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Question 1

What is cloud?

Cloud refers to servers that are accessed over the Internet, and the software and databases that run on those servers. Cloud servers are located in data centers all over the world.

What is cloud computing?

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

Explain the cloud cost model.

Cloud service providers typically use the **Measured Service and Pay-as-Per-Use Pricing Model:**

- The cloud environment provides automatic-metering capability to measure the resources utilized by consumers, which is done in a transparent manner for both providers and users.
- According to the service measured, consumers will be billed.
- As for what is measured a provider will charge a consumer only for the IT resources actually used and/or for the time frame during which the resources were used.
- Similar to how the public pays for different utilities, such as gas, electricity, etc., cloud consumers are charged for their exact use of resources.
- There are typically two pricing schemes provided in the cloud environment: *subscription-based pricing* (like a monthly bill for the service acquired) or *pay-as-per-use pricing*, as outlined in the points above.

Question 2

What are the cloud service models?

The types of cloud service models are:

i. IaaS (Infrastructure as a Service)

ii. PaaS (Platform as a Service)

iii. SaaS (Software as a Service)

Describe what are IaaS, PaaS and SaaS and the relationships among them.

IaaS:
The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications; and possibly limited control of select networking components (e.g. host firewalls).

- IaaS allows distributed virtualized computational resources, such as servers, storage devices, network devices, and virtual machines, to be shared.
- The IaaS environment can be likened to an on-premises infrastructure.
- It can be seen that in an on-premises facility control entirely lies with the enterprise, whereas in an IaaS service model the provider completely controls and maintains the physical infrastructure.
- Cloud users can control the virtual machines and other platforms on top of the physical infrastructure.
- IaaS providers offer (i) servers, (ii) storage, (iii) networks, (iv) hypervisors, and (v) virtual machines to users.
- On top of the virtual machine users install their required guest operating system, middleware, runtime, data, and applications according to their needs:
  - IaaS cloud providers offer their resources on-demand from their large pools of physical infrastructure. Very often the infrastructure is distributed across different geographical locations. IaaS providers employ cloud orchestration technology using software such as OpenStack, Apache CloudStack, or Open Nebula to create and manage virtual machines (VMs). Cloud orchestration involves carrying out automatic resource provisioning according to dynamic needs. It decides the most appropriate physical host to assign to VMs, performs VM migration from one host to another whenever required, allocates storage volumes to VMs, and provides usage information for billing.
  - This kind of service is suitable for organizations that have difficulty funding the basic infrastructure to run their businesses. IaaS is the right choice for organizations looking for high levels of customization for their infrastructure.

  - IaaS normally requires a high degree of technical proficiency to configure the infrastructure acquired from cloud providers. Hence IaaS is more suitable for enterprises with a highly skilled set of developers,network administrators, and database administrators who can work as a team to build applications from scratch, manage network traffic and storage traffic, and maintain and scale up or scale out requirements according to the needs of enterprise applications.
  - Responsibilities are shared by both IaaS providers and consumers. With an IaaS model providers gain control over actual physical hardware resources. Users have control only overresources that are above the virtual machine. In the case of an on-premises infrastructure complete control, responsibility, and management lies with the owners. Among the most popular IaaS providers are Amazon Web Services (AWS), Cisco Metapod, Microsoft Azure, Google Compute Engine (GCE), and Joyent.

PaaS:
The capability provided to the consumer is to deploy onto the cloud infrastructure consumer created or acquired applications created using programming languages, libraries, services, and tools supported by the provider. The consumer does not manager or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment.

- Platform as a Service (PaaS) providers offer users both the hardware structure and software platform needed for applications development.
- In general, PaaS providers offer both the underlying hardware infrastructureand softwareplatform such as web servers, application servers, database servers, and a programming environment (e.g., J2EE, .Net, or Python).
  - Developers can use PaaS as a platform or framework to develop and customize their applications.
  - PaaS makesthe development, testing, and deployment of applications quick and cheaper.
  - PaaS models provide benefits such as increased developer productivity and short time to market for applications.
- However, in the PaaS model users gain control only over applications they install on the platform and data. They have no control over the underlying hardware and platform, which are completely managed by PaaS providers.
- Popular PaaS providers include Google App Engine, Microsoft Azure, and RedHat OpenShift.
- Google App Engine and RedHat OpenShift provide a complete platform for the development of distributed webapplications based on an open-source environment, whereas Microsoft Azure offers a platform for both Windows-based and open-source tools, such as .Net, Python, Ruby, andPHP, for applications.

SaaS: The capability provided to the customer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g. web-based email), or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific applicatoin configuration settings.

- Software as a Service (SaaS) allows cloud service providers to offer completely developed applications to users over the internet on a subscription basis.
- Users can simply log in and use applications completely provided by SaaS providers and run on the providers infrastructures.
- In this model users have no control at all over anything.
- All layers are under the control of SaaS providers.

All the service models have the fundamental characteristics of cloud computing, elasticity, scalability, on-demand computing, multi-tenancy, metering service, and pay-per-use pricing model. Similarly, they have the same limitations, such as data integrity, security, and vendor lock-in.

Question 3

What are the cloud components?
The three major cloud components are:

i. The front end

ii. The network

iii. The backend / the cloud

Please describe the cloud architecture based on these components.
The aforementioned components make up the cloud computing architecture.

Front End:

- The front-end layer of the cloud refers to the user layer.
- Typical cloud users are individuals, enterprises, employees of enterprises, employees on the move, mobile users, laptop users, users having any kind of connected device etc.
- Cloud service providers provide APIs and interfaces for users themselves to access the required service through a web portal.
- Users access the APIs over the internet and consume the required service.

Network:

- Network refers to the broad backbone infrastructure through which cloud service providers offer their services to users.
- The internet is the core network infrastructure that makes cloud computing feasible.
- Services are delivered via the internet.
- Typically, users can access public clouds directly via the internet and private clouds via a secure VPN over the internet.

Back End:

- The back-end layer forms the cloud.
- It consists of six different layers:
  (i) Physical layer
  (ii) Virtualization layer
  (iii) Layer of cloud services
  (iv) Scheduling, provisioning, and pricing layer
  (v) Security
  (vi) Management

(i) *Physical layer*

- The core component of the cloud is the physical infrastructure.
- The physical infrastructure includes bare metal hardware, servers, CPUs, storage devices, network devices, any other network-related hardware, and memory.
- The physical infrastructure is not to be found at a single location, rather it is distributed across different geographical locations.
- Resources are heterogeneous in nature.

(ii) *Virtualization layer*

- The virtualization layer is responsible for considering theoretically all the heterogeneity and physical distribution of the underlying hardware and generate a single, logical view for the entire physical layer of the cloud.
- This is achieved with software called Virtual Machine Monitor (VMM) or hypervisor.
- Hypervisor combines all the physical hardware and produces a unified global and logical view of resources that will then be allocated to multiple tenants according to their dynamic demands.

(iii) *Layers of cloud services*

- Cloud service providers offer different kinds of services.
- The major service classes are Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).
- A cloud service provider generally provides only one kind of service.
- However, a service provider may provide more than one service offering. For example, Azure initially provided only PaaS, but later it started providing both PaaS and even some IaaS services.
- These services are offered on top of the virtualization layer.
- *Infrastructure as a Service*
  * Infrastructure service providers typically offer hardware, storage devices, servers, network components, and other hardware to users to support their operations.
  * Infrastructure service providers are responsible for housing, operating, and maintaining the hardware for clients.
- *Platform as a Service*
  * Platform providers offer a cloud-based computing environment to design, develop, execute, and manage applications.
  * Platform providers typically provide development platforms, middleware, operating systems, programming languages, libraries, runtime environments, application servers, database management servers, load balancers, business analytics services, mobile backend services, integration brokers, business process management systems, rules engines, event processors, and other software tools.
  * PaaS providers are responsible for installation, configuration, operation, licensing, upgradation of software tools, and maintenance of tools.

    * PaaS providers help developers to concentrate only on developing code of concern to them and hence to relieve them of the abovementioned common services.

  - *Software as a Service*
    * Software as a Service provides software applications for consumer use over the internet on demand.
    * Users can subscribe to software applications from SaaS providers with the help of their APIs over the internet.

(iv) *Scheduling, provisioning, and other services*

  - Various management and orchestration services are needed to be able to manage the cloud environment.
  - Cloud orchestration and management are essential processes that take place within the cloud. A cloud orchestrator automates and orchestrates:
    * a scheduling component to schedule resources to different tenants;
    * a provisioning component that provides scheduled resources;
    * monitoring components that monitor the cloud environment;
    * metering services that meter the resources provided; and
    * a pricing component that bills the consumer according to a subscription-based or use-based model.

(v) ***Security***

  - Security in cloud computing is a responsibility shared among cloud service providers and cloud users.
  - In the case of IaaS, for example, providers take on the responsibility of providing security for their physical infrastructure and consumers take on the responsibility of providing security to a guest operating system (OS), platform, applications, and data that they deploy on the infrastructure consumed.

(vi) ***Management***

  - Since cloud computing environment is complex, cloud service providers user various tools to manage, automate, and orchestrate cloud operations and business services.
  - Cloud Management Platform (CMP) tools, cloud automation tools, cloud orchestration tools, cloud brokerage tools, cloud monitoring tools, cloud security tools, etc. are typically used to manage and optimize the cloud.

Question 4

What is virtualisation?

- In the cloud infrastructure, there are three kinds of services, Infrastructure as a Service, Platform as a Service, and Software as a Service.
- IaaS providers theoretically offer any number of of hardware resources, such as servers and storage devices, for use according to the dynamic demands of users.
- PaaS providers offer almost all kinds of platforms along with infrastructure to users wanting to deploy their applications without worrying about the resources needed for load balancing, scalability, performance, etc.
- SaaS providers offer completely developed cloud-deployed software applications that users can consume on a subscription basis.
- These services are provided simultaneously to many consumers.
- The huge resources of cloud service providers are shared among multiple users.
- ***Virtualization*** *is the the technology that enables this kind of sharing of resources among multiple users simultaneously and enables each user to have varying demands.*
- Since cloud service providers offer servers, storage, and networks the concept of virtualization is applied at different levels (such as servers, storage, networks, memory, data, applications, and desktops) so as to yield virtualized storage, virtualized networks, virtualized memory, virtualized data, virtualized applications, virtualized desktops etc.
- Hence, virtualization is key to the implementation of cloud computing.
- In a nutshell, ***virtualization is the creation of virtual resources, such as servers, storage devices, networks, adn desktops, by abstracting the heterogeneity in hardware. This is being pursued by cloud service providers to effectively use their computational resources and maximize their profits.***

Describe different layers of virtualisation.

Server Virtualization

- Server virtualization provides the capability to create many virtual servers on top of the real physical server by separating and abstracting the real server (i.e., a machine with CPU, RAM, hard disk etc.) from the rest of the system.
- The primary objective of server virtualization is to increase resource utilization by partitioning a single physical server into many virtual servers where each virtual server has its own operating system and applications.
- Moreover, each virtual server is unaware of the presence of other servers. Each virtual machine is logically separated from other virtual servers.
- Conventionally, each server is tied to a particular operating system and, typically, a particular application is deployed in a server.

Desktop Virtualization

- In desktop virtualization the hardware, operating system, applications, data, and user profile of a real desktop can be abstracted from a client machine to a remote server.
- After desktop virtualization, a user will work with a virtual desktop in a cloud server.
- When a client accesses a desktop all applications and corresponding data are accessed from a central server.

Data Virtualization

- Data virtualization is the concept of aggregating data from heterogeneous data sources at different locations into single items of data and logical data that can be accessed easily by applications.
- Data virtualization facilitates data access, data integration, and data management by providing a single data management model.
- The primary advantage is that data consumers can retrieve and manipulate data from one or more data sources without knowing the technical details of data storage such as API, access language, storage structure, or its format or location.
- Data virtualization facilitates real-time access to data. Data virtualization reduces data errors and helps to combine the results of data sets from multiple data sources so as to produce *federated data* and make such data available to users.

Application Virtualization

- In application virtualization a given application in a particular operating system is made to execute in a virtual way on any operating system.
- Application virtualization abstracts applications from underlying operating systems.
- Deploying an application in traditional systems means packaging parts of the application and installing the application according to the requirements of the target operating system and machine.
- The application virtualization layer in the cloud environment fools applications into getting deployed in any virtual guest operating system.

Memory virtualization

- The physical memory across different servers is aggregrated into a single large primary memory that is accessible by applications deployed in virtual machines.
- In general, there are three memory addresses: a machine address that represents the actual physical address sent on the bus to memory, a guest physical address that represents the virtual address of memory as seen by the guest OS, and a guest virtual address that represents the virtual address as seen by the guest application.
- As memory is very closely involved with compute logic, enterprises need to add memory to achieve higher performance of applications. However, adding memory is very expensive.

- Memory virtualization helps to share existing memory across many servers as a single larger memory. Hence it helps in achieving higher performance at lower cost.

Network virtualization

- Network virtualization refers to the creation of more than one logical and virtual network that work simultaneously and share the same single physical network.
- These logical networks are also called *network overlays*. Network virtualization allows users to create their network with their own topology, routing, and other application-specific requirements including resource management.
- The most important aspect of network virtualization is that it avoids some of the critical issues associated with the current internet: Internet Protocol (IP) ossification, issues with end-to-end quality of service, and lock-in of customers with their internet service providers.
- Network virtualization handles the above issues, provides high throughput for data transmission, and delivers control over end-to-end quality of service.
- The virtualization layer helps to create virtual networks according to the requirements of the top layer of VMs and their applications.
- Hence, any application can configure its required topology, routing, and the other network stuff with virtual networks instantly and gain network connectivity.
- Network virtualization restricts the movement of data and information across networks and enhances security.
- The most important aspect is that each virtual network is isolated and independent of other networks.

Storage virtualization

- Storage virtualization is the concept of abstracting or hiding heterogeneity among different storage devices from the applications that manage them.
- Different techniques may be used to get the different physical storage devices to aggregrate in a pool of logical storage that can be accessed and managed in a unified way from a centralized console.
- In conventional storage management with no storage virtualization, storage management has to deal with the varying characteristics of different storage devices as well as vendor-specific features.
- Conventionally, storage management has dealt with each device as a discrete unit.
- The primary difficulty with conventional storage is how to deal with heterogeneous storage devices. Another difficulty is that the devices are manufactured by different vendors.
- In *virtualized storage*, various devices are aggregrated into a single pool of logical storage by the storage virtualization layer.

- This layer hides the heterogeneity of devices and provides a uniform way of managing them.

What is hypervisor?

A hypervisor, also called Virtual Machine Monitor (VMM), is essentially computer software, hardware, or firmware that creates and runs virtual machines. It is located in the virtualization layer of the back-end of the cloud architecture.

What does a hypervisor do?

The virtualization layer is responsible for considering theoretically all the heterogeneity and physical distribution of the underlying hardware and generate a single, logical view for the entire physical layer of the cloud. **This is achieved with software called hypervisor.** Hypervisor combines all the physical hardware and produces a unified global and logical view of resources that will then be allocated to multiple tenants according to their dynamic needs.

Question 5

Describe how technological drivers fit into different layers of the cloud architecture.
Cloud computing has developed very rapidly as a result of various technological drivers. These include:

- Open source tools and APIs
- Software defined security
- Virtualization and containerization
- Multi-core technology
- WAN, internet, SOA, Web 2.0
- Parallel programming
- Grid and utility computing
- Software defined networking
- MSA, DevOps, Agile

Figure 1 below depicts how each of these fit into different layers of the cloud architecture.

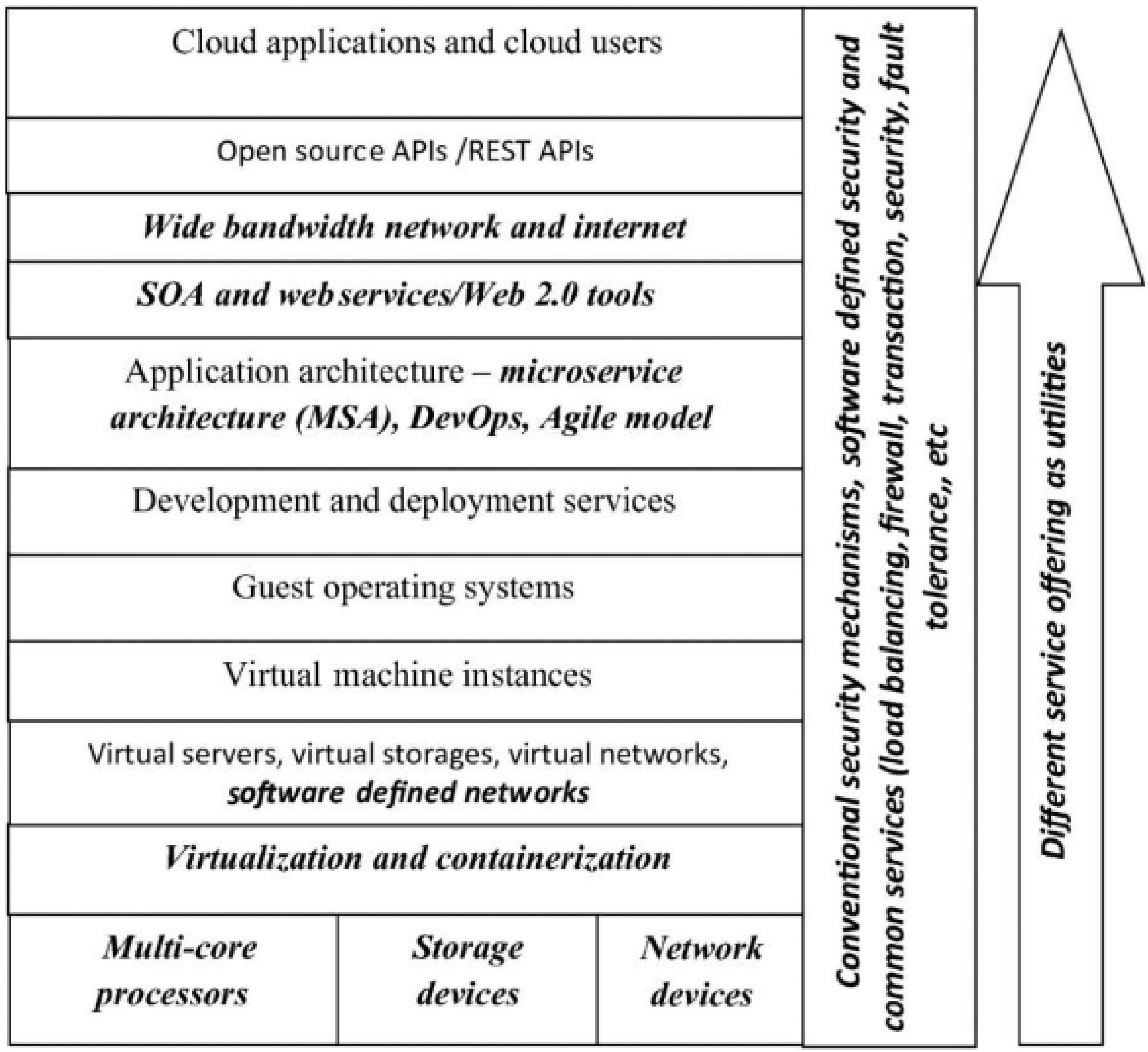

Figure 1: How the different technological drivers fit into different layers of the cloud architecture

- In the cloud infrastructure there are three kinds of services: Infrastructure as a Service, Platform as a Service, and Software as a Service. IaaS providers theoretically offer any number of hardware resources, such as servers, storage devices, and networks, for use according to the dynamic demands of users.
- PaaS providers offer almost all kinds of platforms along with infrastructure to users wanting to deploy their applications without worrying about the resources needed for load balancing, scalability, performance, etc.
- Similarly, SaaS providers offer completely developed cloud-deployed software applications that users can consume on a subscription basis.
- These services are provided simultaneously to many consumers.
- The huge resources of cloud service providers are shared among multiple users.

- Virtualization is the technology that enables this kind of sharing of resources among multiple users simultaneously and enables each user to have varying demands.
- Since cloud service providers offer servers, storage, and networks the concept of virtualization is applied at different levels (such as servers, storage, networks, memory, data, applications, and desktops) so as to yield virtualized servers, virtualized storage, virtualized networks, virtualized data, virtualized applications, virtualized desktops, etc.
- Hence virtualization is key to the implementation of cloud computing.
- Along with virtualization another technique called *containerization* has recently appeared on the scene.
- Containerization is more efficient than virtualization when it comes to the efficient utilization of resources.
- Recent advances in hardware technologies have led to the *production of multi-core processors* at mass scale.
- Corresponding with advances in hardware, software programming models have been developed to support *parallel programming* and simultaneous execution of programs.
- In addition, since cloud computing has its roots in *grid computing* and *utility computing*, both of which cast light on how computing resources could be shared similar to domestic utilities using a *pay-per-use pricing model*, it too can be used in like manner.
- Wrapping technologies (such as service-oriented architecture) form other major pillars supporting cloud computing.
- The internet, IP, WAN, MPLS, WAN, software-defined networks, and software-defined security have significantly influenced the growth of cloud computing.