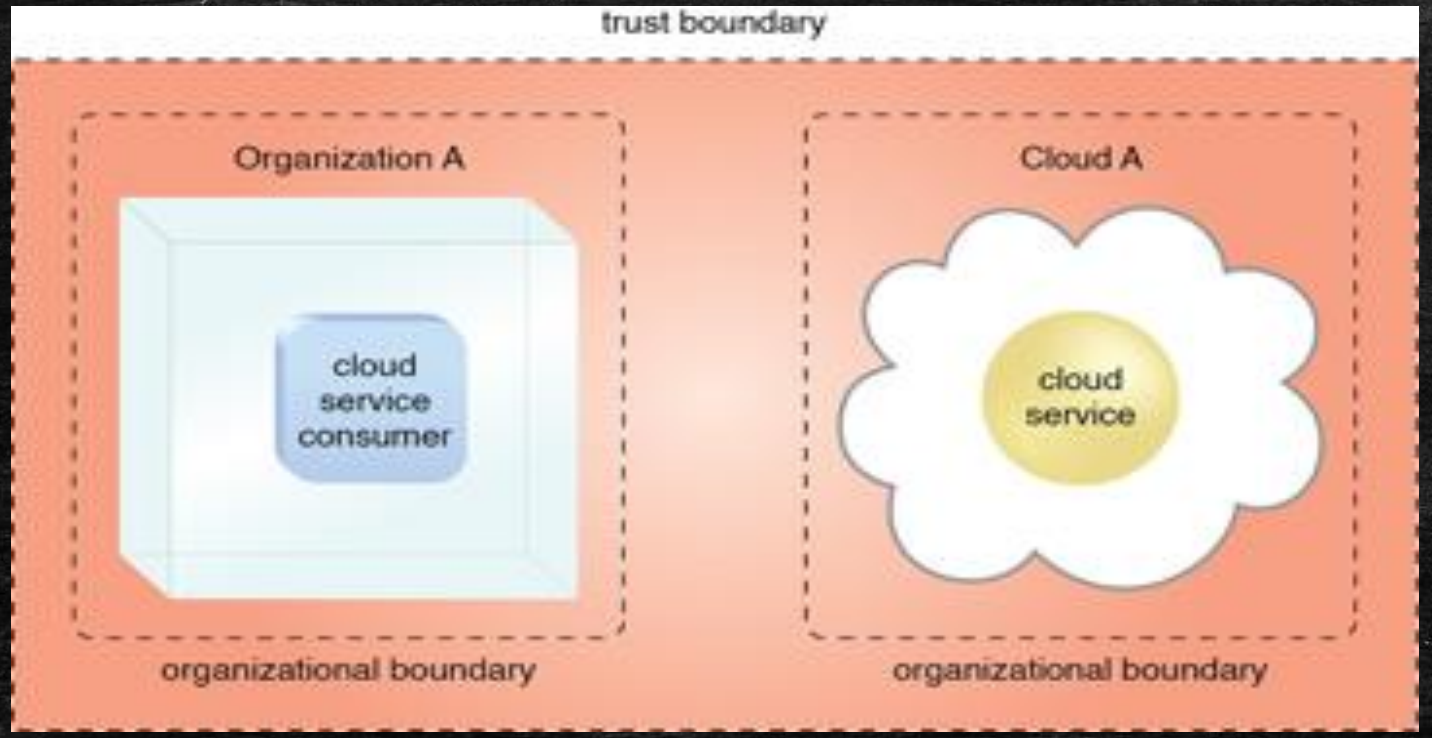


Trust Boundary

- When an organization assumes the role of cloud consumer to access cloud-based IT resources, it needs to extend its trust beyond the physical boundary of the organization to include parts of the cloud environment.
- A trust boundary is a logical perimeter that typically spans beyond physical boundaries to represent the extent to which IT resources are trusted.
- When analyzing cloud environments, the trust boundary is most frequently associated with the trust issued by the organization acting as the cloud consumer.

Trust Boundary

- An extended trust boundary encompasses the organizational boundaries of the cloud provider and the cloud consumer.



Cloud Delivery Models

〈Types of Cloud Computing Models〉

1. Infrastructure as a Service (IaaS)

- IaaS is also known as Hardware as a Service (HaaS).
- It is a computing infrastructure managed over the internet.
- The main advantage of using IaaS is that it helps users to avoid the cost and complexity of purchasing and managing the physical servers.

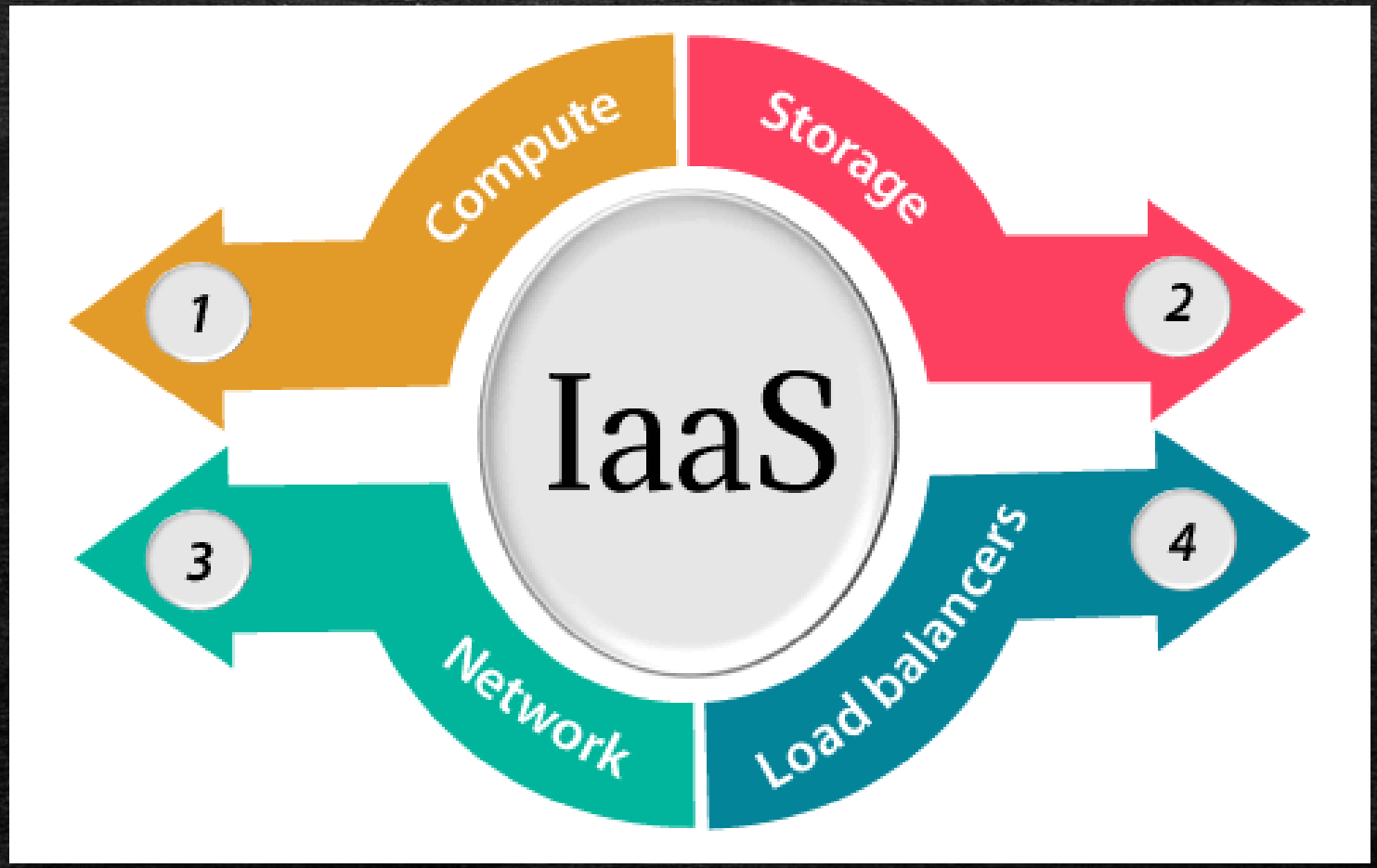
Characteristics of IaaS

- There are the following characteristics of IaaS:
  - Resources are available as a service
  - Services are highly scalable
  - Dynamic and flexible
  - GUI and API-based access
  - Automated administrative tasks

Example of IaaS

- DigitalOcean, Linode, Amazon Web Services (AWS), Microsoft Azure, Google Compute Engine (GCE), Rackspace, and Cisco Metacloud.

IaaS provider provides the following services



IaaS provider provides the following services

- Compute: Computing as a Service includes virtual central processing units and virtual main memory for the Vms that is provisioned to the end- users.
- Storage: IaaS provider provides back-end storage for storing files.
- Network: Network as a Service (NaaS) provides networking components such as routers, switches, and bridges for the Vms.
- Load balancers: It provides load balancing capability at the infrastructure layer.

Advantages of IaaS cloud computing layer

- There are the following advantages of IaaS computing layer:

1. Shared infrastructure: IaaS allows multiple users to share the same physical infrastructure.
2. Web access to the resources: Iaas allows IT users to access resources over the internet.

Advantages of IaaS cloud computing layer

3. Pay-as-per-use model: IaaS providers provide services based on the pay-as-per-use basis. The users are required to pay for what they have used.
4. Focus on the core business: IaaS providers focus on the organization's core business rather than on IT infrastructure.
5. On-demand scalability: On-demand scalability is one of the biggest advantages of IaaS. Using IaaS, users do not worry about to upgrade software and troubleshoot the issues related to hardware components.

Disadvantages of IaaS cloud computing layer

1. Security: Security is one of the biggest issues in IaaS. Most of the IaaS providers are not able to provide 100% security.
2. Maintenance & Upgrade: Although IaaS service providers maintain the software, but they do not upgrade the software for some organizations.
3. Interoperability issues: It is difficult to migrate VM from one IaaS provider to the other, so the customers might face problem related to vendor lock-in.

Top Iaas Providers

IaaS Providers

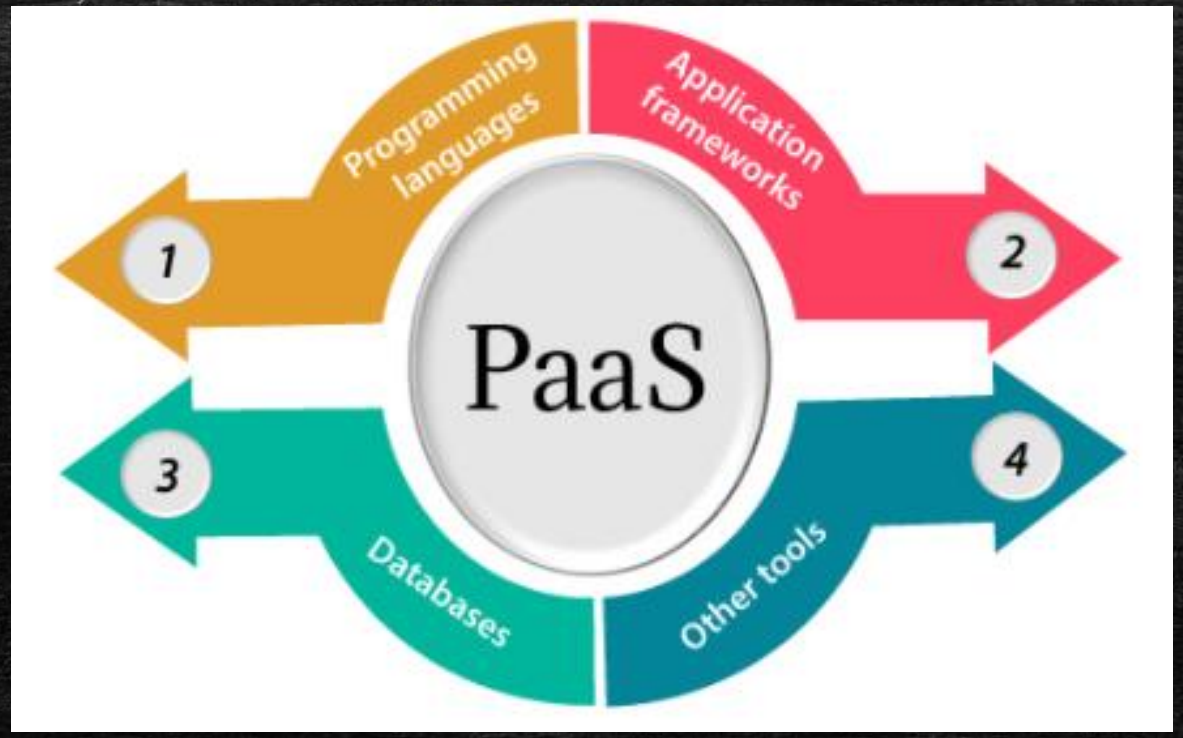
IaaS Vendor	Iaas Solution	Details
Amazon Web Services	Elastic, Elastic Compute Cloud (EC2) MapReduce, Route 53, Virtual Private Cloud, etc.	The cloud computing platform pioneer, Amazon offers auto scaling, cloud monitoring, and load balancing features as part of its portfolio.
Netmagic Solutions	Netmagic IaaS Cloud	Netmagic runs from data centers in Mumbai, Chennai, and Bangalore, and a virtual data center in the United States. Plans are underway to extend services to West Asia.
Rackspace	Cloud servers, cloud files, cloud sites, etc.	The cloud computing platform vendor focuses primarily on enterprise-level hosting services.
Reliance Communications	Reliance Internet Data Center	RIDC supports both traditional hosting and cloud services, with data centers in Mumbai, Bangalore, Hyderabad, and Chennai. The cloud services offered by RIDC include IaaS and SaaS.
Sify Technologies	Sify IaaS	Sify's cloud computing platform is powered by HP's converged infrastructure. The vendor offers all three types of cloud services: IaaS, PaaS, and SaaS.
Tata Communications	InstaCompute	InstaCompute is Tata Communications' IaaS offering. InstaCompute data centers are located in Hyderabad and Singapore, with operations in both countries.

2. Platform as a Service (PaaS)

- PaaS cloud computing platform is created for the programmer to develop, test, run, and manage the applications.
- Platform as a Service (PaaS) provides a runtime environment.
- You can purchase these applications from a cloud service provider on a pay-as-per use basis and access them using the Internet connection.
- In PaaS, back end scalability is managed by the cloud service provider, so end-users do not need to worry about managing the infrastructure.

Services of Platform as a Service (PaaS)

- PaaS providers provide the Programming languages, Application frameworks, Databases, and Other tools:



Characteristics of PaaS

- There are the following characteristics of PaaS:
  - Accessible to various users via the same development application.
  - Integrates with web services and databases.
  - Builds on virtualization technology, so resources can easily be scaled up or down as per the organization's need.
  - Support multiple languages and frameworks.
  - Provides an ability to "Auto-scale".

Example of PaaS

- AWS Elastic Beanstalk, Windows Azure, Heroku, Force.com, Google App Engine, Apache Stratos, Magento Commerce Cloud, and OpenShift.

Advantages of PaaS

- There are the following advantages of PaaS -

1. Simplified Development: PaaS allows developers to focus on development and innovation without worrying about infrastructure management.
2. Lower risk: No need for up-front investment in hardware and software. Developers only need a PC and an internet connection to start building applications.
3. Prebuilt business functionality: Some PaaS vendors also provide already defined business functionality so that users can avoid building everything from very scratch and hence can directly start the projects only.

Advantages of PaaS

4. Instant community: PaaS vendors frequently provide online communities where the developer can get the ideas to share experiences and seek advice from others.

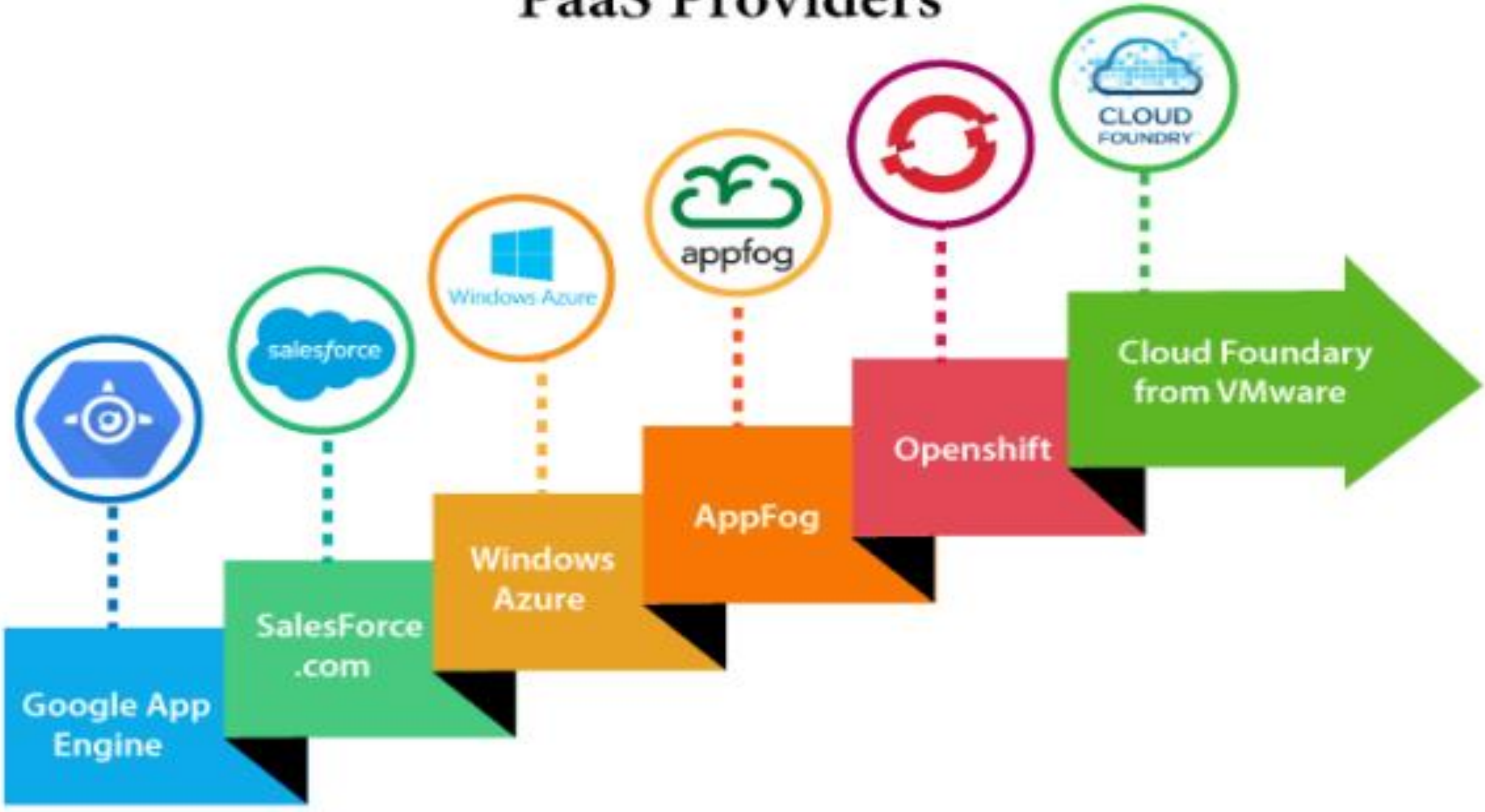
5. Scalability: Applications deployed can scale from one to thousands of users without any changes to the applications.

Disadvantages of PaaS cloud computing layer

1. Vendor lock-in: One has to write the applications according to the platform provided by the PaaS vendor, so the migration of an application to another PaaS vendor would be a problem.
2. Data Privacy: Corporate data, whether it can be critical or not, will be private, so if it is not located within the walls of the company, there can be a risk in terms of privacy of data.
3. Integration with the rest of the systems applications: It may happen that some applications are local, and some are in the cloud. So there will be chances of increased complexity when we want to use data which in the cloud with the local data.

Popular PaaS Providers

PaaS Providers



Providers	Services
Google App Engine (GAE)	App Identity, URL Fetch, Cloud storage client library, Logservice
Salesforce.com	Faster implementation, Rapid scalability, CRM Services, Sales cloud, Mobile connectivity, Chatter.
Windows Azure	Compute, security, IoT, Data Storage.
AppFog	Justcloud.com, SkyDrive, GoogleDocs
Openshift	RedHat, Microsoft Azure.
Cloud Foundry from VMware	Data, Messaging, and other services.

3. Software as a Service (SaaS)

- SaaS is also known as "On-Demand Software".
- It is a software distribution model in which services are hosted by a cloud service provider.
- These services are available to end-users over the internet so, the end-users do not need to install any software on their devices to access these services.

Services provided by SaaS providers

- Business Services:
  - SaaS Provider provides various business services to start-up the business.
  - The SaaS business services include ERP (Enterprise Resource Planning), CRM (Customer Relationship Management), billing, and sales.
- Document Management:
  - SaaS document management is a software application offered by a third party (SaaS providers) to create, manage, and track electronic documents.
  - Example: Slack, Samepage, Box, and Zoho Forms.

Services provided by SaaS providers

- Social Networks:
  - As we all know, social networking sites are used by the general public, so social networking service providers use SaaS for their convenience and handle the general public's information.
- Mail Services :
  - To handle the unpredictable number of users and load on e-mail services, many e-mail providers offering their services using SaaS.

Advantages of SaaS cloud computing layer

1. SaaS is easy to buy

- SaaS pricing is based on a monthly fee or annual fee subscription, so it allows organizations to access business functionality at a low cost, which is less than licensed applications.
- Unlike traditional software, which is sold as a licensed based with an up-front cost (and often an optional ongoing support fee), SaaS providers are generally pricing the applications using a subscription fee, most commonly a monthly or annually fee.

2. One to Many

- SaaS services are offered as a one-to-many model means a single instance of the application is shared by multiple users.

3. Less hardware required for SaaS

- The software is hosted remotely, so organizations do not need to invest in additional hardware.

4. No client-side installation

- SaaS services are accessed directly from the service provider using the internet connection, so do not need to require any software installation.

Disadvantages of SaaS cloud computing layer

1. Security: Actually, data is stored in the cloud, so security may be an issue for some users. However, cloud computing is not more secure than in-house deployment.

2. Latency issue: Since data and applications are stored in the cloud at a variable distance from the end-user, there is a possibility that there may be greater latency when interacting with the application compared to local deployment. Therefore, the SaaS model is not suitable for applications whose demand response time is in milliseconds.

Disadvantages of SaaS cloud computing layer

3. Total Dependency on Internet: Without an internet connection, most SaaS applications are not usable.

4. Switching between SaaS vendors is difficult: Switching SaaS vendors involves the difficult and slow task of transferring the very large data files over the internet and then converting and importing them into another SaaS also.

SaaS Providers

SaaS Providers

Provider	Services
Salseforce.com	On-demand CRM solutions
Microsoft Office 365	Online office suite
Google Apps	Gmail, Google Calendar, Docs, and sites
NetSuite	ERP, accounting, order management, CRM, Professionals Services Automation (PSA), and e-commerce applications.
GoToMeeting	Online meeting and video-conferencing software
Constant Contact	E-mail marketing, online survey, and event marketing
Oracle CRM	CRM applications
Workday, Inc	Human capital management, payroll, and financial management.

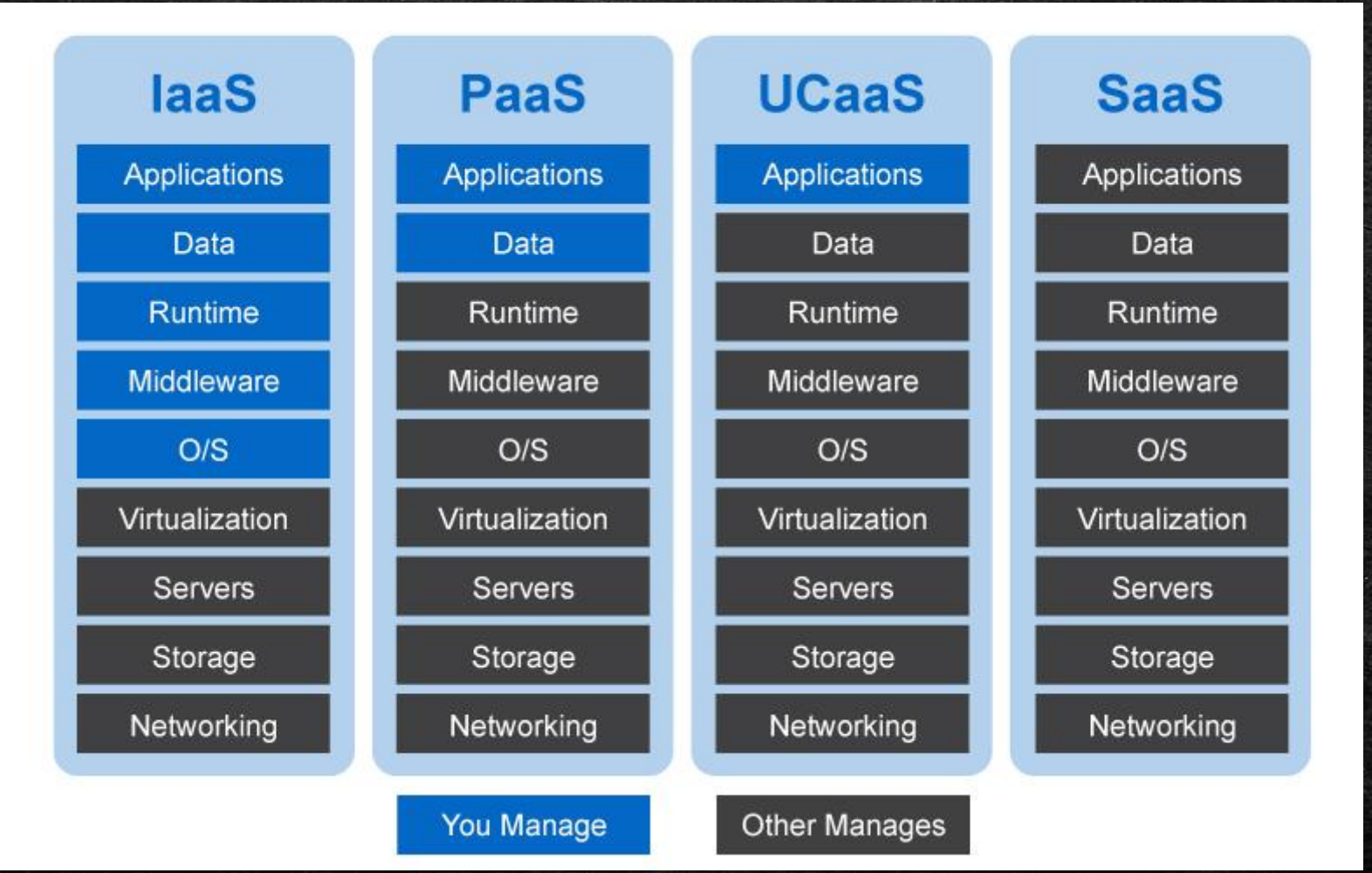
4. Unified Communications-as-a-Service (UCaaS)

- Unified communications-as-a-service (UCaaS) is trending up amid the current crisis as this service model presents communications continuity and remote collaboration services to users, worldwide, via the cloud network.
- Moreover, this service model provides advanced security and reliability, enabling the remote workforce to work seamlessly in a secure, virtualized cloud environment.

Features and benefits of UCaaS

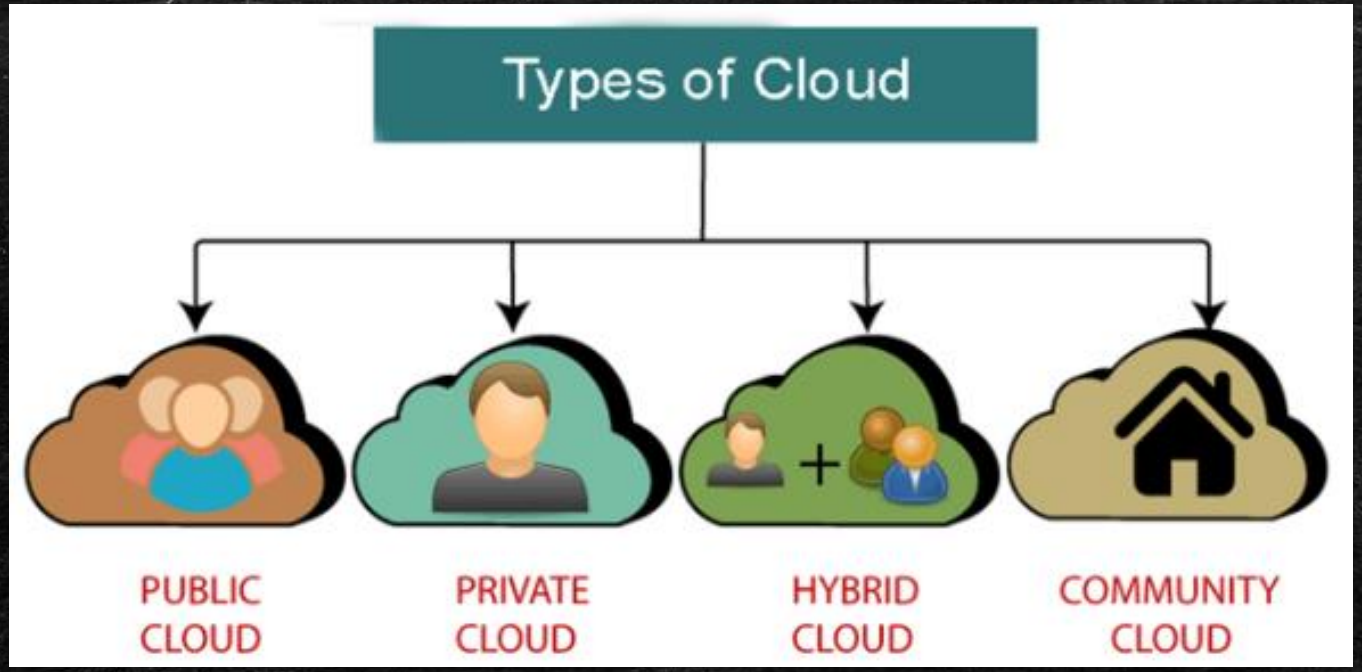
- Centralized management
- Improved response time
- Voice/VoIP technology
- Audio/video conferencing
- Supports BYOD (bring your own device)
- Rich data channel
- Advanced security
- Instant connectivity across devices

The key difference between the three service models of cloud computing



Types of Cloud

- There are the following 4 types of cloud that you can deploy according to the organization's needs-



Public Cloud

- Public Cloud provides a shared platform that is accessible to the general public through an Internet connection.
- Public cloud operated on the pay-as-per-use model and administrated by the third party, i.e., Cloud service provider.
- In the Public cloud, the same storage is being used by multiple users at the same time.
- Public cloud is owned, managed, and operated by businesses, universities, government organizations, or a combination of them.

Advantages of Public Cloud

- There are the following advantages of Public Cloud -
  - Public cloud is owned at a lower cost than the private and hybrid cloud.
  - Public cloud is maintained by the cloud service provider, so do not need to worry about the maintenance.
  - Public cloud is easier to integrate. Hence it offers a better flexibility approach to consumers.

Advantages of Public Cloud

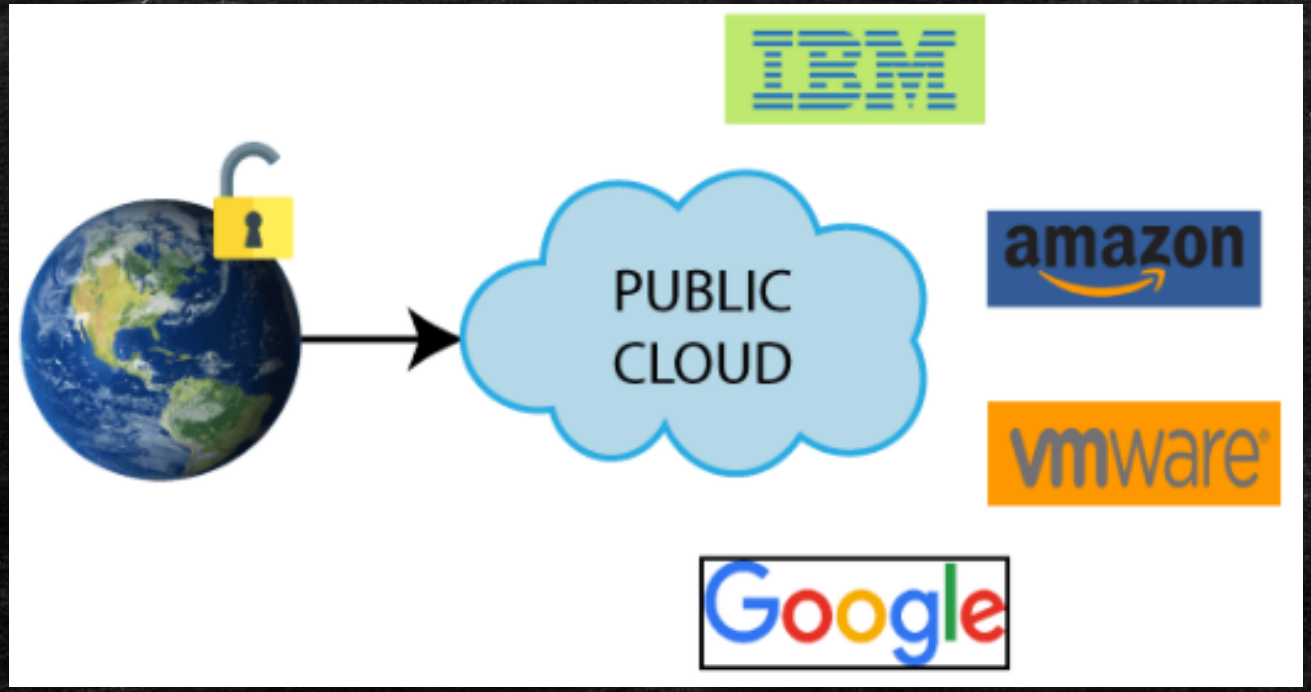
- Public cloud is location independent because its services are delivered through the internet.
- Public cloud is highly scalable as per the requirement of computing resources.
- It is accessible by the general public, so there is no limit to the number of users.

Disadvantages of Public Cloud

- Public Cloud is less secure because resources are shared publicly.
- Performance depends upon the high-speed internet network link to the cloud provider.
- The Client has no control of data.

Examples of Public Cloud

- Example: Amazon elastic compute cloud (EC2), IBM SmartCloud Enterprise, Microsoft, Google App Engine, Windows Azure Services Platform.



Private Cloud

- Private cloud is also known as an internal cloud or corporate cloud.
- Private cloud provides computing services to a private internal network (within the organization) and selected users instead of the general public.
- Private cloud provides a high level of security and privacy to data through firewalls and internal hosting. It also ensures that operational and sensitive data are not accessible to third-party providers.
- HP Data Centers, Microsoft, Elastra-private cloud, and Ubuntu are the example of a private cloud.

Advantages of Private cloud

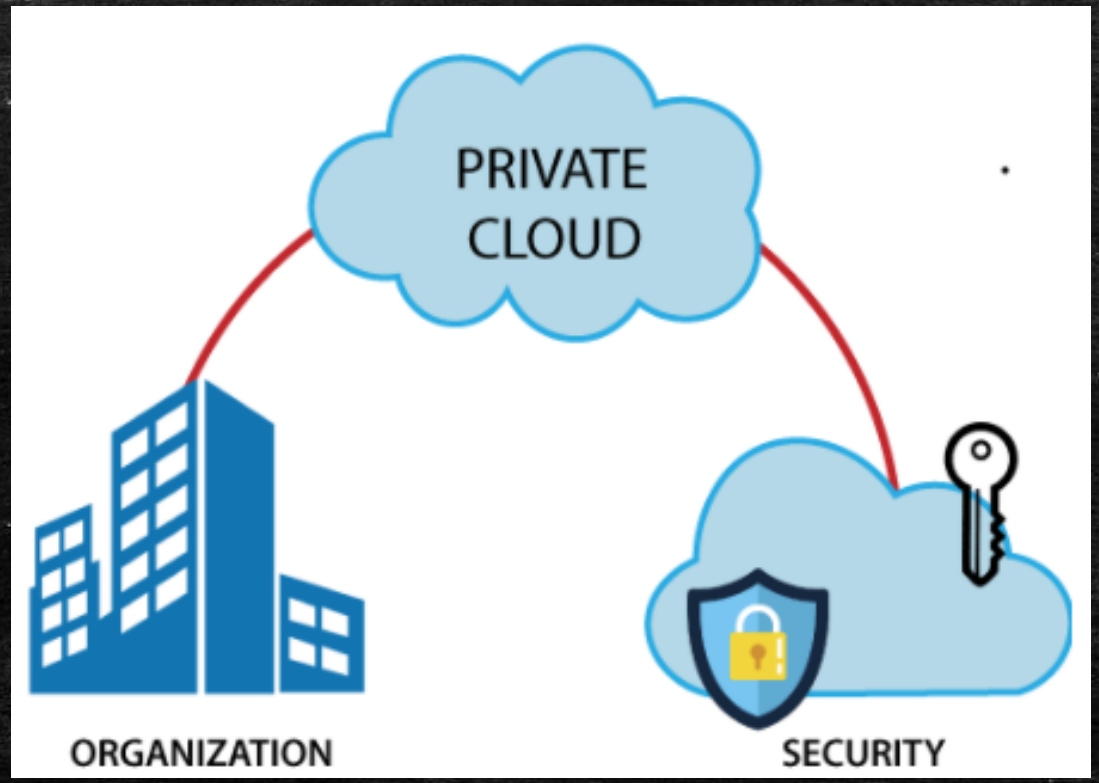
- There are the following advantages of Private Cloud -
  - More Control: Private clouds have more control over their resources and hardware than public clouds because it is only accessed by selected users.
  - Security & privacy: Security & privacy are one of the big advantages of cloud computing. Private cloud improved the security level as compared to the public cloud.
  - Improved performance: Private cloud offers better performance with improved speed and space capacity.

Disadvantages of Private Cloud

- High cost: The cost is higher than a public cloud because set up and maintain hardware resources are costly.
- Restricted area of operations: As we know, private cloud is accessible within the organization, so the area of operations is limited.
- Limited scalability: Private clouds are scaled only within the capacity of internal hosted resources.
- Skilled people: Skilled people are required to manage and operate cloud services.

Examples of Private Cloud

- HP Data Centers, Microsoft, Elastra-private cloud, and Ubuntu are the example of a private cloud.



Hybrid Cloud

- Hybrid cloud is a combination of public and private clouds.
- Hybrid cloud = public cloud + private cloud
- The main aim to combine these cloud (Public and Private) is to create a unified, automated, and well-managed computing environment.
- In the Hybrid cloud, non-critical activities are performed by the public cloud and critical activities are performed by the private cloud.
- Mainly, a hybrid cloud is used in finance, healthcare, and Universities.

Advantages of Hybrid Cloud

- There are the following advantages of Hybrid Cloud -
- Flexible and secure: It provides flexible resources because of the public cloud and secure resources because of the private cloud.
- Cost effective: Hybrid cloud costs less than the private cloud. It helps organizations to save costs for both infrastructure and application support.

Advantages of Hybrid Cloud

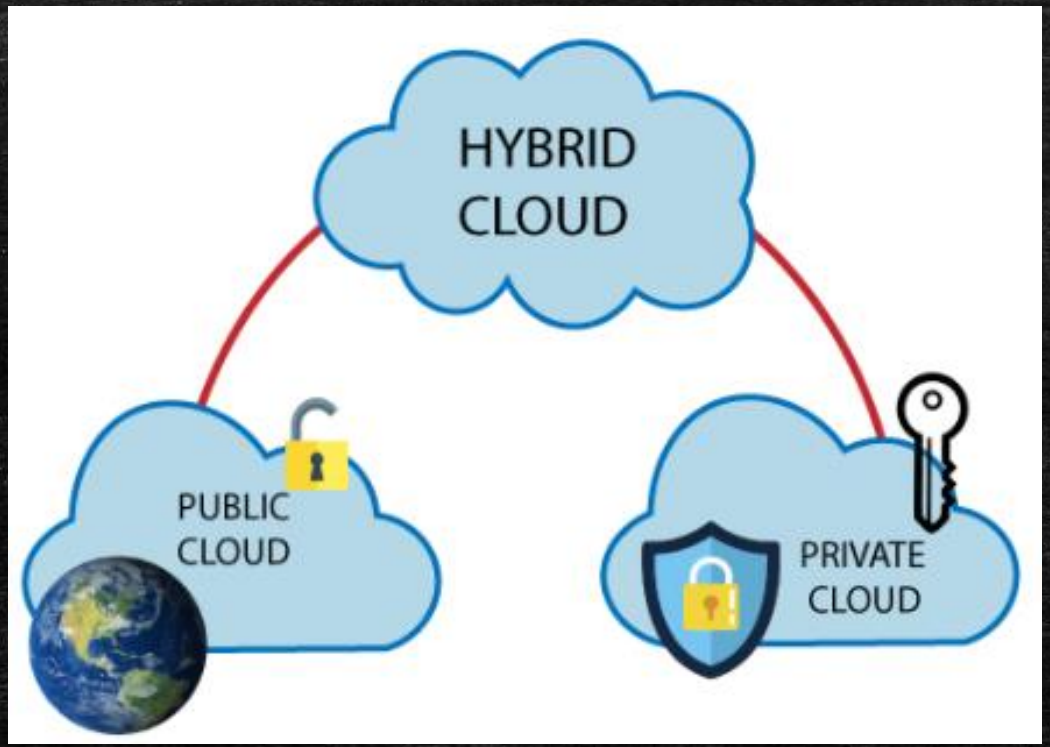
- Security: Hybrid cloud is secure because critical activities are performed by the private cloud.
- Risk Management: Hybrid cloud provides an excellent way for companies to manage the risk.

Disadvantages of Hybrid Cloud

- Networking issues: In the Hybrid Cloud, networking becomes complex because of the private and the public cloud.
- Infrastructure Compatibility: Infrastructure compatibility is the major issue in a hybrid cloud. With dual-levels of infrastructure, a private cloud controls the company, and a public cloud does not, so there is a possibility that they are running in separate stacks.
- Reliability: The reliability of the services depends on cloud service providers.

Examples of Hybrid Cloud

- The best hybrid cloud provider companies are Amazon, Microsoft, Google, Cisco, and NetApp.



Community Cloud

- Community cloud is a cloud infrastructure that allows systems and services to be accessible by a group of several organizations to share the information.
- It is owned, managed, and operated by one or more organizations in the community, a third party, or a combination of them.

Advantages of Community Cloud

There are the following advantages of Community Cloud -

- Cost effective: Community cloud is cost effective because the whole cloud is shared between several organizations or a community.
- Flexible and Scalable: The community cloud is flexible and scalable because it is compatible with every user. It allows the users to modify the documents as per their needs and requirement.

Advantages of Community Cloud

- Security: Community cloud is more secure than the public cloud but less secure than the private cloud.
- Sharing infrastructure: Community cloud allows us to share cloud resources, infrastructure, and other capabilities among various organizations.

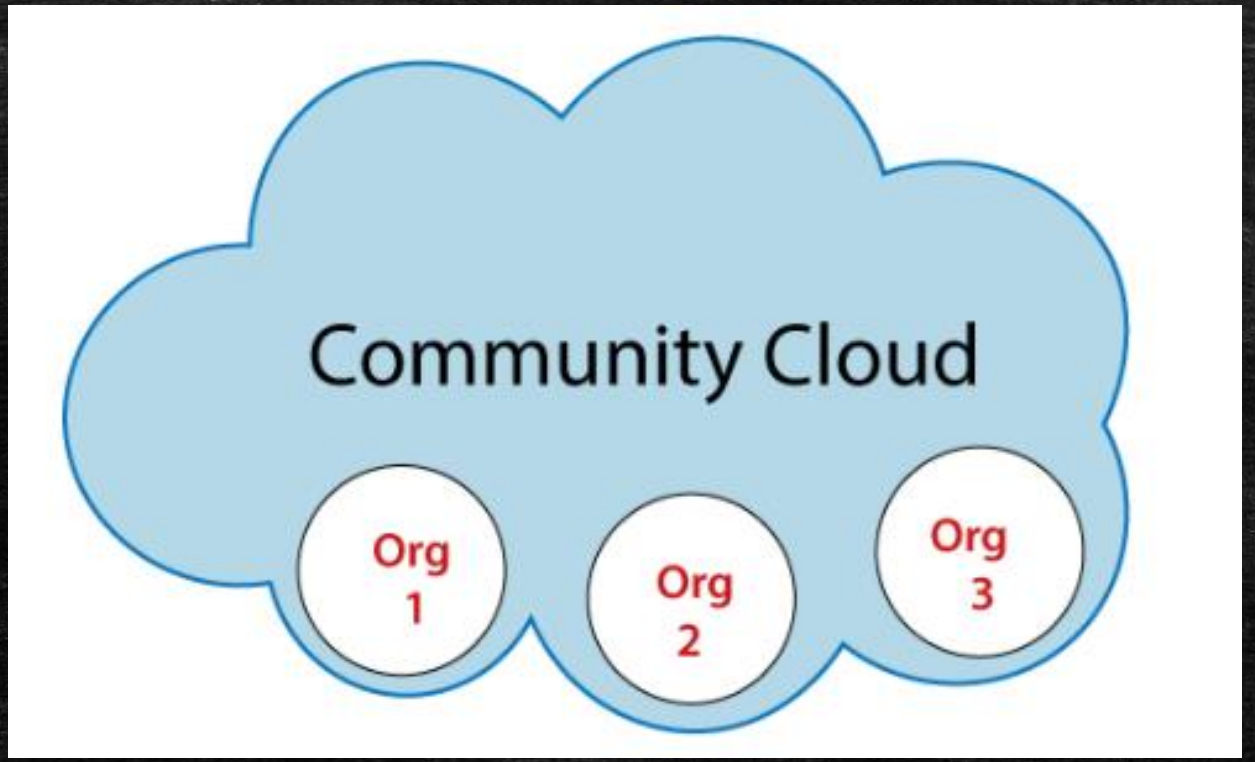
Disadvantages of Community Cloud

There are the following disadvantages of Community Cloud -

- Community cloud is not a good choice for every organization.
- Slow adoption to data
- The fixed amount of data storage and bandwidth is shared among all community members.
- Community Cloud is costly than the public cloud.
- Sharing responsibilities among organizations is difficult.

Examples of Community Cloud

- Our government organization within India may share computing infrastructure in the cloud to manage data.



Virtualization

- Virtualization is a large umbrella of technologies and concepts that are meant to provide an abstract environment whether virtual hardware or an operating system to run applications.
- The term virtualization is often synonymous with hardware virtualization, which plays a fundamental role in efficiently delivering Infrastructure-as-a-Service (IaaS) solutions for cloud computing.

Virtualization

- Virtualization technologies have a long trail in the history of computer science and have been available in many flavors by providing virtual environments at the operating system level, the programming language level, and the application level.
- Moreover, virtualization technologies provide a virtual environment for not only executing applications but also for storage, memory, and networking.
- 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.

Virtualization

- Virtualization technologies have gained renewed interested recently due to the confluence of several phenomena:
- Increased performance and computing capacity:
  - Nowadays, the average end-user desktop PC is powerful enough to meet almost all the needs of everyday computing, with extra capacity that is rarely used.
  - Almost all these PCs have resources enough to host a virtual machine manager and execute a virtual machine with by far acceptable performance.

Virtualization

- Underutilized hardware and software resources:
  - Hardware and software underutilization is occurring due to increased performance and computing capacity, and the effect of limited or sporadic use of resources.

Virtualization

- Lack of space:
  - The continuous need for additional capacity, whether storage or compute power, makes data centers grow quickly.

Virtualization

- Greening initiatives:
  - Recently, companies are increasingly looking for ways to reduce the amount of energy they consume and to reduce their carbon footprint.
  - Data centers are one of the major power consumers; they contribute consistently to the impact that a company has on the environment.
  - Maintaining a data center operation not only involves keeping servers on, but a great deal of energy is also consumed in keeping them cool.
  - Infrastructures for cooling have a significant impact on the carbon footprint of a data center. Hence, reducing the number of servers through server consolidation will definitely reduce the impact of cooling and power consumption of a data center.
  - Virtualization technologies can provide an efficient way of consolidating servers.

Virtualization

- Rise of administrative costs:
  - Power consumption and cooling costs have now become higher than the cost of IT equipment. Moreover, the increased demand for additional capacity, which translates into more servers in a data center, is also responsible for a significant increment in administrative costs.
  - Computers in particular, servers do not operate all on their own, but they require care and feeding from system administrators.

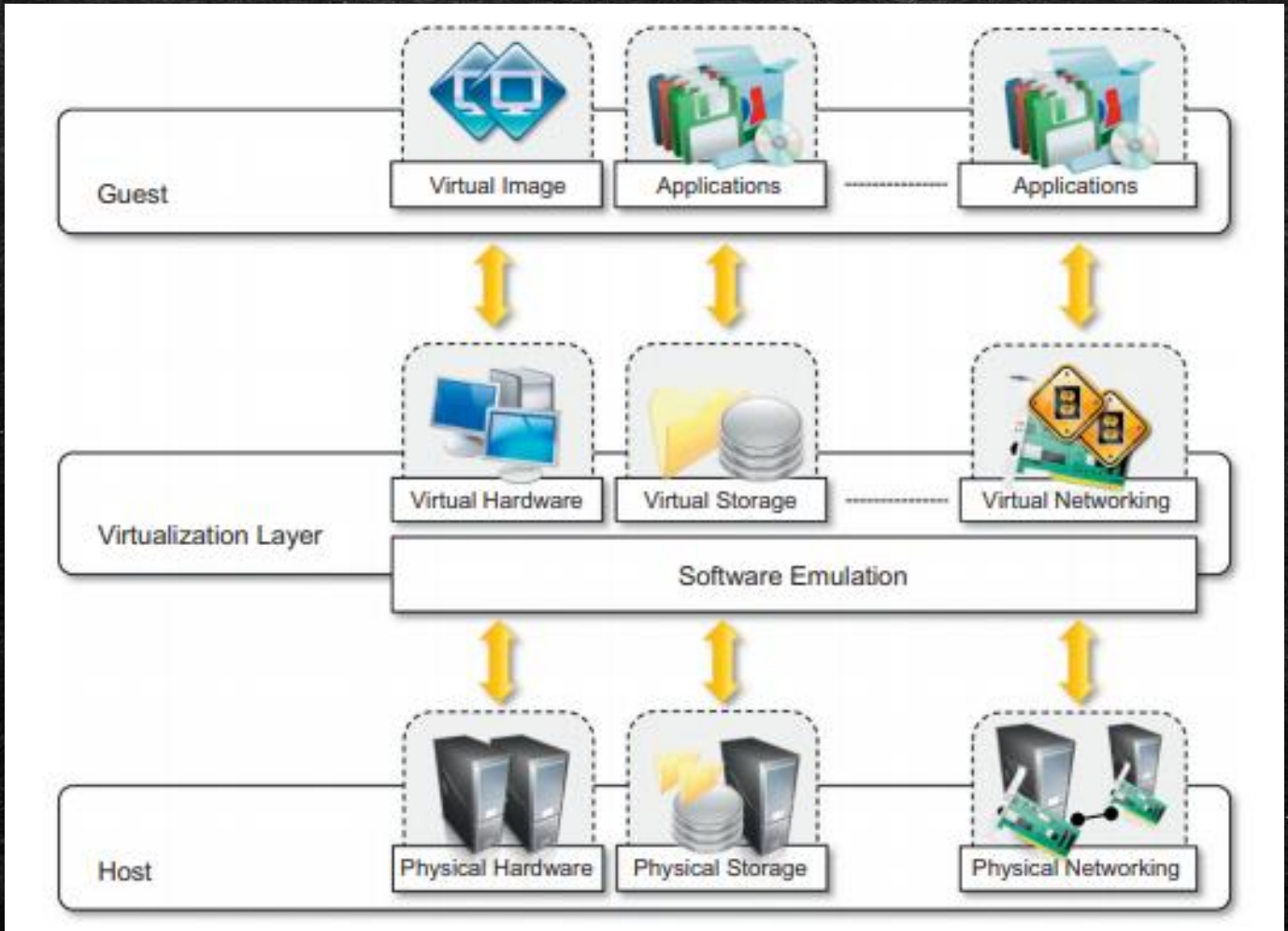
Characteristics of virtualized environments

- 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. In a virtualized environment there are three major components: guest, host, and virtualization layer.

Entities involved in Virtualization

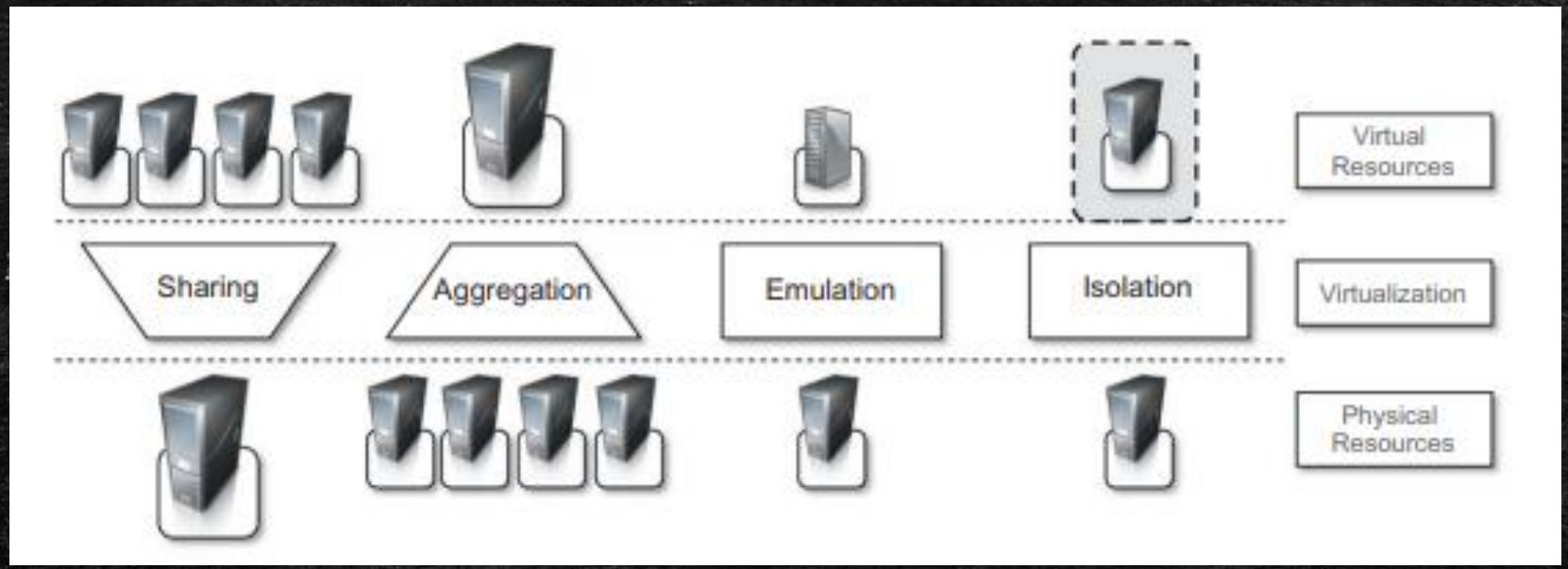
- The guest represents the system component that interacts with the virtualization layer rather than with the host, as would normally happen.
- The host represents the original environment where the guest is supposed to be managed.
- The virtualization layer is responsible for recreating the same or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

The virtualization reference model.

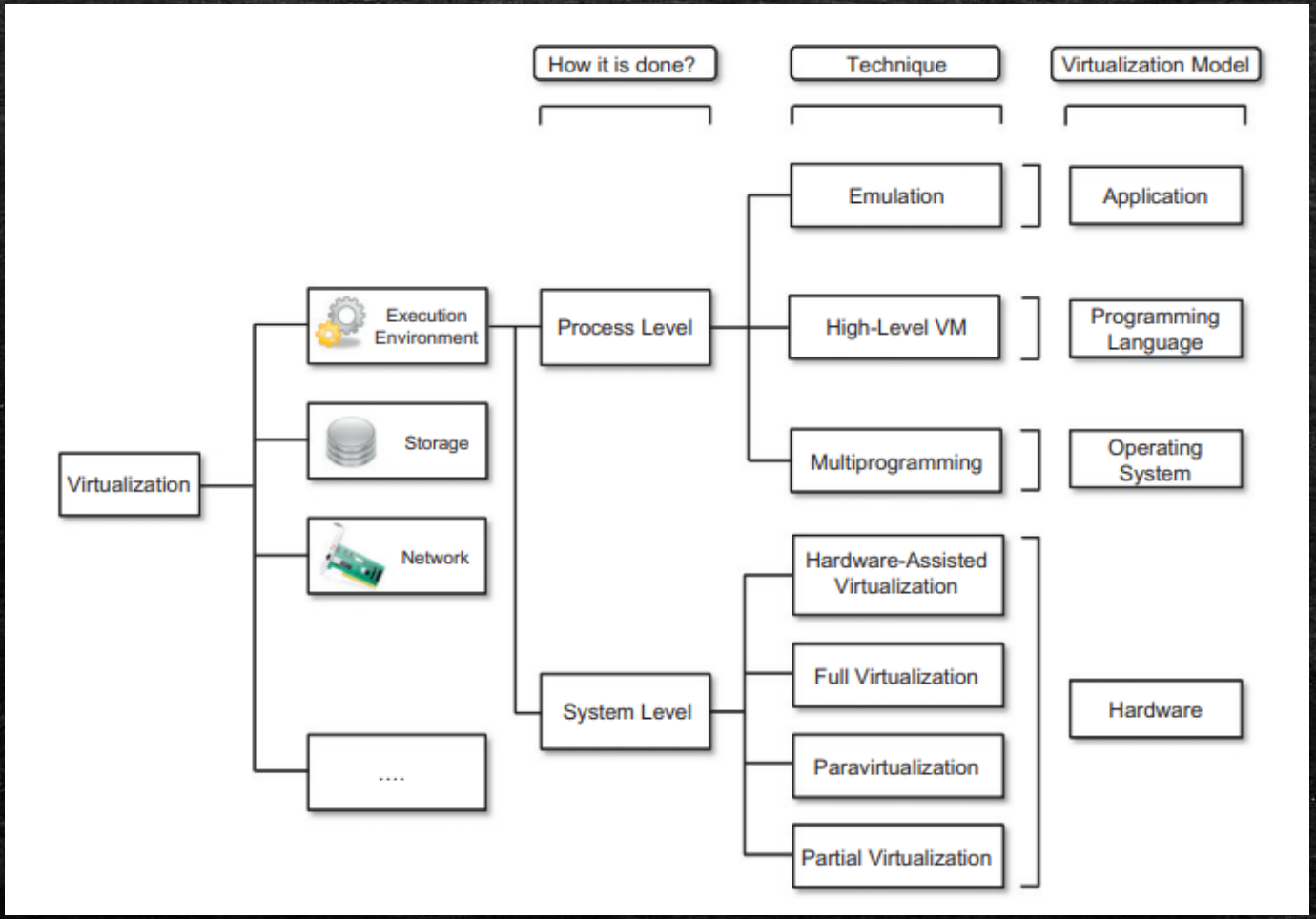


Characteristics of virtualized environments

- Managed execution



A taxonomy of virtualization techniques



Types of Virtualization

- Hardware Virtualization
- Software Virtualization
- Server Virtualization
- Storage Virtualization
- OS Virtualization
- Linux Virtualization
- Windows Virtualization
- Data Virtualization

Hardware Virtualization

- Virtualization means abstraction. Hardware virtualization is accomplished by abstracting the physical hardware layer by use of a hypervisor or VMM (Virtual Machine Monitor).
- The hypervisor manages shared the physical resources of the hardware between the guest operating systems and host operating system.
- The physical resources become abstracted versions in standard formats regardless of the hardware platform.
- The abstracted hardware is represented as actual hardware. Then the virtualized operating system looks into these resources as they are physical entities.

Hardware Virtualization

- When the virtual machine software or virtual machine manager (VMM) or hypervisor software 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.

Usage of Hardware Virtualization

- 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

The main benefits of hardware virtualization are more efficient resource utilization, lower overall costs as well as increased uptime and IT flexibility.

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.

Advantages of Hardware Virtualization

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.

Software Virtualization

- Managing applications and distribution becomes a typical task for IT departments. Installation mechanism differs from application to application. Some programs require certain helper applications or frameworks and these applications may have conflict with existing applications.
- Software virtualization is just like a virtualization but able to abstract the software installation procedure and create virtual software installations.
- Virtualized software is an application that will be "installed" into its own self-contained unit.
- Example of software virtualization is VMware software, virtual box etc.

Advantages of Software Virtualization

1) Client Deployments Become Easier:
   - Copying a file to a workstation or linking a file in a network then we can easily install virtual software.

2) Easy to manage:
   - To manage updates becomes a simpler task. You need to update at one place and deploy the updated virtual application to the all clients.

3) Software Migration:
   - Without software virtualization, moving from one software platform to another platform takes much time for deploying and impact on end user systems. With the help of virtualized software environment the migration becomes easier.

Server Virtualization

- Server Virtualization is the process of dividing a physical server into several virtual servers, called virtual private servers. Each virtual private server can run independently.
- The concept of Server Virtualization widely used in the IT infrastructure to minimizes the costs by increasing the utilization of existing resources.

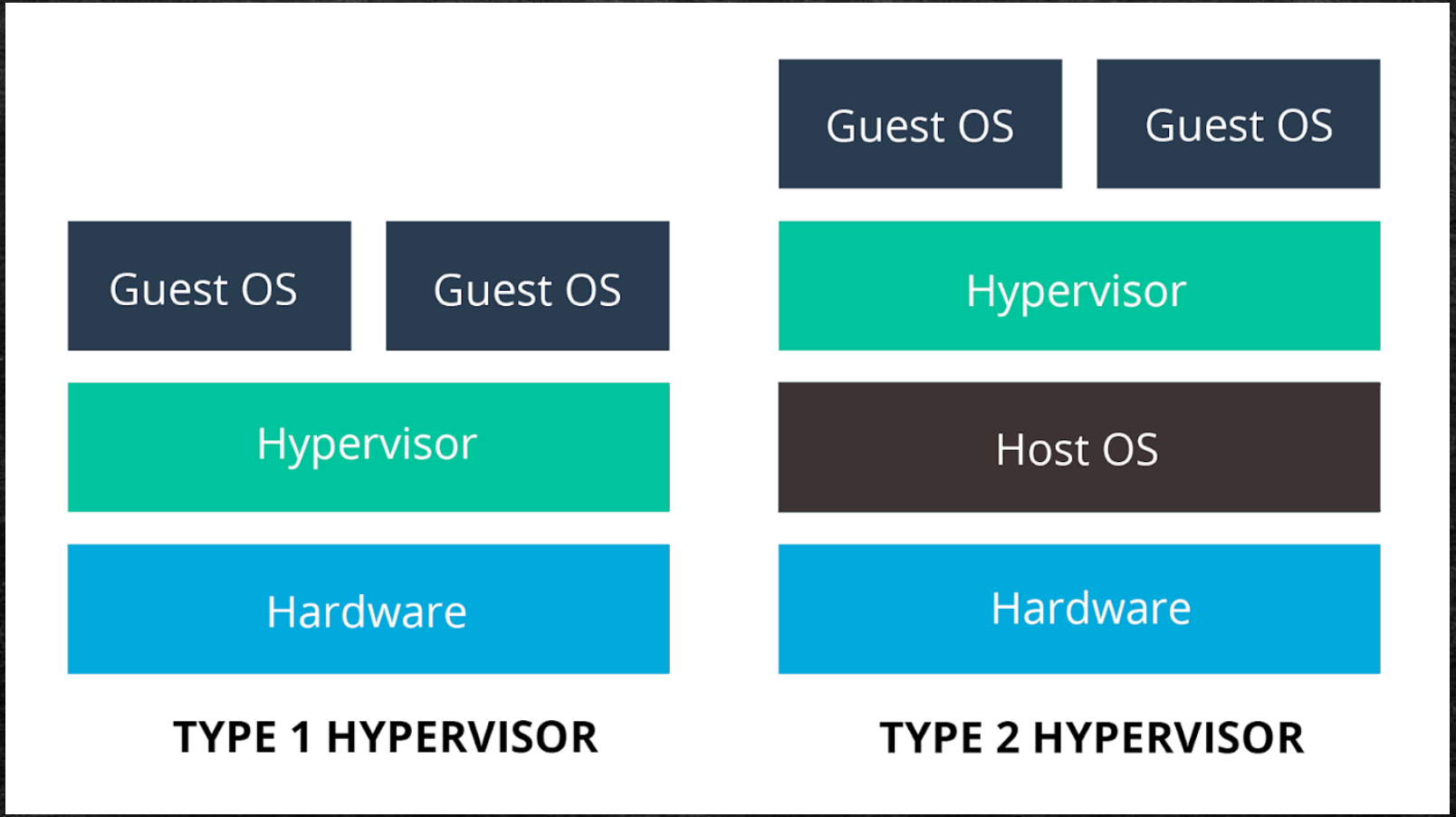
Types of Server Virtualization

1. Hypervisor
   - In the Server Virtualization, Hypervisor plays an important role. It is a layer between the operating system (OS) and hardware. There are two types of hypervisors.
   - Type 1 hypervisor (also known as bare metal or native hypervisors)
   - Type 2 hypervisor (also known as hosted or Embedded hypervisors)
   - The hypervisor is mainly used to perform various tasks such as allocate physical hardware resources (CPU, RAM, etc.) to several smaller independent virtual machines, called "guest" on the host machine.

Bare-Metal

- A bare-metal server is a computer server that hosts one tenant, or consumer, only.
- The term is used for distinguishing between servers that can host multiple tenants and which utilize virtualization and cloud hosting.
- Such servers are used by a single consumer and are not shared between consumers.
- A few examples of Type 1 hypervisors are Citrix/Xen Server, VMware ESXi and Microsoft Hyper-V.
- Examples of type 2 Hypervisors include Microsoft Virtual PC, Oracle Virtual Box, VMware Workstation, Oracle Solaris Zones, VMware Fusion, Oracle VM Server for x86 and more.

Type 1 and 2 Hypervisor



Types of Server Virtualization

2. 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.

Types of Server Virtualization

3. 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.

Types of Server Virtualization

4. Operating System Virtualization
   - Operating system virtualization is also called as system-level virtualization. It is a server virtualization technology that divides one operating system into multiple isolated user-space called virtual environments. The biggest advantage of using server visualization is that it reduces the use of physical space, so it will save money.
   - Linux OS Virtualization and Windows OS Virtualization are the types of Operating System virtualization.
   - FreeVPS, OpenVZ, and Linux Vserver are some examples of System-Level Virtualization.

Types of Server Virtualization

5. Hardware Assisted Virtualization
   - Hardware Assisted Virtualization was presented by AMD and Intel.
   - It is also known as Hardware virtualization, AMD virtualization, and Intel virtualization. It is designed to increase the performance of the processor.
   - The advantage of using Hardware Assisted Virtualization is that it requires less hypervisor overhead.

Types of Server Virtualization

6. Kernel-Level Virtualization
   - Kernel-level virtualization is one of the most important types of server virtualization. It is an open-source virtualization which uses the Linux kernel as a hypervisor. The advantage of using kernel virtualization is that it does not require any special administrative software and has very less overhead.
   - User Mode Linux (UML) and Kernel-based virtual machine are some examples of kernel virtualization.

Advantages of Server Virtualization

There are the following 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.

Advantages of Server Virtualization

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

5. Security
   - It allows uses to store their sensitive data inside the data centers.

Disadvantages of Server Virtualization

There are the following disadvantages of Server Virtualization:

- 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.
- There is no way to measure the performance of virtualized environments.
- It requires a huge amount of RAM consumption.
- It is difficult to set up and maintain.
- Some core applications and databases are not supported virtualization.
- It requires extra hardware resources.

Uses of Server Virtualization

A list of uses of server virtualization is given below -

- 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.

Virtualization and cloud computing

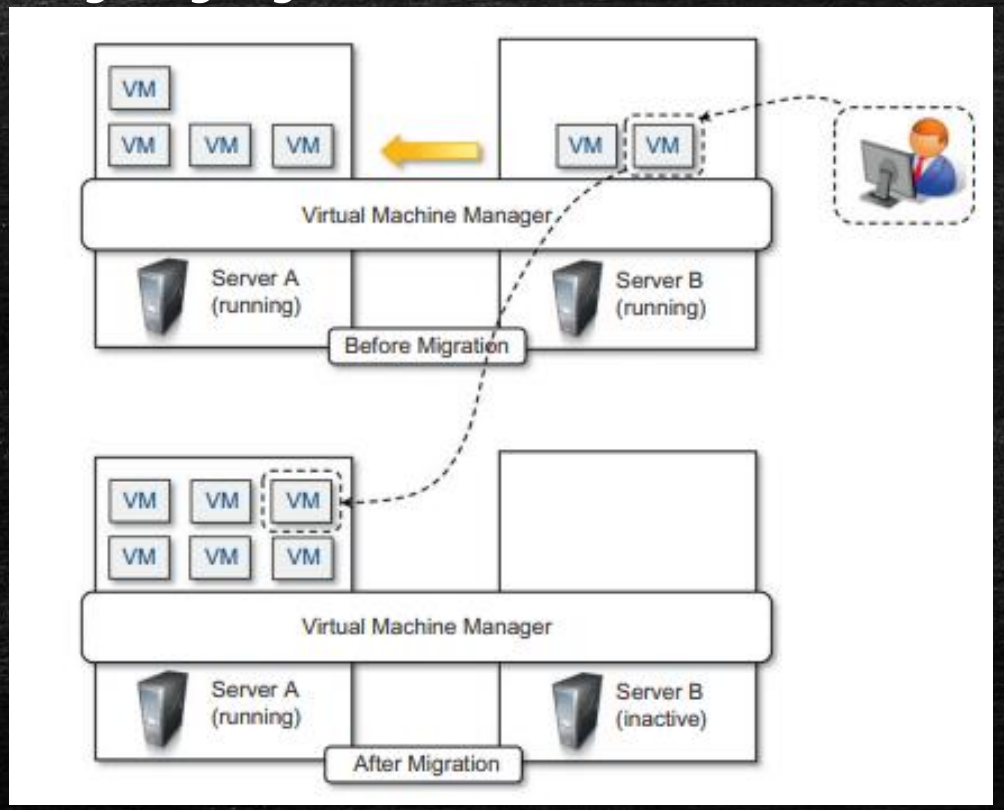
- Virtualization plays an important role in cloud computing since it allows for the appropriate degree of customization, security, isolation, and manageability that are fundamental for delivering IT services on demand.
- Virtualization technologies are primarily used to offer configurable computing environments and storage.
- Virtualization transforms physical hardware into virtual machines.

Virtualization and cloud computing

- Hardware and programming language virtualization are the techniques adopted in cloud computing systems.
- Hardware virtualization is an enabling factor for solutions in the Infrastructure-as-a-Service (IaaS) market segment, while programming language virtualization is a technology leveraged in Platform-as-a-Service (PaaS) offerings.
- Virtualization also allows isolation and a finer control, thus simplifying the leasing of services and their accountability on the vendor side.

Live migration and server consolidation

- Server consolidation and virtual machine migration are principally used in the case of hardware virtualization, even though they are also technically possible in the case of programming language virtualization.



Advantages of virtualization

- Managed execution and isolation are perhaps the most important advantages of virtualization.
- In the case of techniques supporting the creation of virtualized execution environments, these two characteristics allow building secure and controllable computing environments.

Advantages of virtualization

- A virtual execution environment can be configured as a sandbox, thus preventing any harmful operation to cross the borders of the virtual host.
- Moreover, allocation of resources and their partitioning among different guests is simplified, being the virtual host controlled by a program. This enables fine-tuning of resources, which is very important in a server consolidation scenario and is also a requirement for effective quality of service.

Advantages of virtualization

- Portability is another advantage of virtualization, especially for execution virtualization techniques.
- Finally, by means of virtualization it is possible to achieve a more efficient use of resources.
- Multiple systems can securely coexist and share the resources of the underlying host, without interfering with each other.

Advantages of virtualization

- This is a prerequisite for server consolidation, which allows adjusting the number of active physical resources dynamically according to the current load of the system, thus creating the opportunity to save in terms of energy consumption and to be less impacting on the environment.

The other side of the coin: Disadvantages

- Performance degradation
- Inefficiency and degraded user experience

Virtualization Management Tools

- Virtualization management tools are designed to administer the operations and processes of a virtualization environment.
- The number of virtual machines running in the data center can reach hundreds and thousands. For this reason, it becomes imperative to have visibility into the virtualization environment to understand the overall performance and health of the system.
- Businesses use virtualization management tools to administer resources to a variety of machines as well as to handle memory allocation.

Virtualization Management Features & Capabilities

- Virtual machine administrator alerts
- Processor and memory allocation to virtual machines
- Dynamic resource allocation
- Performance monitoring
- Programmable APIs
- Future requirements prediction

Benefits of Virtualization

- More flexible and efficient allocation of resources.
- Enhance development productivity.
- It lowers the cost of IT infrastructure.
- Remote access and rapid scalability.
- High availability and disaster recovery.
- Pay peruse of the IT infrastructure on demand.
- Enables running multiple operating systems.

Principles of Parallel and Distributed Computing

What is parallel processing?

- Processing of multiple tasks simultaneously on multiple processors is called parallel processing.
- The parallel program consists of multiple active processes (tasks) simultaneously solving a given problem.
- A given task is divided into multiple subtasks using a divide-and-conquer technique, and each subtask is processed on a different central processing unit (CPU).
- Programming on a multiprocessor system using the divide-and-conquer technique is called parallel programming.

Hardware architectures for parallel processing

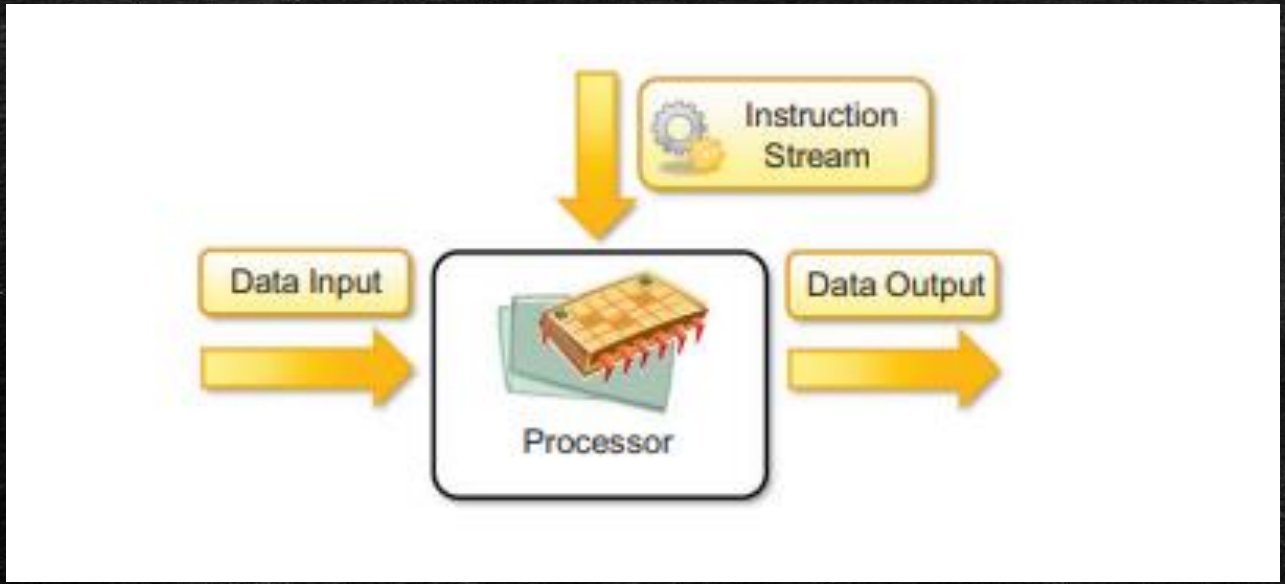
- The core elements of parallel processing are CPUs. Based on the number of instruction and data streams that can be processed simultaneously, computing systems are classified into the following four categories:
  - Single-instruction, single-data (SISD) systems
  - Single-instruction, multiple-data (SIMD) systems
  - Multiple-instruction, single-data (MISD) systems
  - Multiple-instruction, multiple-data (MIMD) systems

Single-instruction, single-data (SISD) systems

- An SISD computing system is a uniprocessor machine capable of executing a single instruction, which operates on a single data stream (see Figure).
- In SISD, machine instructions are processed sequentially; hence computers adopting this model are popularly called sequential computers.
- Most conventional computers are built using the SISD model. All the instructions and data to be processed have to be stored in primary memory.
- The speed of the processing element in the SISD model is limited by the rate at which the computer can transfer information internally.
- Dominant representative SISD systems are IBM PC, Macintosh, and workstations.

Single-instruction, single-data (SISD) systems

- SISD Architecture:



Single-instruction, multiple-data (SIMD) systems

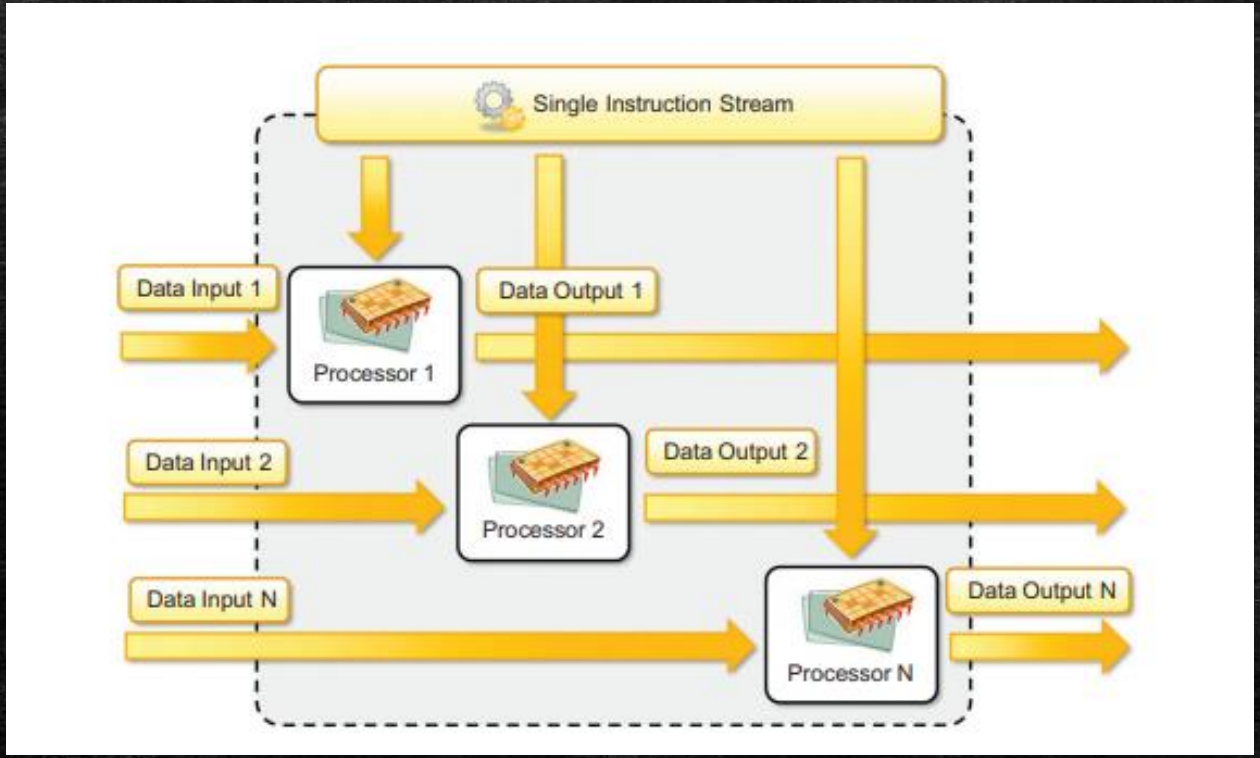
- An SIMD computing system is a multiprocessor machine capable of executing the same instruction on all the CPUs but operating on different data streams (see Figure).
- Machines based on an SIMD model are well suited to scientific computing since they involve lots of vector and matrix operations. For instance, statements such as

  Ci = Ai * Bi

- can be passed to all the processing elements (PEs); organized data elements of vectors A and B can be divided into multiple sets (N-sets for N PE systems); and each PE can process one data set.
- Dominant representative SIMD systems are Cray's vector processing machine and Thinking Machines' cm

Single-instruction, multiple-data (SIMD) systems

- SIMD Architecture:



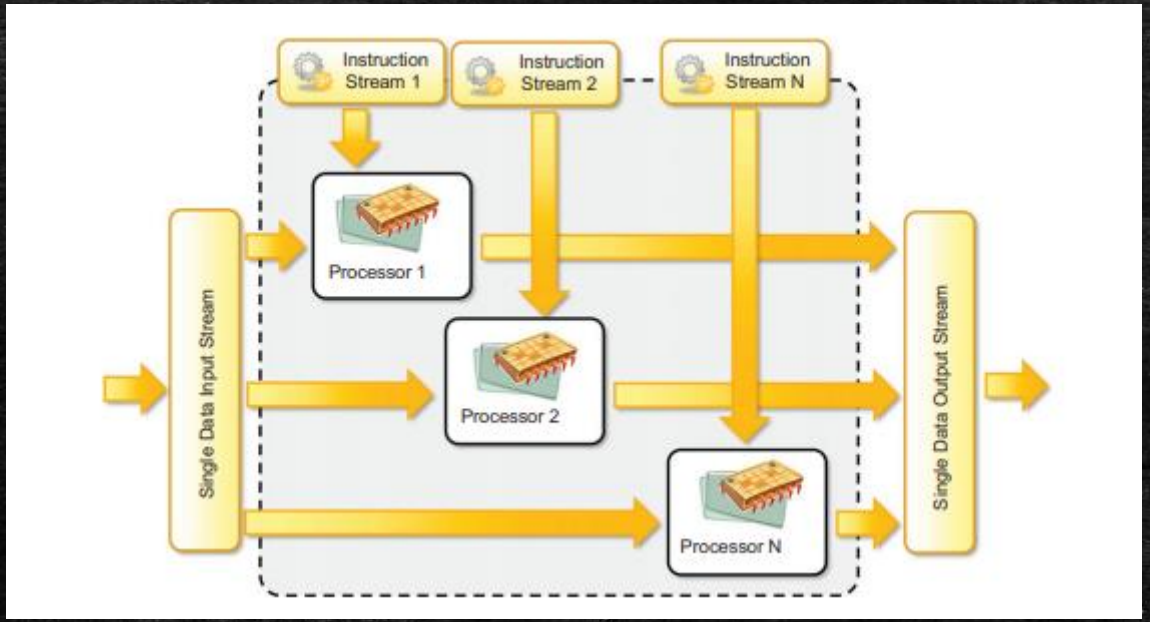
Multiple-instruction, single-data (MISD) systems

- An MISD computing system is a multiprocessor machine capable of executing different instructions on different PEs but all of them operating on the same data set (see Figure). For instance, statements such as:

  y=sin(x) + cos(x) + tan(x)

Multiple-instruction, single-data (MISD) systems

- MISD Architecture:

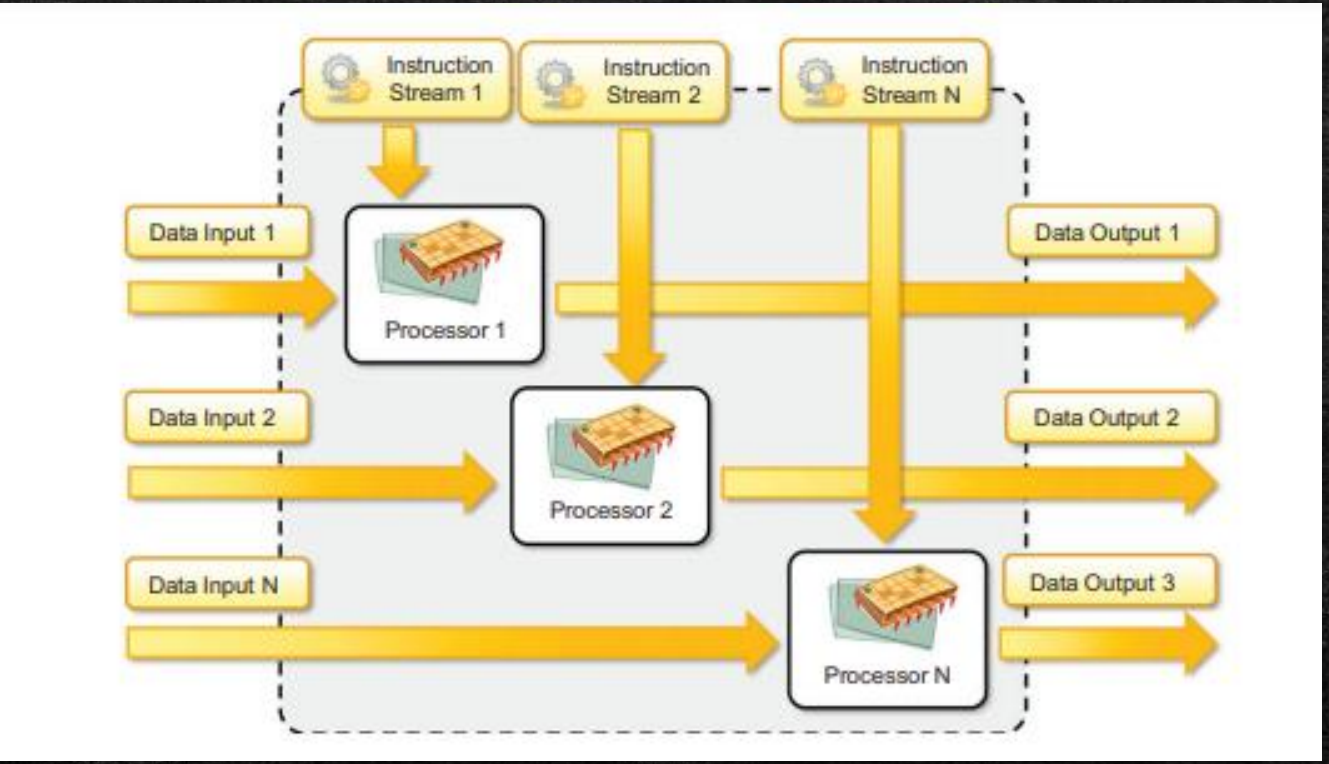


Multiple-instruction, multiple-data (MIMD) systems

- An MIMD computing system is a multiprocessor machine capable of executing multiple instructions on multiple data sets (see Figure).
- Each PE in the MIMD model has separate instruction and data streams; hence machines built using this model are well suited to any kind of application.
- Unlike SIMD and MISD machines, PEs in MIMD machines work asynchronously.
- MIMD machines are broadly categorized into shared-memory MIMD and distributed-memory MIMD based on the way PEs are coupled to the main memory.

Multiple-instruction, multiple-data (MIMD) systems

- MIMD architecture:

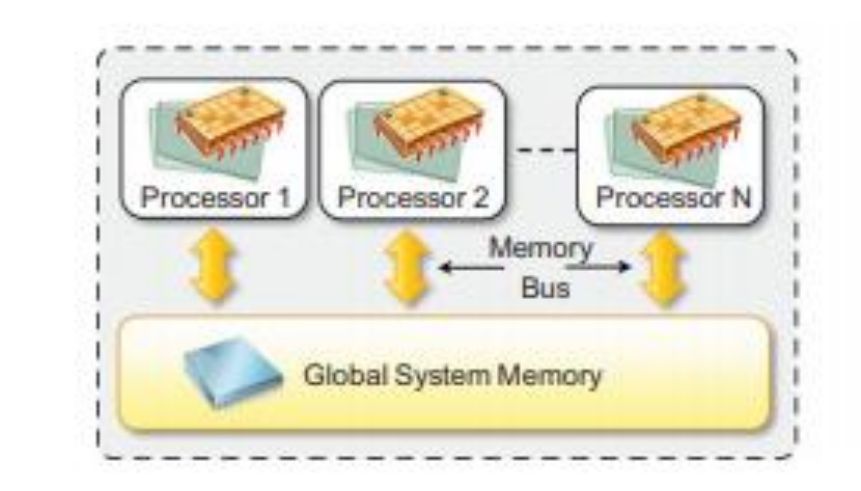


Shared memory MIMD machines

- In the shared memory MIMD model, all the PEs are connected to a single global memory and they all have access to it (see Figure). Systems based on this model are also called tightly coupled multiprocessor systems.
- The communication between PEs in this model takes place through the shared memory; modification of the data stored in the global memory by one PE is visible to all other PEs.
- Dominant representative shared memory MIMD systems are Silicon Graphics machines and Sun/IBM's SMP (Symmetric Multi-Processing).

Shared memory MIMD machines

- Shared Memory MIMD Machine:

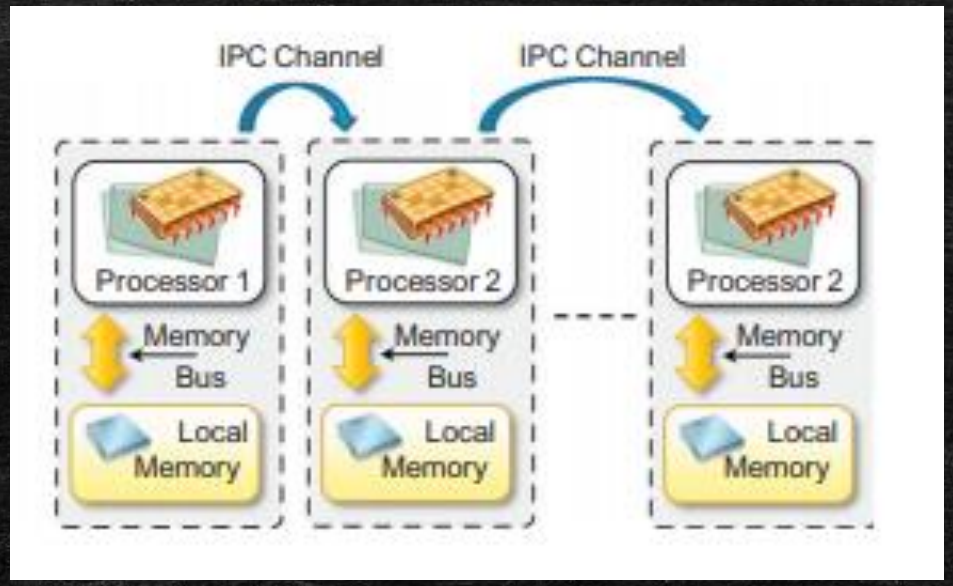


Distributed memory MIMD machines

- In the distributed memory MIMD model, all PEs have a local memory. Systems based on this model are also called loosely coupled multiprocessor systems.
- The communication between PEs in this model takes place through the interconnection network (the interprocess communication channel, or IPC).
- The network connecting PEs can be configured to tree, mesh, cube, and so on.
- Each PE operates asynchronously, and if communication/synchronization among tasks is necessary, they can do so by exchanging messages between them.

Distributed memory MIMD machines

- Distributed memory MIMD machines:



Summary

- The shared-memory MIMD architecture is easier to program but is less tolerant to failures and harder to extend with respect to the distributed memory MIMD model.
- Failures in a shared-memory MIMD affect the entire system, whereas this is not the case of the distributed model, in which each of the PEs can be easily isolated.
- Moreover, shared memory MIMD architectures are less likely to scale because the addition of more PEs leads to memory contention. This is a situation that does not happen in the case of distributed memory, in which each PE has its own memory. As a result, distributed memory MIMD architectures are most popular today.

Approaches to parallel programming

- A sequential program is one that runs on a single processor and has a single line of control. To make many processors collectively work on a single program, the program must be divided into smaller independent chunks so that each processor can work on separate chunks of the problem. The program decomposed in this way is a parallel program.
- A wide variety of parallel programming approaches are available. The most prominent among them are the following:
  - Data parallelism
  - Process parallelism
  - Farmer-and-worker model
- These three models are all suitable for task-level parallelism.

Data parallelism

- In the case of data parallelism, the divide-and-conquer technique is used to split data into multiple sets, and each data set is processed on different PEs using the same instruction.
- This approach is highly suitable to processing on machines based on the SIMD model.

Process parallelism

- In the case of process parallelism, a given operation has multiple (but distinct) activities that can be processed on multiple processors.
- In the case of the farmer and-worker model, a job distribution approach is used: one processor is configured as master and all other remaining PEs are designated as slaves; the master assigns jobs to slave PEs and, on completion, they inform the master, which in turn collects results.
- These approaches can be utilized in different levels of parallelism.

Levels of parallelism

- Levels of parallelism are decided based on the lumps of code (grain size) that can be a potential candidate for parallelism. Table below lists categories of code granularity for parallelism.
- All these approaches have a common goal: to boost processor efficiency by hiding latency.
- To conceal latency, there must be another thread ready to run whenever a lengthy operation occurs.
- The idea is to execute concurrently two or more single-threaded applications, such as compiling, text formatting, database searching, and device simulation.

Levels of Parallelism

- As shown in the table and depicted in Figure, parallelism within an application can be detected at several levels:
  - Large grain (or task level)
  - Medium grain (or control level)
  - Fine grain (data level)
  - Very fine grain (multiple-instruction issue)

Grain Size	Code Item	Parallelized By
Large	Separate and heavyweight process	Programmer
Medium	Function or procedure	Programmer
Fine	Loop or instruction block	Parallelizing compiler
Very fine	Instruction	Processor

Google Classroom code for "Cloud Computing"

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asktoshivsir@gmail.com

Shivkumar Chandey

(+91 9987389441)

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