Module 1: Fundamental Cloud Computing (7 Hours)

Traditional computing- Limitations. Overview of Computing Paradigms-Grid Computing, Cluster Computing, Distributed Computing, Utility Computing, Cloud Computing. NIST reference Model-Basic terminology and concepts. Cloud characteristics, benefits and challenges, Roles and Boundaries. Cloud delivery (service) models-Infrastructure-as-a-Service (IaaS), Platform-as-a-Service(PaaS),Software-as-a-Service (SaaS), XaaS (Anything-as-a-service)-Cloud deployment models- Public cloud, Community cloud, Private cloud, Hybrid cloud

Cloud computing refers to data and applications stored run on a cloud rather than in your local equipment. This can be accessed through internet. Cloud is a giant datacenter which consists of specifically a number of servers which are networked together to perform various functions like running applications, storing data, data processing, web hosting etc. Companies that own these servers are called cloud providers and they are to sell their computers for services

Limitations of Traditional computing

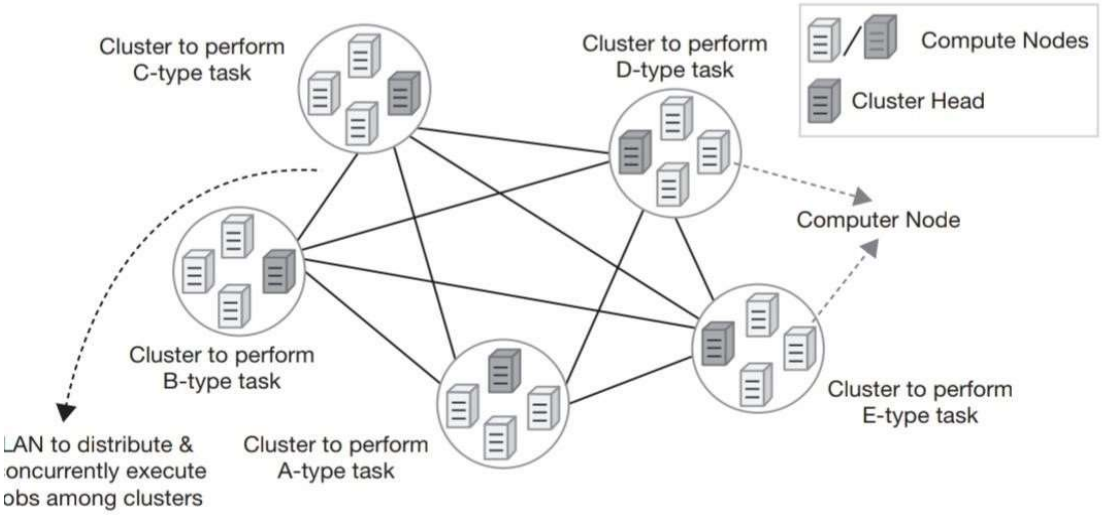
- Administrative overhead
- High maintenance cost
- Time and Space restrictions
- Limited Scalability
- Remote access to system is not available

 # Difference between Traditional computing and Cloud Computing?

Traditional Computing	Cloud Computing
It refers to delivery of different services on local server.	It refers to delivery of different services such as data and programs through internet on different servers.
It takes place on physical hard drives and website servers.	It takes place on third-party servers that is hosted by third-party hosting companies.
User can access data only on system in which data is stored.	It is easy to access data anywhere at any time by user.
It does not require any internet connection to access data or information.	It requires fast, reliable and stable internet connection to access information anywhere at any time.
Software in purchased individually for every user and requires to be updated periodically.	Software is offered as an on-demand service (SaaS) that can be accessed through subscription service

Cluster Computing

- Computing clusters are made of multiple nodes (computers) connected via network which perform similar tasks.
- execution of a task can be faster as it can be distributed and executed in parallel across multiple machines inside a cluster
- All the nodes of a cluster together give impression of a single system.
- *Each node in a simple cluster is set to perform same task or same set of tasks*
- In each cluster, one computer is assigned the job of controlling the cluster. That particular computer (or node) is known as *cluster head*.
- The head's responsibility in such a simple cluster is to divide and distribute jobs among different nodes in that cluster when matching computing tasks appear.
- In an actual *cluster computing* system, multiple clusters (built to perform different type of functionalities) are linked together through a LAN
- when a particular job appears, the cluster head divides and distributes it among matching clusters (designated for those jobs) for faster execution
- *Computers are clustered together to achieve reliability, greater processing power and produce supercomputer like performance*
- In this computing model, a set of computers were reserved to handle specific type of task to make the system more reliable. If any node fails, other nodes in the cluster can handle the load
- *Cluster computing introduced the concept of resource pooling. The pools were made of homogeneous computing systems*



- Performance of such system was largely dependent on the efficiency and accessibility of cluster head. Existence of cluster head raises possibility for single point of failure too.

An advanced computing model called grid computing model was required to eliminate the cluster head problem of cluster computing model

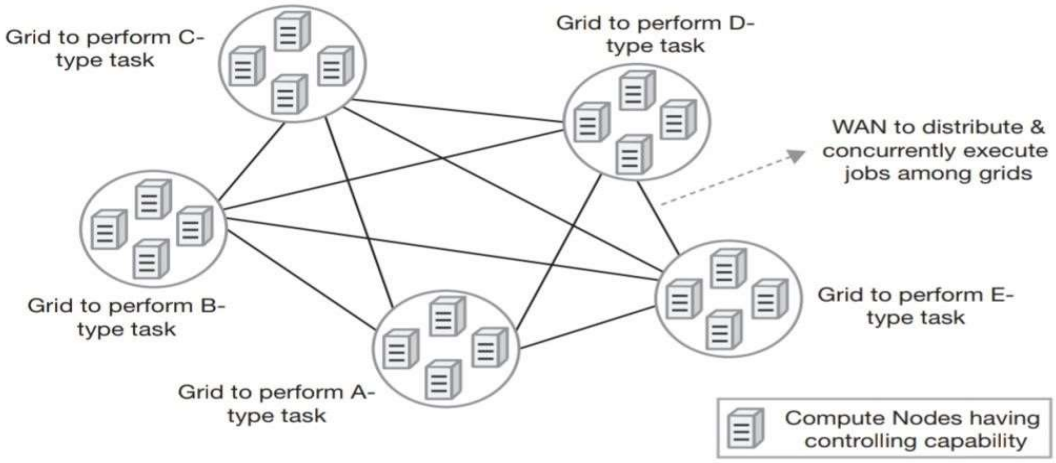
Grid Computing

- In the process of finding a solution to this problem, technologists came up with an idea where each node belonging to a cluster would have same priority. It was required that all of them could perform similar functions and no particular node had to be assigned the role of 'head' among them. This new architecture is called a *Grid*.
- Grid computing concept introduced the idea of decentralization of control in distributed computing environment.
- Another important feature introduced by grid computing is that the computing environment could now be built with heterogeneous computing systems, that is, systems with diverse hardware configurations.
- The other major challenge before setting up a large *distributed computing* environment is establishing cooperation among systems of different administrative domains.

Computing grid introduced distributed computing environment, made up of heterogeneous systems which could be located at separate administrative domains

Characteristics

- Large scale: Grid concept promises to deal with computing resources going up to millions.
- Geographical distribution: Computing resources could be located at distant places.
- Heterogeneity: Computing grid could accommodate resources having different hardware characteristics and using various types of software.
- Resource co-ordination: Resources in a grid could coordinate among themselves to generate aggregated computing capabilities.
- Pervasive access: Resource failure could be handled by granting access to other available resources.
- Unlimited resource addition (scaling): Being a distributed computing model, it allows easy growth of system capacity by adding more resources into an existing system.



Utility Computing

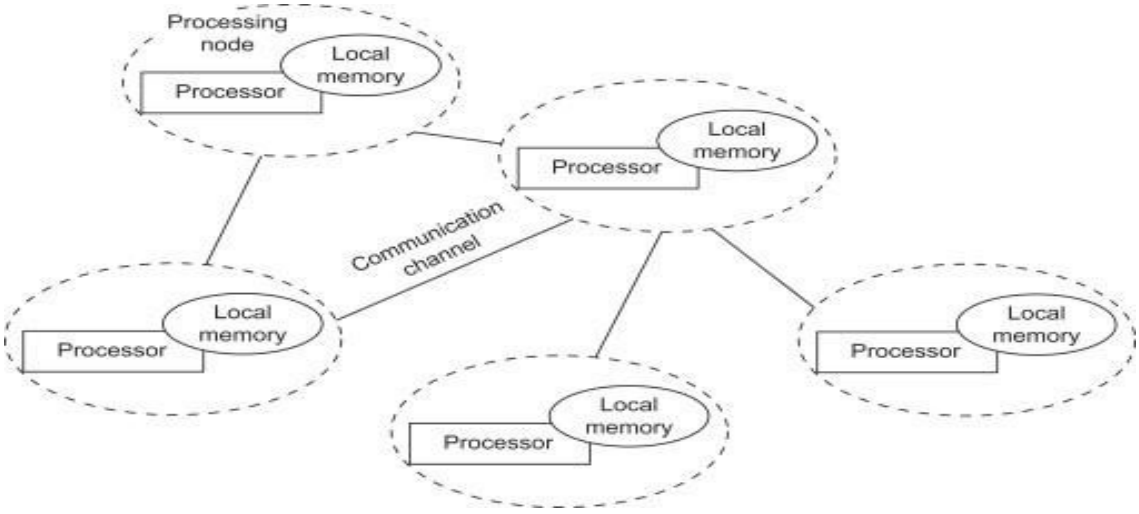
- In utility computing a service provider makes computing resources and infrastructure management available to the customer as needed & charges them for specific wage rather than flat rate.
- Utility is the packaging of system resources such as computations, storage as a metered service.
- Focused on on-demand computing like computing can be delivered as a utility service much like electricity.
- Utility Computing is the packaging and delivery of computing resources, similar to traditional public utilities like electricity, water, or telephone. The model follows pay-per-use mode of payment and on-demand service facility.
- This sort of computing enabled small business owners to afford high-performance computing facilities, which with their limited budget they could have never dreamed of using.
- One important facilitator behind utility computing idea implementation was the virtualization concept of hardware resources like processor, memory, storage, and network.

Distributed Computing

- Distributed computing is a model in which components of a software system are shared among multiple computers or nodes. Even though the software components may be spread out across multiple computers in multiple locations, they're run as one system. This is done to improve efficiency and performance.
- Distributed computing can increase performance, resilience and scalability, making it a common computing model in database and application design.

- Distributed computing networks can be connected as local networks or through WAN if the machines are in a different geographic location.
- Processors in distributed computing systems typically run in parallel.

Cloud computing is also a specialized form of distributed computing



Cluster Computing	Grid Computing	Cloud Computing
A cluster is normally formed with computers of a single location, otherwise the system becomes complex.	Grid is inherently more distributed by its nature. The computers need not to be in the same geographical location.	It allows total distribution of resources like the grids. Hardwa resources are maintained in multiple data centers spread across the globe.
Resources are generally prereserved for specific type of task.	Resources are generally prereserved for specific type of task.	Resources are not pre-reserved specific task. Resource utilizatio is mainly demanddriven.
Computation job takes place in one administrative domain owned by a single party.	Computation could occur over many administrative domains owned by multiple parties as connected together.	Computing resources of a cloud usually owned by a single party. But multiple administrative domains can be combined together to perform the job.
It features the centralized task management and scheduling system.	It features the distributed task management and decentralized scheduling	It features the decentralized tas management with more dynam computing infrastructure.
System is not dynamic in nature. Application mobility is not possible.	System is not dynamic in nature. Application mobility is not possible.	It is a dynamic system. Mobility application is an inherent featu in this system.

NIST Reference Model

- Provided by the National Institute of Standards and Technology (NIST) of U.S. The model was published in a document titled as 'NIST Cloud Computing Reference Architecture' by Information Technology Laboratory of NIST in 2011.

"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. This cloud model is comprised of five essential characteristics, three service models, and four deployment models

- Cloud computing is a model and not a technology.
- Cloud computing enables the users' access pools of computing resources via network.
- The resources are shared among users and made available on-demand.

The prime benefit is the ease of use with very little management tensions for the users

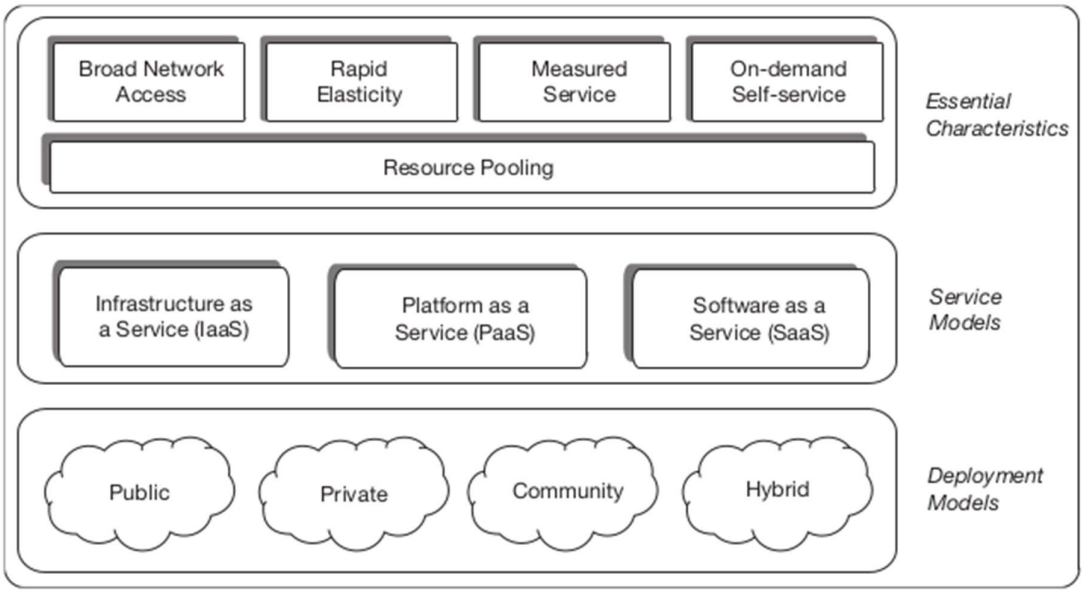


FIG 4.1: The NIST cloud computing model

Deployment and Service Models

- The NIST model of cloud computing separates cloud computing in two categories. One category is based on the operational or deployment pattern of the cloud and the other one is based on the nature of service that the cloud provides.
- **Cloud modeling based on deployment:** It focuses on the access boundary and location of the cloud establishment. The access boundary defines the purpose of using the cloud to some extent. There are four categories of cloud deployment: public cloud, private cloud, community cloud and hybrid cloud.
- **Cloud modeling based on service delivery:** This model describes the type of computing service that is offered to users by the service provider. There are three prime categories of service delivery models, namely Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS)

Actors and their Roles

- **Cloud Consumer**: The cloud consumer is the principal *stakeholder* for the cloud computing service. A cloud consumer represents a person or an organization that maintains a business relationship with, and uses the service from a cloud provider. The cloud consumer uses cloud service and may be billed for the service by the provider.

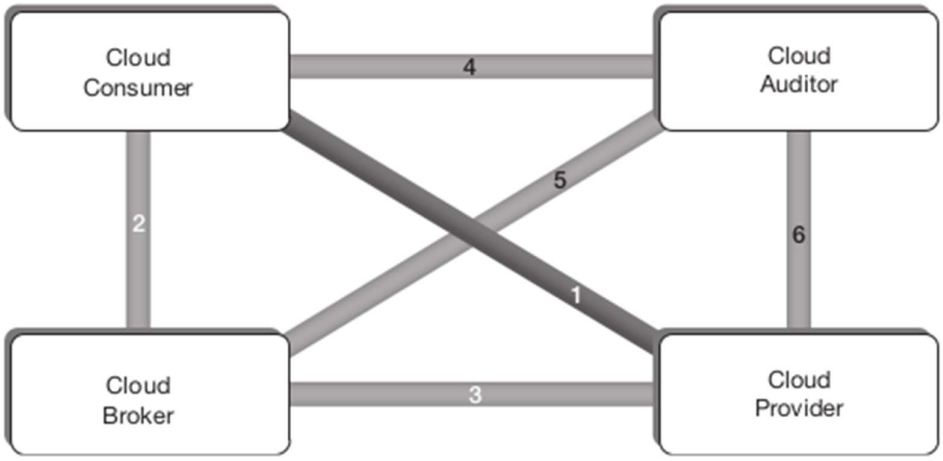


FIG 4.4: Interactions between the Actors in NIST model[4]

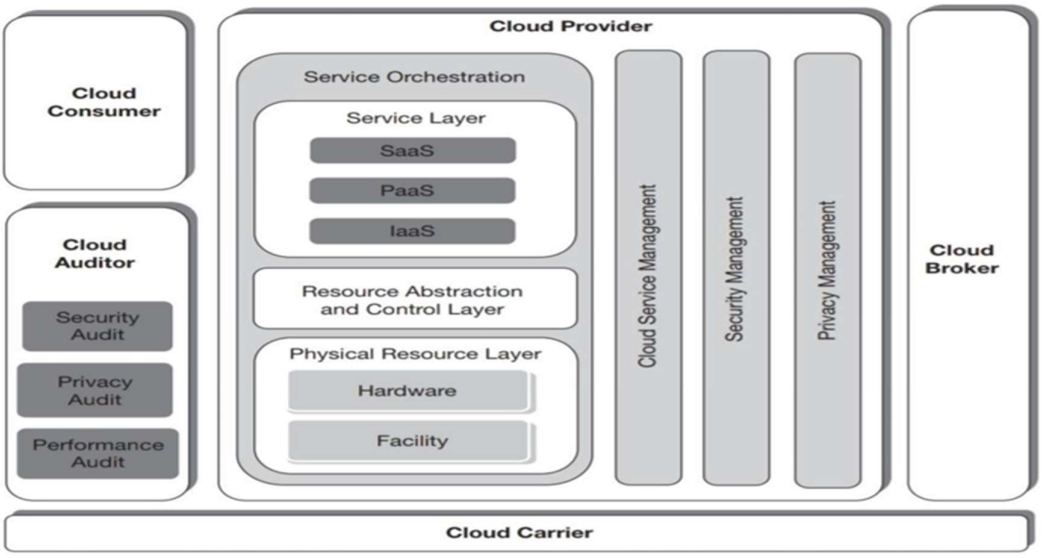
- **Cloud Provider**: A cloud provider is a person or an organization; it is the entity being responsible for making a service available to interested parties. A Cloud Provider acquires and manages the computing infrastructure required for providing the services.
  Cloud Auditor: The cloud services provided by cloud provider to the cloud consumer must comply to some pre-agreed policies and regulations in terms of performance, security etc. The verification of these agreed conditions can be performed by employing a third-party auditor. The cloud auditor is a party who can conduct independent assessment of cloud services and report it accordingly
- **Cloud Broker**: A cloud broker is an entity that manages the use, performance, and delivery of cloud services and negotiates the relationships between cloud providers and cloud consumers. Consumers can avoid the responsibilities of complex tasks by requesting services from brokers instead of consuming services from providers directly.
- **Cloud Carrier**: Cloud computing services are delivered from cloud provider to cloud consumer either directly or via some cloud broker. Cloud carrier acts as an agent in this delivery process. They are the organizations who provide the connectivity and transport facility of services through their network.
  Service Management: The *Service Management* component of cloud provider takes care of the functions needed for the management and operation of cloud services. There are three modules of cloud service management as business support, provisioning/configuration and portability/interoperability.
- **Security & Privacy**: *Security management* in the NIST reference architecture refers towards developing a secure and reliable system. It means protecting the system and its information from unauthorized access. *Privacy management* aims to keep personal or sensitive information secret and saves them from revealing out.
- **Service Orchestration**: Service orchestration refers to the 'composition of system components to support the cloud providers' activities in arrangement, coordination and

management of computing resources in order to provide cloud services to cloud consumers. It has 3 layers.

Service layer: Cloud provider puts interfaces that enables the service consumers to access various computing services. Thus the access interfaces for different types of cloud services (SaaS, PaaS and IaaS) are represented in this layer.

Resource Abstraction & Control layer: At this layer, the abstraction of physical resources are implemented (through the software). Access to any hardware resources goes through this layer and the layer secures the system by controlling resource allocation and access.

Physical Resource layer: The *physical resource layer* is the lowest layer in the stack that houses all of the physical computing resources. Hardware resources include computers (with processor and memory components), storage components (hard disks), network entities (routers, firewalls, switches, network links and interfaces) and other physical computing devices. Facilities include includes power supply, ventilation, cooling, communications and other aspects of a physical plant



Essential Characteristics

On-demand self-service: It is the most attractive feature that users like about this computing model. The on-demand service feature refers to the ability that empowers users to consume the computing facility as much they need at any moment. Being self-service, cloud computing can arrange the on-demand facility for users without any need of human intervention at vendor's

end. A user himself/herself can request cloud services as needed through some interface (generally through web forms) and resources become available within seconds. This feature is known as self-service. The self-service interface must be user-friendly in order to be effective and appealing

Resource pooling: Computing requires resources like processor, memory, storage and network. Cloud computing arranges these resources for users at vendor's end. Users can access and use these resources to satisfy their computing needs as and when required. Unlike traditional computing approach where every enterprise or user possesses its own physical computing resources, here pools of computing resources are maintained at remote locations by the provider which is accessed by all of the users. The resource pools must be reasonably large, flexible and capable of supporting many users simultaneously without any failure.

Broad network access: Cloud computing provides economic advantage to users as it releases them from the inconvenience of setting-up expensive in-house data centers. Instead, the cloud service facility developed and installed at the provider's end is remotely accessed by users through the network. To serve this purpose, strong network infrastructure has to be in place for effort-less and fast delivery of the computing services. Thus, high bandwidth communication links spread over the service area are the essential attributes of cloud computing so that users can access computing from any location and anytime.

Rapid elasticity: Provisioning of adequate and frequently changing demand of resources for a large number of users is a major technical concern in cloud computing. Provider may not know when and how much of resources users will consume prior to actual demand. But the mechanism should be such that the required volume of resources can be arranged at the time of demand from the users. The computing environment must create an impression of limitless repository of resources to users, and they should be able to consume any volume of resources any time. Again when a user no more uses the resources, those have to be taken back immediately so that there is no wastage of valuable resources through idle possessions.

Measured service: As users use computing services provided by cloud vendor, they must pay for it. In cloud computing model, this payment is determined by measuring the usages of computing resources by a user. Hence, the provider must employ some mechanism to measure the actual consumption by each individual user or organization. This means that the usage of the pooled resources has to be calculated and stated (or billed) to every user based on a metering system

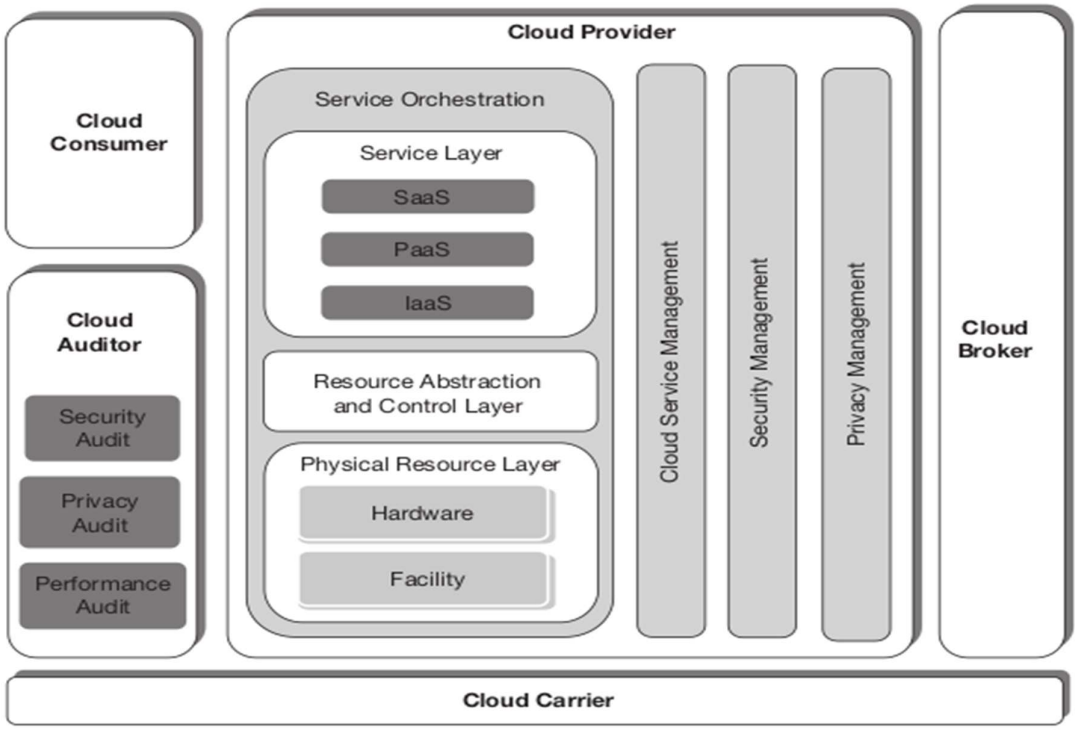


FIG 4.2: NIST cloud computing reference architecture[2]

CLOUD DEPLOYMENT MODELS

- The deployment choice depends on the requirements of the consumer organization.
- The deployment model describe the utility of a cloud and also specifies its access boundary.
- The model also indicates the relative location of the cloud with respect to the location of consumer organization.
- NIST definition mentions about four common deployment models as **public, private, community and hybrid deployments**

Public Cloud

- The public cloud deployment model provides the widest range of access to consumers among all cloud deployments. **Anyone who subscribes it gets open access to this cloud facility.** The consumer can either be an individual user or a group of people representing some organization or an enterprise.
- Public cloud is also referred as external cloud as physical location-wise it remains external or off-premises and the consumers can then remotely access the service.
- A public cloud is hosted and managed by some computing vendors who establishes data centers to provide the service to consumers. The consumers under this cloud deployment model are entirely free from any tensions of infrastructure administration and system management- related issues. But, at the same time they (consumers) would

have low degree of control over the cloud. **Amazon Web Services, Google Cloud, Microsoft Azure and Salesforce.com are some of the popular public clouds**

- Public cloud deployment promotes **multi-tenancy** at its highest degree. **Same physical computing resource can be shared among multiple unrelated consumers.** This provides major advantages as it becomes possible for a single cloud vendor to serve a large number of consumers. When a large number of consumers dispersed around the world share resources from data center of a single vendor that automatically increases resource utilization rates and decreases vendor's cost of service delivery.
- The public cloud providers on the other hand, **make advantage of the magnitude of their operation.** Being large in volume and business, they can afford state-of-the-art technology and skilled people. This ensures better quality of service. Through this model, **consumers can access potentially superior service at a lower cost.** Since different consumers (from different parts of the world) have variable workload demands during a course of a day, week, month or year, a cloud provider can always support loads efficiently during high demand (which is usually raised by a section of its consumers, at any particular moment

Private Cloud

- The private cloud deployment does not provide open access to all. It is mainly for organizational use and access to a private cloud deployment is restricted for general public.
- Private cloud is also referred as internal cloud since it is built to serve internal purpose of the organizations. While public clouds are equally useful for both individual users and organizations, private cloud generally serves the purposes of organizations only.
- For high-security and critical systems, like systems of defense organizations, private cloud is the suggested approach.
- While a public cloud cannot physically reside at any consumer's location (physical boundary),private clouds may reside either inside consumer organization's premises (on-premises) or outside (off-premises) at any neutral location.

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

- Private cloud shares **one-to-one relationship** with consumer while Public cloud maintains **one-to-many relationship**. This depicts that the resources of a private cloud remain devoted for one consumer organization only and cannot be shared with others.
- The features of **multi-tenancy** (where tenants are external unrelated entities) do not apply in private cloud as it is in public cloud. But, such isolation ensures privacy and creates a more secure computing environment.
- Consumers have no control over a public cloud environment. But with the private cloud, consumers can benefit from most of the advantages of cloud computing and **can still hold control over the environment**. For consumers, the cost of availing private cloud

is higher than public cloud as resources remain dedicated for a particular organization here.

Community Cloud

- The community cloud deployment model allows access to a number of organizations or consumers belonging to a community and the model is built to serve some common and specific purpose.
- It is for the use of some community of **people or organizations who share common concerns in business functionalities, security requirements etc.**
- This model allows sharing of infrastructure and resources among multiple consumers belonging to a single community and thus becomes cheaper compared to a private cloud.
- Community cloud deployment can be **on-premises or off-premises.** Physically it may reside on any community member's premises or it may be located in some external location.
- A private cloud is accessible only to one consumer, **one community cloud is used by multiple consumers of a community**. Thus, this deployment model supports multi-tenancy although not in the same degree as public cloud which allows multiple tenants not related with each other. Thus, **the tenancy model of community cloud falls in between that of private cloud and public cloud.**
- The goal of community cloud deployment is to provide the benefits of public cloud, like **multi-tenancy, pay-per-use billing** etc. to its consumers along with added level of **privacy and security** like the private cloud.
- Example of community cloud is some services launched by government of a country with the purpose of providing cloud services to national agencies. The agencies are consumers in this case belonging to a single community (the government).

Hybrid Cloud

- A hybrid cloud is generally created by **combining private or community deployment with public cloud deployment together.** This deployment model helps businesses to take advantage of private or community cloud by storing critical applications and data. There at the same time, it provides the cost benefit by keeping shared data and applications on the public cloud.
- The hybrid cloud can be formed by combining two elements from a set of five different cloud deployments as on-premises private cloud, off-premises private cloud, on-premises community cloud, off-premises community cloud and public cloud, where one among the first four deployments is combined with the last one (public cloud)

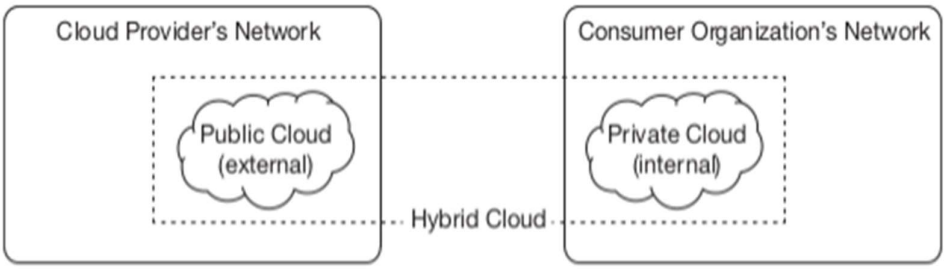


FIG 4.9: A hybrid cloud model

SERVICE DELIVERY MODELS

Three categories of computing services in traditional computing

- Infrastructure Service
- Platform Service
- Software Application Service

Cloud computing talks about delivering these facilities to consumers as computing services through network/internetwork. The benefit for the consumers is that they can avail these facilities over Internet anytime, as much as required, sitting at their own locations in a cost- effective manner. They only need to have a simple and suitable access device (like PC, laptop, tablet, mobile etc.) to access these services. Using these simple devices anyone can access any kind of computing infrastructure, platform or software application on payment-as-per-actual- usage basis.

Primary cloud computing services and are referred to as:

- Platform-as-a-Service (PaaS)
- Infrastructure-as-a-Service(IaaS)
- Software-as-a-Service (SaaS)

Clubbed together these three service models are commonly referred as SPI (Service-Platform-Infrastructure) model. Cloud service providers arrange these services for the cloud consumers. The NIST reference architecture represents these services under 'service orchestration' component of the providers

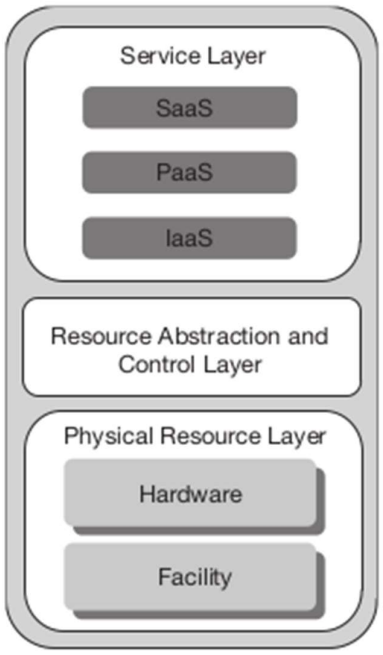


FIG 4.6: Cloud Service Orchestration[6]

Infrastructure-as-a-Service

- Infrastructure-as-a-Service **delivers virtualized-hardware** (not physical, but simulated software) resources to consumers known as virtual resources or virtual components.
- It provides **the facility of remotely using virtual processor, memory, storage and network resources to the consumers.** These virtual resources can be used just like physical (hardware) resources to build any computing setup (like virtual machine or virtual network). For this reason, IaaS is also referred as Hardware-as-a-Service (HaaS).
- Consumers **no longer need to manage or control** the underlying computing infrastructure that they consume as IaaS.

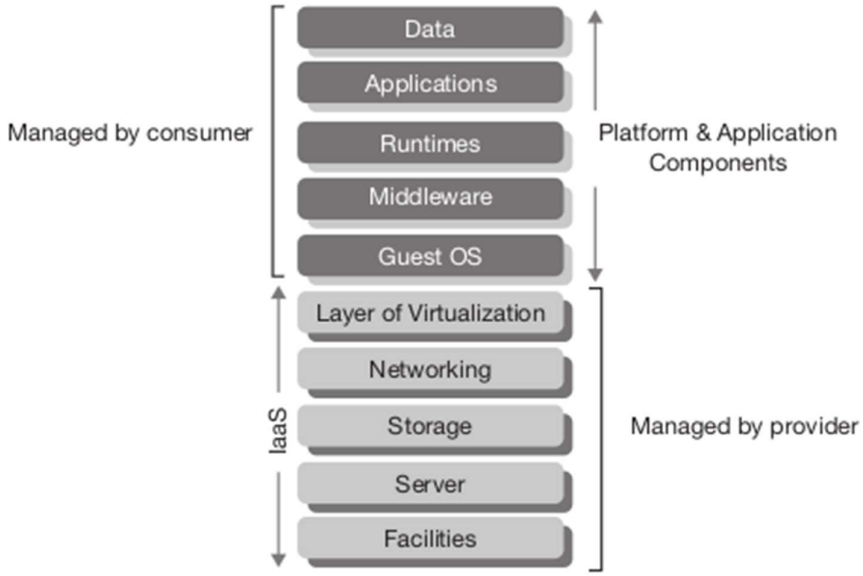


FIG 5.2: IaaS component stack

- It is a computing solution where the complexities and expenses for **managing the underlying hardware are outsourced to some cloud service providers.**
- In traditional system, outsourcing of computing hardware means some other party will provide and manage hardware resources as per the user's requirement. Users there can directly access that hardware and can utilize those resources by installing necessary software over them. In cloud computing IaaS model, provider arranges and manages hardware resources for users but users cannot access those hardware resources directly. **The hardware resources are represented as simulated software components** (implemented through resource virtualization technique) and are delivered to consumers via Internet (or network) using web services. Consumers can use those simulated components just like real hardware devices and can build computing system with necessary processor, memory, storage and network facilities. Thus, the simulated (or virtual) hardware component delivered as per consumers' requirement is the uniqueness of IaaS model. Consumers can access these virtual hardware resources on-demand and any time from any location over the network. They can build computers (virtual computers) using those virtual (or virtualized) hardware components and can even install operating systems and other software over that system.
- Major computing vendors like **Amazon, Google, GoGrid, RackSpace provide IaaS** facility. All of these vendors offer virtualized hardware resources of different types.
- IaaS vendors generally offer custom made virtual machines (made of those virtual components) for consumers.Consumers can install OS and start working over these servers.
- →Amazon EC2 and Google Compute Engine are popular server environments.
- Other than virtual machine, the storage is a very common IaaS offering.

- →Amazon S3 is a popular storage service available as IaaS

Platform-as-a-Service

- In computing, **platform means the underlying system on which software applications can be installed** (and also developed). A computing platform comprises hardware resources, operating system, middleware (if required) and runtime libraries. Application programs are also installed over this platform.
- Application development and deployment in traditional computing require the users' participation in managing hardware, operating system, middleware, web servers and other components. For instance, users must install appropriate framework (like J2EE, .NET) before working in any application platform. **PaaS facility, on the other hand, relieves users from all these tensions and delivers ready-made platform to consumers via internetwork/Internet.**
- PaaS component stack, in addition, provides application (development and deployment) platform over IaaS component stack. A PaaS provider not only delivers fully-managed application development and deployment environment but also takes care of the lower level (infrastructure level) resource management and provisioning.
- PaaS is created by adding additional layers of software over IaaS. With the use of PaaS, collaborative application development becomes easier where multiple users can work from different geographical locations. PaaS also reduces the total cost of ownership (TCO) as computing platform becomes available on rent basis.
- There are many PaaS offerings available in market. **Google App Engine, Microsoft Azure Platform, GoGrid Cloud Center, Force.com are very popular among them.** Open-source PaaS offerings are also available in the market. Cloud foundry is one such which is developed by **VMware.**

  One problem with PaaS model is that it fixes the developed applications with the platform. This causes **portability problem.** For instance, application developed on Google App Engine using any programming language (supported by Google PaaS) uses Google's APIs, and hence,it cannot be run over PaaS facility of other vendors

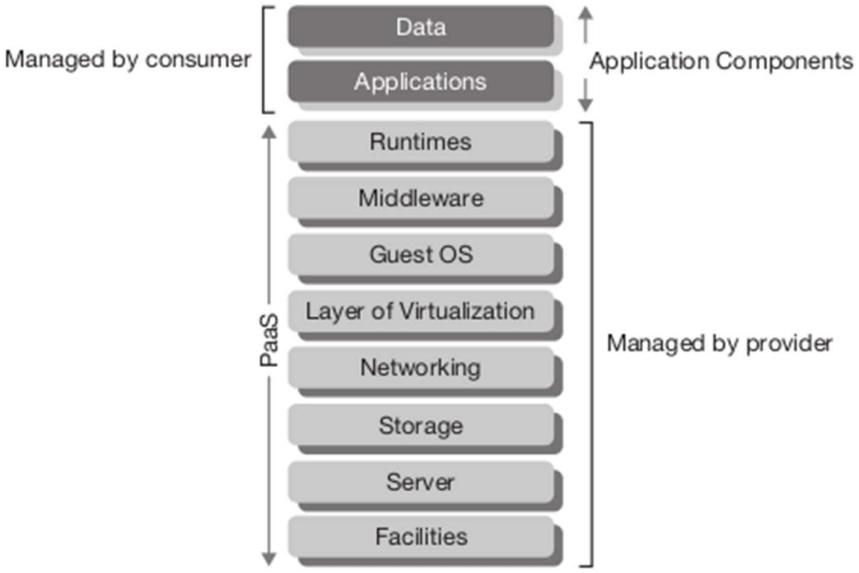


FIG 5.3: PaaS component stack

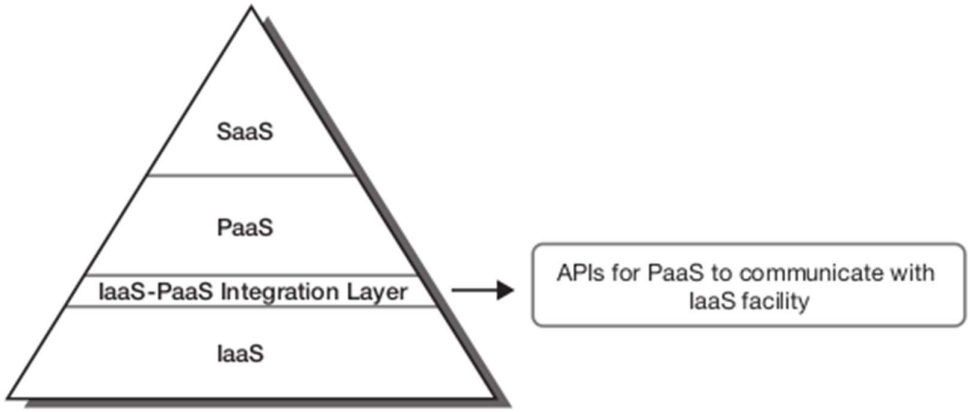


FIG 5.4: Integration of PaaS with IaaS

Software-as-a-Service

- Software-as-a-Service (SaaS) is a way of **delivering application as a service** over the network/ Internet that users can directly consume without the tension of installing or configuring an application.
- In traditional computing, consumers had to pay not only the software licensing fee but also spend a large portion of their budget in setting up the infrastructure and platform over which the application would run. SaaS eliminates this problem and promises easier as well as a cheaper way of using application.

- SaaS applications are sometimes referred as **web-based software,or hosted software.**

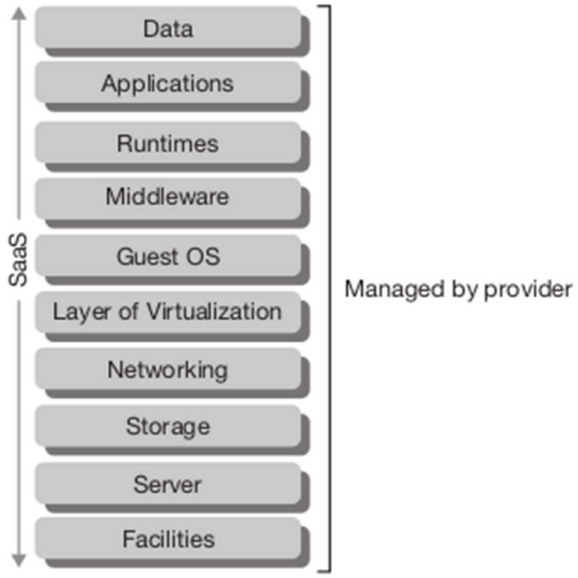


FIG 5.5: SaaS component stack

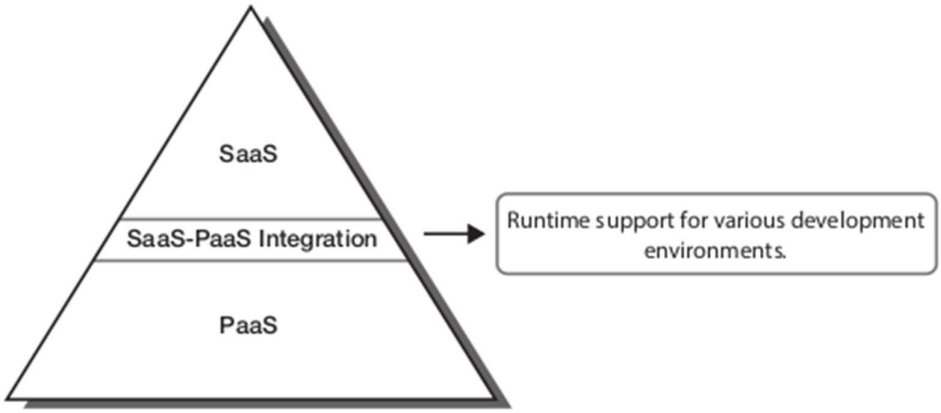


FIG 5.6: Integration of SaaS with PaaS

- SaaS is built by adding layers over PaaS component stack . It is the **facility of using applications administered and delivered by service provider over a cloud infrastructure.**
- In SaaS model, everything is managed by vendor including application upgrade or updates; even the data and application acts upon are also managed (storage in database or file etc.) by SaaS. Users can access the applications through a thin client interface (usually a browser) from any location.

  E-mail facility is one common example of SaaS application that is used by everyone. The CRM (customer relationship management) package of Salesforce.com gained popularity among enterprises since early 2000s. SAP (Systems, Application and

Products) as the solution provider of Enterprise Resource Planning (ERP) entered into the SaaS CRM and ERP markets with its 'Business ByDesign' solution. Oracle launched its CRM SaaS 'On Demand'. There are also many popular SaaS offerings for general users in the market today like GoogleApps, Microsoft Office 365 and else

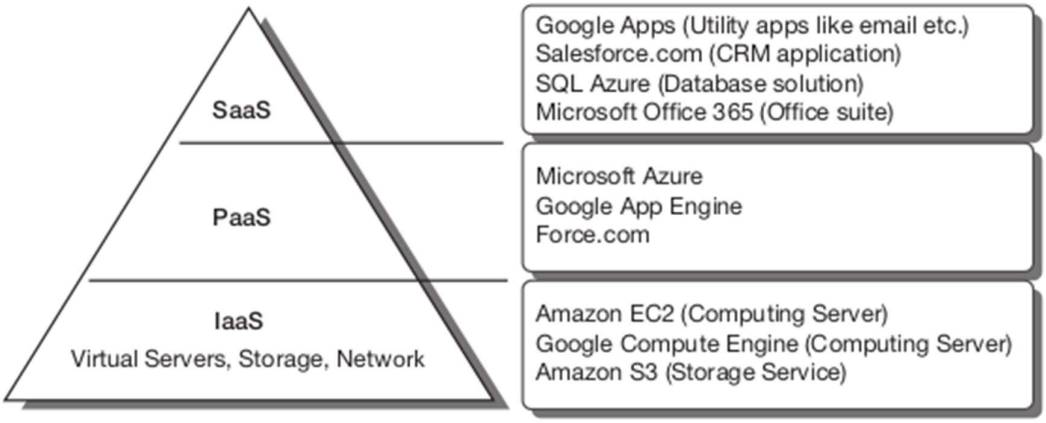


FIG 5.8: The layered cloud service model