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Apex Institute of Technology(CSE)

Subject Name & Subject Code: Cloud Computing and IoT (CSD-385)

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Unit I: Overview of Computing Paradigm

- **Overview of Computing Paradigm: Recent Trends in Computing:; Distributed Computing; Cluster Computing; Grid Computing; Utility Computing; Evolution of Cloud Computing: Migrating into a Cloud.**

- **Cloud Computing Basics: Cloud Computing Overview:; Characteristics; Applications; Benefits; Limitations; Challenges; Infrastructure as a Service; Platform as a Service; Software as a Service.**

Introduction

- **The ACM *Computing Curricula 2005* defined "computing" as**

- **"In a general way, we can define computing to mean any goal-oriented activity requiring, benefiting from, or creating computers. Thus, computing includes designing and building hardware and software systems for a wide range of purposes; processing, structuring, and managing various kinds of information; doing scientific studies using computers; making computer systems behave intelligently; creating and using communications and entertainment media; finding and gathering information relevant to any particular purpose, and so on. The list is virtually endless, and the possibilities are vast."**

What is Cloud Federation?

- **Cloud Federation, also known as Federated Cloud is the deployment and management of several external and internal cloud computing services to match business needs.**

- **It is a multi-national cloud system that integrates private, community, and public clouds into scalable computing platforms.**

- **Federated cloud is created by connecting the cloud environment of different cloud providers using a common standard.**
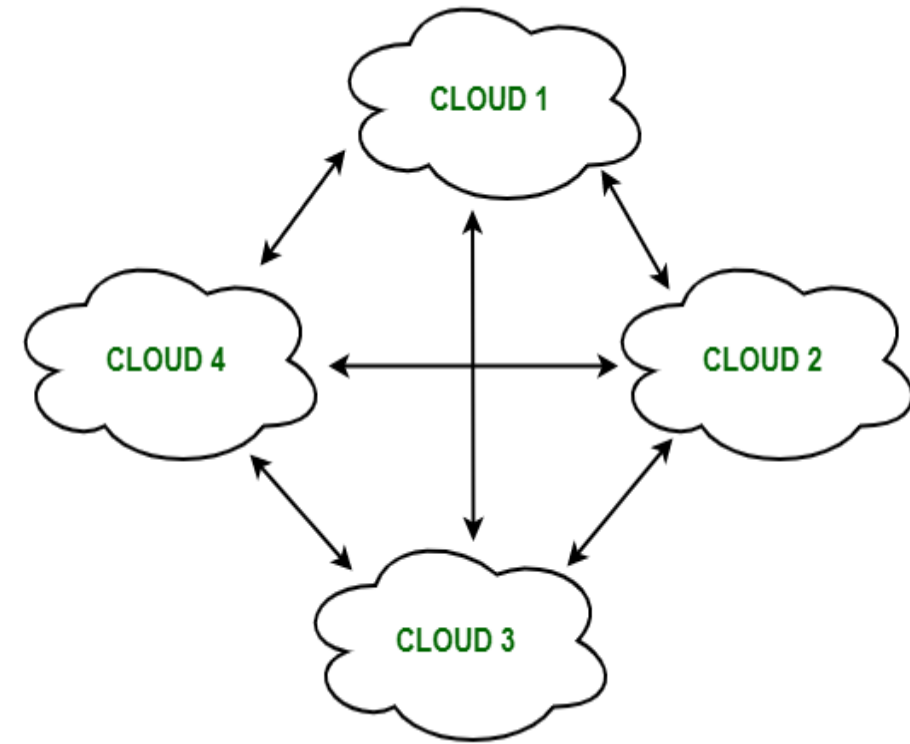
The architecture of Federated Cloud:
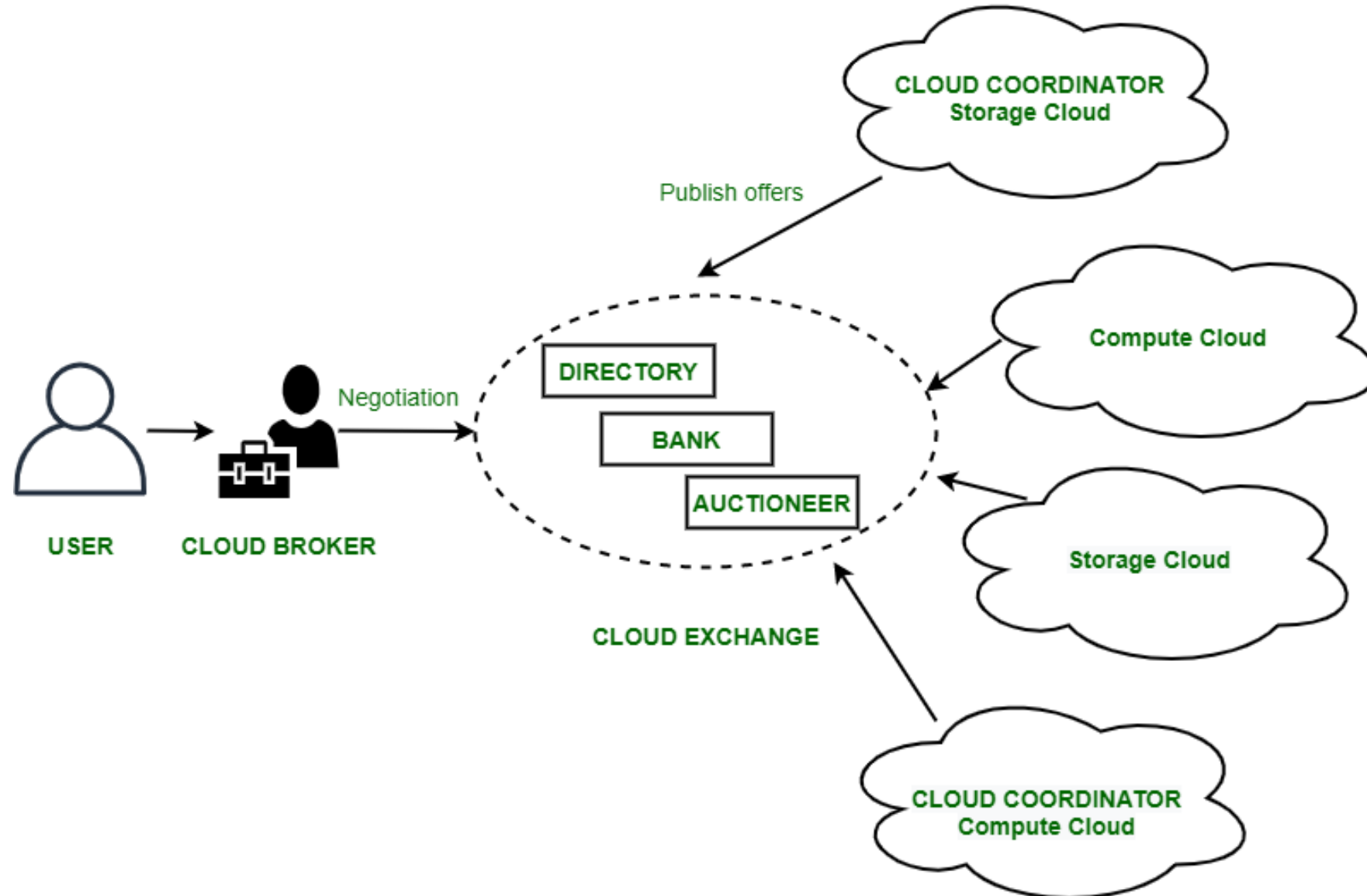
Cloud Exchange

- **The Cloud Exchange acts as a mediator between cloud coordinator and cloud broker.**

- **The demands of the cloud broker are mapped by the cloud exchange to the available services provided by the cloud coordinator.**

- **The cloud exchange has a track record of what is the present cost, demand patterns, and available cloud providers, and this information is periodically reformed by the cloud coordinator.**

- **2. Cloud Coordinator**

- **The cloud coordinator assigns the resources of the cloud to the remote users based on the quality of service they demand and the credits they have in the cloud bank. The cloud enterprises and their membership are managed by the cloud controller.**

- **3. Cloud Broker**

- **The cloud broker interacts with the cloud coordinator, analyzes the Service-level agreement and the resources offered by several cloud providers in cloud exchange. Cloud broker finalizes the most suitable deal for their client.**

Benefits of Federated Cloud:

- **It minimizes the consumption of energy.**

- **It increases reliability.**

- **It minimizes the time and cost of providers due to dynamic scalability.**

- **It connects various cloud service providers globally. The providers may buy and sell services on demand.**

- **It provides easy scaling up of resources.**

Trends in Computing

- **Distributed Computing**

- **Grid Computing**

- **Cluster Computing**

- **Utility Computing**

- **Cloud Computing**

Centralized vs. Distributed Computing

Early computing was performed on a single processor. Uni-processor computing can be called centralized computing.
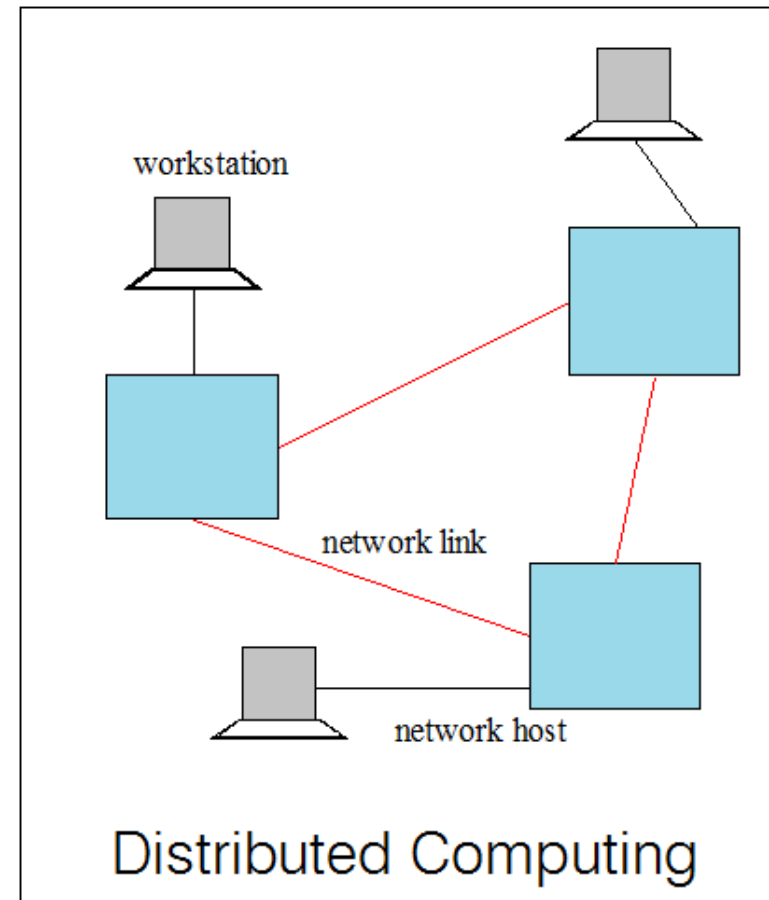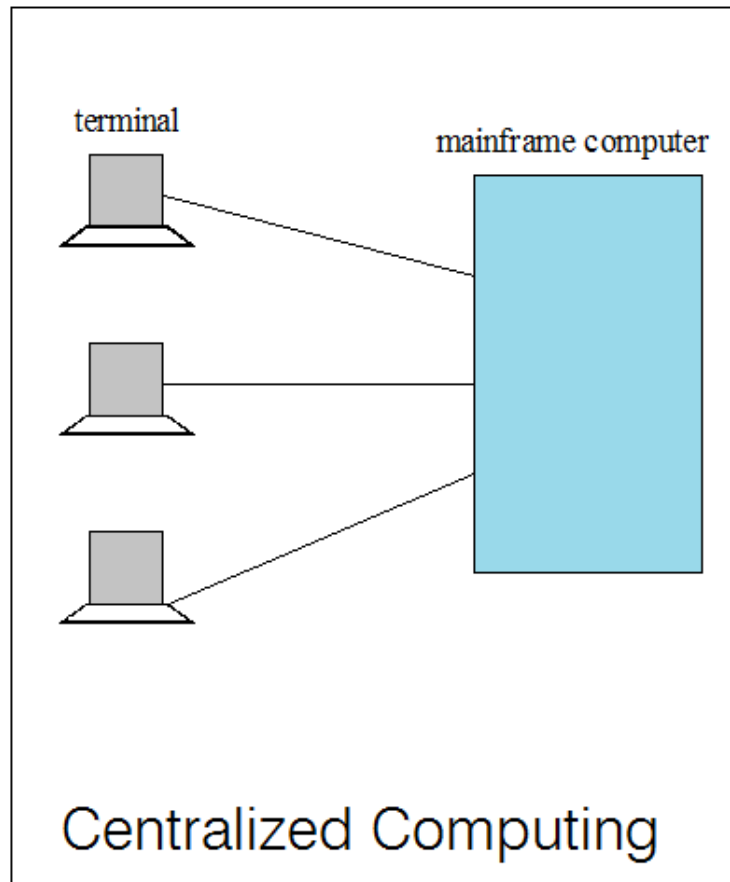
- **Distributed computing is defined as a type of computing where multiple computer systems work on a single problem. Here all the computer systems are linked together and the problem is divided into sub-problems where each part is solved by different computer systems.**

- **The goal of distributed computing is to increase the performance and efficiency of the system and ensure fault tolerance.**

- **In the below diagram, each processor has its own local memory and all the processors communicate with each other over a network.**

Distributed Computing

- **Distributed computing**
  - **Field of computing science that studies distributed system.**
  - **Use of distributed systems to solve computational problems.**
- **Distributed system**
- **Wikipedia**
  - **There are several autonomous computational entities, each of which has its own local memory.**
  - **The entities communicate with each other by message passing.**
- **Operating System Concept**
  - **The processors communicate with one another through various communication lines, such as high-speed buses or telephone lines.**
  - **Each processor has its own local memory**
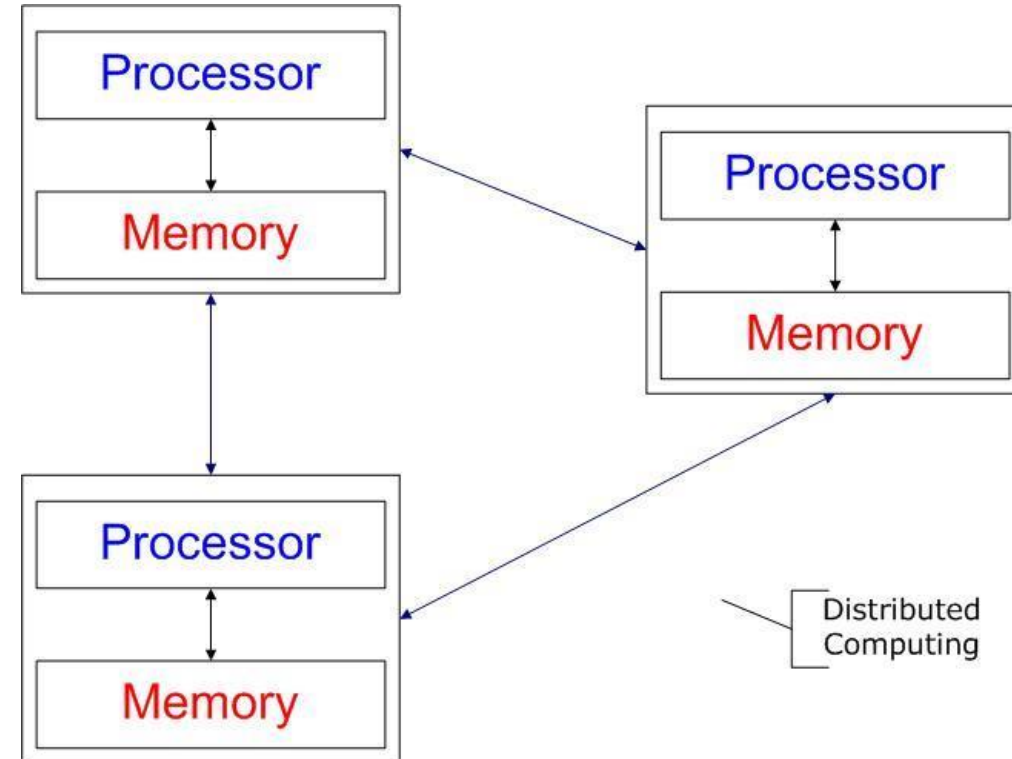
Example Distributed Systems

1. **Internet**

2. **ATM (bank) machines**

3. **Intranets/Workgroups**

4. **Computing landscape will soon consist of ubiquitous network-connected devices**

Computers in a Distributed System

- **Workstations: Computers used by end-users to perform computing**

- **Server Systems: Computers which provide resources and services**

- **Personal Assistance Devices: Handheld computers connected to the system via a wireless communication link.**

Common properties of Distributed Computing

– **Fault tolerance**
  - **When one or some nodes fails, the whole system can still work fine except performance.**
  - **Need to check the status of each node**

– **Each node play partial role**
  - **Each computer has only a limited, incomplete view of the system.**
  - **Each computer may know only one part of the input.**

– **Resource sharing**
  - **Each user can share the computing power and storage resource in the system with other users**

– **Load Sharing**
  - **Dispatching several tasks to each nodes can help share loading to the whole system.**

– **Easy to expand**
  - **We expect to use few time when adding nodes. Hope to spend no time if possible.**

– **Performance**
  - **Parallel computing can be considered a subset of distributed computing**
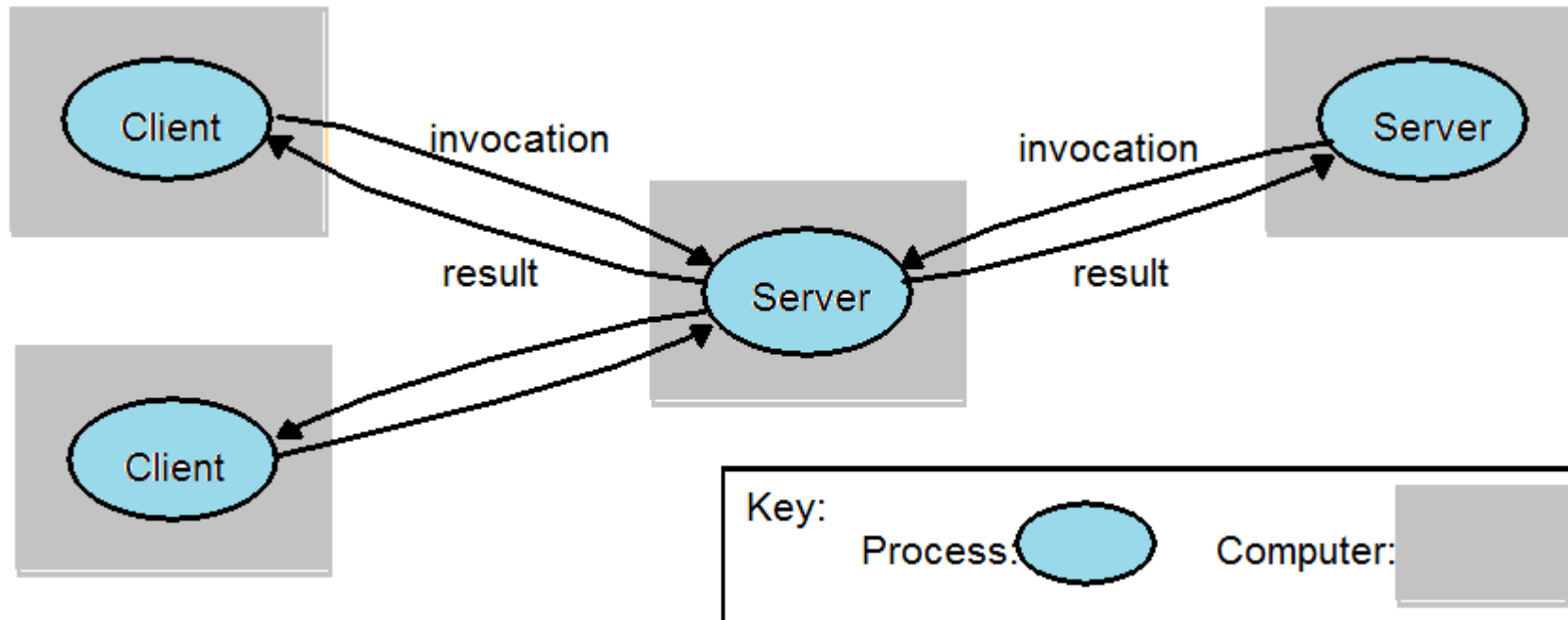
Why Distributed Computing?

- **Nature of application**

- **Performance**
    - **Computing intensive**
    - **The task could consume a lot of time on computing. For example, Computation of Pi value using Monte Carlo simulation**
    - **Data intensive**
    - **The task that deals with a large amount or large size of files. For example, Facebook, LHC(Large Hadron Collider) experimental data processing.**

- **Robustness**
    – **No SPOF (Single Point Of Failure)**
    – **Other nodes can execute the same task executed on failed node.**

Distributed applications

- **Applications that consist of a set of processes that are distributed across a network of machines and work together as an ensemble to solve a common problem**

- **In the past, mostly "client-server"**

  - **Resource management centralized at the server**

- **"Peer to Peer" computing represents a movement towards more "truly" distributed applications**

Clients invoke individual servers

A typical distributed application based on peer processes
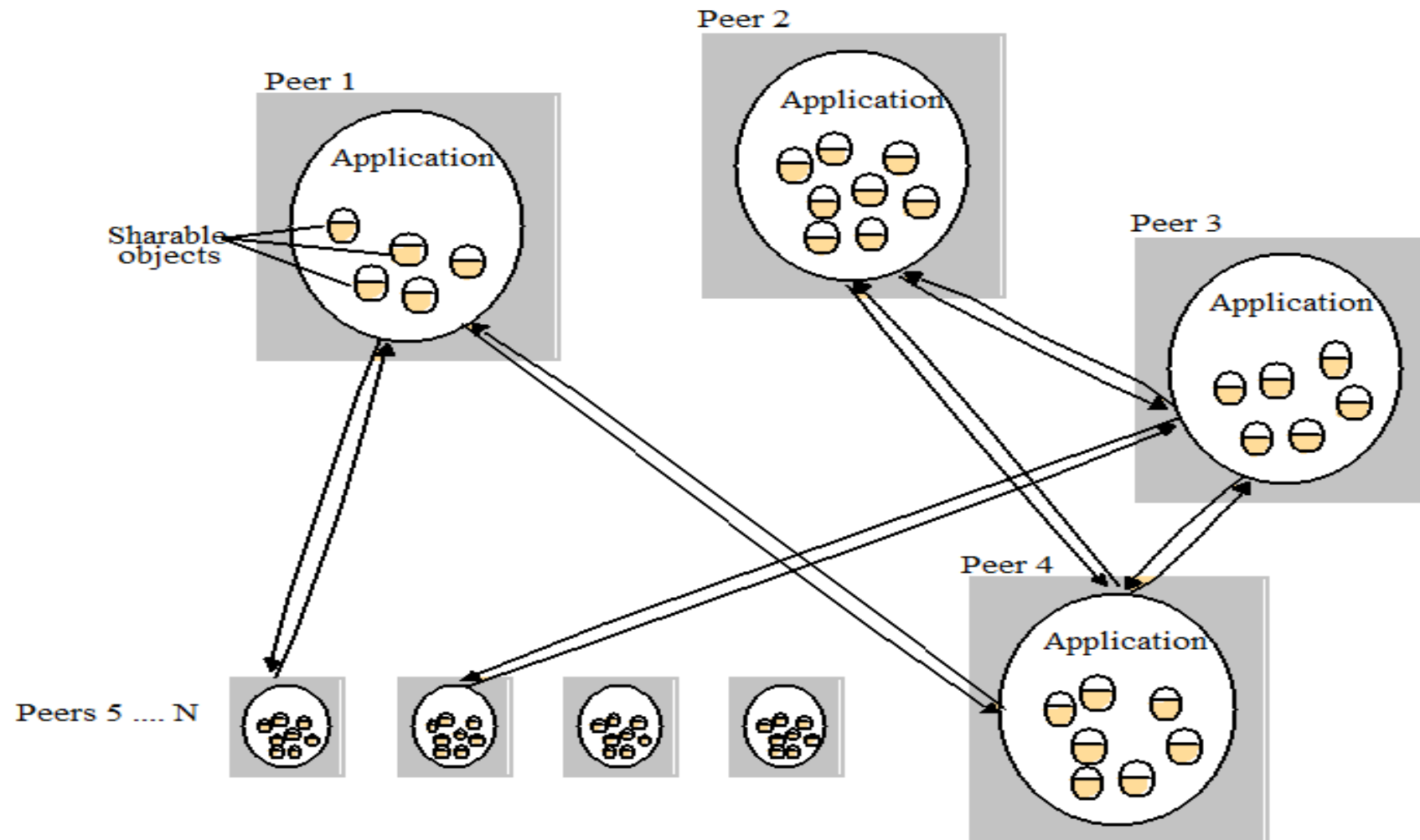
2. Parallel Computing :

- Parallel computing is defined as a type of computing where multiple computer systems are used simultaneously. Here a problem is broken into sub-problems and then further broken down into instructions. These instructions from each sub-problem are executed concurrently on different processors.

- Here in the below diagram you can see how the parallel computing system consists of multiple processors that communicate with each other and perform multiple tasks over a shared memory simultaneously.

- The goal of parallel computing is to save time and provide concurrency.
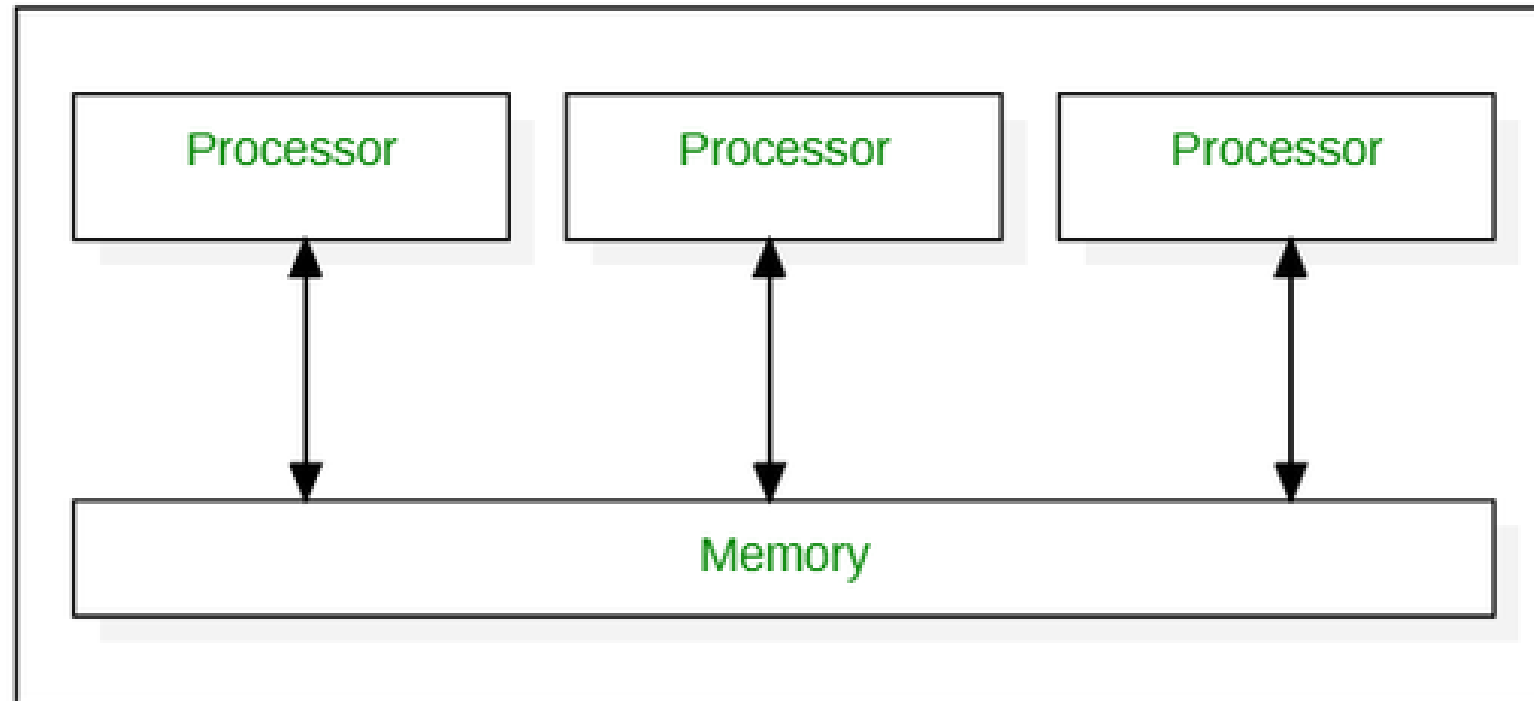
What is Cluster Computing?

- A cluster is a type of parallel or distributed computer system, which consists of a collection of inter-connected stand-alone computers working together as a single integrated computing resource .

- Key components of a cluster include multiple standalone computers (PCs, Workstations, or SMPs), operating systems, high-performance interconnects, middleware, parallel programming environments, and applications.

Cluster Computing?

- **Clusters are usually deployed to improve speed and/or reliability over that provided by a single computer, while typically being much more cost effective than single computer the of comparable speed or reliability**

- **In a typical cluster:**

  - **Network: Faster, closer connection than a typical network (LAN)**

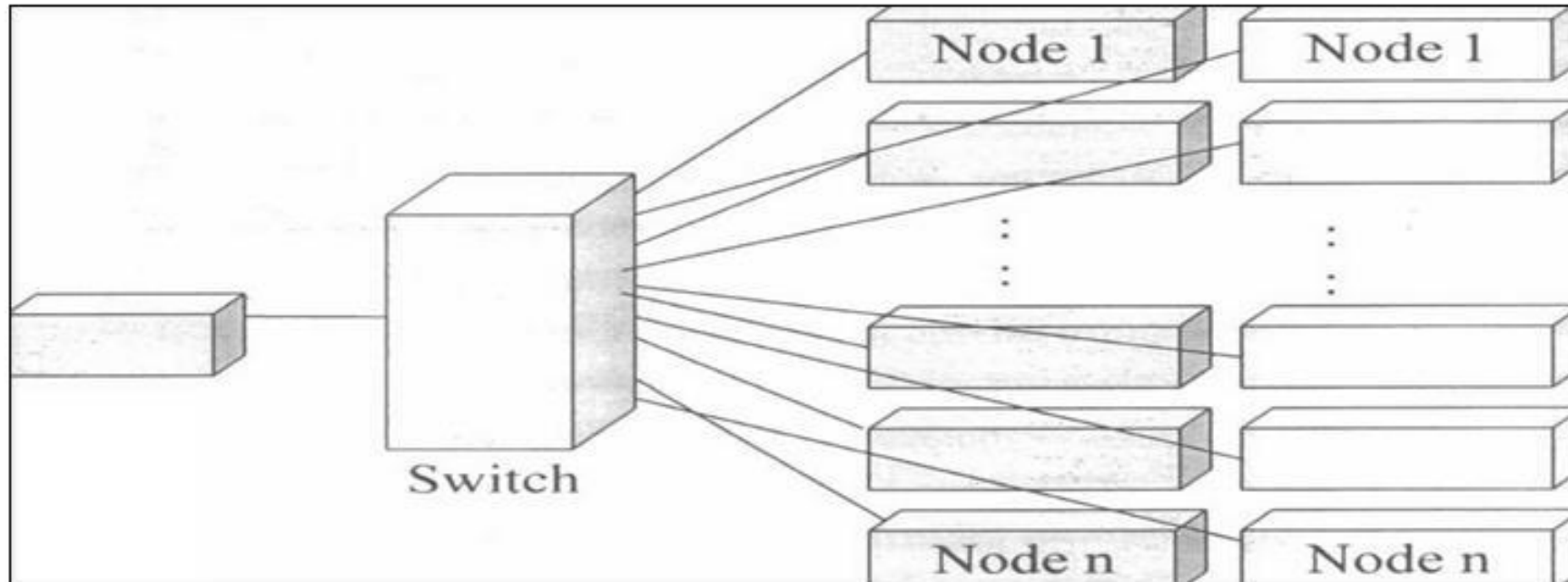 - **Low latency communication protocols**

  - **Loosely coupled than SMP**

- **High Availability or Failover Clusters**

- **Load Balancing Cluster**

- **Parallel/Distributed Processing Clusters**

Cluster Components

Basic building blocks of clusters are broken down into multiple categories:

- Cluster Nodes

- Cluster Network

- Network Characterization

Key Operational Benefits of Clustering

- **System availability:** offer inherent high system availability due to the redundancy of hardware, operating systems, and applications.

- **Hardware fault tolerance:** redundancy for most system components (eg. disk-RAID), including both hardware and software.

- **OS and application reliability:** run multiple copies of the OS and applications, and through this redundancy

- **Scalability.** adding servers to the cluster or by adding more clusters to the network as the need arises or CPU to SMP.

- **High performance:** (running cluster enabled programs)

Grid Computing?

- **Pcwebopedia.com**
  A form of networking. unlike conventional networks that focus on communication among devices, grid computing harnesses unused processing cycles of all computers in a network for solving problems too intensive for any stand-alone machine.

- **IBM**
  Grid computing enables the virtualization of distributed computing and data resources such as processing, network bandwidth and storage capacity to create a single system image, granting users and applications seamless access to vast IT capabilities. Just as an Internet user views a unified instance of content via the Web, a grid user essentially sees a single, large virtual computer.

- **Sun Microsystems**
  Grid Computing is a computing infrastructure that provides dependable, consistent, pervasive and inexpensive access to computational capabilities

- **Electrical Power Grid**
- Users (or electrical appliances) get access to electricity through wall sockets with no care or consideration for where or how the electricity is actually generated.
- "**The power grid**" links together power plants of many different kinds

- **Grid**
- Users (or client applications) gain access to computing resources (processors, storage, data, applications, and so on) as needed with little or no knowledge of where those resources are located or what the underlying technologies, hardware, operating system, and so on are
- "**The Grid**" links together computing resources (PCs, workstations, servers, storage elements) and provides the mechanism needed to access them.

Grid Computing

1. Share more than information: Data, computing power, applications in dynamic environment, multi-institutional, virtual organizations

2. Efficient use of resources at many institutes. People from many institutions working to solve a common problem (virtual organisation)

3. Join local communities.

4. Interactions with the underneath layers must be transparent and seamless to the user.

Need of Grid Computing?

- Today's Science/Research is based on computations, data analysis, data visualization & collaborations

- Computer Simulations & Modelling are more cost effective than experimental methods

- Scientific and Engineering problems are becoming more complex & users need more accurate, precise solutions to their problems in shortest possible time

- Data Visualization is becoming very important

- Exploiting under utilized resources

Who uses Grid Computing ?
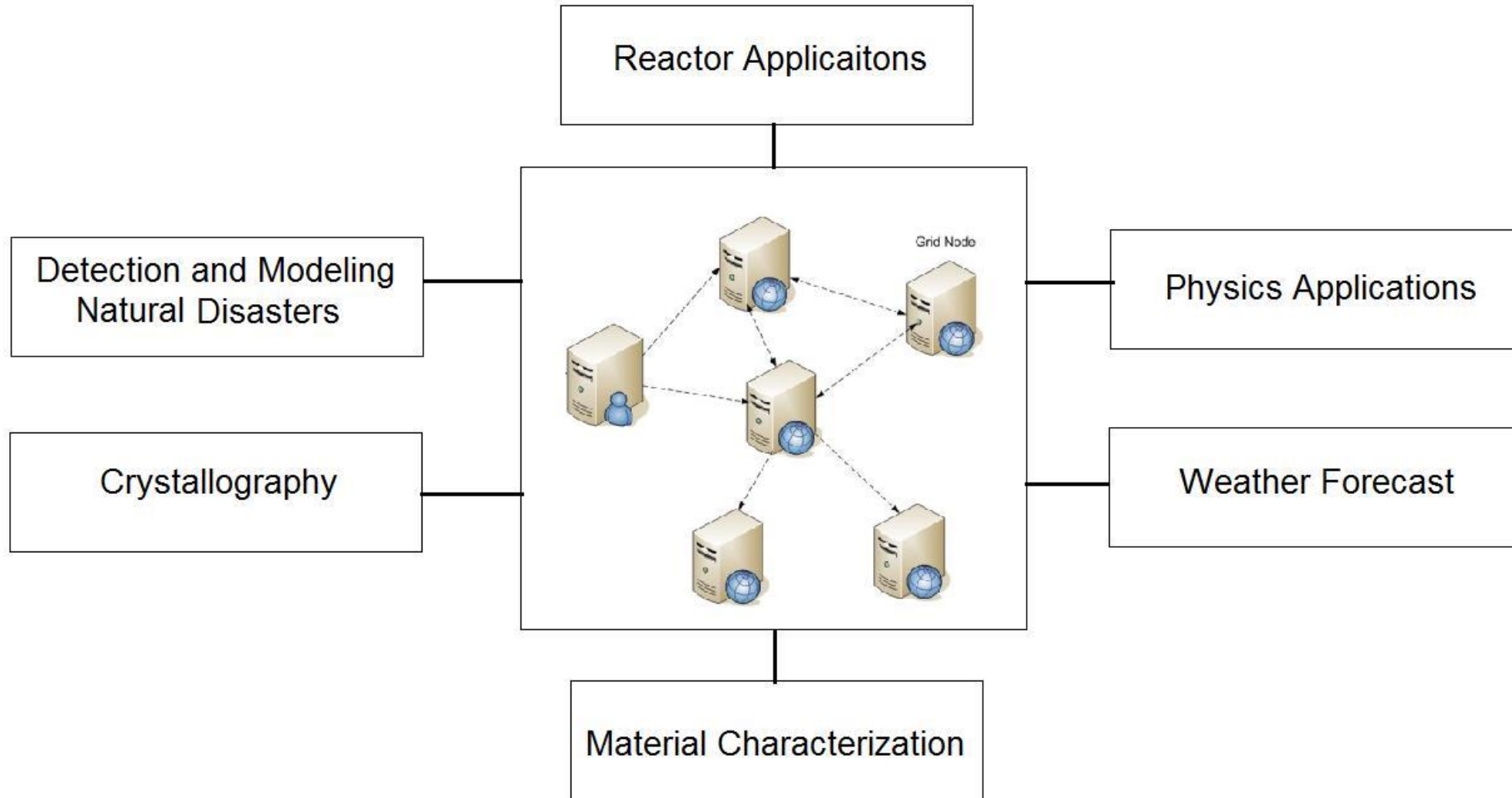
- **Computational Grid:** These grids provide secure access to huge pool of shared processing power suitable for high throughput applications and computation intensive computing.

- **Data Grid:** Data grids provide an infrastructure to support data storage, data discovery, data handling, data publication, and data manipulation of large volumes of data actually stored in various heterogeneous databases and file systems.

- **Collaboration Grid:** With the advent of Internet, there has been an increased demand for better collaboration. Such advanced collaboration is possible using the grid. For instance, persons from different companies in a virtual enterprise can work on different components of a CAD project without even disclosing their proprietary technologies.

- **Network Grid: A Network Grid provides fault-tolerant and high-performance communication services. Each grid node works as a data router between two communication points, providing data-caching and other facilities to speed up the communications between such points.**

- **Utility Grid: This is the ultimate form of the Grid, in which not only data and computation cycles are shared but software or just about any resource is shared. The main services provided through utility grids are software and special equipment. For instance, the applications can be run on one machine and all the users can send their data to be processed to that machine and receive the result back.**

Grid Components

Users
- Large and dynamic population
- Different accounts at different sites
- Personal and confidential data
- Heterogeneous privileges (roles)
- Desire Single Sign-On

"Groups"
- "Group" data
- Access Patterns
- Membership

Grid

Sites
- Heterogeneous Resources
- Access Patterns
- Local policies
- Membership

Users

Grid Server

Grid Client

Network
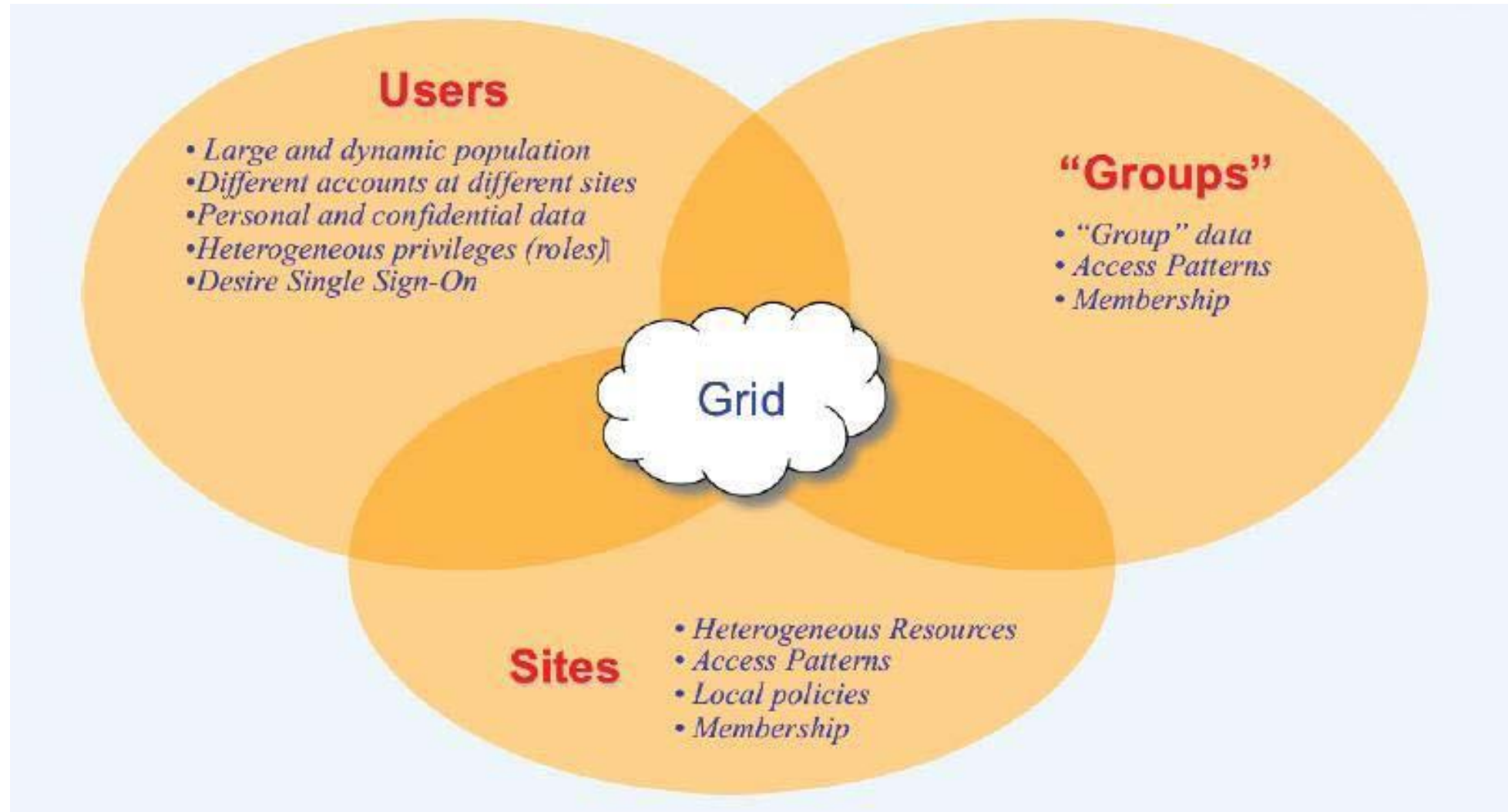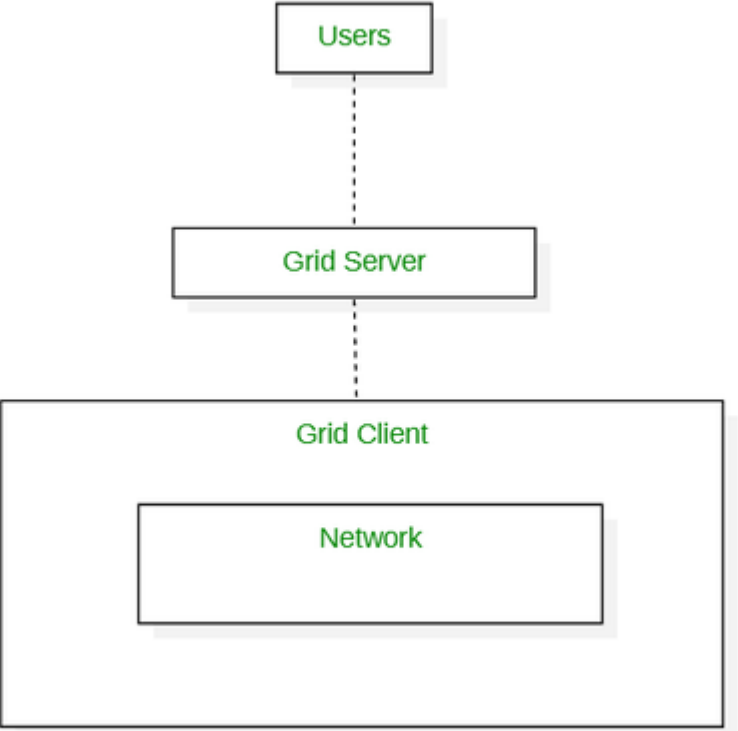
- **Utility Computing is purely a concept which cloud computing practically implements.**

- **Utility computing is a service provisioning model in which a service provider makes computing resources and infrastructure management available to the customer as needed, and charges them for specific usage rather than a flat rate.**

- **This model has the advantage of a low or no initial cost to acquire computer resources; instead, computational resources are essentially rented.**

- **The word utility is used to make an analogy to other services, such as electrical power, that seek to meet fluctuating customer needs, and charge for the resources based on usage rather than on a flat-rate basis. This approach, sometimes known as pay-per-use**

- **"Utility computing" has usually envisioned some form of virtualization so that the amount of storage or computing power available is considerably larger than that of a single timesharing computer.**

IT Function
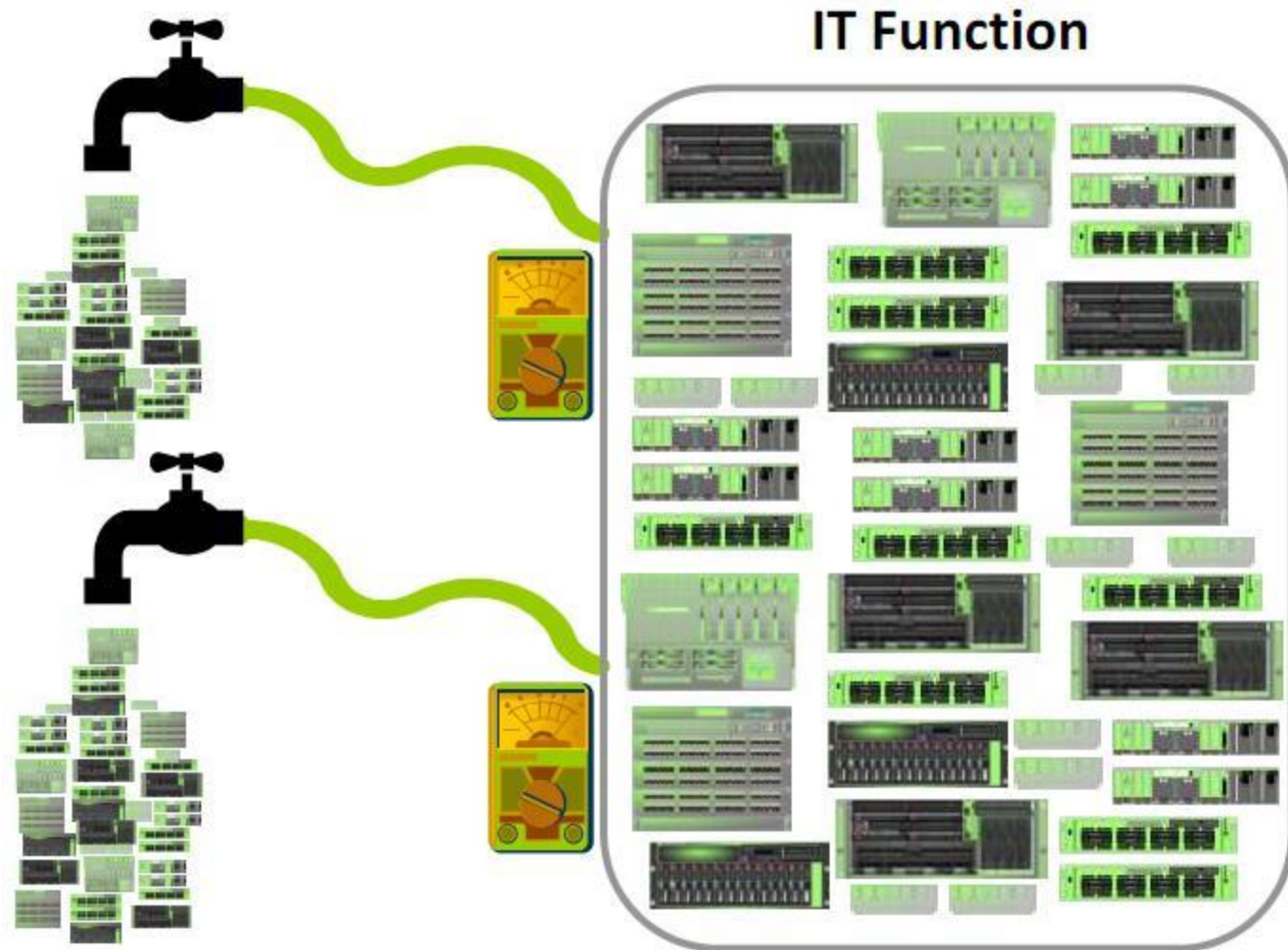
"Utility" Computing ?

a) Pay-for-use Pricing Business Model

b) Data Center Virtualization and Provisioning

c) Solves Resource Utilization Problem

d) Outsourcing

e) Web Services Delivery

f) Automation

On-Demand Cyber Infrastructure
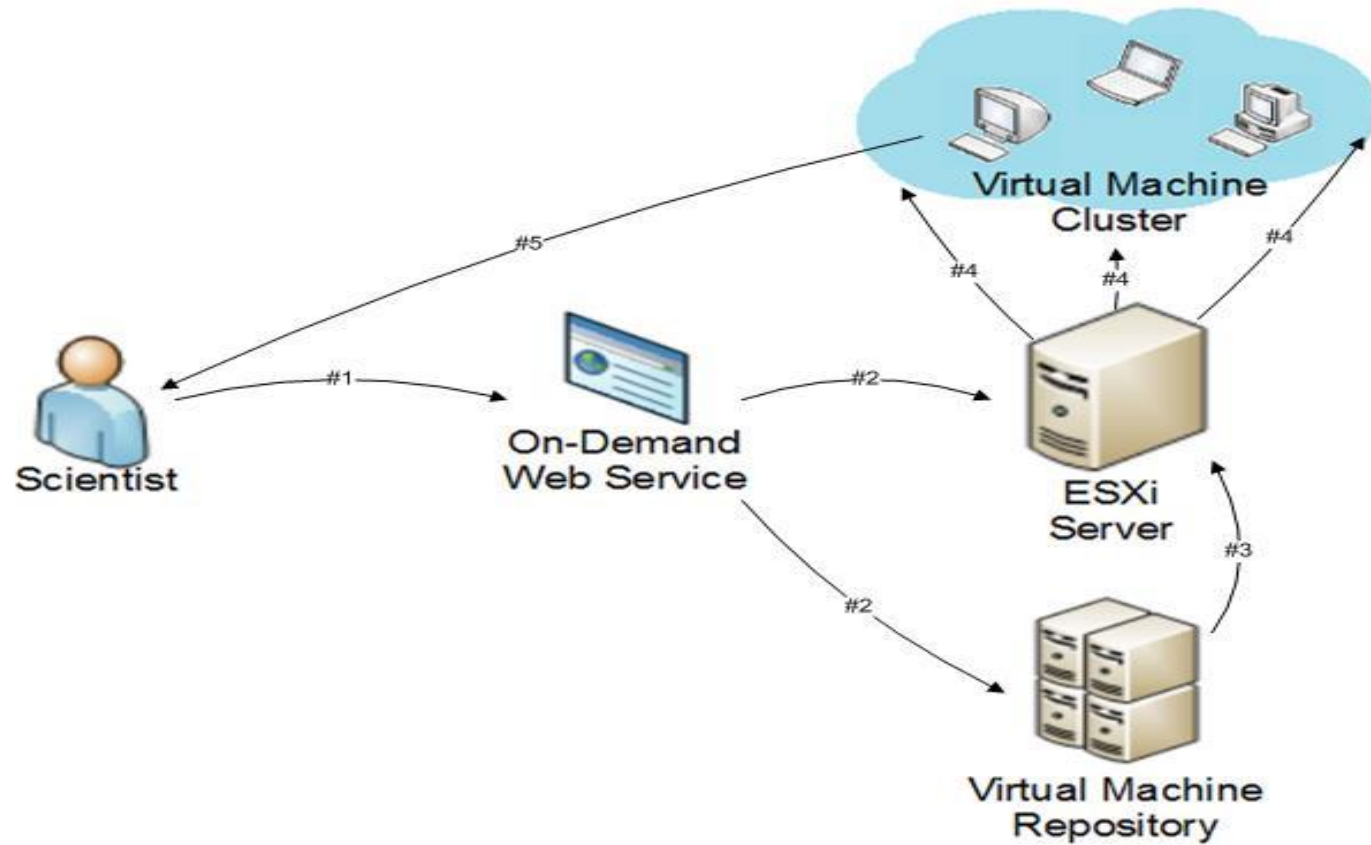
- **Consumer Provider**
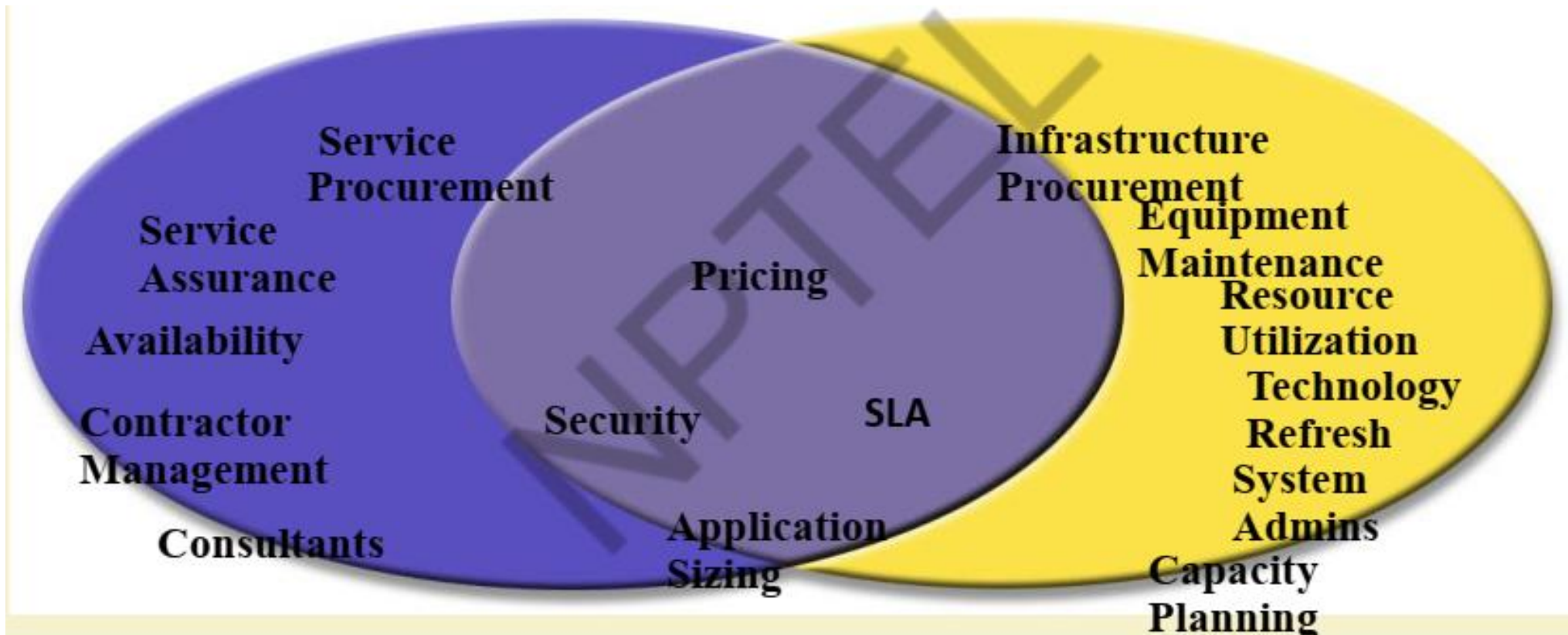
Utility Computing Payment Models

- **Same range of charging models as other utility providers: gas, electricity, telecommunications, water, television broadcasting**
  - **Flat rate**
  - **Tiered**
  - **Subscription**
  - **Metered**
  - **Pay as you go**
  - **Standing charges**
- **Different pricing models for different customers based on factors such as scale, commitment and payment frequency**
- **But the principle of utility computing remains**
- **The pricing model is simply an expression by the provider of the costs of provision of the resources and a profit margin**

Risks in a UC World

- **Data Backup**

- **Data Security**

- **Partner Competency**

- **Defining SLA**

- **Getting value from charge back**

- **US National Institute of Standards and Technology defines Computing as " 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. "**
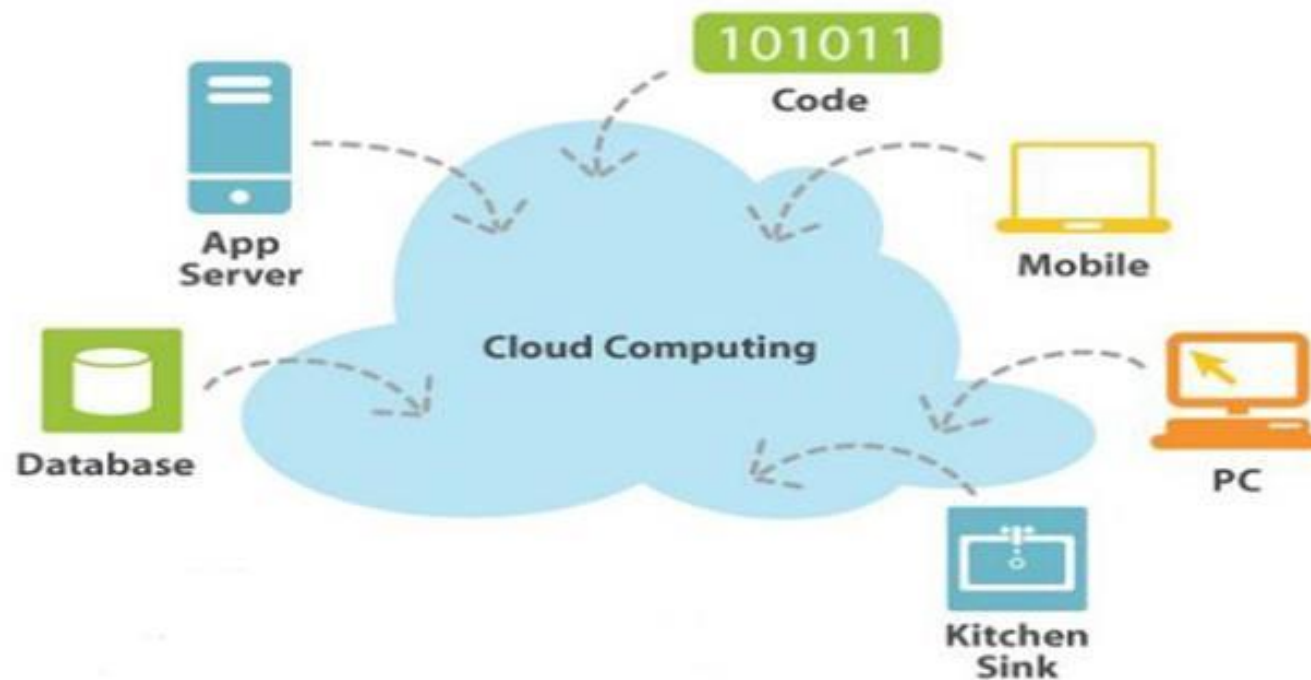
- ## On-demand self-service
  - A consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with each service provider.

- ## 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, tablets, laptops, and workstations).

- ## Resource pooling
  - The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand.

- **Measured Service**

  – Cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be

  – monitored, controlled, and reported, providing transparency for both the provider and consumer of the utilized service.

- **Rapid elasticity**

  – Capabilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward commensurate with demand. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time.

- **Massive Scale**

- **Resilient Computing**

- **Homogeneity**

- **Geographic Distribution**

- **Virtualization**

- **Service Orientation**

- **Low Cost Software**

- **Advanced Security**

- **Software as a Service (SaaS)**
  - The capability provided to the consumer 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 application configuration settings.

  e.g: Google Spread Sheet

- **Cloud Infrastructure as a Service (IaaS)**
  - The capability provided to provision processing, storage, networks, and other fundamental computing resources Consumer can deploy and run arbitrary software

  e.g: Amazon Web Services and Flexi scale.

- **Platform as a Service (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 manage 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.**

Cloud Clients
Web browser, mobile app, thin client, terminal emulator, ...

Application

SaaS
CRM, Email, virtual desktop, communication, games, ...

Platform

PaaS
Execution runtime, database, web server, development tools, ...

Infra-structure

IaaS
Virtual machines, servers, storage, load balancers, network, ...
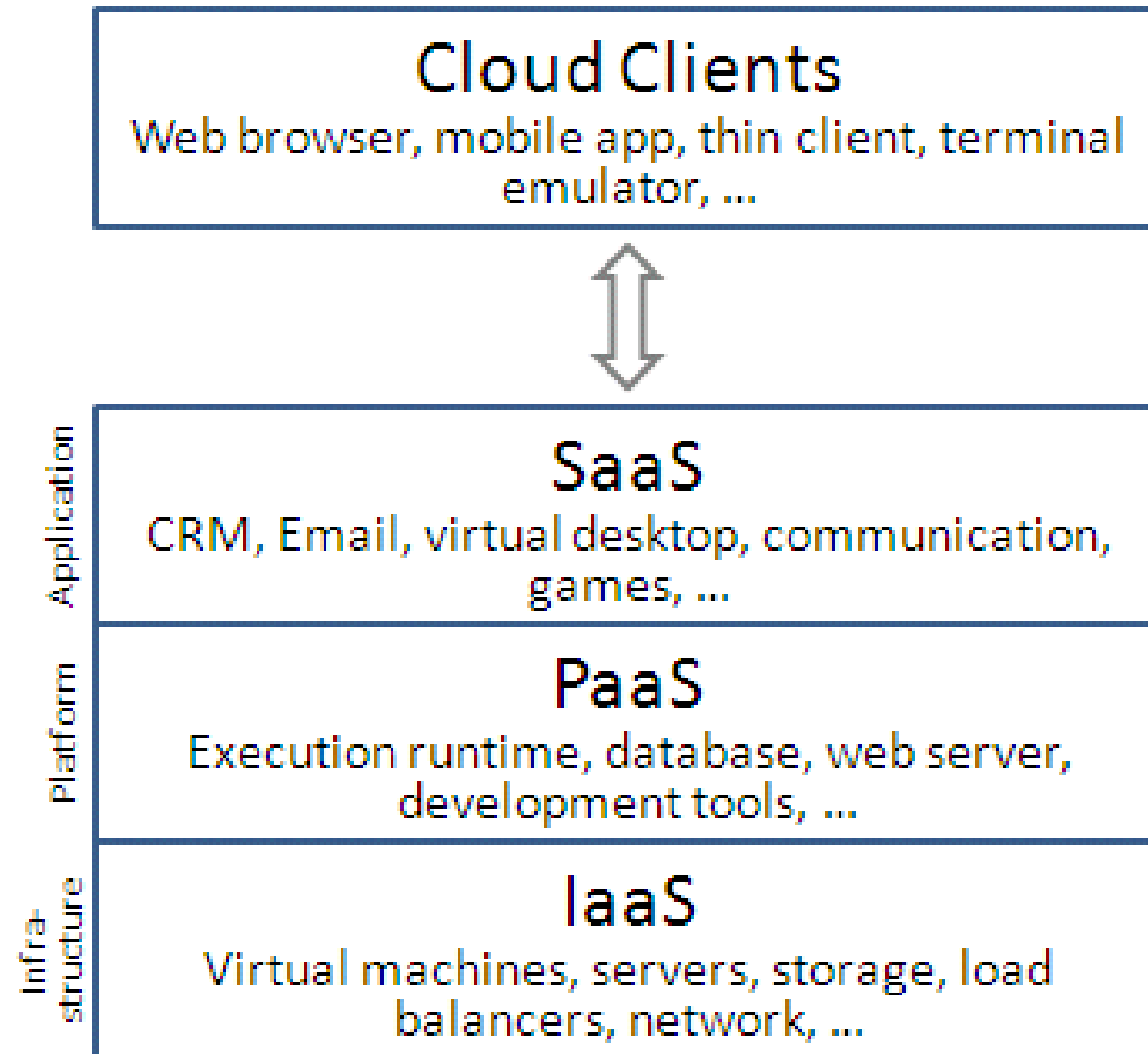
Evolution of Cloud Computing

- **Cloud computing is all about renting computing services. This idea first came in the 1950s. In making cloud computing what it is today, five technologies played a vital role. These are distributed systems and its peripherals, virtualization, web 2.0, service orientation, and utility computing.**

Evolution of Cloud Computing
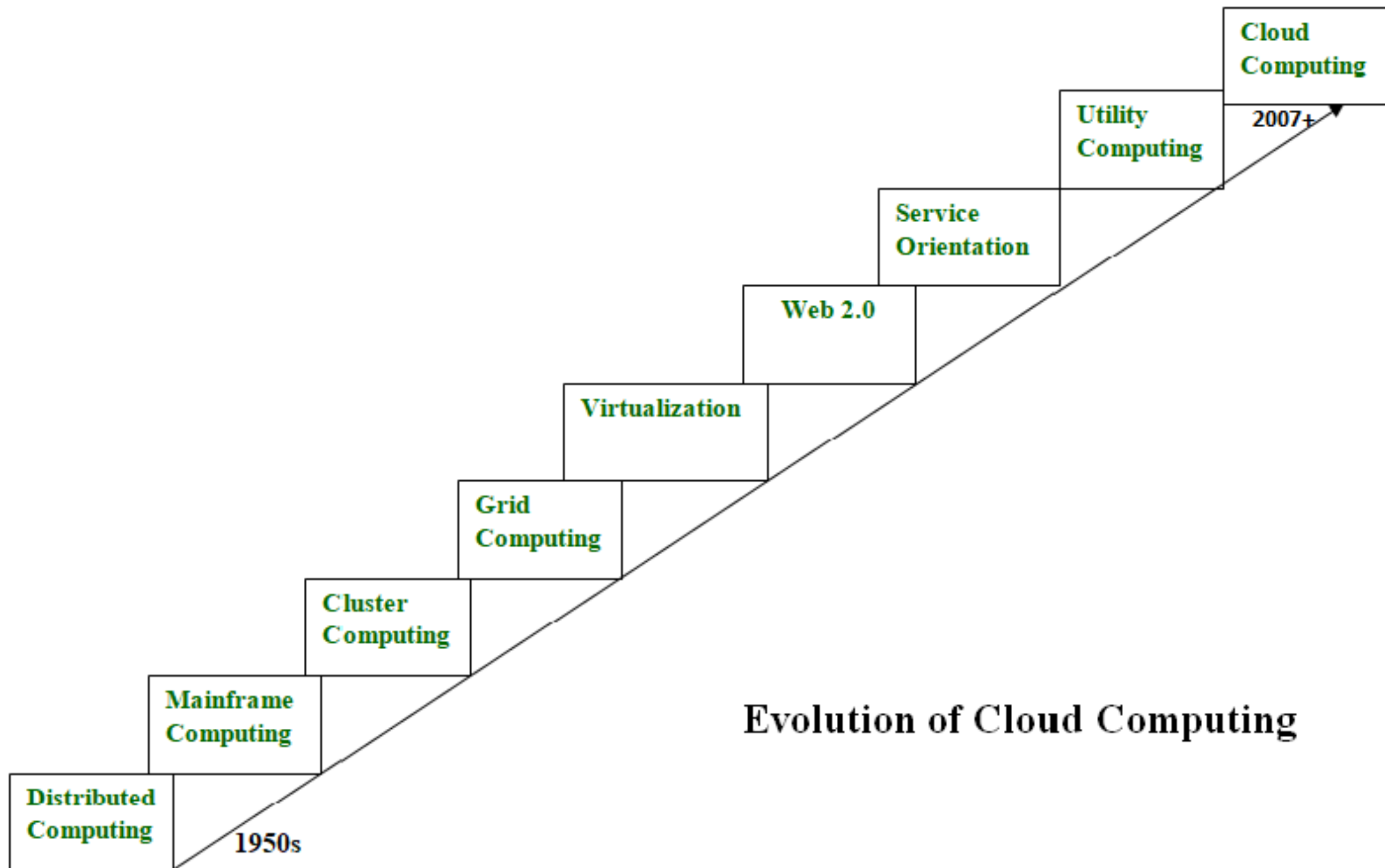
- **Cloud computing is Internet-based computing in which a shared pool of resources is available over broad network access, these resources can be provisioned or released with minimum management efforts and service provider interaction.**

- **Types of Cloud**
- **Public cloud**
- **Private cloud**
- **Hybrid cloud**
- **Community cloud**

Types of Cloud (Deployment Models)

- **Private cloud**

    The cloud infrastructure is operated solely for an organization. e.g Window Server 'Hyper-V'.

- **Community cloud**

    The cloud infrastructure is shared by several organizations and supports a specific goal.

- **Public cloud**

    The cloud infrastructure is made available to the general public. e.g Google Doc, Spreadsheet,

- **Hybrid cloud**

    The cloud infrastructure is a composition of two or more clouds (private, community, or public)

    e.g Cloud Bursting for load balancing between clouds.

- **Public clouds are managed by third parties which provide cloud services over the internet to the public, these services are available as pay-as-you-go billing models.**

- **They offer solutions for minimizing IT infrastructure costs and become a good option for handling peak loads on the local infrastructure. Public clouds are the go-to option for small enterprises, which are able to start their businesses without large upfront investments by completely relying on public infrastructure for their IT needs.**

- **The fundamental characteristics of public clouds are multitenancy. A public cloud is meant to serve multiple users, not a single customer. A user requires a virtual computing environment that is separated, and most likely isolated, from other users.**
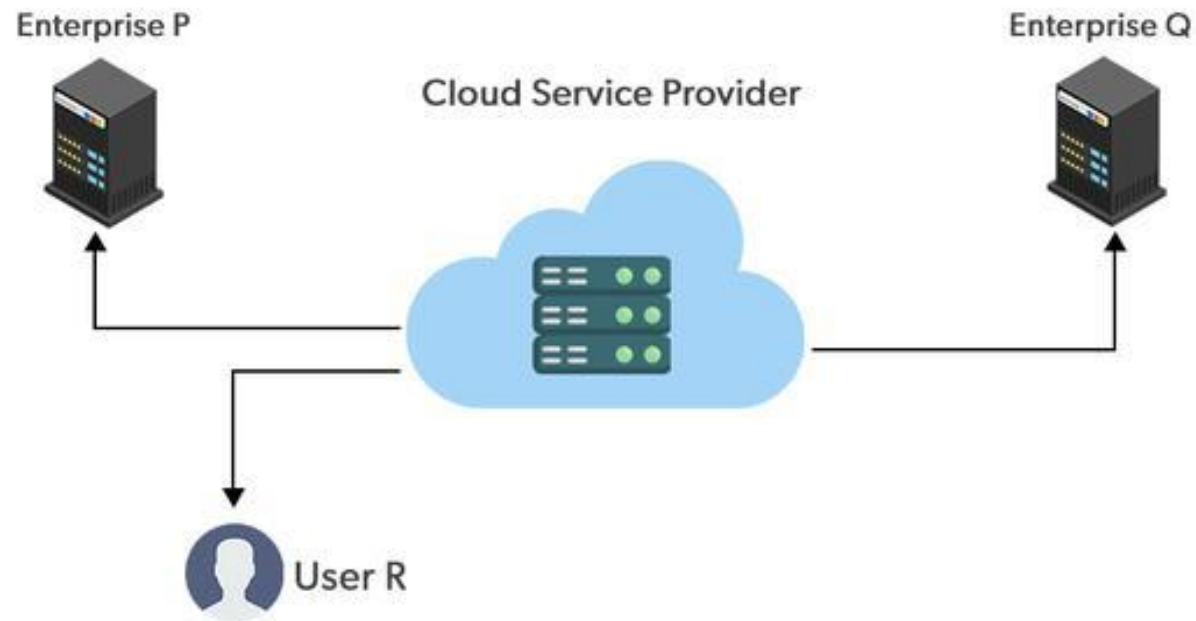
- **Private clouds are distributed systems that work on private infrastructure and provide the users with dynamic provisioning of computing resources. Instead of a pay-as-you-go model in private clouds, there could be other schemes that manage the usage of the cloud and proportionally billing of the different departments or sections of an enterprise.**
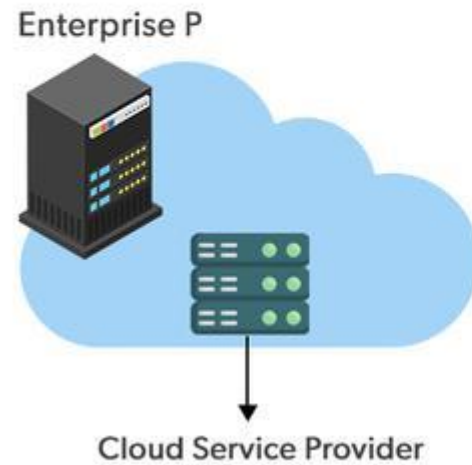
Private cloud
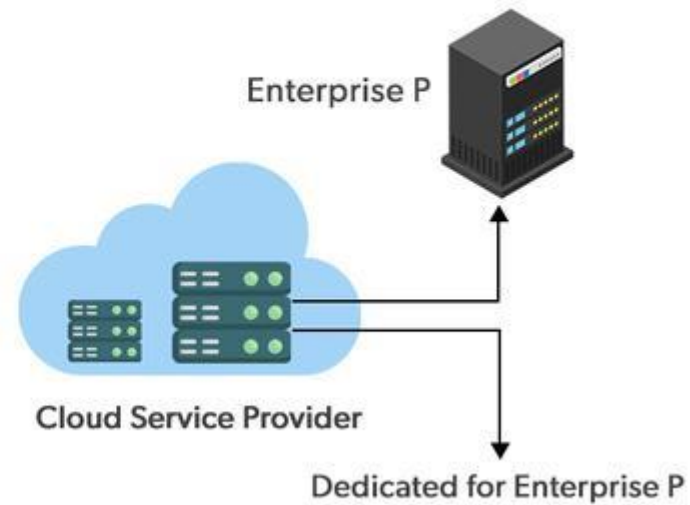
Advantages of using a private cloud are:

- **Customer information protection: In the private cloud security concerns are less since customer data and other sensitive information do not flow out of private infrastructure.**

- **Infrastructure ensuring SLAs: Private cloud provides specific operations such as appropriate clustering, data replication, system monitoring, and maintenance, and disaster recovery, and other uptime services.**

- **Compliance with standard procedures and operations: Specific procedures have to be put in place when deploying and executing applications according to third-party compliance standards. This is not possible in the case of the public cloud.**

Hybrid cloud:

- **A hybrid cloud is a heterogeneous distributed system formed by combining facilities of public cloud and private cloud. For this reason, they are also called heterogeneous clouds.**

- **A major drawback of private deployments is the inability to scale on-demand and efficiently address peak loads. Here public clouds are needed. Hence, a hybrid cloud takes advantage of both public and private clouds.**

Hybrid cloud:
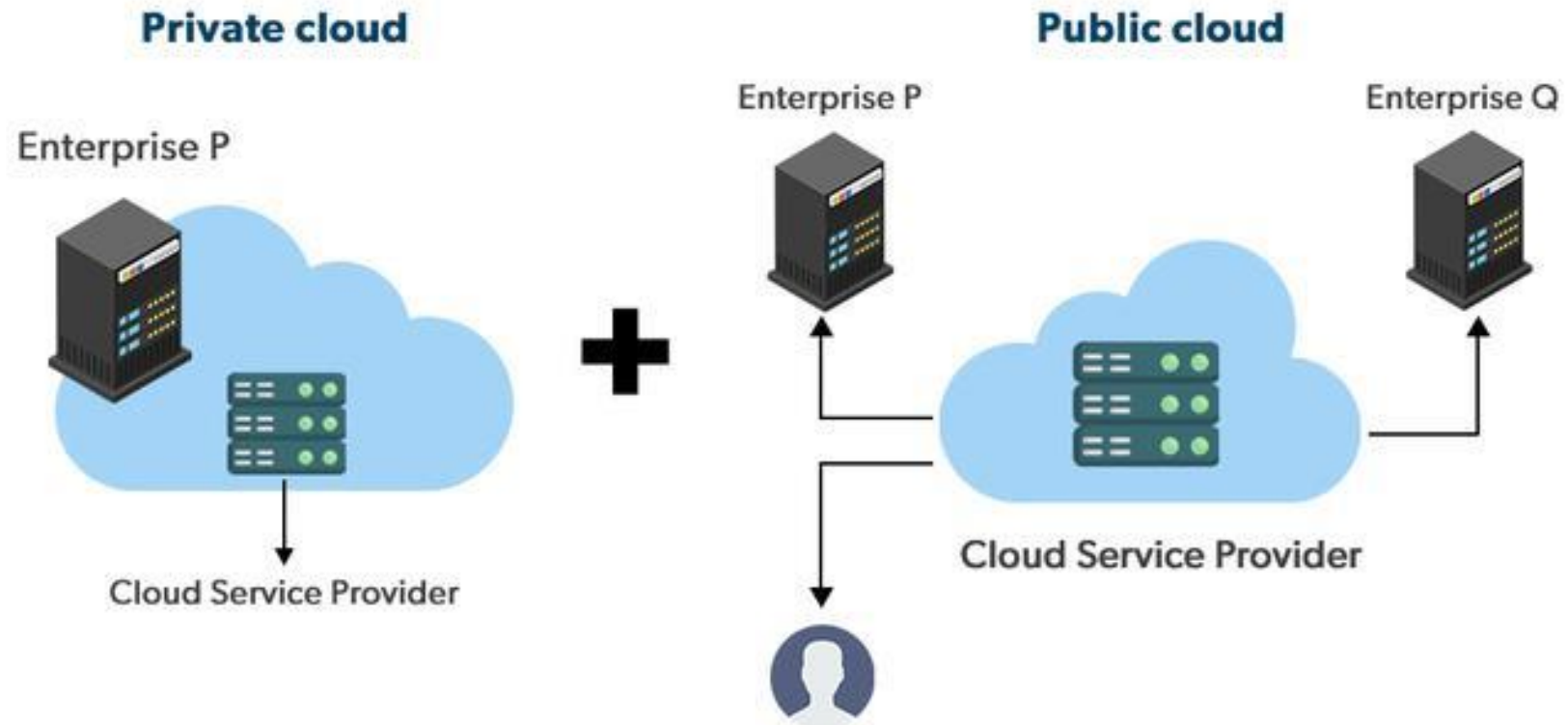
Community cloud:

- **Community clouds are distributed systems created by integrating the services of different clouds to address the specific needs of an industry, a community, or a business sector.**

- **In the community cloud, the infrastructure is shared between organizations that have shared concerns or tasks. The cloud may be managed by an organization or a third party.**

Community cloud:
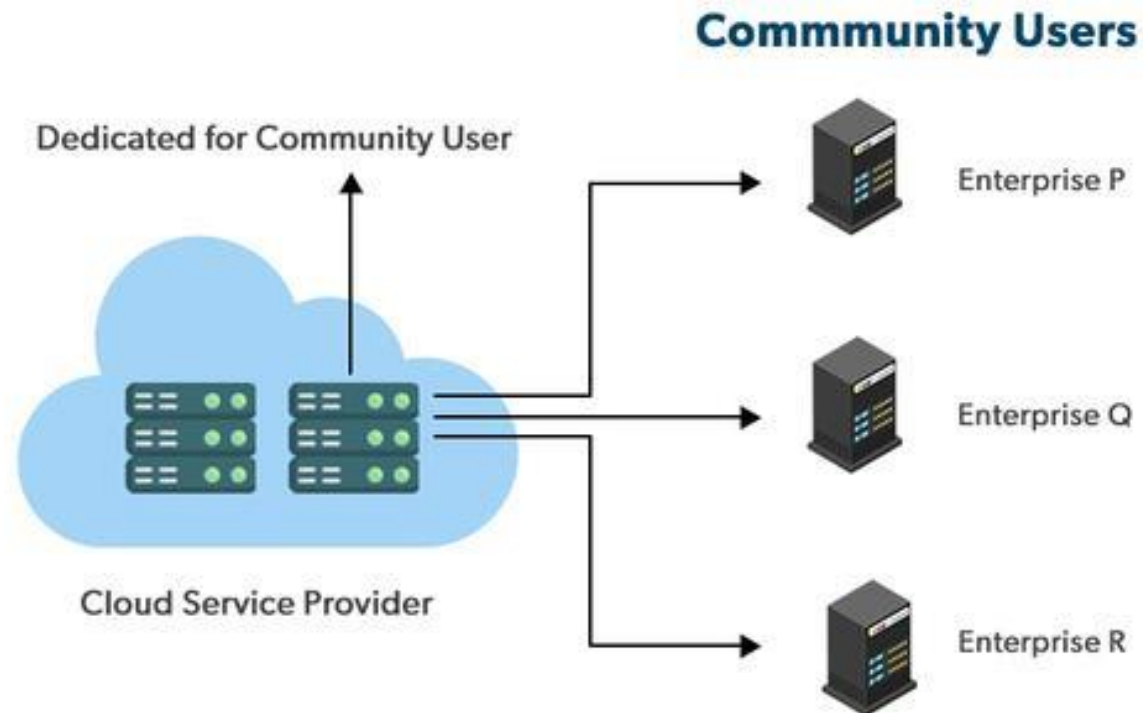
Sectors that use community clouds are:

1. Media industry: Media companies are looking for quick, simple, low-cost ways for increasing the efficiency of content generation. Most media productions involve an extended ecosystem of partners. In particular, the creation of digital content is the outcome of a collaborative process that includes the movement of large data, massive compute-intensive rendering tasks, and complex workflow executions.

2. Healthcare industry: In the healthcare industry community clouds are used to share information and knowledge on the global level with sensitive data in the private infrastructure.

3. Energy and core industry: In these sectors, the community cloud is used to cluster a set of solution which collectively addresses management, deployment, and orchestration of services and operations.

4. Scientific research: In this organization with common interests in science share a large distributed infrastructure for scientific computing.

Cloud Computing Basics

- **Cloud Computing can be defined as the practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer. Companies offering such kinds of cloud computing services are called cloud providers and typically charge for cloud computing services based on usage.**

1. Software as a service (Saas)

2. Platform as a service (PaaS)

3. Infrastructure as a service (IaaS)

4. Anything as a service (XaaS)

Software as a Service(SaaS)

- **Software-as-a-Service (SaaS) is a way of delivering services and applications over the Internet. Instead of installing and maintaining software, we simply access it via the Internet, freeing ourselves from the complex software and hardware management. It removes the need to install and run applications on our own computers or in the data centers eliminating the expenses of hardware as well as software maintenance.**

- **SaaS provides a complete software solution that you purchase on a pay-as-you-go basis from a cloud service provider. Most SaaS applications can be run directly from a web browser without any downloads or installations required. The SaaS applications are sometimes called Web-based software, on-demand software, or hosted software.**

- The capability provided to the consumer 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 application configuration settings.

- e.g: Google Spread Sheet

1. **Cost-Effective: Pay only for what you use.**

2. **Reduced time: Users can run most SaaS apps directly from their web browser without needing to download and install any software. This reduces the time spent in installation and configuration and can reduce the issues that can get in the way of the software deployment.**

3. **Accessibility: We can Access app data from anywhere.**

4. **Automatic updates: Rather than purchasing new software, customers rely on a SaaS provider to automatically perform the updates.**

5. **Scalability: It allows the users to access the services and features on-demand.**

- **The various companies providing *Software as a service* are Cloud9 Analytics, Salesforce.com, Cloud Switch, Microsoft Office 365, Eloqua, dropBox, and Cloud Tran.**

Platform as a Service

- PaaS is a category of cloud computing that provides a platform and environment to allow developers to build applications and services over the internet. PaaS services are hosted in the cloud and accessed by users simply via their web browser.

- A PaaS provider hosts the hardware and software on its own infrastructure. As a result, PaaS frees users from having to install in-house hardware and software to develop or run a new application. Thus, the development and deployment of the application take place independent of the hardware.

- The consumer does not manage 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

- 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 manage 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.

Advantages of PaaS:

- Simple and convenient for users: It provides much of the infrastructure and other IT services, which users can access anywhere via a web browser.

- Cost-Effective: It charges for the services provided on a per-use basis thus eliminating the expenses one may have for on-premises hardware and software.

- Efficiently managing the lifecycle: It is designed to support the complete web application lifecycle: building, testing, deploying, managing, and updating.

- Efficiency: It allows for higher-level programming with reduced complexity thus, the overall development of the application can be more effective.

- The various companies providing Platform as a service are Amazon Web services, Salesforce, Windows Azure, Google App Engine, cloud Bess and IBM smart cloud.

Infrastructure as a Service

- **Infrastructure as a service (IaaS) is a service model that delivers computer infrastructure on an outsourced basis to support various operations. Typically IaaS is a service where infrastructure is provided as an outsource to enterprises such as networking equipment, devices, database, and web servers.**

- **It is also known as Hardware as a Service (HaaS). IaaS customers pay on a per-user basis, typically by the hour, week, or month. Some providers also charge customers based on the amount of virtual machine space they use.**

- **It simply provides the underlying operating systems, security, networking, and servers for developing such applications, services, and for deploying development tools, databases, etc.**

Infrastructure as a Service

- **The capability provided to provision processing, storage, networks, and other fundamental computing resources Consumer can deploy and run arbitrary software**

- **e.g: Amazon Web Services and Flexi scale**

Advantages of IaaS:

- Cost-Effective: Eliminates capital expense and reduces ongoing cost and IaaS customers pay on a per-user basis, typically by the hour, week, or month.

- Website hosting: Running websites using IaaS can be less expensive than traditional web hosting.

- Security: The IaaS Cloud Provider may provide better security than your existing software.

- Maintenance: There is no need to manage the underlying data center or the introduction of new releases of the development or underlying software. This is all handled by the IaaS Cloud Provider.

- The various companies providing Infrastructure as a service are Amazon web services, Bluestack, IBM, Openstack, Rackspace, and Vmware.

Cloud Services Models

Cloud Clients
Web browser, mobile app, thin client, terminal emulator, ...

SaaS
CRM, Email, virtual desktop, communication, games, ...

PaaS
Execution runtime, database, web server, development tools, ...

IaaS
Virtual machines, servers, storage, load balancers, network, ...

Application

Platform

Infra-structure
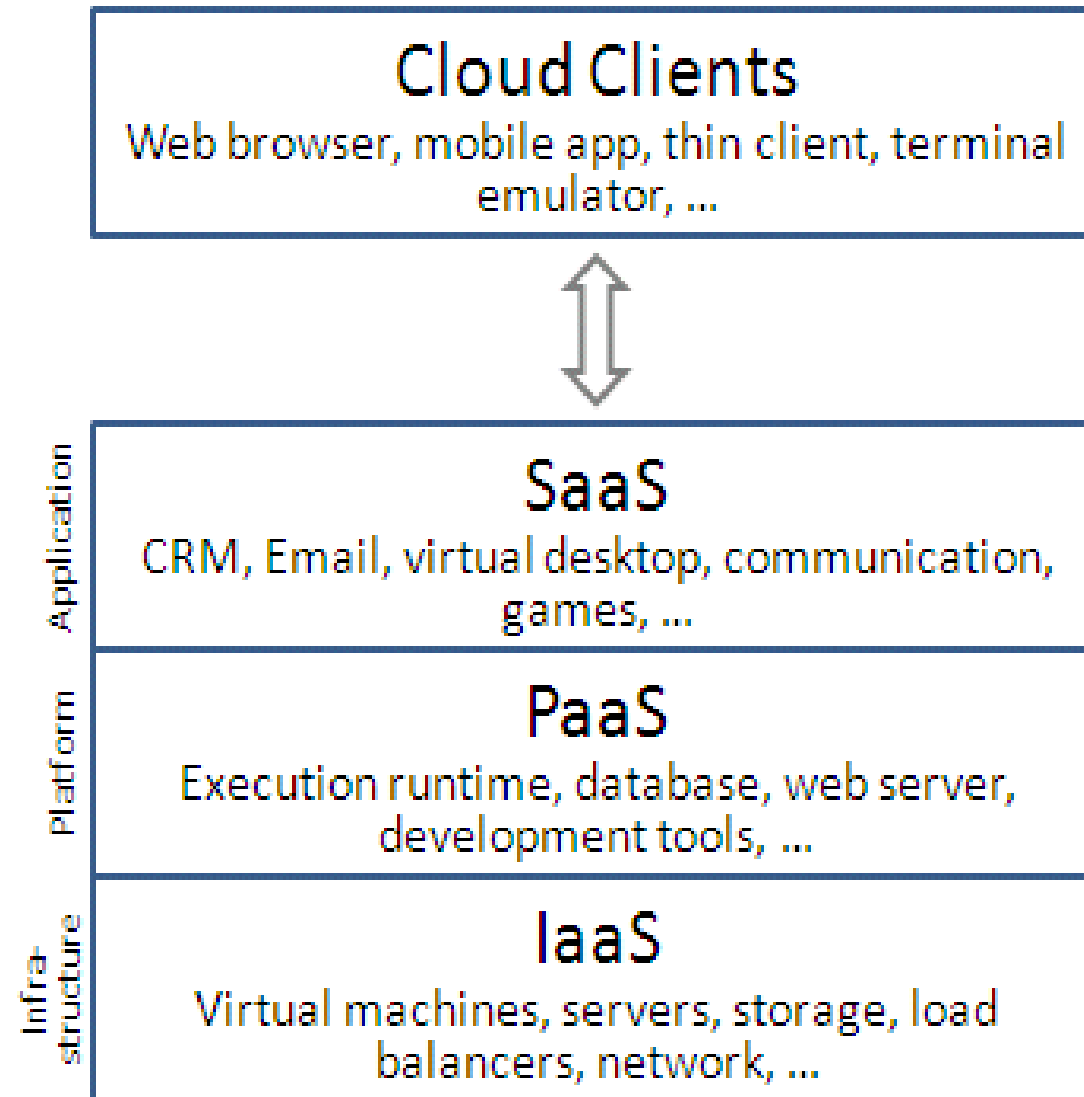
- **Anything as a Service**
- Most of the cloud service providers nowadays offer anything as a service that is a compilation of all of the above services including some additional services.
- **Advantages of XaaS:** As this is a combined service, so it has all the advantages of every type of cloud service.

Cloud and Virtualization

- **Virtual Workspaces:**
  - – **An abstraction of an execution environment that can be made dynamically available to authorized clients by using well-defined protocols,**
  - – **Resource quota (e.g. CPU, memory share),**
  - – **Software configuration (e.g. OS).**

- **Implement on Virtual Machines (VMs):**
  - – **Abstraction of a physical host machine,**
  - – **Hypervisor intercepts and emulates instructions from VMs, and allows management of VMs,**
  - – **VMWare, Xen, KVM etc.**

- **Provide infrastructure API:**
  - – **Plug-ins to hardware/support structures**
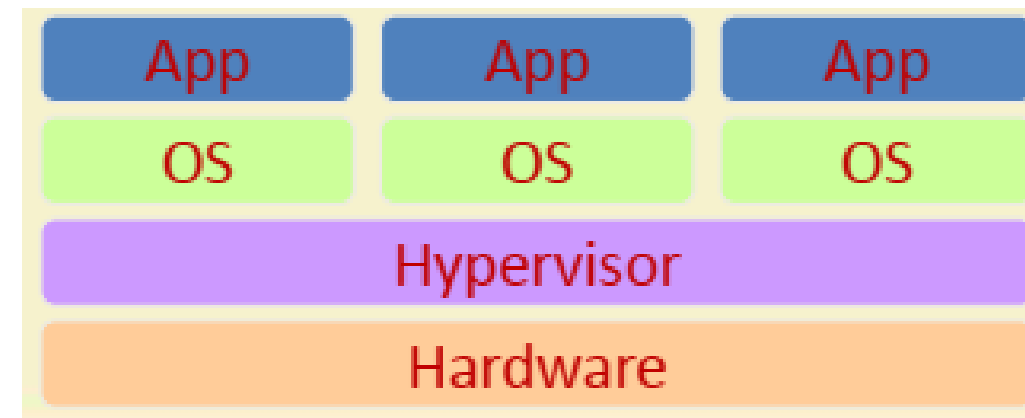
Virtual Machines

- **VM technology allows multiple virtual machines to run on a single physical machine.**
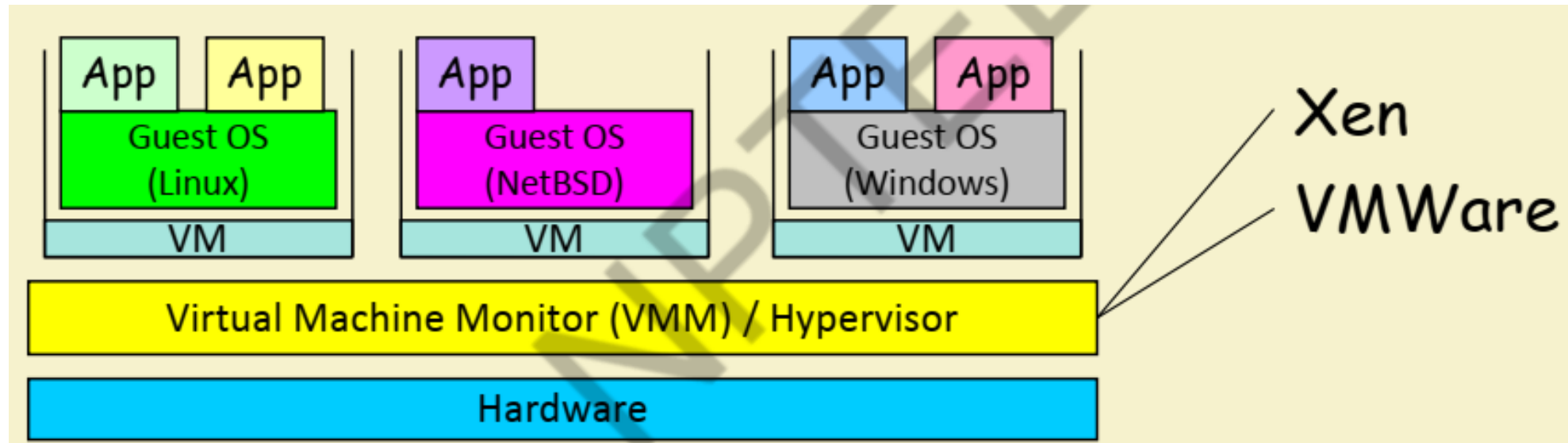
- **Performance: Para-virtualization (e.g. Xen) is very close to raw physical performance!**

- **Advantages of virtual machines:**

  – **Run operating systems where the physical hardware is unavailable,**

  – **Easier to create new machines, backup machines, etc.,**

  – **Software testing using "clean" installs of operating systems and software,**

  – **Emulate more machines than are physically available,**

  – **Timeshare lightly loaded systems on one host,**

  – **Debug problems (suspend and resume the problem machine),**

  – **Easy migration of virtual machines (shutdown needed or not).**

  – **Run legacy systems**

- **Why is it becoming important ?**
  - **Using high-scale/low-cost providers,**
  - **Any time/place access via web browser,**
  - **Rapid scalability; incremental cost and load sharing,**
  - **Can forget need to focus on local IT.**

- **Concerns:**
  - **Performance, reliability, and SLAs,**
  - **Control of data, and service parameters,**
  - **Application features and choices,**
  - **Interaction between Cloud providers,**
  - **No standard API – mix of SOAP and REST!**
  - **Privacy, security, compliance, trust…**

- **Several large Web companies are now exploiting the fact that they have data storage capacity that can be hired out to others.**

  - **Allows data stored remotely to be temporarily cached on desktop computers, mobile phones or other Internet-linked devices.**

- **Amazon's Elastic Compute Cloud (EC2) and Simple Storage Solution (S3) are well known examples**

- **Lower computer costs:**

  – **No need of a high-powered and high-priced computer to run cloud computing's web-based applications.**

  – **Since applications run in the cloud, not on the desktop PC, your desktop PC does not need the processing power or hard disk space demanded by traditional desktop software.**

  – **When you are using web-based applications, your PC can be less expensive, with a smaller hard disk, less memory, more efficient processor...**

  – **In fact, your PC in this scenario does not even need a CD or DVD drive, as no software programs have to be loaded and no document files need to be saved.**

- **Improved performance:**
  - With few large programs hogging your computer's memory, you will see better performance from your PC.
  - Computers in a cloud computing system boot and run faster because they have fewer programs and processes loaded into memory.

- **Reduced software costs:**
  - Instead of purchasing expensive software applications, you can get most of what you need for free.
    - most cloud computing applications today, such as the Google Docs suite.
  - better than paying for similar commercial software
    - which alone may be justification for switching to cloud applications.

Advantages of Cloud Computing

- **Instant software updates**
  - **– Another advantage to cloud computing is that you are no longer faced with choosing between obsolete software and high upgrade costs.**
  - **– When the application is web-based, updates happen automatically available the next time you log into the cloud.**
  - **– When you access a web-based application, you get the latest version without needing to pay for or download an upgrade.**

- **Improved document format compatibility.**
  - **– You do not have to worry about the documents you create on your machine being compatible with other users' applications or OS.**
  - **– There are less format incompatibilities when everyone is sharing documents and applications in the cloud.**

Advantages of Cloud Computing

- **Unlimited storage capacity**
  - **Cloud computing offers virtually limitless storage.**
  - **Your computer's current 1 Tera Bytes hard drive is small compared to the hundreds of Peta Bytes available in the cloud.**

- **Increased data reliability**
  - **Unlike desktop computing, in which if a hard disk crashes and destroy all your valuable data, a computer crashing in the cloud should not affect the storage of your data.**
    - **if your personal computer crashes, all your data is still out there in the cloud, still accessible**
  - **In a world where few individual desktop PC users back up their data on a regular basis, cloud computing is a data-safe computing platform. For e.g. Dropbox, Skydrive**

- **Universal information access**
  - **– That is not a problem with cloud computing, because you do not take your documents with you.**
  - **– Instead, they stay in the cloud, and you can access them whenever you have a computer and an Internet connection**
  - **– Documents are instantly available from wherever you are.**

- **Latest version availability**
  - **– When you edit a document at home, that edited version is what you see when you access the document at work.**
  - **– The cloud always hosts the latest version of your documents as long as you are connected, you are not in danger of having an outdated version.**

- **Easier group collaboration**
  - **Sharing documents leads directly to better collaboration.**
  - **Many users do this as it is an important advantages of cloud computing multiple users can collaborate easily on documents and projects**

- **Device independence**
  - **You are no longer tethered to a single computer or network.**
  - **Changes to computers, applications and documents follow you through the cloud.**
  - **Move to a portable device, and your applications and documents are still available.**

- **Requires a constant internet connection**
    - **Cloud computing is impossible if you cannot connect to the Internet.**
    - **Since you use the Internet to connect to both your applications and documents, if you do not have an Internet connection you cannot access anything, even your own documents.**
    - **A dead Internet connection means no work and in areas where Internet connections are few or inherently unreliable, this could be a deal-breaker.**

- **Does not work well with low-speed connections**
    - **Similarly, a low-speed Internet connection, such as that found with dial-up services, makes cloud computing painful at best and often impossible.**
    - **Web-based applications require a lot of bandwidth to download, as do large documents.**

- **Features might be limited**

    – This situation is bound to change, but today many web-based applications simply are not as full-featured as their desktop-based applications.

    • For example, you can do a lot more with Microsoft PowerPoint than with Google Presentation's web-based offering

- **Can be slow**

    – Even with a fast connection, web-based applications can sometimes be slower than accessing a similar software program on your desktop PC.

    – Everything about the program, from the interface to the current document, has to be sent back and forth from your computer to the computers in the cloud.

    – If the cloud servers happen to be backed up at that moment, or if the Internet is having a slow day, you would not get the instantaneous access you might expect from desktop applications.

- **Stored data might not be secured**

  – **With cloud computing, all your data is stored on the cloud.**

    • **The questions is How secure is the cloud?**

  – **Can unauthorized users gain access to your confidential data ?**

- **Stored data can be lost!**

  – **Theoretically, data stored in the cloud is safe, replicated across multiple machines.**

  – **But on the off chance that your data goes missing, you have no physical or local backup.**

    • **Put simply, relying on the cloud puts you at risk if the cloud lets you down.**

- **HPC Systems**

    – **Not clear that you can run compute-intensive HPC applications that use MPI/OpenMP!**

    – **Scheduling is important with this type of application**

        - **as you want all the VM to be co-located to minimize communication latency!**

- **General Concerns**

    – **Each cloud systems uses different protocols and different APIs**

        - **may not be possible to run applications between cloud based systems**

    – **Amazon has created its own DB system (not SQL 92), and workflow system (many popular workflow systems out there)**

        - **so your normal applications will have to be adapted to execute on these platforms.**

Evolution of Cloud Computing

Business drivers for adopting cloud computing

- **The main reason for interest in cloud computing is due to the fact that public clouds can significantly reduce IT costs.**

- **From and end user perspective cloud computing gives the illusion of potentially infinite capacity with ability to scale rapidly and pay only for the consumed resource.**

- **In contrast, provisioning for peak capacity is a necessity within private data centers, leading to a low average utilization of 5-20 percent.**

IaaS Economics

	In house server	Cloud server
Purchase Cost	$9600 (x86,3QuadCore,12GB RAM, 300GB HD)	0
Cost/hr (over 3 years)	$0.36	$0.68
Cost ratio: Cloud/In house	**1.88**	
Efficiency	40%	80%
Cost/Effective hr	$0.90	$0.85
Power and cooling	$0.36	0
Management Cost	$0.10	$0.01
Total cost/effective hr	$1.36	$0.86
Cost ratio: In house/Cloud	**1.58**	

Benefits for the end user while using public cloud

- **High utilization**

- **High scalability**

- **No separate hardware procurement**

- **No separate power cost**

- **No separate IT infrastructure administration/maintenance required**

- **Public clouds offer user friendly SLA by offering high availability (~99%) and also provide compensation in case of SLA miss.**

- **Users can rent the cloud to develop and test prototypes before making major investments in technology**

Benefits for the end user while using public cloud

- **In order to enhance portability from one public cloud to another, several organizations such as Cloud Computing Interoperability Forum and Open Cloud Consortium are coming up with standards for portability.**

- **For e.g. Amazon EC2 and Eucalyptus share the same API interface.**

- **Software startups benefit tremendously by renting computing and storage infrastructure on the cloud instead of buying them as they are uncertain about their own future.**

Benefits for Small and Medium Businesses (<250 employees)

SMBs & Cloud Services

Tasks in cloud services currently and in 2–3 years

Project Management +92%
- 22%
- 12%

Marketing +73%
- 13%
- 8%

IM* +106%
- 47%
- 23%

Email* +64%
- 65%
- 40%

Online Backup/DB* +111%
- 49%
- 22%

Webconferencing* +110%
- 35%
- 17%

Voice Communication* +131%
- 54%
- 23%

File Sharing* +111%
- 45%
- 21%
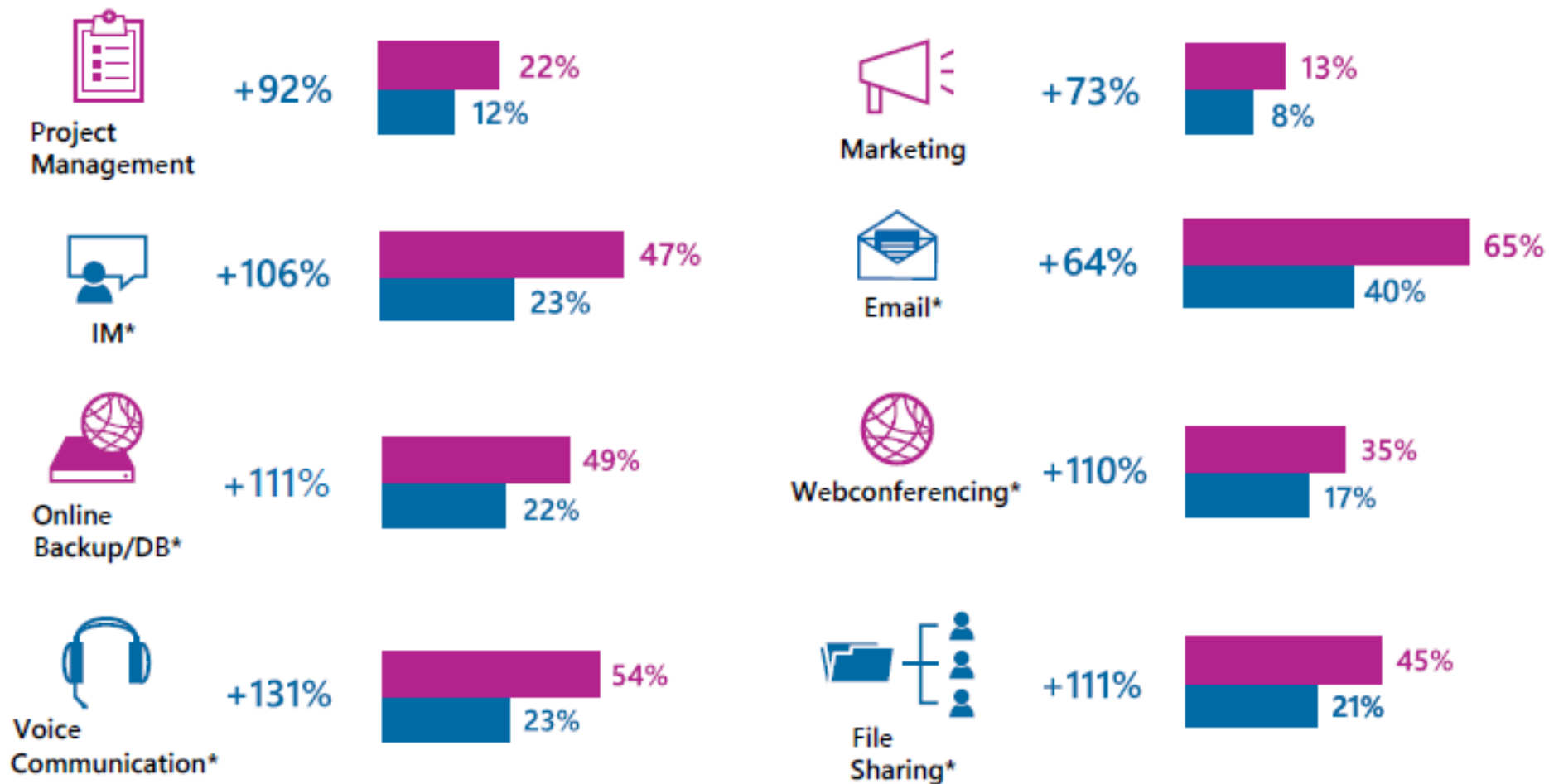
N = 3,000
*Includes free & paid services

■ Currently   ■ 2–3 years

Microsoft | Operator Channels

Source: http://www.microsoft.com/en-us/news/presskits/telecom/docs/SMBCloud.pdf

- **Cost of 1 server with 12 cores and 12 GB RAM is far lower than the cost of 12 servers having 1 core and 1 GB RAM.**

- **Confidentiality of data is preserved**

- **Virtual machines are cheaper than actual machines**

- **Virtual machines are faster to provision than actual machines**

Economics of PaaS vs IaaS

- Consider a web application that needs to be available 24X7, but where the transaction volume is unpredictable and can vary rapidly

- Using an IaaS cloud, a minimal number of servers would need to be provisioned at all times to ensure availability

- In contrast, merely deploying the application on PaaS cloud costs nothing. Depending upon the usage, costs are incurred.

- The PaaS cloud scales automatically to successfully handle increased requests to the web application.

• **No need for the user to handle scaling and load balancing of requests among virtual machines**

• **PaaS clouds also provide web based Integrated Development Environment for development and deployment of application on the PaaS cloud.**

• **Easier to migrate code from development environment to the actual production environment.**

• **Hence developers can directly write applications on the cloud and don't have to buy separate licenses of IDE.**

SaaS benefits

• **Users subscribe to web services and web applications instead of buying and licensing software instances.**

• **For e.g. Google Docs can be used for free, instead of buying document reading software's such as Microsoft Word.**

• **Enterprises can use web based SaaS Content Relationship Management applications, instead of buying servers and installing CRM softwares and associated databases on them.**

Q: Rate the benefits commonly ascribed to the 'cloud'/on-demand model
(1=not important, 5=very important)

Benefit	% responding 4 or 5
Easy/fast to deploy	63.9%
Pay only for what you use	61.5%
Less in-house IT staff, costs	57.0%
Low monthly payments	53.3%
Offers the latest functionality	50.0%
Encourages more standard IT	46.3%
Sharing systems/information simpler	43.4%
It's the way of the future	29.1%

% responding 4 or 5

Source: IDC Enterprise Panel, August 2008 n=244
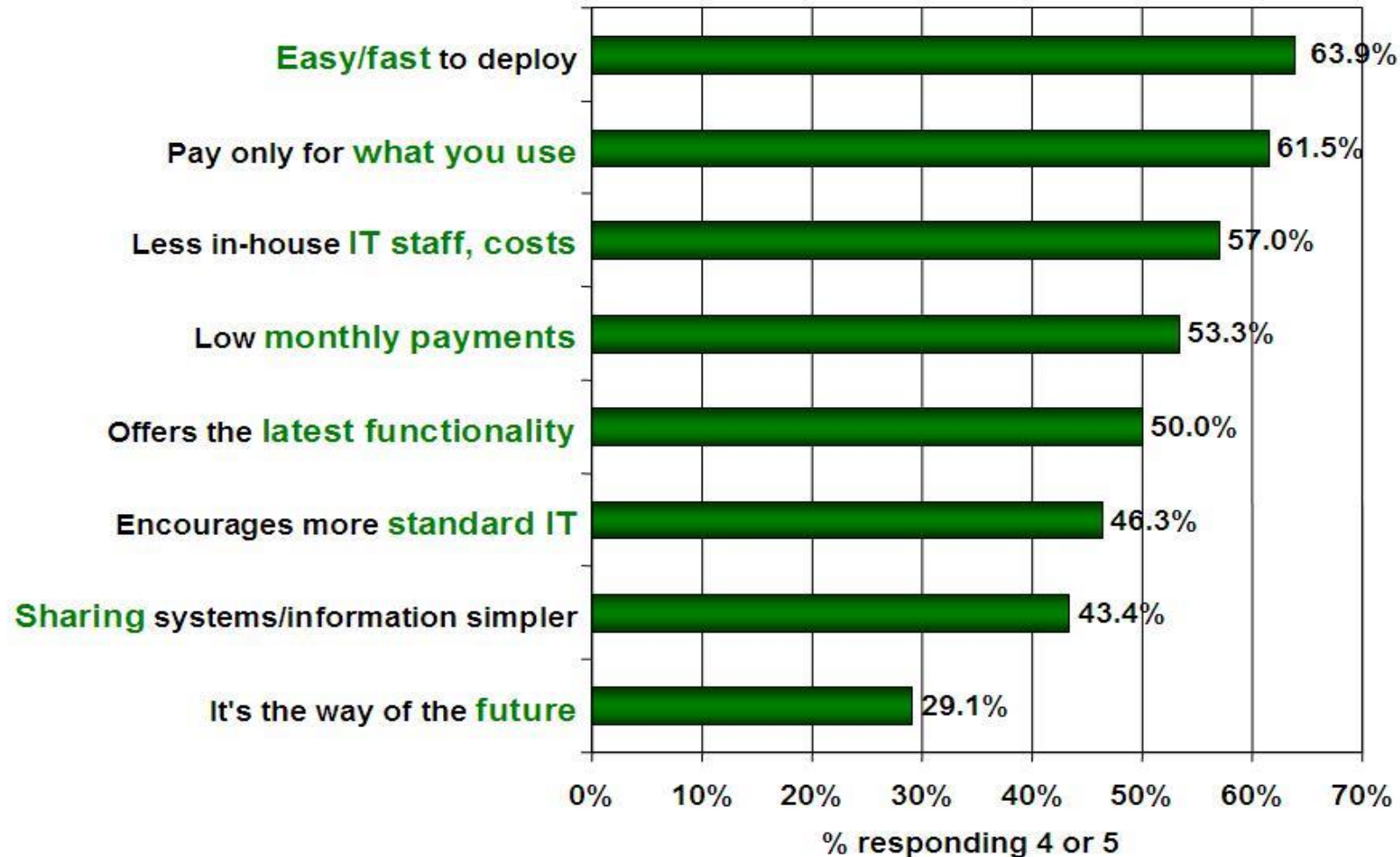
Factors driving investment in cloud

Factors driving investments in cloud per business size

Large companies
Medium companies
Small companies

Reduced cost of infrastructure: 78%, 65%, 64%
Flexibility (grow and reduce resources): 55%, 46%, 56%
Scaleability (minimize impact of flexibility): 40%, 31%, 43%
Business continuity and disaster recovery: 15%, 38%, 37%
Speed of implentation: 30%, 8%, 19%

Factors driving investment in cloud

Source: http://www.cloudtweaks.com/2012/01/infographic-whats-driving-investment-in-cloudcomputing/

Purpose of cloud computing in organizations

- **Analyzing data for research and development**

- **Meeting spikes in demand on our web site or internal systems**

- **Processing and storing applications or other forms**

- **Running data-intensive batch applications (e.g., data conversion, risk modeling, graphics rendering)**

- **Sharing information with the government or regulators**

- **Providing consumer entertainment, information and communication (e.g., music, video, photos, social networks)**

Top cloud applications that are driving cloud adaptation

- **Mail and Messaging**

- **Archiving**

- **Backup**

- **Storage**

- **Security**

- **Virtual Servers**

- **CRM (Customer Relationship Management)**

- **Collaboration across enterprises**

- **Hosted PBX (Private Branch Exchange)**

- **Video Conferencing**

Context: High Level Architectural Approach
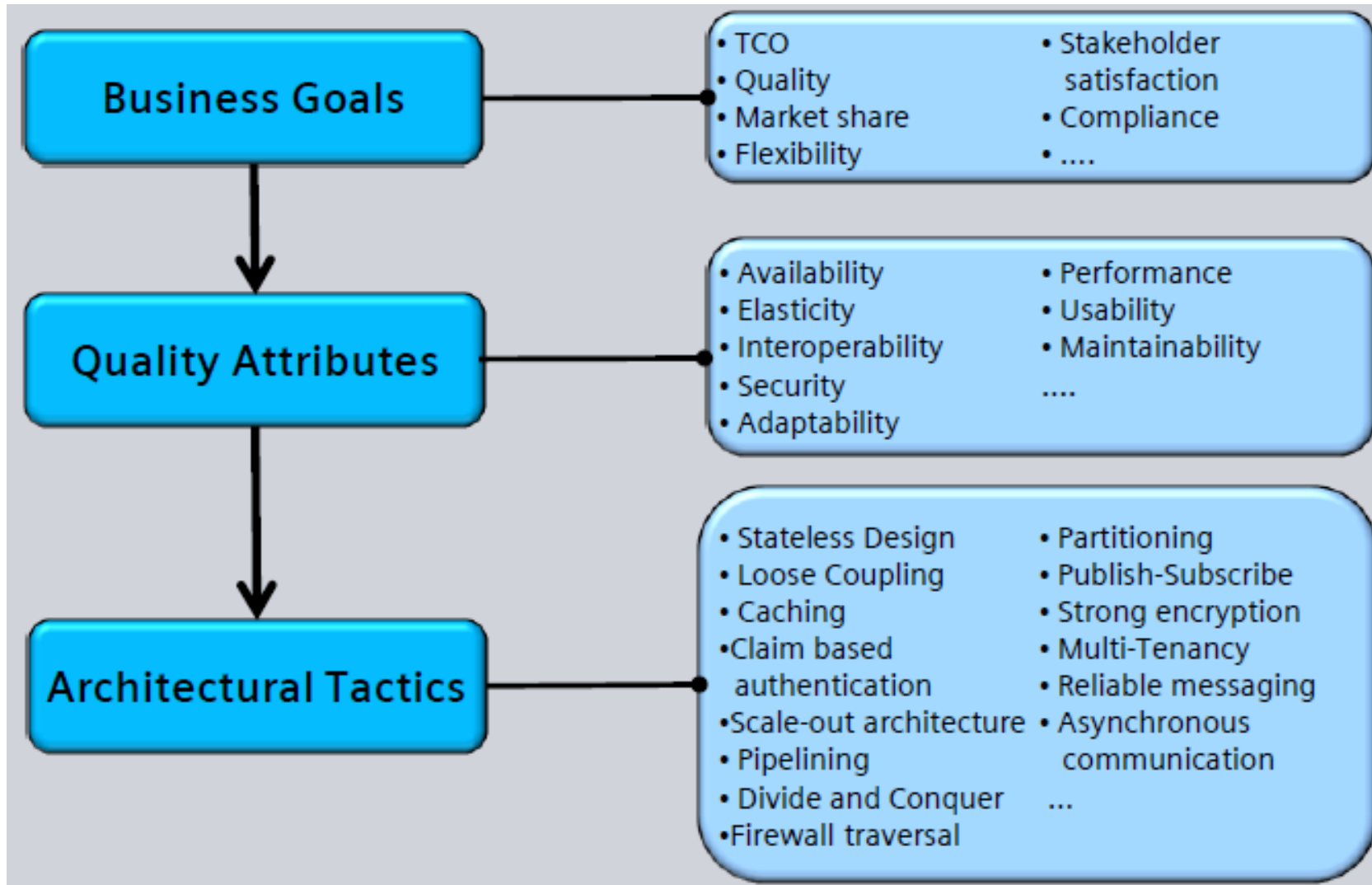
Major building blocks of Cloud Computing Architecture

- **Technical Architecture:**

  - **Structuring according to XaaS stack**

  - **Adopting cloud computing paradigms**

  - **Structuring cloud services and cloud components**

  - **Showing relationships and external endpoints**

  - **Middleware and communication**

  - **Management and security**

- **Deployment Operation Architecture:**

  - **Geo-location check (Legal issues, export control)**

  - **Operation and Monitoring**

Cloud Computing Architecture - XaaS
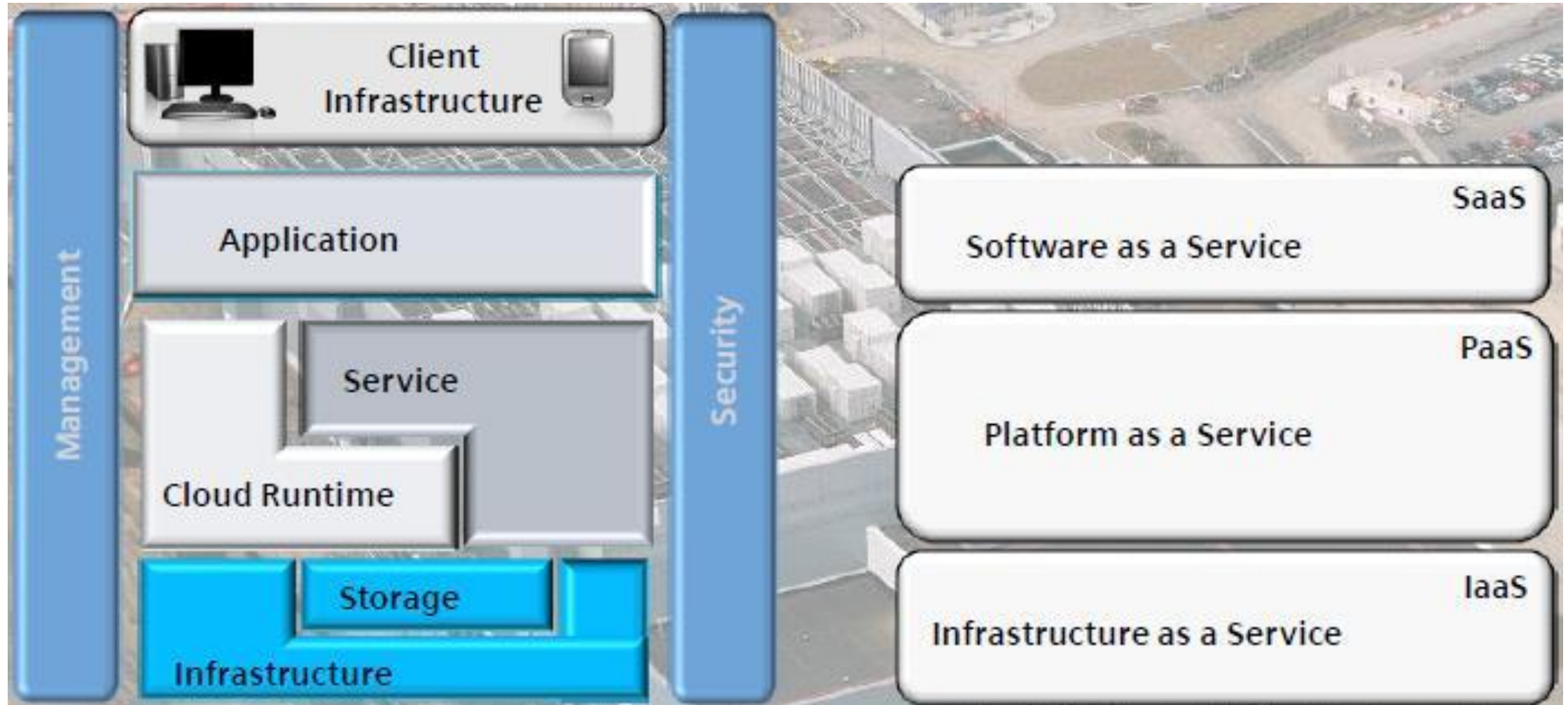
XaaS Stack views: Customer view vs Provider view
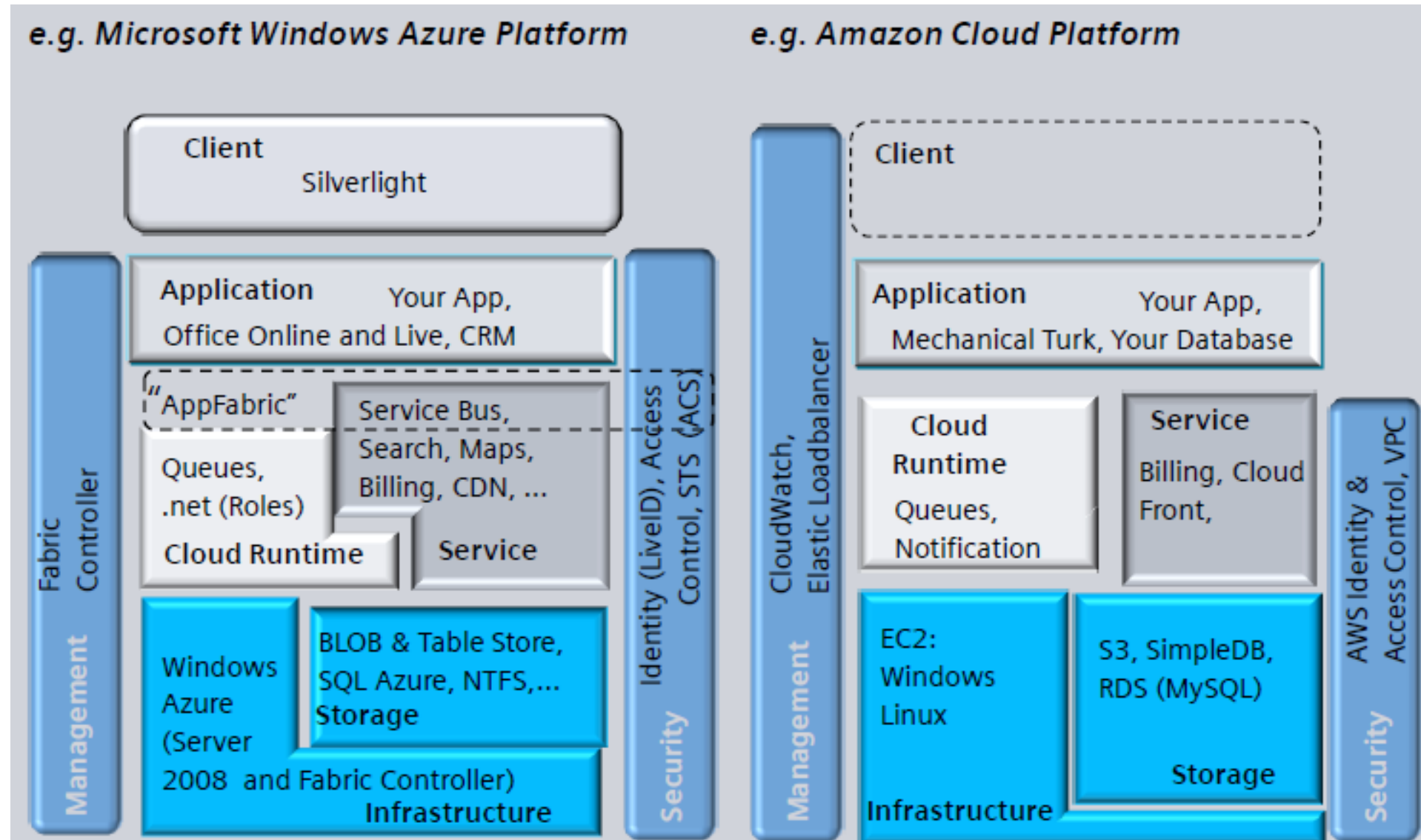
Vertical Scale Up

- Add more resources to a single computation unit i.e. Buy a bigger box
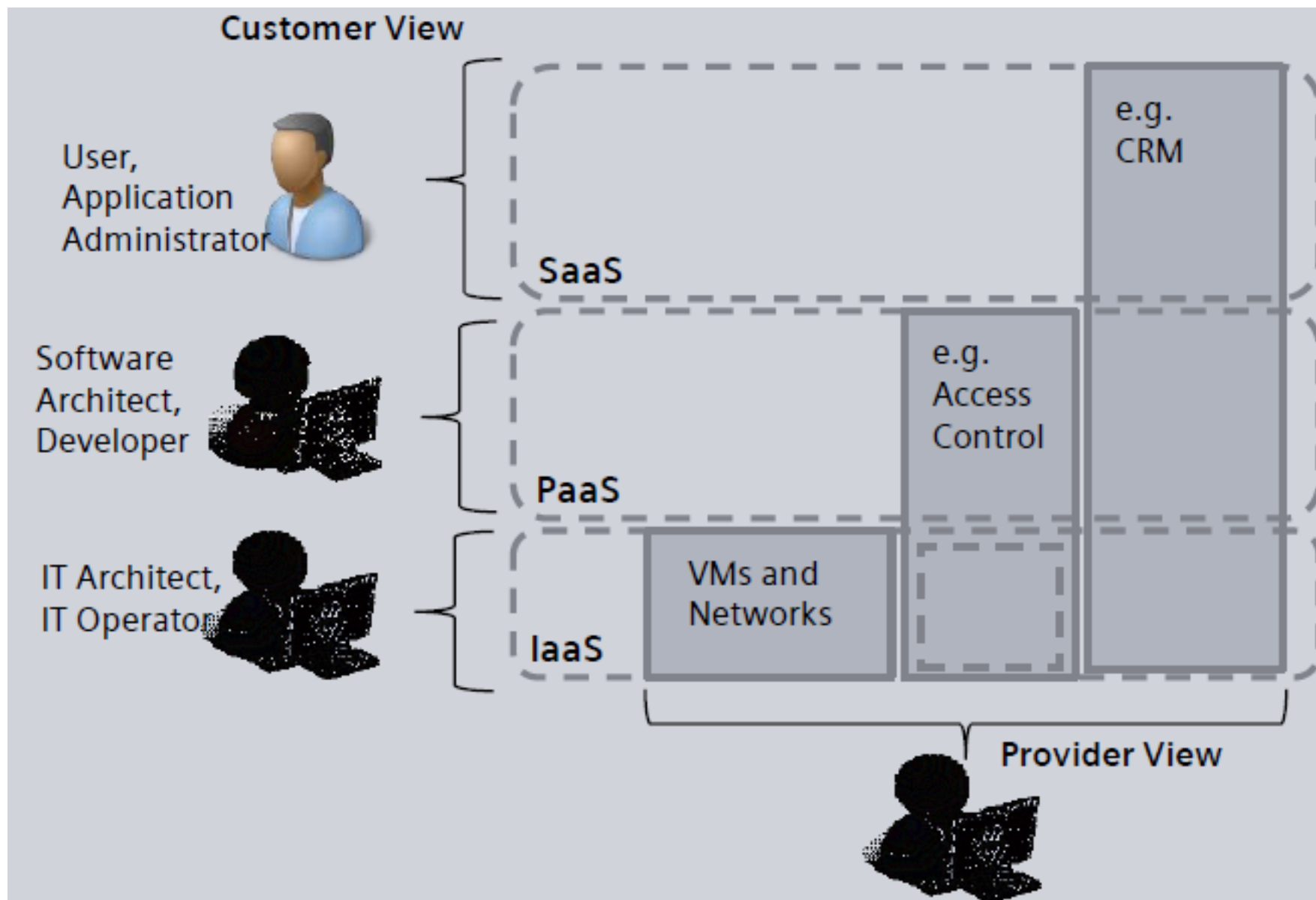
- Move a workload to a computation unit with more resources
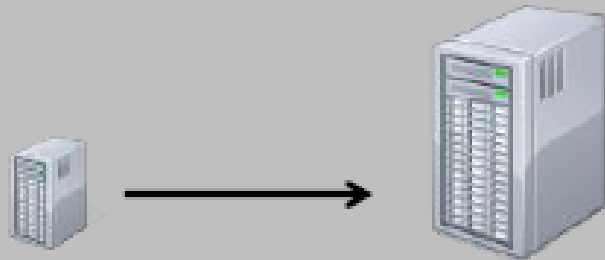
For small scenarios scale up is probably cheaper - code "just works"

Horizontal Scale Out

- Adding additional computation units and having them act in concert

- Splitting workload across multiple computation units

- Database partitioning
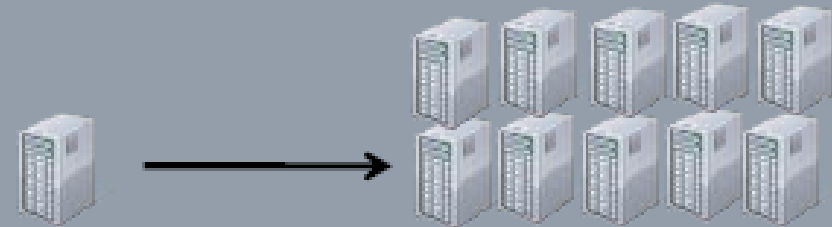
For larger scenarios scale out is the only solution 1x64 Way Server much more expensive that 64x1 Way Servers

- **Combination of Service-Oriented Infrastructure (SOI) and cloud computing realizes to XaaS.**

- **X as a Service (XaaS) is a generalization for cloud-related services**

- **XaaS stands for "anything as a service" or "everything as a service"**

- **XaaS refers to an increasing number of services that are delivered over the Internet rather than provided locally or on-site**

- **XaaS is the essence of cloud computing.**

XaaS

Business Process-as-a-Service (BPaaS)	Horizontal or vertical business processes provided on a subscription basis to companies or industries
Software-as-a-Service (SaaS)	Software applications hosted in the cloud and provided on a subscription basis
Platform-as-a-Service (PaaS)	Virtualized application development and run time platform
Infrastructure-as-a-Service (IaaS)	Raw infrastructure (CPU, memory, storage, network) available on an as-needed basis

Service Models (XaaS)

	Definition	Examples
Software *(maturing)*	Applications that are enabled for the cloud Supports an architecture that can run multiple instances of itself regardless of location Stateless application architecture Monthly subscription-based pricing model	• Google Docs • MobileMe • Zoho
Platform *(nascent)*	A platform that enables developers to write applications that run on the cloud A platform would usually have several application services available for quick deployment	• Microsoft Azure • Google App Engine • Force.com
Infrastructure *(evolving)* (servers, storage, databases)	A highly scaled redundant and shared computing infrastructure accessible using Internet technologies Consists of servers, storage, security, databases, and other peripherals	• Amazon EC2, S3, etc. • Rackspace Mosso offering • Sun's cloud services • Terremark cloud offering

Service Models (XaaS)

- **Most common examples of XaaS are**

- Software as a Service (SaaS)

- Platform as a Service (PaaS)

- Infrastructure as a Service (IaaS)

- **Other examples of XaaS include**

- Business Process as a Service (BPaaS)

- Storage as a service (another SaaS)

- Security as a service (SECaaS)

- Database as a service (DaaS)

- Monitoring/management as a service (MaaS)

- Communications, content and computing as a service (CaaS)

- Identity as a service (IDaaS)

- Backup as a service (BaaS)

- Desktop as a service (DaaS)

Requirements of CSP (Cloud Service Provider)

- Increase productivity

- Increase end user satisfaction

- Increase innovation

- Increase agility

Service Models (XaaS)

- **Broad network access (cloud) + resource pooling (cloud) + business-driven infrastructure on-demand (SOI) + service orientation (SOI) = XaaS**

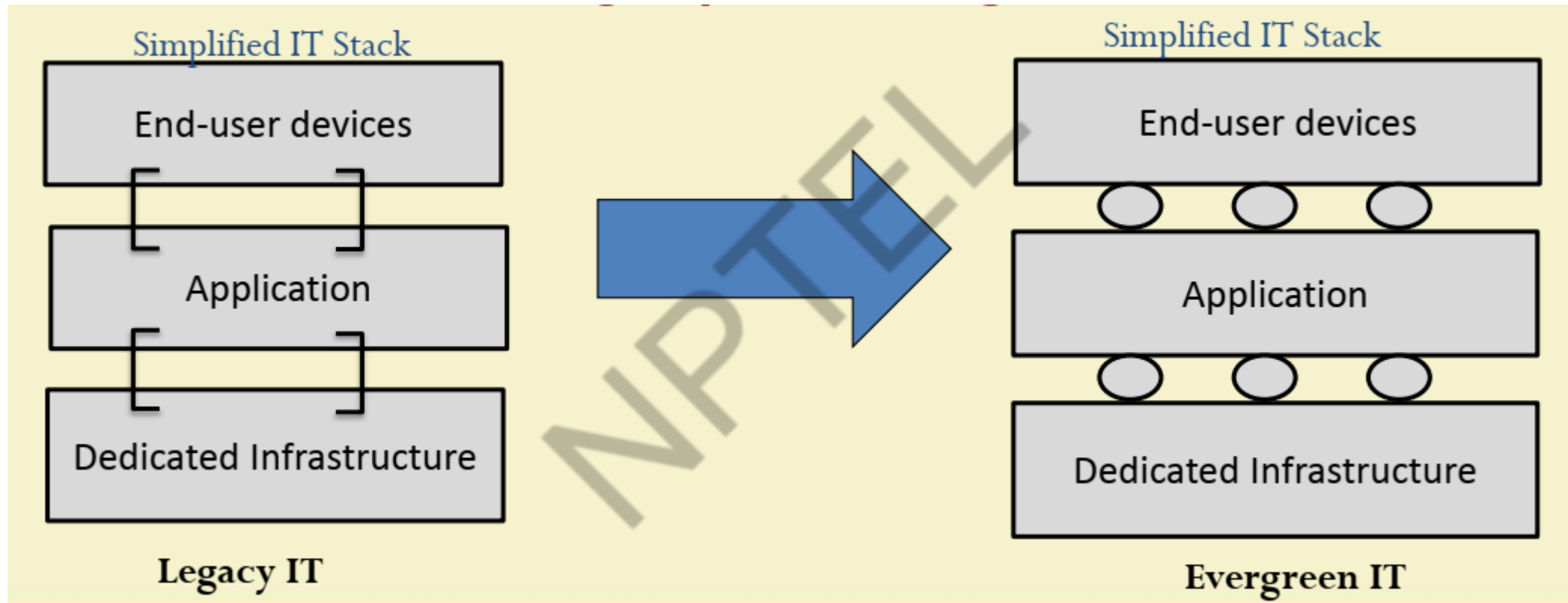- **Xaas fulfils all the 4 demands!**

Classical Service Model

- All the Layers(H/W, Operating System, Development Tools, Applications) Managed by the Users

- Initial IT budget and resources.

- Users bears the costs of the hardware, maintenance and technology.

- Each system is designed and funded for a specific business activity: custom build-to-order

- Systems are deployed as a vertical stack of "layers" which are tightly coupled, so no single part can be easily replaced or changed

- Prevalent of manual operations for provisioning, management

- Result: Legacy IT

Managed by user

Applications
Data
Runtime
Middleware
O/S
Virtualization
Servers
Storage
Network
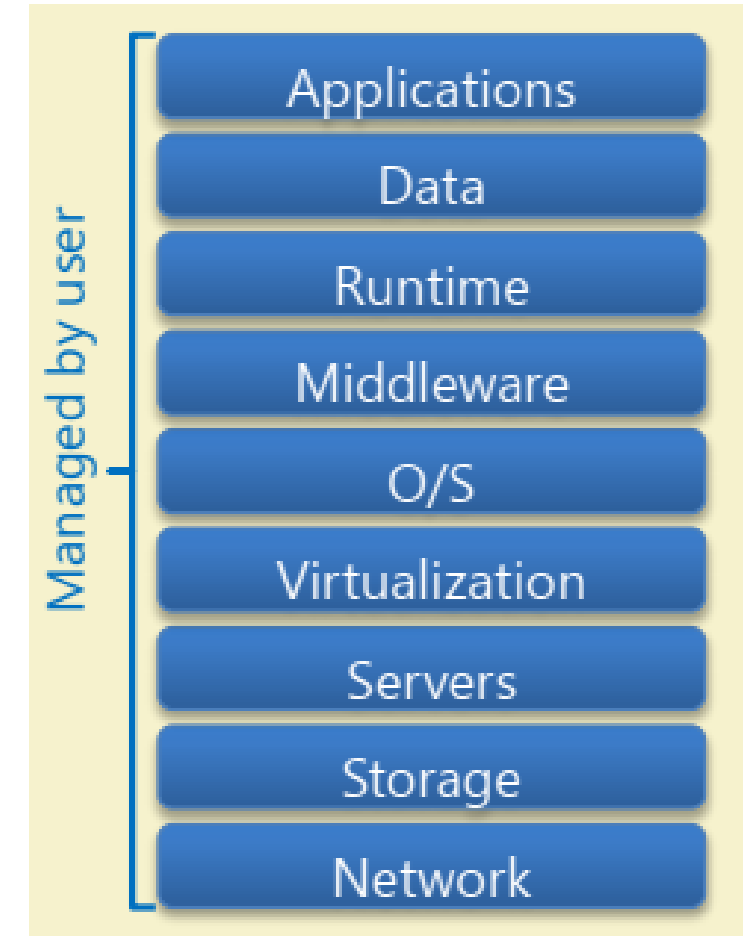
Key impact of cloud computing for IT function: From Legacy IT to Evergreen IT

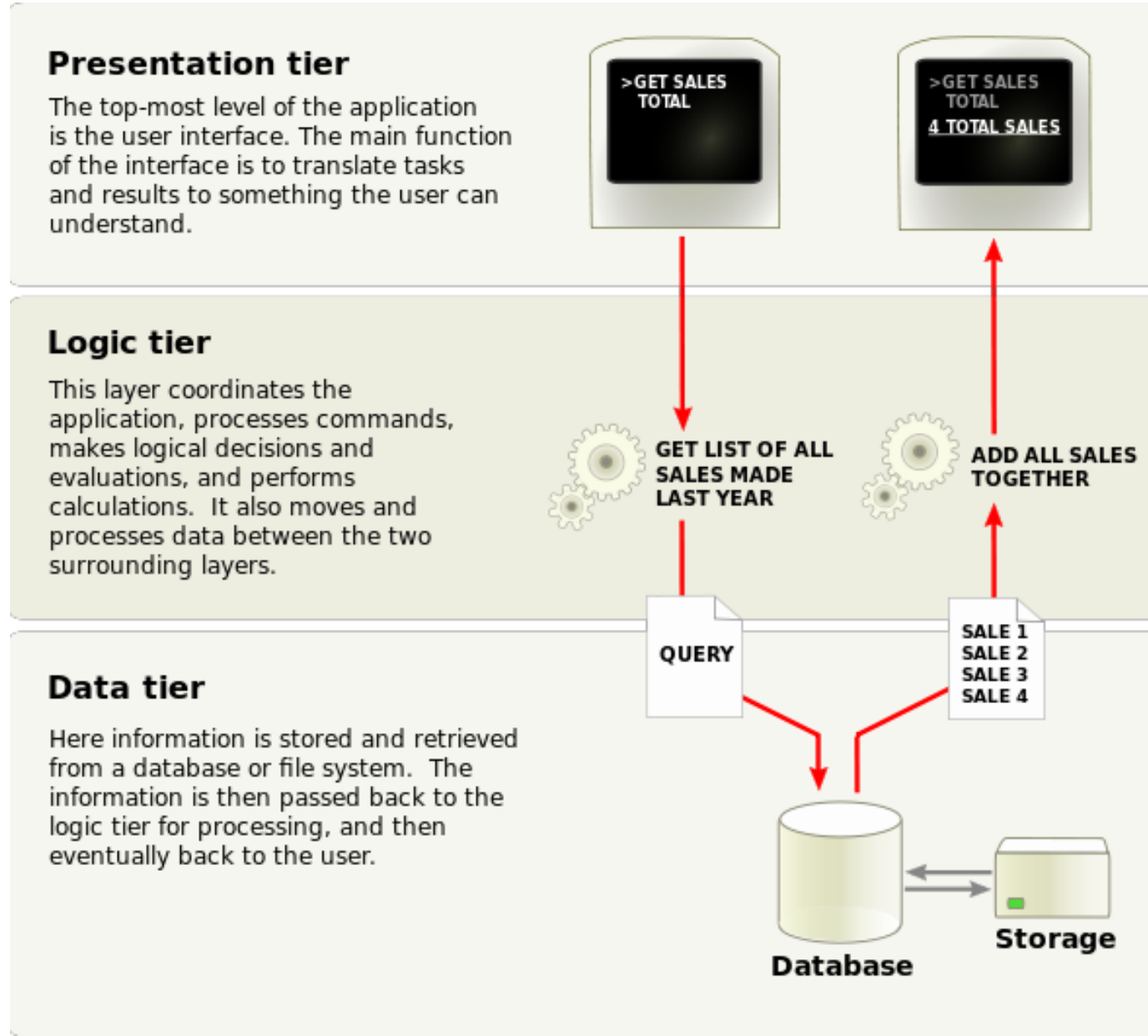|	Business Model	Definition/Example
Traditional		
1	Licensed Software	Traditional Software Licenses (w/ upgrade + maintenance) Examples: Oracle; SAP, Microsoft
2	Hardware Product	Hardware Product sale (e.g. PC, Server, Router) plus maintenance / support services Examples: Cisco, Dell, HP
3	People-based Services	Professional Services Examples: IBM Global Services, Accenture, Wipro
New/ Emerging		
4	SaaS	Software functionality delivered as utility services Examples: Salesforce.com; Taleo; Workday; NetSuite
5	IaaS	Storage-on-demand, compute capacity Examples: eVault; Amazon EC2; Dropbox
6	PaaS	Provide entire web services dev. environment/ platform Examples: Force.com; Azure; Amazon Web Services
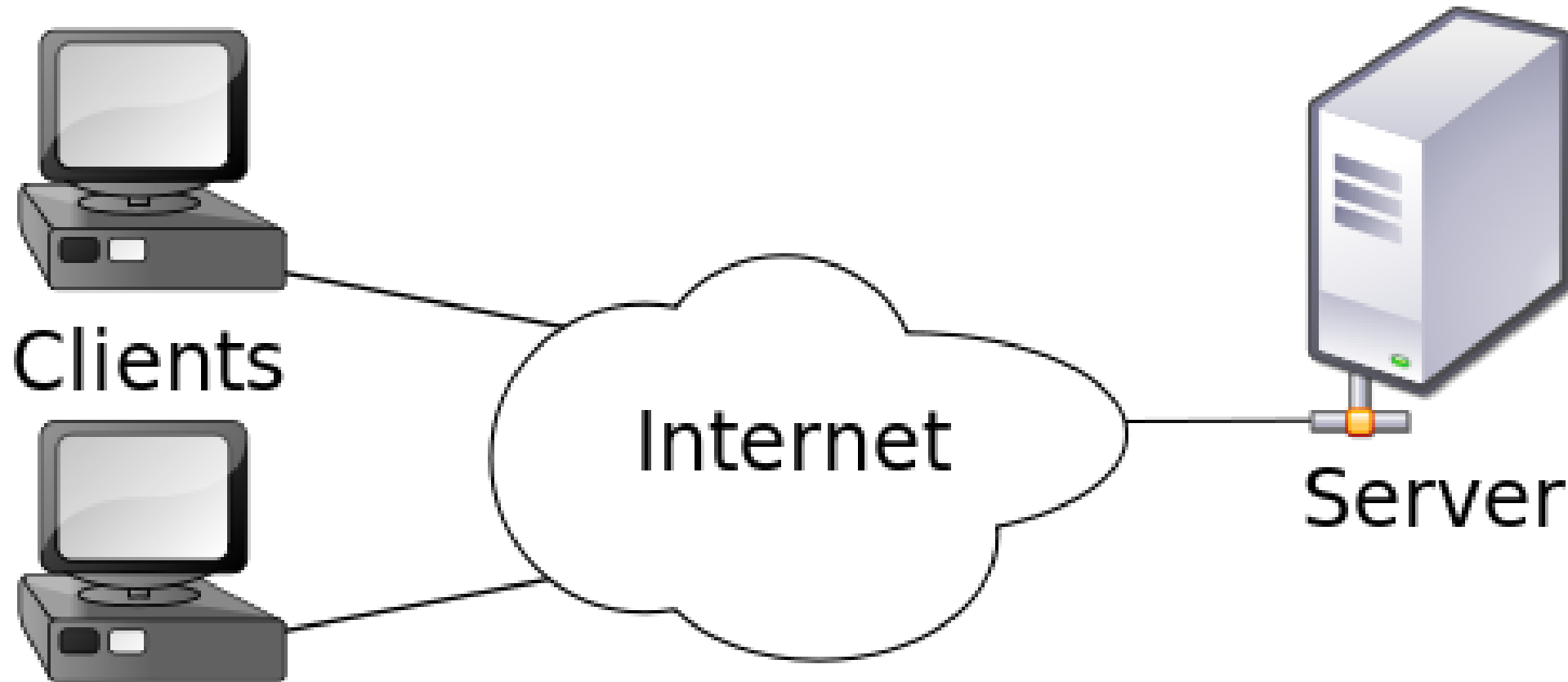
Client Server Architecture

• **Consists of one or more load balanced servers servicing requests sent by the clients**

• **Clients and servers exchange message in request-response fashion**

• **Client is often a thin client or a machine with low computational capabilities**

• **Server could be a load balanced cluster or a stand alone machine.**

Three Tier Client-Server Architecture

Presentation tier

The top-most level of the application is the user interface. The main function of the interface is to translate tasks and results to something the user can understand.

>GET SALES TOTAL

>GET SALES TOTAL
4 TOTAL SALES

Logic tier

This layer coordinates the application, processes commands, makes logical decisions and evaluations, and performs calculations. It also moves and processes data between the two surrounding layers.

GET LIST OF ALL SALES MADE LAST YEAR

ADD ALL SALES TOGETHER

QUERY

SALE 1
SALE 2
SALE 3
SALE 4

Data tier

Here information is stored and retrieved from a database or file system. The information is then passed back to the logic tier for processing, and then eventually back to the user.

Database
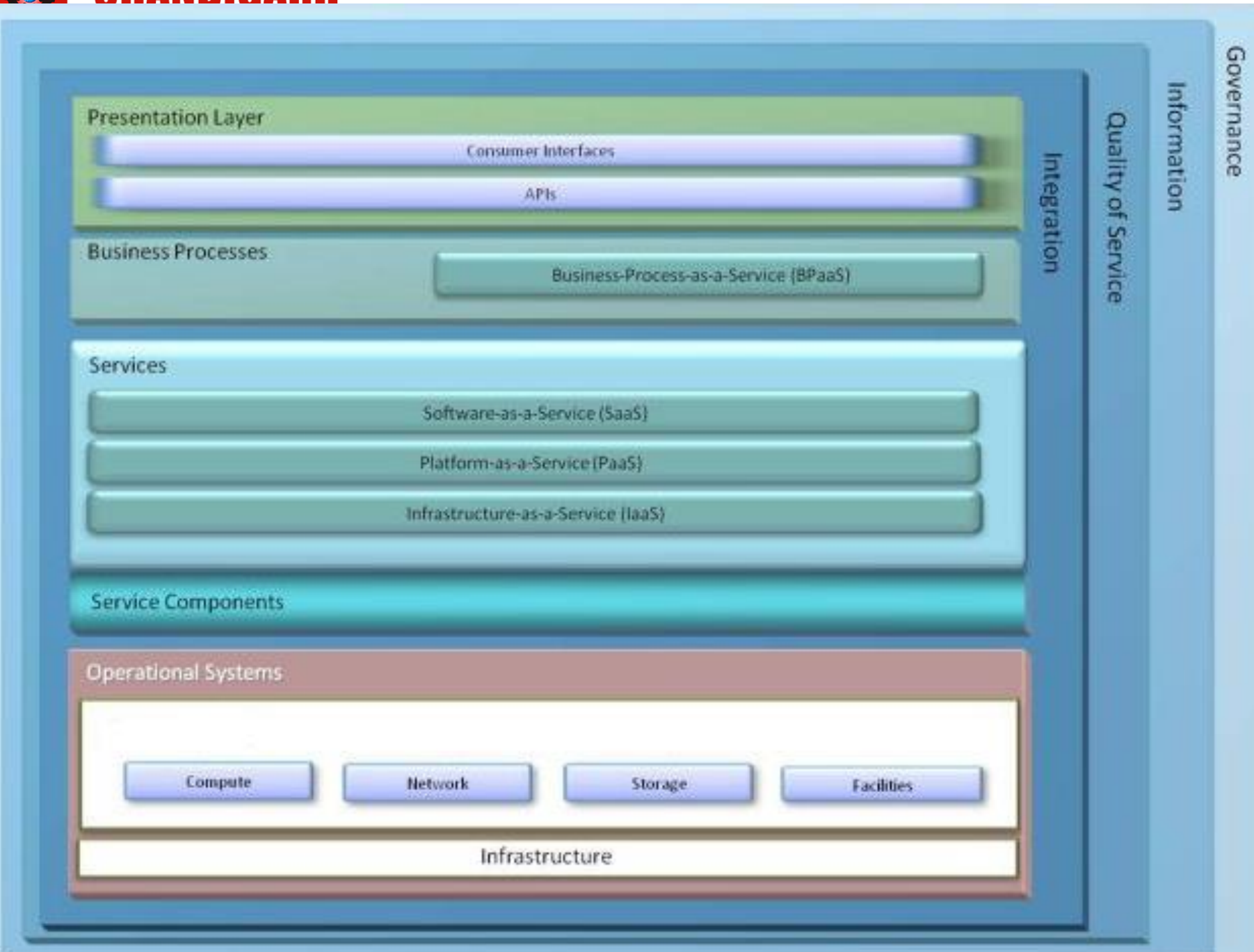
Storage

Client Server model vs. Cloud model

Client server model

- Simple service model where server services client requests

- May/may not be load balanced

- Scalable to some extent in a cluster environment.

- No concept of virtualization

Cloud computing model

- Variety of complex service models, such as, IaaS, PaaS, SaaS can be provided

- Load balanced

- Theoretically infinitely scalable

- Virtualization is the core concept

Cloud Services

CHANDIGARH

Presentation Layer
- Consumer Interfaces
- APIs

Business Processes
- Business-Process-as-a-Service (BPaaS)

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

Service Components

Operational Systems
- Compute
- Network
- Storage
- Facilities

Infrastructure

Integration | Quality of Service | Information | Governance

Cloud service models

Service Class	Main Access & Management Tool	Service content
SaaS	Web Browser	**Cloud Applications** Social networks, Office suites, CRM, Video processing
PaaS	Cloud Development Environment	**Cloud Platform** Programming languages, Frameworks, Mashups editors, Structured data
IaaS	Virtual Infrastructure Manager	**Cloud Infrastructure** Compute Servers, Data Storage, Firewall, Load Balancer

- **SaaS applications are designed for end users and are delivered over the web**

- **PaaS is the set of tools and services designed to make coding and deploying applications quickly and efficiently**

- **IaaS is the hardware and software that powers it all – servers, storage, network, operating systems**

Transportation Analogy

- By itself, infrastructure isn't useful – it just sits there waiting for someone to make it productive in solving a particular problem. Imagine the Interstate transportation system in the U.S. Even with all these roads built, they wouldn't be useful without cars and trucks to transport people and goods. In this analogy, the roads are the infrastructure and the cars and trucks are the platform that sits on top of the infrastructure and transports the people and goods. These goods and people might be considered the software and information in the technical realm

• **SaaS is defined as software that is deployed over the internet. With SaaS, a provider licenses an application to customers either as a service on demand, through a subscription, in a "pay-as-you-go" model, or (increasingly) at no charge when there is opportunity to generate revenue from streams other than the user, such as from advertisement or user list sales.**

SaaS characteristics

- **Web access to commercial software**

- **Software is managed from central location**

- **Software is delivered in a 'one to many' model**

- **Users not required to handle software upgrades and patches**

- **Application Programming Interfaces (API) allow for integration between different pieces of software.**

- **Applications where there is significant interplay between organization and outside world. E.g. email newsletter campaign software**

- **Applications that have need for web or mobile access. E.g. mobile sales management software**

- **Software that is only to be used for a short term need.**

- **Software where demand spikes significantly. E.g. Tax/Billing software's.**

- **E.g. of SaaS: Sales Force Customer Relationship Management (CRM) software**

- **Applications where extremely fast processing of real time data is needed**

- **Applications where legislation or other regulation does not permit data being hosted externally**

- **Applications where an existing on-premise solution fulfills all of the organization's needs**

Platform as a Service

- **Platform as a Service (PaaS) brings the benefits that SaaS bought for applications, but over to the software development world. PaaS can be defined as a computing platform that allows the creation of web applications quickly and easily and without the complexity of buying and maintaining the software and infrastructure underneath it.**

- **PaaS is analogous to SaaS except that, rather than being software delivered over the web, it is a platform for the creation of software, delivered over the web.**

- Services to develop, test, deploy, host and maintain applications in the same integrated development environment. All the varying services needed to fulfill the application development process.

- Web based user interface creation tools help to create, modify, test and deploy different UI scenarios.

- Multi-tenant architecture where multiple concurrent users utilize the same development application.

- Built in scalability of deployed software including load balancing and failover.

- Integration with web services and databases via common standards.

- Support for development team collaboration – some PaaS solutions include project planning and communication tools.

- Tools to handle billing and subscription management

- **PaaS is especially useful in any situation where multiple developers will be working on a development project or where other external parties need to interact with the development process**

- **PaaS is useful where developers wish to automate testing and deployment services.**

- **The popularity of agile software development, a group of software development methodologies based on iterative and incremental development, will also increase the uptake of PaaS as it eases the difficulties around rapid development and iteration of software.**

- **PaaS Examples: Microsoft Azure, Google App Engine**

Scenarios where PaaS is not ideal

- **Where the application needs to be highly portable in terms of where it is hosted.**

- **Where proprietary languages or approaches would impact on the development process**

- **Where a proprietary language would hinder later moves to another provider – concerns are raised about vendor lock in**

- **Where application performance requires customization of the underlying hardware and software**

- **Infrastructure as a Service (IaaS) is a way of delivering Cloud Computing infrastructure – servers, storage, network and operating systems - as an on-demand service.**

- **Rather than purchasing servers, software, datacenter space or network equipment, clients instead buy those resources as a fully outsourced service on demand.**

Characteristics of IaaS

- **Resources are distributed as a service**

- **Allows for dynamic scaling**

- **Has a variable cost, utility pricing model**

- **Generally includes multiple users on a single piece of hardware**

Scenarios where IaaS makes sense

- **Where demand is very volatile – any time there are significant spikes and troughs in terms of demand on the infrastructure**

- **For new organizations without the capital to invest in hardware**

- **Where the organization is growing rapidly and scaling hardware would be problematic**

- **Where there is pressure on the organization to limit capital expenditure and to move to operating expenditure**

- **For specific line of business, trial or temporary infrastructural needs**

- **Where regulatory compliance makes the offshoring or outsourcing of data storage and processing difficult**

- **Where the highest levels of performance are required, and on-premise or dedicated hosted infrastructure has the capacity to meet the organization's needs**

Provider	Software	Pricing model
Salesforce.com	CRM	Pay per use
Google Gmail	Email	Free
Process Maker Live	Business process management	Pay per use
XDrive	Storage	Subscription
SmugMug	Data sharing	Subscription
OpSource	Billing	Subscription
Appian Anywhere	Business process management	Pay per use
Box.net	Storage	Pay per use
MuxCLoud	Data processing	Pay per use

Feature comparison of PaaS providers

Provider	Target to Use	Programming language, Frameworks	Programming Models	Persistence options
Aneka	.NET enterprise applications, Web applications	.NET	Threads, Task, MapReduce	Flat files, RDBMS
AppEngine	Web applications	Python, Java	Request-based Web programming	BigTable
Force.com	Enterprise applications	Apex	Workflow, Request-based Web programming, Excel-like formula language	Own object database
Azure	Enterprise applications, Web applications	.NET	Unrestricted	Table/BLOB/queue storage, SQL Services
Heroku	Web applications	Ruby on Rails	Request-based Web programing	PostgreSQL, Amazon RDS
Amazon Elastic MapReduce	Data processing	Hive and Pirg, Cascading, Java, Ruby, Perl, Python, PHP, C++	MapReduce	Amazon S3

| Provider	Geographic distribution of data centers	User interfaces and APIs	Hardware capacity	Guest operating systems	Smallest billing unit
Amazon E2C	US Europe	CLI, WS, Portal	CPU: 1_20 EC2 compute units Memory: 1.7-15 GB Storage: 160-1690 GB, 1 GB – 1 TB (per ESB units)	Linux Windows	Hour
Flexiscale	UK	Web console	CPU: 1-4 Memory: 0.5-16 GB Storage: 20-270 GB	Linux, Windows	Hour
GoGrid		REST, Java, PHP, Python, Ruby	CPU: 1-6 Memory: 0.5-8 GB Storage: 30-480 GB	Linux, Windows	Hour
Joyent	US		CPU: 1/16-8 Memory: 0.25-32.5 GB Storage: 5-100GB	OpenSolaris	Month
RackSpace	US	Portal, REST, Python, PHP, Java, .NET	CPU: Quad-core Memory: 0.25-16 GB Storage: 10-620 GB	Linux	Hour
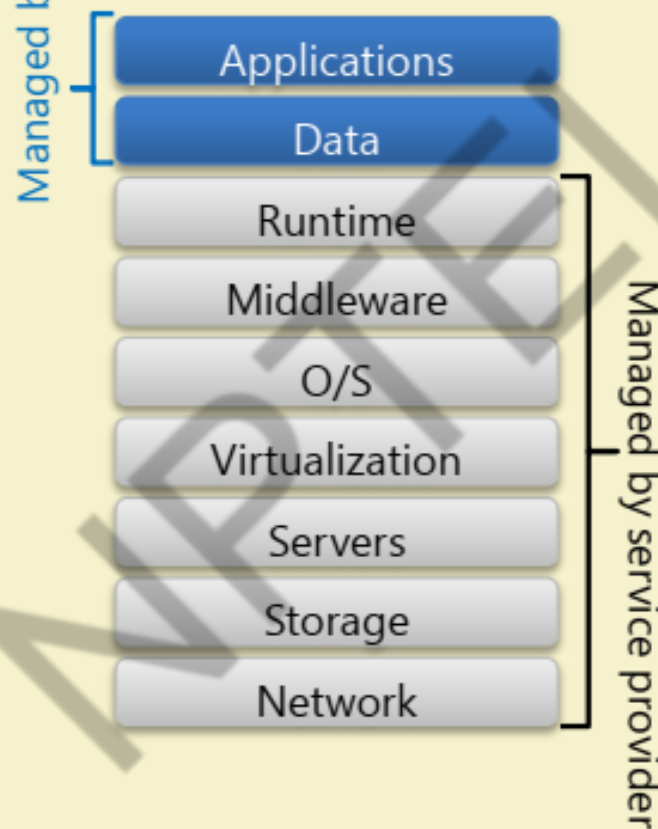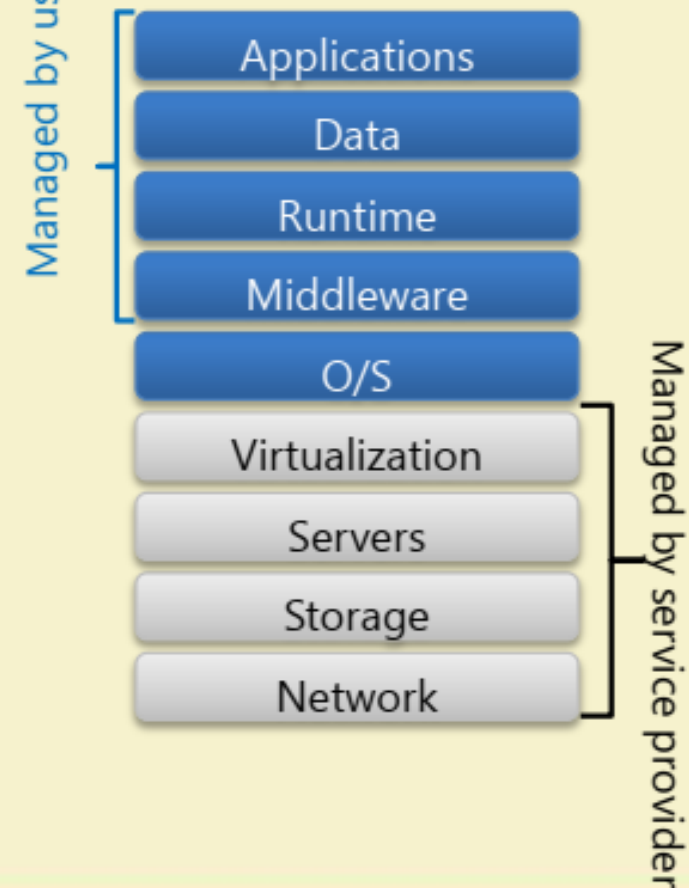
Role of Networking in cloud computing

- In cloud computing, network resources can be provisioned dynamically.

- Some of the networking concepts that form the core of cloud computing are Virtual Local Area Networks, Virtual Private Networks and the different protocol layers.

- Examples of tools that help in setting up different network topologies and facilitate various network configurations are OpenSSH, OpenVPN etc.

Networking in different cloud models

OSI Layer	Example Protocols	IaaS	PaaS	SaaS
7 Application	HTTP, FTP, NFS, SMTP, SSH	Consumer	Consumer	Provider
6 Presentation	SSL, TLS	Consumer	Provider	Provider
5 Session	TCP	Consumer	Provider	Provider
4 Transport	TCP	Consumer	Provider	Provider
3 Network	IP, IPSec	Consumer	Provider	Provider
2 Data Link	Ethernet, Fibre channel	Provider	Provider	Provider
1 Physical	Copper, optic fibre	Provider	Provider	Provider

- **Definition: "Network Functions Virtualisation aims to transform the way that network operators architect networks by evolving standard IT virtualisation technology to consolidate many network equipment types onto industry standard high volume servers, switches and storage, which could be located in Datacentres, Network Nodes and in the end user premises, as illustrated in Figure 1. It involves the implementation of network functions in software that can run on a range of industry standard server hardware, and that can be moved to, or instantiated in, various locations in the network as required, without the need for installation of new equipment."**

Network Function Virtualization