INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and
Control

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Topic Lecture – 22
Introduction to
Sequence Control, PLC, RLL

Good afternoon we are going to start lesson 18.

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Which is on a new subject it is a new module on sequence control so we are going to have our first introduction today on sequence control on the kinds of controllers that are used for sequence control namely programmable logic controllers or PLCs and we are going to take a first look at the programming languages the languages which are used to specify control programs for PLCs.

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So as usual we will first look at the instructional objectives so after learning the lesson the student should be able to state three differences between analog and sequence control this is important because traditionally an electrical or manufacturing or chemical engineering student is typically exposed to analog control while the kind of control that we are considering here at different in nature so it is important to understand the differences between analog control and sequence control.

Obviously we should know he will be she should be able to do give an example of industrial sequence control an actual practical example and he should the programmable logic controllers are controllers which are primarily used in the industry to implement sequence control he should be able to know three of it is major functions the major functional characteristics he should also know the major components the major structural components of the PLC.

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And you should be able to describe a typical program execution cycle that takes place in PLCs and how this program execution cycles affect the control performance and finally he should be able to know what are the typical elements of a an relay ladder logic program which is one of the programming languages which is used for programming a PLC and know the various interpretations of the symbols used in this language. So first of all let us try to understand what is sequence or logic control.

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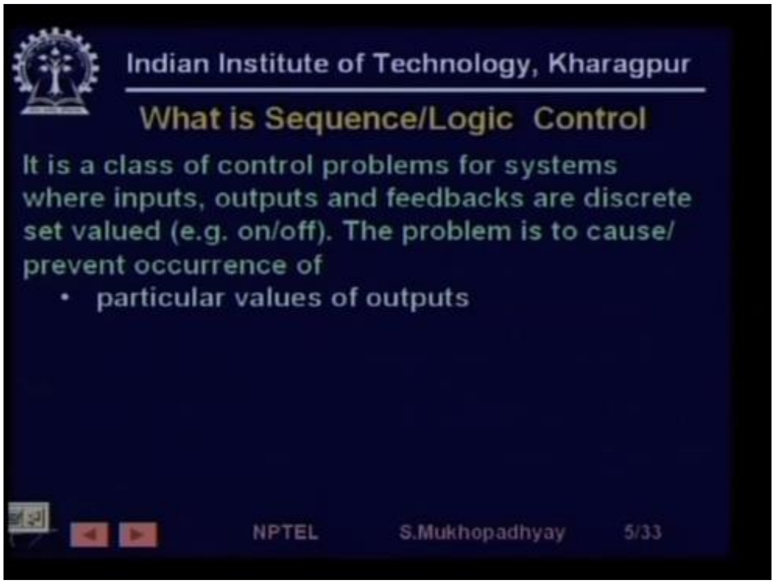

So as I said it Is fundamentally different not fundamentally may be very significantly different from analog controls from various aspects so we need to understand what it is so I constructed and this is my definition words are mine so it is a class of control problems for systems where inputs outputs and feedbacks are discrete set valued actually I would rather say that they are for the purpose of control it is it is taken that they said valued that is the intermediate values are not considered.

So for example a switch it stays 99.999 percent of the time in on state or off state but obviously it goes from the on state to the off state and that timing is so short that we choose to ignore it so we say that it is a switch is a system which says in either one of the one of two states so it is either on or off we actually choose to ignore the times when it is going from on to off because it is too small enough no consequence for us so in that sense the inputs and outputs and feedbacks are discrete set valued like on off and the problem is to cause or prevent occurrences of either particular values of outputs or combinations of outputs.

So when this switch one is off switch one should not switch two should not be on so you know giving a given example from it from daily life if let us say let us take a daily life example of a railway crossing so if the incoming train coming sensor is on then the gate should be off so some particular combinations are allowed and some or some particular combinations could be prohibited so the purpose of control is to ensure that in all future behavior of the system those combinations of outputs either must occur or cannot occur as is specified.

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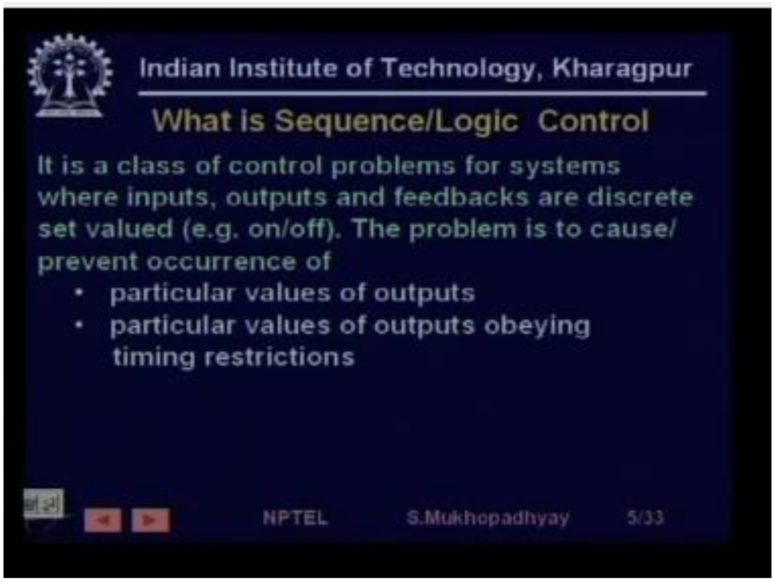

Similarly we could also have timing restrictions so you can say that after the train coming sensor becomes on within one minute the gate closed sensor should be come on, so now you are giving some timing restriction so you must ensure that the system the gate becomes closed within one minute of the train coming sensor be coming on.

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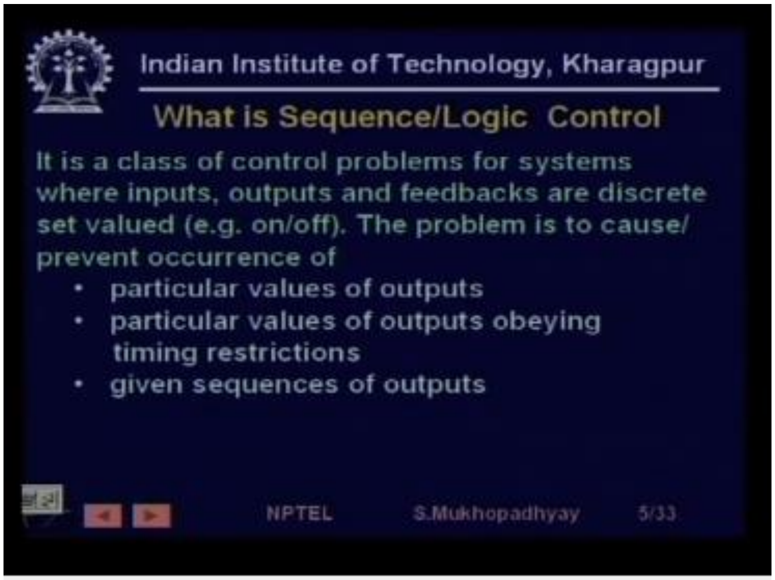

We might also like some given sequences of outputs, right. So for example suppose let us say let us take a buffer where some machine is producing parts and then putting them in the buffer and the buffer from time to time gets emptied, so the states through which the buffer goes so maybe the buffer capacity is two, so and every time the machine is dropping apart we are the buffer is getting filled.

So the buffer should never go to the overflowing States so it should go to part count 0 part count 1, part count 3 then empty part state and then again come to part count 0. So the buffer should all only go to certain states and should not go through go to go to some other states so only some particular sequences of outputs or events should be allowed.

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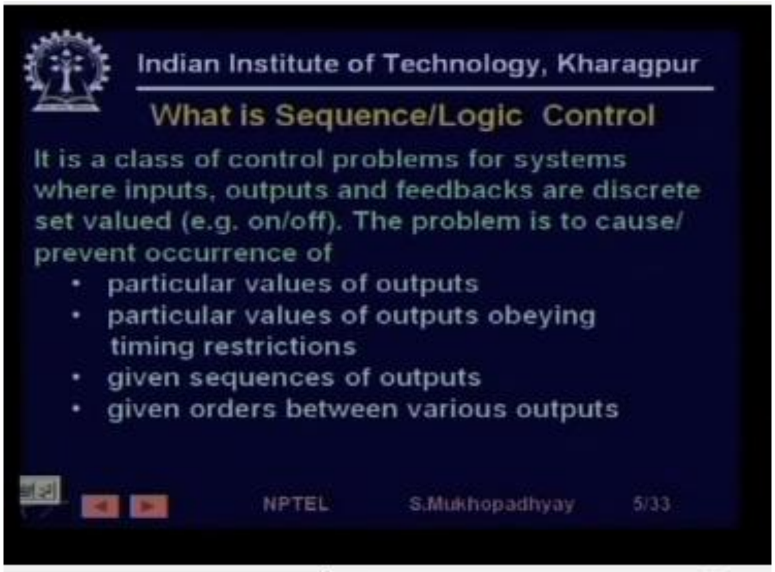

Or there could be some given orders between various outputs so after this occurred that must occur so they are these are you know sequencing orders, sometimes also called interlocks if this has already occurred that cannot occur so this kind of so basically what I what we are trying to say is that if the system states are assumed to be discreet this kind of statements are made about the desired behavior of the system.

And then the problem of control is to realize them by exercising the inputs to the process, so this is typically a sequence or logic control problem why they are called sequence of logic control because it is a finite state thing so it is described more by logical methods than by numerical methods, before we look at them in more conceptual ways let us take an example.

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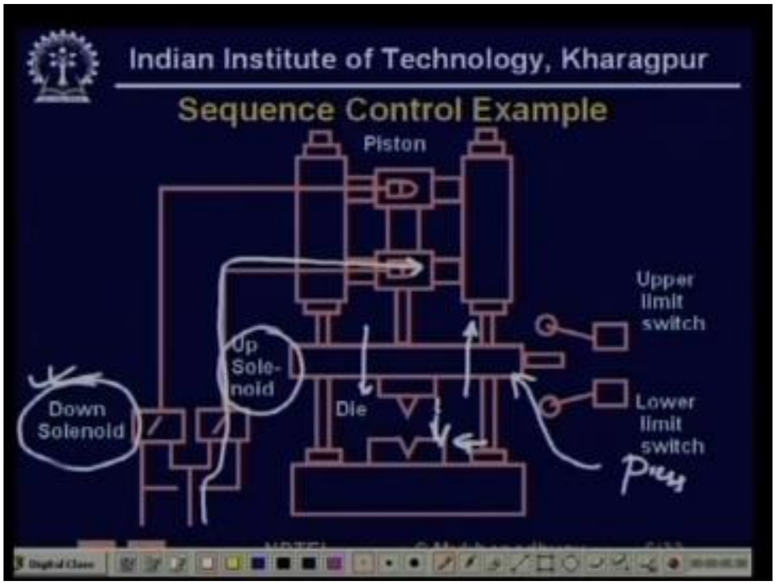

So you know look at this is what is what is it, it is supposed to be a it is supposed to be a die it is supposed to be a stamping press you know so if you look at this then so this is the stamp this is the press, okay. So there are two solenoids up solenoid and down solenoid so if the up solenoid is energized these are hydraulic presses so if the up solenoid press is energized then the pressurized fluid flows through this path and goes into the machine.

So the machine is constructing such a manner that then this press this press goes up similarly if the down solenoid is energized then this press goes down and this so this is your this is your metal sheet it comes down and stamps on it, so it keeps stamping retracting stamping retracting and creating a particular shape of sheet metal, you know these things are typically used in making let us say car bodies, right. So it is a hydraulic stamp press, okay.

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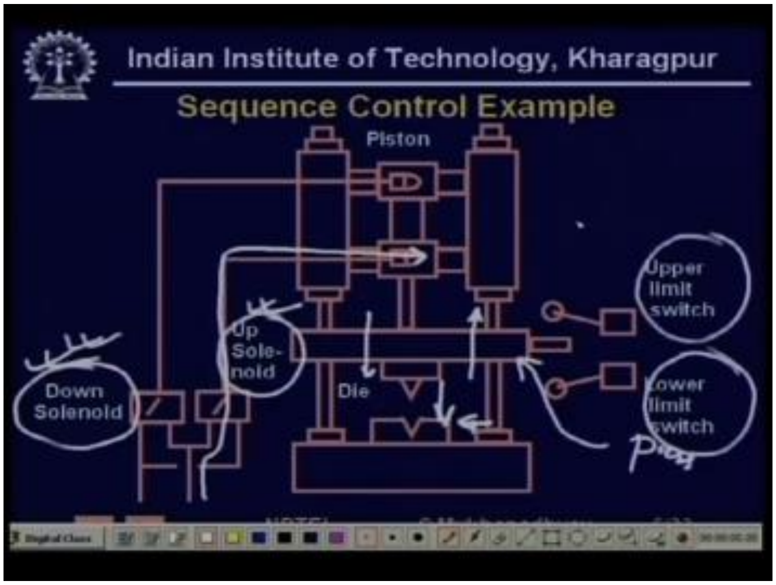

So and obviously after the there are so what happens is that the after the it goes up the up solenoid may be de-energized, so whether it has reached the topmost position or the down most position this needs to be sensed so there are two sensors this is the upper limit switch and lower limit switch and these are the two actuators the down solenoid and the up solenoid are the actuators.

And this thing is the is our system so this is a typical example of a sequence control problem where we are interested in only see the system is everything is analog if you look fine enough, so the obviously the piston cannot the system cannot instantaneously come down from the up to the down state. But what we mean is that for the control of this system we are not interested for the sequence control in this of the system we are not interested to know the intermediate states.

We want to only ensure that if this machine is supposed to stamp if that command is given then it should periodically come down and then go up, come down and go up, so only that we are only interested in the our control problem is only to ensure that it periodically goes through the up down, up down, up down sequence that is all. So in this sense it is a sequence control problem, right.

So this is, there are n number of such other problems for example, there are many other application example.

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For example, a plant startup shutdown sequence, so when a plant is started up initially you have to bring up levels to search initially automatic control may not be immediately applied, so first you have to you know maybe fill some chamber so then start so first open the valve then you start the pump then once so the level starts feeling then you see when it has reached some sufficient level then you switch off the palm then you switch off the valve.

So basically and then you start the heater, so let the temperature come up then maybe the automatic control will start. So initially for these startup shutdown sequences nobody when you may not be interested in doing an analog controls but rather the system is actually operated based on discrete controls. Similar things happen for shutdown sequences so once things have to be shut down there are certain such you know sub discrete control actions have to be taken, so for such things typically sequence all or logic controllers are used.

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There is a conveyors, conveyors are very widely used material handling systems, so in conveyors you do not bother about what is going to be the motor speed maybe you do not bother about that, so you only have to start the conveyor or stopped the conveyor maybe when you detect the part on the conveyor you will started. If you then after the part es out from the other end then you stop it. So conveyors are typical examples who had a lot of you know very simple PLC controls take place sequence control.

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Similarly there could be automated assembly operations, so for example you have a pick and place Robo, so the Robo you know it goes to certain states so it is, so maybe it is situated somewhere and it is going to the picking up item X from the left hand side of the workspace then putting it on the machine then operating the machine then again picking it up then and then putting it on the beam which is on the right side of the workspace, so the overall sequence through which a robo goes or maybe picks a fix an electronic component places it on the PCB.

So such operations are typically described and controlled by a sequence controllers. Now we must understand that this is actually a robo when it is for its move it has very sophisticated controls, it has servo motors in his various joints it has analog controls on all of them. But here we are thinking of designing the controls are at a different level, where we are not interested in that speed control loop is actually in place and it is working but at a lower level. So only this sequencing tells us that what set point to give at what time, so it is a kind of you know set point sequencing if you look at it from the analog control point of view.

So based on the sequence of the digital controller or the discrete event controller corresponding analog set points are being downloaded on the analog controllers and the analog controllers are actually taking place and controlling the motion of the robo and then taking them through the final states. So as far as the sequence from control problem is concerned we are not interested in knowing or in describing on solving how a robo arm is moving from one point xy to another point x1y1.

We are not interested in that we are just saying you just making a mechanism by which the proper sequence of commands can be specified to the analog controllers and the, and then analog controller will be expected to take care of that motion, right so in this sense it is actually a supervisory control problem so sequencer logic problems are often applied at a supervisory level to provide set points to the analog controllers which are working below it at an at an automatic control level right.

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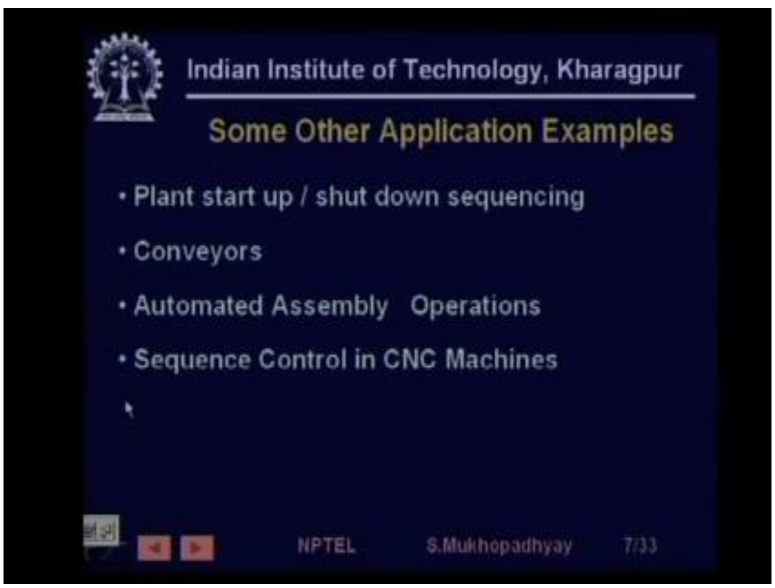

So similarly sequence control in CNC machines where depending on the geometry of the part to be cut depending on the machine configuration sometimes you have to you have to move the bed this way sometimes we have to move the bed that way sometimes you have to extract the spindle up you may you may have to change the tool you may have to switch on some lubricant flow so various kinds of you know again supervisory control actions must be specified in fact in a PLC there are I mean it is it if you see if you see a CNC machine controls.

Then you can very clearly see that there are two different control systems usually on two different control processors so you have generally have a high-speed microprocessor or a DSP sometime which are much faster and actually control the various motels and you have a PLC generally I mean gee fan or whatever I mean some make of PLC and which will give which will basically control these various motions and maybe also monitor the machine so.

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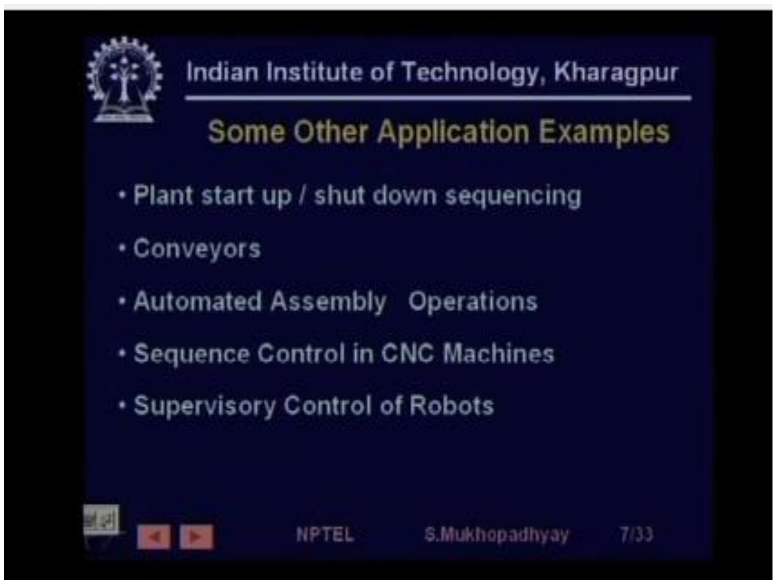

Supervisory control of robots as i have told.

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So sequence that is why PLC's are used hugely in I mean this kind of discrete-event control problems are very common in actually in industrial processes and I mean you will find literally hundreds of them now we must realize since we are I thought that since we are you know this is a new kind of control problem and you know we are the same motor or the same Robo about which we learnt from analog control point of view we are still using them but now trying to construct completely different types of models for them and trying to solve different types of control problems.

It is useful to understand that a model of a process is actually I mean what kind of model you will you will construct for a process entirely depends on what is it which aspect of the system behavior you actually want to capture so it is not always so for example.

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Let us say imagine that if you are trying to model a computer then there are various architectural models for a computer there may be a one Norman architecture there may be a reduced instruction set architecture there are several you know well-known architectures of computers I mean models around which computers are constructed now you know computers are typically.

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You know very large digital circuits I means sequential digital circuits which are sometimes thought of as a as you know state machines so state machines are again half there are various kinds of state machines so if you when you are seeing the computer at the state machine level then you are using models like you know mealy machine move machine basically automatic theoretical so again these state machines are made of what they are actually made of digital circuits.

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So digital circuits how do we describe digital circuits we know that we describe combinational circuits using karnaugh maps or you know some of product Boolean formula or if there are sequential circuits then we describe them as state transition tables.

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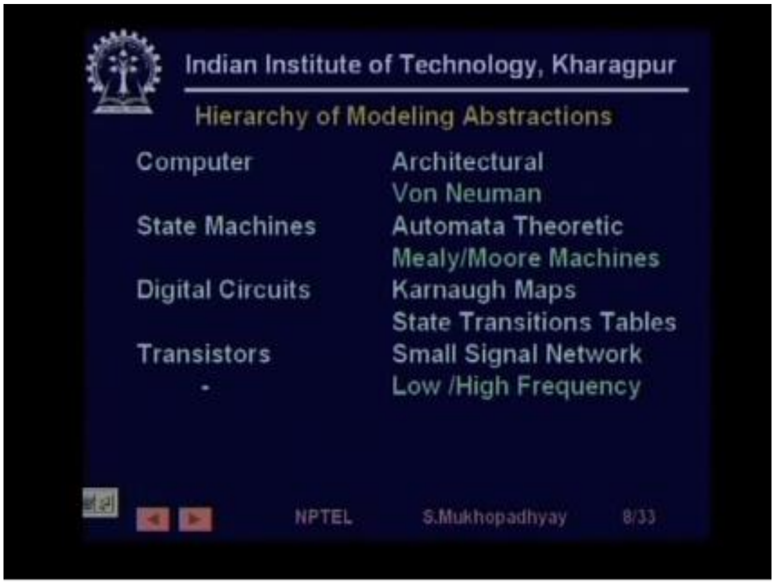

So now what are the ETL circus made of they are made of transistors the transistors are actually the moment you come to a transistor there that you have come down to the analog level so there you start describing voltages currents and their time behavior so you have various kinds of you know small signal network models either low-frequency models or high frequency models we have we have learned several kinds of models again transistors are made up of semiconductors.

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So semiconductors have you know physical models you know electrons holes energy bands so you see that but you obviously will not describe a state machine by as a of transistors so everything so there is a whole hierarchy of abstractions so as you go up and up you consider more and more things and you consider them in more and more abstracted ways you know but sometimes it happens it also happens that the same device is being looked at as something by one person and by another thing as another person for example say if you are if you have the desire if you are the user of a digital circuit then you will use a model like in you know a matter of an and gate or am gate or flip-flop.

So you use one kind of models but imagine the semi conductor imagine the gate designer I mean the VLSI designer of the gate so he is so why you construct why you look at a gate not as transistors but rather whether the digital circuit because you know that the circuit is such that for most of the time just like the switch example I gave it will either stay in a 5 volt state or a 1 volt state so it's either 0 or 1 so it suffices to describe when it will go to 0 and when you go to one.

It is not important at all to describe the transitions of how exactly the voltage signal will rise from 0 to 1that is not important at all on the other hand the person who they look at the VLSI designer who wants to design the gate so you know the gate circuit is such there it will automatically go from 0 to 1 or 1 to 0 but the beauty of design or the or the whole credit of design goes into understanding that how exactly how fast you can make it rise how much less power can be dissipated and things like that.

So on the other hand the circuit designer is only concerned mostly concerned about the transition part from 0 to 1 so he obviously cannot take a view of the same gate as that of an as that a an gate model he has to take a view of the same device as a non-linear transistor circuit because his attention is focused only on the transition on the analog behavior right, so it is important to understand that.

So therefore this is what I am saying that even for industrial processes there is obviously analog Behavior everything is analog but if the if we know that the analog behavior can be taken care of by the analog controls which exists at a lower level then the problem can be simplified if we assume the existence of suitable analog controllers then the problem can be simplified to that of only specifying sudden discreet command and how those commands will be realized that is taken care of by something else.

So we are not interested in modeling that therefore we will simplify the models and use different models and then solve a sequence control problem that is the whole idea right so it is very important to understand that.

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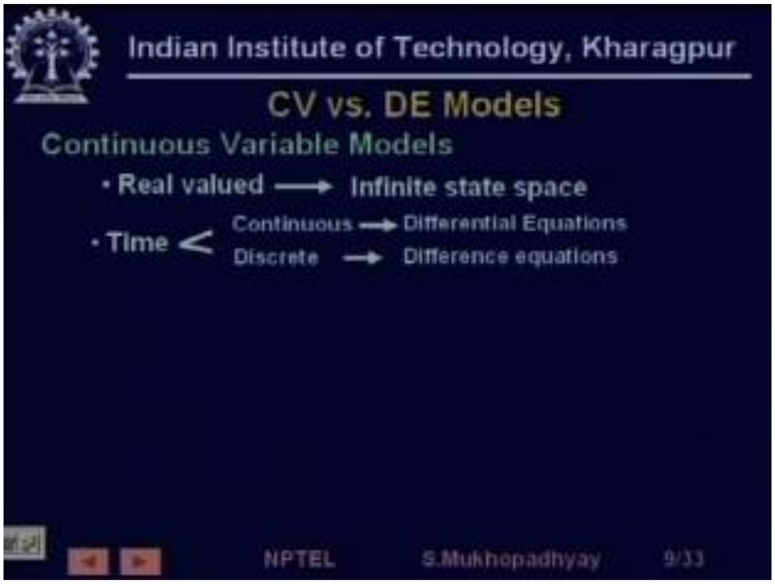

If you look at continuous variable models they are the signals a real-valued they have they have actually have an infinite number of possibilities of values and time is also time is sometimes continuous sometimes discrete so when we have continuous time models then we have time continuously varying but for all practical implementations especially using computers we must discredited time that is we must consider values only at certain instants of time.

Now you must realize that we are discrediting the time axis we are not discrediting the variable value variable value is axis is still continuous variable value can be anything so but the time axis is sometimes discredited so that is why it is called a continuous variable models where variables can take any value contrary to this in discrete even models.

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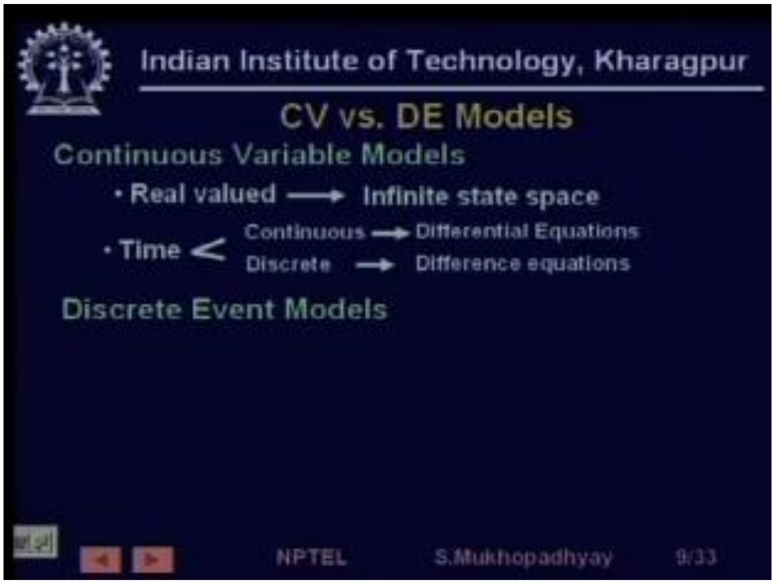

Which are which we are going to use for sequence or logic control problems typically the values of variables that we will consider will be considering finite so let us say our typical example is on off you know some tank level low medium high so we are not interested in knowing what exactly how many meters we are only considering we are already thinking that the tank is in the tank level could take one of three symbolic values.

So each of those symbols actually represent some kind of an analog level value range so if it is 0 to 2 meters we just call it low we indicated by a symbol low if it is 2 to 4 meters we call it medium and if it is 4 to 6 meters we call it high so we may define a control problem where we are not interested in knowing the value but we are only interested to see that the moment the water level falls from low to from high to medium start the pump. So we are we are interested in specifying such things.

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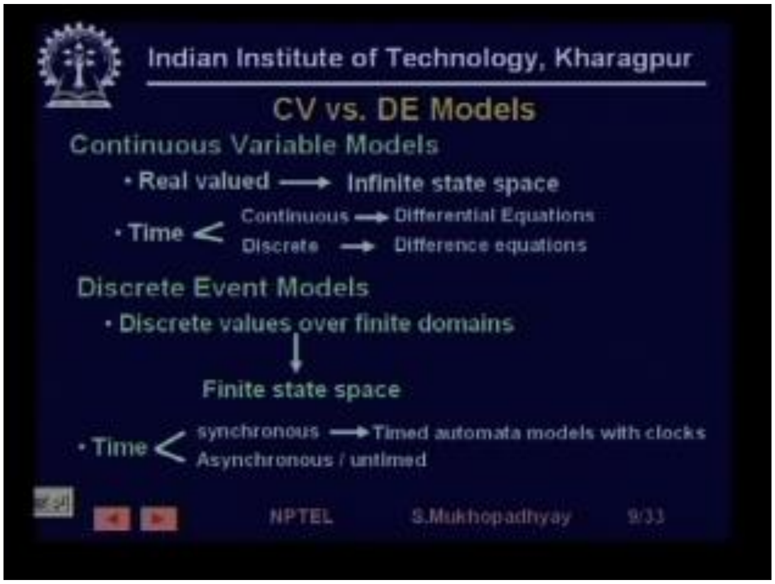

Discrete values over finite domains and therefore we have we have we have what is known as the finite state space so the combinations of variables that can exist in a in a in a system are going to be finite similarly time you know we have two kinds of models this we are not going to see too much but we have two kinds of models called synchronous or an asynchronous where you know the way we assume that all variable changes also occur at along with some clocks just like just like a master-slave flip-flop is a synchronous device so you know.

So sometimes we have a synchronous so at any time certain variables can change so it's like you know time discretization here so if the time is if variables can change from one value to another value at any point of time we call it asynchronous if it only happens ascertain periods of you know clock ticks we call it synchronous so this is the so once we quantize once we create a discrete you know this kind of enough discreet finite state description of the system then it is easy to construct the then we can construct the behavior of the system.

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So typically we have in such systems three kinds of variables they are the input variables input variables are some things which are applied externally okay there then there are output variables and then there are state variables so output variables are something you know which we which we can say which we can maybe sense or see and there may be some other variables which we cannot see but the but the system goes through there okay so typically consider systems and in most of industrial control problems we have we have only a finite number of system states .

Now these states what is behavior is the is the pattern by which states change from the amine system continuously moves evolves from one state to another. Now why should the state change the state change could change either by an external event so you so a room was in dark state now you know somebody comes and gives an input or changes an input variable say as witch from on to off to on so as a consequence of this the system the room state goes from dark to light it right so this is a state change caused by an external events sometimes systems also go by because of their internal dynamics without any other external input given it can it might it might change state right.

So there may be some arrangement in the system by which suppose after it is made on let us look at a let's look at a mono short-timer you know he is a common electrical examples so there maybe something that once you press it some bulb glows up and then its dynamics is such that that again after some time by itself without any input being applied it will come down so state changes are sometimes caused by external events and sometimes caused because of you know their own internal dynamics they might come down.

Similarly state changes also at every state there are there are some outputs which are exerted by the systems as states change as the system goes from one state to another the outputs are also changed and these outputs changes are perceived in the external world and there are sometimes called events right so you could have events or outpost caused by state changes.

So this is so when we have to describe a system will we will presently see an example we have to basically wherever we want to model a system for the purpose of logical sequence control we have to find out which are the variables which are the input variables which are the output variables how those change what input change what input exertion causes what state change so basically if you can describe these then we have got the system model.