Charotar University of Science and Technology [CHARUSAT]

Faculty of Technology and Engineering

Computer Science & Engineering

CS451: Advance Computing

Unit 1 - Introduction to Computing Technology

COMPUTING TECHNOLOGY

Computing technology is the use of tools and systems to store, process, and communicate data. It includes a wide range of devices and systems. It includes the tools, devices, and methods used to program computers.

Examples of computing technology: computers, tablets, smartphones, the web, cloud computing, email, text messages, and social media.

Computing technology in the workplace

- Computing technology professionals are needed in many industries, including business, arts and entertainment, sports and recreation, fashion design, and marketing.
- Computing technology can be used to automate clinical laboratories and develop hospital information systems.
- Computing technology in daily life: Computing technology is used in many aspects of daily life, including careers, communication, and entertainment.

CLUSTER COMPUTING

Cluster

A cluster in computing is a group of computers that work together to complete a task. Clusters are made up of nodes, which are individual computers that are connected to each other.

What is Cluster Computing?

Cluster computing is a type of distributed computing that involves connecting multiple computers to work together as a single system. The computers, or nodes, are connected over a network and programmed to perform the same task.

- A collection of tightly or loosely connected computers that work together so that they act as a single entity. A computer cluster is a set of interconnected computers that work together as a single system, often to improve performance, reliability, or scalability. The computers in the cluster are typically connected via a network and can either work tightly (with tightly coupled systems) or loosely (with loosely coupled systems).
  Tightly Coupled Systems: The computers in a tightly coupled cluster share resources like memory and processors. They are typically used for tasks requiring high processing power or large amounts of memory, where coordination between the nodes (computers) is frequent and critical. An example of tightly coupled clusters is supercomputers.
  Loosely Coupled Systems: In a loosely coupled cluster, each node works independently, with minimal interaction or resource sharing. These types of clusters are

often used for tasks that don't require as tight coordination between nodes. For example, a web server farm where each server runs independently but contributes to handling web traffic.

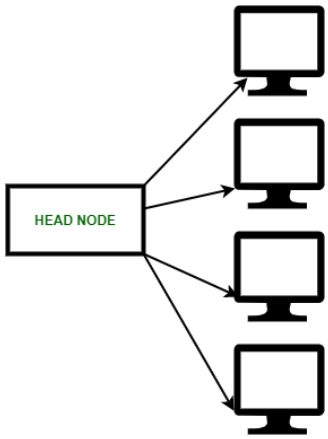

Figure 1:Cluster Computing

- The connected computers execute operations all together thus creating the idea of a single system.
- The clusters are generally connected through fast local area networks (LANs).
- Benefits: Improved performance, fault tolerance, scalability, cost-effective.

The benefits of using a computer cluster include:

- **Improved Performance**: Clusters can handle more processing tasks by distributing workloads across multiple nodes, which leads to faster processing and improved overall system performance. This is especially beneficial for resource-intensive applications such as scientific simulations, data analytics, and web services.
- **Fault Tolerance**: Since multiple nodes are involved, if one node fails, the remaining nodes can continue to operate, ensuring that the system remains available. Clusters often have redundancy mechanisms, such as data replication or load balancing, to maintain service even when hardware failures occur.
- **Scalability**: Clusters can be easily expanded by adding more nodes. As demand increases, additional resources (processing power, memory, storage) can be added without significant reconfiguration, allowing for seamless scaling to meet the growing needs of the application or service.
- **Cost-Effective**: Instead of relying on a single high-performance machine, clusters use multiple less expensive commodity computers. This can significantly reduce costs while still providing the same (or even better) performance and reliability. The distributed nature of clusters also allows for more efficient use of resources, further optimizing cost.

Types of Cluster computing:

1. **High performance (HP) clusters**: HP clusters use computer clusters and supercomputers to solve advance computational problems. They are used to performing functions that need nodes to communicate as they perform their jobs. They are designed to take benefit of the parallel processing power of several nodes.

2. **Load-balancing clusters**: Incoming requests are distributed for resources among several nodes running similar programs or having similar content. This prevents any single node from receiving a disproportionate amount of task. This type of distribution is generally used in a web-hosting environment.
3. **High Availability (HA) Clusters**: HA clusters are designed to maintain redundant nodes that can act as backup systems in case any failure occurs. Consistent computing services like business activities, complicated databases, customer services like e-websites and network file distribution are provided. They are designed to give uninterrupted data availability to the customers.

Importance of Cluster Computing

1. Cluster computing gives a relatively inexpensive, unconventional to the large server or mainframe computer solutions.
2. It resolves the demand for content criticality and process services in a faster way.
3. Many organizations and IT companies are implementing cluster computing to augment their scalability, availability, processing speed and resource management at economic prices.
4. It ensures that computational power is always available.
5. It provides a single general strategy for the implementation and application of parallel high-performance systems independent of certain hardware vendors and their product decisions.

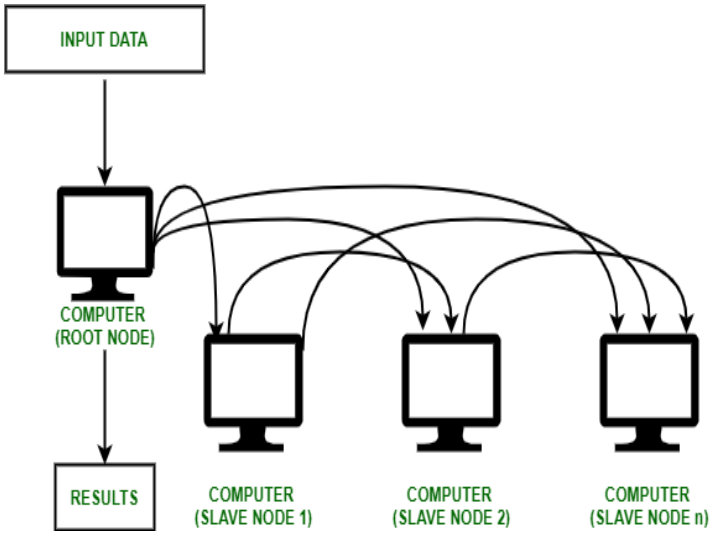

Figure 2:A Simple Cluster Computing Layout

Classification of Cluster:

1. **Open Cluster**: In an Open Cluster, each node has its own public IP address, and these nodes can be accessed directly over the internet or a web network. This makes it easier for external systems to interact with the cluster.
   Security Concerns: The open exposure of nodes to the internet increases the security risks because the cluster's individual nodes are directly reachable from external networks. This setup might lead to vulnerabilities, such as unauthorized access or attacks, unless robust security measures (e.g., firewalls, encryption, intrusion detection) are implemented.

Open clusters are generally used when there is a need for external access to individual nodes or when nodes need to communicate freely with external systems (e.g., public-facing websites or distributed applications).

2. **Closed Cluster**: In a Closed Cluster, the nodes are not directly accessible from the external network. Instead, they are hidden behind a gateway node or a proxy node. This gateway node serves as the only entry point into the cluster, which shields the nodes from direct exposure to the internet.
   Security Benefits: Since the internal nodes are not directly accessible from the external network, the security of the closed cluster is enhanced. Access to the nodes is tightly controlled and limited to the gateway node, reducing the risk of attacks and unauthorized access.
   IP Address Management: Fewer IP addresses are required in a closed cluster because only the gateway node needs a public IP, and the internal nodes can communicate using private IP addresses. This reduces the overall IP address requirement and simplifies network management.
   Closed clusters are well-suited for computational tasks where internal nodes perform tasks without needing direct interaction with external systems. For example, a private research cluster used for scientific simulations or large-scale data analysis, where internal communication is more important than external access.

Cluster Computing Architecture:

- It is designed with an array of interconnected individual computers and the computer systems operating collectively as a single standalone system.
- It is a group of workstations or computers working together as a single, integrated computing resource connected via high speed interconnects.
- A node – Either a single or a multiprocessor network having memory, input and output functions and an operating system.
- Two or more nodes are connected on a single line or every node might be connected individually through a LAN connection.

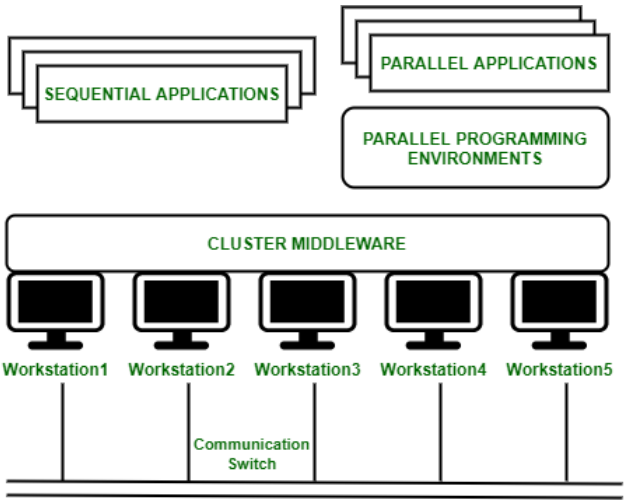

Figure 3: Cluster Computing Architecture

Components of a Cluster Computer:

- Cluster Nodes
- Cluster Operating System
- The switch or node interconnect
- Network switching hardware

The components of a cluster computer include several key elements that work together to form a high-performance, scalable, and fault-tolerant system. These components enable the cluster to function as a unified system, processing tasks efficiently. Here's a breakdown of each component:

Cluster Nodes:

- Cluster nodes are individual computers or servers that are part of the cluster. Each node has its own CPU, memory, storage, and network interface but is connected to other nodes in the cluster to share resources and tasks.
- Nodes perform the actual computational work in the cluster. They can operate independently on different tasks or work together to solve a single problem (depending on the configuration of the cluster).
- Types: Nodes can be categorized based on their role in the cluster:
    - Master Node: Manages and coordinates the tasks between the other nodes.
    - Worker Nodes: Perform computations or tasks assigned by the master node

Cluster Operating System:

- The cluster operating system is the software that manages the hardware and software resources of the cluster, as well as the communication between the nodes. It is responsible for distributing tasks, managing resources, and ensuring that the nodes work together effectively.
- The operating system handles:
  Task scheduling: Assigning tasks to the appropriate nodes.
  Resource management: Allocating CPU, memory, and storage efficiently across nodes.
  Fault tolerance: Ensuring the cluster continues to operate if a node fails.
- Examples:
  Popular cluster operating systems include:
  Linux-based (e.g., CentOS, Ubuntu)
  Specialized cluster OS like Beowulf or OpenMPI, which are designed for high-performance computing clusters.

The Switch or Node Interconnect:

- The switch or interconnect refers to the network hardware used to connect the nodes in the cluster. This allows the nodes to communicate with each other, share data, and synchronize tasks.
- Role: It is crucial for performance, as fast and reliable communication between nodes is required for effective task distribution and coordination. The interconnect can be:

  Network Switches: These are used in traditional clusters where each node is connected via Ethernet or other networking protocols.

High-speed Interconnects: In high-performance computing clusters, specialized interconnects like InfiniBand or Fibre Channel are used for faster communication with minimal latency.

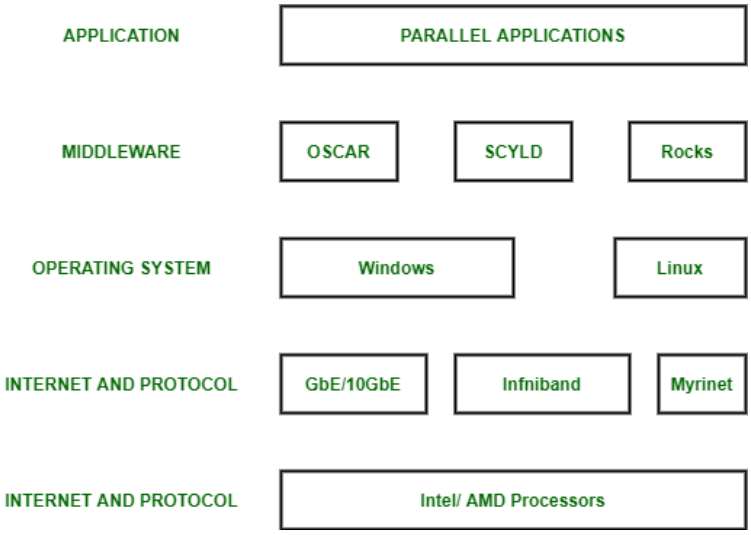

Figure 4: Cluster Components

Network Switching Hardware:

- This refers to the physical devices that manage the communication between the cluster nodes. Network switches are responsible for directing network traffic, ensuring that data is sent to the correct node and efficiently managing the data flow.
- Role: Network switches connect all the nodes in the cluster, allowing them to exchange data. The performance of the switching hardware directly affects the overall speed and efficiency of the cluster, especially in tasks that require high throughput and low latency.
  Basic Switches: Used in simpler clusters for low to medium-performance applications.
  High-performance Switches: For larger clusters with high-performance needs, specialized switches with low latency, high throughput, and redundancy features are used.

Advantages of Cluster Computing:

1. **High Performance:** The systems offer better and enhanced performance than that of mainframe computer networks.
2. **Easy to manage**: Cluster Computing is manageable and easy to implement.
3. **Scalable:** Resources can be added to the clusters accordingly.
4. **Expandability**: Computer clusters can be expanded easily by adding additional computers to the network. Cluster computing is capable of combining several additional resources or the networks to the existing computer system.
5. **Availability**: The other nodes will be active when one node gets failed and will function as a proxy for the failed node. This makes sure for enhanced availability.
6. **Flexibility:** It can be upgraded to the superior specification or additional nodes can be added.

Disadvantages of Cluster Computing:

1. **High cost:** It is not so much cost-effective due to its high hardware and its design.
2. **Problem in finding fault:** It is difficult to find which component has a fault.
3. **More space is needed:** Infrastructure may increase as more servers are needed to manage and monitor.
4. **Increased Power Consumption**: So many computers require more power to operate
5. **High Dependency on Head Node**: If Head Node goes down, entire cluster goes down.

Applications of Cluster Computing:

- Various complex computational problems can be solved.
- It can be used in the applications of aerodynamics, astrophysics and in data mining.
- Weather forecasting.
- Image Rendering.
- Various e-commerce applications.
- Earthquake Simulation.
- Petroleum reservoir simulation.

GRID COMPUTING

Grid computing is a distributed architecture that combines computer resources from different locations to achieve a common goal. It breaks down tasks into smaller subtasks, allowing concurrent processing.

What is Grid Computing?

- Grid Computing can be defined as a network of computers working together to perform a task that would rather be difficult for a single machine.
- All machines on that network work under the same protocol to act as a virtual supercomputer.
- The tasks that they work on may include analyzing huge datasets or simulating situations that require high computing power.
- Computers on the network contribute resources like processing power and storage capacity to the network.
- Grid Computing is a subset of distributed computing, where a virtual supercomputer comprises machines on a network connected by some bus, mostly Ethernet or sometimes the Internet.
- It can also be seen as a form of Parallel Computing where instead of many CPU cores on a single machine, it contains multiple cores spread across various locations.
- The concept of grid computing isn't new, but it is not yet perfected as there are no standard rules and protocols established and accepted by people.

Why is Grid Computing Important?

- **Scalability**: It allows organizations to scale their computational resources dynamically. As workloads increase, additional machines can be added to the grid, ensuring efficient processing.

- **Resource Utilization**: By pooling resources from multiple computers, grid computing maximizes resource utilization. Idle or underutilized machines contribute to tasks, reducing wastage.
- **Complex Problem Solving**: Grids handle large-scale problems that require significant computational power. Examples include climate modelling, drug discovery, and genome analysis.
- **Collaboration**: Grids facilitate collaboration across geographical boundaries. Researchers, scientists, and engineers can work together on shared projects.
- **Cost Savings**: Organizations can reuse existing hardware, saving costs while accessing excess computational resources. Additionally, cloud resources can be cost-effectively.

Working of Grid Computing

A Grid computing network mainly consists of these three types of machines

- **Control Node**: A computer, usually a server or a group of servers which administrates the whole network and keeps the account of the resources in the network pool.
- **Provider**: The computer contributes its resources to the network resource pool.
- **User**: The computer that uses the resources on the network.

➢ When a computer makes a request for resources to the control node, the control node gives the user access to the resources available on the network. When it is not in use it should ideally contribute its resources to the network. Hence a normal computer on the node can swing in between being a user or a provider based on its needs.

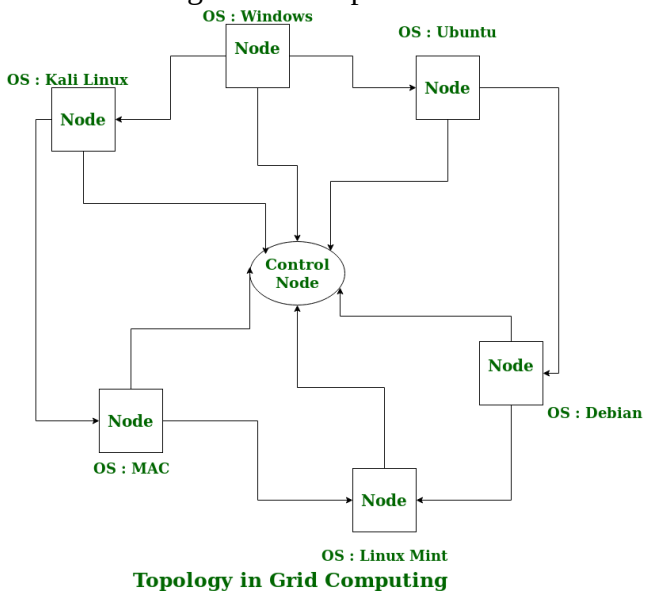

Figure 5: Topology in Grid Computing

➢ The nodes may consist of machines with similar platforms using the same OS called homogeneous networks, else machines with different platforms running on various different OSs called heterogeneous networks. This is the distinguishing part of grid computing from other distributed computing architectures.

➢ For controlling the network and its resources a software/networking protocol is used generally known as Middleware. This is responsible for administrating the network and the control nodes are merely its executors. As a grid computing system should use only

unused resources of a computer, it is the job of the control node that any provider is not overloaded with tasks.

Middleware in Grid Computing:

- For controlling the network and its resources a software/networking protocol is used generally known as Middleware.
- This is responsible for administrating the network and the control nodes are merely its executors.
- Another job of the middleware is to authorize any process that is being executed on the network. In a grid computing system, a provider gives permission to the user to run anything on its computer, hence it is a huge security threat to the network. Hence a middleware should ensure that there is no unwanted task being executed on the network.

What are the Types of Grid Computing?

Computational grid: A computational grid is a collection of high-performance processors. It enables researchers to utilize the combined computing capacity of the machines. Researchers employ computational grid computing to complete resource-intensive activities like mathematical calculations.

Scavenging grid: Similar to computational grids, CPU scavenging grids have a large number of conventional computers. Scavenging refers to the process of searching for available computing resources in a network of normal computers.

Data grid: A data grid is a grid computing network that connects multiple computers together to enable huge amounts of data storage. You can access the stored data as if it were on your local system, without worrying about where it is physically located on the grid.

Use Cases of Grid Computing:

- Genomic Research
- Drug Discovery
- Cancer Research
- Weather Forecasting
- Risk Analysis
- Computer-Aided Design (CAD)
- Animation and Visual Effects
- Collaborative Projects

Advantages of Grid Computing:

- Not Centralized: It is not centralized, as there are no servers required, except the control node which is just used for controlling and not for processing.
- Multi-OS Compatibility: Multiple heterogeneous machines i.e. machines with different Operating Systems can use a single grid computing network.
- Cost-Effective: We don’t need to set up huge rooms filled with a lot of computers and servers and other hardware.
- Grid Computing provide high resources utilization.
- Grid Computing allow parallel processing of task.

- Grid Computing is designed to be scalable.

Disadvantages of Grid Computing:

- Resource Sharing Difficulties: Licensing across many servers may make it prohibitive for some applications. Many groups are reluctant with sharing resources.
- High Dependency on Control Node: Trouble in the control node can come to halt in the whole network.
- The software of the grid is still in the evolution stage.
- Grid computing introduce Complexity.
- Limited Flexibility
- Security Risks

Applications of Grid Computing:

- Modeling financial risks, seismic activity, weather patterns, or human genome
- Reducing the cost of resource-intensive engineering applications
- Analyzing massive amounts of data generated from scientific experiments
- Supporting pervasive computing and intelligent devices
- Enabling scientific research collaboration and e-Science
- Providing commercial applications and services

Difference between Grid and Cluster Computing:

Cluster Computing	Grid Computing
• Homogeneity of nodes is necessary	• Homogeneity of nodes isn't necessary
• Computers in a cluster are dedicated to the same work and perform no other task.	• Computers in a grid contribute their unused processing resources to the grid computing network.
• Computers are located close to each other.	• Computers may be located at a huge distance from one another.
• Computers are connected by a high speed local area network bus.	• Computers are connected using a low speed bus or the internet.
• Computers are connected in a centralized network topology.	• Computers are connected in a distributed or de-centralized network topology.
• Scheduling is controlled by a central server.	• It may have servers, but mostly each node behaves independently.
• System has a centralized resource manager. (Centralized Resource Management)	• Every node manages resources on its own. (Distributed Resource Management)
• Whole system functions as a single system.	• Every node is autonomous, and anyone can opt out anytime.

CLOUD COMPUTING

Cloud

- A **cloud** refers to a distinct IT environment that is designed for the purpose of remotely provisioning scalable and measured IT resources. The term originated as a metaphor or the Internet which is, in essence, a network of networks providing remote access to a set of decentralized IT resources.
- Prior to cloud computing becoming its own formalized IT industry segment, the symbol of a cloud was commonly used to represent the Internet in a variety of specifications and mainstream documentation of Web-based architectures.

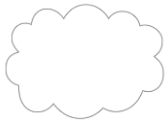

Figure 6: The symbol used to denote the boundary of a cloud environment.

- It is important to distinguish the term "cloud" and the cloud symbol from the Internet. As a specific environment used to remotely provision IT resources, a cloud has a finite boundary.
- There are many individual clouds that are accessible via the Internet. Whereas the Internet provides open access to many Web-based IT resources, a cloud is typically privately owned and offers access to IT resources that is metered.
- Much of the Internet is dedicated to the access of content-based IT resources published via the World Wide Web. IT resources provided by cloud environments, on the other hand, are dedicated to supplying back-end processing capabilities and user-based access to these capabilities.
- Another key distinction is that it is not necessary for clouds to be Web-based even if they are commonly based on Internet protocols and technologies. Protocols refer to standards and methods that allow computers to communicate with each other in a pre-defined and structured manner.
- A cloud can be based on the use of any protocols that allow for the remote access to its IT resources.

IT Resource

An IT resource is a physical or virtual IT-related artifact that can be either software based, such as a virtual server or a custom software program, or hardware-based, such as a physical server or a network device.

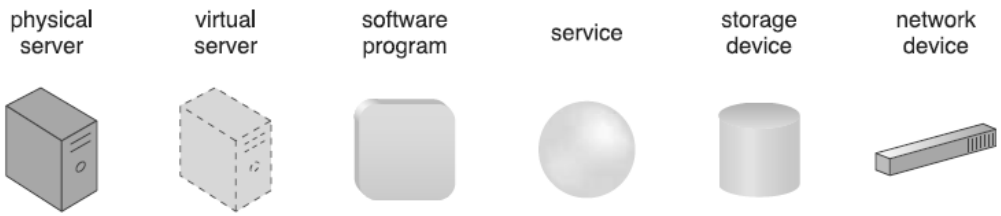

Figure 7: Examples of common IT resources and their corresponding symbols.

Cloud Computing

What is Cloud Computing?

"Cloud computing is the delivery of computing services - including servers, storage, databases, networking, software, analytics, and intelligence - over the Internet."

- **Cloud Computing** means storing and accessing the data and programs on remote servers that are hosted on the internet instead of the computer's hard drive or local server. Cloud computing is also referred to as Internet-based computing, it is a technology where the resource is provided as a service through the Internet to the user. The data that is stored can be files, images, documents, or any other storable document.
- You typically pay only for cloud services you use, helping you lower your operating costs, run your infrastructure more efficiently, and scale as your business needs change.

The following are some of the Operations that can be performed with Cloud Computing

- Storage, backup, and recovery of data
- Delivery of software on demand
- Development of new applications and services
- Streaming videos and audio

How Cloud Computing Works?

Cloud computing helps users in easily accessing computing resources like storage, and processing over internet rather than local hardwares. Here we discussing how it works in nutshell:

- Infrastructure: Cloud computing depends on remote network servers hosted on internet for store, manage, and process the data.
- On-Demand Access: Users can access cloud services and resources based on-demand they can scale up or down the without having to invest for physical hardware.
- Types of Services: Cloud computing offers various benefits such as cost saving, scalability, reliability and accessibility it reduces capital expenditures, improves efficiency.

Origins of Cloud Computing

- Mainframe computing in the 1950s and the internet explosion in the 1990s came together to give rise to cloud computing. Since businesses like Amazon, Google, and Salesforce started providing web-based services in the early 2000s.
- The term "cloud computing" has gained popularity. Scalability, adaptability, and cost-effectiveness are to be facilitated by the concept's on-demand internet-based access to computational resources.
- These days, cloud computing is pervasive, driving a wide range of services across markets and transforming the processing, storage, and retrieval of data

Roles in Cloud Computing:

Cloud Infrastructure Providers – The ones who own and manage the network infrastructure and resources including hardware and system software.

- Own, maintain, and manage the underlying cloud infrastructure, including data centers, networking, storage, and computing power.
- Provide the foundational resources that cloud services operate on.
- Examples: Amazon Web Services (AWS), Microsoft Azure, Google Cloud Platform (GCP), IBM Cloud

Cloud Service Providers – The ones who offer cloud services such as on-demand computing, utility computing, data processing, software services, storage, development platforms etc.

- Offer various cloud-based services like IaaS (Infrastructure as a Service), PaaS (Platform as a Service), and SaaS (Software as a Service).
- Manage cloud resources, software applications, and services that consumers use on demand.
- Examples: AWS, Azure, Google Cloud, Salesforce (SaaS), Dropbox (SaaS)

Cloud Consumers – The ones who use the cloud services in order for their work.

- Organizations, businesses, or individuals that use cloud services for storage, computing, software applications, and other resources.
- Can be startups, enterprises, educational institutions, or individual developers utilizing cloud-based applications.
- Examples: Companies using Google Workspace, developers using AWS EC2, businesses running ERP software on the cloud

Cloud Auditor – The ones who conduct independent assessment of cloud services and manage the security, performance audits.

- Conducts independent assessments of cloud services to evaluate security, performance, compliance, and reliability.
- Ensures that cloud service providers meet industry standards and regulatory requirements.
- Examples: External security firms, regulatory bodies, third-party audit services like CSA STAR (Cloud Security Alliance)

Cloud Broker – The ones who negotiate relationships between Cloud Providers and Cloud Consumers. They play the advisory role especially for consumers who have a hybrid mix of resources from multiple providers.

- Acts as an intermediary between Cloud Providers and Cloud Consumers, helping businesses select, manage, and integrate cloud services.
- Especially useful for organizations using multi-cloud or hybrid cloud solutions.
- May provide additional services like cost optimization, integration, and governance.
- Examples: Cloud resellers, consulting firms like Accenture, IBM Cloud Brokerage, RightScale (Flexera)

Cloud Carrier - The intermediary ones who provide connectivity and transport of cloud services from Cloud Providers to Cloud Consumers. Most ISPs have taken the role of cloud carriers as they provide the requisite bandwidth needed to connect consumers with providers as well as capabilities that support the connectivity.

- Provides connectivity and transport of cloud services from Cloud Providers to Cloud Consumers.
- Ensures secure and reliable data transmission through high-speed networks, fiber optics, and ISPs.
- Examples: Internet Service Providers (ISPs), telecommunications companies like AT&T, Verizon, and fiber optic networks

CLOUD DELIVERY MODELS

Cloud delivery models define how cloud services are provided and consumed. The three primary Cloud Delivery Models are:

1. Infrastructure as a Service (IaaS)
2. Platform as a Service (PaaS)
3. Software as a Service (SaaS)
4. UnifiedCommunications-as-a-service (UCaaS)

1. Infrastructure as a Service (IaaS):

- Infrastructure-as-a-service (IaaS) is one of the most pliable cloud computing service models which presents the required infrastructure and all the computing resources to users in an entirely remote environment.
- IaaS is a highly expandable and lucrative service as outsourcing data centers, cloud components and servers annihilate the necessity for establishing an in-house infrastructure.
- This service model can aid you to upscale and downscale your infra service on-demand.
- Infrastructure-as-a-Service (IaaS) is a cloud computing model that provides virtualized computing resources such as servers, storage, networking, and data centers over the internet. Instead of investing in physical infrastructure, businesses can rent resources on demand, making it a cost-effective and scalable solution.

Key Features of IaaS:

- Highly Scalable – Easily scale resources up or down based on demand.
- Pay-as-You-Go Pricing – Only pay for what you use, reducing costs.
- Remote Accessibility – Manage infrastructure from anywhere via the cloud.
- No Hardware Maintenance – The cloud provider handles hardware, networking, and security.

Benefits of IaaS:

- Eliminates the Need for On-Premises Infrastructure – No upfront investment in data centers.
- Cost-Efficient – Saves costs on hardware, power, cooling, and maintenance.
- Faster Deployment – Instant provisioning of servers and storage.
- Disaster Recovery & Backup – Ensures data protection and business continuity.

Examples of IaaS Providers:

- Amazon Web Services (AWS) – EC2, S3
- Microsoft Azure – Virtual Machines, Blob Storage

- Google Cloud Platform (GCP) – Compute Engine
- IBM Cloud, Oracle Cloud, DigitalOcean

IaaS is ideal for businesses, developers, and enterprises needing a flexible, on-demand infrastructure without the overhead of managing physical hardware.

2. Platform as a Service (PaaS):

- In Platform-as-a-Service (PaaS) model, the vendor assists companies with middleware, database management systems, OS, web servers and development tools.
- All of these encapsulate a remote environment where users can build, compile and run their software products without requiring any in-house hardware/software.
- Platform-as-a-Service (PaaS) is a cloud computing model that provides a complete development and deployment environment in the cloud. It includes middleware, databases, operating systems, development tools, and web servers, allowing developers to build, test, and deploy applications without managing underlying hardware or infrastructure.

Key Features of PaaS:

- Rapid Product Development – Speeds up application development and deployment.
- Web-Based User Interface – Accessible from anywhere via a browser.
- Multi-Tenant Architecture – Supports multiple users and applications on the same platform.
- Pre-Coded App Components – Reduces coding time with built-in templates and APIs.
- Third-Party Integrations – Seamless integration with external services and databases.

Benefits of PaaS:

- Reduces Development Time – Developers focus on coding rather than infrastructure setup.
- Cost-Effective – No need to invest in hardware, software, or maintenance.
- Supports Remote & Mobile Workforce – Developers can collaborate from anywhere.
- Automatic Scaling & Updates – Easily scale applications as per demand.

Examples of PaaS Providers:

- Google App Engine
- Microsoft Azure App Services
- AWS Elastic Beanstalk
- IBM Cloud Foundry
- Heroku

PaaS is ideal for startups, developers, and businesses looking for a streamlined environment to build and deploy applications quickly without worrying about infrastructure management.

3. Software as a Service (SaaS)

- Software-as-a-service (SaaS) presents a comprehensive product that is run and administered by a cloud service provider/vendor.
- SaaS is a service in the cloud, extending an entire software suite in pay-per-use form.
- It is made accessible to the consumers via a ubiquitous network, i. e. the internet.

- SaaS is a cloud computing model in which a cloud service provider hosts applications and makes them available to users over the internet. Instead of purchasing and installing software on individual computers, users can access it via a web browser on a subscription basis.
- SaaS applications are managed entirely by the provider, including updates, security, and infrastructure maintenance, reducing the burden on users.

How SaaS Works?

- The software is hosted on cloud servers rather than installed on users' local devices.
- Users access the software via an internet connection using a web browser or mobile app.
- The SaaS provider handles all maintenance, security updates, and scalability.
- Users typically pay a subscription fee based on usage, features, or number of users.

Key Features of SaaS

- On-Demand Access – No need for installation; just log in and use the service.
- Platform Independence – Accessible on different operating systems (Windows, macOS, Linux) via a browser.
- Multi-Tenancy Architecture – A single software instance serves multiple customers securely.
- Single Sign-On (SSO) – Users can access multiple services with one login.
- Scalability & Automatic Updates – SaaS providers handle upgrades, ensuring users always have the latest version.
- Pay-as-You-Go Pricing – Subscription-based or usage-based pricing reduces upfront costs.
- Remote Collaboration – Enables teams to collaborate globally with real-time access to shared applications.

Benefits of SaaS

- Cost-Effective – No need for hardware or software installation; reduces IT expenses.
- Ease of Use – Intuitive, user-friendly interfaces with quick deployment.
- Accessibility – Users can access SaaS applications from anywhere with an internet connection.
- Security & Compliance – SaaS providers ensure high-level security, encryption, and compliance with regulations.
- Automatic Backups & Recovery – No risk of data loss due to built-in backup systems.

Examples of SaaS Applications

- Google Workspace – Google Docs, Sheets, Gmail, and Drive for productivity.
- Microsoft Office 365 – Cloud-based Word, Excel, PowerPoint, and Outlook.
- Salesforce – Leading CRM platform for customer management.
- Dropbox & Google Drive – Cloud storage services.
- Zoom & Microsoft Teams – Video conferencing and collaboration tools.
- Netflix & Spotify – Streaming services that use SaaS infrastructure.

4. UnifiedCommunications-as-a-service (UCaaS):

- UnifiedCommunications-as-a-service (UCaaS) 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.
- UCaaS platform not only empowers the mobile workforce to connect and collaborate over phone/video calls but also enables them to share files, documents or resources via the cloud infrastructure for streamlined workflows.
- Unified Communications-as-a-Service (UCaaS) is a cloud-based communication model that integrates multiple communication tools such as voice calls, video conferencing, instant messaging, file sharing, and collaboration tools into a single platform. It ensures seamless remote communication and collaboration for businesses and teams worldwide.

Key Features of UCaaS:

- Cloud-Based Communication – Voice, video, and messaging in one platform.
- Remote Workforce Enablement – Supports work-from-anywhere models.
- File & Resource Sharing – Enables document collaboration via the cloud.
- Security & Reliability – Encrypted communication for data protection.
- Scalability – Easily scales as per business needs.

Benefits of UCaaS:

- Enhanced Collaboration – Connect teams effortlessly across different locations.
- Cost-Effective – Reduces expenses on traditional phone systems and hardware.
- Increased Productivity – Streamlined workflows and efficient communication.
- Flexibility & Mobility – Ideal for hybrid and remote work environments.

Examples of UCaaS Providers:

- Microsoft Teams
- Zoom Phone
- Cisco Webex
- RingCentral
- Google Meet

UCaaS is ideal for businesses, enterprises, and remote teams that need seamless, secure, and scalable communication solutions to stay connected and productive.

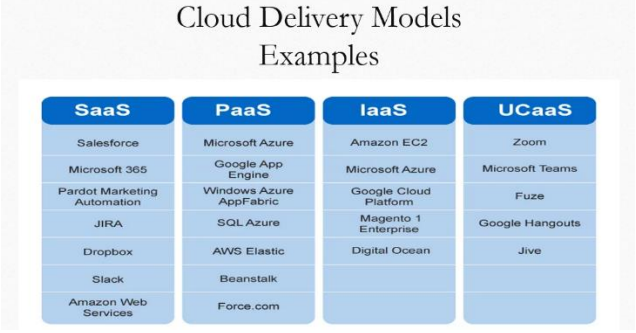

Figure 8: Cloud Delivery Models Examples

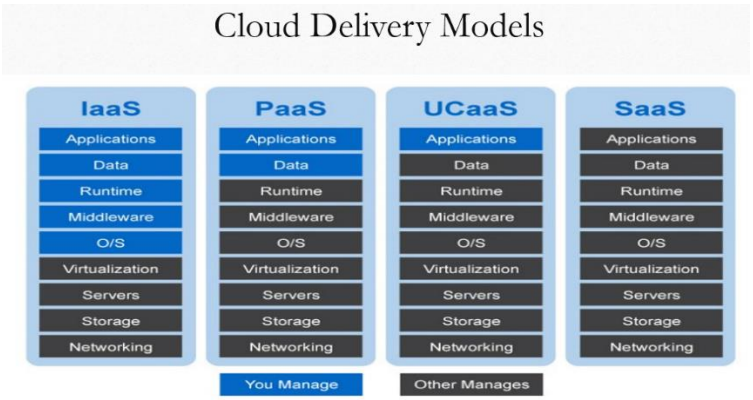

Figure 9: Cloud Delivery Models

The Cloud Delivery Models define how cloud services are provided and managed:

- IaaS (Infrastructure-as-a-Service) – Provides virtualized computing resources like servers, storage, and networking. Users control applications, data, and OS while the provider manages infrastructure. (Example: AWS EC2, Google Compute Engine)
- PaaS (Platform-as-a-Service) – Offers a platform with OS, runtime, and development tools, allowing developers to build and deploy applications without managing infrastructure. (Example: Google App Engine, Microsoft Azure App Services)
- UCaaS (Unified Communications-as-a-Service) – Delivers communication tools like messaging, video conferencing, and file sharing via the cloud, enabling seamless collaboration. (Example: Zoom, Microsoft Teams, Cisco WebEx)
- SaaS (Software-as-a-Service) – Fully managed software applications accessible via the internet, eliminating the need for installation or maintenance. (Example: Google Workspace, Dropbox, Salesforce)

CLOUD DEPLOYMENT MODELS

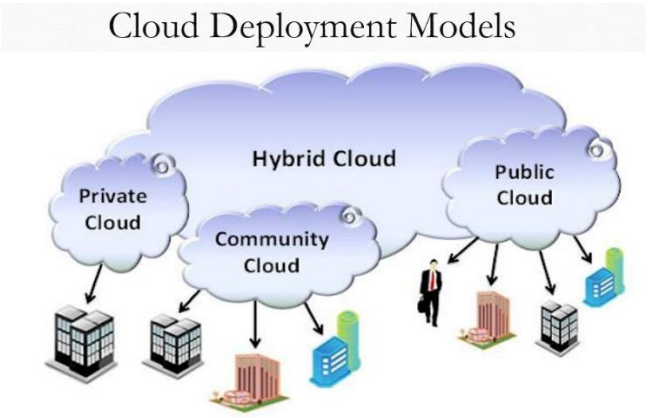

Figure 10: Cloud Deployment Models

In cloud computing, we have access to a shared pool of computer resources (servers, storage, programs, and so on) in the cloud. You simply need to request additional resources when you require them. Getting resources up and running quickly is a breeze thanks to the clouds. It is possible to release resources that are no longer necessary. This method allows you to just pay for what you use. Your cloud provider is in charge of all upkeep.

What is a Cloud Deployment Model?

Cloud Deployment Model functions as a virtual computing environment with a deployment architecture that varies depending on the amount of data you want to store and who has access to the infrastructure.

Types of Cloud Computing Deployment Models

The cloud deployment model identifies the specific type of cloud environment based on ownership, scale, and access, as well as the cloud's nature and purpose. The location of the servers you're utilizing and who controls them are defined by a cloud deployment model. It specifies how your cloud infrastructure will look, what you can change, and whether you will be given services or will have to create everything yourself. Relationships between the infrastructure and your users are also defined by cloud deployment types. Different types of cloud computing deployment models are described below.

- Public Cloud
- Private Cloud
- Hybrid Cloud
- Community Cloud

Public Cloud

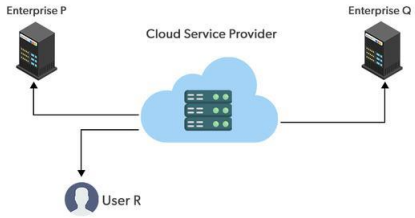

Figure 11: Public Cloud

- The public cloud makes it possible for anybody to access systems and services.
- The public cloud may be less secure as it is open to everyone.
- The public cloud is one in which cloud infrastructure services are provided over the internet to the general people or major industry groups.
- The infrastructure in this cloud model is owned by the entity that delivers the cloud services, not by the consumer. It is a type of cloud hosting that allows customers and users to easily access systems and services.
- This form of cloud computing is an excellent example of cloud hosting, in which service providers supply services to a variety of customers. In this arrangement, storage backup and retrieval services are given for free, as a subscription, or on a per-user basis. For example, Google App Engine etc.

Advantages of the Public Cloud Model

- Minimal Investment: Because it is a pay-per-use service, there is no substantial upfront fee, making it excellent for enterprises that require immediate access to resources.

- No setup cost: The entire infrastructure is fully subsidized by the cloud service providers, thus there is no need to set up any hardware.
- Infrastructure Management is not required: Using the public cloud does not necessitate infrastructure management.
- No maintenance: The maintenance work is done by the service provider (not users).
- Dynamic Scalability: To fulfill your company's needs, on-demand resources are accessible.

Disadvantages of the Public Cloud Model

Less secure: Public cloud is less secure as resources are public so there is no guarantee of high-level security.

Low customization: It is accessed by many public so it can't be customized according to personal requirements.

Private Cloud

- The private cloud deployment model is the exact opposite of the public cloud deployment model. It's a one-on-one environment for a single user (customer).
- There is no need to share your hardware with anyone else. The distinction between private and public clouds is in how you handle all of the hardware.
- It is also called the "internal cloud" & it refers to the ability to access systems and services within a given border or organization.
- The cloud platform is implemented in a cloud-based secure environment that is protected by powerful firewalls and under the supervision of an organization's IT department. The private cloud gives greater flexibility of control over cloud resources.

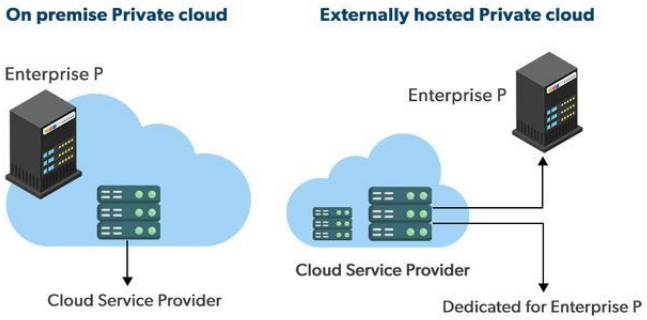

Figure 12: Private Cloud

Advantages of the Private Cloud Model

- Better Control: You are the sole owner of the property. You gain complete command over service integration, IT operations, policies, and user behavior.
- Data Security and Privacy: It's suitable for storing corporate information to which only authorized staff have access. By segmenting resources within the same infrastructure, improved access and security can be achieved.
- Supports Legacy Systems: This approach is designed to work with legacy systems that are unable to access the public cloud.

- Customization: Unlike a public cloud deployment, a private cloud allows a company to tailor its solution to meet its specific needs.

Disadvantages of the Private Cloud Model

- Less scalable: Private clouds are scaled within a certain range as there is less number of clients.
- Costly: Private clouds are more costly as they provide personalized facilities.

Hybrid Cloud

- By bridging the public and private worlds with a layer of proprietary software, hybrid cloud computing gives the best of both worlds.
- With a hybrid solution, you may host the app in a safe environment while taking advantage of the public cloud's cost savings.
- Organizations can move data and applications between different clouds using a combination of two or more cloud deployment methods, depending on their needs.

Advantages of the Hybrid Cloud Model

- Flexibility and control: Businesses with more flexibility can design personalized solutions that meet their particular needs.
- Cost: Because public clouds provide scalability, you'll only be responsible for paying for the extra capacity if you require it.
- Security: Because data is properly separated, the chances of data theft by attackers are considerably reduced.

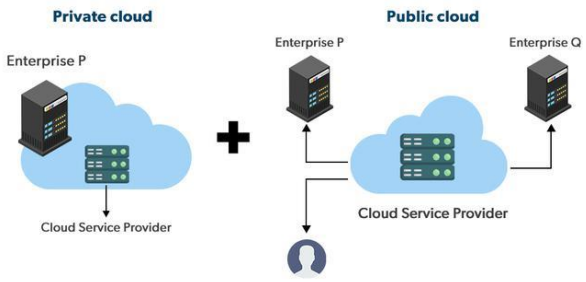

Figure 13: Hybrid Cloud

Disadvantages of the Hybrid Cloud Model

- Difficult to manage: Hybrid clouds are difficult to manage as it is a combination of both public and private cloud. So, it is complex.
- Slow data transmission: Data transmission in the hybrid cloud takes place through the public cloud so latency occurs.

Community Cloud

- It allows systems and services to be accessible by a group of organizations. It is a distributed system that is created by integrating the services of different clouds to address the specific needs of a community, industry, or business.

- The infrastructure of the community could be shared between the organization which has shared concerns or tasks. It is generally managed by a third party or by the combination of one or more organizations in the community.

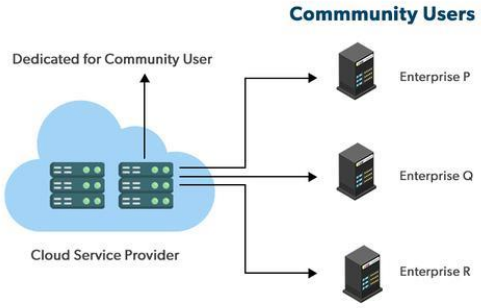

Figure 14: Community Cloud

Advantages of the Community Cloud Model

- Cost Effective: It is cost-effective because the cloud is shared by multiple organizations or communities.
- Security: Community cloud provides better security.
- Shared resources: It allows you to share resources, infrastructure, etc. with multiple organizations.
- Collaboration and data sharing: It is suitable for both collaboration and data sharing.

Disadvantages of the Community Cloud Model

- Limited Scalability: Community cloud is relatively less scalable as many organizations share the same resources according to their collaborative interests.
- Rigid in customization: As the data and resources are shared among different organizations according to their mutual interests if an organization wants some changes according to their needs they cannot do so because it will have an impact on other organizations.

What is the Right Choice for Cloud Deployment Model?

As of now, no such approach fits picking a cloud deployment model. We will always consider the best cloud deployment model as per our requirements. Here are some factors which should be considered before choosing the best deployment model.

- Cost: Cost is an important factor for the cloud deployment model as it tells how much amount you want to pay for these things.
- Scalability: Scalability tells about the current activity status and how much we can scale it.
- Easy to use: It tells how much your resources are trained and how easily can you manage these models.
- Compliance: Compliance tells about the laws and regulations which impact the implementation of the model.
- Privacy: Privacy tells about what data you gather for the model.

- Each model has some advantages and some disadvantages, and the selection of the best is only done on the basis of your requirement. If your requirement changes, you can switch to any other model.

Overall Analysis of Cloud Deployment Models

The overall Analysis of these models with respect to different factors is described below:

Factors	Public Cloud	Private Cloud	Community Cloud	Hybrid Cloud
Initial Setup	Easy	Complex, requires a professional team to setup	Complex, requires a professional team to setup	Complex, requires a professional team to setup
Scalability and Flexibility	High	High	Fixed	High
Cost-Comparison	Cost-Effective	Costly	Distributed cost among members	Between public and private cloud
Reliability	Low	Low	High	High
Data Security	Low	High	High	High
Data Privacy	Low	High	High	High

DESIRED FEATURES OF A CLOUD

- **Self-Service** – Users can access and manage cloud resources on-demand without human intervention.
- **Per Usage Meter and Billing** – Cloud services are charged based on actual consumption, ensuring cost efficiency.
- **Elasticity** – Resources can be scaled up or down dynamically based on demand.
- **Low Cost** – Eliminates the need for heavy infrastructure investments, reducing operational expenses.
- **Customization** – Offers flexibility to tailor services based on business requirements.

CLOUD COMPUTING ADVANTAGES

- **Backup-Restore Data** – Cloud services provide automated data backup and restoration capabilities, ensuring data protection and recovery in case of loss.
- **Virtually Unlimited Storage** – Cloud computing offers scalable storage solutions, eliminating limitations of physical storage.
- **Improved Collaboration** – Teams can work together remotely, sharing documents and data in real time.
- **Excellent Accessibility** – Users can access cloud-based applications and data from anywhere with an internet connection.
- **Pay Per Use** – Cloud services follow a pay-as-you-go model, meaning users only pay for the resources they consume.
- **Low Maintenance Cost** – Cloud providers handle maintenance, reducing the need for costly infrastructure and IT support.

- **Mobility** – Cloud computing allows users to access data and applications from multiple devices, ensuring flexibility.
- **Data Security** – Cloud providers implement high-level security measures to protect sensitive information.

CLOUD COMPUTING DISADVANTAGES

- **Heavy Reliance on Internet Connectivity** – Since cloud services are accessed online, a stable and high-speed internet connection is essential. Any disruption in connectivity can affect productivity and access to resources.
- **Vendor Lock-in** – Migrating data, applications, or services from one cloud provider to another can be complex and costly due to differences in platforms, compatibility issues, and contractual limitations.
- **Limited Control** – Organizations using cloud services have limited control over the underlying infrastructure, as it is managed by the service provider. This can lead to restrictions in customization and system performance optimization.
- **Security Concerns** – Despite strong security measures, cloud services can still be vulnerable to cyber threats, data breaches, and unauthorized access. Companies handling sensitive information must implement additional security protocols to mitigate risks.

APPLICATIONS OF CLOUD COMPUTING

Cloud computing is widely used across various industries due to its flexibility, scalability, and cost-effectiveness. Some of its key applications include:

- **Storage** – Cloud storage services (e.g., Google Drive, Dropbox, OneDrive) allow users to store, access, and share data from anywhere.
- **Backup & Recovery** – Cloud platforms offer reliable backup and disaster recovery solutions, ensuring data is safe even in case of hardware failure or cyberattacks.
- **Big Data** – Cloud computing enables organizations to process and analyze vast amounts of data efficiently, supporting data-driven decision-making in industries like finance, healthcare, and marketing.
- **Development & Testing** – Cloud environments provide virtualized development and testing platforms, reducing the need for expensive infrastructure and enabling faster deployment of applications.
- **E-Commerce** – Online businesses rely on cloud computing for hosting websites, managing customer data, processing payments, and ensuring seamless shopping experiences.
- **Education** – Cloud-based learning platforms (e.g., Google Classroom, Coursera, edX) enable remote learning, online assessments, and collaboration among students and teachers.
- **E-Governance** – Governments use cloud computing for digital services, citizen engagement, public data management, and efficient administrative operations.
- **Medical Applications** – Cloud solutions help in telemedicine, electronic health records (EHRs), and remote patient monitoring, improving healthcare accessibility and efficiency.
- **Entertainment Applications** – Streaming platforms (e.g., Netflix, Spotify, YouTube) use cloud computing to deliver media content efficiently to users worldwide.

- **Military Applications** – Defense organizations use cloud computing for secure communication, intelligence analysis, remote surveillance, and battlefield management.

CLOUD COMPUTING CHALLENGES

Despite its advantages, cloud computing comes with several challenges:

- **Data Privacy and Security** – Cloud environments are vulnerable to cyber threats, unauthorized access, and data breaches, making security a primary concern.
- **Cost and Resource Management** – While cloud services reduce hardware costs, managing cloud resources efficiently can be expensive and complex.
- **Difficult to Manage Multi-Clouds** – Organizations using multiple cloud providers face challenges in integration, compatibility, and monitoring across different platforms.
- **High Dependence on Network** – Cloud services require a stable internet connection, and downtime or network failures can disrupt operations.
- **Lack of Knowledge and Expertise** – Many businesses struggle with cloud adoption due to a shortage of skilled professionals who can manage and optimize cloud environments effectively.

RISKS OF CLOUD COMPUTING

- **Unauthorized Access to Data:**

Your data is in the hands of the cloud service provider, he can do whatever he likes with it (Example – Facebook users' data was shared with some other organizations)

- **Security Risks at the Vendor:**

Cloud providers may face cyber threats, insider attacks, or poor security implementations, leading to data exposure.

- **Compliance and Legal Risks:**

If a company outsources the processing or storage of data that it is required to protect, then it is relying on a cloud service provider to maintain their compliance.

If the company does not have adequate legal protections, then it may be liable when there is a data breach at the cloud service that exposes the company's data.

In other words, unless you are protected in writing, then a cloud service provider might not be liable for a breach of your data on its systems.

- **Lack of Control**

when you use a cloud service provider, the vendor is in control. You have no guarantee that the features you use today will be provided for the same price tomorrow. The vendor can double its price, and if your clients are depending on that service, then you might be forced to pay.

Also, who controls access to your data in a cloud service? What happens if you are not able to make payment?

If you get behind on your bill, then you may be surprised to find your data is held hostage by the vendor.

- **Availability**

When you rely on a cloud service, then you are putting the availability of your business in the hands of two services: the cloud vendor and your ISP.