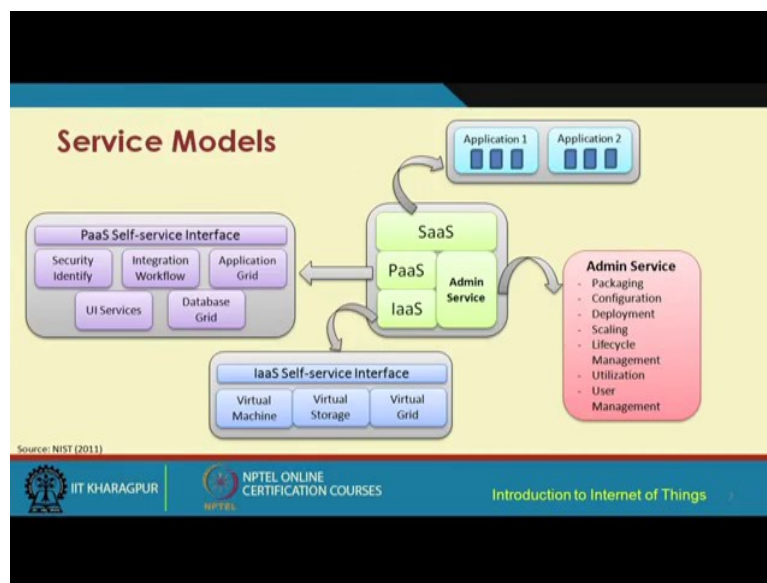


**Introduction to Internet of Things**  
**Prof. Sudip Misra**  
**Department of Computer Science and Engineering**  
**Indian Institute of Technology, Kharagpur**

**Lecture – 38**  
**Cloud Computing - Service Models**

So, the next lecture on the series on cloud computing for internet of things is on the service models. So, we briefly in the previous lecture have gone through the different types of service models we have seen that there are 3 core service models that have been popular since the inception of cloud computing. The first one is software as a service, the second one is platform as a service and the third one is infrastructure as a service. So, let us try to go through the details further of each of these clouds cloud models.

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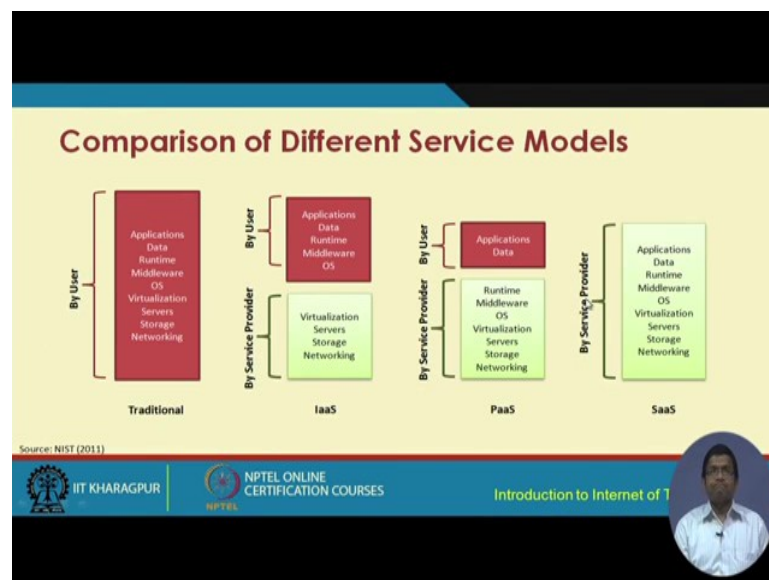
So, as we can see over here we have these different applications which have to be served and for service serving these applications we need to take help of the software resources the platform and the infrastructure.

So, what we have we have software as a service, we have platform as a service and we have the infrastructure as a service. So, infrastructure is surface on top of virtual machines virtual storage and virtual grid. So, we have this infrastructure as a surface made available and then we have the platform as a service which includes security identification integration workflow application grid user interface services database grid and so, on and then we have this

software as a service which we serving different applications as well. In fact, all these service models are serving different applications are serving different customers and so on and then we have these administrative services which are in addition.

So, these administrative services include things like packaging configuration deployments scaling lifecycle management utilization user management and so on.

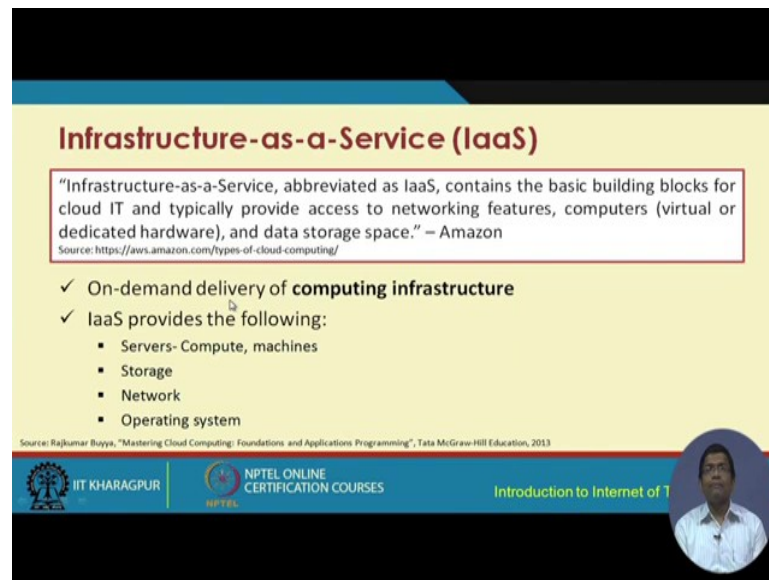
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So, when we compare that the these 3 service models the serve the software as a service the platform as a service and the infrastructure as a service with respect to the traditional computing computing paradigm then we see we observe a few things. So, whereas, traditionally starting from applications data runtime middleware operating system virtualization service offerings storage networking all these things would have to be done by the user himself, in the case of infrastructure as a service concerns about or issues of applications data runtime middleware and operating system are done at the user end whereas, virtualization server storage Networking are taken care of by the service provider.

So, as you can see over here in this model the operating system is at the user end. In the platform as a service as we can see compared to infrastructure as a service where the OS was as part of the user here only 2 things applications and data are taken care of by the user the rest of the other things are taken care of by the service provider end and in software as a service everything is taken care of by the service provider.

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**Infrastructure-as-a-Service (IaaS)**

"Infrastructure-as-a-Service, abbreviated as IaaS, contains the basic building blocks for cloud IT and typically provide access to networking features, computers (virtual or dedicated hardware), and data storage space." – Amazon  
Source: <https://aws.amazon.com/types-of-cloud-computing/>

- ✓ On-demand delivery of **computing infrastructure**
- ✓ IaaS provides the following:
  - Servers- Compute, machines
  - Storage
  - Network
  - Operating system

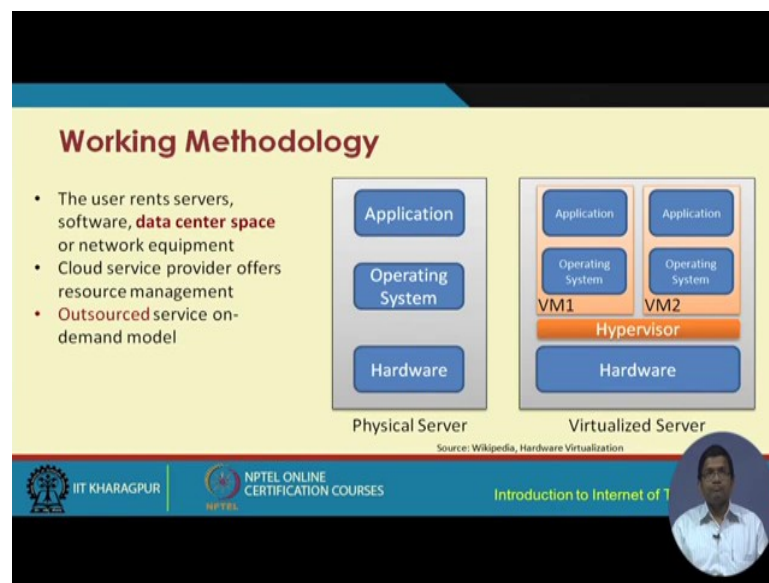
Source: Rajkumar Buyya, "Mastering Cloud Computing: Foundations and Applications Programming", Tata McGraw-Hill Education, 2013

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So, this is a side by side comparison between infrastructure as a service platform as a service software as a service and the traditional computing methodology. So, we start with each of these service models and try to understand what is inside. So, as per the definition of Amazon, infrastructure as a service which is appreciated as IaaS contains the basic building blocks for cloud it and typical typically provide access to Networking features computers which are virtual or dedicated hardware and data storage space. So, we have this computing infrastructure which has to be made available on demand to the different users through some kind of virtualization mechanism. So, infrastructure as a service provides the following features it has servers for computation and the different machines are also made available like different workstations etcetera. So, so servers and machines then we have the storage we have Network we have the operating system.

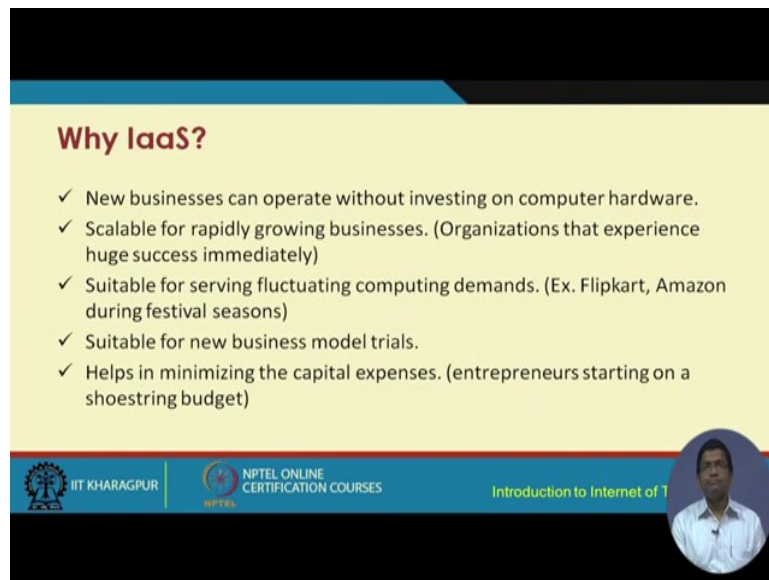
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The working methodology is like this we have a physical server and then we have this virtualized server the users rent the servers the software and the data center space or Network equipment the cloud service provider offers the resource management and the outsourced service on demand is made available for use. So, this is the physical server here we have the hardware on top of that on top of hardware we have the OS and the apps and in comparison in the virtualized server we have hardware as before then we have some virtual machines. So, these virtual machines VM 1 and VM 2 would include the operating system and the application layers.

So, we have on top of the hardware multiple virtual machines executing and there is the concept of hypervisor which basically manages this show by sitting between the hardware layer and the VM layer. So, the VM layer basically contains the VMs the hardware layer the actual physical hardware and the hypervisor is sort of playing some kind of a managerial role in between these 2.


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**Why IaaS?**

- ✓ New businesses can operate without investing on computer hardware.
- ✓ Scalable for rapidly growing businesses. (Organizations that experience huge success immediately)
- ✓ Suitable for serving fluctuating computing demands. (Ex. Flipkart, Amazon during festival seasons)
- ✓ Suitable for new business model trials.
- ✓ Helps in minimizing the capital expenses. (entrepreneurs starting on a shoestring budget)

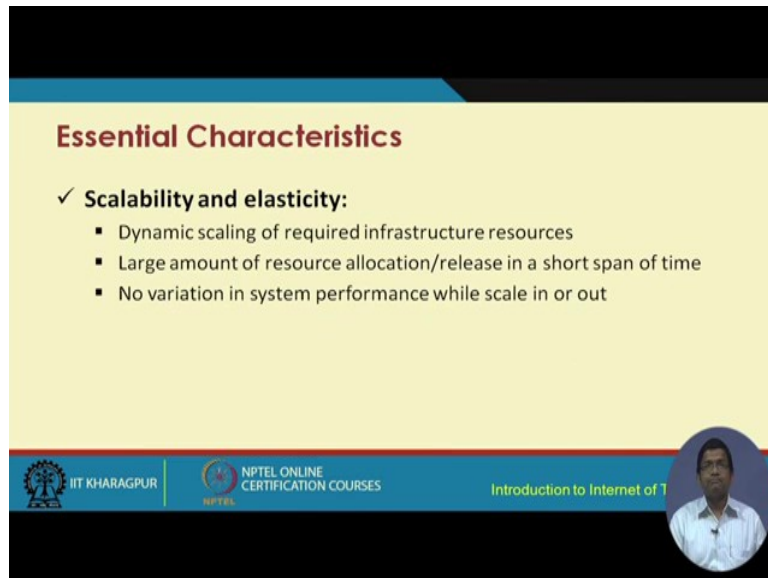
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So, why do we need infrastructure as a service? So, basically new businesses can kick start without basically having to invest on vine computing hardware and this is a scalable model by which rapidly whenever the businesses need some resources they can subscribe pay for and start using the resources and whenever they do not required they will not waste the resources and will stop utilizing them.

So, it is suitable for serving fluctuating computing demands example Flipkart, Amazon, etcetera during festive seasons you know they need more infrastructure during festive seasons because of the obvious you know obviousness due to the up search in the business. So, you know, but at the other times of the year they do not need this.


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**Essential Characteristics**

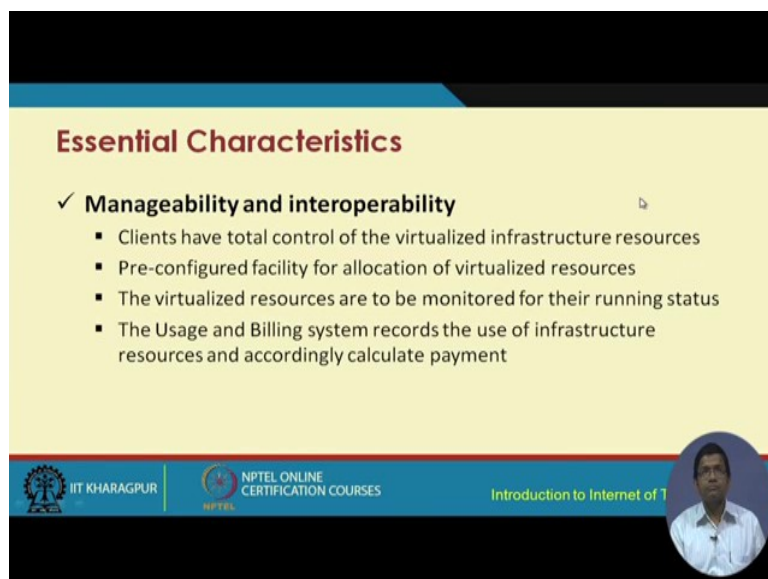
- ✓ **Scalability and elasticity:**
  - Dynamic scaling of required infrastructure resources
  - Large amount of resource allocation/release in a short span of time
  - No variation in system performance while scale in or out

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So, as you can see that there is fluctuating computing demand and whenever required you use those resources whenever not required you release the resources and so on. So, it is suitable for new business model trials it helps in minimizing the capital expenses. Scalability issue and elasticity dynamic scaling of required infrastructure resources is made possible through infrastructure service having large amount of resource allocation or release in a short span of time is possible in the infrastructure as a service model and there is no variation in system performance while scaling up or down.


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**Essential Characteristics**

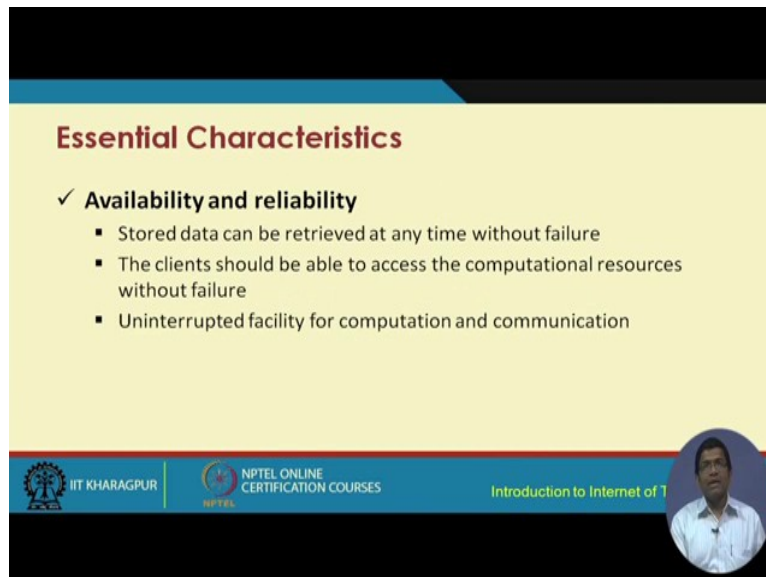
- ✓ **Manageability and interoperability**
  - Clients have total control of the virtualized infrastructure resources
  - Pre-configured facility for allocation of virtualized resources
  - The virtualized resources are to be monitored for their running status
  - The Usage and Billing system records the use of infrastructure resources and accordingly calculate payment

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Manageability and inter probability clients in this particular model have total control of the virtualized infrastructure resources they can do whatever they want with the resources that are offered to them.

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The slide is titled "Essential Characteristics" in a bold, dark red font. Below the title, there is a section header "✓ Availability and reliability" in bold black font. Under this header, there are three bullet points, each preceded by a small square icon. The first bullet point states "Stored data can be retrieved at any time without failure". The second bullet point states "The clients should be able to access the computational resources without failure". The third bullet point states "Uninterrupted facility for computation and communication". At the bottom of the slide, there is a blue horizontal bar containing logos for IIT KHARAGPUR and NPTEL ONLINE CERTIFICATION COURSES, along with the text "Introduction to Internet of T". A small circular inset image of a man in a white shirt is visible in the bottom right corner of the slide.

**Essential Characteristics**

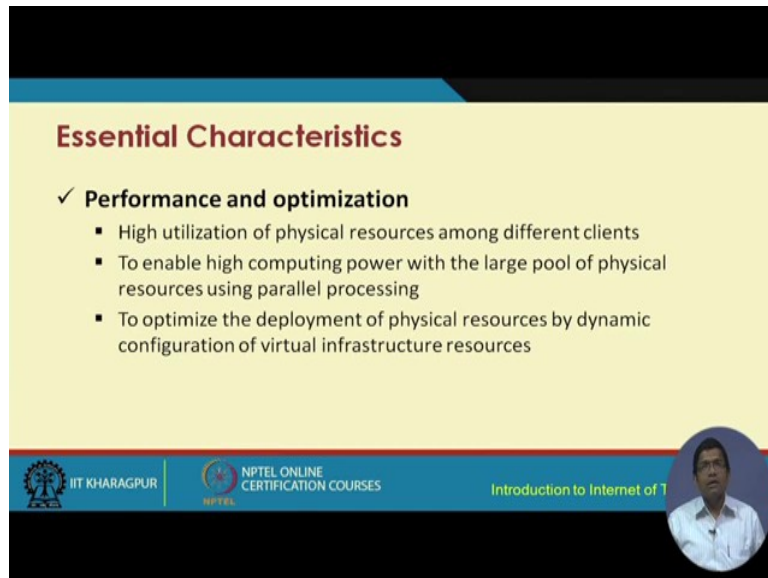
- ✓ **Availability and reliability**
  - Stored data can be retrieved at any time without failure
  - The clients should be able to access the computational resources without failure
  - Uninterrupted facility for computation and communication

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So, they can preconfigured they can preconfigured the facility for the allocation or can virtualize the resources and these virtualized resources are to be monitored for their running status the overall health and so on and the usage and the billing system records the use of the infrastructure resources and accordingly calculates the payment availability and reliability. So, storing of the data and the retrieval of the stored data can be made possible at any time without any failure of any any kind whatsoever; whatsoever be the failure. So, it is not possible you know the resources can be made available reliably and be made available at anytime anywhere the clients should be able to access the computational resources without failure and there should be uninterrupted facility for computation and communication in terms of performance.




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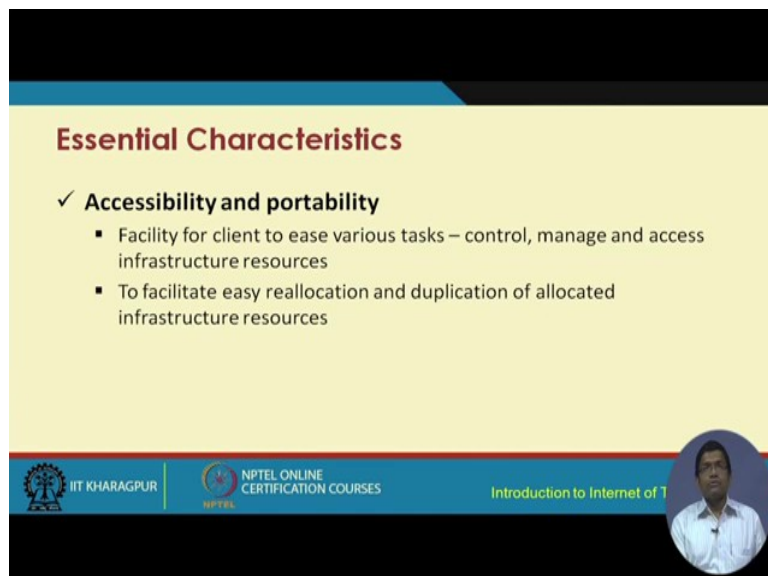
**Essential Characteristics**

- ✓ **Performance and optimization**
  - High utilization of physical resources among different clients
  - To enable high computing power with the large pool of physical resources using parallel processing
  - To optimize the deployment of physical resources by dynamic configuration of virtual infrastructure resources

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**Essential Characteristics**

- ✓ **Accessibility and portability**
  - Facility for client to ease various tasks – control, manage and access infrastructure resources
  - To facilitate easy reallocation and duplication of allocated infrastructure resources

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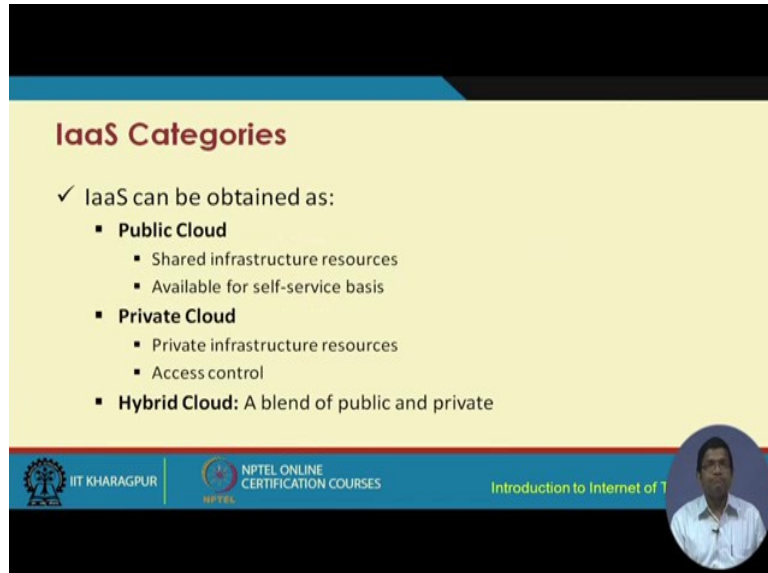


And optimization high utilization of physical resources among the different clients is possible through the use of the infrastructure as a service model; it is also possible to enable high computing power with the large pool of physical resources using parallel processing. And it is also possible to optimize the deployment of physical resources by dynamically configuring the virtual infrastructure resources in terms of accessibility and portability this basically provides the facility for client to ease out various tasks with respect to control management access infrastructure access and so on and to facilitate the easy reallocation and duplication of



the allocated infrastructure resources. IaaS can be obtained as a public cloud a private cloud.

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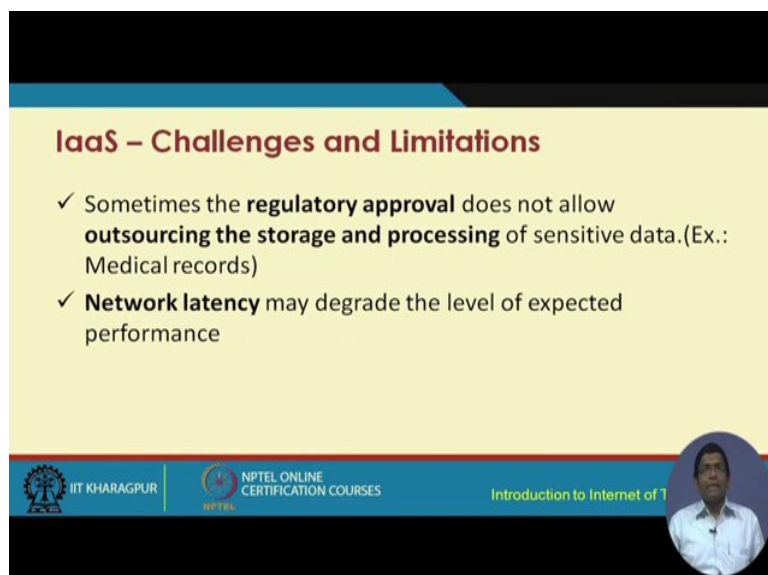
**IaaS Categories**

- ✓ IaaS can be obtained as:
  - **Public Cloud**
    - Shared infrastructure resources
    - Available for self-service basis
  - **Private Cloud**
    - Private infrastructure resources
    - Access control
  - **Hybrid Cloud:** A blend of public and private

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And the hybrid cloud and each of these we have already discussed in the fundamentals lecture on cloud computing for IoT.

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**IaaS – Challenges and Limitations**

- ✓ Sometimes the **regulatory approval** does not allow **outsourcing the storage and processing** of sensitive data.(Ex.: Medical records)
- ✓ **Network latency** may degrade the level of expected performance

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So, the challenges and limitations of infrastructure as a service includes that there is sometimes in certain places regulatory approval that is required for the use of outsourcing outsourced storage.

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### IaaS – Challenges and Limitations (contd.)

- ✓ Users may require **automated decision making** of job scheduling to available resources
- ✓ **Seamless scaling** of services independent of traffic variation
- ✓ Developers have to focus on **low level system details**

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And outsourced processing through the cloud model and Network latency may degrade the level of expected performance as well users may require automated decision making of job scheduling to available resources and seamless scaling of service services independent of traffic variation and developers have to focus on low level system details these are some of these limitations of infrastructure as a service.

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### Platform-as-a-Service (PaaS)

"Platform-as-a-service remove the need for organizations to manage the underlying infrastructure (usually hardware and operating systems) and allow you to focus on the deployment and management of your applications." – Amazon  
Source: <https://aws.amazon.com/types-of-cloud-computing/>

- ✓ PaaS provides the **platform** which allows developers to create applications which can be offered as services via Internet
- ✓ Simplifies the application development and deploy providing the **cloud-aware** feature
- ✓ PaaS is an **application middleware** offered as a service to developers
- ✓ Provides **abstraction and security** for deployed applications.

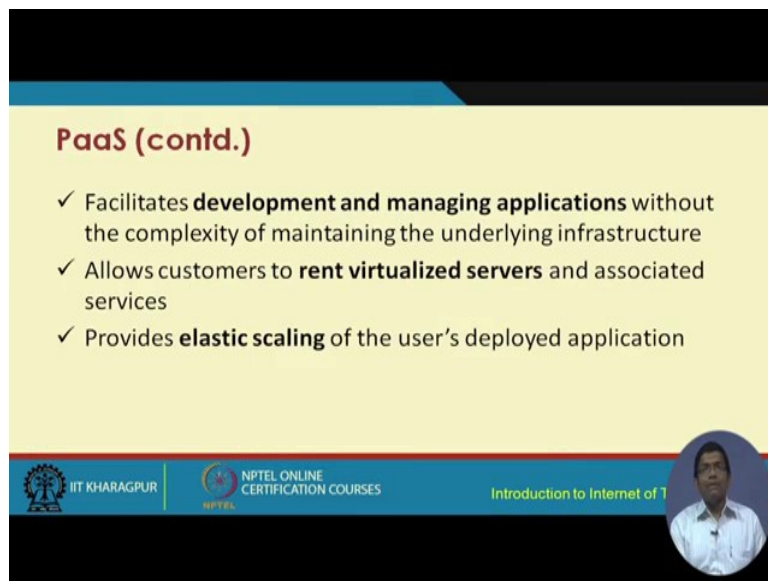
Source: Rajkumar Buyya, "Mastering Cloud Computing: Foundations and Applications Programming", Tata McGraw-Hill Education, 2013

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Next comes the platform as a service. So, here I will read out the definition for you platform is a service removes the need for organizations to manage the underlying infrastructure which

is usually a hardware and operating system combination and allows you to focus on the deployment and management of your application. So, as you can understand application development firms would be strongly benefited through the use of platform as a service. So, platform as a service provides the platform which allows the developers to create applications which can be offered as services via the internet it basically makes the applications you know easy to develop it simplifies the application development and deploy and deployment by providing the cloud aware features. Platform as a service is an application middleware.


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**PaaS (contd.)**

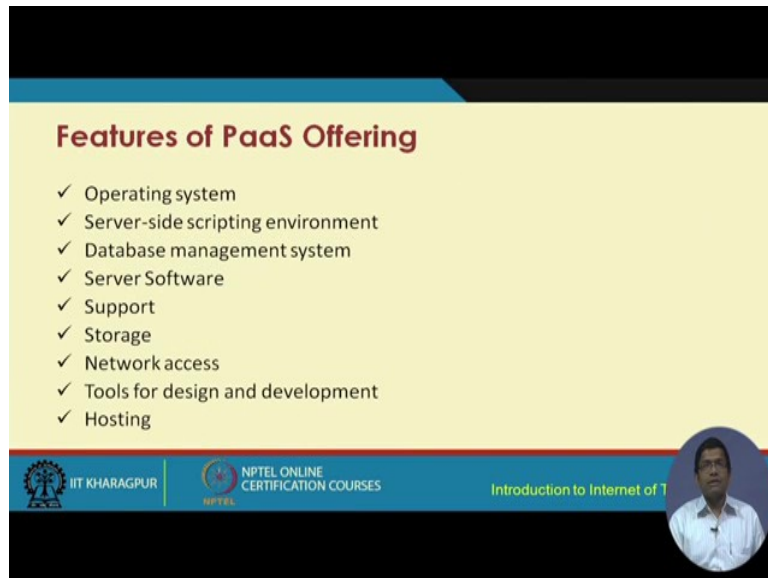
- ✓ Facilitates **development and managing applications** without the complexity of maintaining the underlying infrastructure
- ✓ Allows customers to **rent virtualized servers** and associated services
- ✓ Provides **elastic scaling** of the user's deployed application

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Which is offered as a service to the developers it provides the abstraction and security for the developed applications, it facilitates the development and management applications without the complexity of maintaining the underlying infrastructure it allows customers to rent virtualized these servers and the associated services.


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**Features of PaaS Offering**

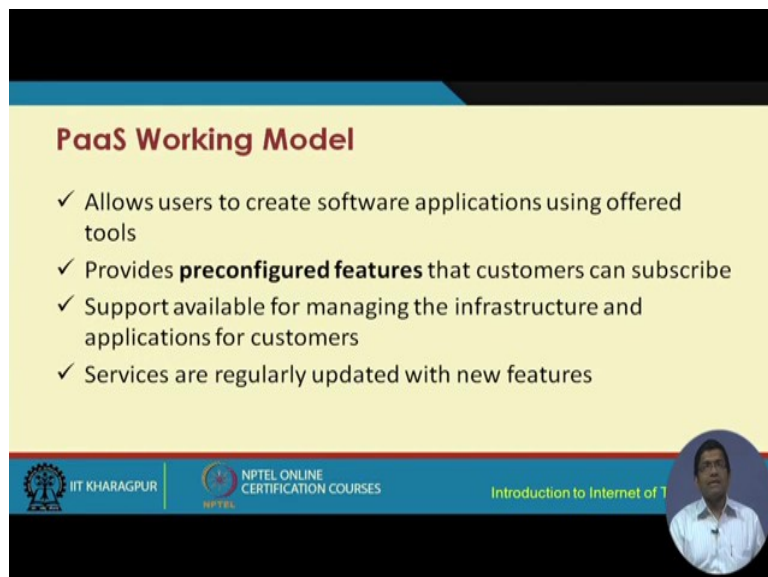
- ✓ Operating system
- ✓ Server-side scripting environment
- ✓ Database management system
- ✓ Server Software
- ✓ Support
- ✓ Storage
- ✓ Network access
- ✓ Tools for design and development
- ✓ Hosting

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And provides elastic scaling of the users deployed application. There are different features of platform as a service in terms of operating system you know operating system can be made available through the platform as a service based on the choice of the in the developers or the users server side scripting is possible, database management is possible server software support net storage, Network access offering different tools for design.


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**PaaS Working Model**

- ✓ Allows users to create software applications using offered tools
- ✓ Provides **preconfigured features** that customers can subscribe
- ✓ Support available for managing the infrastructure and applications for customers
- ✓ Services are regularly updated with new features

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And development of software and hosting these are all made available as different features of platform as a service the working model is like this that it allows the users to create the

software applications using offer tools and it provides the preconfigured features that the customers can subscribe it supports the available it support supports availability and management of the infrastructure and applications for customers and the services are regularly updated with new features.

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### Business Advantages

- ✓ Facility for accessing key **middleware services** without worrying about the underlying complexities of managing individual hardware and software elements
- ✓ Ease of access for the **development and deployment tools**
- ✓ Freedom from managing development and deployment tools individually

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The business advantages are with respect to the middleware service support the development and deployment tools the easy access to them and also the freedom for managing development and deployment tools individually.

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### Software-as-a-Service (SaaS)

"Software as a Service provides you with a completed product that is run and managed by the service provider. In most cases, people referring to Software as a Service are referring to end-user applications." – Amazon  
Source: <https://aws.amazon.com/types-of-cloud-computing/>

- ✓ SaaS is a **simplified model of software delivery** over Internet
- ✓ Operation, maintenance and technical support is provided by the service provider
- ✓ Typically offered via web browser working as a **thin-client**
- ✓ Supports a fully **pay-as-you-go** model

Source: Software Services for e-Business and e-Society: Proceedings of 9th IFIP WG 6.1 Conference on e-Business, e-Services and e-Society, I3E 2009, Nancy, France, September 23-25, 2009.

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And finally, the software is a service. Again the Amazon definition I will read out software is a service provides you with a completed product that is run and managed by the service provider in most cases people referring to software as a service are referring to end user applications.

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**SaaS (contd.)**

- ✓ Remote access of software via Internet where web-browser acts as a thin-client
- ✓ Facility for access and control of commercial software via Internet
- ✓ Multi-tenant application delivery in a one-to-many model

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So, SaaS is a simplified model of software development delivery or over the internet it typically uses web browser working as a thin client and supports a fully pay as you go model it also has some additional features for example, remote access of software is possible via the internet where the web browser acts as a thin client, it also has facilities for access and control of commercial software via the internet. And also this multi tenancy application delivery to multiple people at the same time multiple tenants at the same time in one to many model is made possible through software as a service.



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Advantages	
Traditional Software	SaaS
Customers install, manage & maintain	Customers uses over the Internet
Runs on individual organization on dedicated instantiation	Runs on multiple customers simultaneously
Cross platform support required	No concerns for cross platform support
Less frequent version updates & purchased separately	More frequent updates for enhanced user satisfaction
Separate costs incurred for upgrades	No separate cost
Vulnerable to software piracy	Less vulnerable to software piracy

Source: Software Services for e-Business and e-Society: Proceedings of 9th IFIP WG 6.1 Conference on e-Business, e-Services and e-Society, I3E 2009, Nancy, France, September 23-25, 2009.



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Compared to the traditional software the comparison with software as a service is given in this particular table the advantages include for example, with respect to traditional software customers have to traditionally install manage and maintain the application the software. Whereas, in software as a service the customers simply use all these over the internet the traditional software runs on individual organization on dedicated instantiation whereas, software as a service runs on multiple customers simultaneously clock sorry cross platform support is required in traditional software.

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### SaaS Architecture

- ✓ **Scalability**
  - To maximize application concurrency
  - To optimize the shared pool of resources such as threads and network connections
- ✓ **Multi-tenancy**
  - Important architectural shift from designing isolated, single-tenant applications
  - Ability to accommodate users from multiple companies at the same time
  - Transparency to all the users
  - Maximize the sharing of resources across tenants while distinguishing user's individual data

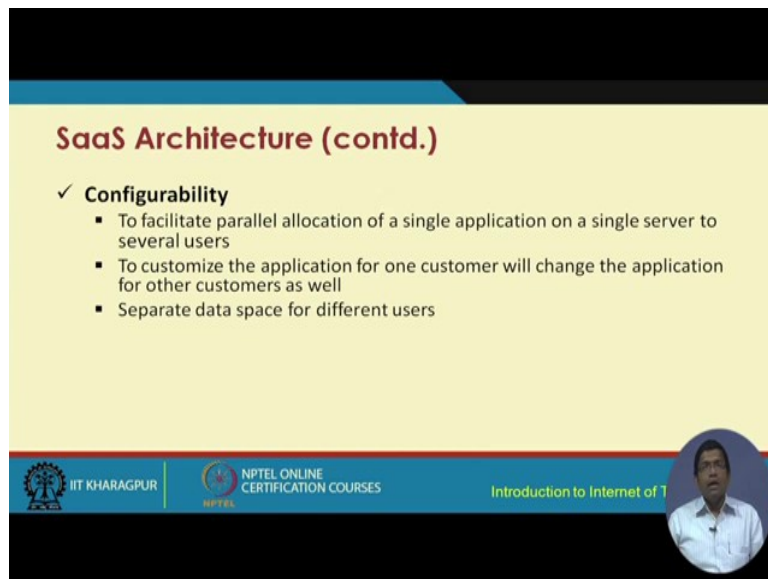
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Whereas in software as a service there is no concern for cross platform support like this; there are different other advantages of software as a service over the traditional software scalability is to maximize the application concurrency to optimize the share resource share resource pool such as threads and Network connections multi-tenancy it is an important architectural shift from designing isolated single tenant applications to supporting multiple tenant applications it has the ability to accommodate users from multiple companies at the same time.

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**SaaS Architecture (contd.)**

- ✓ **Configurability**
  - To facilitate parallel allocation of a single application on a single server to several users
  - To customize the application for one customer will change the application for other customers as well
  - Separate data space for different users

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And there is transparency that is improved by the use of this model amongst all the users in terms of configurability it is about to facilitate it; it facilitates parallel allocation of a single application on a single server to several users to customize the application for one customer.

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**Limitations of SaaS**

- ✓ Centralized control
- ✓ Switching cost
- ✓ Limited flexibility
- ✓ Data security and privacy

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Video feed of a speaker.

While changing the application for other customers as well. The limitations of SaaS include supporting centralized control. So, that is not a very good thing it is a limitation switching the cost. So, switching cost rather switching cost between different software limited flexibility it has immediate flexibility and there are data security and privacy concerns in this model. So, these are the 3 main models of cloud the software as a service, platform as a service and infrastructure as a service and we have gone through the different advantages and limitations of each of these models and as we will see later on that these models coupled with few other concepts are required in order to meaningfully develop and deploy IoT services maybe for Smartphone applications or maybe for smart cities applications.

Thank you.