UNIT 1

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Introduction to Cloud Computing

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Introduction

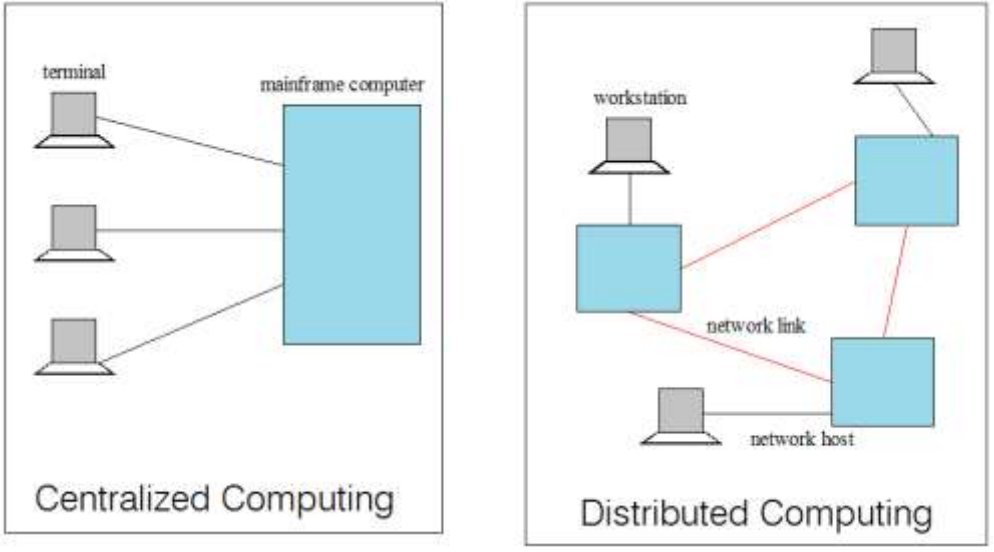
The ACM Computing Curricula 2005 defined "**computing**" as

"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.

Trends in Computing

- Distributed Computing
- Grid Computing
- Cluster Computing
- Cloud Computing

Distributed Computing



- Early computing was performed on a single processor. Uni-processor computing can be called centralized computing.

Distributed Computing/System?

- **Distributed computing**
  – Field of computing science that studies distributed system.
  – Use of distributed systems to solve computational problems.

- **Distributed system**

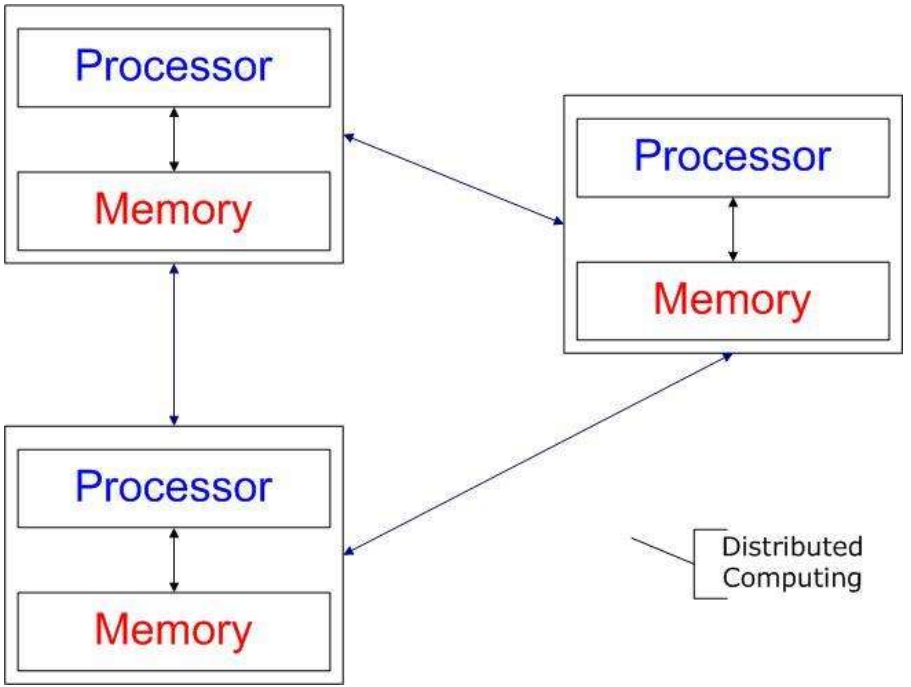
  -- Wikipedia

  > 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

- Internet
- ATM (bank) machines
- Intranets/Workgroups
- Computing landscape will soon consist of ubiquitous network-connected devices

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 Analogy

- **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

> “The Grid" links together computing resources (Pcs, workstations, servers, storage elements) and provides the mechanism needed to access them.

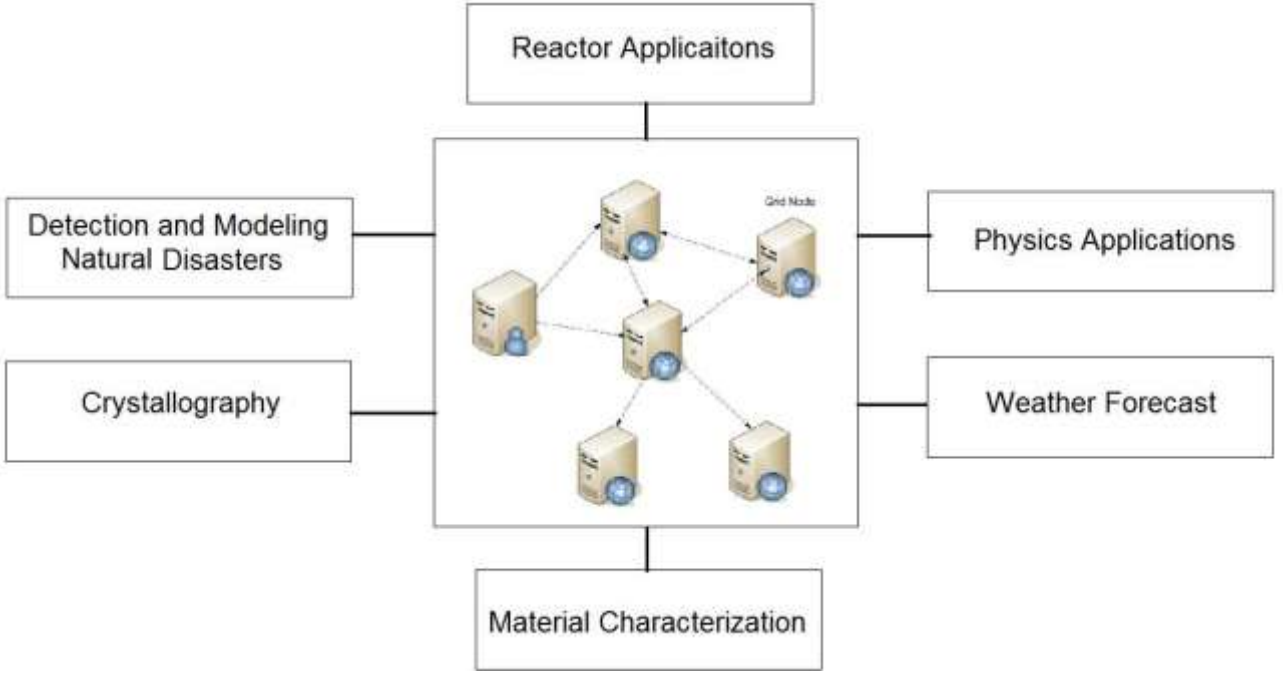
Grid Computing

- 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 ?



Type of Grids

- **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.

Type of Grids

- **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.

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

Key Operational Benefits of Clustering

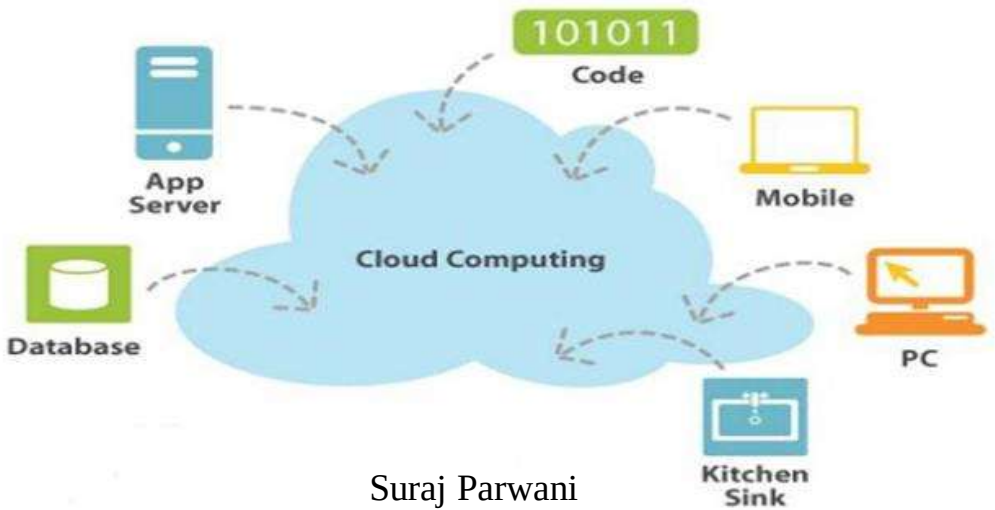
- System availability: offer inherent high system availability due to the redundancy of hardware, operating systems, and applications.
- Hardware fault tolerance: redundancy for most system components (eg. disk-RAID), including both hardware and software.
- OS and application reliability: run multiple 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)

What is Cloud ?

- The term Cloud refers to a Network or Internet. In other words, we can say that Cloud is something, which is present at remote location. Cloud can provide services over network, i.e., on public networks or on private networks, i.e., WAN, LAN or VPN.
- Applications such as e-mail, web conferencing, customer relationship management (CRM),all run in cloud.

Cloud Computing

- Cloud computing is a model for enabling 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.



Essential Characteristics

- **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.

Cloud Characteristics

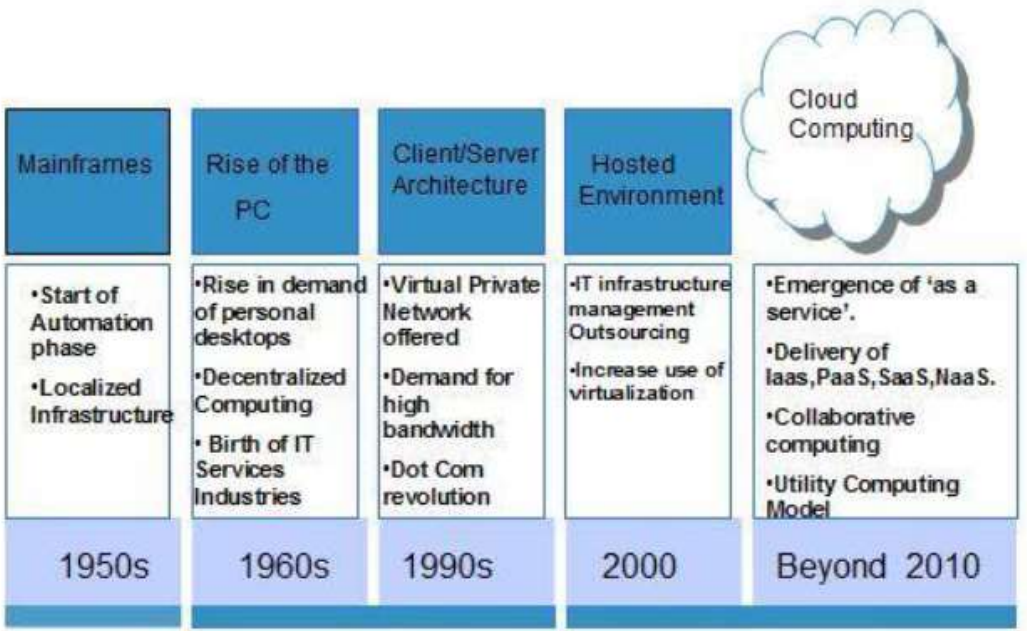
- Measured Service
- – Cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported,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

Common Characteristics

- Massive Scale
- Resilient Computing
- Homogeneity
- Geographic Distribution
- Virtualization
- Service Orientation
- Low Cost Software
- Advanced Security

History

- The concept of Cloud Computing came into existence in 1950 with implementation of mainframe computers, accessible via thin/static clients. Since then, cloud computing has been evolved from static clients to dynamic ones from software to services.



Cloud Services Models

- **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.

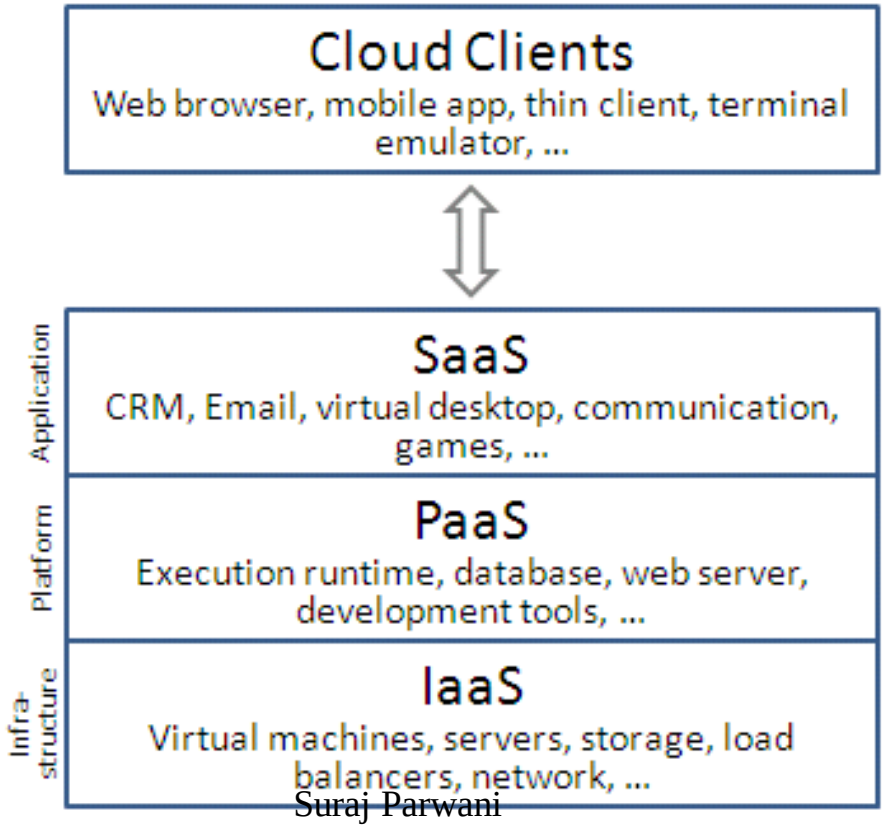
  > The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems,storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.
  e.g: Google Spread Sheet

- **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.

Cloud Services Models

- **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 Services Models



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.

Advantages of Cloud Computing

- **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.

Advantages of Cloud Computing

- **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. Like 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 PetaBytes 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

Advantages of Cloud Computing

- **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.

Advantages of Cloud Computing

- **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

Disadvantages of Cloud Computing

- **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.

Disadvantages of Cloud Computing

- **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.

Disadvantages of Cloud Computing

- **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.

Disadvantages of Cloud Computing

- **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

Reasons of Cloud Computing

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

- From an 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 of private cloud

- 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.

PaaS Benefits

- 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 softwares 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.

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

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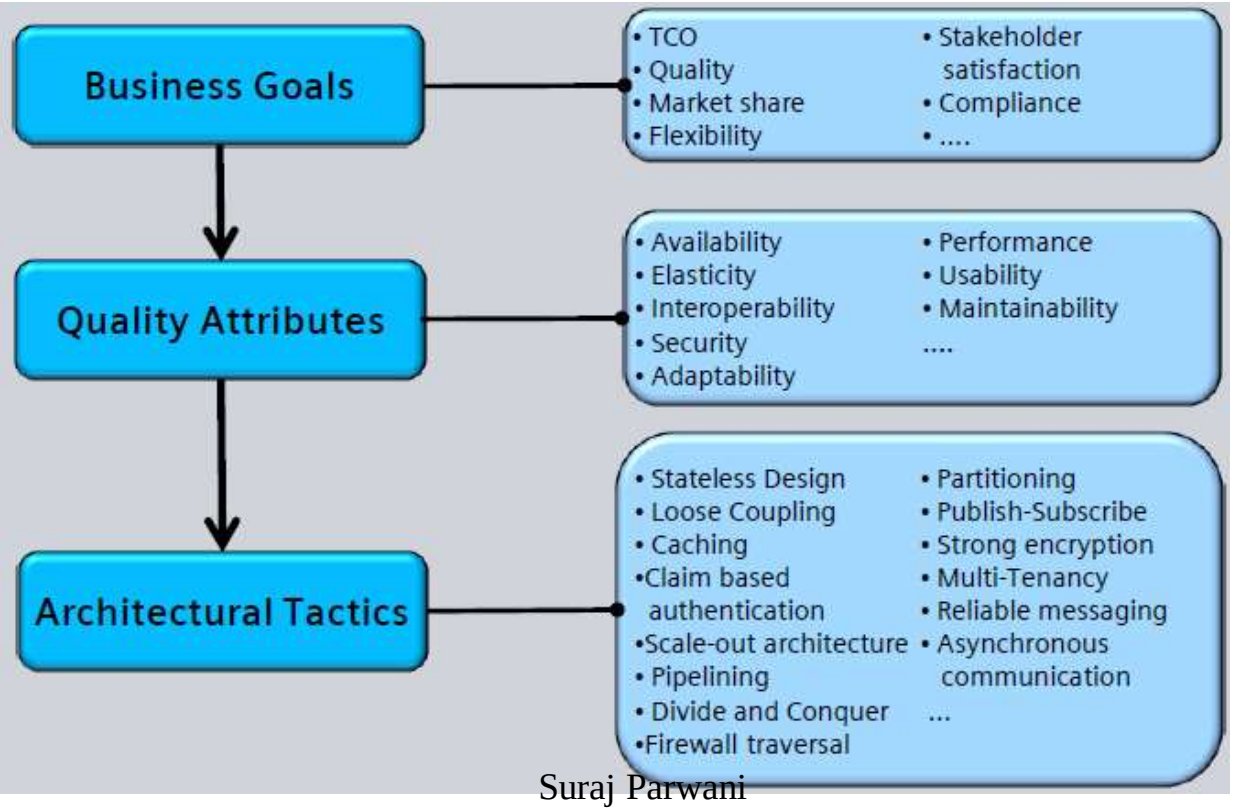
Context: High Level Architectural Approach

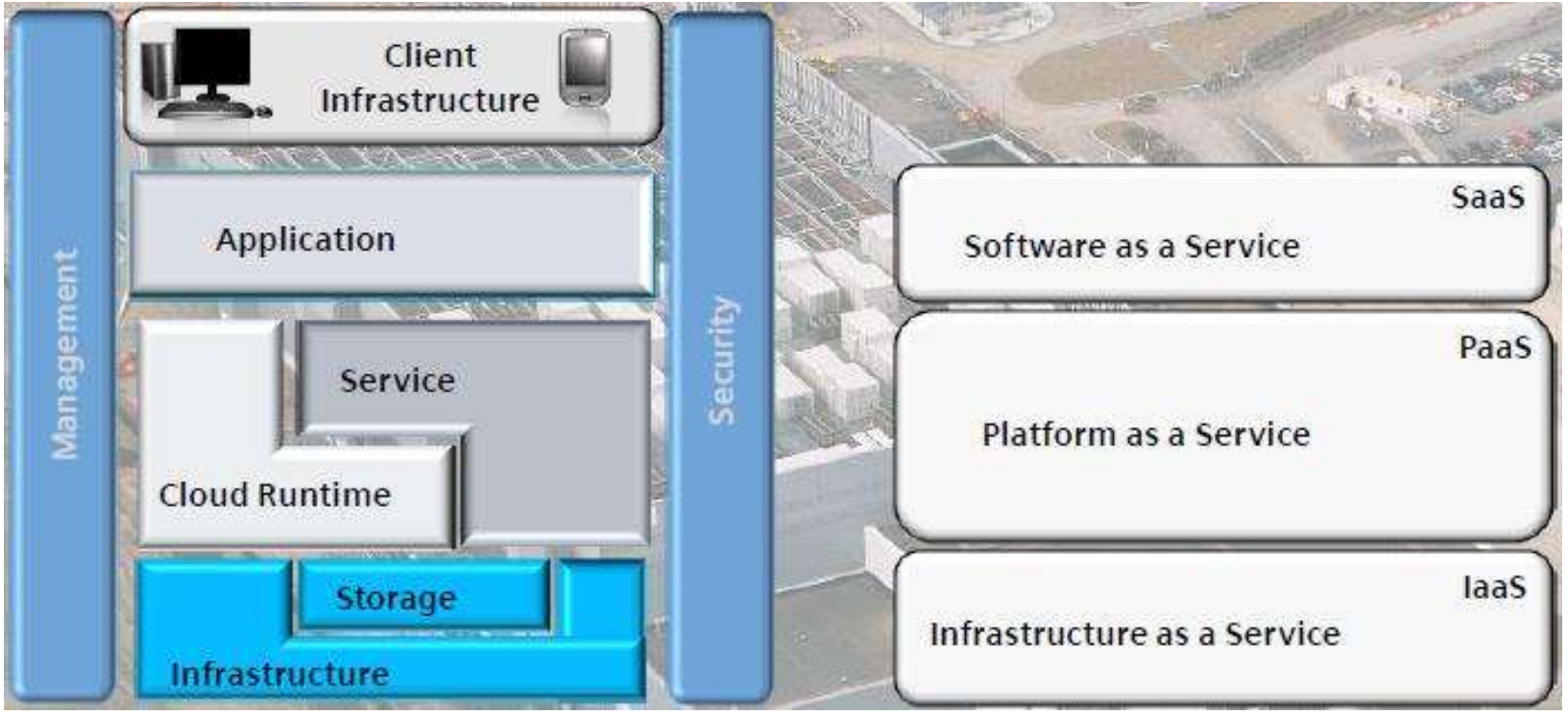


Major building blocks of Cloud Computing Architecture

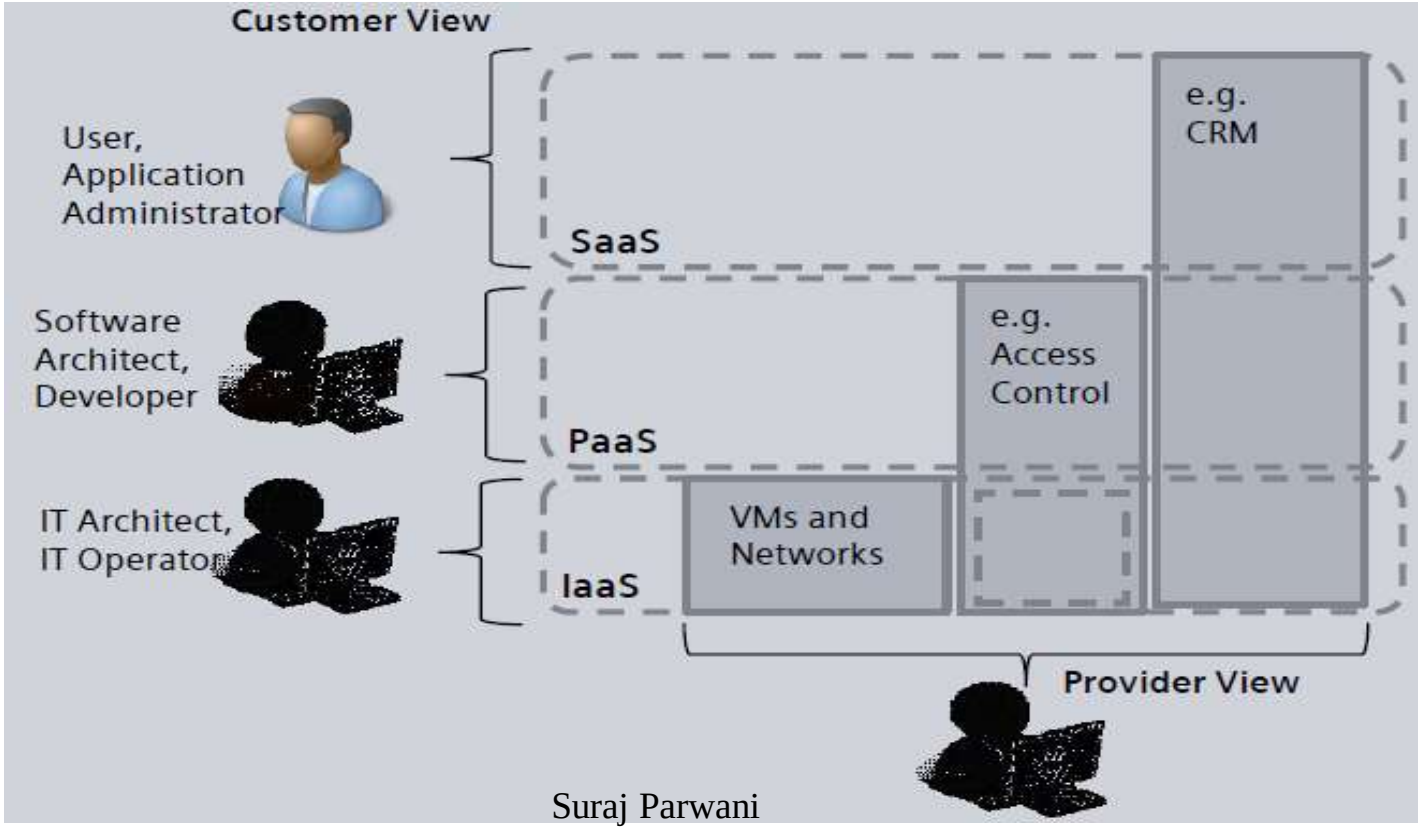
- Technical Architecture:
- – Structuring according to XaaS stack
- – Adopting cloud computing paradigms
- – Structuring cloud services and cloud components
- – Showing relationships and external endpoints
- – Middleware and communication
- – Management and security

- Deployment Operation Architecture:
- – Geo-location check (Legal issues, export control)

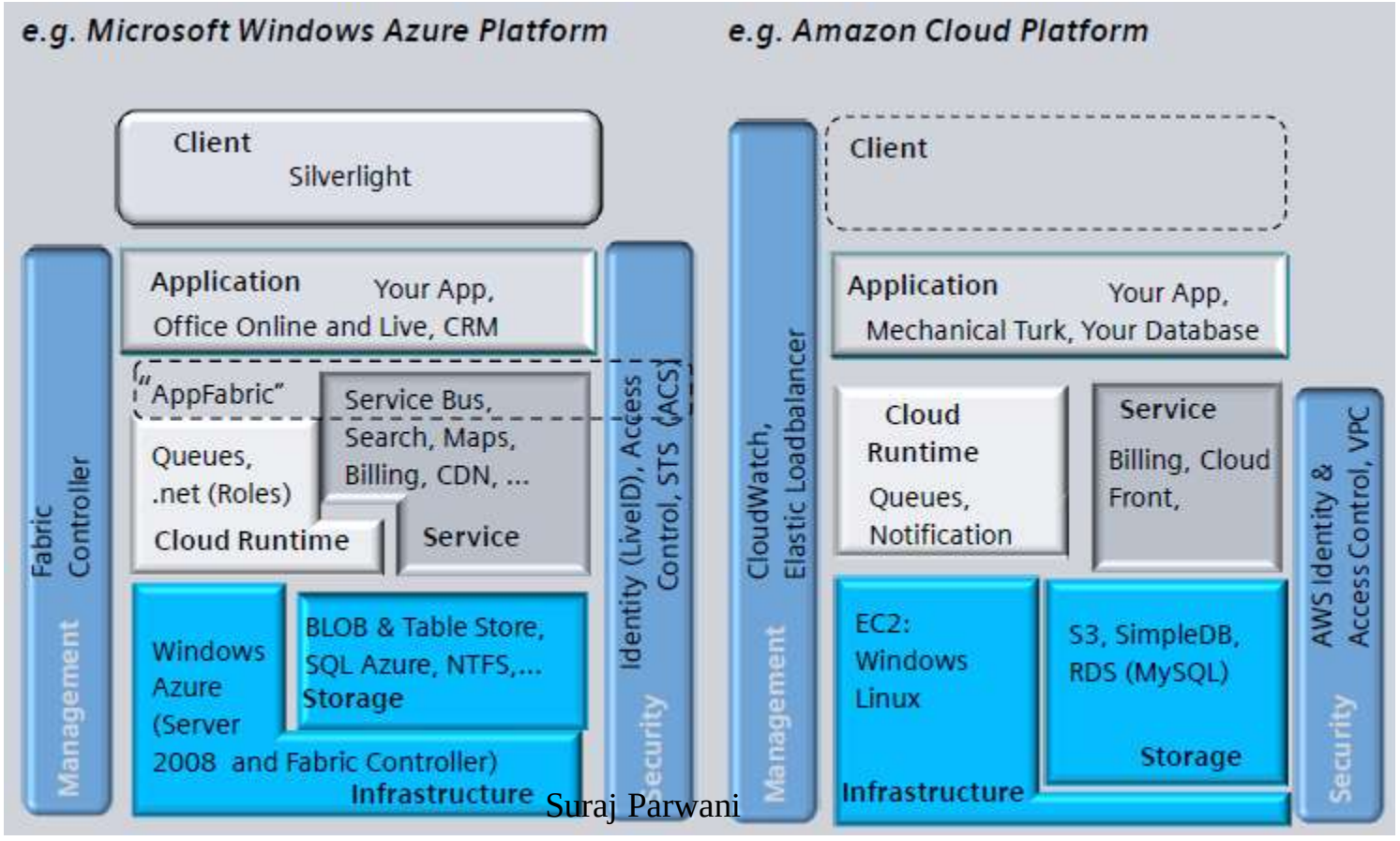
Cloud Computing Architecture - XaaS



XaaS Stack views: Customer view vs Provider view



Microsoft Azure vs Amazon EC2



Architecture for elasticity

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

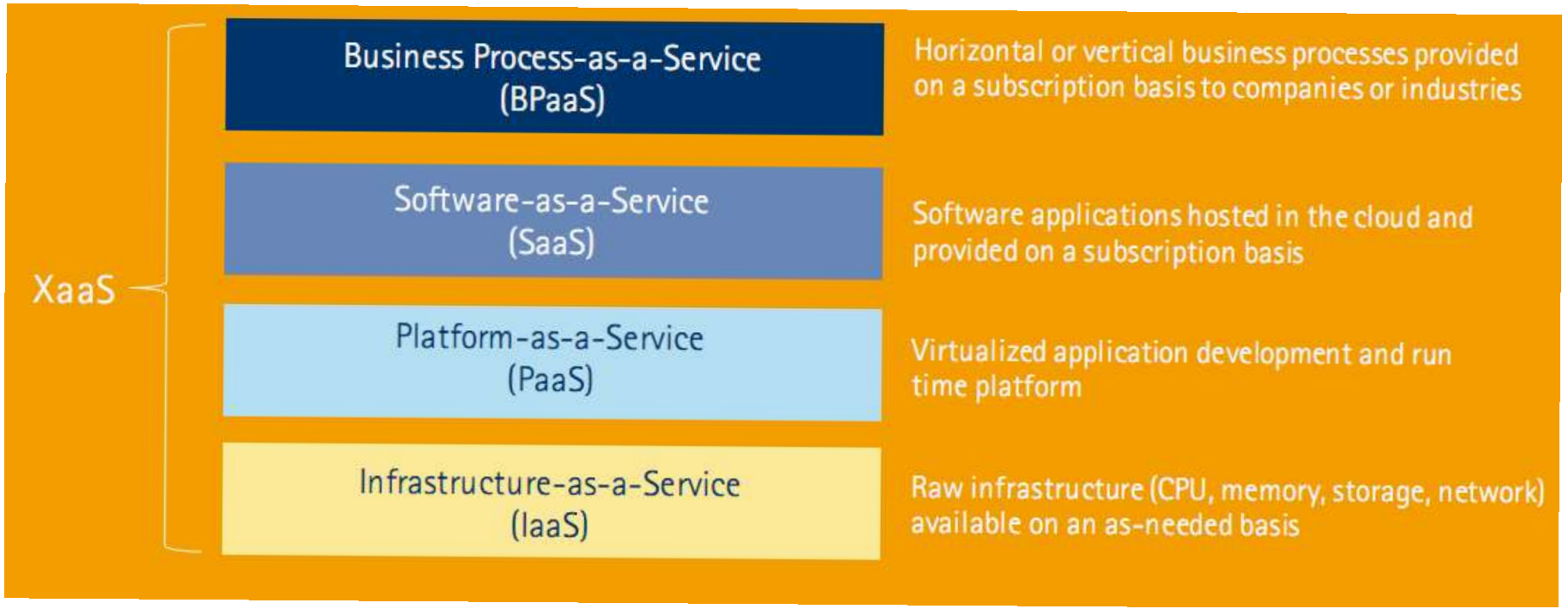
- Adding additional computation units and having them act in concert
- Splitting workload across multiple computation units
- Database partitioning

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

Service Models (XaaS)

- 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.

Service Models (XaaS)



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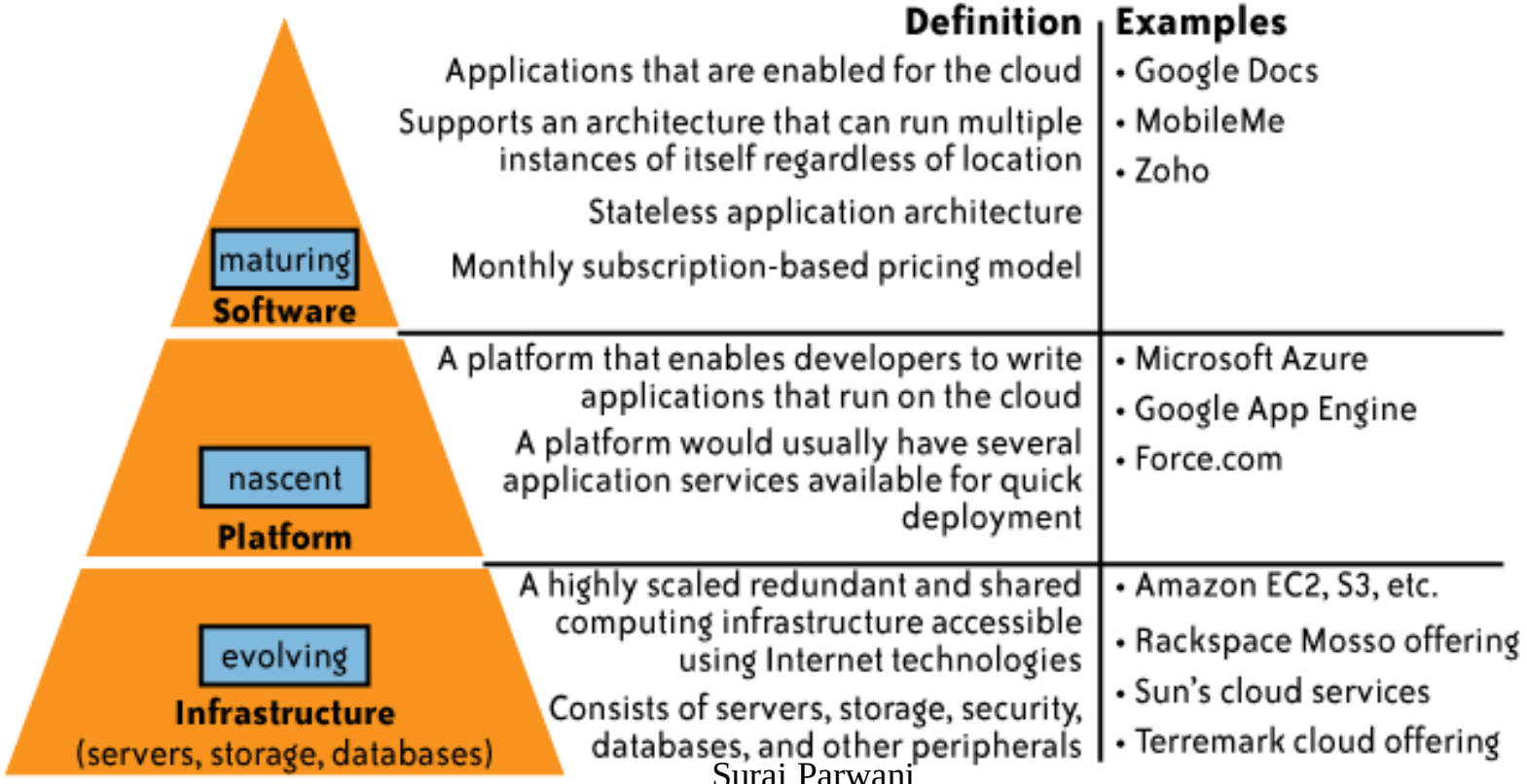
Service Models (XaaS)



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)

Requirements of CSP (Cloud Service Provider)

- Increase productivity
- Increase end user satisfaction
- Increase innovation
- Increase agility

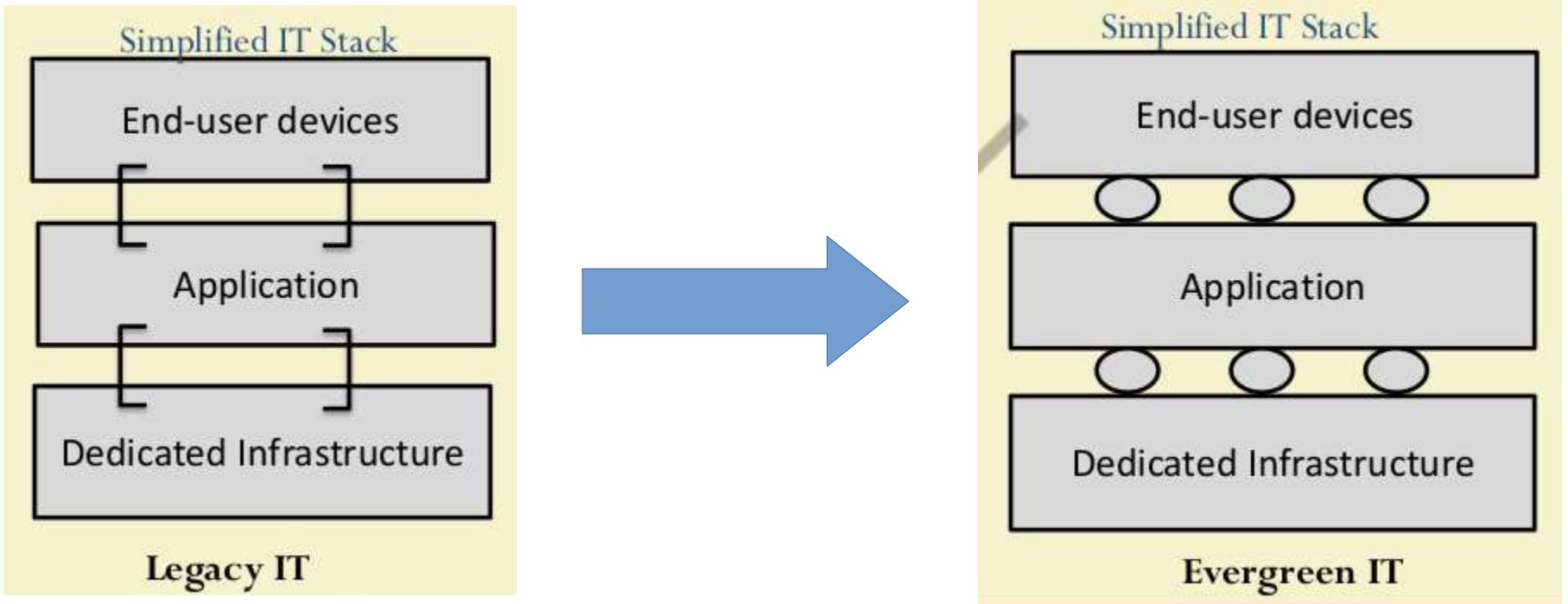
Service Models (XaaS)

- 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

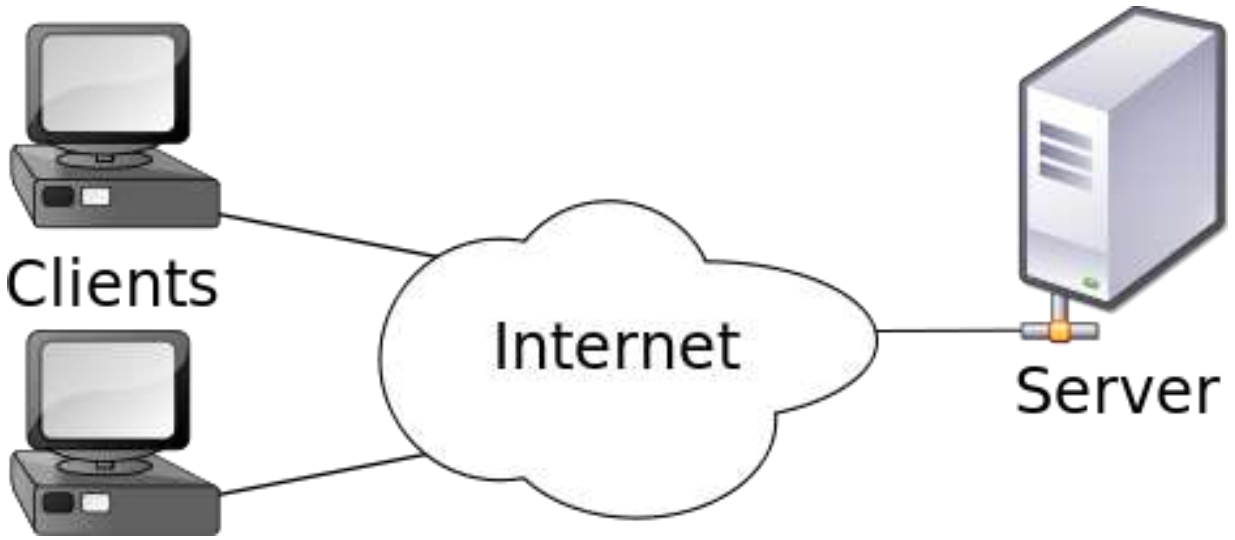
Key impact of cloud computing for IT function: From Legacy IT to Evergreen IT



Classic Model vs. XaaS

		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

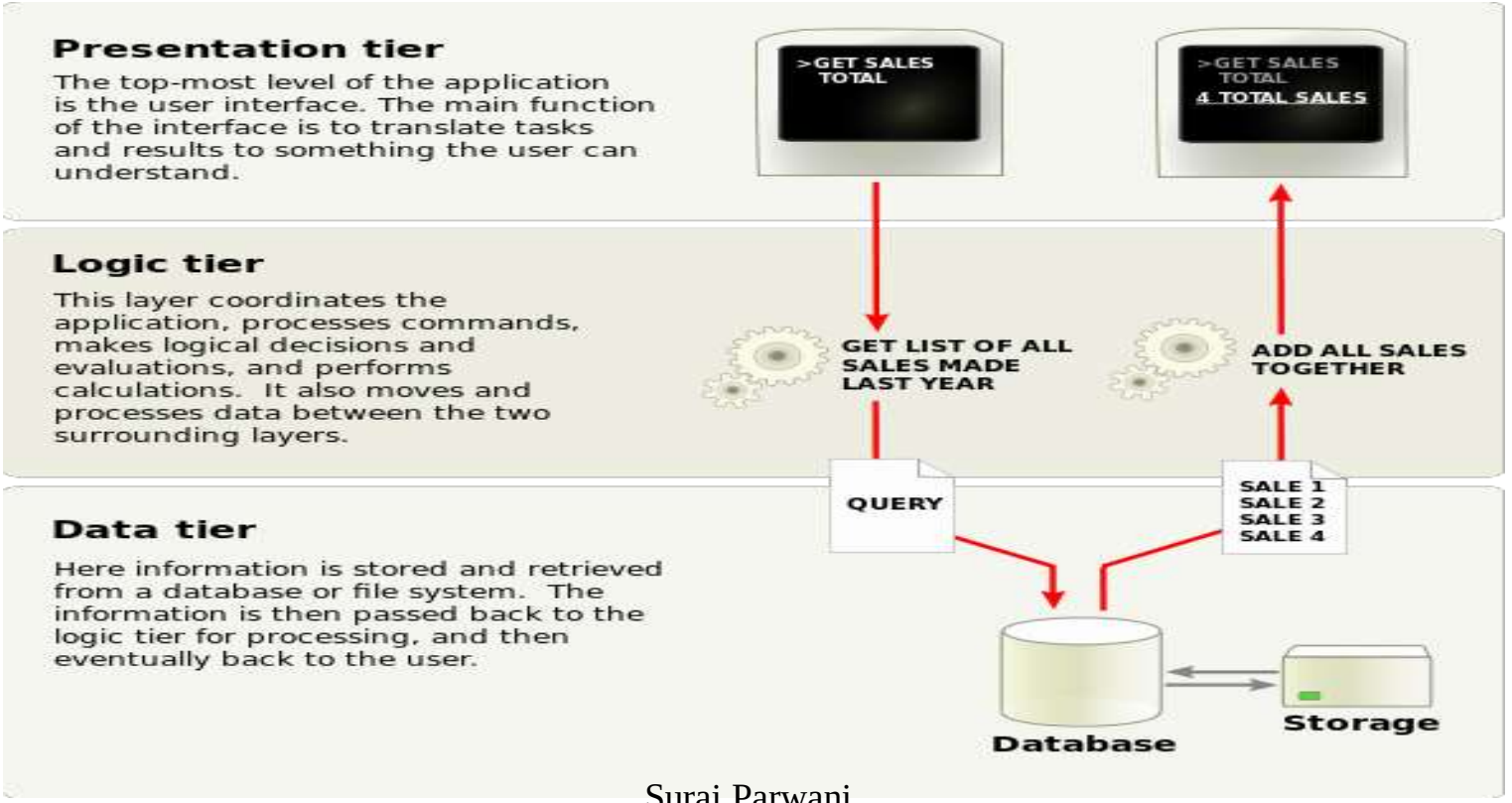
Client Server Architecture



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.

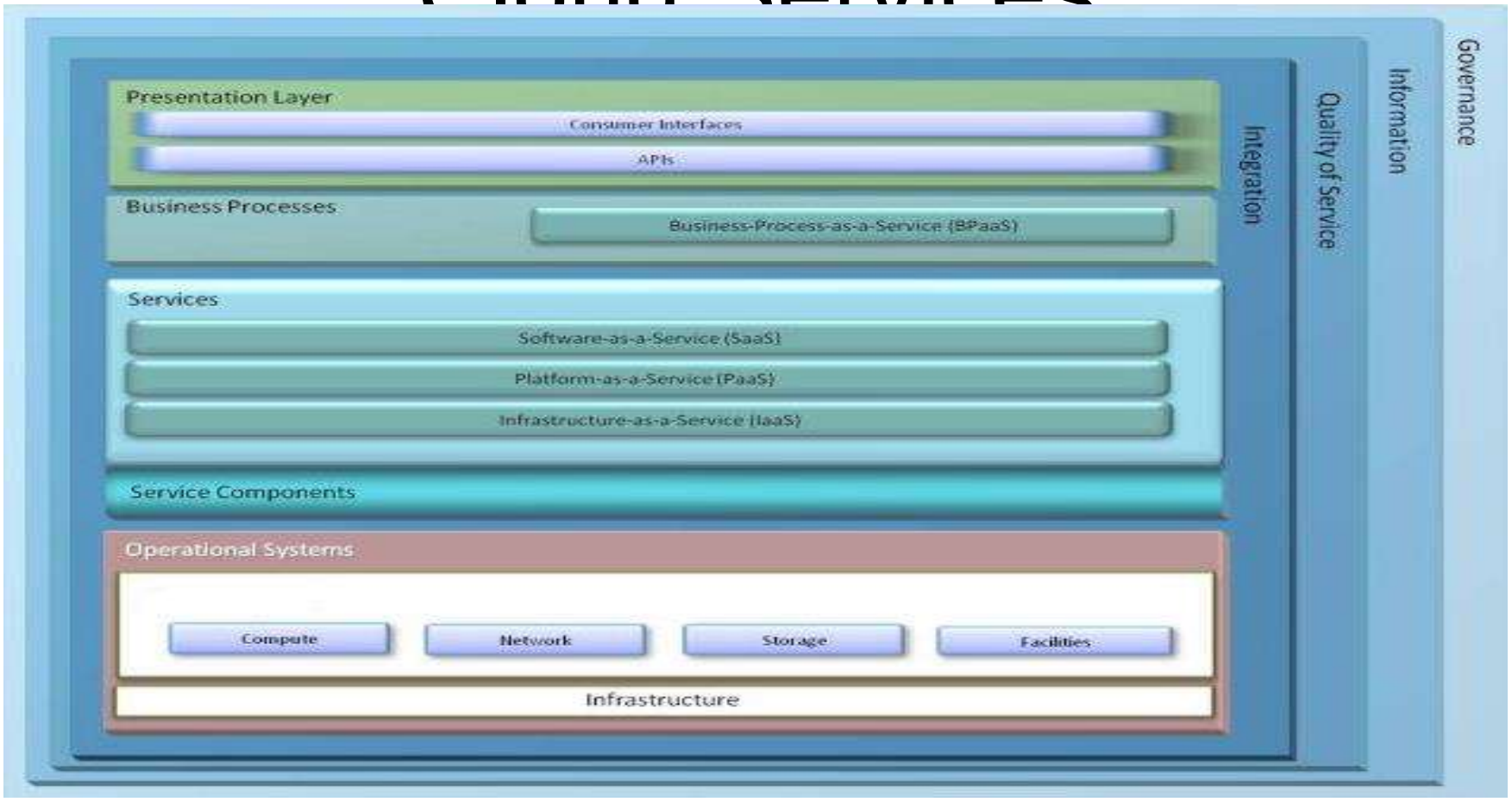
Three Tier Client-Server Architecture



Client Server Model vs. Cloud Model

Client server model	Cloud computing model
Simple service model where server services client requests	Variety of complex service models, such as, IaaS, PaaS, SaaS can be provided
May/may not be load balanced	Load balanced
Scalable to some extent in a cluster environment.	Theoretically infinitely scalable
No concept of virtualization	Virtualization is the core concept

Cloud Services



Simplified description of cloud service models

- **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

Software as a Service

- 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 SaaS is used

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

Applications where SaaS may not be the best option

- 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.

Characteristics of PaaS

- 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

Scenarios where PaaS is used

- 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

- 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

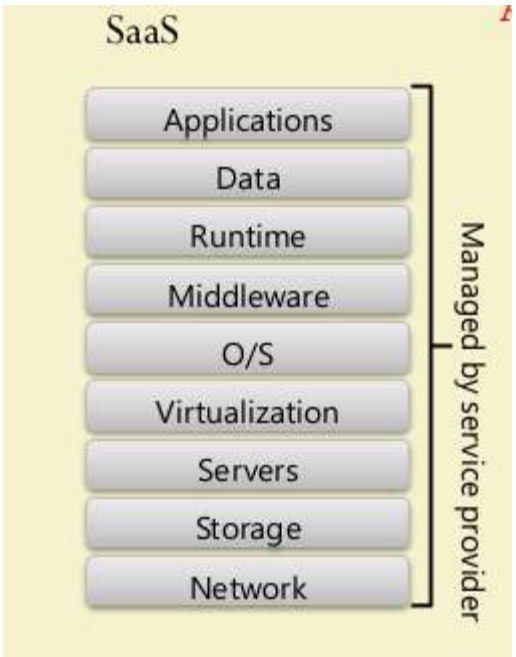
Scenarios where IaaS makes sense

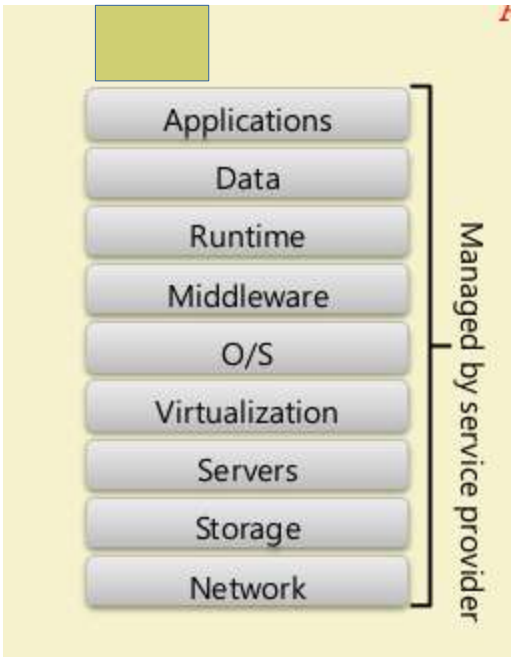
- Where demand is very volatile – any time there are significant spikes and troughs in terms of demand on the infrastructure
- For new organizations without the capital to invest in hardware
- Where the organization is growing rapidly and scaling hardware would be problematic
- Where there is pressure on the organization to limit capital expenditure and to move to operating expenditure
- For specific line of business, trial or temporary infrastructural needs

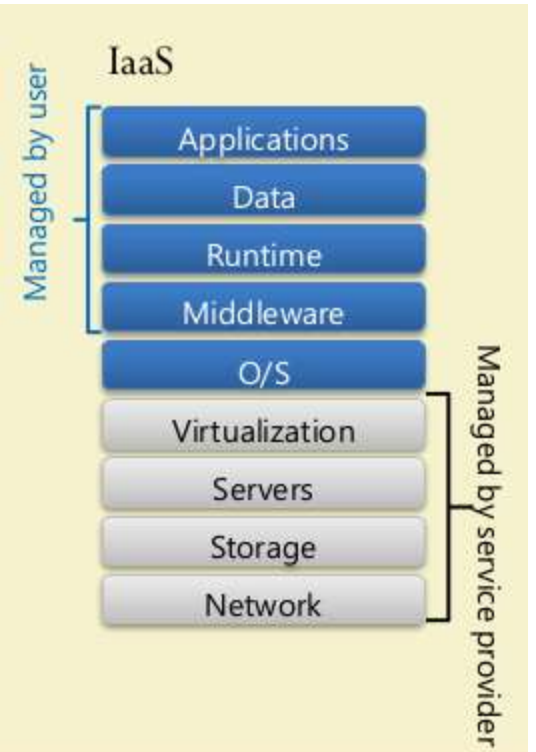
Scenarios where IaaS may not be the best option

- 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

XaaS

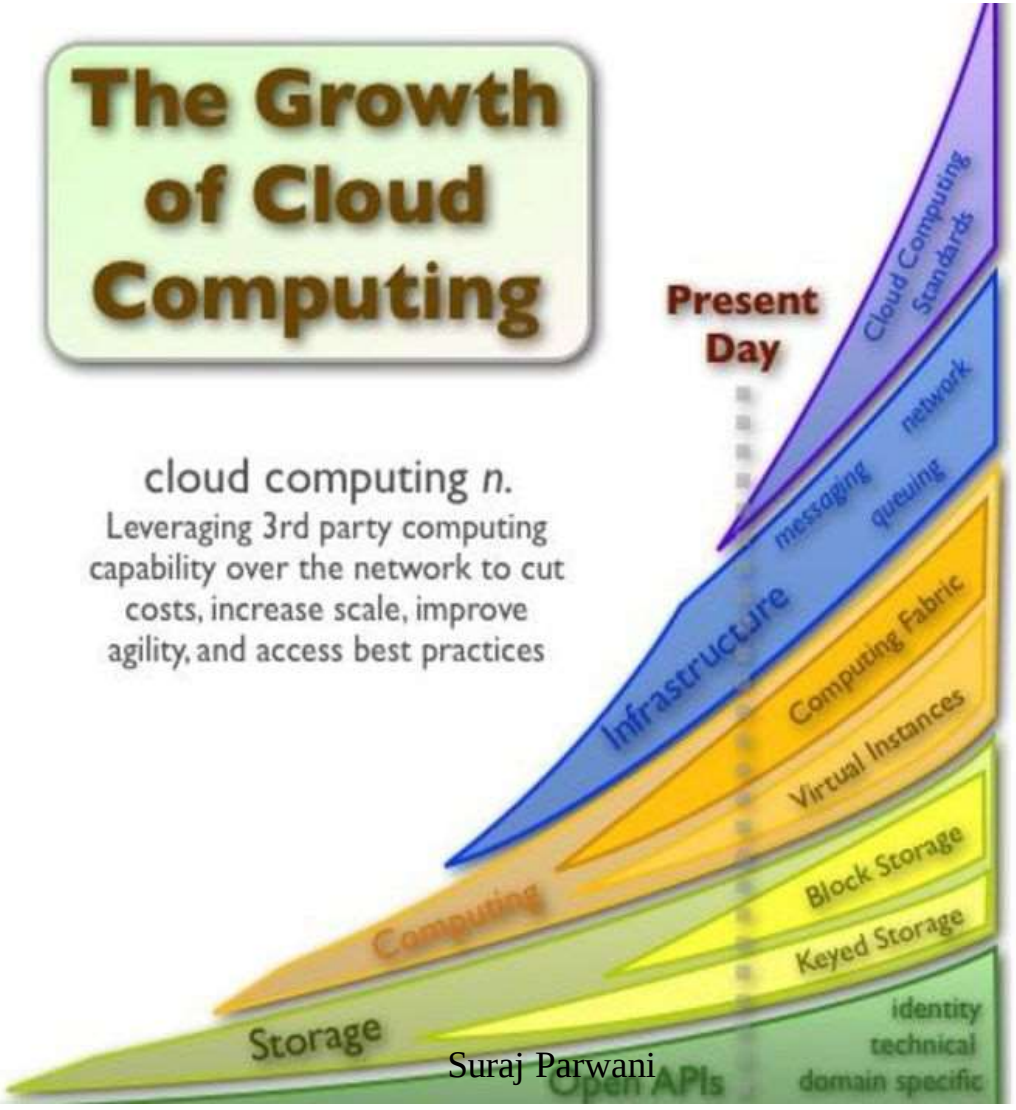

SaaS
Applications
Data
Runtime
Middleware
O/S
Virtualization
Servers
Storage
Network
Managed by service provider


Applications
Data
Runtime
Middleware
O/S
Virtualization
Servers
Storage
Network
Managed by service provider


IaaS
Managed by user
Applications
Data
Runtime
Middleware
O/S
Virtualization
Servers
Storage
Network
Managed by service provider

Cloud vs Grid vs Cluster Computing

Cloud	Grid	Cluster
Consolidation of resources	Segregation of resources	Aggregation of resources
Single system made up of many systems	Collection of systems that act together like a single system	Group of nodes that are connected to each other
Works with different hardware and OS	Works with different hardware and OS	All the connected systems should have same OS and hardware
Follows centralized architecture	Follows distributed architecture	Follows centralized architecture
Suffers from a single point of failure	All the nodes work independently, hence no single point of failure	Suffers from a single point of failure
The owners have less control over the systems on the cloud	The owners have full control and management over the grid's systems	Have no owners, and each node works independently
Job execution is self-managed	Scalability of execution allows for the transfer of a job's execution to an available processor	The scheduling of jobs affects execution. Jobs, therefore, wait until their designated runtime
Used in Dropbox, Gmail	Used in simulations, automations	Used in web servers, search engines


The Growth of Cloud Computing
Present Day
cloud computing *n.*
Leveraging 3rd party computing capability over the network to cut costs, increase scale, improve agility, and access best practices
Cloud Computing Standards
Infrastructure
messaging
network
queuing
Computing Fabric
Virtual Instances
Computing
Block Storage
Keyed Storage
Storage
identity
technical
domain specific
Open APIs

Future Of Cloud Computing

- Cross Platform Integration

  - The industry is moving towards hybrid and multi-cloud environments

- - Cloud efforts increased flexibilty for cross-platform integrations
- - The multi-cloud approach trend opens a new space for start-ups to offer innovative services that create seamless cross-platform collaboration on various cloud platform.

Cloud Computing Through AI

- Cloud Computing has democratized AI capabilities for everyone.
- 5G, self-driving cars,cancer research and crisis response planning are the future of cloud based AI
- AI plays significant role in running and maintaining cloud data centers by optimising hardware networks, cooling systems and power consumption

Cloud Gaming : The Future of Gaming

- Cloud gaming fastest growing industry
- Leading global companies offering dedicated cloud computing capabilities
- Massive game libraries are available to gamers via cloud
- The need to spend massive amounts on dedicated gaming hardware will become obsolete

Adoption of Hybrid & On-prem cloud

- Org. Are becoming increasingly aware of benefits of hybrid cloud enviroments
- Hybrid cloud env. Allow users to select individual elements from the service providers product suite as per their requirements
- The need to move in raw computing and storgae infrastructure increases, enabling businesses to move their existing systems onto the cloud without adapting to pre-installed software.

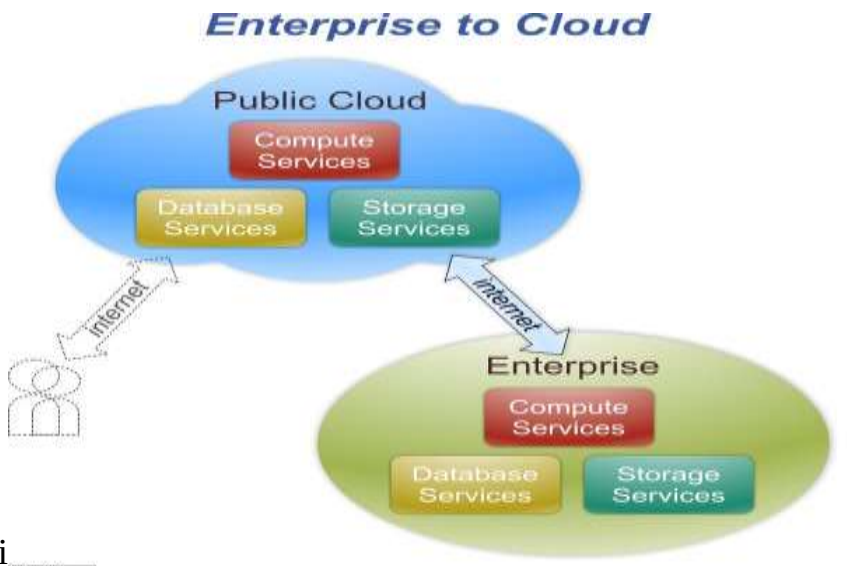
Architecture – Deployment Models

- Public Cloud
- Private Cloud
- Hybrid Cloud
- Community Cloud

Public Cloud

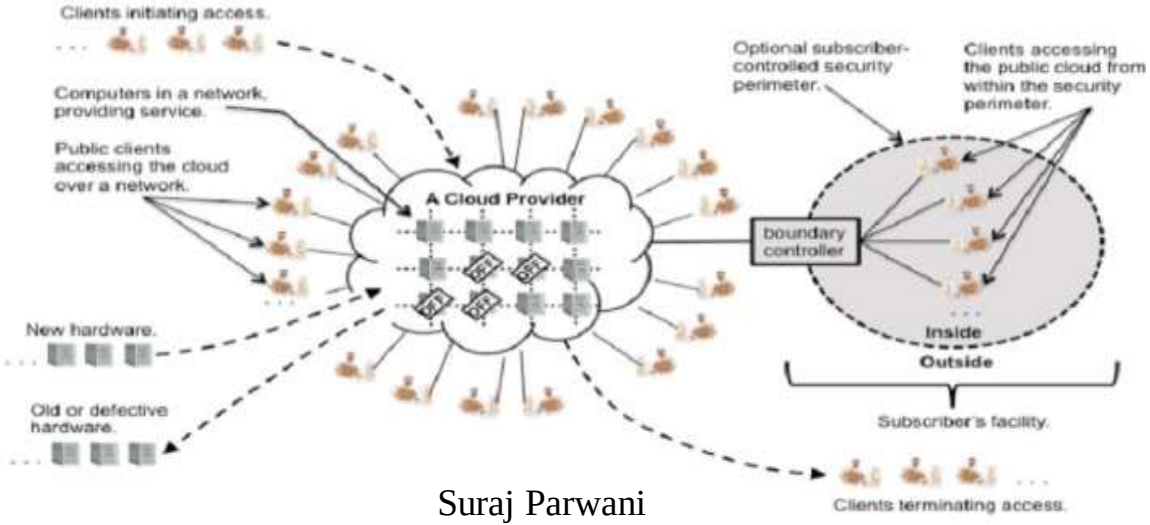
- Cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of them. It exists on the premises of the cloud provider

- Examples of Public Cloud:
- - Google App Engine
- - Microsoft Windows Azure
- - IBM Smart Cloud
- - Amazon EC2



Public Cloud

- In Public setting, the provider's computing and storage resources are potentially large; the communication links can be assumed to be implemented over the public Internet; and the cloud serves a diverse pool of clients (and possibly attackers).



Public Cloud

- Workload locations are hidden from clients (public):
- – In the public scenario, a provider may migrate a subscriber's workload, whether processing or data, at any time.
- – Workload can be transferred to data centres where cost is low
- – Workloads in a public cloud may be relocated anywhere at any time unless the provider has offered (optional) location restriction policies

- Risks from multi-tenancy (public):
- – A single machine may be shared by the workloads of any combination of subscribers (a subscriber's workload may be co-resident with the workloads of competitors or adversaries)
- - Introduces both reliability and security risk

Public Cloud

- Organizations considering the use of an on-site private cloud should consider:
- – Network dependency (public):
- • Subscribers connect to providers via the public Internet.
- • Connection depends on Internet’s Infrastructure like
- – Domain Name System (DNS) servers
- – Router infrastructure,
- – Inter-router links

Public Cloud

- Limited visibility and control over data regarding security (public):
- – The details of provider system operation are usually considered proprietary information and are not divulged to subscribers.
- – In many cases, the software employed by a provider is usually proprietary and not available for examination by subscribers
- – A subscriber cannot verify that data has been completely deleted from a provider's systems.

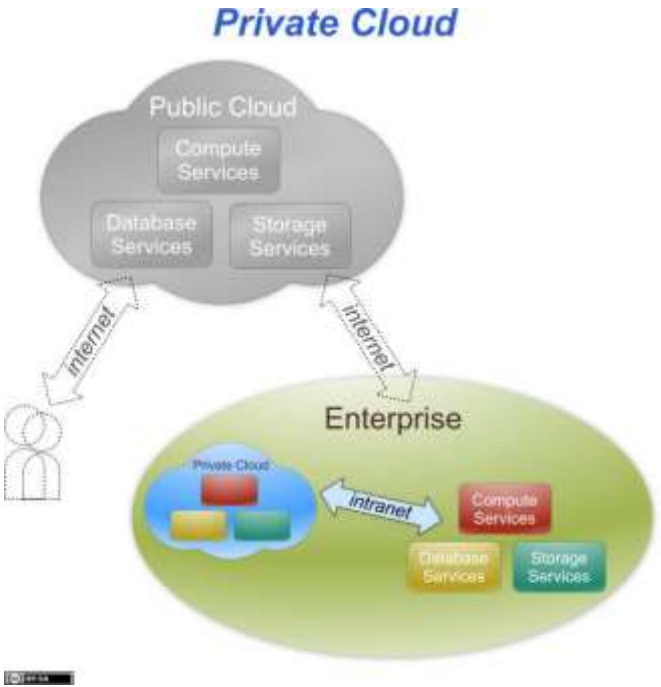
- Elasticity: illusion of unlimited resource availability (public):
- – Public clouds are generally unrestricted in their location or size.
- – Public clouds potentially have high degree of flexibility in the movement of subscriber workloads to correspond with available resources

Public Cloud

- Low up-front costs to migrate into the cloud (public)
- Restrictive default service level agreements (public):
- – The default service level agreements of public clouds specify limited promises that providers make to subscribers

Private Cloud

- The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by the organization, a third party, or some combination of them, and it may exist on or off premises.



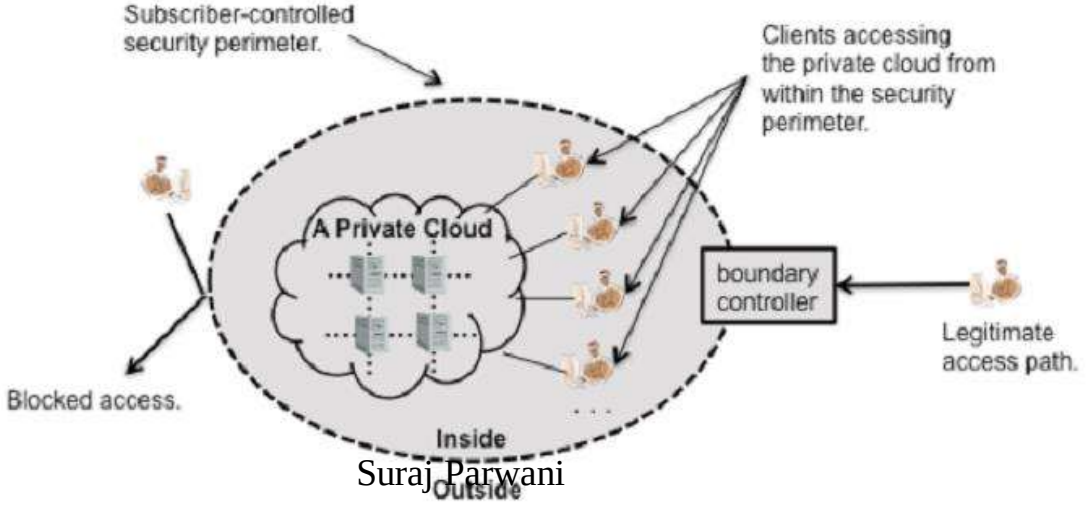
- Examples of Private Cloud:
- – Eucalyptus
- – Ubuntu Enterprise Cloud - UEC
- – Amazon VPC (Virtual Private Cloud)
- – VMware Cloud Infrastructure Suite
- – Microsoft ECI data center.

Private Cloud

- Contrary to popular belief, private cloud may exist off premises and can be managed by a third party. Thus, two private cloud scenarios exist, as follows:
- On-site Private Cloud
- – Applies to private clouds implemented at a customer’s premises.
- Outsourced Private Cloud
- – Applies to private clouds where the server side is outsourced to a hosting company.

On-site Private Cloud

- The security perimeter extends around both the subscriber's on-site resources and the private cloud's resources.
- Security perimeter does not guarantees control over the private cloud's resources but subscriber can exercise control over the resources



On-site Private Cloud

- Organizations considering the use of an on-site private cloud should consider:
- – Network dependency (on-site-private):
- – Subscribers still need IT skills (on-site-private):
- • Subscriber organizations will need the traditional IT skills required to manage user devices that access the private cloud, and will require cloud IT skills as well.
- – Workload locations are hidden from clients (on-site-private):
- • To manage a cloud's hardware resources, a private cloud must be able to migrate workloads between machines without inconveniencing clients. With an on-site private cloud, however, a subscriber organization chooses the physical infrastructure, but individual clients still may not know where their workloads physically exist within the subscriber organization's infrastructure

On-site Private Cloud

- Risks from multi-tenancy (on-site-private):
- – Workloads of different clients may reside concurrently on the same systems and local networks, separated only by access policies implemented by a cloud provider's software. A flaw in the software or the policies could compromise the security of a subscriber organization by xposing client workloads to one another

- Data import/export, and performance limitations (on-site-private):
- – On-demand bulk data import/export is limited by the on-site private cloud's network capacity, and real-time or critical processing may be problematic because of networking limitations.

On-site Private Cloud

- Potentially strong security from external threats (on-site-private):
- – In an on-site private cloud, a subscriber has the option of implementing an appropriately strong security perimeter to protect private cloud resources against external threats to the same level of security as can be achieved for non-cloud resources.

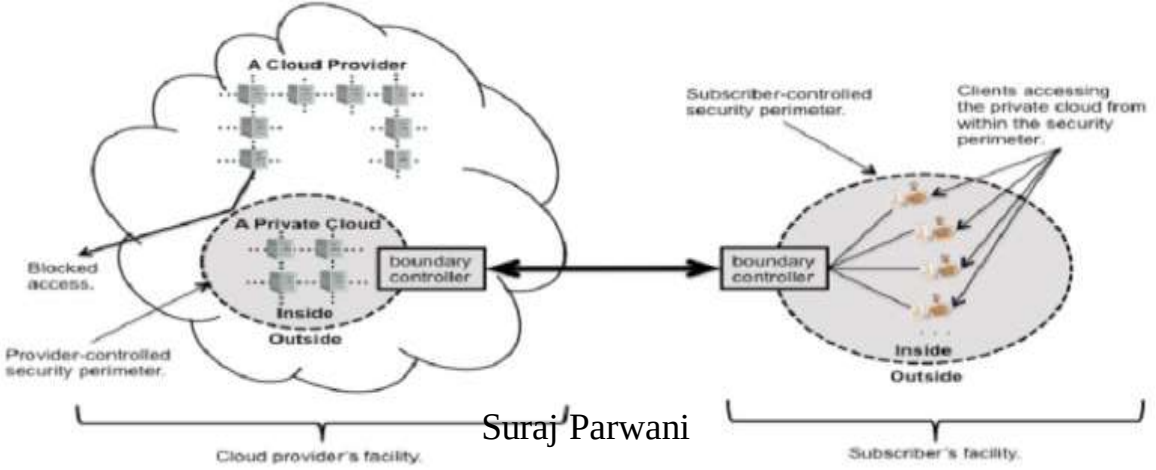
- Significant-to-high up-front costs to migrate into the cloud (on-site-private):
- – An on-site private cloud requires that cloud management software be installed on computer systems within a subscriber organization. If the cloud is intended to support process-intensive or data-intensive workloads, the software will need to be installed on numerous commodity systems or on a more limited number of high-performance systems. Installing cloud software and managing the installations will incur significant up-front costs, even if the cloud software itself is free, and even if much of the hardware already exists within a subscriber organization.

On-site Private Cloud

- Limited resources (on-site-private):
- – An on-site private cloud, at any specific time, has a fixed computing and storage capacity that has been sized to correspond to anticipated workloads and cost restrictions

Outsourced Private Cloud

- Outsourced private cloud has two security perimeters, one implemented by a cloud subscriber (on the right) and one implemented by a provider.
- Two security perimeters are joined by a protected communications link.
- The security of data and processing conducted in the outsourced private cloud depends on the strength and availability of both security perimeters and of the protected communication link



Outsourced Private Cloud

- Organizations considering the use of an outsourced private cloud should consider:
- – Network Dependency (outsourced-private):
- • In the outsourced private scenario, subscribers may have an option to provision unique protected and reliable communication links with the provider.
- – Workload locations are hidden from clients (outsourced-private):
- – Risks from multi-tenancy (outsourced-private):
- • The implications are the same as those for an on-site private cloud

Outsourced Private Cloud

- Data import/export, and performance limitations (outsourced-private):
- – On-demand bulk data import/export is limited by the network capacity between a provider and subscriber, and real-time or critical processing may be problematic because of networking limitations. In the outsourced private cloud scenario, however, these limits may be adjusted, although not eliminated, by provisioning high-performance and/or high-reliability networking between the provider and subscriber.

- Potentially strong security from external threats (outsourced-private):
- – As with the on-site private cloud scenario, a variety of techniques exist to harden a security perimeter. The main difference with the outsourced private cloud is that the techniques need to be applied both to a subscriber's perimeter and provider's perimeter, and that the communications link needs to be protected.

Outsourced Private Cloud

- Modest-to-significant up-front costs to migrate into the cloud (outsourced-private):
- – In the outsourced private cloud scenario, the resources are provisioned by the provider
- – Main start-up costs for the subscriber relate to:
- • Negotiating the terms of the service level agreement (SLA)
- • Possibly upgrading the subscriber's network to connect to the outsourced private cloud
- • Switching from traditional applications to cloud-hosted applications,
  • Porting existing non-cloud operations to the cloud
  • Training

Outsourced Private Cloud

- Extensive resources available (outsourced-private):
- – In the case of the outsourced private cloud, a subscriber can rent resources in any quantity offered by the provider. Provisioning and operating computing equipment at scale is a core competency of providers.

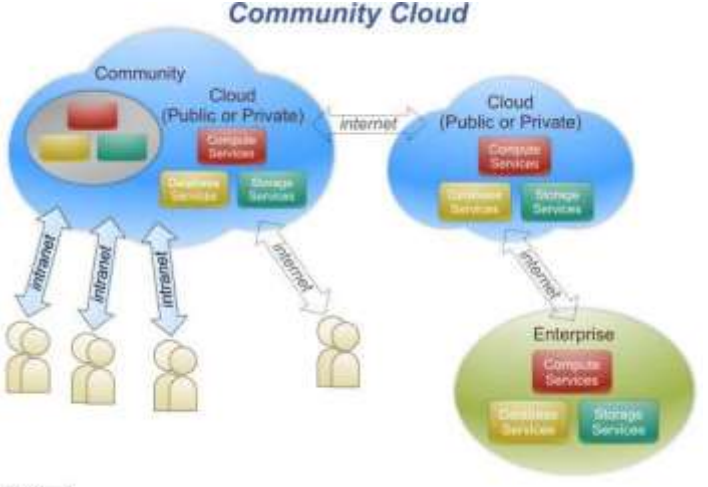
Community Cloud

- Cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises.

- Examples of Community Cloud:

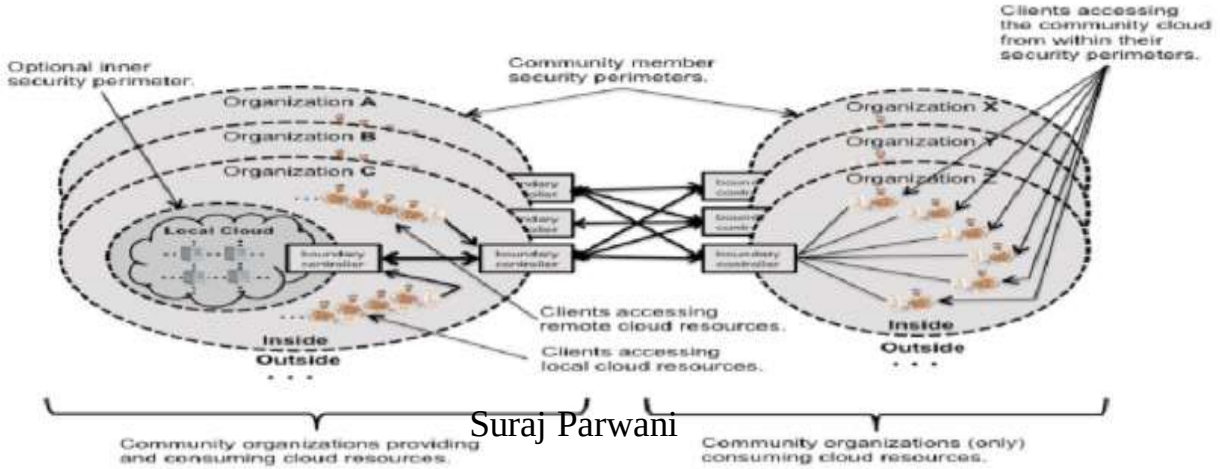
  --- Google Apps for Government

  --- Microsoft Government Community Cloud



On-site Community Cloud

- Community cloud is made up of a set of participant organizations. Each participant organization may provide cloud services, consume cloud services, or both
- At least one organization must provide cloud services
- Each organization implements a security perimeter



On-site Community Cloud

- The participant organizations are connected via links between the boundary controllers that allow access through their security perimeters

- Access policy of a community cloud may be complex
- – Ex. :if there are N community members, a decision must be made, either implicitly or explicitly, on how to share a member's local cloud resources with each of the other members
- – Policy specification techniques like role-based access control (RBAC),attribute-based access control can be used to express sharing policies.

On-site Community Cloud

- Organizations considering the use of an on-site community cloud should consider:
- – Network Dependency (on-site community):
- • The subscribers in an on-site community cloud need to either provision controlled inter-site communication links or use cryptography over a less controlled communications media (such as the public Internet).
- • The reliability and security of the community cloud depends on the reliability and security of the communication links

On-site Community Cloud

- Subscribers still need IT skills (on-site-community).
- – Organizations in the community that provides cloud resources, requires IT skills similar to those required for the on-site private cloud scenario except that the overall cloud configuration may be more complex and hence require a higher skill level.
- – Identity and access control configurations among the participant organizations may be complex

- Workload locations are hidden from clients (on-site-community):
- – Participant Organizations providing cloud services to the community cloud may wish to employ an outsourced private cloud as a part of its implementation strategy

On-site Community Cloud

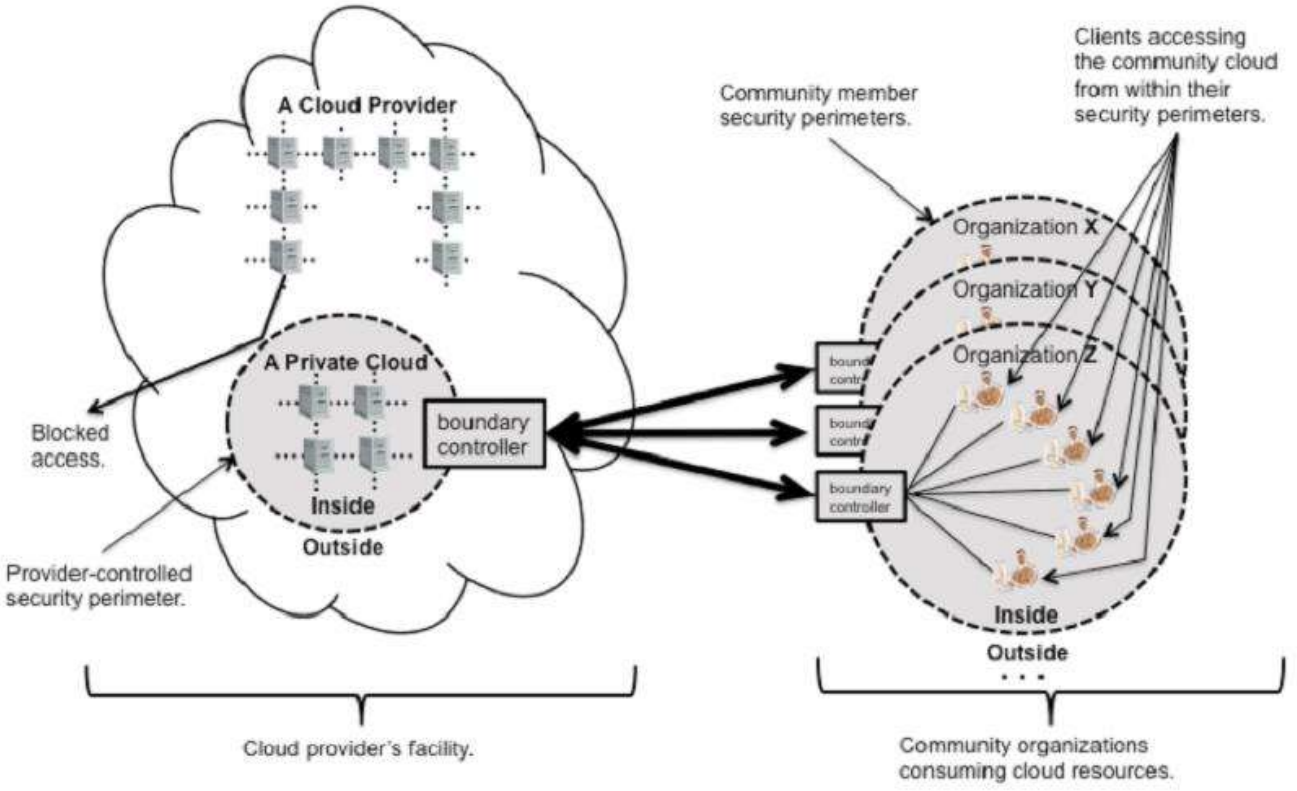
- Data import/export, and performance limitations (on-site-community):
- – The communication links between the various participant organizations in a community cloud can be provisioned to various levels of performance, security and reliability, based on the needs of the participant organizations. The network-based limitations are thus similar to those of the outsourced-private cloud scenario.

- Potentially strong security from external threats (on-site-community):
- – The security of a community cloud from external threats depends on the security of all the security perimeters of the participant organizations and the strength of the communications links. These dependencies are essentially similar to those of the outsourced private cloud scenario, but with possibly more links and security perimeters.

On-site Community Cloud

- Highly variable up-front costs to migrate into the cloud (on-site-community):
- – The up-front costs of an on-site community cloud for a participant organization depend greatly on whether the organization plans to consume cloud services only or also to provide cloud services. For a participant organization that intends to provide cloud services within the community cloud, the costs appear to be similar to those for the on-site private cloud scenario (i.e., significant-to-high).

Outsourced Community Cloud



Outsourced Community Cloud

- Organizations considering the use of an on-site community cloud should consider:

- Network dependency (outsourced-community):
- – The network dependency of the outsourced community cloud is similar to that of the outsourced private cloud. The primary difference is that multiple protected communications links are likely from the community members to the provider's facility.

- Workload locations are hidden from clients (outsourced- community).
- – Same as the outsourced private cloud

Outsourced Community Cloud

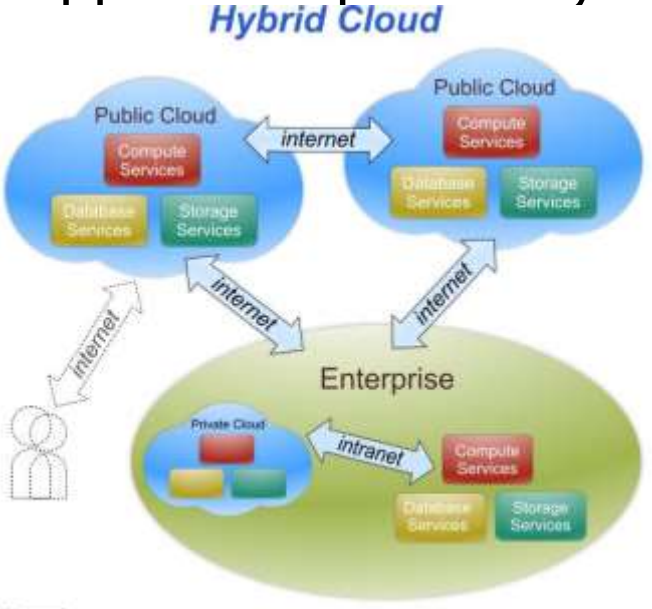
- Risks from multi-tenancy (outsourced-community):
- – Same as the on-site community cloud
- Data import/export, and performance limitations (outsourced- community):
- – Same as outsourced private cloud
- Potentially strong security from external threats (outsourced- community):
- – Same as the on-site community cloud
- Modest-to-significant up-front costs to migrate into the cloud (outsourced-community):
- -- Same as outsourced private cloud
- Extensive resources available (outsourced-community).

- – Same as outsourced private cloud

Hybrid Cloud

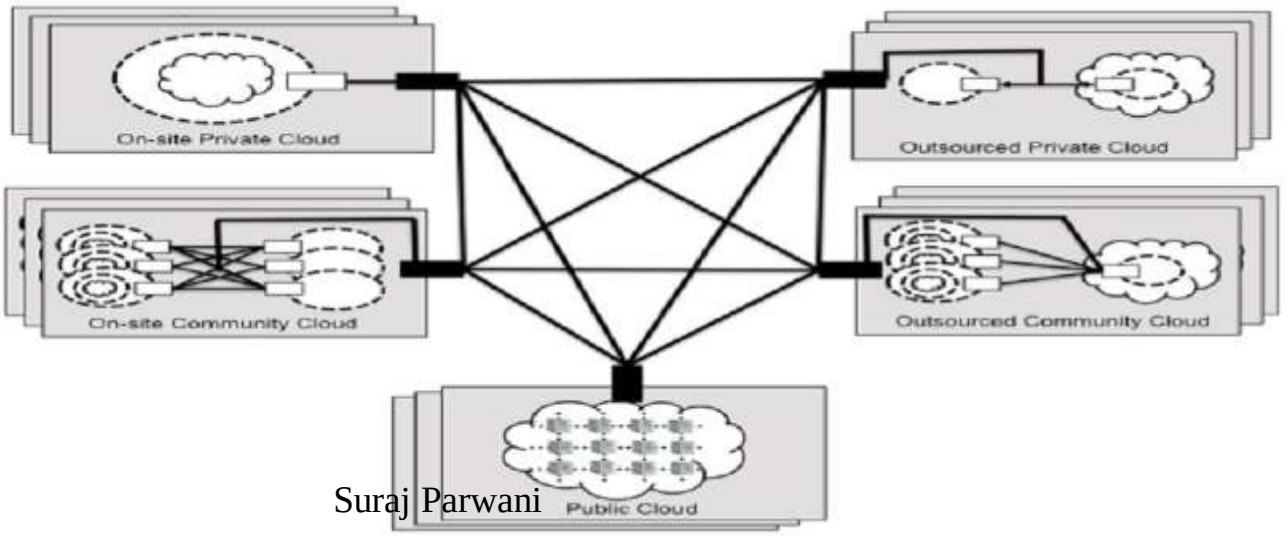
- The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability

- Examples of Hybrid Cloud:
- – Windows Azure (capable of Hybrid Cloud)
- – VMware vCloud (Hybrid Cloud Services)



Hybrid Cloud

- A hybrid cloud is composed of two or more private, community, or public clouds.
- They have significant variations in performance, reliability, and security properties depending upon the type of cloud chosen to build hybrid cloud



Hybrid Cloud

- A hybrid cloud can be extremely complex
- A hybrid cloud may change over time with constituent clouds joining and leaving