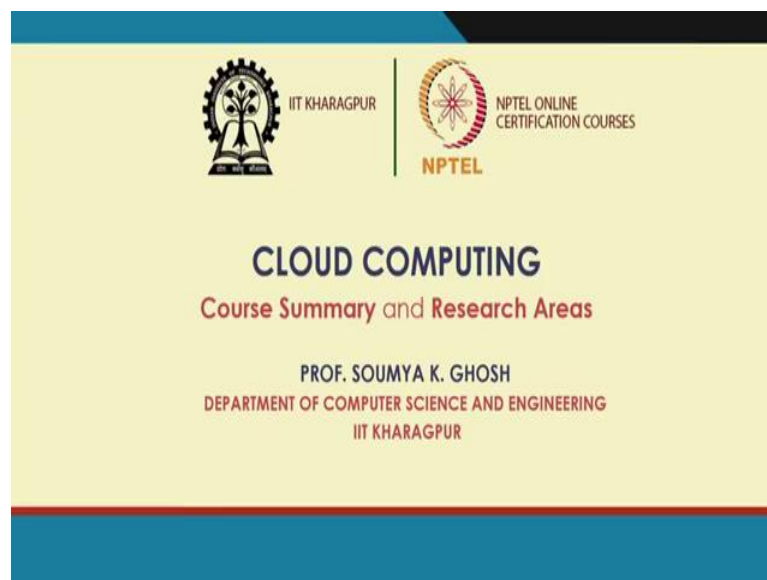**Cloud Computing**
Prof. Soumya Kanti Ghosh
Department of Computer Science and Engineering
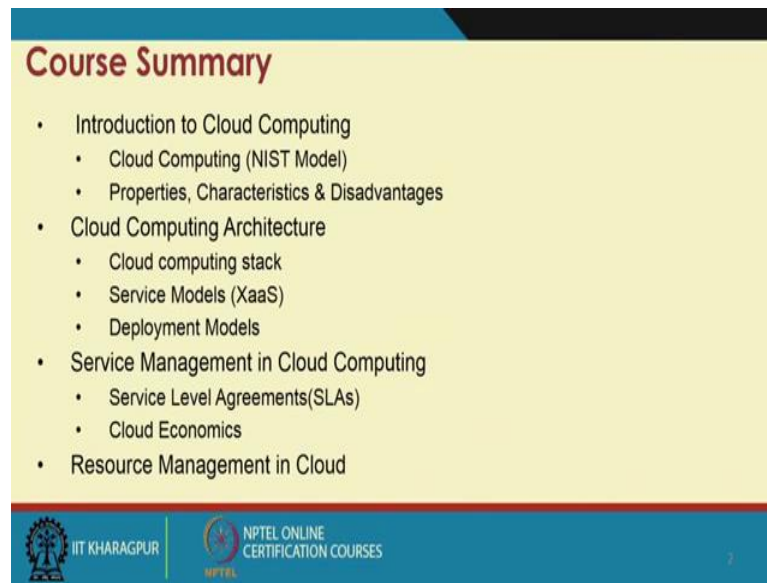**Indian Institute of Technology, Kharagpur**

Lecture – 40
Course Summary and Research Areas

Hello. So, welcome to our final lecture on cloud computing course. So, today what we are trying to discuss is we will be discussing is primarily looking at; what we tried to cover in this course and also we will give you an quick overview or of that what are the possible openings or what are the possible research directions which you can explore or you can study more if you are interested in this particular field, right.

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So, in this particular course, we try to discuss on some of the topic or some of the areas of cloud computing as we all understand; there is a vast area; vast area of things, rather if you can see that every topic itself is a course by itself. So, what my major effort was to give you an overview and what are the possible challenges; what are the different characteristics of cloud or different properties of cloud and what are the different aspects; we tried to look into and which service that technology involved into things.

So, we tried we started with basic introduction with cloud computing with a basic NIST definition and which what we emphasize that it everything as a service. So, and then try to see that the basic property characteristics, rather advantageous and disadvantages of such type of computing as we discussed and try to reiterate that it is not suddenly a new technology which suddenly drop from the sky. So, there is a evolution process, we started, there are several effort towards this sort of activity, like we have gone through phrases of cluster computing, grid computing, distributed computing and finally, came up to this cloud computing.

The basic beauty or the basic characteristics of this sort of computing as we have seen is that it is what we call a form of a utility computing like as a utility services like electricity or water or anything, you can basically pay as you go model, right. It is a metered service, scalable service; you can scale to at infinite scaling and the other thing

is that it do not have to maintain the infrastructure at your end. So, you need somewhere as to hook into the thing and then start computing.

And also we have seen that if basic architecture and try to look at the basic cloud computing stack, there the popular service models like a though it is a anything as a service, we have seen primarily infrastructure as a service, platform as a service and software as a service, the primarily these 3 there are different other type of service anything which can be manifested it as a service mode is a is possible in this sort of framework right.

So, rather though it is not mentioned explicitly in the slide, what we have seen that the basically the foundation technologies like service oriented architecture web services and xml technology. So, we have gone through those things also, right, we have taken an overview of those things also which helped us into interoperate and make these service oriented architecture possible. So, this basic service oriented architecture or service oriented approach is the; what we can say foundation of or another pillar of this cloud computing architecture.

Then also we have seen some aspects of service management primarily with respect to service level agreements, right; SLAs which plays a important role because as a loosely couple heterogeneous services are talking to each other; these service level agreements plays a important role in realizing this sort of framework right, unless we have a strong service level agreement or then, otherwise it is very difficult to have a to maintain a quality of appropriate quality of services, right.

So, whenever someone is taking is leveraging cloud, then it is a organization or individual is expecting some sort of a reliability from the cloud, right like if I am taking if on behalf of our institute for running a lab; we are taking outsourcing our system to the cloud, then what I am expecting that there will be a faithful uptime, right, it is a of a particular level says I 99 percent; 99.9 percent and so and so forth which will be supported by the cloud.

If it is more missing critical operations like bank or similar financial or even some of the say defense or disasters management or those type of operations, then we what we require is more or health care systems, then why what we require is more high level availability and reliability on the things. So, how to bound that whether what I am paying

for or what I have agreed upon whether I get that services. So, for we require a strong SLAs and that every clouds service provider specially, these commercial provider have provide a SLA format though there are what we have seen there are differences between the formats and type of things, but it is plays a important role in our in having cloud services.

Similarly, we talked cloudonomics is cloud is always a good thing, right. So, what is the economy behind the cloud, when we should go for cloud, when we should not or stick to our own in house computing facility, whether it is infrastructure platform and so and so forth. So, though so, if there is a particular economy which comes into play and we have seen that we need to look at that those economic aspects whenever we are going to basically outsource some of my business or part of my business to cloud, right.

So, cloudonomics specifically what economy in cloud what we have looked into. There can be other aspects even cloud may be economically beneficially, but my other constraint like may be security constraint, my privacy constraint may not allow me to push all the data to the cloud right like IIT Kharagpur may decide that I can run the labs on cloud, but I may not put my student data, employee data on cloud because finally, it is on the third part domain. So, that type of thing also come into play. So, it is not only whether; it is economical in terms of money it is also to be that what should be the organization policy individual policy; how much I should push on the cloud and so and so forth.

So, never the less; cloud economics plays the important role to decide when to go for cloud and when to take it on in a house type of things. Then we have discussed I believe one or 2 lectures on cloud resource management in cloud, right. So, it is a very important issue, right resources resource management in the cloud is play a both from the providers and particularly also sometimes it is from the consumer end, but never the less for the resource management; the resources management in from the provider sense plays a vital role, right. Like I have though I say that I have infinite resources as my backend, right, but it is, but it is tangible, right, I cannot say that it is not there is a limitation of the things not only that resource also takes lots of other energy, right.

So, it comes with back to back that some sort of a consumption and so on and so forth like even I have; I can give a number of there is no constant the resources is to maintain

the resources; I need to have lot of energy at the things. So, appropriate resource management. So, that overall it is beneficial in terms of that say profitability of the service provider, it is not adverse to our environment or consuming more energy, this appropriate resource management plays an important role. Not only that if you see the literature or recent works in several that peer reviewed journals or top level conferences this resource management is always a plays a important part of that.

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So, this is a very vital aspects in case of a cloud management or cloud computing. Then we have seen data management in cloud, it is a very tricky issue. Finally, whenever the data is in cloud; it is your data or our data is on third party, right. So, I do not know that what is happening to the data though; there are definitely security issues apart from the security issues, there are several issues like how whether what will happen that data if it is lost or something how what about the scalability of the data if the quickly I can grow on the data, what should be accessibility of the data is there in the cloud, it is not cloud storage is not lost however, I do not have appropriate bandwidth to access the data.

So, there are several issues in case of data management; we have seen some of the things like Google file system; HDFs, Hadoop file systems and what we have seen that that how the application policies works and how this huge data thing are maintained not only that it also while talking to this data management the one thing in variably come is that big data management how this big data can be managed in cloud, right. So, we have seen

that other technologies like a map reduce sort of technologies where we can paralyze this operations and do and can have a better efficiency or of processing a particular work in the cloud.

So, this is very again, they are very interesting area to work on or study more and type of things, then of course, one major concern in cloud is cloud security; we have also tried to looked into some aspect of cloud securities tried to show some of the recent train in the things; we have discussed these in 3-4 lectures. So, there are several aspects of the things like one is identity and access management, access control mechanism; whether it should be role base access control or use of risk base of access control and type of things. There are different aspects like trust, reputation, risks competence and type of things, right.

So, how to handle them; how to take a call considering all the things; how to further; for example, how do I calculate trust of a particular provider or even how the provider try to profile his own customer, right. So, there are major issues in their definitely authentication is another major aspect; how to authenticate, how the authentication protocol will run on the things and as we understand that security in say data security in cloud is also a major aspects like it may not be always possible to encrypt the data. Even if you encrypt the data, how this key management will work on the things, right your data is in third party aspects and then how these overall key management aspects will work in this type of there.

So, this is also a very strong field because as more organization, more individuals are going towards this sort of infrastructure pushing their data, their applications. services on the cloud. So, how this security is maintained or how this security data security can be guaranteed becomes a major resource. As we have seen in our country also now several major competitive exams are being conducted over clouding infrastructure.

Now, those securities like how this question paper will be encrypted; how the answers will be encrypted and securely transmitted and if it is stored in the third party whether there is a possibility of any leakage of any data. So, there that needs lot of study and what we have seen that is a major one of the research area also and one of the most what we say talked about concerned about our challenges in cloud.

Also we tried to show you some of the open source as commercial cloud, right, though it is not possible to cover everything, but we have tried with open stack and also we have

shown how in our IIT Kharagpur, we have implemented with help of students; a experimental cloud called Meghamala and how it is serving to a research community though in a small scale, but it is a operational thing though it is experimental. So, it is based on totally open source things on open stack, and there are several open commercial cloud like Amazon, Azure, Google cloud platform, IBM Bluemix and so on and so forth.

We have tried to show some example cases. So, that it will gives you a opportunity to quickly know about the things and work on this type of have a feel on the things, the basic idea is to have a feel of the things and finally, we last few lectures we discussed about some of the related technologies and some of the what we say companion technologies to cloud computing like one is fog computing. So, what we are seeing that the devices in recent days or last one decade are becoming more resourceful. So, that there is some sort of a it is not only acquisition of information and forwarding the information, we can basically have the opportunity to process the information.
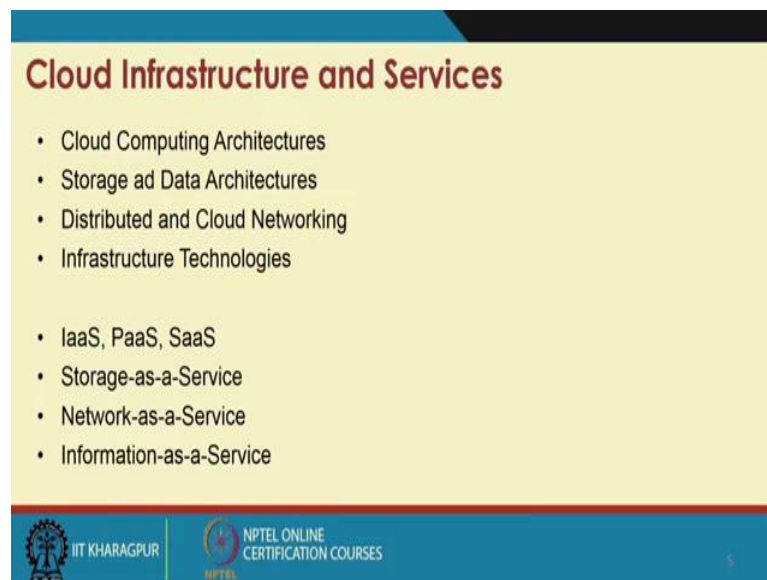
So, if that is the situation why not do some operation at much lower level, and then we can provide the result to the things. This will not only help us in reducing the bandwidth requirement to connect to the cloud, but also some of the local decisions which could have been done at a local thing; we can basically achieve that this will help us in having more quote unquote some sort of a real time application to run more faith fully, right.

So, this some of the aspects; we have tried to see in then we have talked about sensor network sensor cloud, right that as we have sensors are omnipresent these days. So, why not if there is a formation of a sensor cloud. We talked about container technology like specifically on the Docker technology that how it can be used for in the context of cloud computing; how this cloud and this container technologies there and of course, this green cloud or like that it comes to that energy management, resource management of the cloud can be there.

So, some of the things what we have tried and what we have discussed may be discussed which may help you in finding your future research directions. Now what we tried to again I let me repeat what I tried to do in this course is to basically open up these different avenues, right. So, it is within some of this sort time period, it may not be possible to discuss everything in details, but definitely we see that lot of opportunities are there.

Now, let me with given these backgrounds. So, let just discuss about some of the research areas in cloud you may find in the internet; I do have found some of most of the things in the internet and like. So, just want to discuss some of these aspects of the things.
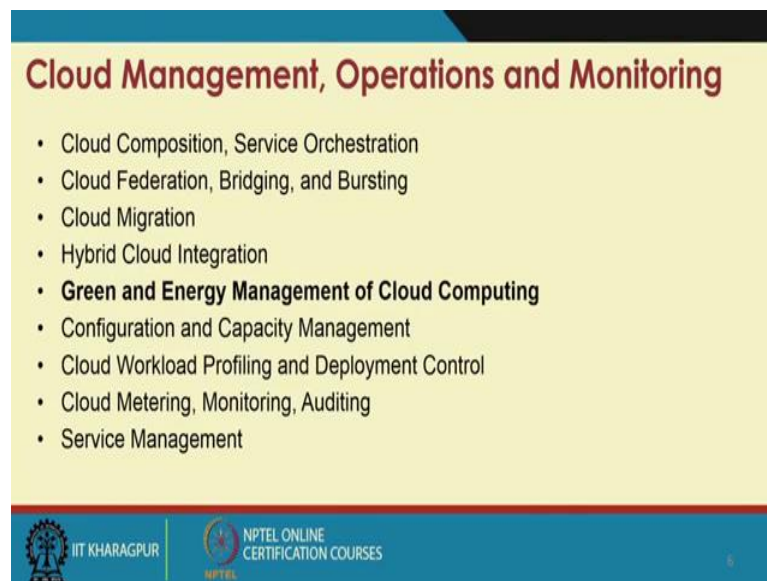
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So, one definitely if we look at the course and things, one definitely this infrastructure and services plays a important role like a cloud computing architecture storage data architecture distributed and cloud networking infrastructure technologies these part a important role and it is sort of a with the hardware and other related technologies upcoming technologies coming in to play.

So, it is never a saturation field, right it is always there is a scope of contributing into the things and making the infrastructure more intelligent and meaning full. Apart from there are services like there are basic services like IaaS, PaaS, SaaS which are also evolving every day or in a regular fashion; there are other type of services which are becoming very popular one is storage as a service again very tricky and critically issue critical service which everybody needs from the individual to organizations every federal agencies everybody needs it and there are other services like network as a service like I want to setup a network or based under that rather I can have different network; I want to have different network configuration at different part of the day or different time period based on my requirement or my clients requirement, I want to set up a things.

So, what I require instead of giving a physical network, I want to have a network as a service type of things; there can be other type of services like a information as a service. So, information being accessed as a service even people talked about concept like science as a service and type of things, right. So, there are there are lot of opportunity both research study and type of higher studies in the area of cloud infrastructure and services. So, this is one of the important core fields.

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Of course the management operation and monitoring is another interesting area or important area. So, cloud composition service orchestration between services, cloud federation bridging busting cloud busting and those type of thing, cloud migration hybrid cloud integration like green and energy management of cloud computing, I kept it in bold because that is that stand out that this is not only a research field, it is also a major challenge and requirement to make this cloud computing a success, right.

Configuration and capacity management how to how do I configure reconfigure my infrastructure as a service provider and how to estimate; my capacity type of things cloud work load profiling and deployment control again another important aspects and if you see these are the things which are not exact these are not in isolation there are interconnected, right, then cloud metering monitoring and auditing of the services service management. So, there are different aspects of cloud management operation and monitoring which plays a important role.
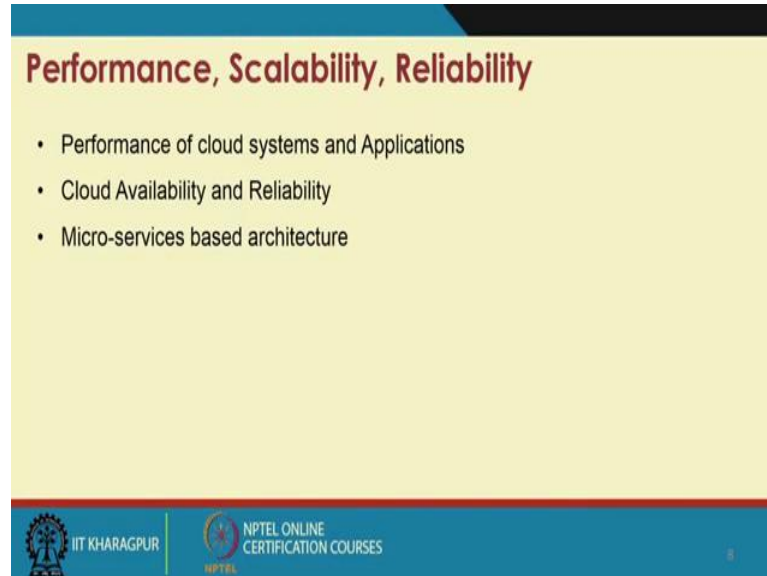
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And as we already discussed that cloud security is an important is need to be appropriately addressed. So, that people or organizations get confident to store their data in to this cloud there are not only technological issues, there are several legal issues, right if there is a data leakage; how this need to be handled in the law of things; if I need to be handed in the federal law then the physically the data should be stored may be has to be stored in the physical boundary within the physical boundary of a particular country or particular state, right.

So, there are several issues which need to be addressed. So, privacy data privacy access control issues identity management there are issues of side channel attacks which are becoming popular like the it is; it may not be the directly looking at the activities, but looking at the some other activities or basically understanding the basic operational things I can basically adjust some of the things; we have discussed during the security while we are discussing about the cloud security in our previous lecture that what we have seen that when we there is form a in a paper which we says that by looking by understanding the basic philosophy of allotment and type of things I am able to guess somewhat that say the IP address block and type of things in a particular of another client if I can; if somebody can do that then, there is a possibility of the security bridge, right.

So, these are different security aspects especially if it is mission critical things, then the organization or individual ones that security should be there. So, there is a whether; there

is a question that whether security as a service can evolve right whether we can provide security as a service in the in this context another.

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Another interesting and of course, important aspect is that performance scalability and reliability of cloud computing, right.

So, performance and of cloud systems and applications is a another major issue like how to measure performance how to basically maintain that performance at particular level of performance and with proper resource management cloud availability and reliability is that like micro service based architecture. So, a service may that different micro service.
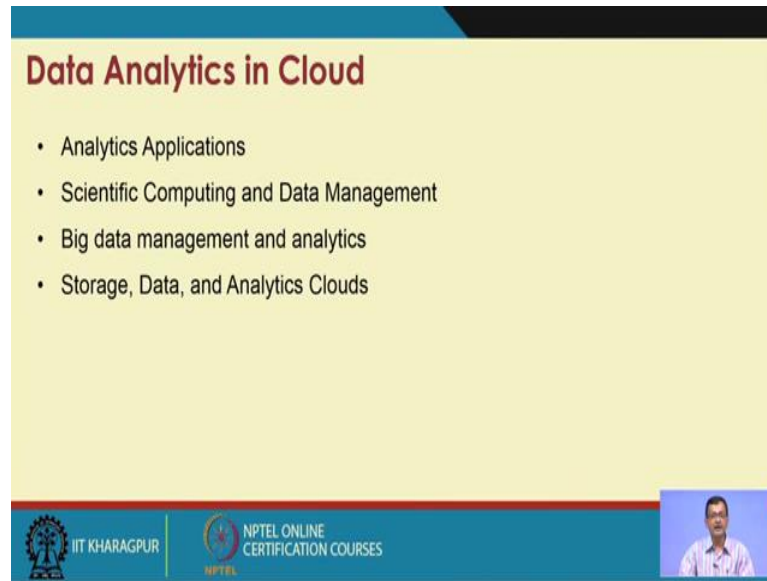
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So, whether my particular underlining architecture can support this type of micro services; so, I whether I can design a micro services based architecture for handling for better performance scalability and reliability; of course system software and hardware plays a important role like virtualization technologies whether the better virtualization technologies service compositions cloud provisioning orchestration and hardware architecture support for the cloud computing. So, instead of taking any hardware whether the whether the hardware itself has is supported to this implement this cloud. So, this is also a important aspect; it need to for in order to work on that you need to know more about the internal working or internal more implementation details of architecture and development of architecture and type of things.

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Data analytics in cloud data analytics is the buzz; what these days we with huge volume of data and every aspects of the things, whether it is business banking metrological data or educational data where everywhere this analytics is there whether and as cloud; what we have seen its a it is a infrastructure which can hold huge volume of data may be and also application running on the data, right. So, yeah and not only that it tries to give ensure interoperability between the between the different data sources.

So, this data analytics in cloud is one of the; one of the very hot topic of research. So, there are different analytics application developing analytic as a scientific computing and data management So, it is not that data management and computing a separate, but whether I can my management goes in more hand to hand with the computing aspect big data management analytics storage data and analytics clouds. So, these are these are some of the things which are coming up in a big way and there is a lot of opportunity to work on this areas.

And another aspect like cloud computing the service management in cloud is; they are like services discovery and recommendation services composition services quality of QoS management, right the QoS management of the services, right.

So, what we are trying to look at. So, security and privacy services security and privacy of these services. So, different services are there what about the security or privacies of these services there is a semantic services, right. So, that is whenever what like a different domain has different type of dynamics into the things, right different type of semantics into the; if I try to look at that whether predictions and type of things. So, there is underlying semantics into the things; how to incorporate that semantics and come up with semantic services so and service oriented software engineering aspects where how to put it on the cloud.

So, these are the some of this other aspects which are which are which are becoming popular and finally, they are several technologies which are coming up and how cloud and those technologies come into play; we have already discussed these things like one is fog IoT cloud is another aspect sensor IoT clouds sensor cloud; things are there and this container technology as a we have looked into Docker technologies. So, how these technologies and cloud computing can go hand in hand to provide better services.

So, these are some of the aspects which we try to look into while as a future scope or what we say that recent trend in research. So, one major one good place to find the that what are the different what are the upcoming field or what are the present direction of the research is looking at top level channel general transaction and looking that what sort of special issues or sort of scope of things are there and also top level conferences say; what they are scope of the topics; they are looking for those type of things are there.

So, with these let me conclude this course hope you have enjoyed these particular course and there and you could find some interest in this particular aspect of cloud computing. So, what I believe or what I basically look forward to is that this will help you in further higher studies; in this aspects and also those who are interested in research in this field will find lot of opportunities are there.

So, there are some of the things which you can look into that there are several cloud simulators are available it is it may not be always possible to develop infrastructure or

getting infrastructure or higher cloud to experiment. So, there are simulators which we can; which you can work on to see that whether things are whether; whatever you experiment on the or whatever you are thinking can implement on the things. So, with these let me conclude these course and thank you very much to participate to for participating in this course.

Thank you.