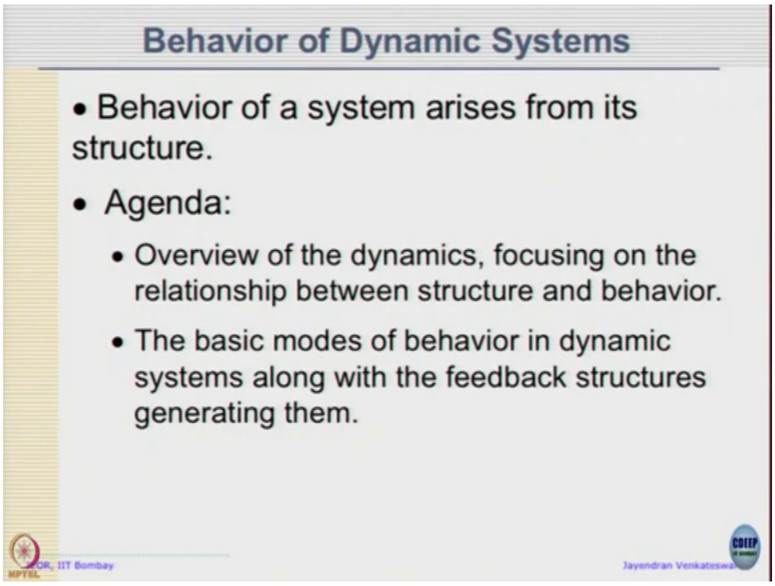
Introduction to System Dynamics Modeling
Prof. Jayendran Venkateswaran
Department of Industrial Engineering and Operations Research
Indian Institute of Technology, Bombay

Dynamics of Stocks and Flow (Contd) & Patterns of Behavior
Lecture – 6.3
Patterns of Behaviour: Types

So, brief introduction I want to give today is on something called as Patterns of Behavior which is kind of follow ups on that.

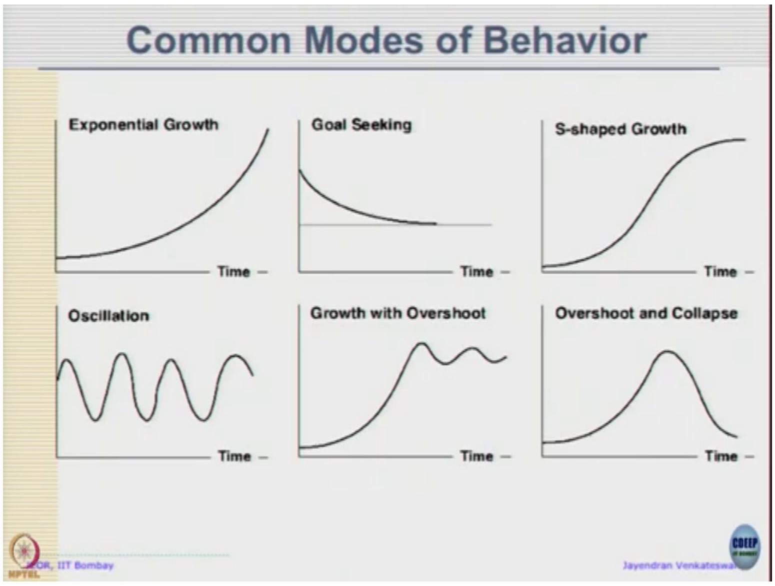
(Refer Slide Time: 00:23)



See we all know why we are trying the system dynamics is because the behavior of system arises from its structure that it's fundamental idea that we are trying it out. We are not saying that the entire behavior of system is exogenous. If you do it, then there is nothing there is no need for solving any issues or trying to model a system. We are trying to understand only because we know that the behavior and the system arise from its structure.

So, in this set of lectures what we are going to do is overview of the dynamics, what kind of dynamics actually are out there, how many types of graphs we can actually see and based on that is it possible to actually isolate or classify these dynamics. And if we can think of classification surely people already worked it out and are there any generic structures that we can come up with in our causal diagrams that we have been seeing, this can be used to kind of explain those dynamics. So, that is what we are going to see without much it is funfair. These are the basic modes of behavior.

(Refer Slide Time: 01:30)

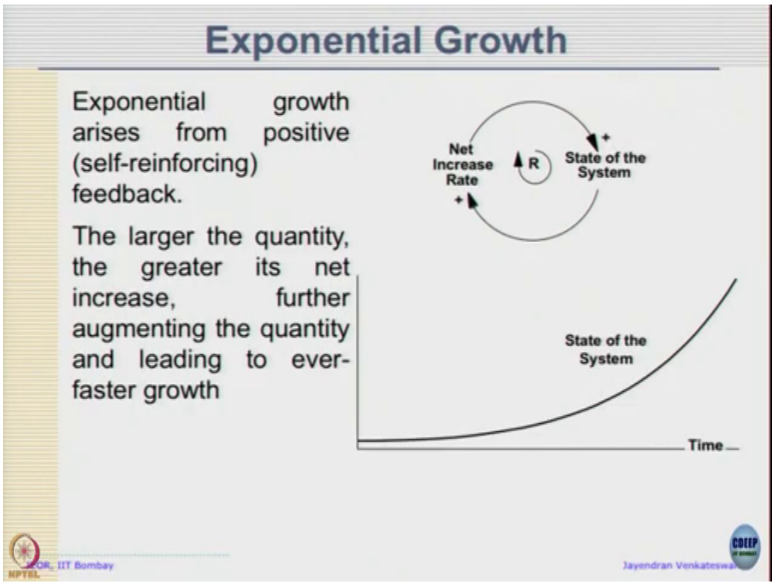


Exponential growth, goal seeking, S-shape, oscillations, growth with overshoot, overshoot and collapse effects. Exponential growth its very easy to imagine and goal seeking and oscillations are kind of very fundamental behaviors. A combination of these three systems is what results in other behaviors called as S-shape growth, growth with overshoot and then over shoot with collapse.

So, this goal seeking can also have a behavior from zero and saturating there that is also kind of goal seeking it can go like this exponential is increasing like this. So, other one is called accelerated collapse which goes like this and then falls down like that.

So, that is called an accelerated collapse which is common in when stock market collapses. It is usually not a slow collapse; it is an accelerated collapse. That means overnight things crash then that can be modeled as using the same underlying structure that we use to model Exponential growth.

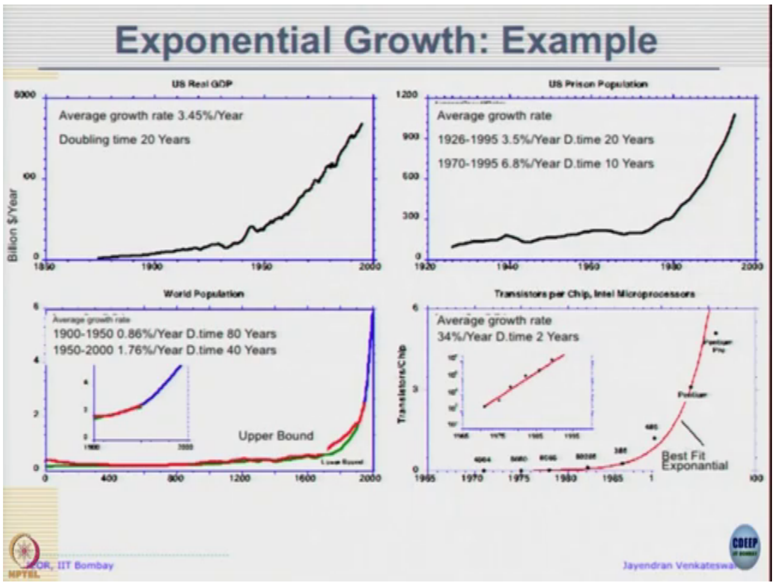
(Refer Slide Time: 02:39)



Let us quickly look at it exponential growth. That means there is a positive self-reinforcing feedback in the system. That means the state of system is there and the net increase, there is a net increase in the system and the contribution state of system. State of system again contributes to the net increase rate and that is going to feed each other until it cause an exponential growth.

A simple example could be if you have bank account, then interest keeps adding to the account and then every year it just gets kind of accumulates those amount may be small. We leave it for 100 years and you get a very large amount of money. So, that is the exponential growth. So, state of system if you plot, you will get an exponential increase.

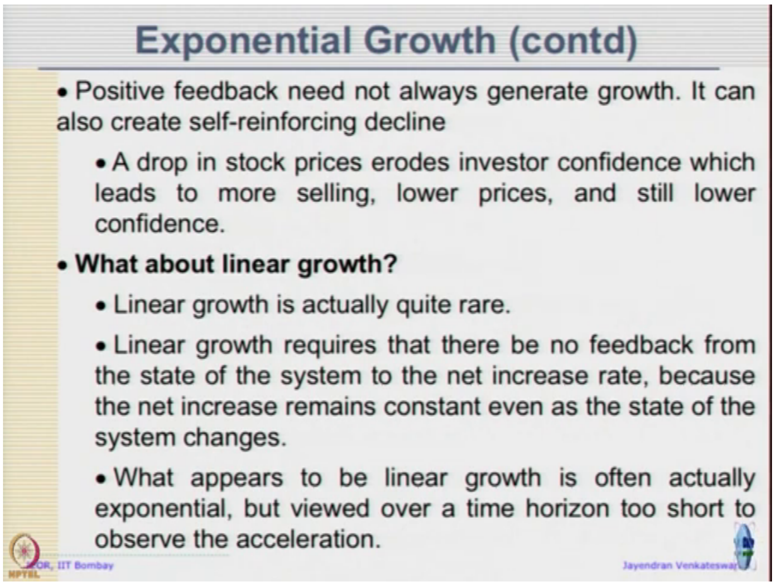
(Refer Slide Time: 03:31)



It is common in many scenarios. For example, if you are modeling the what is it US GDP average growth rate is 3.45 percent per year and doubling time is 20 years. US prison population again as I told if you draw the correlation it will be high, but that does not mean anything.

So, or world population transistors per chip or many other behaviors of biological systems wherever have you seen in paper, you may see when he sets graphs for systems. All it means is there is an underlying positive feedback reinforcing loop where the net change in loop affects the state of system which affects the net increase rate in a positive fashion which results in exponential growth. So, if you see such behavior that is underlying model that we have to discuss in where is that loop that is occurring.

(Refer Slide Time: 04:37)



Positive feedback need not always generate growth. It can also create self reinforcing decline as it will accelerate decay. Like a drop in stock price, erodes investor confidence which leads to more selling lowest prices still lowest confidence, but it happens so fast that it results in collapse.

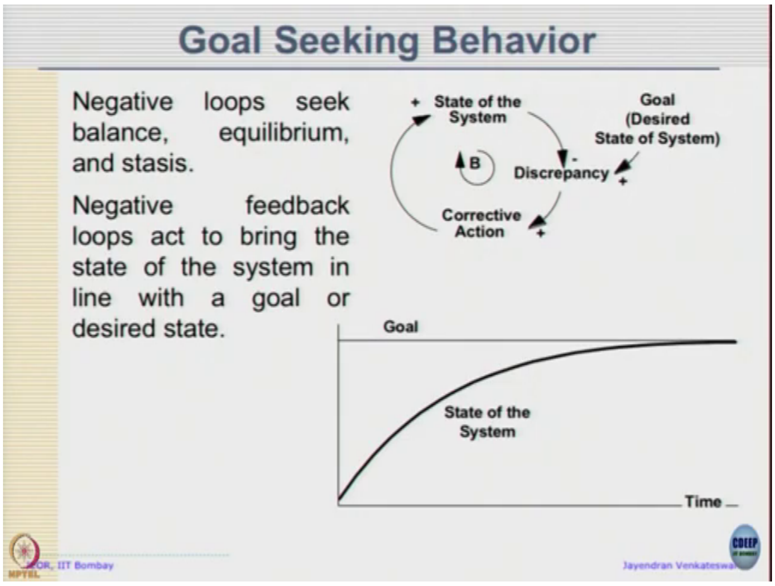
Many such thing in India you can occurred like you know when I am not sure whether you have heard it like this chit funds and when there is a rumor that bank or wherever you put money is unable to pay you, then there is huge rush of people suddenly trying to withdraw money leading to collapse. That is what I mean by accelerated collapse.

Initially people are fine, then suddenly one guy goes and he is denied money today, then he goes and talks to people and then suddenly the message goes so fast that this results in accelerated collapse in the system. What about linear growth? Linear growth is actually quite rare.

Linear growth requires there is no feedback from the state of the system at all, it just happens on its own there is no feedback because net increase rate must remain constant even if system state changes. Only then you will get a linear growth, we just plotted it. So, that means there is no feedback coming in about state of system. So, then there is what?

So, the other one is what appears to be linear can actually be exponential, but viewed on a very short horizon. The time horizon is very very small and will find that the growth looks linear but actually if you wait long enough, it will result in a feedback within the system. So, that is an exponential growth.

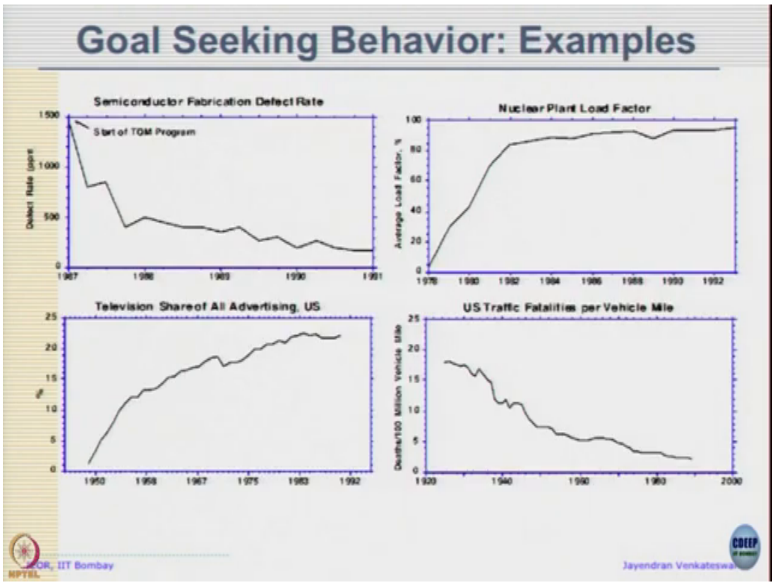
(Refer Slide Time: 06:14)



So, the general structure for a goal seeking behavior there is a graph we saw. So, whenever there is a goal that seeking behavior, it means there has to be a goal. There is entire you know the title is self revealing, there is a goal. That is a goal seeking is a desired state of system there is actual state and major discrepancy I am taking a corrective action and I am going to correct it until I restore goal whatever it is.

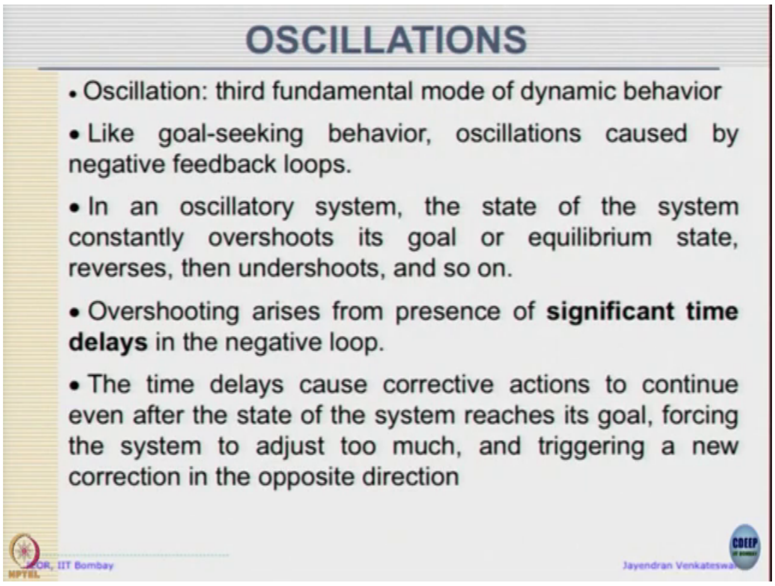
So, this negative feedback loop acts to bring the state of system in line with the goal or the desired state that we want, itis quite intuitive. The behavior we can expect it something like this. The goal can be approached from the bottom to the top or from top to the bottom.

(Refer Slide Time: 06:59)



There are nice examples like semi-conductor fabrication defect rate. If we model defect rate when it is exponential kind of goes down exponentially that is goal seeking behavior. Nuclear plant load factor can rapidly increase up to over 80 percent load, but afterwards very very slowly it increases or television share of all advertising US traffic fatalities per vehicle. So, all these things over kind of a goal seeking behavior over time. Again x axis is time we are looking at time changing behavior.

(Refer Slide Time: 07:36)

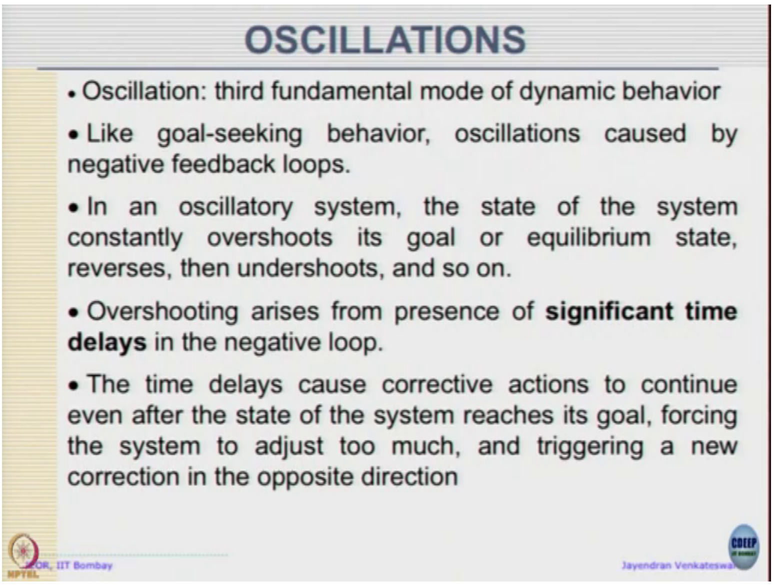


The third fundamental mode is called Oscillations. Like goal seeking behavior, oscillations also is caused by negative feedback loops, but something is constantly changing right that is what oscillations mean. This very simple modeling kind of construct that causes that fluctuations is the presence of delays in the system.

If you do not know the current state precisely, then you are going to assume something and take a corrective action and the corrective action takes some time before it affects the state of system and it takes time for it, observe the state of system and then identify the gaps and then decide which character I should take. So, all these delays allow makes us to overshoot our goal, then again go below the goal, then again we take corrective action, go above the goal etcetera.

So, we are kind of oscillating through or oscillating over time. So, overshoot arises from presence of significant time delays negatively. So, when you observe systems whose graphs has oscillating behavior, then the thing you should understand is there are some significant time delays being involved. Let us start to identify those time delays, what is causing the delay, how we can reduce it or just identifying it right. Now, we are not prescribing action, we are only trying to understand and discover what is happening.

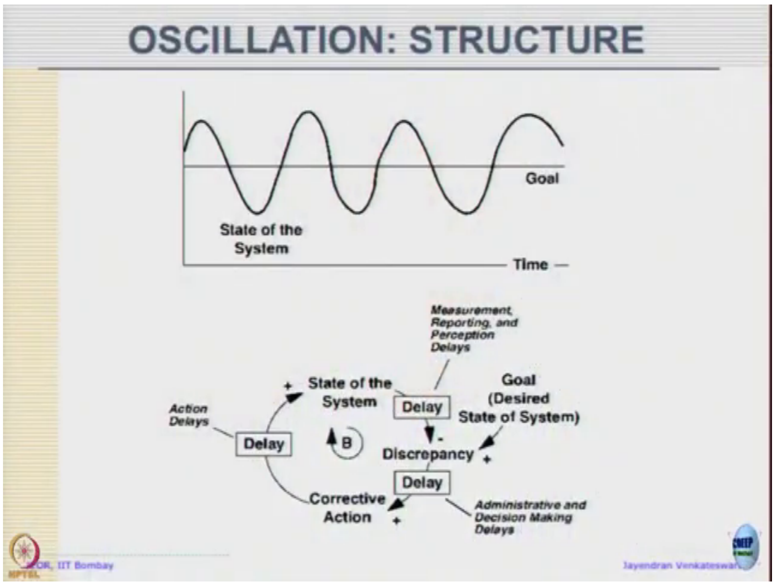
(Refer Slide Time: 08:54)



So, if there is oscillations for example, it takes time for a company measure and report inventory level. Trust me or not people do not have good inventory visibility. If you look at a warehouse, it takes a week or even a month to figure out what is the inventory, but we during the month there are so many transactions. So, value you got was itself kind of redundant now.

The time for management then has to meet based on that you know all managers will meet have some meeting, 2-3 weeks later make some nice fancy power point presentations and somebody who said this a corrective action and then some memos will be issued and corrective action suggestions will be taken. So, all these things involve lot of delays. The result is you are going to have oscillations right, sufficiently long delay at any one of these points will cost inventory to oscillate.

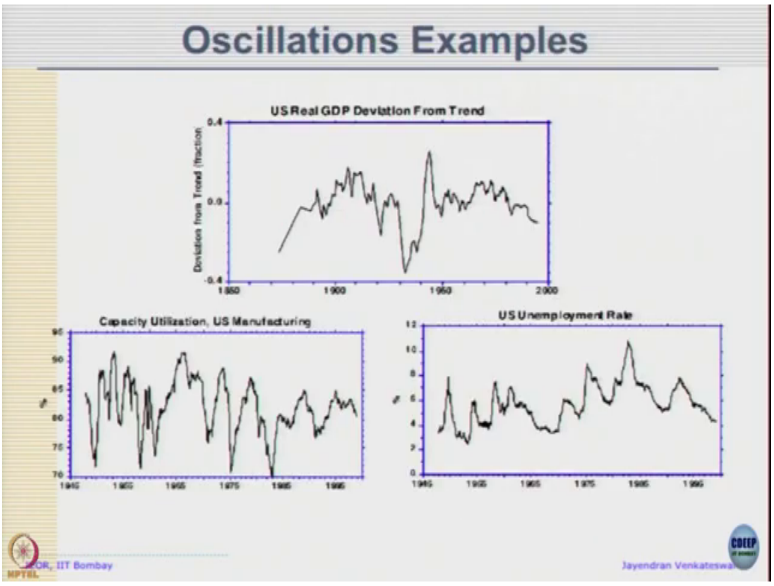
(Refer Slide Time: 09:44)



So, the underlying structure is very similar to goal seeking system except that now there is a measurement, reporting and perception delays in the system between the state and discrepancy, discrepent, the corrective action, this administrative decision making delays that is involved in the system and within corrective of action state of system there are something called as action delays.

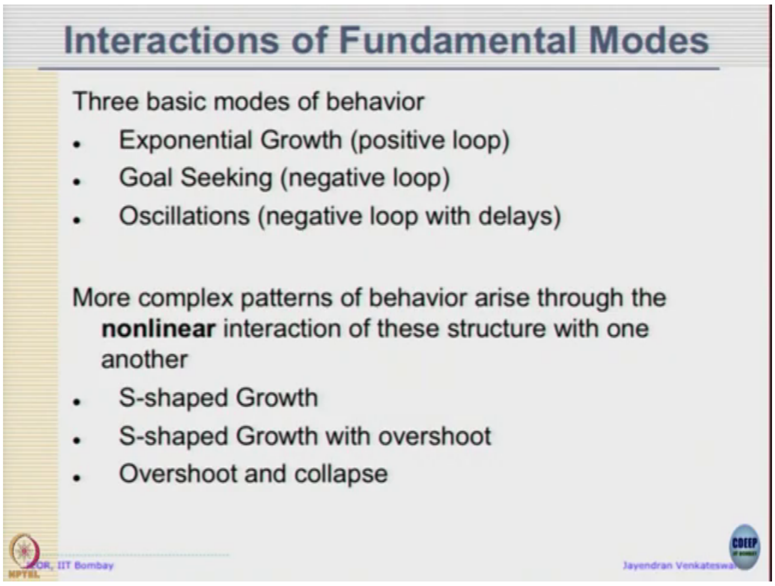
Even if I say this is what has to happen, we do not do it even if you know assignment is due tomorrow, yes I have to work on it you will say [FL]. So, that is called action delay that is delaying throughout action and then it will ask you to oscillate and again we are not trying to solve the problem, we are just trying to understand and model it right now.

(Refer Slide Time: 10:26)



Again unfortunately fortunately there is a nice graph. Unfortunately reality is not so nice and smooth, but still you can figure out there is some oscillation that is happening like the capacity utilization manufacturing or unemployment rate or US real GDP. So, that means there is a lot of delays that is happening without decision making. It is not that people do not have goals, people have goals, but somehow there is a lot of delays in various points. Let us try to uncover that and capture it in our model. So, that is what this rise to teach us.

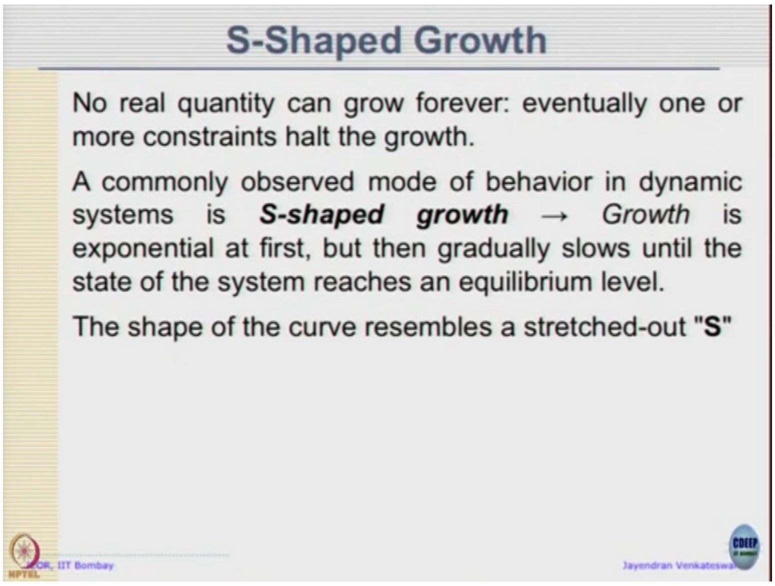
(Refer Slide Time: 11:02)



So, these are the fundamental modes, exponential growth; positive loop, goal seeking; negative feedback loop or there is a goal oscillations there is a negative loop with delays. A mix of these can cater to more variety of behavior. The more complex patterns which are where the there is a non-linear interaction in the structure like for the exponential growth and goal seeking will find that the underlying structure is actually a linear model.

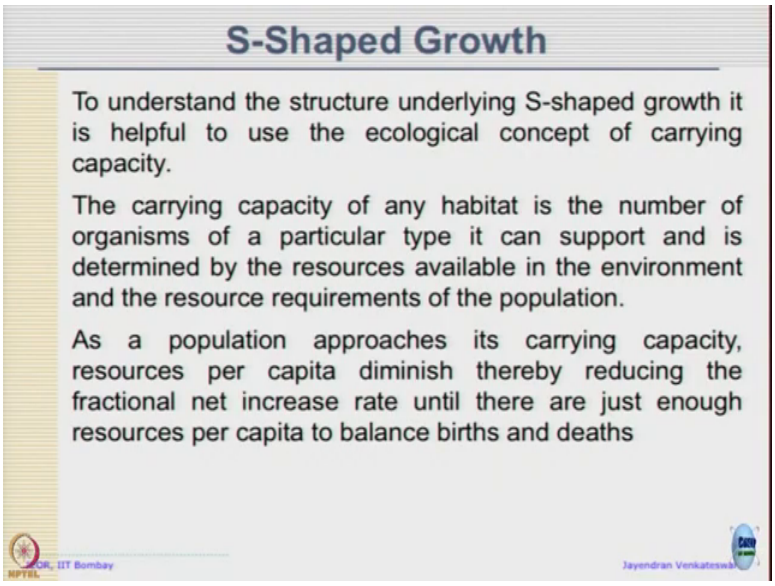
So, you can actually apply various linear control systems techniques to look at them, but once system becomes non-linear when you will get more interesting behaviors, you can get S-shape growth. S-shape growth overshoot, overshoot collapse and things like that.

(Refer Slide Time: 11:49)



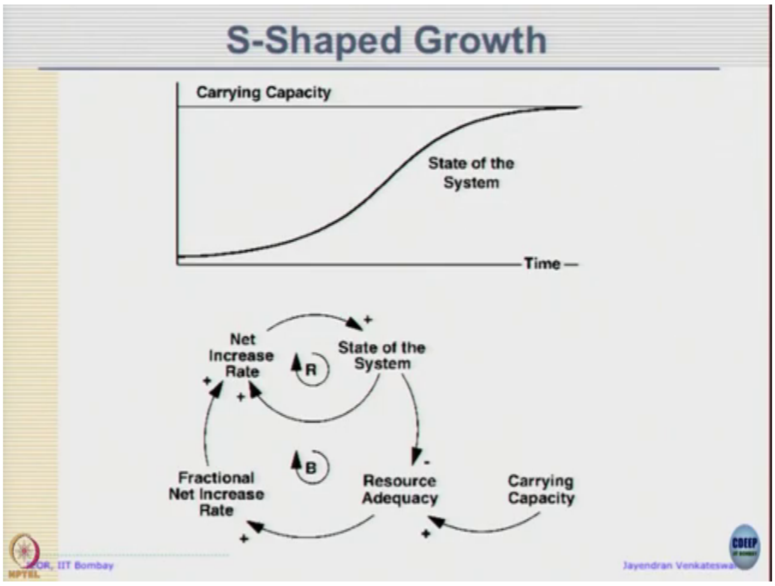
Let us quickly explain what is S-shape growth. No real quantity can grow forever, eventually one or more constant halts the growth. A commonly observed mode of behavior in dynamic system called S-shaped growth; that is growth is exponential at first and then gradually it slows down until I hit the state of the system, rapidly increase and then slowly saturate or reach the equilibrium. It kind of resembles a stretch goal yes.

(Refer Slide Time: 12:16)



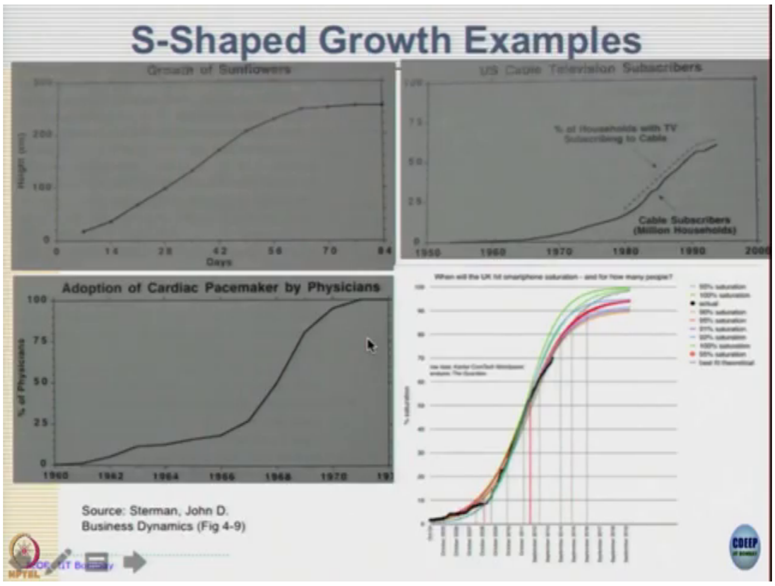
So, one way to understand it is there is some sort of a carrying capacitive in the system like or rather initially the system allows you the exponential growth after which some constraints starts limiting its growth. Recall the land use example I talked about. Currently there was a lot of lands, the people started coming and as the lands capacity starts increasing, we can expect that the growth will seize at some point.

(Refer Slide Time: 12:44)



So, that is what is written here say S-shape kind of a stretch growth as so the first part is you can see here is exponential increase at some point it starts to slowly saturate. Initially the positive feedback is active and starts growing the system very nicely up to this point after which the carrying capacity of system that how much system can absorb will start to dominate and then, it will decrease the overall rate of increase which will allow the system to saturate at some point.

(Refer Slide Time: 13:19)

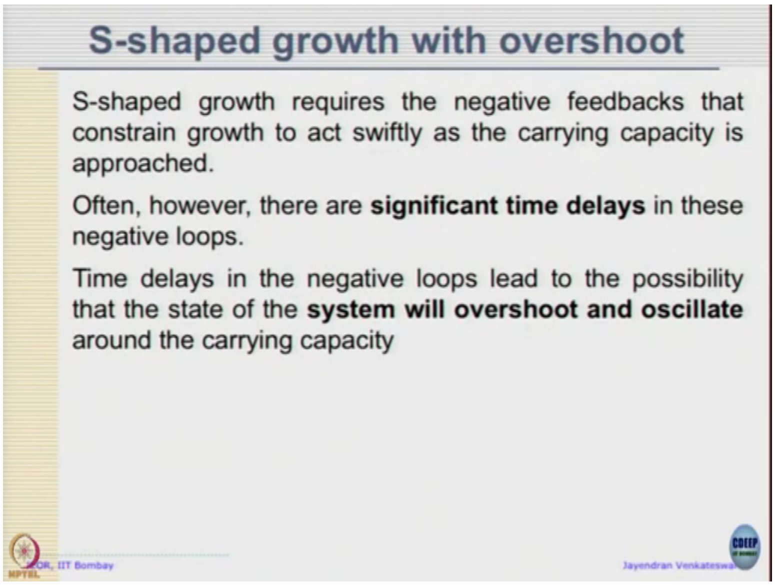


,

You can see many such examples like say growth of sunflowers, US cable Television subscribers, adoption of pacemakers by physicians. When will UK hit Smartphone saturation? So many such options are given all other kinds of S-shape saturating.

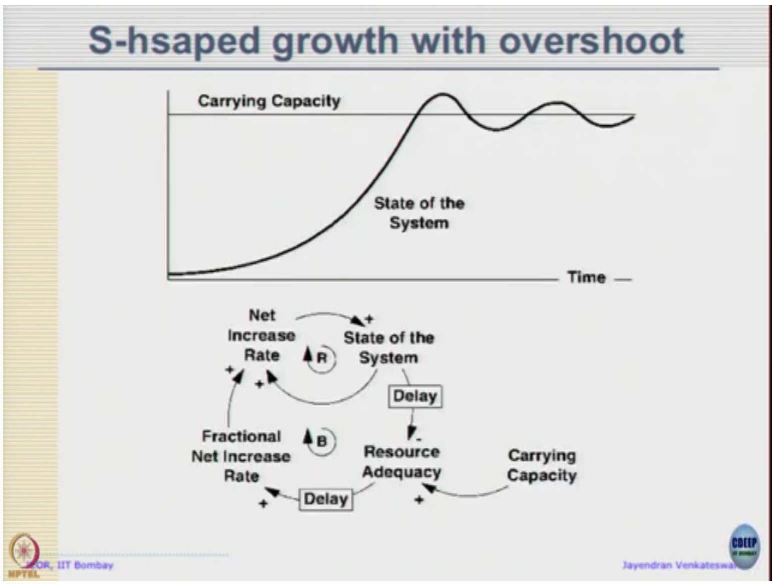
Once everybody buy cell phones, they are saturated. Now you are expanding people second cell phone, third cell phone etcetera. We look at replacement purchases and things like that. So, there is a positive loop with a negative loop again there is no major delays in the system. Without delays itself it kind of choses shape over time. If a delay happens what will happen? We can expect some oscillations right.

(Refer Slide Time: 14:04)



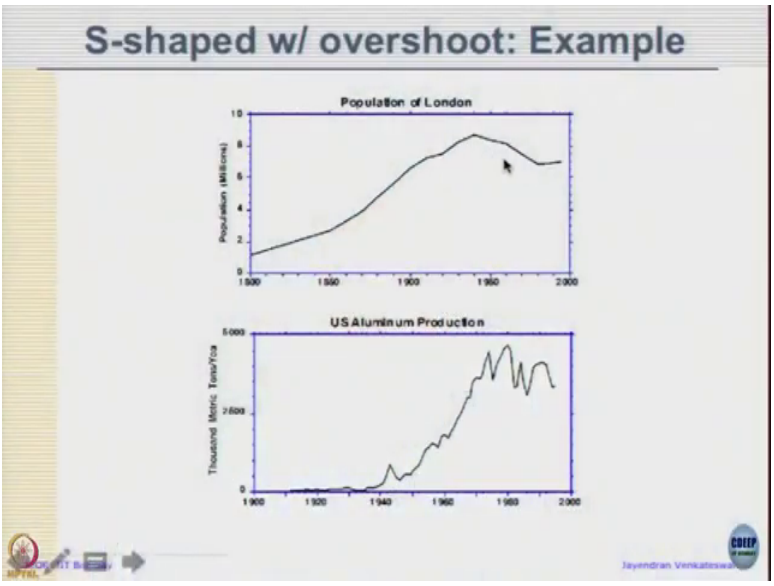
It exactly will happen, if there is significant time delays in negative loops, then you end up having oscillation because you will overshoot your goals and then again you are taking very drastic corrective action again it falls down.

(Refer Slide Time: 14:16)



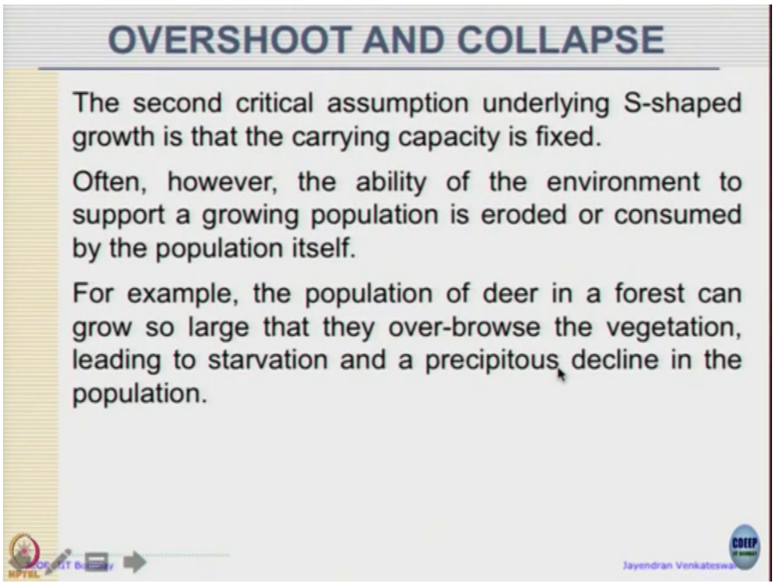
Very similar idea exponential growth again over goal, but there was a delay before negative feedback kick them. So, it allows you to overshoot and then you take more corrective action came down and again you go up and kind of fluctuates.

(Refer Slide Time: 14:35)



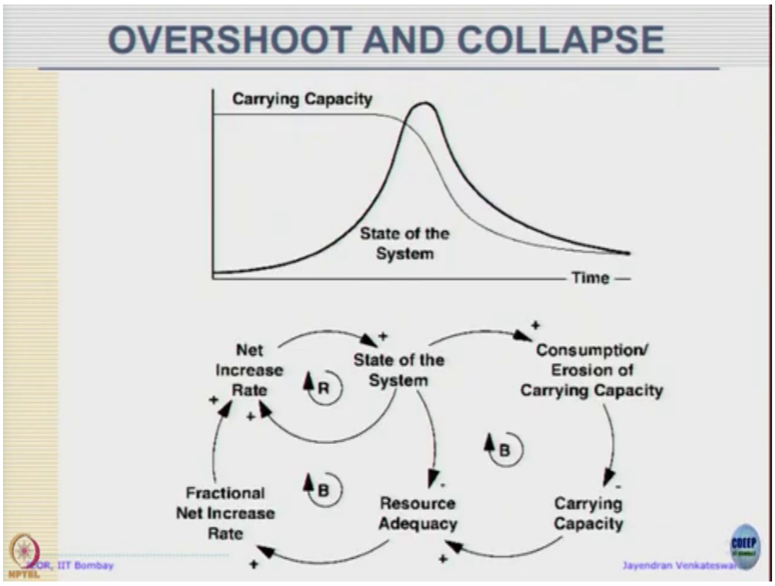
So, whenever graph goes up and then kind of comes down maybe it is going to go again up sometime in future. So, exponential growth kind of dipping and coming down. Similarly here aluminum production goes up, saturates and then starts fluctuating at around the point perhaps it is an S-shaped growth. So, here there is no rules, no regulation, lot of aluminum production zoomed after that you are using the resources that puts a constraint in the system.

(Refer Slide Time: 15:04)



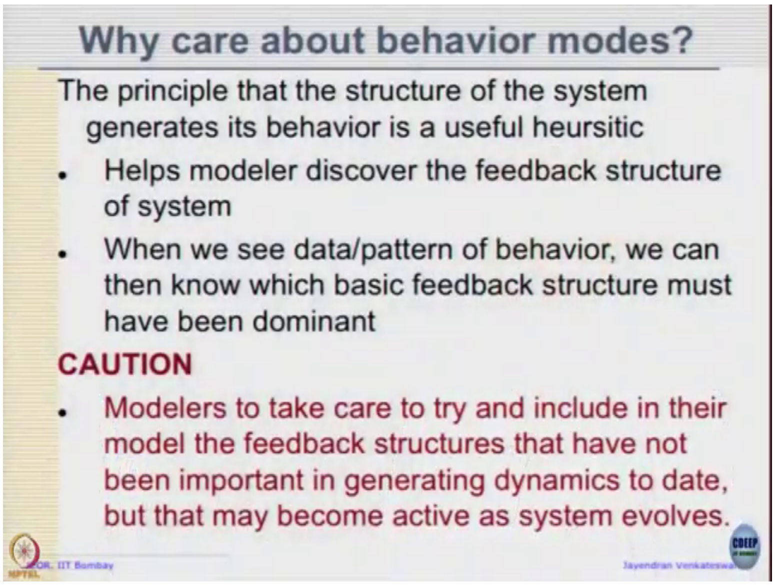
Second critical assumption underlying this S-shaped is a carrying capacities is fixed. In some reason the carrying capacity starts eroding faster you are not going to oscillate, you are going to come down crashing because system cannot take it anymore. So, that part is for example, population of deer can grow so large that the overgrowth vegetation leading to starvation and precipitous decline in the entire population itself.

(Refer Slide Time: 15:33)



So, behavior could be it increases and then goes above your capacity and starts oscillate, but then rapid collapse happens. So, the left half is same as what we saw earlier a few minutes ago, but now the carrying capacity also is affected by state of the system consumption, erosional capacity. Such capacity falls down this loop becomes more tighter. That means, you actually reduce your goal a nice ambition, but whatever reason your goal itself eroded and once a goal eroded, then your entire system state to start following that particular goal because this becomes a dominant behavior.

(Refer Slide Time: 16:12)



So, why care about these behavior modes? See the principle that the structure of system generates behavior is very useful heuristic. So, we can try to learn to ask right questions. It helps modeler discover the feedback structure of system, when we see data and patterns of behavior we can then know what basic feedback structure might have been dominant different points in time. If you see S-shape then you know there was some positive feedback sometime in the past.

So, what was it that was enabling it? Maybe it was a good administrator, maybe there was absence of rules something has happened oh great, but now it is not it is kind of saturating. So, is there any other dominant loop that is happening? It allows us to uncover what kind of dynamics that could have occurred which we will get only if we look at it over time, so its not.

So, math alone is not going to help you just getting your correlations and it is not going to help you have to understand what might have increased, then what kind of links could have been there, then work with that. Quick caution is if you are only looking at the past, then we do not know what is happening in the future. So, that also has to be kept in mind.

So, yeah I want to do this quick introduction because we will be revisiting this again and again or expect you to revisit it again and again because in this course what we are going to do is from next class, same model, the positive feedback system simulated learn how to actually put in numbers and simulate see the properties how it work happens.

Then simulate goal seeking systems, various kinds of goals seeking systems whether you are able to achieve the goal, not achieve the goals things like that and then we will start increasing the delays within them and see you are able to replicate these kind of behaviors. So, when as and when we go doing that and then we will do S-shape growth, we will do more complex systems where you know in mix of all these behaviors.

So, it will be good for you to always come back to this and use it as a reference because sometimes a model becomes so complex because we are using so many variables, but underlying structure will be only this. We have added more variables just for the completion of problem, but the core structure will always come back to you.

So, you keep this as a reference keep looking at it, but we will be spending enough time with each types of behaviors in the first half of the course. And second half we will start looking at modeling of system, more deeper analysis and more prescriptions and things like that.

Thank you. I will just stop here.