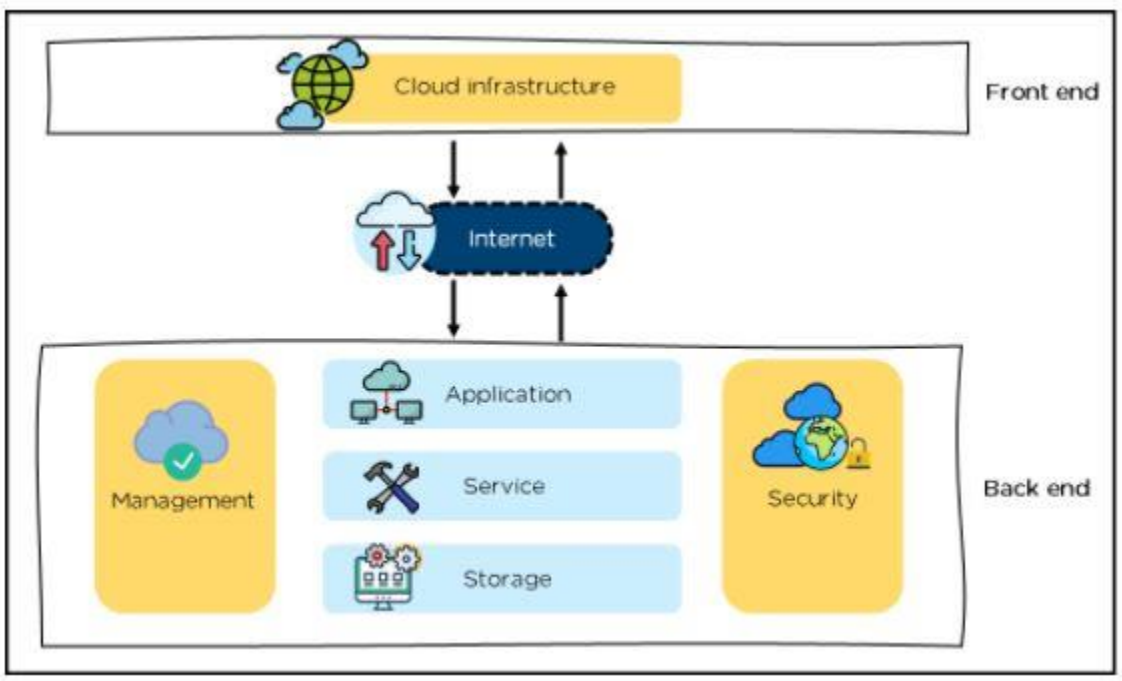
Unit 2
Cloud Computing Architecture

Cloud computing architecture is simple; it clearly states the components and subcomponents embedded in it There's no question that cloud computing is here to stay. It touches every part of our lives today, offering many advantages in terms of flexibility, storage, sharing, maintenance, and much more.

A standard internet connection or a virtual network provides us access to cloud-based applications and services like Google Docs, Skype, and Netflix. Most companies are shifting their businesses into the cloud as they require significant storage, which cloud platforms provide. A cloud computing architecture provides higher bandwidth to its users due to which data over the cloud can be used from anywhere across the world at any time. Due to its architecture, it not only shares resources among client source consumers but also with open-source communities like Microsoft and Red hat.

Cloud Computing Architecture is divided into two parts, i.e., front-end and back-end. Front-end and back-end communicate via a network or internet. A diagrammatic representation of cloud computing architecture is shown below:



Cloud Computing Architecture

Front-End

- It provides applications and the interfaces that are required for the cloud-based service.
- It consists of client's side applications, which are web browsers such as Google Chrome and Internet Explorer.
- Cloud infrastructure is the only component of the front-end.
- Cloud infrastructure consists of hardware and software components such as data storage, server, virtualization software, etc.
- It also provides a Graphical User Interface to the end-users to perform respective tasks.

Back-End

It is responsible for monitoring all the programs that run the application on the front-end

It has a large number of data storage systems and servers. The back-end is an important and huge part of the whole cloud computing architecture, as shown below:

The components of the back-end cloud architecture are mentioned below. Let's understand them in detail one by one.

Application

- It can either be a software or a platform
- Depending upon the client requirement, the application provides the result to the end-user (with resources) in the back end.

Service

- Service is an essential component in cloud architecture
- Its responsibility is to provide utility in the architecture
- In a Cloud, few widely used services among the end-users are storage application development environments and web services

Storage

- It stores and maintains data like files, videos, documents, etc. over the internet
- Some of the popular examples of storage services are below:
    - Amazon S3
    - Oracle Cloud-Storage
    - Microsoft Azure Storage
- Its capacity varies depending upon the service providers available in the market

Management

- Its task is to allot specific resources to a specific task, it simultaneously performs various functions of the cloud environment.
- It helps in the management of components like application, task, service, security, data storage, and cloud infrastructure
- In simple terms, it establishes coordination among the cloud resources

Security

- Security is an integral part of back-end cloud infrastructure
- It provides secure cloud resources, systems, files, and infrastructure to end-users
- Also, it implements security management to the cloud server with virtual firewalls which results in preventing data loss

Benefits of Cloud Computing Architecture

The cloud computing architecture is designed in such a way that:

- It solves latency issues and improves data processing requirements
- It reduces IT operating costs and gives good accessibility to access data and digital tools
- It helps businesses to easily scale up and scale down their cloud resources
- It has a flexibility feature which gives businesses a competitive advantage
- It results in better disaster recovery and provides high security

- It automatically updates its services
- It encourages remote working and promotes team collaboration

Cloud Computing Architecture Components

Some of the important components of Cloud Computing architecture that we will be looking into are as follows:

- Hypervisor
- Management Software
- Deployment Software
- Network
- Cloud Server
- Cloud Storage

Components of Cloud architecture

Hypervisor

- It is a virtual machine monitor which provides Virtual Operating Platforms to every user
- It also manages guest operating systems in the cloud
- It runs a separate virtual machine on the back end which consists of software and hardware
- Its main objective is to divide and allocate resources

Management Software

- Its responsibility is to manage and monitor cloud operations with various strategies to increase the performance of the cloud
- Some of the operations performed by the management software are:
    - compliance auditing
    - management of overseeing disaster
    - contingency plans

Deployment Software

- It consists of all the mandatory installations and configurations required to run a cloud service
- All deployment of cloud services is performed using a deployment software
- The three different models which can be deployed are the following:

- SaaS - Software as a service hosts and manages applications of the end-user.

Example: Gmail

- PaaS - Platform as a service helps developers to build, create, and manage applications.

Example: Microsoft Azure

- IaaS - Infrastructure as a service provides services on a pay-as-you-go pricing model.

Network

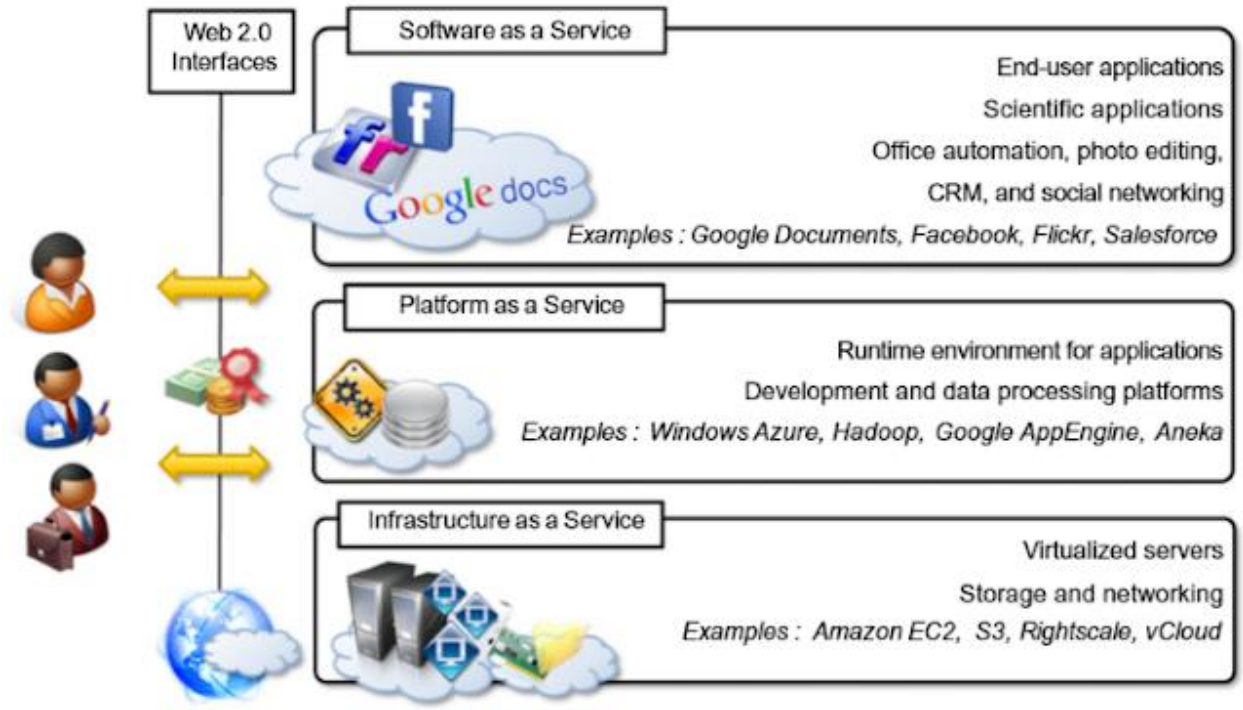
- It connects the front-end and back-end. Also, allows every user to access cloud resources
- It helps users to connect and customize the route and protocol
- It is a virtual server which is hosted on the cloud computing platform
- It is highly flexible, secure, and cost-effective

Cloud Storage

- Here, every bit of data is stored and accessed by a user from anywhere over the internet
- It is scalable at run-time and is automatically accessed
- Data can be modified and retrieved from cloud storage over the web

Cloud Reference Model

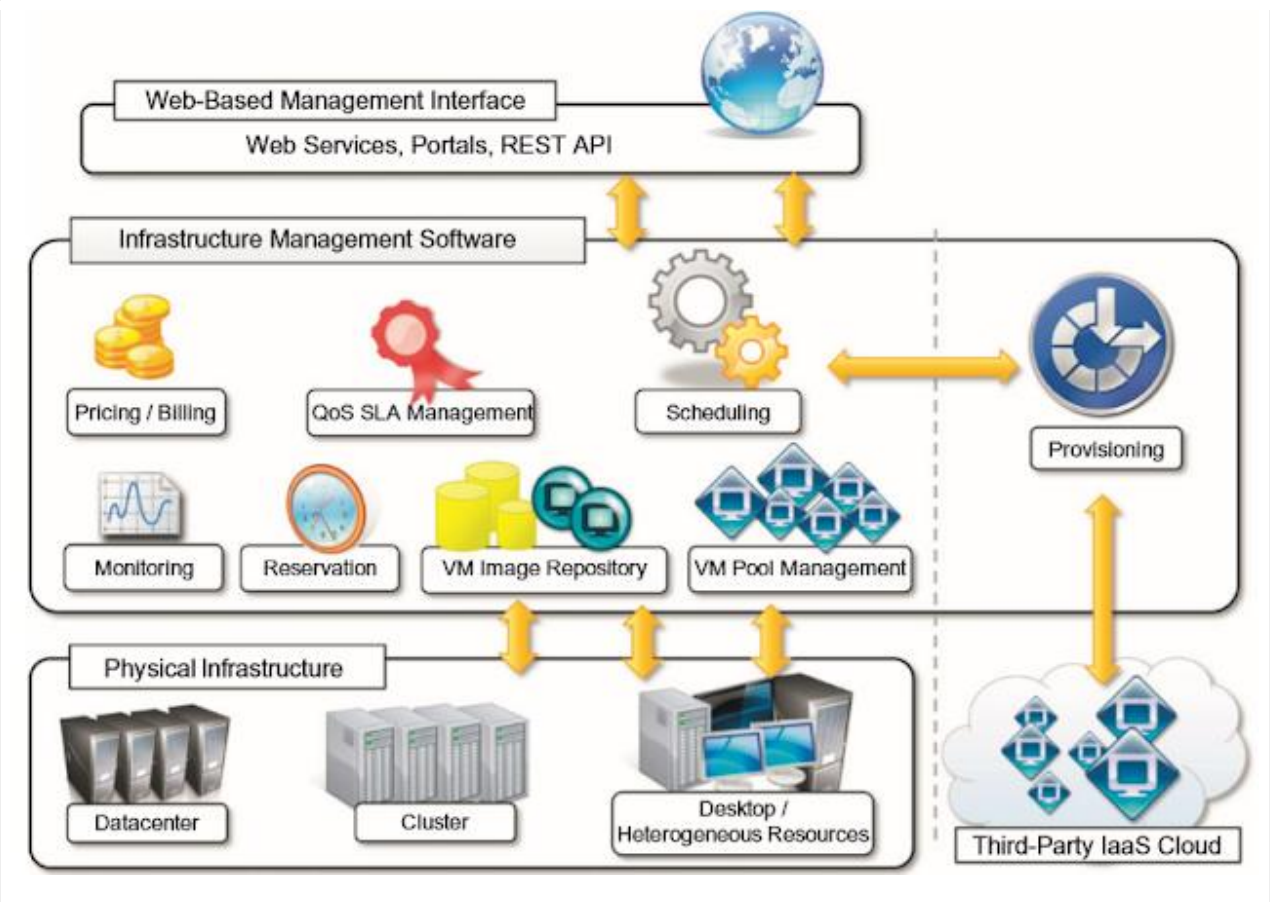
The reference model for cloud computing is an abstract model that characterizes and standardizes a cloud computing environment by partitioning it into abstraction layers and cross-layer functions.



IaaS | Infrastructure as a Service

1. IaaS stands for infrastructure as a service.
2. Infrastructure as service or IaaS is the basic layer in cloud computing model.
3. IaaS offers servers, network devices, load balancers, database, Web servers etc.
4. IaaS delivers customizable infrastructure on demand.
5. IaaS examples can be categorized in two categories
    a. IaaS Management layer
    b. IaaS Physical infrastructure
6. Some service providers provide both above categories and some provides only management layer.
7. IaaS management layer also required integration with other IaaS solutions that provide physical infrastructure.
8. On virtual machines applications are installed and deployed.
9. One of the examples of virtual machine is Oracle VM.
10. Hardware virtualization includes workload partitioning, application isolation, sandboxing, and hardware tuning.
11. Instead of purchasing user can access these virtual hardware's on pay per use basis.
12. users can take advantage of the full customization offered by virtualization to deploy their infrastructure in the cloud.
13. Some virtual machines can be with pre-installed operating systems and other software's.

14. On some virtual machines operating systems and others software's can be installed as per use.
15. Some examples:
    1. Amazon Web Services (AWS),
    2. Microsoft Azure,
    3. Google Compute Engine (GCE)



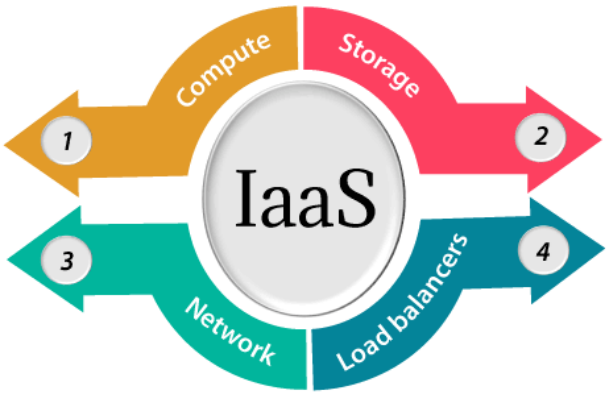
Characteristics of IaaS

There are the following characteristics of IaaS -

- Resources are available as a service
- Services are highly scalable
- Dynamic and flexible
- GUI and API-based access
- Automated administrative tasks

IaaS provider provides the following services -

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



Advantages of IaaS cloud computing layer

There are the following advantages of IaaS computing layer -

1. Shared infrastructure

IaaS allows multiple users to share the same physical infrastructure.

2. Web access to the resources

Iaas allows IT users to access resources over the internet.

3. Pay-as-per-use model

IaaS providers provide services based on the pay-as-per-use basis. The users are required to pay for what they have used.

4. Focus on the core business

IaaS providers focus on the organization's core business rather than on IT infrastructure.

5. On-demand scalability

On-demand scalability is one of the biggest advantages of IaaS. Using IaaS, users do not worry about to upgrade software and troubleshoot the issues related to hardware components.

Disadvantages of IaaS cloud computing layer

1. Security

Security is one of the biggest issues in IaaS. Most of the IaaS providers are not able to provide 100% security.

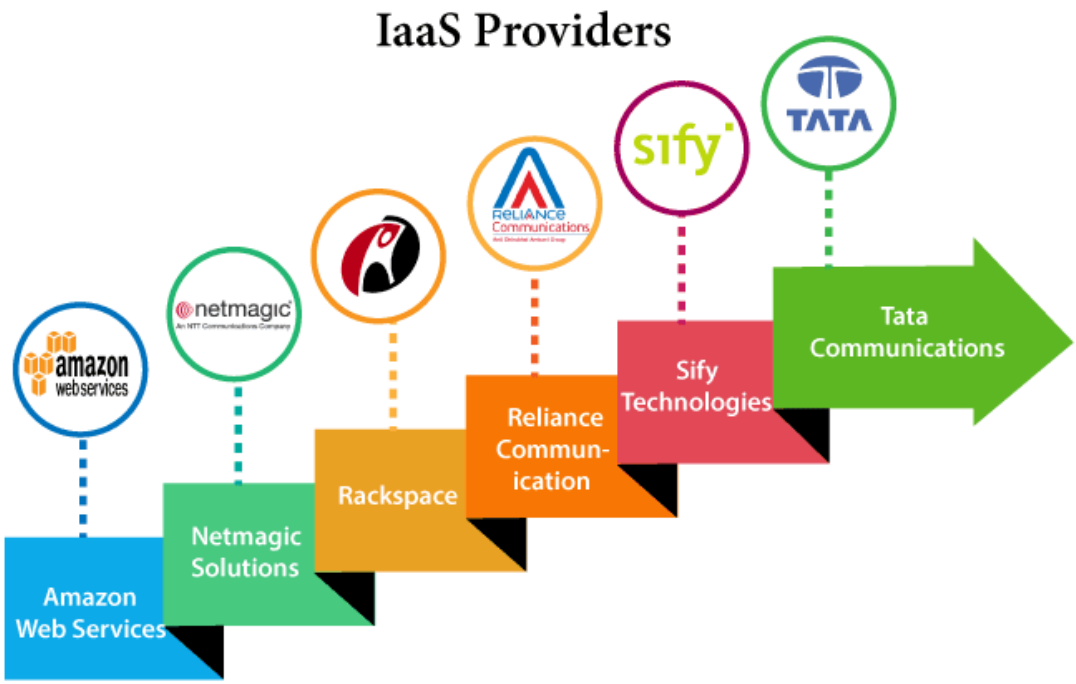
2. Maintenance & Upgrade

Although IaaS service providers maintain the software, but they do not upgrade the software for some organizations.

3. Interoperability issues

It is difficult to migrate VM from one IaaS provider to the other, so the customers might face problem related to vendor lock-in.

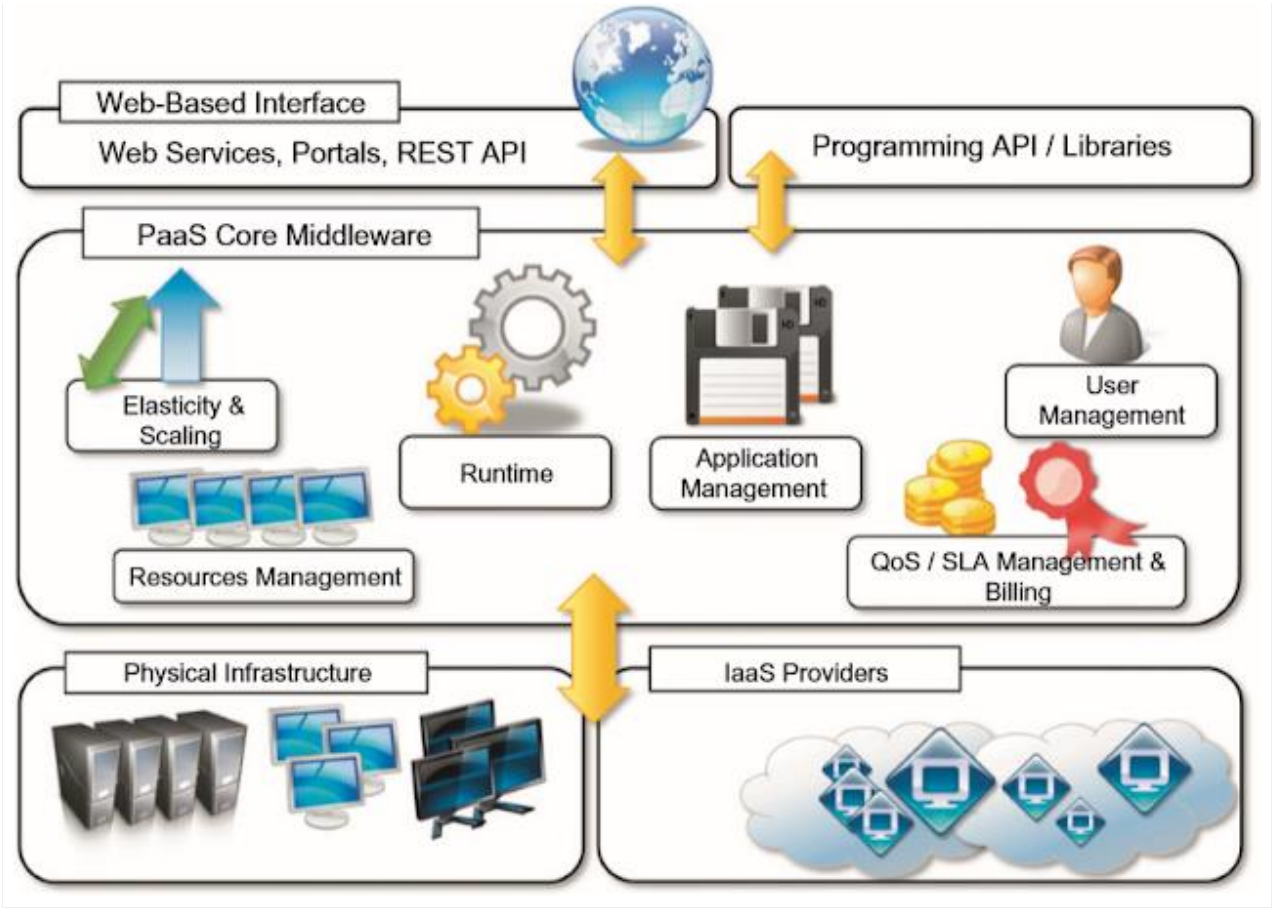
Top Iaas Providers who are providing IaaS cloud computing platform



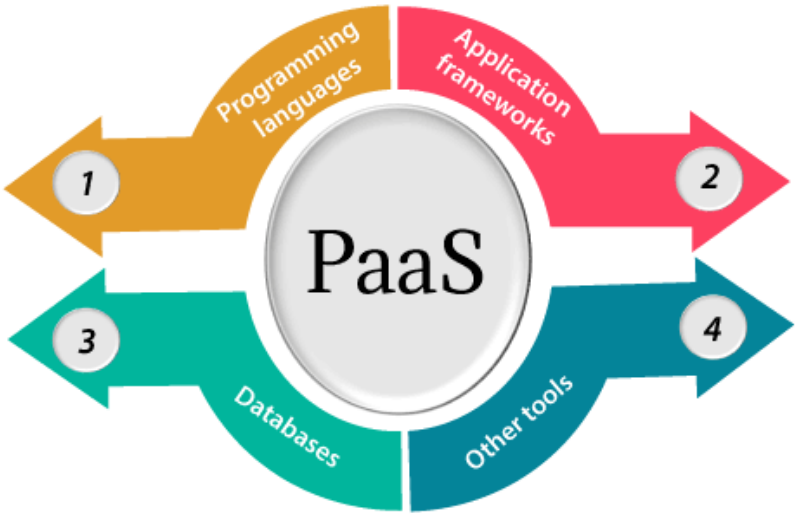
IaaS Vendor	Iaas Solution	Details
Amazon Web Services	Elastic, Elastic Compute Cloud (EC2) MapReduce, Route 53, Virtual Private Cloud, etc.	The cloud computing platform pioneer, Amazon offers auto scaling, cloud monitoring, and load balancing features as part of its portfolio.
Netmagic Solutions	Netmagic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

PaaS | Platform as a service

1. PaaS stands for platform as a service.
2. PaaS provides a computing platform with a programming language execution environment.
3. PaaS provide a development and deployment platform for running applications in the cloud.
4. PaaS constitute the middleware on top of which applications are built.
5. Application management is the core functionality of the middleware.
6. PaaS provides run time environments for the applications.
7. PaaS provides
    a. Applications deployment
    b. Configuring application components
    c. Provisioning and configuring supporting technologies
8. For users PaaS interfaces can be in the form of a Web-based interface or in the form of programming APIs and libraries.
9. PaaS solutions generally include the infrastructure as well.
10. Pure PaaS offered only the user-level middleware.
11. PaasS classification:
    a. PaaS-I: Runtime environment with Web-hosted application development platform. Rapid application prototyping. For example Force.com which is a combination of middleware and infrastructure product type.
    b. PaaS-II: Runtime environment for scaling Web applications. The runtime could be enhanced by additional components that provide scaling capabilities. For example Google AppEngine which is a combination of middleware and infrastructure product type. Appscale is middlware product type.
    c. PaaS-III: Middleware and programming model for developing distributed applications in the cloud. For example Microsoft Azure which is a combination of middleware and infrastructure product type. Manjrasoft Aneka is a middleware product type.
12. Some examples:
    a. Google App Engine
    b. Force.com



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



1. Programming languages

PaaS providers provide various programming languages for the developers to develop the applications. Some popular programming languages provided by PaaS providers are Java, PHP, Ruby, Perl, and Go.

2. Application frameworks

PaaS providers provide application frameworks to easily understand the application development. Some popular application frameworks provided by PaaS providers are Node.js, Drupal, Joomla, WordPress, Spring, Play, Rack, and Zend.

3.Databases

PaaS providers provide various databases such as ClearDB, PostgreSQL, MongoDB, and Redis to communicate with the applications.

4. Other tools

PaaS providers provide various other tools that are required to develop, test, and deploy the applications.

Characteristics of PaaS:

1. Runtime framework: The runtime framework executes end-user code according to the policies set by the user and the provider.
2. Abstraction: PaaS offer a way to deploy and manage applications on the cloud rather than a virtual machine on top of which the IT infrastructure is built and configured.
3. Automation: PaaS deploy the applications automatically.
4. Cloud services: Provide services for creation, delivery, monitoring management, reporting of applications.

Advantages of PaaS

There are the following advantages of PaaS -

1) Simplified Development

PaaS allows developers to focus on development and innovation without worrying about infrastructure management.

2) Lower risk

No need for up-front investment in hardware and software. Developers only need a PC and an internet connection to start building applications.

3) Prebuilt business functionality

Some PaaS vendors also provide already defined business functionality so that users can avoid building everything from very scratch and hence can directly start the projects only.

4) Instant community

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

5) Scalability

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

Disadvantages of PaaS cloud computing layer

1) Vendor lock-in

One has to write the applications according to the platform provided by the PaaS vendor, so the migration of an application to another PaaS vendor would be a problem.

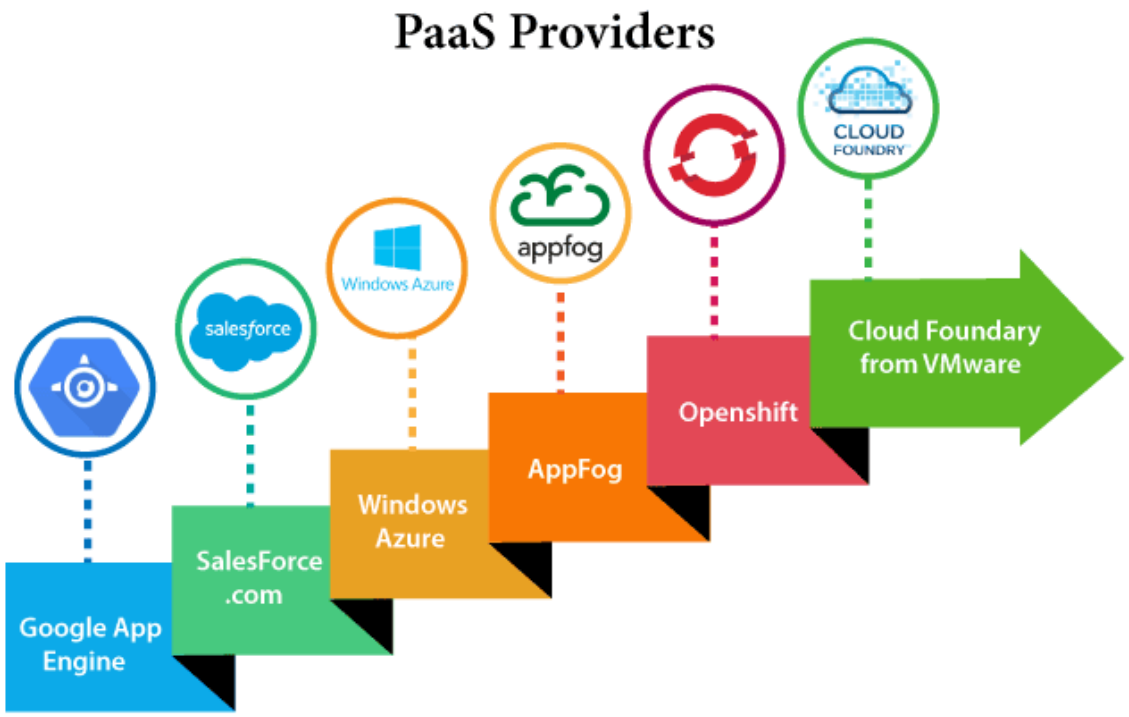
2) Data Privacy

Corporate data, whether it can be critical or not, will be private, so if it is not located within the walls of the company, there can be a risk in terms of privacy of data.

3) Integration with the rest of the systems applications

It may happen that some applications are local, and some are in the cloud. So there will be chances of increased complexity when we want to use data which in the cloud with the local data.

Popular PaaS Providers



The below table shows some popular PaaS providers and services that are provided by them -

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

Cloud Foundry from VMware	Data, Messaging, and other services.

SaaS | Software as a service

1. SaaS stands for software as a service.
2. Software as a service (SaaS) allows users to connect to and use cloud-based apps over the Internet.
3. SaaS is the service with which end users interact directly.
4. It provides a means to free users from complex hardware and software management.
5. In SaaS customer do not new to purchase the software and required the license.
6. They simply access the application website, enter their credentials and billing details, and can instantly use the application.
7. Customer can customize their software.
8. Application is available to the customer on demand.
9. SaaS can be considered as a "one-to-many" software delivery model.
10. In SaaS applications are built as per the user needs.
11. From the examples mentioned below we can find why SaaS is considered as one to many models.
12. Some examples:
    a. Gmail
    b. Google drive
    c. Dropbox
    d. WhatsApp

Characteristics of SaaS:

1. The product sold to customer is application access.
2. The application is centrally managed.
3. The service delivered is one-to-many.
4. The service delivered is an integrated solution delivered on the contract, which means provided as promised.

There are the following services provided by SaaS providers -

Business Services - SaaS Provider provides various business services to start-up the business. The SaaS business services include **ERP** (Enterprise Resource Planning), **CRM** (Customer Relationship Management), **billing**, and **sales**.

Document Management - SaaS document management is a software application offered by a third party (SaaS providers) to create, manage, and track electronic documents.

Example: Slack, Samepage, Box, and Zoho Forms.

Social Networks - As we all know, social networking sites are used by the general public, so social networking service providers use SaaS for their convenience and handle the general public's information.

Mail Services - To handle the unpredictable number of users and load on e-mail services, many e-mail providers offering their services using SaaS.

Advantages of SaaS cloud computing layer

1) SaaS is easy to buy

SaaS pricing is based on a monthly fee or annual fee subscription, so it allows organizations to access business functionality at a low cost, which is less than licensed applications.

Unlike traditional software, which is sold as a licensed based with an up-front cost (and often an optional ongoing support fee), SaaS providers are generally pricing the applications using a subscription fee, most commonly a monthly or annually fee.

2. One to Many

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

3. Less hardware required for SaaS

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

4. Low maintenance required for SaaS

Software as a service removes the need for installation, set-up, and daily maintenance for the organizations. The initial set-up cost for SaaS is typically less than the enterprise software. SaaS vendors are pricing their applications based on some usage parameters, such as a number of users using the application. So SaaS does easy to monitor and automatic updates.

5. No special software or hardware versions required

All users will have the same version of the software and typically access it through the web browser. SaaS reduces IT support costs by outsourcing hardware and software maintenance and support to the IaaS provider.

6. Multidevice support

SaaS services can be accessed from any device such as desktops, laptops, tablets, phones, and thin clients.

7. API Integration

SaaS services easily integrate with other software or services through standard APIs.

8. No client-side installation

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

Disadvantages of SaaS cloud computing layer

1) Security

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

2) Latency issue

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

3) Total Dependency on Internet

Without an internet connection, most SaaS applications are not usable.

4) Switching between SaaS vendors is difficult

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

Popular SaaS Providers

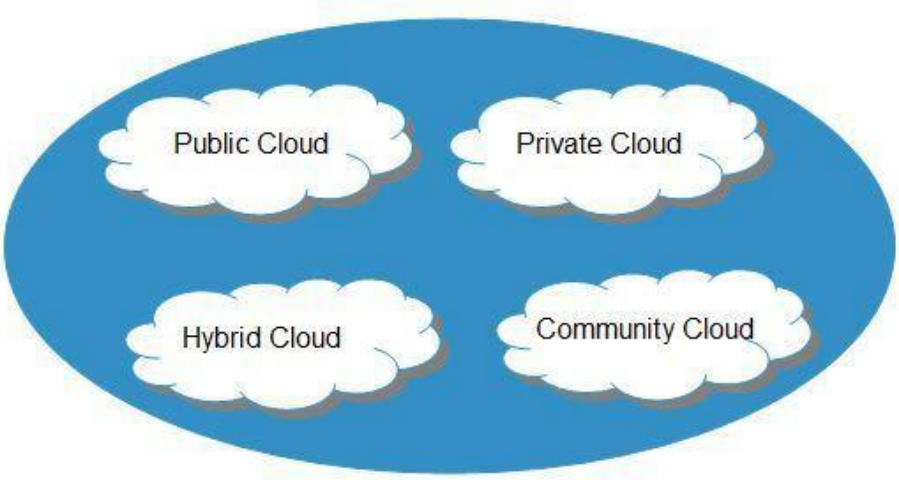
The below table shows some popular SaaS providers and services that are provided by them -

Provider	Services
Salseforce.com	On-demand CRM solutions
Microsoft Office 365	Online office suite
Google Apps	Gmail, Google Calendar, Docs, and sites
NetSuite	ERP, accounting, order management, CRM, Professionals Services Automation (PSA), and e-commerce applications.

GoToMeeting	Online meeting and video-conferencing software
Constant Contact	E-mail marketing, online survey, and event marketing
Oracle CRM	CRM applications
Workday, Inc	Human capital management, payroll, and financial management.

Deployment models

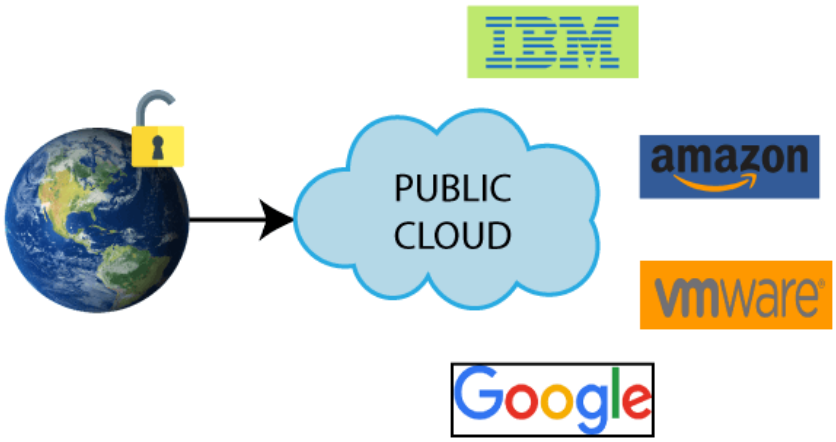
Deployment models define the type of access to the cloud, i.e., how the cloud is located? Cloud can have any of the four types of access: public, private, hybrid and community.

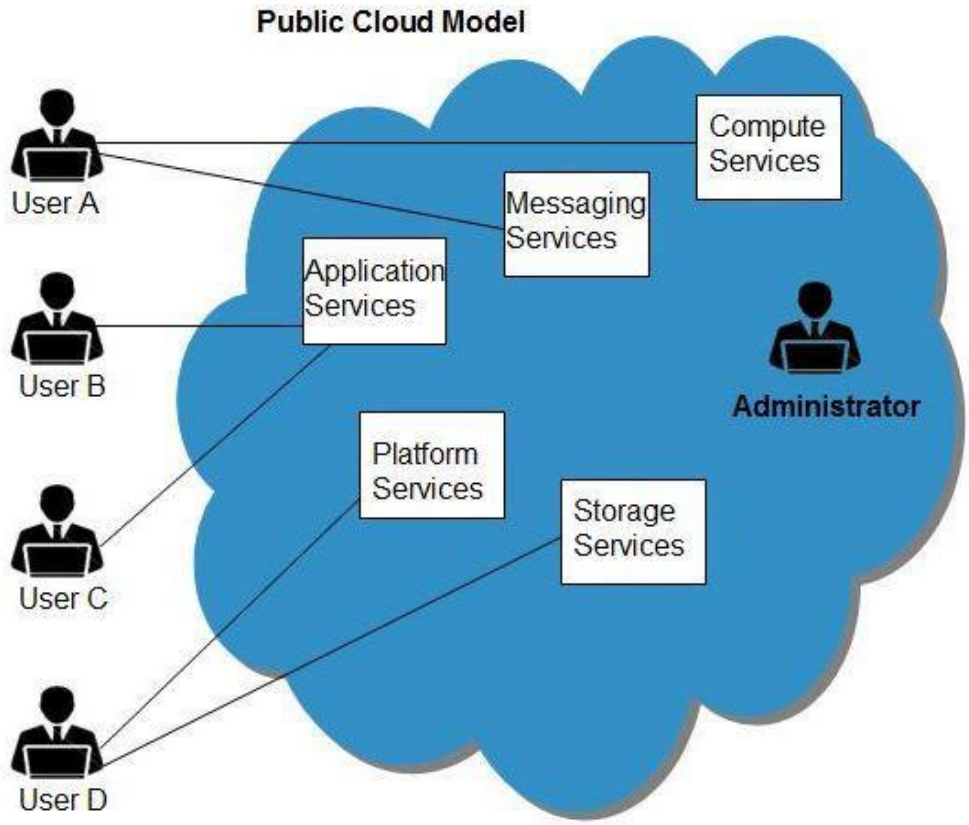


Public cloud:

The **public cloud** allows systems and services to be easily accessible to general public.

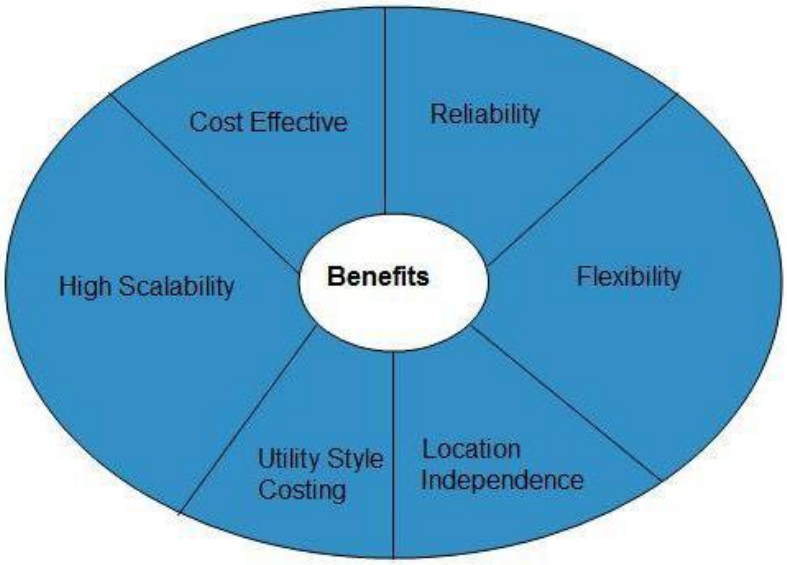
Amazon Elastic Compute Cloud (EC2), Microsoft Azure, IBM's Blue Cloud, Sun Cloud, and Google Cloud are examples of the public cloud.





Benefits

There are many benefits of deploying cloud as public cloud model. The following diagram shows some of those benefits:



Cost effective
Since **public cloud** share same resources with large number of consumer, it has low cost.

Reliability
Since **public cloud** employs large number of resources from different locations, if any of the resource fail, public cloud can employ another one.

Flexibility
It is also very easy to integrate public cloud with private cloud, hence gives consumers a flexible approach.

Location independence
Since, **public cloud** services are delivered through internet, therefore ensures location independence.

Utility style costing
Public cloud is also based on **pay-per-use** model and resources are accessible whenever consumer needs it.

High scalability
Cloud resources are made available on demand from a pool of resources, i.e., they can be scaled up or down according the requirement.

Disadvantages
Here are the disadvantages of public cloud model:

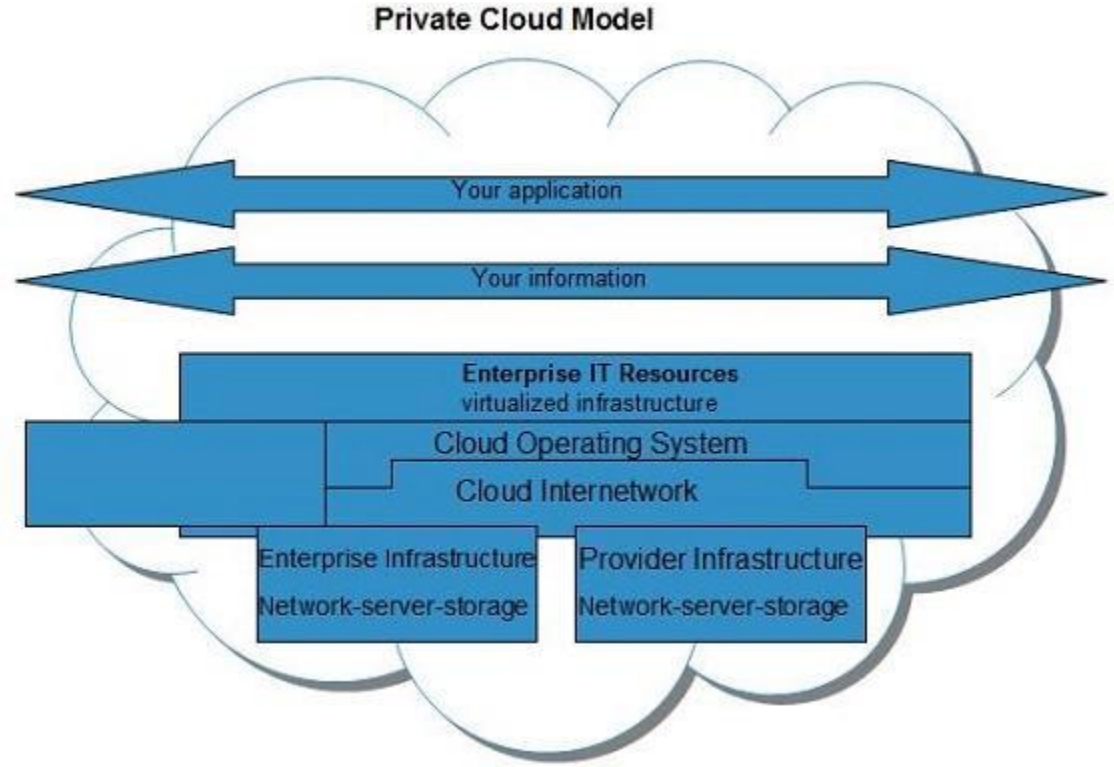
Low security

In **public cloud model,** data is hosted off-site and resources are shared publicly, therefore does not ensure higher level of security.

Less customizable
It is comparatively less customizable than private cloud.

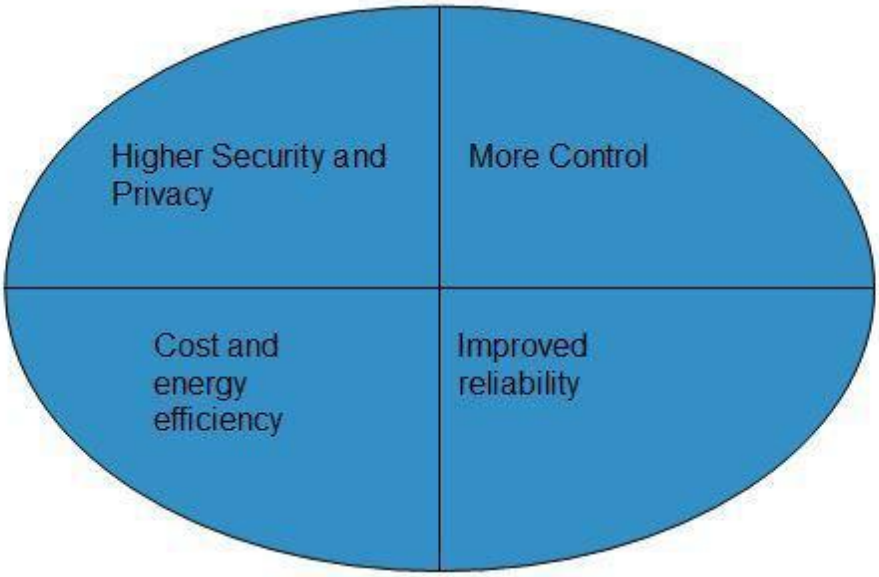
Private cloud:

The **private cloud** allows systems and services to be accessible within an organization. The private cloud is operated only within a single organization. However, it may be managed internally or by third-party. The chief advantage of these systems is that the enterprise retains full control
Over corporate data, security guidelines, and system performance.



Benefits

There are many benefits of deploying cloud as private cloud model. The following diagram shows some of those benefits:



Higher security and privacy
Private cloud operations are not available to general public and resources are shared from distinct pool of **resources, therefore, ensures high security and privacy.**

More control
Private clouds have more control on its resources and hardware than public cloud because it is accessed only within an organization.

Cost and energy efficiency
Private cloud resources are not as cost effective as public clouds but they offer more efficiency than public cloud.

Disadvantages
Here are the disadvantages of using private cloud model:

Restricted area
Private cloud is only accessible locally and is very difficult to deploy globally.

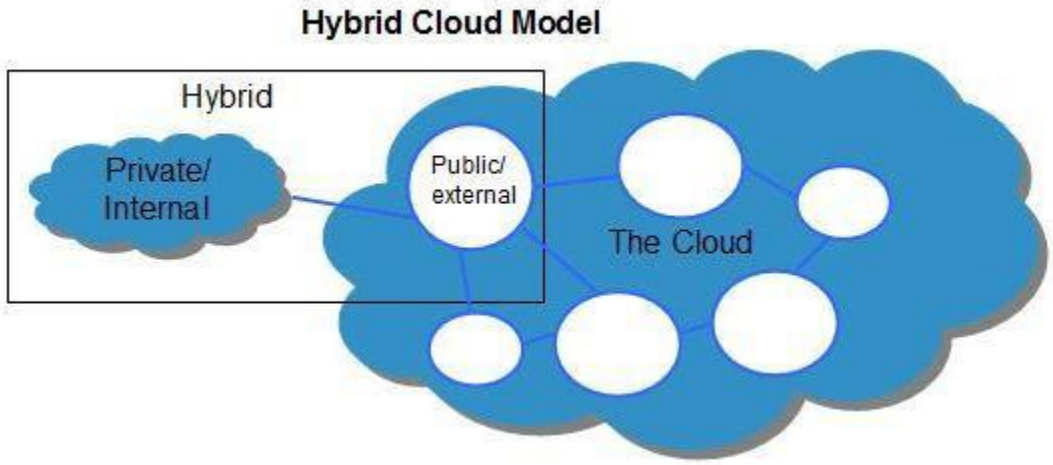
Inflexible pricing
In order to fulfill demand, purchasing new hardware is very costly.

Limited scalability
Private cloud can be scaled only within capacity of internal hosted resources.

Additional skills
In order to maintain cloud deployment, organization requires more skilled and expertise.

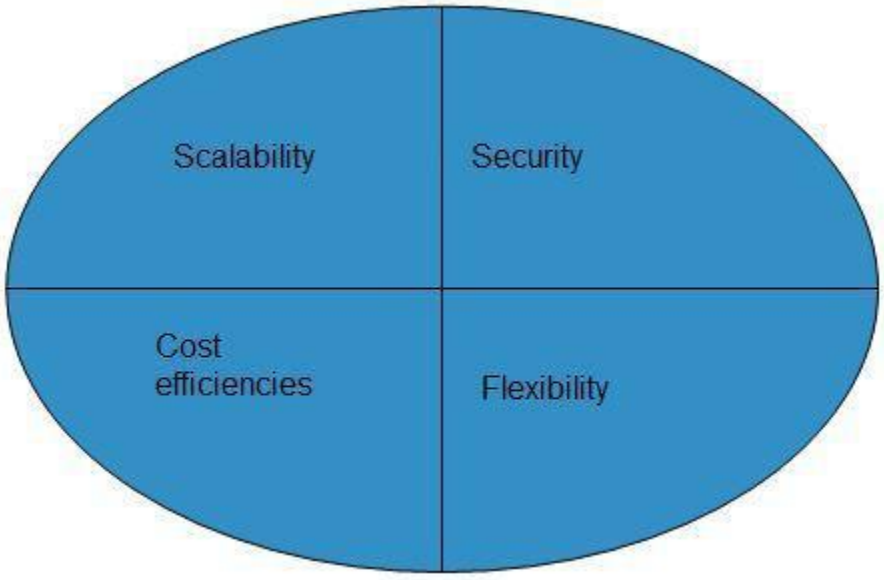
Hybrid cloud:

This can be a combination of private and public clouds that support the requirement to retain some data in an organization, and also the need to offer services in the cloud. A company may use internal resources in a private cloud and maintain total control over its proprietary data. It can then use a public cloud storage provider for backing up less sensitive information.



Benefits

There are many benefits of deploying cloud as hybrid cloud model. The following diagram shows some of those benefits:



Scalability

It offers both features of public cloud scalability and private cloud scalability.

Flexibility

It offers both secure resources and scalable public resources.

Cost efficiencies
Public cloud are more cost effective than private, therefore hybrid cloud can have this saving.

Security
Private cloud in hybrid cloud ensures higher degree of security.

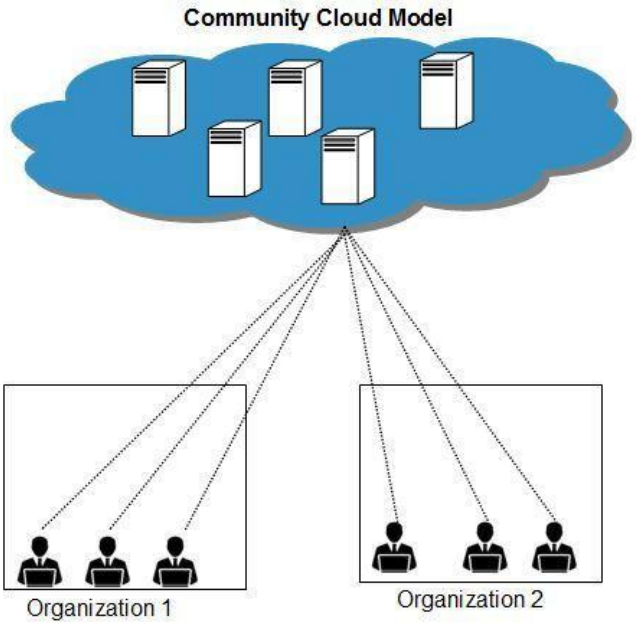
Disadvantages
Networking issues
Networking becomes complex due to presence of private and public cloud.

Security compliance
It is necessary to ensure that cloud services are compliant with organization's security policies.

Infrastructural dependency
The **hybrid cloud model** is dependent on internal it infrastructure, therefore it is necessary to ensure redundancy across data centers.

Community cloud:

The **community cloud** allows system and services to be accessible by group of organizations. It shares the infrastructure between several organizations from a specific community. It may be managed internally or by the third-party.



Benefits
There are many benefits of deploying cloud as **community cloud** model. The following diagram shows some of those benefits:

Cost effective

Community cloud offers same advantage as that of public\ cloud at low cost. Sharing between organizations community cloud provides an infrastructure to share cloud resources and capabilities among several organizations.

Security

Community cloud is comparatively more secure than the public cloud.

Issues

 since all data is housed at one location, one must be careful in storing data in community cloud because it might be accessible by others.

 It is also challenging to allocate responsibilities of governance, security and cost.

Service Oriented Architecture (SOA)

A Service-Oriented Architecture or SOA is a design pattern which is designed to build distributed systems that deliver services to other applications through the protocol. It is only a concept and not limited to any programming language or platform.

Service

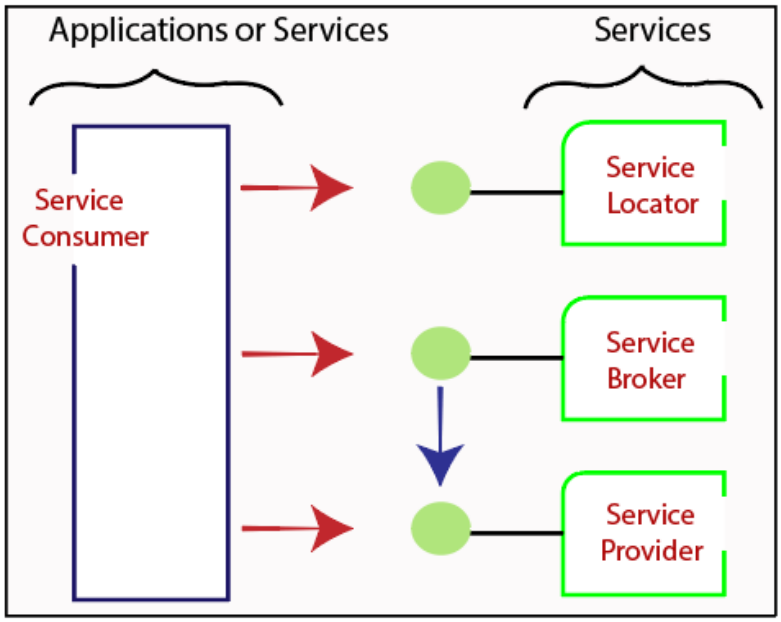
A service is a well-defined, self-contained function that represents a unit of functionality. A service can exchange information from another service. It is not dependent on the state of another service. It uses a loosely coupled, message-based communication model to communicate with applications and other services.

Service Connections

The figure given below illustrates the service-oriented architecture. Service consumer sends a service request to the service provider, and the service provider sends the service response to the service consumer. The service connection is understandable to both the service consumer and service provider.

Service-Oriented Terminologies

Let's see some important service-oriented terminologies:



- **Services -** The services are the logical entities defined by one or more published interfaces.
- **Service provider -** It is a software entity that implements a service specification.
- **Service consumer -** It can be called as a requestor or client that calls a service provider. A service consumer can be another service or an end-user application.
- **Service locator -** It is a service provider that acts as a registry. It is responsible for examining service provider interfaces and service locations.
- **Service broker -** It is a service provider that pass service requests to one or more additional service providers.

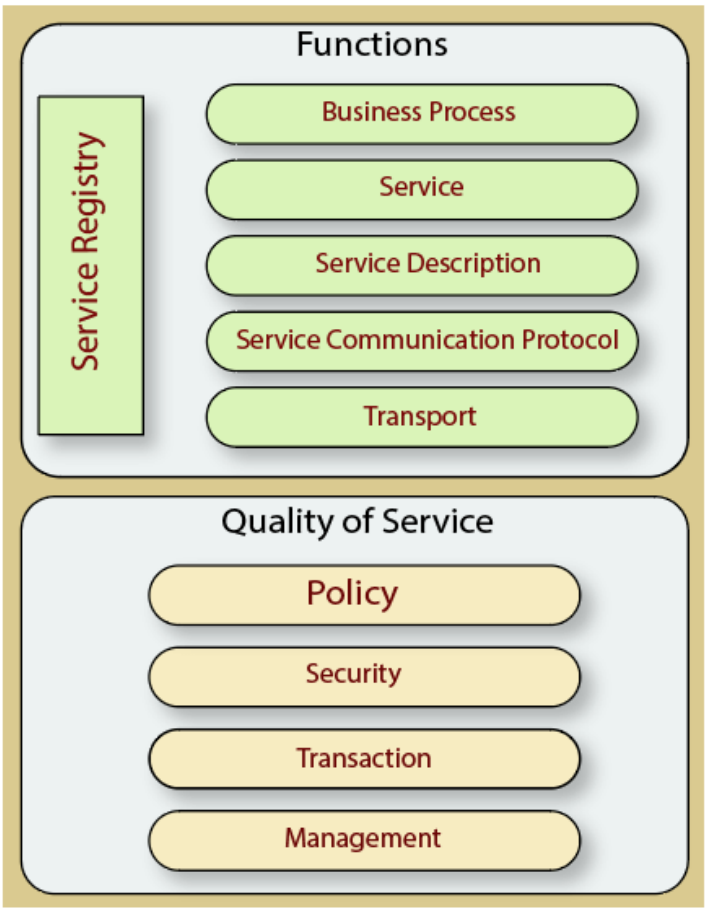
Characteristics of SOA

The services have the following characteristics:

- They are loosely coupled.
- They support interoperability.
- They are location-transparent
- They are self-contained.

Components of service-oriented architecture

The service-oriented architecture stack can be categorized into two parts - functional aspects and quality of service aspects.



Functional aspects

The functional aspect contains:

- **Transport** - It transports the service requests from the service consumer to the service provider and service responses from the service provider to the service consumer.
- **Service Communication Protocol** - It allows the service provider and the service consumer to communicate with each other.
- **Service Description** - It describes the service and data required to invoke it.
- **Service** - It is an actual service.

- **Business Process** - It represents the group of services called in a particular sequence associated with the particular rules to meet the business requirements.
- **Service Registry** - It contains the description of data which is used by service providers to publish their services.

Quality of Service aspects

The quality-of-service aspects contains:

- **Policy** - It represents the set of protocols according to which a service provider makes and provide the services to consumers.
- **Security** - It represents the set of protocols required for identification and authorization.
- **Transaction** - It provides the surety of consistent result. This means, if we use the group of services to complete a business function, either all must complete or none of the complete.
- **Management** - It defines the set of attributes used to manage the services.

Advantages of SOA

SOA has the following advantages:

- **Easy to integrate** - In a service-oriented architecture, the integration is a service specification that provides implementation transparency.
- **Manage Complexity** - Due to service specification, the complexities get isolated, and integration becomes more manageable.
- **Platform Independence** - The services are platform-independent as they can communicate with other applications through a common language.
- **Loose coupling** - It facilitates to implement services without impacting other applications or services.
- **Parallel Development** - As SOA follows layer-based architecture, it provides parallel development.
- **Available** - The SOA services are easily available to any requester.
- **Reliable** - As services are small in size, it is easier to test and debug them.
-

Practical applications of SOA:
SOA is used in many ways around us whether it is mentioned or not.

1. SOA infrastructure is used by many armies and air force to deploy situational awareness systems.
2. SOA is used to improve the healthcare delivery.
3. Nowadays many apps are games and they use inbuilt functions to run. For example, an app might need GPS so it uses inbuilt GPS functions of the device. This is SOA in mobile solutions.
4. SOA helps maintain museums a virtualized storage pool for their information and content.

Security, trust, and privacy

Security, trust, and privacy issues are major obstacles for massive adoption of cloud computing. The traditional cryptographic technologies are used to prevent data tampering and access to sensitive information. The massive use of virtualization technologies exposes the existing system to new threats, which previously were not considered applicable.

For example, it might be possible that applications hosted in the cloud can process sensitive information; such information can be stored within a cloud storage facility using the most advanced technology in cryptography to protect data and then be considered safe from any attempt to access it without the required permissions. Although these data are processed in memory, they must necessarily be decrypted by the legitimate application, but since the application is hosted in a managed virtual environment it becomes accessible to the virtual machine manager that by program is designed to access the memory pages of such an application. In this case, what is experienced is a lack of control over the environment in which the application is executed, which is made possible by leveraging the cloud. It then happens that a new way of using existing technologies creates new opportunities for additional threats to the security of applications. The lack of control over their own data and processes also poses severe problems for the trust we give to the cloud service provider and the level of privacy we want to have for our data.

On one side we need to decide whether to trust the provider itself; on the other side, specific regulations can simply prevail over the agreement the provider is willing to establish with us concerning the privacy of the information managed on our behalf. Moreover, cloud services delivered to the end user can be the result of a complex stack of services that are obtained by third parties via the primary cloud service provider. In this case there is a chain of responsibilities in terms of service delivery that can introduce more vulnerability for the secure management of data, the enforcement of privacy rules, and the trust given to the service provider. In particular, when a violation of privacy or illegal access to sensitive information is detected, it could become difficult to identify who is liable for such violations. The challenges in this area are, then, mostly concerned with devising secure and trustable systems from different perspectives: technical, social, and legal.