DS4110PE: CLOUD COMPUTING

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References

Text Books:

1. Essentials of cloud Computing: K. Chandra sekhran, CRC press, 2014

ReferenceBooks:

1.**Cloud Computing**: Principles and Paradigms by Rajkumar Buyya, James Broberg and And rzej M. Goscinski, Wiley,2011.

2. Distributed and Cloud Computing, KaiHwang, GeofferyC. Fox, Jack J. Dongarra, Elsevier,2012.

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Prerequisites

- This course provides an insight into cloud computing

- Include-distributed system models
- software environments
- cloud computing architecture

Content

Unit–1 Introduction, Cloud Computing, High-Performance Computing

Unit–2 Motivation for Cloud Computing, Principles of Cloud Computing

Unit–3 Cloud architecture, Phases of Cloud Migration Approaches for Cloud Migration.

Unit–4 Cloud Service Models

Unit–5 Cloud Service Providers

UNIT-1

Computing Paradigms

CLOUD COMPUTING INTRODUCTION

➢What is computing?

- The process of utilizing computer technology to complete a task.
- Computing may involve computer hardware and/or software, but must involve some form of a computer system.

➢What is paradigms?

- A style or a way of doing something.
- A set of practices to be followed to accomplish a task.

➢Computing Paradigms

- In the domain of computing, there are many different standard practices being followed based on inventions and technological advancements.

Computing Paradigms

- The various computing paradigms:

~High performance computing,

~Parallel computing

~Cluster computing,

~Distributed computing

~Grid computing,

~Cloud computing,

~Bio-computing,

~Mobile computing,

~Quantum computing,

~Optical computing,

~Nano computing.

High Performance Computing

High Performance Computing

- In high-performance computing systems, a pool of processors areconnected with other resources like memory, storage, and input and output devices, and the deployed software is enabled to run in the entire system of connected components.

- The processor machines can be of homogeneous or heterogeneous type.

- The legacy meaning of high-performance computing (HPC) is the supercomputers; however, it is not true in present-day computingscenarios.

- Thus, examples of HPC include a small cluster of desktopcomputers or personal computers (PCs) to the fastest supercomputers.

- HPC systems are normally found in those applications where it is required to use or solve scientific problems.

- Most of the time, the challenge in working with these kinds of problems is to perform suitable simulation study, and this can beaccomplished by HPC without any difficulty.

- Scientific examples such as protein folding in molecular biology and studies on developing models and applications based on nuclear fusion are worth noting as potential applications for HPC.

High Performance Computing


High-Performance Computing
Supercomputing Power for Your Mission-Critical Applications

Parallel Computing

Parallel Computing

- **Serial Computing:**
- Traditionally, software has been written for ***serial*** computation:
  - A problem is broken into a discrete series of instructions
  - Instructions are executed sequentially one after another
  - Executed on a single processor
  - Only one instruction may execute at any moment in time

Parallel Computing

- **Parallel Computing:**
- In the simplest sense, **parallel computing** is the simultaneous use of multiple compute resources to solve a computational problem:
  - A problem is broken into discrete parts that can be solved concurrently
  - Each part is further broken down to a series of instructions
  - Instructions from each part execute simultaneously on different processors
  - An overall control/coordination mechanism is employed

Distributed Computing

Distributed Computing

- Distributed computing is also a computing system that consists of multiple computers or processor machines connected through a network,which can be homogeneous or heterogeneous, but run as a single system.
- The connectivity can be such that the CPUs in a distributed system can bephysically close together and connected by a local network, or they can be geographically distant and connected by a wide area network.
- The heterogeneity in a distributed system supports any number of possible configurations in the processor machines, such as mainframes,PCs, workstations, and minicomputers.

- The goal of distributed computing is to make such a network work as a single computer.
- Distributed computing systems are advantageous over centralized systems, because there is a support for the following characteristicfeatures:
  1. **Scalability:** It is the ability of the system to be easily expandedby adding more machines as needed, and vice versa, without affecting the existing setup.
  2. **Redundancy or replication**: Here, several machines can provide the same services, so that even if one is unavailable (orfailed), work does not stop because other similar computing supports will be available.

Distributed Computing

Centralized

- A system with centralized multiprocessor parallel architecture. Inthe late 1980 s Centralized systems have been progressively replaced by distributed systems.

Characteristics of centralized system

- Non autonomous components
- usually homogeneous technology
- Multiple users share the same resources at all time
- single point of control
- single point of failure

Distributed Computing

- Set of tightly coupled programs executing on one or more computers which are interconnected through a network and coordinating their actions. These programs know about one another and carry out tasks that none could carry out in isolation
- **Characteristics of distributed system**
- Autonomous components
- Mostly build using heterogeneous technology
- System components may be used exclusively
- Concurrent processes can execute
- Scalability- possibility of adding new hosts
- openness- easily extended and modified
- Heterogeneity-supports various H/W S/w platforms
- Resource sharing- H/w, S/W and data
- fault tolerance- ability to function correctly even if faults occur

Distributed Computing

- the following are the different application of the distributedsystem.
- Global positioning System
- World Wide Web
- Air Traffic Control System
- Automated Banking System
- In the World Wide Web application the data or application were distributed on the several number of the heterogeneous computer system, but for the end user or the browser it seemsto be a single system from which user got the information.
- The multiple number of computer working concurrently and perform the resource sharing in the World Wide Web.

Cluster Computing

Cluster Computing

- A cluster computing system consists of a set of the same or similartype of processor machines connected using a dedicated network infrastructure.
- All processor machines share resources such as a common home directory and have a software such as a message passing interface (MPI) implementation installed to allow programs to be run acrossall nodes simultaneously.
- This is also a kind of HPC category.
- The individual computers in a cluster can be referred to as nodes.

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- The reason to realize a cluster as HPC is due to the fact that the individual nodes can work together to solve a problem larger thanany computer can easily solve.
- And, the nodes need to communicate with one another in order towork cooperatively and meaningfully together to solve the problem in hand.
- If we have processor machines of heterogeneous types in a cluster,this kind of clusters become a subtype and still mostly are in the experimental or research stage.

Cluster Computing

- A computer cluster help to solve complex operations more efficiently with much faster processing speed, better data integritythan a single computer and they only used for mission-critical applications.
- The Clustering methods have identified as- HPC IAAS, HPC PAAS, that are more expensive and difficult to setup and maintainthan a single computer.

A computer cluster defined as the addition of processes for delivering large-scale processing to reducedowntime and larger storage capacity as compared to other desktop workstation or computer

Cluster Computing

- Some of the critical Applications of Cluster Computers are GoogleSearch Engine, Petroleum Reservoir Simulation, Earthquake Simulation, Weather Forecasting.
- **Cluster Can be classified into two category Open and Close Cluster.**
- **Open Cluster**: All nodes in Open Cluster are needed IPs, and thatare accessible through internet/web, that cause more security concern.
  Close Cluster: On the other hand Close Cluster are hide behind the gateway node and provide better security.

Cluster Computing

- **Types of Cluster computing**
- 1. **Load-balancing clusters**: As the name implies, This system isused to distribute workload across multiple computers. That system
- distributes the processing load as possible across a cluster of computers.
  2. **High availability (HA) clusters**: A high availability clusters (HA cluster) are the bunch of computers that can reliably utilise for
- redundant operations in the event of nodes failure in Cluster computing.
  3. **High performance (HP) clusters**: This computer networking methodology use supercomputers and Cluster computing to solveadvanced computation problems.

Advantages of using Cluster computing

- 1. **Cost efficiency**: In a Cluster computing Cost efficiency is the ratio of cost to output that is the connecting group of the computeras computer cluster much cheaper as compared to mainframe computers.
  2. **Processing speed**: The Processing speed of computer cluster is the same as a mainframe computer.
  3. **Expandability**: The best benefit of Cluster Computing is that itcan be expanded easily by adding the additional desktop workstation to the system.
  4. **High availability of resources**: If any node fails in a computercluster, another node within the cluster continue to provide uninterrupted processing. When a mainframe system fails, the entire system fails.

Grid Computing

- The computing resources in most of the organizations areunderutilized but are necessary for certain operations.
- The idea of grid computing is to make use of such non utilizedcomputing power by the needy organizations, and thereby the return on investment (ROI) on computing investments can be increased.
- Thus, grid computing is a network of computing or processor machines managed with a kind of software such as middleware, inorder to access and use the resources remotely.
- The managing activity of grid resources through the middleware is called grid services.

- Grid services provide access control, security, access to data including digital libraries and databases, and access to large-scaleinteractive and long-term storage facilities.
- Grid computing is more popular due to the following reasons:
  - ~Its ability to make use of unused computing power, and thus, itis a cost-effective solution (reducing investments, only recurring costs)
  - ~As a way to solve problems in line with any HPC-based application
  - ~Enables heterogeneous resources of computers to work cooperatively and collaboratively to solve a scientific problem
- Researchers associate the term grid to the way electricity is distributed in municipal areas for the common man.

Cloud Computing

- The computing trend moved towards cloud from the concept of grid computing, particularly when large computing resources arerequired to solve a single problem, using the ideas of computing power as a utility and other allied concepts.

- However, the potential difference between grid and cloud is that grid computing supports leveraging several computers in parallelto solve a particular application, while cloud computing supports leveraging multiple resources, including computing resources, todeliver a unified service to the end user.

Bio Computing

Bio computing

- Bio computing systems use the concepts of biologically derived orsimulated molecules (or models) that perform computational processes in order to solve a problem.
- The biologically derived models aid in structuring the computer programs that become part of the application.
- Biocomputing provides the theoretical background and practical tools for scientists to explore proteins and DNA.
- DNA and proteins are nature’s building blocks, but these building blocks are not exactly used as bricks.

- The function of the final molecule rather strongly depends on the order of these blocks.
- Thus, the bio computing scientist works on inventing the order suitable for various applications mimicking biology.
- Bio computing shall, therefore, lead to a better understanding oflife and the molecular causes of certain diseases.

the processing (or computing) elements aresmall (i.e., handheld devices) and the communication between various resources is taking place using wireless media.

- Inmobile computing communication for voice applications (e.g., cellular phone)is widely established throughout the world and witnesses a very rapid growth in all its dimensions including the increase in the number of subscribers of various cellular networks.

An extension of this technology is the ability to send and receivedata across various cellular networks using small devices such assmart phones

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- Quantum computing is the area of study focused on developing computer technology based on the principles of quantum theory,which explains the nature and behavior of energy and matter on the quantum (atomic and subatomic) level.
- Quantum computing is an as-of-yet theoretical computing modelthat uses a very different form of data handling to perform calculations.
- The emergence of quantum computing is based on a new kind ofdata unit that could be called non-binary, as it has more than twopossible values.
- Manufacturers of computing systems say that there is a limit forcramming more and more transistors into smaller and smaller spaces of integrated circuits (ICs) and thereby doubling the processing power about every 18 months.

Optical Computing

- Optical computing system uses the photons in visible light orinfrared beams, rather than electric current, to perform digitalcomputations.
- An electric current flows at only about 10% of the speed of light.
- This limits the rate at which data can be exchanged over longdistances and is one of the factors that led to the evolution ofoptical fiber.
- By applying some of the advantages of visible and/or IR networksat the device and component scale, a computer can be developed that can perform operations 10 or more times faster than a conventional electronic computer.

Nano computing

- Nano computing refers to computing systems that are constructed from nanoscale components.
- The silicon transistors in traditional computers may be replaced by transistors based on carbon nanotubes.
- The successful realization of nanocomputers relates to the scale and integration of these nanotubes or components.
- The issues of scale relate to the dimensions of the components; they are, at most, a few nanometers in at least two dimensions.
- The issues of integration of the components are twofold: first, themanufacture of complex arbitrary patterns may be economically infeasible, and second, nanocomputers may include massive quantities of devices.

UNIT-II
Cloud ComputingFundamentals

Introduction

- Modern computing with our laptop or desktop or even with tablets/smartphones using the Internet to access the data and details thatwe want, which are located/stored at remote places/computers, through the faces of applications like Facebook, e-mail, and YouTube, brings theactual power of information that we need instantaneously within no time.
- Even if millions of users get connected in this manner, from anywhere in the world, these applications do serve what these users–customers want.
- This phenomenon of supply of information or any other data and detailsto all the needy customers, as and when it is asked, is the conceptual understanding and working of what is known as cloud computing.

Introduction

- **CLOUD:** The word ‘Cloud’ means a cluster of servers, network, software, interface etc., which are required for the user to execute aparticular task.

- **COMPUTING**: It refers to the delivery of this cluster as a service to the user so that user can use it as and when required.

- **CLOUD COMPUTING**: It is the practice of using a network of remote servers hosted on the Internet to store, manage and processdata, rather than a local server or a personal computer.

Motivation for Cloud Computing

- Let us review the scenario of computing prior to the announcement and availability of cloud computing:
- The users who are in need of computing are expected to invest money oncomputing resources such as hardware, software, networking, and storage;
- This investment naturally costs a bulk currency to the users as they haveto buy these computing resources, keep these in their premises, and maintain and make it operational—all these tasks would add cost.
- And, this is a particularly true and huge expenditure to the enterprises that require enormous computing power and resources.

Motivation for Cloud Computing

- It is a computing solution growing in popularity, especially among individuals and small- and medium-sized companies (SMEs).
- In the cloud computing model, an organization's core computerpower resides offsite and is essentially subscribed to rather than owned.
- Thus, cloud computing comes into focus and much needed only when we think about what computing resources and information technology(IT) solutions are required.
- This need caters to a way to increase capacity or add capabilities onthe fly without investing in new infrastructure, training new personnel, or licensing new software.
- Cloud computing encompasses the subscription based or pay-per-useservice model of offering computing to end users or customers over the Internet.

The Need for Cloud Computing

- The main reasons for the need and use of cloud computing are convenience and reliability.
- In the past, if we wanted to bring a file, we would have to save it toa Universal Serial Bus (USB) flash drive, external hard drive, or compact disc (CD) and bring that device to a different place.
- Instead, saving a file to the cloud (e.g., use of cloud applicationDrop box) ensures that we will be able to access it with any computer that has an Internet connection.
- The cloud also makes it much easier to share a file with friends, making it possible to collaborate over the web.

Defining Cloud Computing

- In the simplest terms, cloud computing means storing and accessing data and programs over the Internet from a remote location or computer instead of our computer's hard drive.
- This so called remote location has several properties such as scalability,elasticity etc., which is significantly different from a simple remote machine.
- The cloud is just a metaphor for the Internet.
- When we store data on or run a program from the local computer's hard drive, that is called local storage and computing.
- For it to be considered cloud computing, we need to access our data or programs over the Internet.
- The end result is the same; however, with an online connection, cloudcomputing can be done anywhere, anytime, and by any device.

Cloud Computing is a Service

- The simplest thing that any computer does is allow us to store and retrieve information.
- We can store our family photographs, our favorite songs, or evensave movies on it, which is also the most basic service offered bycloud computing.
- Let us look at the example of a popular application called Flickr toillustrate the meaning of this section.

While Flickr started with an emphasis on sharing photos and images, it has emerged as a great place to store those images.

- **In many ways, it is superior to storing the images on your computer**:

1. First, Flickr allows us to easily access our images no matter wherewe are or what type of device we are using. While we might upload thephotos of our vacation from our home computer, later, we can easily access them from our laptop at the office.

2. Second, Flickr lets us share the images. There is no need to burn them to a CD or save them on a flash drive. We can just send someoneour Flickr address to share these photos or images.

3. Third, Flickr provides data security. By uploading the images to Flickr, we are providing ourselves with data security by creating a backup on the web. And, while it is always best to keep a local copy—either on a computer, a CD, or a flash drive—the truth is that we are farmore likely to lose the images that we store locally than Flickr is of losing our images.

Cloud Computing is a Service

- **Infrastructure as a Service (Iaas)**
- Iaas refers to providing the complete access to the servers operating system. Typically, Iaas provides hardware, storage, servers and data center space or network components, it may alsoinclude software.
- IaaS gives users automated and scalable environments with extreme flexibility and control.
- Eg: EC2(Elastic Compute cloud)
- Usually billed based on usage
- Usually multi tenant virtualized environment
- Can be coupled with Managed Services for OS and application support

- **Platform as a Service (Paas)**
- In Paas, one does not get access to the whole operating system. Rather access is given at a Dashboard level, where a user uploadsthe data and the rest is taken care by the cloud provider.
- Eg: Elastic Beanstalk
- PaaS provides a framework for quickly developing and deployingapplications by automating infrastructure provisioning and management.
- PaaS provides all of the facilities required to support the completelife cycle of building and delivering web applications and servicesentirely from the Internet.
- Multi tenant environments
- Highly scalable multi tier architecture

Cloud Computing is a Service

- **Software as a Service (Saas)**
- Saas refers to the practice of directly providing the software to thecustomer, without making any server or dashboard available to them.
- Eliminating the need to install and run programs on individual devices. Saas makes applications available through the internet.
- Eg: Facebook, GoogleDocs, Netflix
- Usually billed based on usage
- Usually multi tenant environment
- Highly scalable architecture

5-4-3 Principles of Cloud computing

The 5-4-3 principles put forth by NIST describe

- (a) the five essential characteristic features that promote cloud computing,
- (b) the four deployment models that are used to narrate the cloud computing opportunities for customers while looking at architectural models, and
- (c) the three important and basic service offering models of cloud computing.

Principles of Cloud computing

Essential, which means that if any of these characteristics is missing, then it is not cloud computing:

1. **On-demand self-service:** A consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiringhuman interaction with each service's provider.
2. **Broad network access:** Capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms(e.g., mobile phones, laptops, and personal digital assistants[PDAs]).

Principles of Cloud computing

3. Elastic resource pooling:

- The provider's computing resources are pooled to serve multiple consumers using a multitenant model, with different physical andvirtual resources dynamically assigned and reassigned according to consumer demand.
- There is a sense of location independence in that the customer generally has no control or knowledge over the exact location ofthe provided resources but may be able to specify the location ata higher level of abstraction (e.g., country, state, or data center).
- Examples of resources include storage, processing, memory, and network bandwidth.

Four Cloud Deployment Models

Private cloud providers

- HPE. By most estimates, Hewlett Packard Enterprise (HPE) is a key leader in the **private cloud** market. ...
- VMware. The Wikibon report said that VMware was tied with HP for first place in the true **private cloud** market for 2015 with 7 percent ofthe market. ...
- Dell. ...

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- Dell. ...
- Oracle. ...
- IBM. ...
- Microsoft. ...
- Cisco. ...
- NetApp.

1. Public cloud:

The cloud infrastructure is provisioned for open use by the general public.

It may be owned, managed, and operated by a business, academic, orgovernment organization, or some combination of them. It exists on the premises of the cloud provider.

2. Public cloud:

- Amazon Web Services. Amazon Web Services (AWS) is the undisputed market leader in **cloud computing**. ...
- Microsoft Azure. It's a little more difficult to figure out how much revenue Microsoft generates from **cloud computing**. ...
- Google **Cloud** Platform.

IBM **Cloud**.

3. Community cloud:

- The cloud infrastructure is shared by several organizations andsupports a specific community that has shared concerns (e.g., mission, security requirements, policy, and compliance considerations).
- It may be managed by the organizations or a third party and may exist on premise or off premise.

3.Hybrid cloud:

- The cloud infrastructure is a composition of two or more distinctcloud infrastructures (private, community, or public) that remainunique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).

Benefits of Cloud Computing

1. **Achieve economies of scale:** We can increase the volume output orproductivity with fewer systems and thereby reduce the cost per unit of a project or product.
2. **Reduce spending on technology infrastructure:** It is easy to access data and information with minimal upfront spending in a pay-as-you-go approach, in the sense that the usage and paymentare similar to an electricity meter reading in the house, which is based on demand.
3. **Globalize the workforce:** People worldwide can access the cloud with Internet connection.
4. **Streamline business processes:** It is possible to get more work done in less time with less resource.
5. **Reduce capital costs:** There is no need to spend huge money on hardware, software, or licensing fees.

6. **Pervasive accessibility:** Data and applications can be accessed anytime, anywhere, using any smart computing device, makingour life so much easier.
7. **Monitor projects more effectively:** It is possible to confine within budgetary allocations and can be ahead of completion cycle times.
8. **Less personnel training is needed:** It takes fewer people to do more work on a cloud, with a minimal learning curve on hardwareand software issues.
9. **Minimize maintenance and licensing software:** As there is no toomuch of on-premise computing resources, maintenance becomes simple and updates and renewals of software systems rely on the cloud vendor or provider.
10. **Improved flexibility:** It is possible to make fast changes in our work environment without serious issues at stake.

Drawbacks of Cloud Computing

1. The main point in this context is that if we lose our Internet connection, we have lost the link to the cloud and thereby to thedata and applications.
2. There is also a concern about security as our entire working withdata and applications depend on other's (cloud vendor or providers) computing power.
3. while cloud computing supports scalability (i.e., quickly scaling upand down computing resources depending on the need), it does not permit the control on these resources as these are not owned by the user or customer.
4. Depending on the cloud vendor or provider, customers may face restrictions on the availability of applications, operating systems,and infrastructure options.

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UNIT 3
Cloud Computing Architecture andManagement

- **Cloud architecture,**
- **Layers,**
- **Anatomy of the Cloud,**
- **Network Connectivity in Cloud Computing,**
- **Applications on the Cloud,**
- **Managing the Cloud,**
  - **Managing the Cloud Infrastructure**
  - **Managing the Cloud application,**
- **Migrating Application to Cloud,**
- **Phases of Cloud Migration Approaches for CloudMigration**

Introduction

- **Cloud computing is similar to other technologies in away that it also has several basic concepts that one should learn before knowing its core concepts.**
- **There are several processes and components of cloudcomputing that need to be discussed.**
- **One of the topics of such prime importance isarchitecture.**
- **Architecture is the hierarchical view of describing atechnology.**
- **This usually includes the components over which theexisting technology is built and the components that are dependent on the technology.**

- **Management is important because of the quality ofservice (QoS) factors that are involved in the cloud.**
- **These QoS factors form the basis for cloud computing.**
- **All the services are given based on these QoS factors.**
- **Similarly, application migration to the cloud also playsa very important role.**
- **Not all applications can be directly deployed to thecloud.**
- **An application needs to be properly migrated to the cloud to be considered a proper cloud application thatwill have all the properties of the cloud.**

Cloud Architecture

- **Any technological model consists of an architecturebased on which the model functions, which is a hierarchical view of describing the technology.**
- **The cloud also has an architecture that describes itsworking mechanism.**
- **It includes the dependencies on which it works andthe components that work over it.**
- **The cloud is a recent technology that is completelydependent on the Internet for its functioning.**

The cloud architecture can be divided into fourlayers based on the access of the cloud by the user. They are as follows:

- **Layer 1 (User/Client Layer)**
  - **This layer is the lowest layer in the cloud architecture. All the users or client belong to thislayer.**
  - **This is the place where the client/user initiates theconnection to the cloud.**
  - **The client can be any device such as a thin client, thick client, or mobile or any handheld device thatwould support basic functionalities to access a webapplication.**

- **The thin client here refers to a device that is completely dependent on some other system forits complete functionality.**
- **In simple terms, they have very low processingcapability.**
- **Similarly, thick clients are general computersthat have adequate processing capability.**
- **They have sufficient capability for independentwork.**
- **Usually, a cloud application can be accessed inthe same way as a web application.**
- **But internally, the properties of cloud applications are significantly different.**

Thus, this layer consists of client devices.

- **Layer 2 (Network Layer)**
  - **This layer allows the users to connect to the cloud.**
  - **The whole cloud infrastructure is dependent on thisconnection where the services are offered to the customers.**
  - **This is primarily the Internet in the case of a publiccloud.**
  - **The public cloud usually exists in a specific locationand the user would not know the location as it is abstract.**
  - **And, the public cloud can be accessed all over theworld.**
  - **In the case of a private cloud, the connectivity may beprovided by a local area network (LAN).**
  - **Even in this case, the cloud completely depends on thenetwork that is us**

- Layer 3 (Cloud Management Layer)
  - **This layer consists of software's that are used inmanaging the cloud.**
  - **The software's can be a cloud operating system (OS),a software that acts as an interface between the data center (actual resources) and the user, or a management software that allows managing resources.**

Layer 4 (Hardware Resource Layer)

- Layer 4 consists of provisions for actual hardwareresources.
- Usually, in the case of a public cloud, a data center is used inthe back end.
- Similarly, in a private cloud, it can be a data center, which isa huge collection of hardware resources interconnected to each other that is present in a specific location or a high configuration system.
- This layer comes under the purview of SLAs.
- This is the most important layer that governs the SLAs.
- This layer affects the SLAs most in the case of data centers.
- Whenever a user accesses the cloud, it should be available tothe users as quickly as

possible and should be within the time that is defined by the SLAs.

- **As mentioned, if there is any discrepancy in provisioningthe resources or application, the service provider has to pay the penalty.**
- **Hence, the data center consists of a high-speed network connection and a highly efficient algorithm to transfer thedata from the data center to the manager.**
- **There can be a number of data centers for a cloud, and similarly, a number of clouds can share a data center.**

Anatomy of the Cloud

- Cloud anatomy can be simply defined as the structure of thecloud.
- Cloud anatomy cannot be considered the same as cloudarchitecture.
- It may not include any dependency on which or over whichthe technology works, whereas architecture wholly defines and describes the technology over which it is working.
- Architecture is a hierarchical structural view that definesthe technology as well as the technology over which it is dependent or/and the technology that are dependent on it.

Thus, anatomy can be considered as a part of architecture

- **There are basically five components of the cloud:**

1. **Application: The upper layer is the application layer.**
   In this layer, any applications are executed.
2. **Platform: This component consists of platforms thatare responsible for the execution of the application.**
   This platform is between the infrastructure and theapplication.
3. **Infrastructure: The infrastructure consists of resources over which the other components work. Thisprovides computational capability to the user.**
4. **Virtualization: Virtualization is the process of makinglogical components of resources over the existing physical resources. The logical components are isolatedand independent, which form the infrastructure.**

5. Physical hardware: The physical hardware is providedby server and storage units.

Network Connectivity in Cloud Computing

Cloud computing is a technique of resource sharing whereservers, storage, and other computing infrastructure in multiple locations are connected by networks.

- **In the cloud, when an application is submitted for its execution, needy and suitable resources are allocated from this collection of resources; as these resources are connectedvia the Internet, the users get their required results.**
- **For many cloud computing applications, network performancewill be the key issue to cloud computing performance.**
- **Since cloud computing has various deployment options, we now consider the important aspects related to the cloud deployment models and their accessibility from the viewpointof network connectivity.**

Public Cloud Access Networking

- **In this option, the connectivity is often through the Internet, though some cloud providers may be able to support virtualprivate networks (VPNs) for customers.**
- **Accessing public cloud services will always create issues related to security, which in turn is related to performance.**
- **One of the possible approaches toward the support of security is to promote connectivity through encrypted tunnels, so that the information may be sent via secure pipeson the Internet.**
- **This procedure will be an overhead in the connectivity, andusing it will certainly increase delay and may impact performance**

Private Cloud Access Networking

- **In the private cloud deployment model, since the cloud is part of an organizational network, the technology and approaches are local to the in-housenetwork structure.**
- **This may include an Internet VPN or VPN servicefrom a network operator.**
- **If the application access was properly done with an organizational network—connectivity in a precloud configuration—transition to private cloud computingwill not affect the access performance.**

Public Intracloud Networking

- **Another network connectivity consideration in cloud computing is intracloud networking for public cloud services.**
- **Here, the resources of the cloud provider and thus the cloud service to the customer are based on the resources that are geographically apart from each other but still connected via theInternet.**
- **Public cloud computing networks are internal to the service provider and thus not visible to the user/customer;**
- **however, the security aspects of connectivity and the accessmechanisms of the resources are important.**
- **Another issue to look for is the QoS in the connected resources worldwide.**

Private Intracloud Networking

- The most complicated issue for networking and connectivity incloud computing is private intracloud networking.
- Private intracloud networking is usually supported over connectivity between the major data center sites owned by thecompany.
- All cloud computing implementations will rely on intracloudnetworking to link users with the resource to which their application was assigned.

Applications on the Cloud

- The power of a computer is realized through the applications.
- There are several types of applications.

STAND-ALONE APPLICATION:

- The first type of applications that was developed and used was astand-alone application.
- A stand-alone application is developed to be run on a singlesystem that does not use network for its functioning.
- These stand-alone systems use only the machine in which they are installed.
- The functioning of these kinds of systems is totally dependent on the resources or features available within the system.

- **<u>WEB APPLICATION:</u>**
- **The web applications were different from the stand-alone applications in many aspects.**
- **The main difference was the client server architecturethat was followed by the web application.**

Unlike stand-alone applications, these systems weretotally dependent on the network for its working

1. Multitenancy:

- Multitenancy is one of the important properties of cloud that make it different from other types of application in which the software can be shared by different users with full independence.
- Here, independence refers to logical independence.
- Each user will have a separate application instance and the changes in one application would not affect the other.
- There are no restrictions in the number of applications being shared.
- Web application and cloud application are similar as the users use the same way to access both.

2. Elasticity:

- **Elasticity is also a unique property that enables the cloud to serve better.**
- **According to Herbst et al. , elasticity can be defined as the degree to which a system is able to adapt to workload changes by provisioning and deprovisioning resources in an autonomic mannersuch that at each point in time, the available resources match the current demand as closely as possible.**
- **Elasticity allows the cloud providers to efficiently handle the number of users, from one to several hundreds of users at a time.**
- **In addition to this, it supports the rapid fluctuation of loads, that is, the increase or decrease in the number of users and their usage canrapidly change.**

1. Heterogeneous cloud platform:

- **The cloud platform supports heterogeneity, wherein any type of application can be deployed in the cloud.**
- **Because of this property, the cloud is flexible for the developers, which facilitates deployment.**
- **The applications that are usually deployed can be accessed by the users using a web browser**

3. Quantitative measurement:

- The services provided can be quantitatively measured. The user is usually offered services based on certain charges.
- Here, the application or resources are given as a utility on a pay-per-use basis.
- Thus, the use can be monitored and measured.
- Not only the services are measureable, but also the link usage and severalother parameters that support cloud applications can be measured.
- This property of measuring the usage is usually not available in a web application and is a unique feature for cloud-based applications.

4. On-demand service:

- **The cloud applications offer service to the user, ondemand, that is, whenever the user requires it.**
- **The cloud service would allow the users to access webapplications usually without any restrictions on time, duration, and type of device used.**
- **The previously mentioned properties are some of the features that make cloud a unique application platform.**
- **These properties mentioned are specific to the cloud hence making it as one of the few technologies that allowsapplication developers to suffice the user's needs seamlessly without any disruption.**

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1. Managing the Cloud Infrastructure

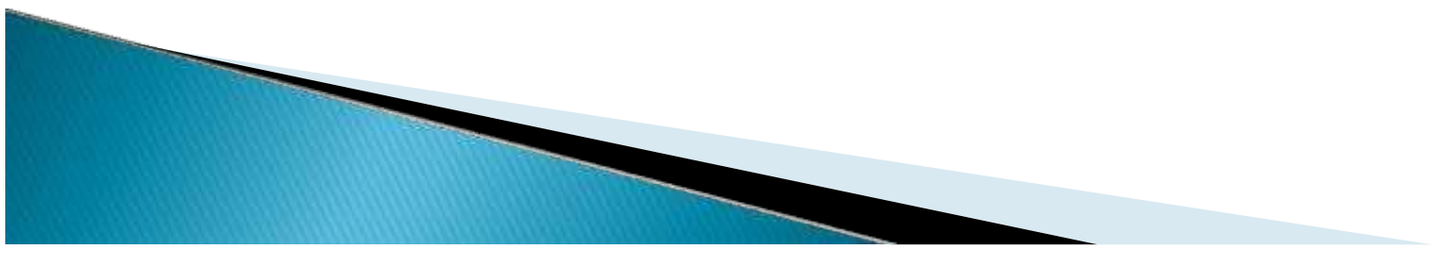
- **The infrastructure of the cloud is considered to be thebackbone of the cloud.**
- **This component is mainly responsible for the QoS factor.**
- **If the infrastructure is not properly managed, then the whole cloud can fail and QoS would be adversely affected.**
- **The core of cloud management is resource management.**
- **Resource management involves several internal tasks suchas resource scheduling, provisioning, and load balancing.**
- **These tasks are mainly managed by the cloud service provider's core software capabilities such as the cloud OSthat is responsible for providing services to the cloud andthat internally controls the cloud.**

2. Managing the Cloud Application

- **Business companies are increasingly looking to move or buildtheir corporate applications on cloud platforms to improve agility or to meet dynamic requirements that exist in the globalization of businesses and responsiveness to market demands.**
- **But, this shift or moving the applications to the cloudenvironment brings new complexities.**
- **Applications become more composite and complex, which requires leveraging not only capabilities like storage and database offered by the cloud providers but also third-partySaaS capabilities like e-mail and messaging.**
- **So, understanding the availability of an application requires inspecting the infrastructure, the services it consumes, and theupkeep of the application.**

Migrating Application to Cloud

- **Cloud migration encompasses moving one or moreenterprise applications and their IT environments from the traditional hosting type to the cloud environment, either public, private, or hybrid.**
- **Cloud migration presents an opportunity to significantly reduce costs incurred on applications.**
- **This activity comprises, of different phases likeevaluation, migration strategy, prototyping, provisioning, and testing.**



Phases of Cloud Migration

1.<u>Evaluation</u>:

- **Evaluation is carried out for all the components like current infrastructure and application architecture, environment in terms of compute, storage, monitoring, and management, SLAs, operational processes, financial considerations, risk, security, compliance, and licensing needs are identified to builda business case for moving to the cloud.**

2.<u>Migration strategy</u>:

- **Based on the evaluation, a migration strategy is drawn—a hot plug strategy is used where the applications and their data andinterface dependencies are isolated and these applications can be operationalized all at once.**
- **A fusion strategy is used where the applications can be partially migrated; but for a portion of it, there are dependencies based on existing licenses, specialized server requirements like mainframes, or extensive interconnectionswith other applications.**

Prototyping:

- **Migration activity is preceded by a prototyping activity to validateand ensure that a small portion of the applications are tested on the cloud environment with test data setup.**

3.Provisioning:

- **Premigration optimizations identified are implemented. Cloudservers are provisioned for all the identified environments, necessary platform software's and applications are deployed, configurations are tuned to match the new environment sizing,and databases and files are replicated.**
- **All internal and external integration points are properly configured. Web services, batch jobs, and operation and management software are set up in the new environments.**

4.Testing:

- **Postmigration tests are conducted to ensure that migration has been successful.**
- **Performance and load testing, failure and recovery testing, and scale-out testing are conducted against the expected traffic loadand resource utilization levels.**

Approaches for Cloud Migration

- **The following are the four broad approaches for cloud migration that have been adopted effectively by vendors:**

1. **<u>Migrate existing applications:</u>**
   - **Rebuild or rearchitect some or all the applications, taking advantage of some of the virtualization technologies around to accelerate the work.**
   - **But, it requires top engineers to develop new functionality.**
   - **This can be achieved over the course of several releases with the timing determined by customer demand.**

2. **<u>Start from scratch</u>:**
   - **Rather than cannibalize sales, confuse customers with choice, and tie up**

engineers trying to rebuild existing application, it may be easier to start again.

- Many of the R&D decisions will be different now, and with some of the more sophisticated development environments, one can achieve more even with asmall focused working team.

3. Separate company:

- One may want to create a whole new company with separate brand, management, R&D, and sales.
- The investment and internet protocol (IP) may come from the existing company, but many of the conflicts disappear once a new born in the cloudcompany is established.
- The separate company may even be a subsidiary of the existing company. What is important is that the new company can act, operate, and behavelike a cloud-based start-up.

4. Buy an existing cloud vendor:

- For a large established vendor, buying a cloud-based competitor achieves two things.
- Firstly, it removes a competitor, and secondly, it enables the vendor to hit the ground running in the cloud space.
- The risk of course is that the innovation, drive, and operational approach ofthe cloud-based company are destroyed as it is merged into the larger acquirer.

Cloud Service Models

Introduction

- Cloud computing is a model that enables the endusers to access the shared pool of resources suchas compute, network, storage, database, and application as an on-demand service without theneed to buy or own it.
- The services are provided and managed by the service provider, reducing the management effortfrom the end user side.
- The essential characteristics of the cloud includeon-demand self-service, broad network access, resource pooling, rapid elasticity, and measuredservice.

- The NIST definition of the three basic servicemodels is given as follows:

1. IaaS:
   - The ability given to the infrastructure architects todeploy or run any software on the computing resources provided by the service provider.
   - Here, the underlying infrastructures such as compute, network, and storage are managed bythe service provider.
   - Thus, the infrastructure architects are exemptedfrom maintaining the data center or underlying infrastructure.
   - [illegible] users are responsible for managing applications that are

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   - Here, the underlying infrastructures such as compute, network, and storage are managed bythe service provider.
   - Thus, the infrastructure architects are exemptedfrom maintaining the data center or underlying infrastructure.
   - The end users are responsible for managing applications that are

running on top of the serviceprovider cloud infrastructure.

- Generally, the IaaS services are provided from the serviceprovider cloud data center.
- The end users can access the services from their devicesthrough web command line interface (CLI) or applicationprogramming interfaces (APIs) provided by the service providers.
- Some of the popular IaaS providers include Amazon Web Services (AWS), Google Compute Engine, OpenStack, andEucalyptus.

3. PaaS:

- The ability given to developers to develop and deploy an application on the development platform provided by theservice provider.
- Thus, the developers are exempted from managing thedevelopment platform and underlying infrastructure.
- Here, the developers are responsible for managing thedeployed application and configuring the developmentenvironment.

4. PaaS:
   - The ability given to developers to develop and deploy an application on the development platform provided by theservice provider.
   - Thus, the developers are exempted from managing thedevelopment platform and underlying infrastructure.
   - Here, the developers are responsible for managing thedeployed application and configuring the developmentenvironment.
   - Generally, PaaS services are provided by the service provider on an on-premise or dedicated or hosted cloudinfrastructure.
   - The developers can access the development platform overthe Internet through web CLI, web user interface (UI), andintegrated development environments (IDEs).
   - Some of the popular PaaS providers include Google App Engine, Force.com, Red Hat OpenShift, Heroku, and EngineYard.

1. SaaS:
   - The ability given to the end users to access an applicationover the Internet that is hosted and managed by the service provider.
   - Thus, the end users are exempted from managing or controlling an application, the development platform, andthe underlying infrastructure.
   - Generally, SaaS services are hosted in service provider– managed or service provider–hosted cloud infrastructure.
   - The end users can access the services from any thin clientsor web browsers.
   - Some of the popular SaaS providers include Saleforce.com, Google Apps, and Microsoft office 365.

Infrastructure as a Service

- IaaS changes the way that the compute, storage, andnetworking resources are consumed.
- In traditional data centers, the computing power isconsumed by having physical access to the infrastructure. IaaS changes the computing from a physical infrastructure to a virtual infrastructure.
- IaaS provides virtual computing, storage, and networkresources by abstracting the physical resources.
- Technology virtualization is used to provide the virtualresources.
- All the virtual resources are given to the virtual machines(VMs) that are configured by the service provider.

- The targeted audience of IaaS is the IT architect.
- The IT architect can design virtual infrastructure, network, load balancers, etc., based on their needs.
- The IT architects need not maintain the physical servers as it is maintained by the service providers.
- The physical infrastructure can be maintained by theservice providers themselves.
- Thus, it eliminates or hides the complexity of maintaining the physical infrastructure from the ITarchitects.

1. Compute: Computing as a Service includes virtualcentral processing units (CPUs) and virtual main memory for the VMs that are provisioned to the end users.
2. Storage: STaaS provides back-end storage for theVM images. Some of the IaaS providers also provide the back end for storing files.
3. Network: Network as a Service (NaaS) providesvirtual networking components such as virtual router, switch, and bridge for the VMs.
4. Load balancers: Load Balancing as a Service mayprovide load balancing capability at the infrastructure layer.

Characteristics of IaaS

- IaaS providers offer virtual computing resources to theconsumers on a payas-you-go basis.
- IaaS contains the characteristics of cloud computing such as on-demand self-service, broad network access,resource pooling, rapid elasticity, and measured service.
- Apart from all these, IaaS has its own uniquecharacteristics as follows:

1. Web access to the resources:

– The IaaS model enables the IT users to accessinfrastructure resources

over the Internet.

- When accessing a huge computing power, the IT userneed not get physical access to the servers.

Through any web browsers or management console, the users can access the required infrastructure.

2. Centralized management:

- Even though the physical resources are distributed, themanagement will be from a single place.
- The resources distributed across different parts can be controlled from any management console.
- This ensures effective resource management and effective resource utilization.

3. Elasticity and dynamic scaling:

- IaaS provides elastic services where the usage of resources can be increased or decreased according to the requirements.
- The infrastructure need depends on the load on the application. According to the load, IaaS services can providethe resources.

- The load on any application is dynamic and IaaS services are capable of proving the required services dynamically

4. Shared infrastructure:

- IaaS follows a one-to-many delivery model and allows multiple ITusers to share the same physical infrastructure.
- The different IT users will be given different VMs. IaaS ensures high resource utilization.

5. Preconfigured VMs:

- IaaS providers offer preconfigured VMs with operating systems (OSs), network configuration, etc. The IT users can select any kind ofVMs of their choice.
- The IT users are free to configure VMs from scratch.
- The users can directly start using the VMs as soon as they subscribed to the services.

6. Metered services:

- IaaS allows the IT users to rent the computing resources instead ofbuying it.
- The services consumed by the IT user will be measured, and the users will be charged by the IaaS providers based on the amount ofusage.

Suitability of IaaS

1. Unpredictable spikes in usage:

- When there is a significant spike in usage of computing resources, IaaS is the best option for IT industries.
- When demand is very volatile, we cannot predict the spikes and troughs in terms of demand of the infrastructure.
  - In this situation, we cannot add or remove infrastructureimmediately according to the demand in a traditional infrastructure.
  - If there is an unpredictable demand of infrastructure, then it is recommended to use IaaS services.

2. Limited capital investment:

  - New start-up companies cannot invest more on buying infrastructure for their business needs.

- And so by using IaaS, start-up companies can reduce the capital investment on hardware. IaaS is the suitable option for start-upcompanies with less capital investment on hardware

3. Infrastructure on demand:
   - Some organizations may require large infrastructure for a shortperiod of time.
   - For this purpose, an organization cannot afford to buy more on-premise resources.
   - Instead, they can rent the required infrastructure for a specific period of time.
   - IaaS best suits the organizations that look for infrastructure on demand or for a short time period.

- IaaS helps start-up companies limit its capital expenditure.
- While it is widely used by start-up companies, there aresome situations where IaaS may not be the best option.

1. When regulatory compliance does not allow off-premise hosting:
   - For some companies, its regulation may not allow the applicationand data to be hosted on third-party off-premise infrastructure.

2. When usage is minimal:
   - When the usage is minimal and the available on-premise infrastructure itself is capable of satisfying their needs.

3. When better performance is required:
   - Since the IaaS services are accessed through the Internet, sometimes the performance might be not as expected due to network latency.

4. When there is a need for more control on physical infrastructure:
   - Some organizations might require physical control over the underlying infrastructure.
   - As the IaaS services are abstracted as virtual resources, it is not

possible to have more control on underlying physical infrastructure.

Pros and Cons of IaaS

- Being one of the important service models of cloud computing, IaaS provides lot of benefits to the IT users.
- The following are the benefits provided by IaaS:

1. Pay-as-you-use model:
   - The IaaS services are provided to the customers on a pay-per-use basis.
   - This ensures that the customers are required to pay for what they have used.
   - This model eliminates the unnecessary spending on buying hardware.

2. Reduced TCO:
   - Since IaaS providers allow the IT users to rent the computing resources, they need not buy physical hardware for running their business.
   - The IT users can rent the IT infrastructure rather than buy it by spending large amount.
   - IaaS reduces the need for buying hardware resources and thus reduces

the TCO.

3. Elastic resources:
   - IaaS provides resources based on the current needs.
   - IT users can scale up or scale down the resources whenever they want.
   - This dynamic scaling is done automatically using some load balancers.
   - This load balancer transfers the additional resource request to the new server and improves application efficiency.

4. Better resource utilization:
   - Resource utilization is the most important criteria to succeed in the IT business.
   - The purchased infrastructure should be utilized properly toincrease the ROI.
   - IaaS ensures better resource utilization and provides high ROIfor IaaS providers.

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5. Supports Green IT:
   - In traditional IT infrastructure, dedicated servers areused for different business needs.
   - Since many servers are used, the power consumptionwill be high.
   - This does not result in Green IT.
   - In IaaS, the need of buying dedicated servers is eliminated as single infrastructure is shared betweenmultiple customers, thus reducing the number of servers to be purchased and hence the power consumption that results in Green IT.

- Even though IaaS provides cost-related benefits to small-scale industries, it lacks in providing securityto the data.

- The following are the drawbacks of IaaS:

1. Security issues:
   - Since IaaS uses virtualization as the enabling technology,hypervisors play an important role.
   - There are many attacks that target the hypervisors to compromise it.
   - If hypervisors get compromised, then any VMs can be attacked easily.
   - Most of the IaaS providers are not able to provide 100% security to the VMs and the data stored on the VMs.

2. Interoperability issues:
   - There are no common standards followed among the different

IaaS providers.

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

- Performance issues:
  - IaaS is nothing but the consolidation of availableresources from the distributed cloud servers.
  - Here, all the distributed servers are connectedover the network.
  - Latency of the network plays an important role indeciding the performance.
  - Because of latency issues, sometimes the VMcontains issues with its performance.

Platform as a Service

- PaaS changes the way that the software is developed anddeployed.
- In traditional application development, the application will bedeveloped locally and will be hosted in the central location.
- In stand-alone application development, the applications willbe developed and delivered as executables.
- Most of the applications developed by traditional development platforms result in a licensing-based software,whereas PaaS changes the application development from local machine to online. PaaS providers provide the development PaaS from the data center.
- The developers can consume the services over the Internet asshown in Figure 5.6.

- PaaS allows the developers to develop their applicationonline and also allows them to deploy immediately on the same platform.
- PaaS consumers or developers can consume language runtimes, application frameworks, databases, messagequeues, testing tools, and deployment tools as a service over the Internet.
- Thus, it reduces the complexity of buying andmaintaining different tools for developing anapplication.
- Typical PaaS providers may provide programming languages, application frameworks, databases, andtesting tools as shown in Figure 5.7.
- Some of the PaaS providers also provide build tools,deployment tools, and software load balancers as
  a service:

1. Programming languages:
   - PaaS providers provide a wide variety of programming languages for the developers todevelop applications.
   - Some of the popular programming languages provided by PaaS vendors are Java, Perl, PHP, Python,Ruby, Scala, Clojure, and Go.

2. **Application frameworks:**
   - PaaS vendors provide application frameworks thatsimplify the application development.
   - Some of the popular application development frameworks provided by a PaaS provider include Node.js, Rails, Drupal, Joomla, WordPress, Django,EE6, Spring, Play, Sinatra, Rack, and Zend.

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Characteristics of PaaS

- PaaS development platforms are different from the traditional application development platforms.
- The following are the essential characteristics that make PaaS unique from traditional development platforms:

1. All in one:
   - Most of the PaaS providers offer services to develop, test, deploy, host, and maintain applications in the same IDE.

- Additionally, many service providers provide all the programming languages, frameworks, databases, and other development-relatedservices that make developers choose from a wide variety of development platforms.

2. Web access to the development platform:

- A typical development platform uses any IDEs for developing applications.
- Typically, the IDE will be installed in the developer's machines.

But, PaaS provides web access to the development platform

- Using web UI, any developer can get access to the development platform.
- The web-based UI helps the developers create, modify, test, and deploy different applications on the same platform.

3. Offline access:

- A developer may not be able to connect to the Internet for as whole day to access the PaaS services.
- When there is no Internet connectivity, the developers should be allowed to work offline.
- To enable offline development, some of the PaaS providers allow the developer to synchronize their local IDE with the PaaSservices.

The developers can develop an application locally and deploy itonline whenever they are connected to the Internet

4. Built-in scalability:

- Scalability is an important requirement for the new generation

web or SaaS applications

- It is very difficult to enable the dynamic scalability for any application developed using traditional development platforms.
- But, PaaS services provide built-in scalability to an applicationthat is developed using any particular PaaS.
- This ensures that the application is capable of handling varyingloads efficiently.

5. Collaborative platform:

- Nowadays, the development team consists of developers whoare working from different places.
- There is a need for a common platform where the developerscan collaboratively work together on the same project.
- Most of the PaaS services provide support for collaborative development.
- To enable collaboration among developers, most of the PaaS

6. Diverse client tools:

- To make the development easier, PaaS providers provide a wide

variety of client tools to help the developer.

- The client tools include CLI, web CLI, web UI, REST API, andIDE.
- The developers can choose any tools of their choice.
- These client tools are also capable of handling billing andsubscription management.

Suitability of PaaS

•Most of the start-up SaaS development companies and independent software vendors (ISVs) widely use PaaS indeveloping an application.
•PaaS technology is getting attention from other traditional software development companies also.

- PaaS is a suitable option for the following situations:
- **Collaborative development:**
  - To increase the time to market and development efficiency, there is aneed for a common place where the development team and other stakeholders of the application can collaborate with each other.
  - Since PaaS services provide a collaborative development environment, it is a suitable option for applications that need collaboration among developers and other third parties to carry outthe development process.

1. Automated testing and deployment:
   - Automated testing and building of an application are very usefulwhile developing applications at a very short time frame.
   - The automated testing tools reduce the time spent in manual testing tools.
   - Most of the PaaS services offer automated testing and deployment capabilities.

- The development team needs to concentrate more on development rather than testing and deployment.
- Thus, PaaS services are the best option where there is a need for automated testing and deployment of the applications

2. Time to market:
   - The PaaS services follow the iterative and incremental development methodologies that ensure that the application is in the market as per the time frame given.
   - For example, the PaaS services are the best option forapplication development that uses agile developmentmethodologies.
   - If the software vendor wants their application to be in the market as soon as possible, then the PaaS services are thebest option for the development.

- PaaS is used widely to accelerate the application development process to ensure the time to market.

- Most of the start-up companies and ISVs startedmigrating to the PaaS services.

- Even though it is used widely, there are some situationswhere PaaS may not be the best option:

1. **Frequent application migration:**
   - The major problem with PaaS services are vendor lock-in.
   - Since there are no common standards followed among PaaS providers, it is very difficult to migrate the application from onePaaS provider to the other.
2. **Customization at the infrastructure level:**
   - PaaS is an abstracted service, and the PaaS users do not have full control over the underlying infrastructure.
   - There are some application development platforms that need some configuration or customization of underlying infrastructure.
   - In these situations, it is not possible to customize the underlying infrastructure with PaaS.
   - If the application development platform needs any configuration at the hardware level, it is not recommended to go for PaaS.

3. Flexibility at the platform level:

- PaaS provides template-based applications where all the different programming languages, databases, and messagequeues are predefined.
- It is an advantage if the application is a generic application.

4. Integration with on-premise application:

- A company might have used PaaS services for some set of applications.
- For some set of applications, they might have used on-premise platforms.
- Since many PaaS services use their own proprietary technologies to define the application stack, it may not matchwith the on-premise application stack.
- This makes the integration of application hosted in on-premise platform and PaaS platform a difficult job.

Pros and Cons of PaaS

- The main advantage of using PaaS is that it hides the complexity of

maintaining the platform and underlyinginfrastructure.

- This allows the developers to work more on implementingthe important functionalities of the application.
- Apart from this, the PaaS has the following benefits:

1. **Quick development and deployment:**
   - PaaS provides all the required development and testing tools to develop, test, and deploy the software in one place.
   - Most of the PaaS services automate the testing and deployment process as soon as the developer completes thedevelopment.
   - This speeds up application development and deployment than traditional development platforms.
2. **Reduces TCO:**
   - The developers need not buy licensed development and testing toolsif PaaS services are selected.
   - Most of the traditional development platforms requires high-endinfrastructure for its working, which increases the TCO of the application development company.
   - But, PaaS allows the developers to rent the software, developmentplatforms, and testing tools to develop, build, and deploy the application.
   - PaaS does not require high-end infrastructure also to develop the application, thus reducing the TCO of the development company.

3. Supports agile software development:

- Nowadays, most of the new-generation applications are developedusing agile methodologies.
- Many ISVs and SaaS development companies started adopting agilemethodologies for application development.
- PaaS services support agile methodologies that the ISVs and other development companies are looking for.

4. Different teams can work together:

- The traditional development platform does not have extensivesupport for collaborative development.
- PaaS services support developers from different places to worktogether on the same project.
- This is possible because of the online common development platform provided by PaaS providers.

5. Ease of use:

- The traditional development platform uses any one of CLI- or IDE-based interfaces for development.
- Some developers may not be familiar with the interfaces provided by the application development platform.
- This makes the development job a little bit difficult.
- But, PaaS provides a wide variety of client tools such as CLI, web CLI, web UI, APIs, and IDEs.

- The developers are free to choose any client tools of their choice.
- Especially, the web UI–based PaaS services increase the usability ofthe development platform for all types of developers.

6. Less maintenance overhead:

- In on-premise applications, the development company or softwarevendor is responsible for maintaining the underlying hardware.
- They need to recruit skilled administrators to maintain the servers.
- This overhead is eliminated by the PaaS services as the underlying infrastructure is maintained by the infrastructure providers.
- This gives freedom to developers to work on the applicationdevelopment.

7. Produces scalable applications:

- Most of the applications developed using PaaS services are webapplication or SaaS application.
- These applications require better scalability on the extra load.
- For handling extra load, the software vendors need to maintain an additional server.
- It is very difficult for a new start-up company to provide extra serversbased on the additional load.
- But, PaaS services are providing built-in scalability to the application that is developed using the PaaS platform.

- PaaS provides a lot of benefits to developers when compared to the traditional development environment.
- On the other hand, it contains drawbacks, which are described in the following:

1. Depends on Internet connection:
   - Since the PaaS services are delivered over the Internet, thedevelopers should depend on Internet connectivity for developing the application.
   - Even though some of the providers allow offline access,most of the PaaS providers do not allow offline access.
   - With slow Internet connection, the usability and efficiencyof the PaaS platform do not satisfy the developer requirements.
   - The major drawback with PaaS providers are vendor lock-in.
   - The main reason for vendor lock-in is lack of standards. There are no common standards followed among the different PaaS providers.
   - The other reason for vendor lock-in is proprietary technologies used by PaaS providers.
   - Most of the PaaS vendors use the proprietary technologies that are not compatible with the other PaaS providers.

- The vendor lock-in problem of PaaS services does not allow the applications to be migrated from one PaaS provider to the other.

2. Security issues:

- Like in the other cloud services, security is one of the major issues inPaaS services.
- Since data are stored in off-premise third-party servers, many developers are afraid to go for PaaS services.
- Of course, many PaaS providers provide mechanisms to protect theuser data, and it is not sufficient to feel the safety of onpremise deployment.
- When selecting the PaaS provider, the developer should review the regulatory, compliance, and security policies of the PaaS provider withtheir own security requirements.
- If not properly reviewed, the developers or users are at the risk of data security breach.

3. Less flexibility:

- PaaS providers do not give much freedom for the developers to define their own application stack.
- Most of the PaaS providers provide many programming languages, databases, and other development tools.
- But, it is not extensive and does not satisfy all developer needs.
- Only some of the PaaS providers allow developers to extend the PaaS tools with the custom or new programming languages.

- Still most of the PaaS providers do not provide flexibility to the developers

Software as a Service

SaaS changes the way the software is delivered to the customers. Inthe traditional software model, the software is delivered as a license-based product that needs to be installed in the end user device.

Since SaaS is delivered as an on-demand service over the Internet,there is no need to install the software to the end user's devices.

SaaS services can be accessed or disconnected at any time based on the end user's needs.

SaaS services can be accessed from any lightweight web browsers on any devices such as laptops, tablets, and smartphones.

Some of the SaaS services can be accessed from a thin client thatdoes not contain much storage space and cannot run much software like the traditional desktop PCs.

The important benefits of using thin clients for accessing the SaaS application are as follows: it is less vulnerable to attack, has a longerlife cycle, consumes less power, and is less expensive

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4. **Business services:**
   - Most of the SaaS providers started providing a variety of business services

that attract start-up companies.

- The business SaaS services include ERP, CRM, billing, sales, and human resources.

5. **Social networks:**
   - Since social networking sites are extensively used by the general public,many social networking service providers adopted SaaS for their sustainability.
   - Since the number of users of the social networking sites is increasingexponentially, cloud computing is the perfect match for handling thevariable load.
6. **Document management:**
   - Since most of the enterprises extensively use electronic documents, most ofthe SaaS providers started providing services that are used to create, manage, and track electronic documents.
7. **Mail services:**
   - E-mail services are currently used by many people.
   - The future growth in e-mail usage is unpredictable.
   - To handle the unpredictable number of users and the load on e-mail services, most of the e-mail providers started offering their services as SaaSservices.

Characteristics of SaaS

- *SaaS services are different and give more benefitsto end users than the traditional software.*

- The following are the essential characteristics of SaaS services that make it unique from traditionalsoftware:

1. **One to many:**
   - SaaS services are delivered as a one-to-many modelwhere a single instance of the application can be shared by multiple tenants or customers
2. **Web access:**
   - SaaS services provide web access to the software.
   - It allows the end user to access the application from any location if the device is connected to the Internet.
3. **Centralized management**:
   - Since SaaS services are hosted and managed from the central location, management of the SaaS applicationbecomes easier.
   - Normally, the SaaS providers will perform the automaticupdates that ensure that each tenant is accessing the most recent version of the application without any user-side updates.
4. **Multidevice support**:
   - SaaS services can be accessed from any end user devices such as desktops,

laptops, tablets, smartphones, and thinclients.

5. **Better scalability:**
   - Since most of the SaaS services leverage PaaS and IaaS for its development and deployment, it ensures a betterscalability than the traditional software.
   - The dynamic scaling of underlying cloud resources makesSaaS applications work efficiently even with varying loads.

6. **High availability:**
   - SaaS services ensure the 99.99% availability of user dataas proper backup and recovery mechanisms are implemented at the back end.

7. **API integration:**
   - SaaS services have the capability of integrating with other
   - software or service through standard APIs

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- SaaS is popular among individuals and start-up companies because of the benefits it provides.
- Most of the traditional software users are looking for SaaS versions ofthe software as SaaS has several advantages over traditional applications.
- SaaS applications are the best option for the following:

1. On-demand software:
   - The licensing-based software model requires buying full packagedsoftware and increases the spending on buying software.
   - Some of the occasionally used software does not give any ROI.

- Because of this, many end users are looking for a software that they can use as and when they needed.
- If the end users are looking for on-demand software rather than thelicensing-based full-term software, then the SaaS model is the best option.

2. Software for start-up companies:
   - When using any traditional software, the end user should buy devices with minimum requirements specified by thesoftware vendor.
   - This increases the investment on buying hardware for start-up companies.
   - Since SaaS services do not require high-end infrastructurefor accessing, it is a suitable option for start-up companies that can reduce the initial expenditure on buying high-end hardware.

3. **Software compatible with multiple devices:**
   - Some of the applications like word processors or mail services need better accessibility from different devices.
   - The SaaS applications are adaptable with almost all thedevices.
4. **Software with varying loads:**

- We cannot predict the load on popular applications such associal networking sites.
- The user may connect or disconnect from applications anytime.
- It is very difficult to handle varying loads with the traditionalinfrastructure.
- With the dynamic scaling capabilities, SaaS applications can handle varying loads efficiently without disrupting the normalbehavior of the application.

5. Most of the traditional software vendors moved to SaaS business as it is an emerging software delivery model thatattracts end users.
6. But still many traditional applications do not have its SaaSversions.

This implies that SaaS applications may not be the bestoption for all types of software

- The SaaS delivery model is not the best option for the applications mentioned in the following:

1. Real-time applications:
   - Since SaaS applications depend on Internet connectivity, it may notwork better with low Internet speed.
   - If data are stored far away from the end user, the latency issues maydelay the data retrieval timings.

- Real-time applications require fast processing of data that may not bepossible with the SaaS applications because of the dependency on high-speed Internet connectivity and latency issues.

2. Applications with confidential data:
   - Data security, data governance, and data compliance are always issueswith SaaS applications.
   - Since data are stored with third-party service providers, there is no surety that our data will be safe.
   - If the stored confidential data get lost, it will make a serious loss to the organization.
   - It is not recommended to go for SaaS for applications that handle confidential data.

- Better on-premise application:
- Some of the on-premise applications might fulfill allthe requirements of the organization.
- In such situations, migrating to the SaaS model maynot be the best option.

Pros and Cons of SaaS

- SaaS applications are used by a wide range of individuals and start-up industries for its cost-related benefits.

1. No client-side installation:

- SaaS services do not require client-side installation of the software.
- The end users can access the services directly from the service provider datacenter without any installation.
- There is no need of high-end hardware to consume SaaS services.
- It can be accessed from thin clients or any handheld devices, thus reducing the initial expenditure on buying high-end hardware.

2. Cost savings:

- Since SaaS services follow the utility-based billing or pay-as-you-go billing, itdemands the end users to pay for what they have used.
- Most of the SaaS providers offer different subscription plans to benefit different customers.
- Sometimes, the generic SaaS services such as word processors are given for free to the end users.

3. Less maintenance:

- SaaS services eliminate the additional overhead of maintaining the software from the client side.
- For example, in the traditional software, the end user is responsible for performing bulk updates.

But in SaaS, the service provider itself maintains the automatic updates,monitoring, and other maintenance activities of the applications

1. **Ease of access:**
   - SaaS services can be accessed from any devices if it is connected to the Internet.
   - Accessibility of SaaS services is not restricted to any particular devices.
   - It is adaptable to all the devices as it uses the responsive web UI.

2. **Dynamic scaling**:
   - SaaS services are popularly known for elastic dynamic scaling.
   - It is very difficult for on-premise software to provide dynamicscaling capability as it requires additional hardware.
   - Since the SaaS services leverage elastic resources provided bycloud computing, it can handle any type of varying loads without disrupting the normal behavior of the application.

3. **Disaster recovery:**
   - With proper backup and recovery mechanisms, replicas are maintained for every SaaS services.
   - The replicas are distributed across many servers.

- If any server fails, the end user can access the SaaS from otherservers.
- It eliminates the problem of single point of failure.
- It also ensures the high availability of the application.

4. Multitenancy:

- Multitenancy is the ability given to the end users to share asingle instance of the application.
- Multitenancy increases resource utilization from the service provider side.
- Even though SaaS services are used by many individuals and start-up industries, the adoption from the large industries isvery low.
- The major problem with SaaS services is security to the data.

• The following are the major problems with SaaS services:

1. Security:

- Security is the major concern in migrating to SaaS application.
- Since the SaaS application is shared between many end users, there is a possibility of data leakage.
- Here, the data are stored in the service provider data center.
- We cannot simply trust some third-party service provider to store

our company-sensitive and confidential data.

- The end user should be careful while selecting the SaaS provider to avoid unnecessary data loss.

2. Connectivity requirements:

- SaaS applications require Internet connectivity for accessing it. Sometimes, the end user's Internet connectivity might be very slow.
- In such situations, the user cannot access the services with ease.
- The dependency on high-speed Internet connection is a major problem in SaaS applications.

3. Loss of control:

- Since the data are stored in a third-party and off premise location, the end user does not have any control over the data.
- The degree of control over the SaaS applicationand data is lesser than the on-premise application.

Other Cloud Service Models

- The basic cloud services such as IaaS, PaaS, and SaaS are widely used by many individual and start-up companies.
- Now, cloud computing becomes the dominant technology thatdrives the IT world.
- Because of the extensive use of basic cloud services, the end usersrealize the importance and

benefits of specific services such as network, storage, and database.

- The basic cloud service models are the unified models that contain multiple services in it.
- Now, the end users' expectation changed, and they are expecting the individual services to be offered by service providers.
- This makes most of the service providers to think about the separate services that meet end user requirements

- Many service providers already started offering separate services such as network, desktop, database, and storage on demand as given in thefollowing:
- NaaS:
  - It is an ability given to the end users to access virtual network services that are provided by the service provider.
  - Like other cloud service models, NaaS is also a business model for delivering virtual network services over the Internet on a pay-per-usebasis.
  - In on-premise data center, the IT industries spent a lot of money to buy network hardware to manage in-house networks.
  - But, cloud computing changes networking services into a utility-based service.
  - NaaS allows network architects to create virtual networks, virtual network interface cards (NICs), virtual routers, virtual switches, and othernetworking components.
  - Additionally, it allows the network architect to deploy custom routing protocols and enables the design of efficient in-network services, such asdata aggregation, stream processing, and caching.

- Some of the popular services provided by NaaS include virtual privatenetwork (VPN), bandwidth on demand (BoD), and mobile network virtualization.

- **Desktop as a Service (DEaaS)**
  - It is an ability given to the end users to use desktop virtualization without buying and managing their own infrastructure.
  - DEaaS is a pay-per-use cloud service delivery model in which theservice provider manages the back-end responsibilities of data storage, backup, security, and upgrades.
  - The end users are responsible for managing their own desktop images, applications, and security.
  - Accessing the virtual desktop provided by the DEaaS provider is device, location, and network independent.
  - DEaaS services are simple to deploy, are highly secure, and produce better experience on almost all devices.

1. STaaS

- It is an ability given to the end users to store the data on the storage services provided by the service provider.
- STaaS allows the end users to access the files at any time from anyplace.
- The STaaS provider provides the virtual storage that is abstractedfrom the physical storage of any cloud data center

- STaaS is also a cloud business model that is delivered as a utility.
- Here, the customers can rent the storage from the STaaS

provider.
- STaaS is commonly used as a backup storage for efficient disaster recovery.

2. DBaaS

- It is an ability given to the end users to access the database service without the need to install and maintain it.
- The service provider is responsible for installing and maintaining the databases.
- The end users can directly access the services and can pay according to their usage.
- DBaaS automates the database administration process.
- The end users can access the database services through any API or web UIs provided by the service provider.
- The DBaaS eases the database administration process.
- Popular examples of DBaaS include SimpleDB, DynamoDB, MongoDB as a Service, GAE datastore, and ScaleDB.

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- Popular examples of DBaaS include SimpleDB, DynamoDB, MongoDB as a Service, GAE datastore, and ScaleDB.

5. Data as a Service (DaaS)

- It is an ability given to the end users to access the data that are provided by the service provider over the Internet.
- DaaS provides data on demand.
- The data may include text, images, sounds, and videos. DaaS is closely related to other cloud service models such as SaaS andSTaaS.
- DaaS can be easily integrated with SaaS or STaaS for providing the composite service.
- DaaS is highly used in geography data services and financial data services.
- The advantages of DaaS include agility, cost effectiveness, anddata quality.

UNIT 5

CLOUD SERVICE PROVIDERS

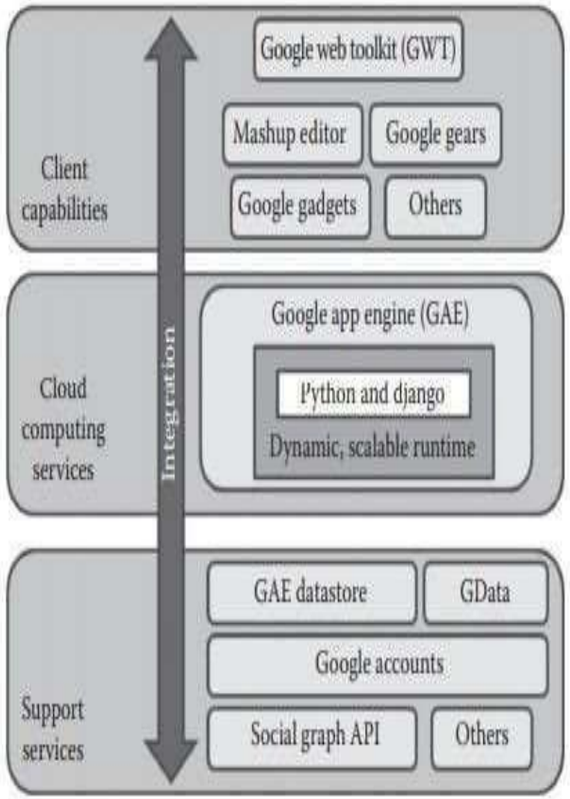

FIGURE 11.2
Google App Engine. (Adapted from http://rdn-consulting.com/blog/tag/azure/, accessed January 16, 2014).

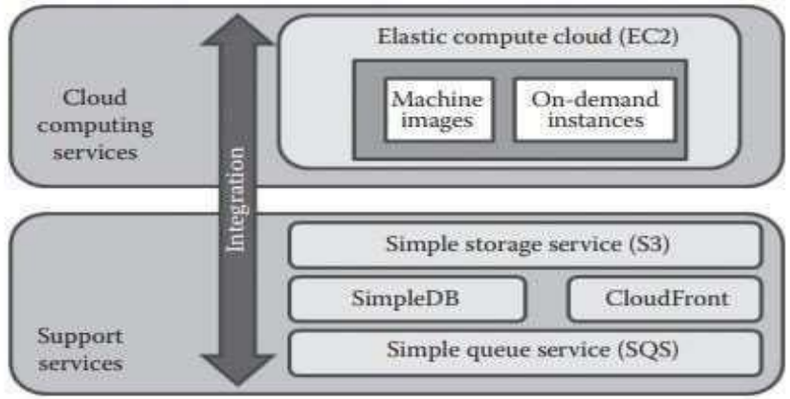

FIGURE 11.3
AWS. (Adapted from http://rdn-consulting.com/blog/tag/azure/, accessed January 16, 2014).

CLOUD MODELS

VIRTUAL MODELS

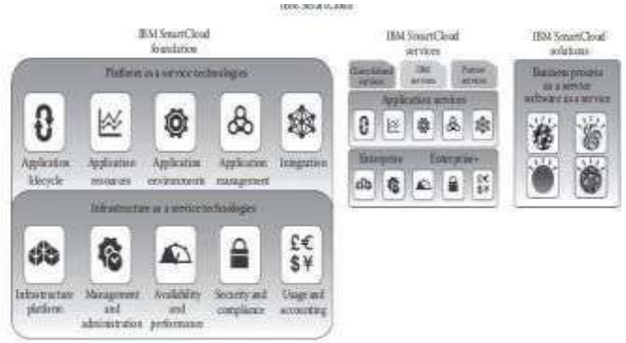

FIGURE 11.4
Architecture of IBM SmartCloud. (Adapted from Transitioning to IBM smart cloud notes, Smart Cloud White Paper-IBM)

THANK YOU

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