Cloud Computing Foundation

Module 1 Study Guide

CLOUD COMPUTING FOUNDATION

Cloud Computing Foundation

Welcome to your Study Guide

This document is supplementary to the information available to you online. You can use it to study offline, to print out and to annotate key points as part of your studies.

Study Guide Icons

	**Tip**	This will remind you of something you need to take note of or give you some exam guidance.
	**Definition**	Key concept or term that you need to understand and remember.
	**Role**	Job title or responsibility.
	**Purpose or Objective**	For a process, practice or activity.

Cloud Computing Foundation

Contents

1. Module Objectives

The objectives for this module were for you to understand and explain:

- The concept of cloud computing
- How cloud computing evolved
- Cloud computing architectures
- Drivers and limitations of cloud computing

2. The Concept of Cloud Computing

	**Cloud Computing**	*"Service management is a set of specialized organizational capabilities for enabling value to customers in the form of services."*

NIST says that for cloud computing there are "five essential characteristics, three service models, and four deployment models"

The five characteristics of cloud computing are:

	**On-demand self-service:**	Within an existing contract, a user or customer can add new services, storage space or computing power without a formal request for change
	**Broad network access:**	This is what Microsoft's Bill Gates envisioned in the late nineties: *"any time, any place, and any device"*, and of course also with enough bandwidth
	**Resource pooling:**	This characteristic is also known as Multi-tenancy, meaning users/customers share a varied type and level of resources
	**Rapid elasticity:**	This characteristic is about the fundamental cloud aspects of flexibility and scalability, for example, web shops need a standard amount of transaction ability during the year, but need to peak around Christmas, but they do not want to pay for this peak ability during the rest of the year

	**Measured service:**	This means monitored, controlled, and reported services and enables a pay-per-use service model; It has similarities to the mobile telephone concept of service bundles, where you pay a standard subscription for basic levels, and pay extra for additional service without changing the contract

The ISO/IEC 17788 standard recognizes a sixth characteristic:

	**Multi-tenancy**	*A feature where physical or virtual resources are allocated in such a way that multiple tenants and their computations and data are isolated from and inaccessible to one another. Typically, and within the context of multi-tenancy, the group of cloud service users that form a tenant will all belong to the same cloud service customer organization. There might be cases where the group of cloud service users involves users from multiple different cloud service customers, particularly in the case of Public Cloud and Community Cloud deployments. However, a given cloud service customer organization might have many different tenancies with a single cloud service provider representing different groups within the organization.*

Cloud computing is an integrated part of people's lives and online activity. It is accessed using social media sites such as Facebook, twitter, Instagram, when uploading information to Wiki based sites, playing games online, blogging, video calling, or using online email or accessing a dropbox.

Cloud computing examples for businesses include:

- CRM
- Backup services
- ERP
- Financial

> *"There was a time when every household, town, farm or village had its own water well. Today, shared public utilities give us access to clean water by simply turning on the tap; Cloud computing works in a similar fashion. Just like water from the tap in your kitchen, Cloud computing services can be turned on or off quickly as needed. Like at the water company, there is a team of dedicated professionals making sure the service provided is safe, secure and available on a 24/7 basis. When the tap isn't on, not only are you saving water, but you aren't paying for resources you don't currently need."*
>
> Vivek Kundra Federal CIO, United States Government

3. Deployment Models for Cloud Computing

The cloud characteristic that enables the cloud provider to monitor and control the provision of services is the 'Measured Service' characteristic. This can include:

- Paying for what you use
- Monitoring effective use of resources

There are many different clouds; for an end-user of web-based services like social media, webmail, online storage, collaboration software, blogs, video calling and so on, there seems to be only one cloud, the world wide web.

For enterprises, public sector organizations and non-government organizations it is more of a cloudy sky. Most of these own their own IT infrastructure, buy IT services from service providers and use several web services. *For example, an organization's email infrastructure typically consists of Exchange servers where every employee has their own ID and mailbox, agenda and corporate contact list, but most employees will also have access to a webmail account connecting them to the corporate mail server through the Internet, so there is a Private and a Public aspect.*

The four cloud deployment models are illustrated below:

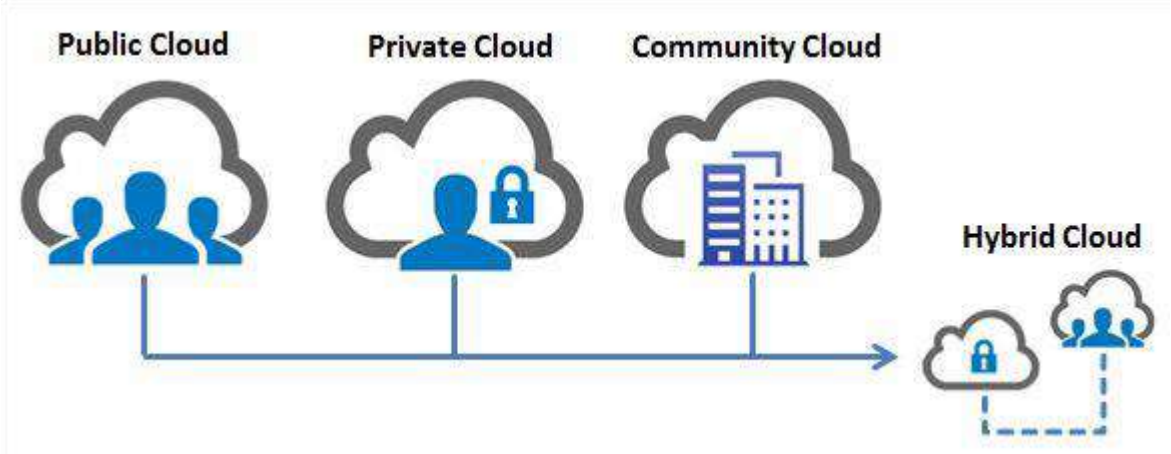

Figure 1.1: Cloud Deployment Models

Table 1 shows some examples for each deployment model:

Deployment Model	Model Example
Public Cloud	Google AppEngine, Windows Azure, Amazon Elastic Compute Cloud
Private Cloud	Amazon Virtual Private Cloud, VMware Private Cloud
Community Cloud	Google Apps for Government, Microsoft Government Community Cloud
Hybrid Cloud	Public plus private cloud for example: Windows Azure plus VMWare

Table 1: Examples of Deployment Models

3.1 Private Cloud

The Private Cloud:

- Resides on a private network that runs on (part of) a data center that is exclusively used by one organization
- Owned, managed and run by either the organization itself, a third party or a combination of the two
- Supports the organization's business objectives in an economically sound way
- High security (compliance with legislation and regulations)

	**Tip**	All types of cloud have the five characteristics of cloud computing, if not the services are just classical examples of hosting or ASP and not a cloud!

	**ASP**	*'An application service provider (ASP) is a business providing computer-based services to customers over a network; such as access to a particular software application using a standard protocol'* (Source: Wikipedia)

3.2 Public Cloud

These are Public Cloud's features:

- Delivery of off-site services over the internet
- Sharing of resources; 'multi-tenancy' can indicate a lower level of security and privacy
- Aimed at a wide audience
- Compelling services like email and social media
- Enables social networking and collaboration

Sharing basic infrastructure like storage, data base servers or applications can all cause (data) security and privacy issues, but a Public Cloud can be very secure if organizations work closely with their cloud provider in terms of compliance.

3.3 Community Cloud

A Community Cloud is a type of shared private cloud, it may have these features:

- Delivers services to a specific group of organizations and/or individuals that share a common goal
- Sharing of data, platforms and applications
- Sharing of capital expenditure for otherwise (too) expensive facilities
- 24/7 access and support
- Shared service and support contracts
- Economics of scale

Examples of specific groups or organizations and/or individuals that it may refer to are regional or national educational or research institutes, community centers or commercial organizations wishing to share very high security facilities for transaction processing like stock exchange trading companies.

3.4 Hybrid Cloud

Hybrid Cloud is a mix of models combining several Private and Public Cloud solutions from several providers into one (virtual) IT infrastructure.

Choosing specific services for either Private or Public Cloud suitability is balancing:

- Security
- Privacy
- Compliance versus price

Cloud deployment models can be secure or risky depending on the type chosen and management by the business and IT department. Privacy is often mentioned as a limitation of cloud computing and does need to be carefully assessed when choosing a deployment model.

An example could be the way insurance companies work with insurance agents. There is a lot of interaction between the two sides, but the company's and agents' infrastructures can and will not be integrated in the traditional way. In this scenario a Public Cloud extension could build a bridge between the two.

4. Service Models for Cloud Computing

There are many types of Cloud services such as:

- Webmail
- Hosted Exchange
- Online storage
- Online backup
- Social media

All of the types of cloud services can be grouped under three main cloud service models as can be seen from the figure below:

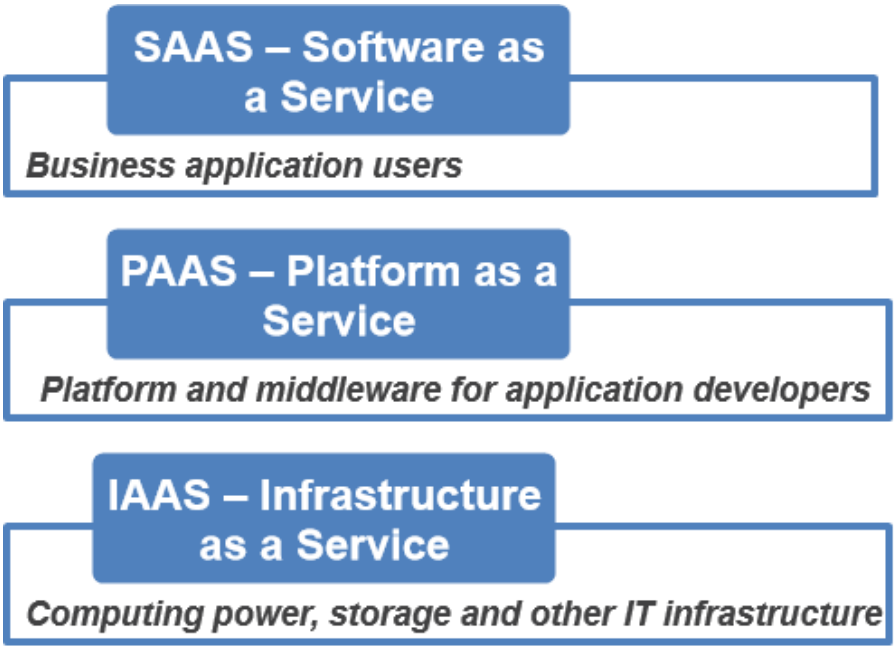

Figure 1.2: Cloud Service Models

	Tip	These service models can be abbreviated into the acronym SPI.

4.1 SaaS – Software as a Service

SaaS is the most common type of cloud service:

- SaaS provides licensed multi-tenant access to software and its functions remotely as a web-based service
- With SaaS, organizations don't buy or develop their own business applications and run and manage them on their own IT Infrastructure

	**Multi-tenancy**	*'Multi-tenancy is an architecture in which a single instance of a software application serves multiple customers, each customer is called a tenant'* (Source: https://whatis.techtarget.com)

SaaS extends the idea of the ASP model. Many types of SaaS services were developed from ASP solutions into cloud solutions. The table below shows some examples:

ASP Solutions	Cloud Solutions
Application hosting	Multi-tenancy
Pay per licence	Pay per use
Emulation	Web based interfaces
Remote desktop services	Elastic services

Table 2: ASP and Cloud Solutions

	**Emulation**	Emulation refers to the ability of a computer program in an electronic device to emulate (or imitate) another program or device

	**Remote Desktop Services**	Remote Desktop Services (RDS), known as Terminal Services in Windows Server 2008 and earlier, is one of the components of Microsoft Windows that allow a user to take control of a remote computer or virtual machine over a network connection

Typical examples of SaaS solutions are:

- Customer Relationship Management (CRM)
- HR
- ERP or Enterprise Resource Planning
- Billing and invoicing
- Web Hosting
- E-commerce
- Transaction processing
- Online collaboration
- Other business processes

The key characteristics of SaaS are:

- Software hosted offsite
- Software on demand
- Software package
- No modification of the software
- Plug-in software: external software used with internal applications (Hybrid Cloud)
- SaaS vendor with advanced technical knowledge
- User entangled with vendor

The key benefits are:

- The customer does not need to focus on the development and management of these applications
- The provider is responsible for updates and managing licenses
- A customer pays by means of a subscription or pay-per-use model

Sub-types, or maybe simply other names for SaaS, are "software on demand," "hosted services" and "application service provisioning." DBaaS (Database as a Service) has emerged as a sub-variety of SaaS.

4.2 PaaS – Platform as a Service

PaaS means that the customer doesn't have to own a computer platform but can use it "on demand" which can save costs in ownership, management and maintenance.

	**Platform**	*'A platform is a group of technologies that are used as a base upon which other applications, processes or technologies are developed. In personal computing, a platform is the basic hardware (computer) and software (operating system) on which software applications can be run.'* (Source: https://www.techopedia.com)

In a typical software development environment, platforms are used for the time the project runs, and a new project may have other, newer requirements. During some stages of the development process, like testing, an up-scaled environment might be needed to simulate a production, and PaaS services can offer this on-demand scalability.

The following table shoes the types of PaaS:

Type of PaaS	Description
Public PaaS	It is formed from SaaS and is found in Cloud Computing between SaaS and Infrastructure as a Service (IaaS)
Private PaaS	Typically, it can be downloaded and installed either on a company's on-premises infrastructure, or in a public cloud. Once the software is installed, the private PaaS arranges the application and database components into a single hosting platform
Hybrid PaaS	This registers multiple cloud infrastructures as independent pools and merge those different pools into a single resource pool. This leads to resource normalization while still preserving identity of origin
Mobile PaaS	PaaS provides development capabilities for mobile app designers and developers

Open PaaS	It does not include hosting, but provides open source software allowing a PaaS provider to run applications in an open source environment
PaaS for Rapid Development	Enterprise public cloud platforms for rapid developers is defined by Forrester Research as an emerging trend

Table 3: Types of PaaS

	**Normalization**	Normalization is the process of reorganizing data in a database so that … there is no redundancy of data and data dependencies are logical (Source: https://www.webopedia.com/)

The following table displays some variations on PaaS:

Variations on PaaS	Description
Software development environment	A customer can develop an application without purchasing a dedicated development environment, and without having to configure and manage the components like hardware, middleware and the different software layers - Microsoft Azure and the Google App engine are examples of such a service
Hosting environment for applications	This service only consists of services at the hosting level like security and on-demand scalability
Online storage	Web based interfaces
Remote desktop services	Cloud solutions, because of their architecture with Storage Area Network (SAN) servers, not only offer online storage but also extremely rapid data exchange between instances of online storage

Table 4: Variations on PaaS

	**Middleware**	Software that acts as a bridge between an operating system or database and applications, especially on a network

The key characteristics of PaaS are:

- Mostly used for remote application development
- Remote application support
- Platform may have special features
- Low development costs

4.3 IaaS – Infrastructure as a Service

IaaS provides access to virtualized computing resources in the Cloud across the internet. These resources include a virtual server space, network connections, bandwidth, IP addresses and load balancers. To do this, hardware resources are pulled from servers and networks usually distributed across numerous data centers that the cloud provider maintains, while the client gains access to the virtualized components to build their own IT platforms. Hardware resources include CPU, memory, disk storage.

	**Load Balancer**	*'In computing, load balancing improves the distribution of workloads across multiple computing resources, such as computers, a computer cluster, network links, central processing units, or disk drives'* (Source: Wikipedia)

IaaS services are sold by hardware service providers, such as Amazon Web Services, where a customer can rent physical or virtual hardware like storage, servers or internet connectivity. Services are sold according to a utility computing service and billing model. Utility computing is the process of providing computing service through an on-demand, pay-per-use billing method.

The background of IaaS can be found in the merger between IT and Telecom infrastructure and services in the past decade.

The key characteristics of IaaS are:

Dynamic scaling - Dynamic scaling tests that an evolving system exhibits self-similarity. In general, a function is said to exhibit dynamic scaling if it satisfies: Here the exponent is fixed by the dimensional requirement

Desktop virtualization - Desktop virtualization is software technology that separates the desktop environment and associated application software from the physical client device that is used to access it

Policy-based services - An IaaS provider provides policy-based services and is responsible for housing, operating and maintaining the infrastructure equipment it provides for a client

5. The Evolution of Cloud Computing

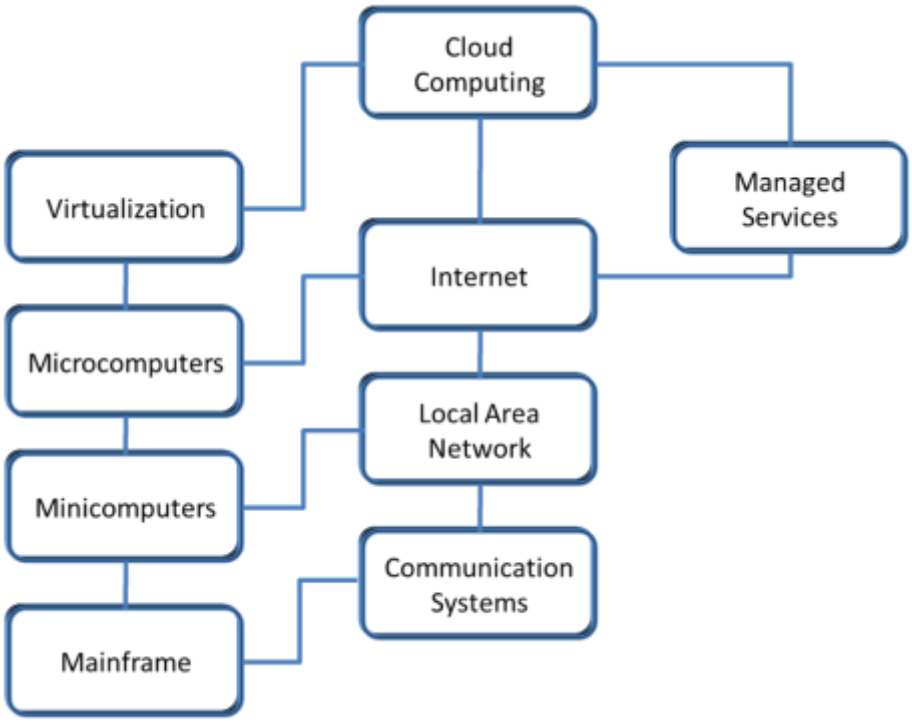

Figure 1.3: Overview of Evolution of Cloud Computing

These factors have contributed to the cloud as it appears today:

- The development of the Internet
- Moving from mainframe computing to personal devices connected to the Internet
- The development of computer networks

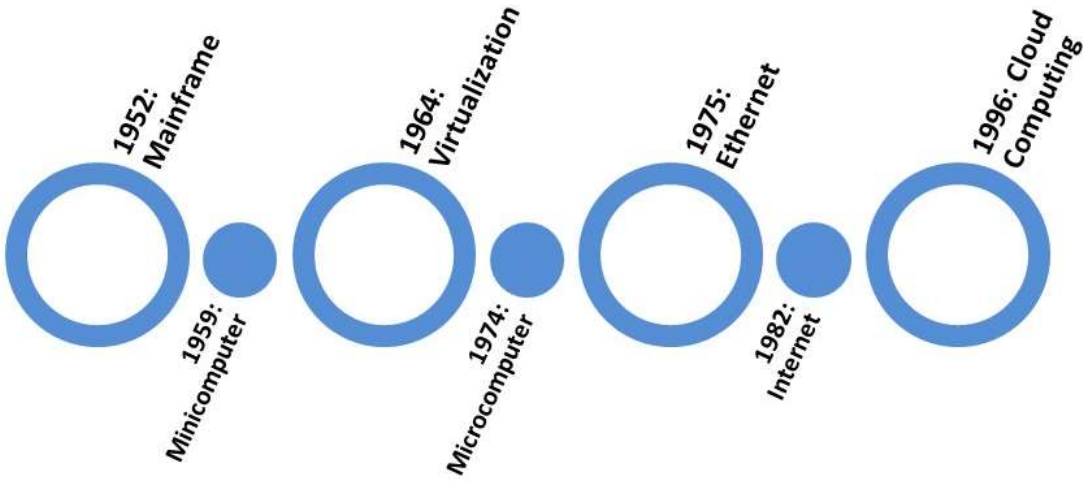

Figure 1.4: Timeline

5.1 Networks and Servers

The first mainframe computers were not connected to a network. At first, they had a point-to-point connection with a terminal. The first terminals did not even have a monitor. When business applications started to run on mainframes, users got their own terminals, but these were not interconnected. All data processing and information sharing was done on the mainframe computer. When decentralized computing started to appear the first mini computers were developed. The first generation of these decentralized computers with their own attached terminals were called mini computers These decentralized computers were connected through local (LAN) or wide area (WAN) connections to the central mainframe computer.

When IBM started selling their first microcomputer, the IBM PC, it was predicted that there would only be a need for a few of these per office, and most likely stand-alone. Almost immediately there was a need to connect these PC's to the central computers through a network. Instead of having a mainframe terminal plus a PC on a desk, it was possible to have a PC connected to a network and access the mainframe with a terminal emulation program.

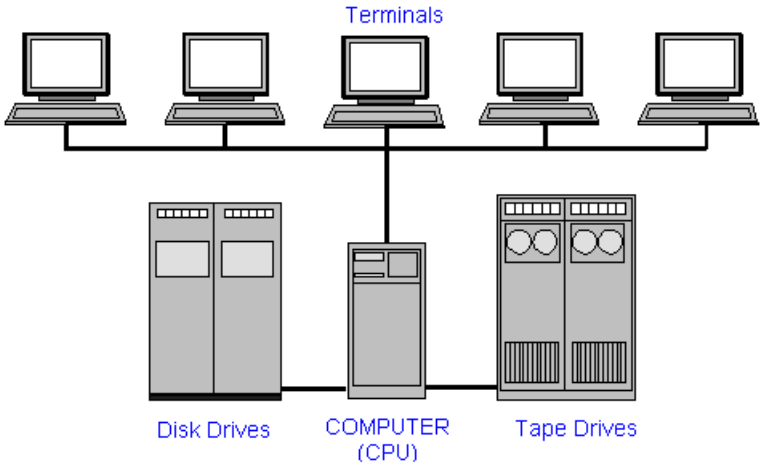

Figure 1.5: Minicomputer

In summary, these are the features of the minicomputer:

- Easier to purchase
- Smaller
- Cheaper
- First specialized, later multi-tasking
- Development of LAN

	**LAN/WAN**	*'A local area network (LAN) is a computer network that interconnects computers within a limited area such as a residence, school, laboratory, university campus or office building…a wide area network (WAN) not only covers a larger geographic distance, but also generally involves leased telecommunication circuits.'* (Source: Wikipedia)

	**Ethernet**	*'Ethernet is a family of computer networking technologies commonly used in local area networks (LAN), metropolitan area networks (MAN) and wide area networks (WAN)…Over time, Ethernet has largely replaced competing wired LAN technologies such as Token Ring, FDDI and ARCNET'* (Source: Wikipedia)

As the microcomputer developed, we can see the following happened:

- They became smaller and smaller
- Moved from single user to multi user
- Limited memory and storage became limitless
- The simple operating system became multi OS

	**Multi-OS**	*'Multi OS is an operating system that allows multiple application program to be installed and to reside separately and securely on a smart card. Each program is isolated by the operating system so that no application can interfere with another one.'* (https://whatis.techtarget.com/)

At the same time as the microcomputer, or PC, several network topologies were developed, many with their own protocol.

	**Network Topology**	*Network topology is the arrangement of the elements of a communication network.* (Source: Wikipedia)
	**Communication Protocol**	*In telecommunication, a communication protocol is a system of rules that allow two or more entities of a communications system to transmit information via any kind of variation of a physical quantity* (Source: Wikipedia)

The most popular protocol today is the star topology in combination with the TCP/IP protocol.

	**Tip**	It is important to realize that the Transmission Control Protocol (TCP) / Internet protocol (IP) stack is the core protocol of the Internet

The next development was client-server architecture:

- PCs were now able to connect to several different mini computers called servers, for example, file servers, application servers etc.
- With increasing bandwidth and speed of the networks, servers and capacity, and ever cheaper and smaller personal devices to connect to networks we entered the age of the Internet and Application Hosting by ASP (application service providers)
- The Cloud service SaaS is based on these ASP solutions

	**File Server**	A device which controls access to separately stored files, as part of a multi-user system

	**Application Server**	*'An application server is a software framework that provides both facilities to create web applications and a server environment to run them'* (Source:Wikipedia)

5.2 The Role of the Internet

The vision for a global network originally came from American computer scientist J. C. R. Licklider, (1963) in his memo: "*Memorandum for Members and Affiliates of the Intergalactic Computer Network*". This vision was later realized in 1969 in the form of the ARPANET but was designed for the USA armed forces

Funding from the National Science Foundation Network (NSFNET) along with private funding for commercial extensions, led to worldwide participation in developing new networking technologies, and the merger of many networks leading to the internet as it is known today. The original network protocol NCP was replaced by TCP/IP in 1983 and is now leading protocol.

To make the Internet accessible to everyone, first there needed to be two other developments:

- personal devices such as laptop, smart phone, tablet
- network connectivity

These developments happened in parallel and started with terminals connected to a mainframe giving access to central computing facilities and applications.

Network and server forms:

Service Forms	Uses	Special services on Intelligent Devices
Dial up with modem	Dedicated terminal	Terminal server (remote access)
Dedicated leased-line	Access to time sharing services	Batch processing (job entry)

Table 5: Network and Server Forms

The Internet runs many services such as:

- WWW
- FTP (File Transfer Protocol)
- SMTP (Simple Mail Transfer Protocol -or email)
- IP telephony
- HTTP (Hypertext Transfer Protocol)

5.3 Virtualization

Virtualization means the creation of a virtual version of something rather than an actual version, including:

- A virtual computer hardware platform
- Operating system (OS)
- Storage device or computer network resources

	**Network Resources**	*'All forms of data, information and hardware devices that can be accessed by a group of computers through the use of a shared connection can be considered as network resources. These types of resources are also known as shared resources.'* (Source: https://www.quora.com/)

In Virtualization: A Manager's Guide (2011), Daniel Kuznetzky states that '*the earliest form of application virtualization was developed by mainframe suppliers, such as IBM…*' An example is the IBM VM/370 from 1972. Since the 1990s, Windows has also become the center of virtualization developments by Microsoft, Citrix, VMware and others. Citrix Systems, Inc. is an American multinational software company that provides server, application and desktop virtualization, networking, software as a service, and cloud computing technologies and VMware, Inc. is a subsidiary of Dell Technologies that provides cloud computing and platform virtualization software and services.

Virtualization means that hardware, applications and data can be located anywhere in the cloud; we only need to access and use them. Virtualization is the solution for integrating:

- High-speed computers
- Large storage capacity
- Internet

Virtualization leads us to the concept of the cloud:

- Virtualized operating environment
- Thin clients
- Web-based delivery

	**Virtual Machine**	*'A virtual machine (VM), or Virtualized operating environment, is a software program or operating system that not only exhibits the behaviour of a separate computer, but is also capable of performing tasks such as running applications and programs like a separate computer. A virtual machine, usually known as a guest is created within another computing environment referred as a "host." Multiple virtual machines can exist within a single host at one time. A virtual machine is also known as a guest.'* (Source: https://www.techopedia.com/definition/4805/virtual-machine-vm)

	**Thin Client**	*'A thin client is a lightweight computer that has been optimized for establishing a remote connection with a server-based computing environment. The server does most of the work, which can include launching software programs, crunching numbers, and storing data. This contrasts with a fat client or a conventional personal computer'* (Source: Wikipedia)

The key features of virtualization are:

- It multiplies the use of high-performance computers
- Puts extra/excess capacity to use
- Multi-tenancy

Kuznetzky (2011) recognizes 5 different types of virtualization:

Types of Virtualization	Description
Access virtualization	Access to any application from any device
Application virtualization	Enables applications to run on many different operating systems and hardware platforms
Processing virtualization	Makes one system seem like many, or many seem like one
Network virtualization	Presents an artificial view of the network that's different from reality
Storage virtualization	Allows many systems to share the same storage devices, hide the location of storage systems, and more

Table 6: Types of Virtualization

5.4 Managed Services

Managed services describes the practice of outsourcing day-to-day management responsibilities and functions. It is a strategic method for improving operations and cutting expenses. Managed services can include a range of different business processes and functions; this course focused on managed IT services provided by a third party

An old example, since mainframe days, is application hosting by an IT provider. In the late 1990s applications were offered by providers, meaning that they were no longer owned by the customer. This first example of shared managed services was delivered by ASPs or application service providers.

A good example of an early ASP is Microsoft's Hotmail, which was a free web-based email service, but they could be anything from office suites for word-processing and spreadsheets to enterprise applications such as sales automation or customer relationship management. This cloud-based email provider is now called Outlook.com which still provides a free email service to end users. Because of the bursting internet or dot-com bubble in the early 2000s the ASP slowly developed into one of the major cloud service models SaaS.

Managed services need a good service management framework

IBM Redbooks and many industry best practices were used to create the IT Infrastructure Library, now referred to as ITIL®

	**IBM Redbooks**	IBM Redbooks are technical content developed and published by IBM's International Technical Support Organization (ITSO). They typically provide positioning and value guidance, installation and implementation experiences, typical solution scenarios, and step-by-step "how-to" guides.

The ITIL® framework for IT Service Management was developed in the early 1970s and has had several versions.

The key internal ITIL® processes, or ones that are managed by the organization for a cloud data center include:

- Availability management
- Capacity management
- Security management
- Service continuity management

External, or outsourced, processes include:

- **Service level management** - Maintaining, managing, reporting on and improving service levels sold to and agreed with the customer
- **Financial management** - Financial Management means planning, organizing, directing and controlling the financial activities of the enterprise

The advantages of managed services are:

- Accessibility and availability to work wherever and whenever you need with user support
- Shift of focus from IT to the core business for the outsourcing organization
- No need for highly trained IT staff within the outsourcing organization - the customer's own IT department can shift their focus from operational issues to more high value activities, as they are no longer responsible for constant server updates and other maintenance. The CIO will still need to have an awareness of maintenance and service issues so they can solve problems quickly when they arise

The focus now shifts to IT governance. The key issues are shown in the following table:

Governance Focus	Issues
Performance	Can the cloud services support our business model now, and when it is transforming?
Compliance	Do the services comply with relevant national and international legislation?
Contingency	What happens if the cloud provider goes out of business?

Table 7: Governance Issues

How can a customer stay 'in the driver's seat'? One way is through audit models focusing on the IT service management processes, data center performance and compliance issues. Data centers with a history of platform and application hosting often use the following ISO/IEC audit standards and guidelines for their internal and external audit mechanisms:

ISO/IEC audit standards
ISO 19011:2011; Guidelines for auditing management systems
ISO/IEC 20000-1:2011; Information technology -- Service management -- Part 1: Service management system requirements
ISO/IEC 20000-2:2012; Information technology -- Service management -- Part 2: Guidance on the implementation of service management systems
ISO/IEC TR 20000-9:2015; Information technology -- Service management -- Part 9: Guidance on the application of ISO/IEC 20000-1 to cloud services
ISO/IEC 27001:2013; Information technology -- Security techniques -- Information security management systems -- Requirements
ISO/IEC 27002:2013; Information technology -- Security techniques -- Code of practice for information security controls
ISO/IEC 27007:2011; Information technology -- Security techniques -- Guidelines for information security management systems auditing
ISO/IEC DIS 27017; Information technology -- Security techniques -- Code of practice for information security controls based on ISO/IEC 27002 for cloud services (under development)
ISO/IEC 27018:2014; Information technology -- Security techniques -- Code of practice for protection of personally identifiable information (PII) in public clouds acting as PII processors
ISO/IEC CD 27036-4; Information technology -- Information security for supplier relationships -- Part 4: Guidelines for security of Cloud services (under development)
ISO/IEC 24762:2008; Information technology -- Security techniques -- Guidelines for information and communications technology disaster recovery services

Table 8: ISO/IEC audit standards and guidelines

For customers of cloud services, good governance practices are increasingly important. These are the international standards and frameworks for corporate governance of IT:

- COBIT™5 - Guidance for executive management to govern IT within the enterprise
- ISO/IEC 38500:2015- Information technology -- Governance of IT for the organization

5.5 Benefits and Limitations

Cloud computing is evolving quickly with companies of all shapes and sizes adapting to offer and to take advantage of this new technology. Industry experts believe that this trend will continue to grow and develop. While cloud computing is beneficial, it can have downsides, especially for smaller businesses

The main benefits of cloud computing are:

- **Reduced cost** - The potential to reduce costs relates to the pay-per-use and/or subscription model, meaning organizations do not have to invest in IT infrastructure upfront. For cloud providers costs are lower because of the economies of scale and the multi-tenancy principle; no space is left unused
- **Automation** - The customer is no responsible for updates, security patches and backups and keeping software up to date
- **On demand - flexibility + scalability = elasticity** - Cloud computing offers more flexibility as a customer can change the 'cloud mix' of services in a dynamic way to support business demands and requirements. Enterprises can scale their IT infrastructure up or down on demand
- **More mobility -** Data and applications can be accessed through the Internet from any type of smart computing device at anytime and anywhere
- **Shared resources (Multi-tenancy)** - Customers share resources allowing smaller organizations to have access to large scale IT facilities, services and support. Users belonging to one or more customers can work together in a shared project environment
- **Back to core business** - Most types of start-up business do not need to own and operate IT, so they can focus on their own strategic goals
- **More for less** - More IT functionality for a lower price: by sharing

The possible disadvantages of cloud computing are:

- **Internet access** - Usually, no internet access means no cloud access
- **Security** - Cloud data centers can be high security and highly managed, but also low security and badly managed. How can this be checked?
- **Privacy** - In case of public or hybrid cloud it is important to know where data is stored in combination with varying national and international legislation on privacy, do you know who can access your data?
- **Vendor lock-in -** Staying with a provider that doesn't meet your needs, just to avoid the difficult process of migrating your cloud services

	Tip	Note that security and privacy can also be a benefit if the customer is proactive and chooses a reputable cloud vendor

Another aspect that could be considered an advantage or disadvantage is the service level agreement; does the agreement allow for flexibility and scalability? If so it's an advantage but if not it's a disadvantage, the customer has a responsibility to get this right.

6. Cloud Computing Architectures

There are two key architectural principles that apply to cloud computing:

- Multipurpose architecture
- Multi-tenancy

	**Architecture**	*'Cloud computing architecture refers to the components and subcomponents required for cloud computing. These components typically consist of a front-end platform (fat client, thin client, mobile device), back end platforms (servers, storage), a cloud-based delivery, and a network (Internet, Intranet, Intercloud)'* (Source: Wikipedia)

6.1 Multipurpose Architecture

In the past most architectures were exclusively owned and single purpose. Single purpose architecture allows for a single instance of a piece of software per client to run on the SaaS server. Two examples are:

- Accounting systems
- Storage of healthcare data

In cloud computing the infrastructure is multipurpose. An example could be a system on which data is not only stored, but also distributed over the Internet.

The key characteristics of multipurpose architecture can be seen in this table below:

Multipurpose Architecture Characteristics	
Multi-tiered	(often referred to as n-tier architecture) is a client–server architecture in which presentation, application processing, and data management functions are physically separated (Source: Wikipedia)
Virtualization (server)	Many different types of implementation can run on the same platform in a virtual environment, so it is easy to guarantee scalability to all customers. Re-installing a new dedicated virtual platform is much quicker and easier than (re-)installing a physical server
Interoperable layers	This means that cloud layers can interact with each other and exchange information
Open standards	Open standards are the key to having interoperable layers and flexibility in the cloud and avoids vendor lock in, Open Stack is an example of an open industry initiative
Portability	The ability for software to be transferred from one machine to multiple operating systems

Table 9: key Characteristics of Multipurpose Architecture

	Open Stack	*OpenStack is a free and open-source software platform for cloud computing, mostly deployed as infrastructure-as-a-service, whereby virtual servers and other resources are made available to customers* (Source: Wikipedia)

When the server virtualization is the operating system the hypervisor is the separating layer between guest operating systems and the hardware. This is illustrated in the figure below:

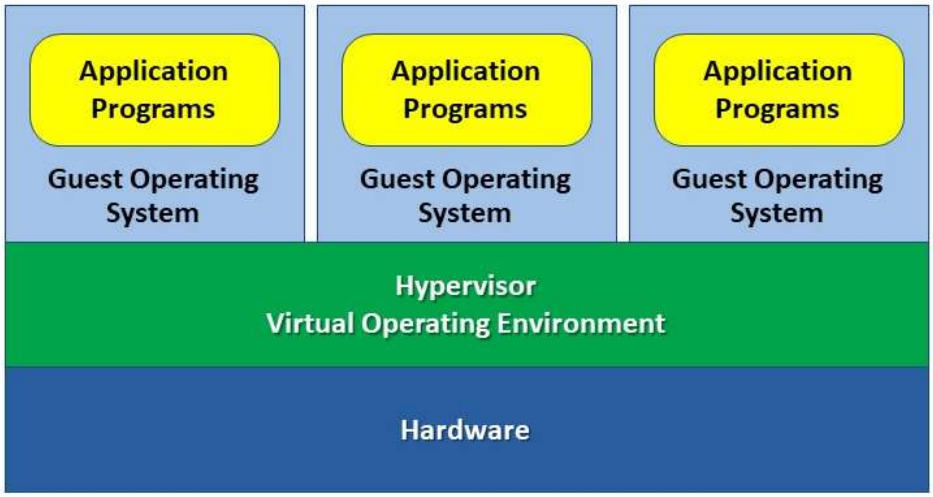

Figure 1.6: Virtualization as OS

	**Hypervisor**	*'A hypervisor or virtual machine monitor is computer software, firmware or hardware that creates and runs virtual machines. A computer on which a hypervisor runs one or more virtual machines is called a host machine, and each virtual machine is called a guest machine'* (Source: Wikipedia)

In this next example the host operating system is used as the first tier of access control:

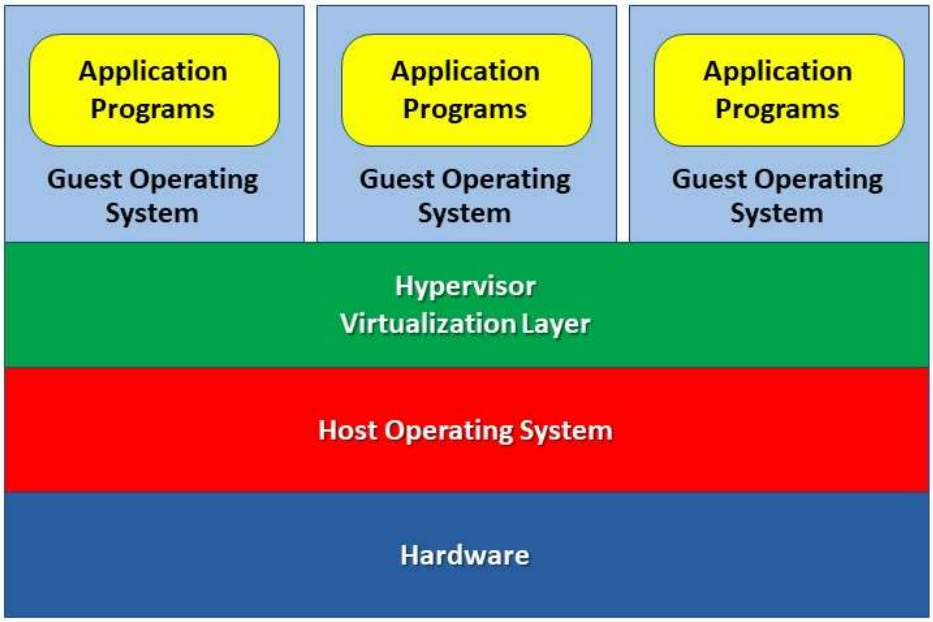

Figure 1.7: Virtualization Host OS

	**Host OS**	A host OS is the software installed on a computer that interacts with the underlying hardware and is usually used to describe an operating system used in a virtualized server to differentiate it from the guest operating system (Source: TechTarget)

Tiered architecture is a client-server architecture with different tiers for database, application and load balancing:

Figure 1.8: Tiered Architecture

	**Load balancing**	Load balancing is a way for distributing tasks onto multiple computers, for example, distributing incoming HTTP requests or tasks for a web application onto multiple servers
	**Web front end**	This can also be called the presentation layer and consists of the user interface
	**Business logic**	This is also called the application tier and includes the business logic that drives the core capabilities
	**Database**	This is the data tier and it is the database management system that provides access to application data

6.2 Multi-tenancy

Multi-tenancy is an architecture that enables a single instance of a software application to serve multiple customers called tenants. Tenants may be given the ability to customize some parts of the application, such as color of the user interface (UI) or business rules, but they cannot customize the application's code. A key element of multi-tenancy is security, as if it cannot be guaranteed on all levels of the infrastructure, customers will be hesitant to adopt this model.

The meaning of multi-tenancy architecture has broadened because of new service models that take advantage of virtualization and remote access. A SaaS provider, for example, can run one instance of its application on one instance of a database and provide web access to multiple customers. Each tenant's data is isolated and remains invisible to other tenants.

In "Multi-Tenancy Misconceptions in Cloud Computing", Srinivasan Sundara Rajan states the business case for multi-tenancy:

	**Multi-tenancy**	*"a large number of users, basically multi tenants, makes the Cloud platform most efficient in terms of usability of the application and 'Do More with Less Resources"* (Rajan 2011)

Rajan gives some examples of multi-tenant solutions:

- Salesforce.com: a SaaS-based CRM application for various businesses using common framework and multi tenancy model
- Microsoft Dynamics CRM Online offering
- Multi-tenancy IaaS/PaaS offerings from Amazon or IBM or Microsoft Azure

6.3 Service Oriented Architecture

	**SOA**	*'Service-Oriented Architecture (SOA) is an architectural style that supports service orientation. Service orientation is a way of thinking in terms of services and service-based development and the outcomes of services'* (© the Open Group™)

The Open Group™ also defined a service to be:

- a logical representation of a repeatable business activity that has a specified outcome (e.g., check customer credit; provide weather data, consolidate drilling reports)
- self-contained
- may be composed of other services
- a black box to consumers of the service.

	**Black Box**	A complex system or device whose internal workings are hidden or not readily understood

In The Cloud-SOA Connection by P Krill (2009) he asks the question:
'Can we build a datacenter infrastructure on SOA principles?'

G Cuomo answers: '*Yes, and that's the cloud, so it's a service-oriented infrastructure, … It's taking that architectural principle of SOA and applying it to an infrastructure*'

SOA is the instance of interoperability, portability and scalability. A service-oriented architecture is basically a collection of services that communicate with each other by simply passing data between two or more services or a jointly managed activity. Connecting these services in many cases involves web services using XML. One might say that there would be no cloud without SOA.

	XML	Extensible Markup Language (XML) is a markup language that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable (Source: Wikipedia)