Intelligent Systems and Control

Prof. Laxmidhar Behera

Department of Electrical Engineering

Indian Institute of Technology, Kanpur

Introduction

I am Laxmidhar Behera, in Department of Electrical Engineering, IIT, Kanpur. I will be teaching you all Intelligent Control and this will be an introductory lecture; this is the first lecture. In this introductory lecture, I will cover those aspects of intelligent control that will give you a holistic view or a complete picture of this subject. Why intelligent control? Why we should learn this topic?

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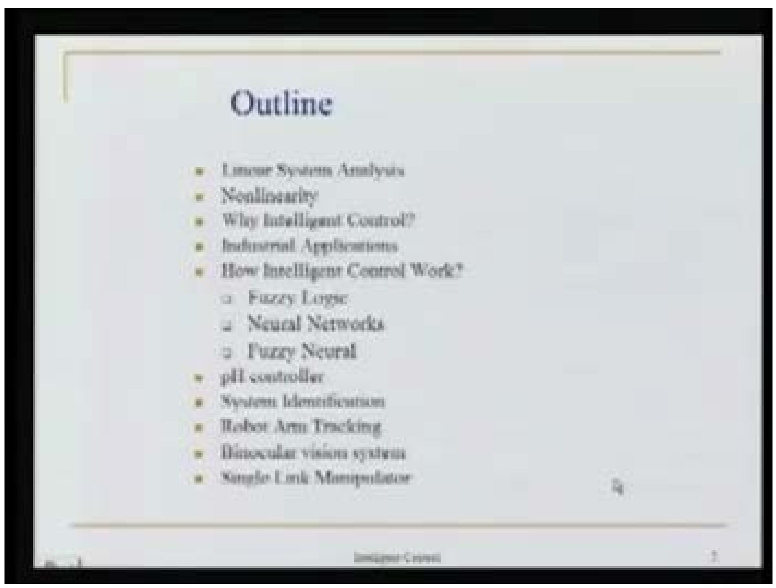

Here is the outline. All those who will be looking forward to attending this lecture series I assume that all of you have sufficient background on linear control systems. When we talk about intelligent control, most of the time we talk about controlling the non-linear systems. One of the reasons for studying intelligent control is that it is not so difficult to design linear control systems, but is difficult to design non-linear control systems. We will cover in this intelligent control course, fuzzy logic, neural networks and fuzzy neural; these are the tools. There are various tools, actually for intelligent control techniques. But, in this course we will limit our focus on these three things - fuzzy logic, neural network and fuzzy neural network. In today's introductory class, I will show you some of these typical examples, where intelligent control is pretty nice. They are pretty interesting as well as exciting, also challenging.

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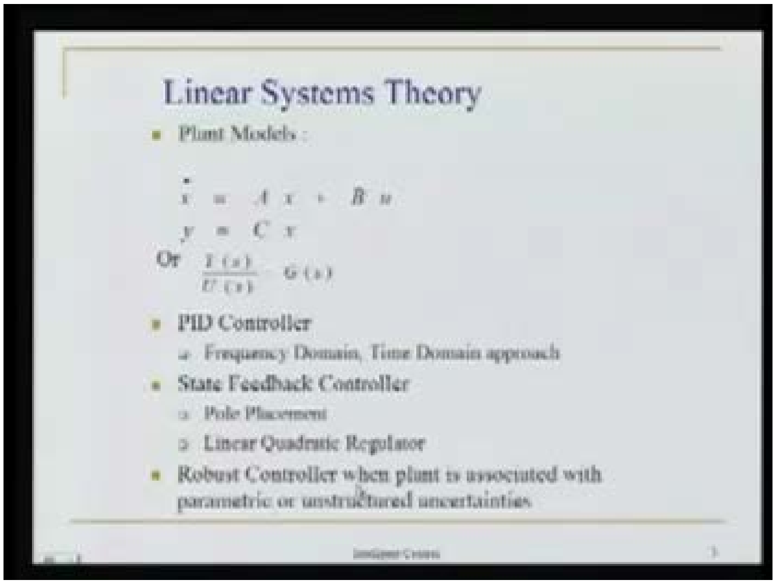

I will just remind you what linear systems theory is. You express the system model either using state space or using transfer function. Let me tell you how you design a control system? We have a plant. The plant maybe a power system, plant maybe a pH reactor, plant may be a robot manipulator; any physical device that is of interest to us and we want to control the device. Controlling device means that we regulate some of the variables that are of importance in this device, like maybe speed of a motor or the pH value of a reactor or the voltage level in the power system bus bar. There are various physical variables that we would like to govern or control. Before we can control, we must know the system as it is, the plant as it is. That is where we talk about mathematical models. Once we derive a mathematical model and these mathematical models are derived using the basic principles of science whether it is physics, chemistry or biology, we have physical laws in these fields. Using these laws like, for example, if I am simply talking about the motor, the dynamic model of a motor, I must be very clear about the principles by which electro-mechanical device works. There is a mechanical principle, there is an electrical principle combined together.

These physical principles should be very clear to me before I can prescribe a physical device using a mathematical model. These mathematical models can be of various types, but popularly they are either state space models or transfer function models. Once you have a mathematical model, we do not again look at the physical system for designing control system. We design a control system for the mathematical model and after designing a control system for the mathematical model that we have derived for a physical system, we test on the real system our control algorithm. As far as the design is concerned, always we value the mathematical model of the system that has been derived and these two categories either state space or transfer function, those are very widely studied in literature and most of our control systems are based on these two different models.

As far as transfer functions are concerned the industrial controllers are normally designed, the PID controller, either using frequency domain approach or time domain approach. All of you might have heard about root locus method that is under time domain approach, using Bode plot Nyquest diagram, this is the frequency domain. In state feedback controller, you must have heard about pole placement, linear quadratic regulator; this is an optimal control and also, robust controller. This is another type of controller, when we assume these plant models are not exact; they are inexact. This is a kind of an overview of the linear systems; that is, we have state space model or a transfer function model of an actual plant and for these two models, we design various types of controllers. For transfer function, we design a PID controller or PID compensator using frequency domain or time domain approach and for state feedback controller we design pole placement linear quadratic regulator. When models are not exact, when there are certain uncertainties, we talk about robust controllers. If I design a controller for a particular plant with certain uncertainty, the mathematical model is given to me, but that is little uncertain. Then how robust is my control system in the presence of uncertainties?

Another question is that the linear systems are very well understood most of the time in literature. From design-principle-wise, linear systems are well covered. But is our system linear? This is a very formal question: is our system linear - the real system; physical system.

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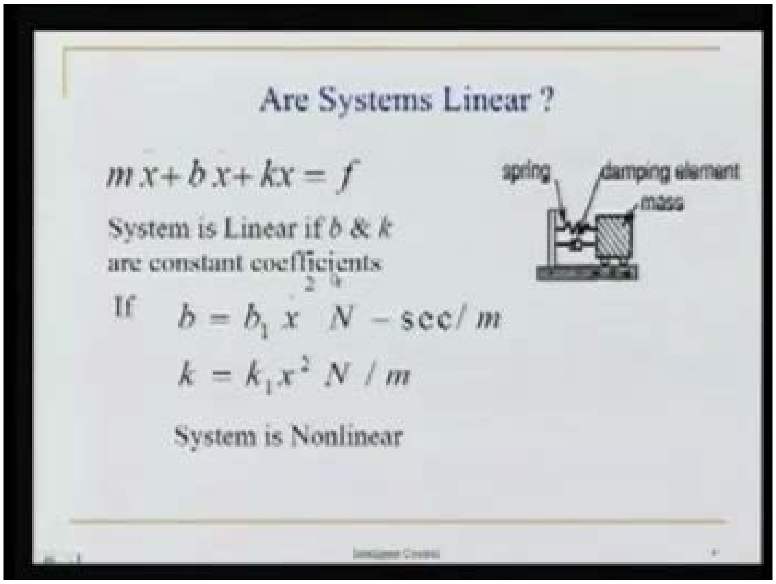

Here is a simple, familiar physical device that you are looking. This is mass damper and spring system. I would expect that you have taken the control system course and you must have studied this system in the beginning of the course. This is a popular second order model of this mx double dot plus bx dot plus kx equal to f. The system is linear. If b and k are constant coefficients, then the system is linear, but if these coefficients b and k have the following functional relationship b_1x dot square is b and k_1x square is k and if we put these things here, the system becomes non-linear. What I am suggesting to you is that most of the times the physical systems, although the model is a linear systems theory, they are non-linear and there are also systems which are inherently non-linear.

I will take a special class on non-linear systems during this lecture series, but we will not talk much about this difference between linear and non-linear. From the mathematical principle, we will discuss that as course progresses. What I am trying to say is that most of the systems we encounter are naturally non-linear rather than linear. For non-linear systems, researchers and control engineers have developed various theories to tackle these kinds of plants. When the plant is non-linear, there are certain popular control methodologies. You have not come across these methodologies in linear system theory.

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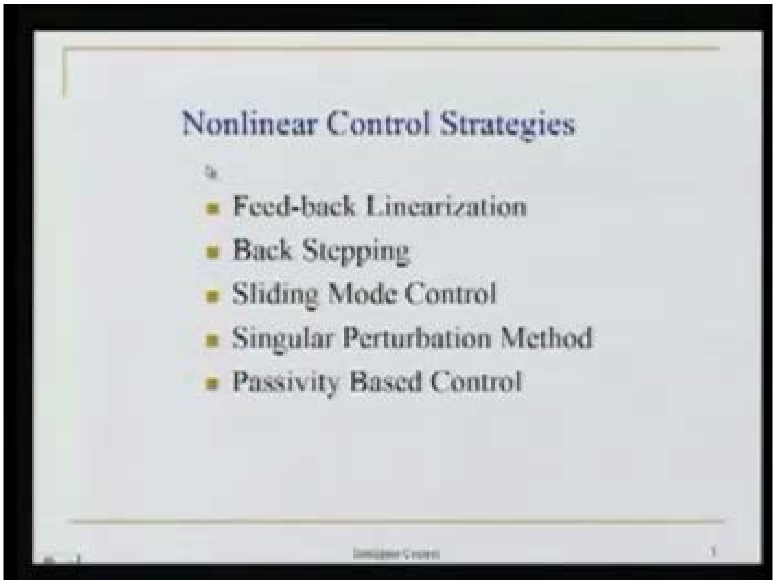

They are known as feedback linearization, back-stepping, sliding mode control, singular perturbation method and the passivity-based control. These are all various categories of non-linear control methodologies. We will not be discussing in detail about these methodologies, but we will adapt these principles while designing intelligent control. In intelligent control, it is not something concept-wise. Apart from what we are studying, linear control theory or non-linear control theory, rather these concepts are taken very nicely and in a very convenient manner they are put forth in such a way that the control designs become very easy and particularly, you can adapt to any kind of plant.

Here is the limitation of non-linear control strategies.

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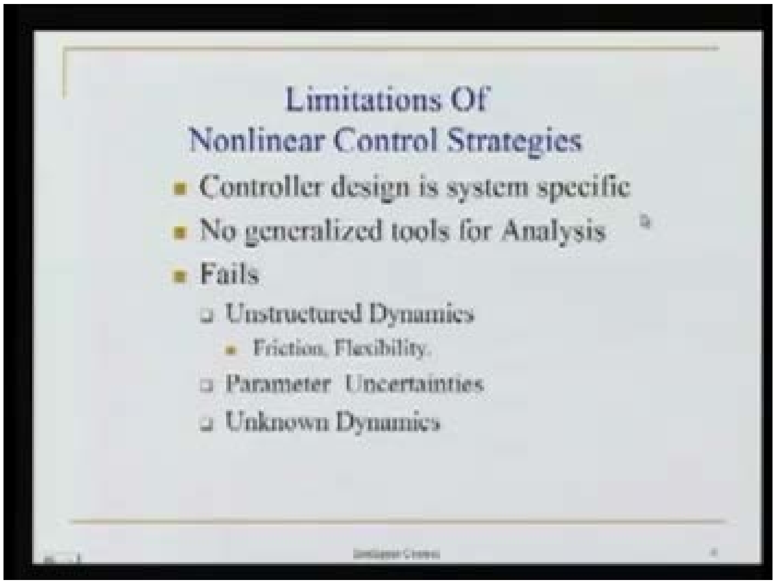

The controller design is system specific. Normally, just like a linear system theory, for a generalized second order linear system you can always have a generalized control law. Similarly, for a generalized nth order system, you can have a generalized control law. but controller design for non-linear control system you cannot say that it is some …(Refer Slide Time: 12.45 min) Every non-linear system has a different structure and that is why we cannot actually make a kind of a generalized control law for a non-linear system within the domain of non-linear control theory.

That is why the controller design becomes system specific. We design a control system for a specific non-linear plant with specific non-linear model. No generalized tool for analysis actually is present in non-linear control theory. Also, whenever there is unstructured dynamics, then this theory may fail that is the stability may not be guaranteed. Also, when there are parametric uncertainties, unknown dynamics we do not know how within the paradigm of non-linear control theory they can be taken into account. Although we have certain methodologies to adapt, the robust control methodology, adaptive control methodology for non-linear system to take some of these issues into account, but in general classical non linear control strategies are not so robust against unstructured dynamics, parametric uncertainties and unknown dynamics.

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That is why we are now talking about intelligent control. Before we talk about intelligent control, is it that linear system theories are not intelligent? Is it that non-linear control theories are not intelligent? It is. One may argue, yes you need intelligence to design control system, whether it is a linear control theory or non-linear control theory. But, in this case when we talk specifically intelligent control theory, certain work in artificial intelligence, certain results in artificial intelligence that is motivated to understand intelligence, has been used in the frame of intelligent control and that is why we say intelligent control. That is, when we coin the word intelligence, intelligent control, some of these tools that we have worked in the field of artificial intelligence like neural network, fuzzy logic, ….., like that when I use these tools in designing control systems, then historically the field has been known as intelligent control.

Now what is intelligence? I would say something mysterious. Turing proposed it to be combination of five components and you say that this is intelligence and it has five component: perception, problem solving, reasoning, learning is very important, particularly. As far as this course is concerned, this is one of the most important components that we will be considering. Language understanding; we will not be considering much of this component of intelligence. But, actually, what is intelligence is very difficult to answer. But for the time being probably we can say these components, when they are there probably they constitute together intelligence.

Now, we will talk about intelligence again. Normally the intuition we have for using the term intelligence comes from the human way of doing things, the human way of solving things. Normally we always ask a question, how you solve a problem? How we rotate our hand or rotate our head when we track a target or when we want to pick a ball how do we move? Or when we play soccer in the football field, how do we give a pass or how do you intercept a football? The human way of working is something that we know very little about. That is why when we talk about intelligence, we always try to understand how a biological organism functions in a specific situation. When a machine can mimic the way the biological organism behave to situation, to environment then we say probably they are intelligent machine.

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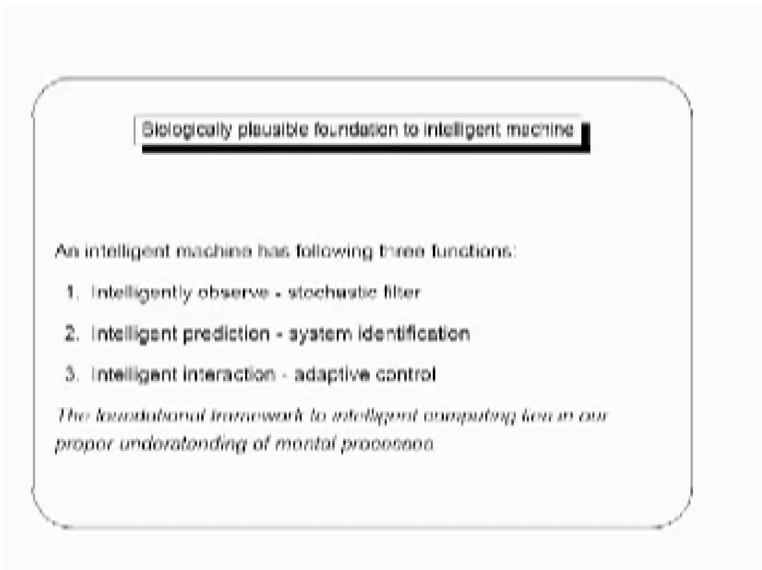

When I say here they are biological plausible foundation to intelligent machine, I coin three particular terms; intelligently observed, intelligent prediction and intelligent interaction. Observation means that we get certain data and I used a filter and now I have faithful data. Using this data, I want to make a model of the system. This is called system identification. Why? Because once you have a model you can predict about the system behavior. This is all control. How do you control? We observe and then predict and finally with intelligent interaction based on the model, I can predict various behaviors and according to the desired behavior, whatever my desired behavior, I interact. This is called adaptive control in classical terms. The basic foundation for an intelligent machine, when I talk about intelligently observed, intelligent prediction and intelligent interaction, the classical counter parts are stochastic filter, system identification and adaptive control.

As I said, here, real intelligence is what determines the normal thought process of a human.

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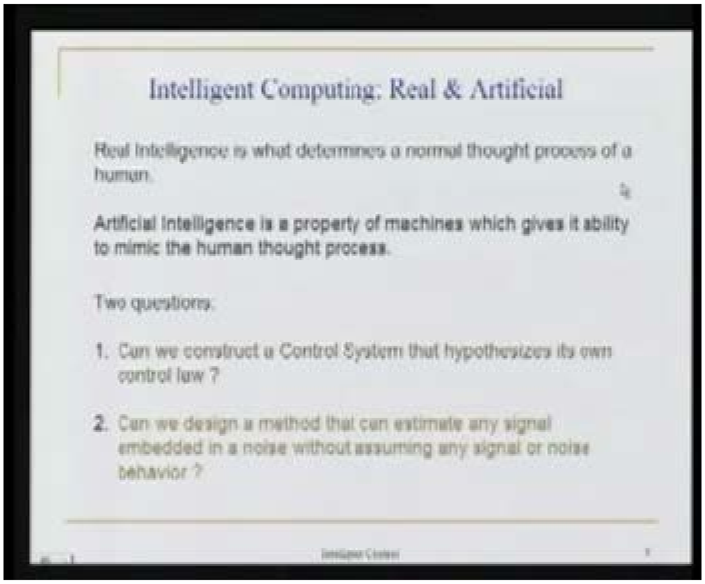

Artificial intelligence is a property of machines which gives it ability to mimic the human thought process. The intelligent machines are developed based on the intelligence of a subject, of a designer, of a person, of a human being. Now two questions: can we construct a control system that hypothesizes its own control law? We encounter a plant and looking at the plant behavior, sometimes, we have to switch from one control system to another control system where the plant is operating. The plant is may be operating in a linear zone or non-linear zone; probably an operator can take a very nice intelligent decision about it, but can a machine do it? Can a machine actually hypothesize a control law, looking at the model? Can we design a method that can estimate any signal embedded in a noise without assuming any signal or noise behavior?

That is the first part; of what I am trying to say, before we model a system, we need to observe. That is we collect certain data from the system and How do we actually do this? this data is polluted or corrupted by noise. How do we separate the actual data from the corrupted data? This is the second question. The first question is that can a control system be able to hypothesize its own control law? These are very important questions that we should think of actually.

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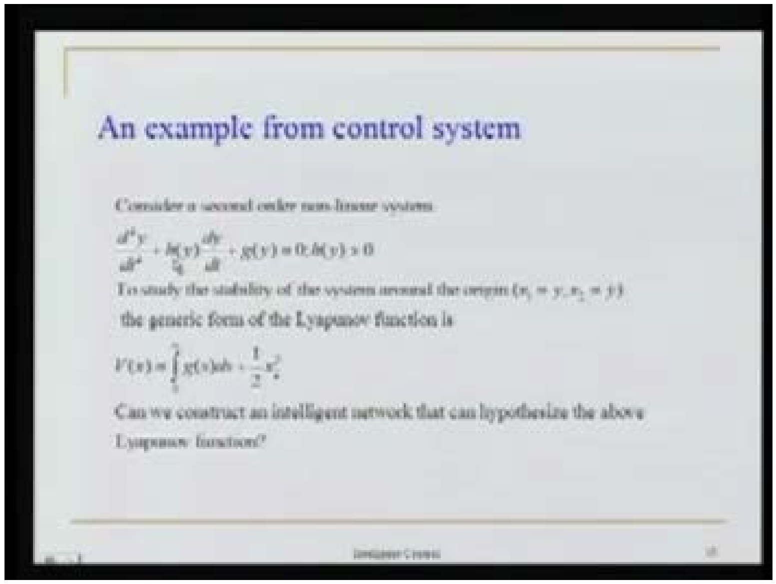

Now let me give you a simple example. What you are seeing is actually a second order non-linear system. This is h y is a non-linear function, g y is another non-linear function. If we actually want to study the stability of this type of function, then if given that h y is greater than 0, always it is positive. Then the stability analysis we do using Lyapunov stability theory. But, unfortunately in Lyapunov stability theory, the person who is actually analyzing has to hypothesize what must be a valid Lyapunov function. Here you see we have a Lyapunov function V x 0 to x_1. This is the function g, integrated function g from 0 to x_1 plus half x_2 square, where you convert this non-linear system to state space model, where two states are y and y dot, x_1 and x_2. Then this becomes a valid Lyapunov function. Then you can see that using this Lyapunov function, you can always say whether this system is stable or not stable. But can we construct an intelligent network or intelligent machine that can hypothesize the above Lyapunov function? That is given a non-linear function, can the machine come up with its own hypothesis that this is going to be right Lyapunov function for this system. If it can, probably we can say that we have an intelligent network or intelligent machine here, sitting right in front of us. We do not have to think that my machine can actually predict proper Lyapunov function for any system. The Lyapunov function is most of the time defined for a non-linear system, because for linear system the form of Lyapunov function is already known. But for non-linear system, Lyapunov function is system specific; it is not known.

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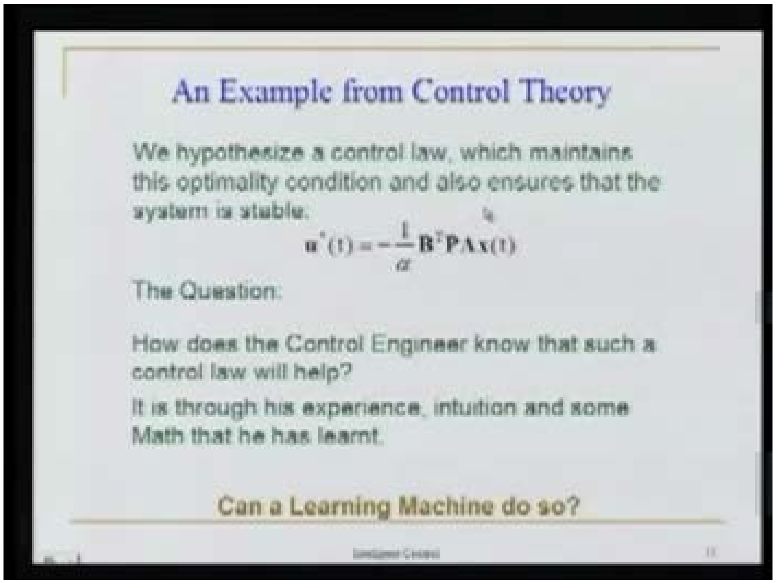

This is a typical control law for a linear system. We normally find in this typical control law, this control structure is valid for any linear system, whether we design a state feedback controller, linear quadratic regulator and so forth. As I said earlier, based on our experience we know this is a generic structure of a control law for a linear system and how do we know this? How does the control engineer know that such a control law will help? It is through his experience, intuition and some mathematics that he has learnt. Based on that the moment I look at a linear system, I can always say this is the generic form of control law, state feedback control law. But can a learning machine do so? This is the question. If I am actually doing intelligent control, I am trying to learn intelligent control, can I say that the machine that I have designed goes through the data from the system and then says this is going to be a generic control law for the system. Can we predict or can my machine predict? This again is the same thing that I said; when I have a signal, the signal can be DC - time independent, sinusoidal, modulated; various types of signals I can have.

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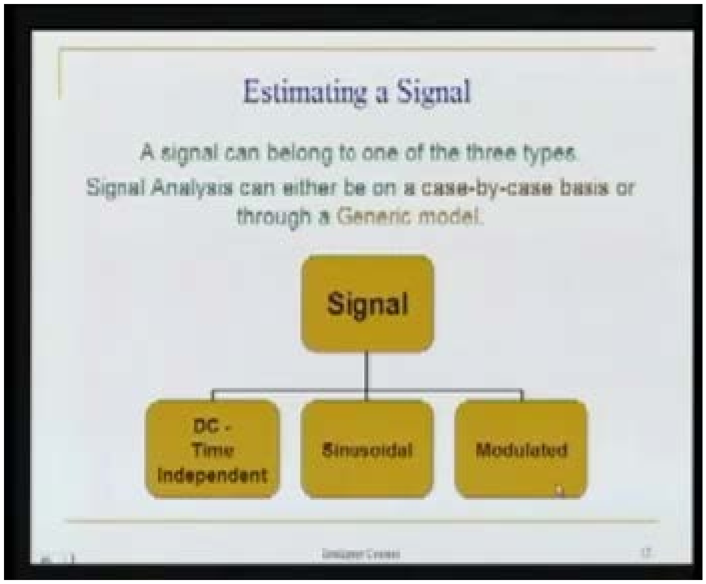

These signals are corrupted with noise and I want to separate the signal from the corrupted signal.

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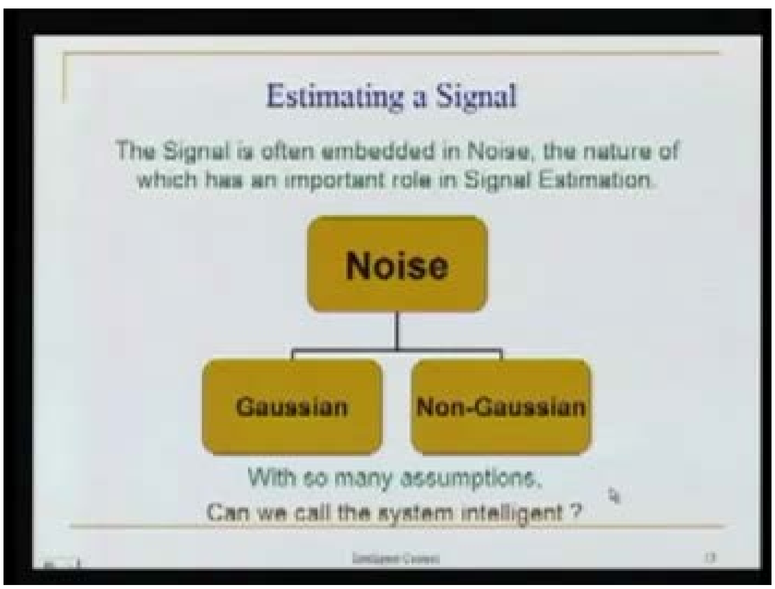

When I want to estimate the corruption of the noise that has been injected into the signal maybe Gaussian, non-Gaussian and many things, then with all these assumptions that means in classical approach, when I try to separate a signal from this corrupted counter part, then I always assume what kind of signal it can be, assume what kind of noise it can be. I always take these models into account and then I propose an estimator. But in general, can we say this kind of methodology is intelligent? This is the question. We have to make many assumptions before we make a predictive model. What I said until now is that I just raised certain issues in your mind about intelligent control. What is intelligence? Why do we need intelligent control?

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Here we can summarize it saying the topic is why intelligent control. First is you should take care of model uncertainties; that is, when we derive mathematical model of any non-linear plant the model is not always exact. There are always associated uncertainties. Second, my control system should be adaptive to change in environment and also it should be distributed in nature.

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Let us ask this question that where would we really like to use this kind of methodology? One of the very typical situations is in an unmanned vehicle; not only the flying one, we can probably design a laboratory sized automobile where driver is a machine, instead of a human being.

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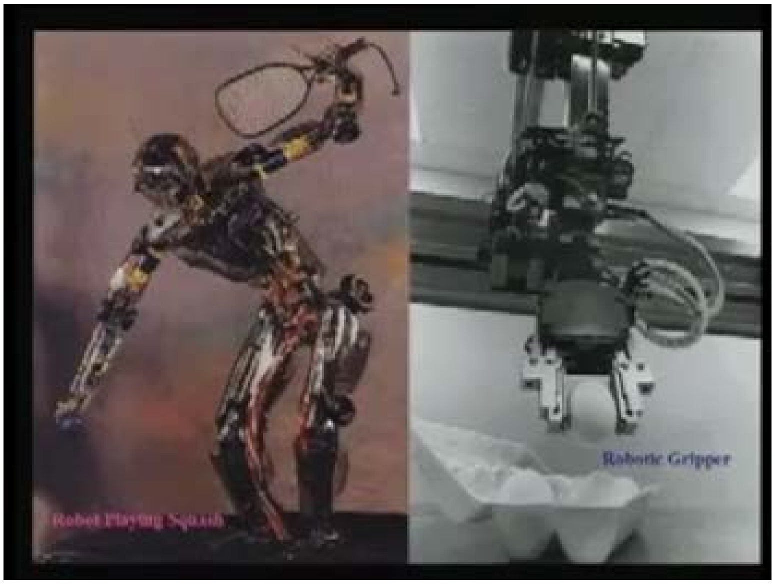

Here, you can see that a robot is playing squash or even robot can play soccer. Here, you see a robotic gripper picking a delicate substance like an egg.

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This is another kind of robot gripper.

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There can be many varieties of sophisticated machines in applications like health-care, mine exploration and detection, security, this soil balance monitoring, industrial cleaning and so forth. Even here you can see robotic surgery. These are all activities that require expertise. An expert, a human expert does these things very well. Can we replace the human experts by an intelligent machine? This is one of the questions that we always ask when we talk about intelligent control. By saying that what we are going to do with intelligent control, it is not that intelligent control completely rejects the methodologies that we have learnt in control theory, linear control theory, and non-linear control theory. It does not reject.

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It also uses even conventional control methods and also these conventional control skills can be very nicely or adaptably coupled in specific situations which normally we call switching control using intelligent control techniques.

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Here are some of the definitions of levels of intelligence. At the lowest level, we have to sense the environment, like if I want to do temperature control I must have temperature sensor. I want to do position control then I have to have a position sensor. Then a higher level of intelligence; this is the ability to recognize objects and events, like a robot should be able to recognize where the ball is if it wants to play soccer. If it is surgery, a robotic surgery is taking place then the robot there should be able to identify each and every organ of the human body. Similarly, also to represent knowledge in a world model, the way we manipulate the objects in this world and the advanced is a very high level of intelligence that we still do not understand; the capacity to perceive and understand. I will talk about this at the end this lecture today.

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Let us be a little speedy here, because I wanted to give a little feel of this entire subject today, in this introductory class. Here are various methodologies that we adapt while designing intelligent control system. Automata theory we use; hybrid system concept, Petri nets, neural networks, fuzzy logic and evolution algorithm. Basically, we will mostly focus on these last three tools, because they have become very popular in designing intelligent control theory.

What is fuzzy logic?

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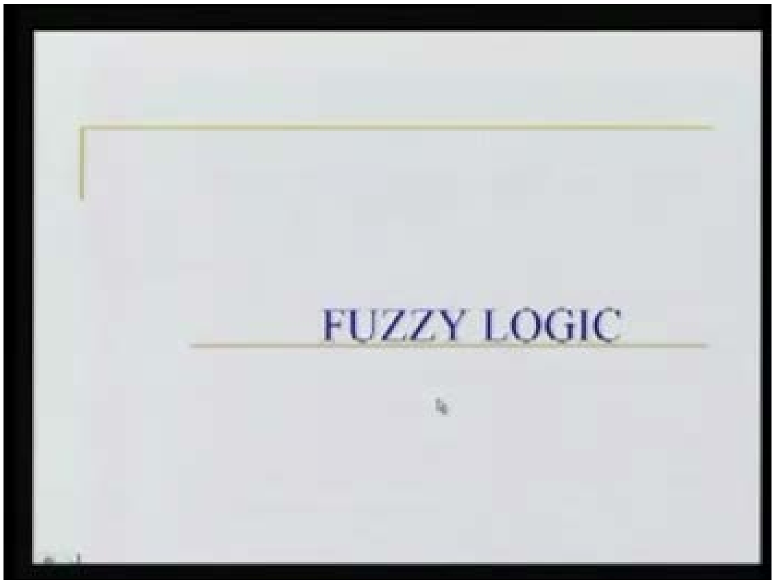

Most of the time, people are fascinated about fuzzy logic controller. At some point of time in Japan, the scientists designed fuzzy logic controller even for household appliances like a room heater or a washing machine. Its popularity is such that it has been applied to various engineering products. In this lecture series, we will discuss in detail what fuzzy logic is. Today, I will not talk in detail; I will just give you a little idea of fuzzy logic.

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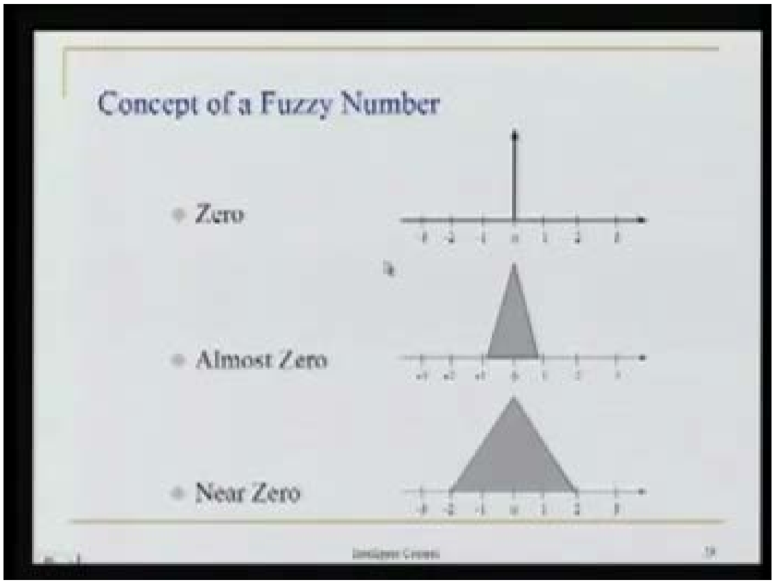

This is a line and in this line, you have 0 1 2 3 and this is minus 1 minus 2 minus 3. When I say 0, it is 0. Thus, if it is 0 then I say it is 0. Its truth value is 1 and if it is not 0, its truth value is 0. But the moment I say almost 0, then I can think of a picture like this that between almost like minus 1 to 1, the values around 0 is 0, because this is almost 0. You can see that this gradient allows me to allow maximum weightage of the value very near to 0 and as the value goes away from 0, the truth value reduces. We are discussing the concept of a fuzzy number. We talked about 0, almost 0. I am not very precise, but that is the way I use my day to day language in interpreting the real world. When I say near 0, maybe the bandwidth of this triangle; this triangle represents actually the truth value. You can see that it is more, bandwidth increases near 0. This is the concept of fuzzy number.

I will give you a little explanation, as we discuss specifically fuzzy logic controller aspect. In this course, we will discuss in more detail about this concept. For the moment, let me tell you that when I say fuzzy logic, that is the variables that we encounter in physical devices, I use the fuzzy number to describe these variables and using this methodology when I design a controller, I say it is a fuzzy logic controller.

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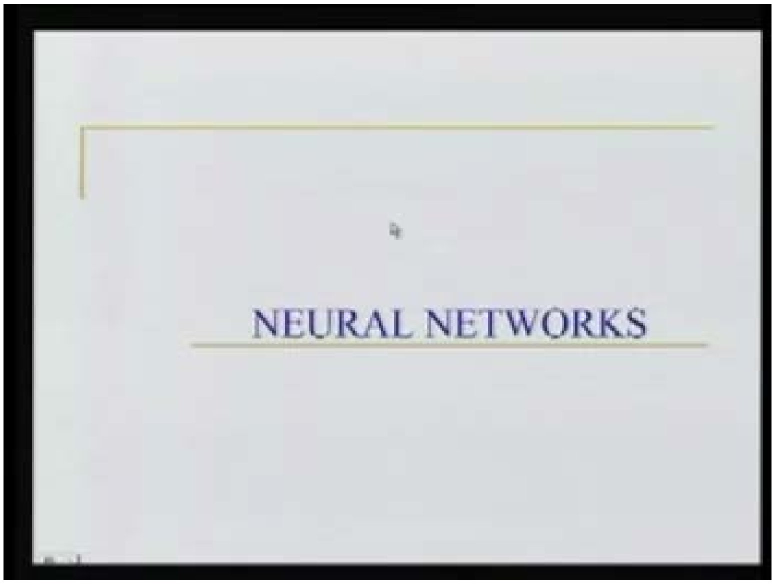

Now, it is neural network.

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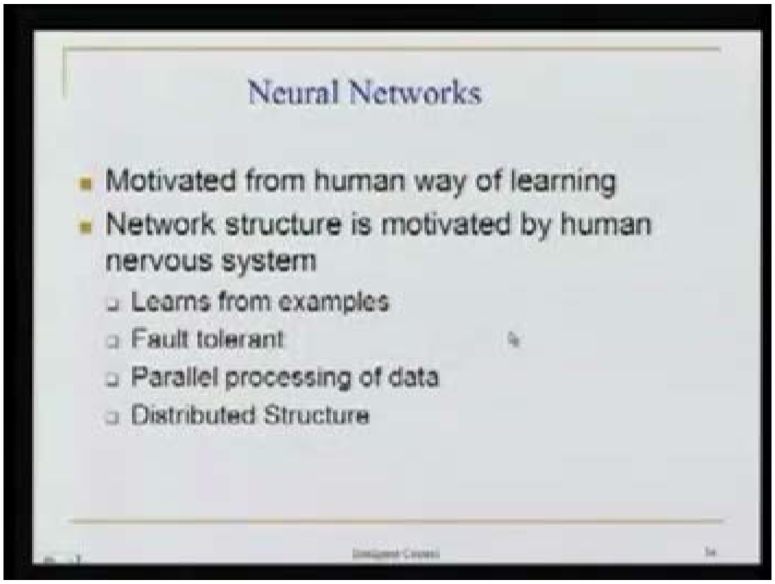

Neural networks are basically inspired by various way of observing the biological organism. Most of the time, it is motivated from human way of learning. It is a learning theory. This is an artificial network that learns from example and because it is distributed in nature, fault tolerant, parallel processing of data and distributed structure.

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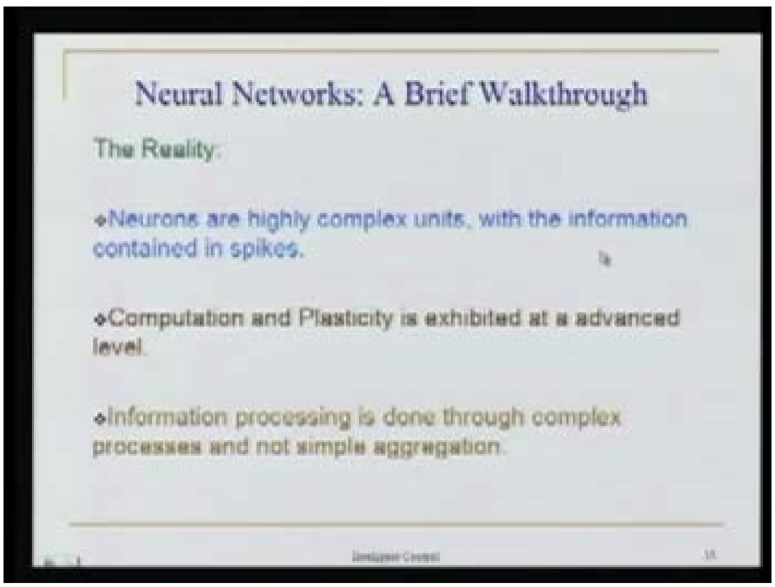

This is the neural network that we normally design. But if you look at the actual neuron, the biological neuron, they are highly complex units with information contained in spikes. The computation and plasticity is exhibited at an advanced level. Information processing is done through complex processes and not simple aggregation. But, when we talk about artificial neural network, neurons are elementary units; can be digital, analog and we can also make some spike models. There are basic computations - summation, multiplication and here is a very simple Mcculloch-Pitts Neuron model.

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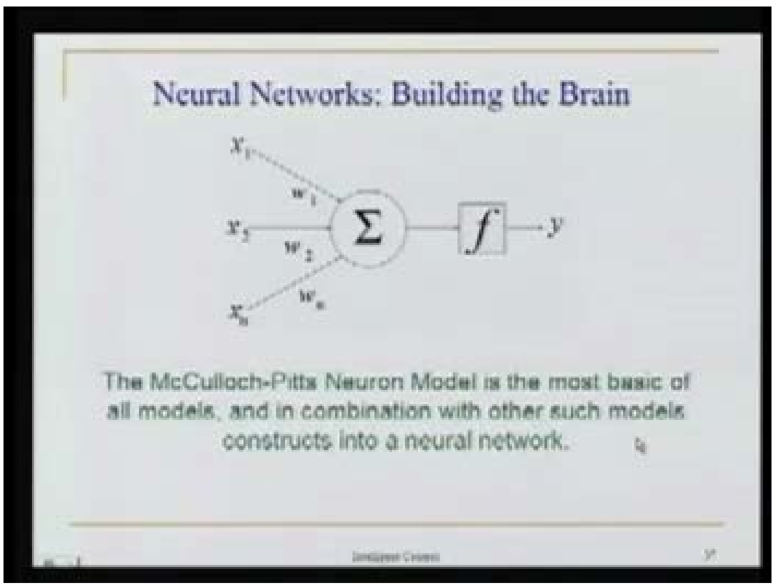

Here are your inputs and these are all synaptic weights. They are all summed here and then there is an activation function and here is your output y. In a way, your output is summation of the signal multiplied with synaptic weight over many input channels.

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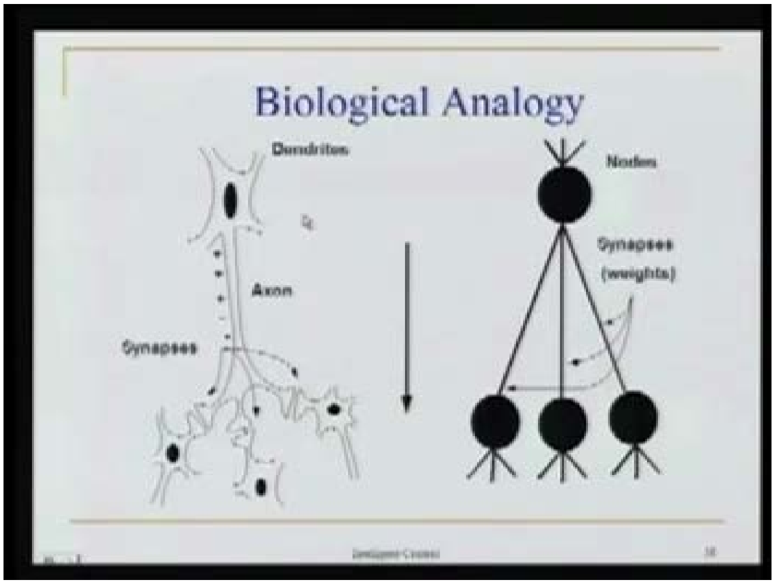

You can see that this is a specific neuron. This is the axon. Through axon this neuron actuates the signal and this signal is sent out through synapses to various neurons. Similarly This is a biological neuron and here it is a classical artificial neuron and you can see, this is a computational unit. There are many inputs reaching this. It is like here; this is one input, another input, another input and another input. This input excites this neuron. Similarly, there are many inputs that excite this computational unit and the output again excites many other units like here. Like that taking certain concepts in actual neural network, we develop these artificial computing models having similar structure.

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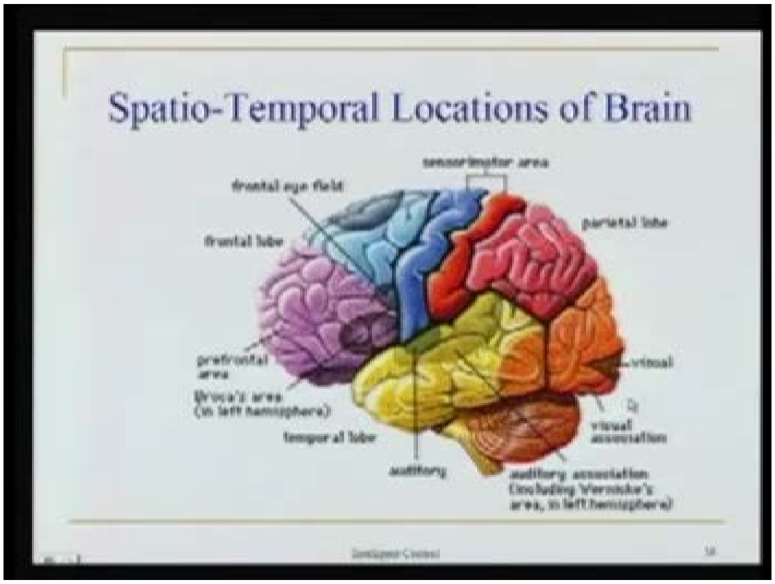

Although we do that, let us try to see what exactly we are up to. This is a brain and you see that in this brain, there are various locations. This is auditory and this is the visual cortex. There are various locations where various functions take place in the brain.

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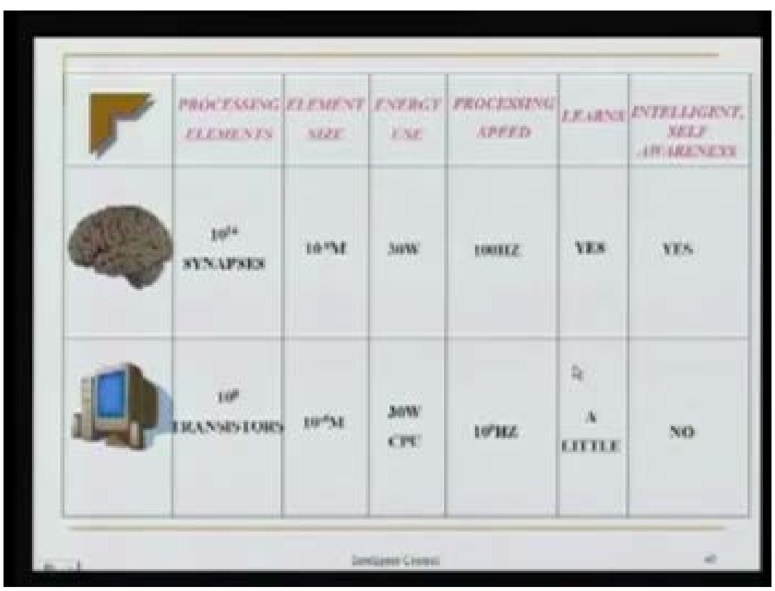

If we look at a computer and a brain, this is the central processing unit and a brain. Let us compare the connection between our high speed computers that are available in the market today and a brain. Approximately there are 10 to the power of 14 synapses in the human brain, whereas typically you will have 10 to the power of 8 transistors inside a CPU. The element size is almost comparable, both are 10 to the power minus 6 and energy use is almost like 30 Watts and comparable actually; that is energy dissipated in a brain is almost same as in a computer. But you see the processing speed. Processing speed is only 100 hertz; our brain is very slow, whereas computers nowadays, are some Giga hertz.

When you compare this, you get an idea that although computer is very fast, it is very slow to do intelligent tasks like pattern recognition, language understanding, etc. These are certain activities which humans do much better, but with such a slow speed, 100 Hz. ….. contrast between these two, one of the very big difference between these two is the structure; one is brain, another is central processing unit is that the brain learns, we learn. Certain mapping that is found in biological brain that we have studied in neuroscience is not there in a central processing unit and we do not know whether self awareness takes place in the brain or somewhere else, but we know that in a computer there is no self-awareness.

Let us see what we will be covering in this course. When we discuss neural network, we will be covering some of the popular learning methods.

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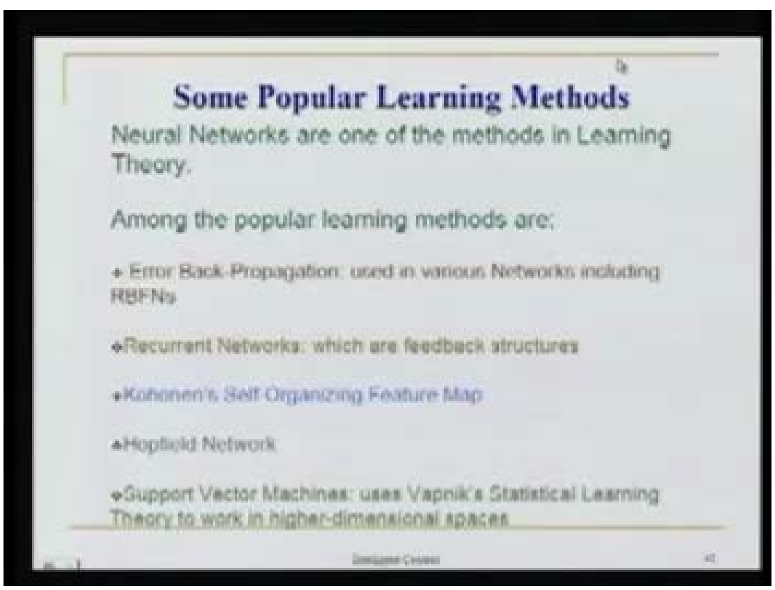

Neural networks are analogous to adaptive control concepts that we have in control theory and one of the most important aspects of intelligent control is to learn the control parameters, to learn the system model. Some of the learning methodologies we will be learning here is the error-back propagation algorithm, real-time learning algorithm for recurrent network, Kohonen's self organizing feature map, Hopfield network and if time permits we may also discuss about support vector machines.

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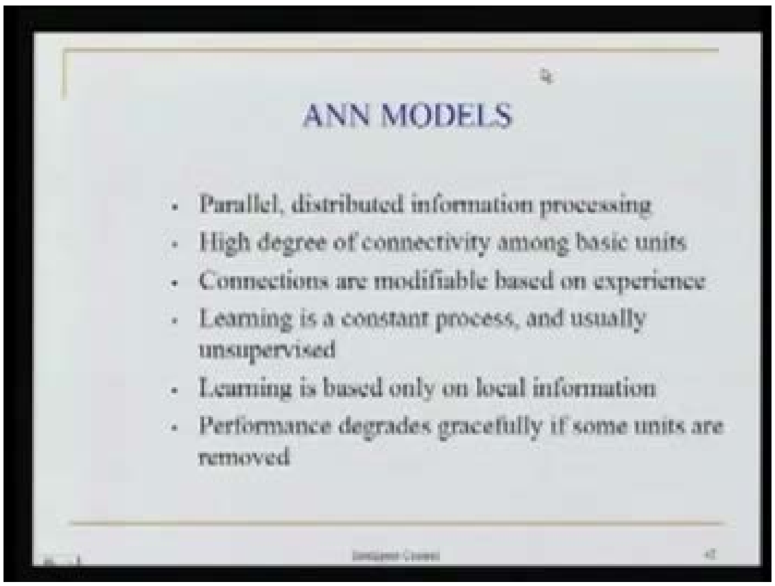

As I have already said, these are all summary of neural networks. We will discuss these concepts in a more rigorous manner in the next class. Some of the applications that we will rigorously take up in this course is like we will show how to design a fuzzy logic controller.

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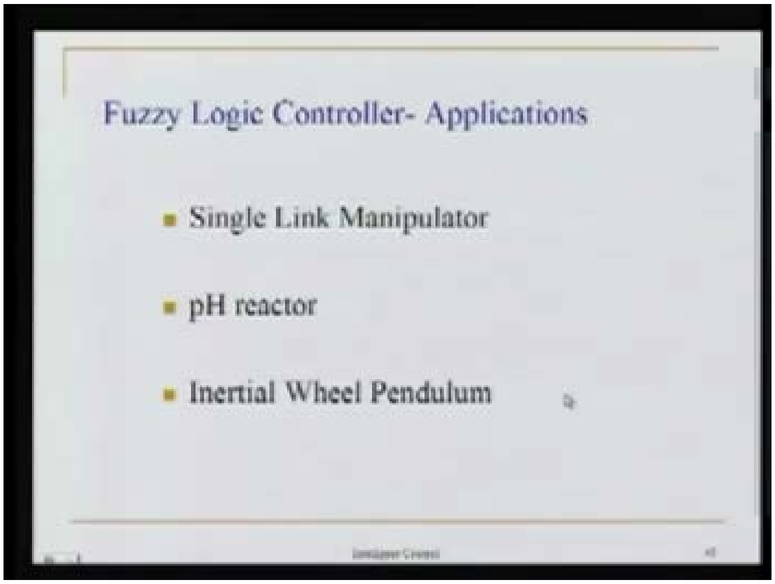

Let me summarize now, what we have talked about. We have talked about fuzzy logic controller, fuzzy logic neural network. We did not talk much about evolutionary computation. This also we will talk as we take that specific subject. Under fuzzy logic controller, when you learn through this course, these are some of the interesting physical devices that we will consider for designing. One is the single link manipulator. We will take a very simple system so that we can design it completely. We will simulate it. Sometimes, I will also show you some of the experimental results like inertia wheel pendulum. This is in my lab and my students who are working on this particular system have certain nice, interesting results and I will demonstrate that also in this course. Inertia wheel pendulum, pH reactor, single link manipulator; these are nice interesting non-linear systems and very interesting to see how we can design controller using fuzzy logic concepts. These are the details that single link manipulator has.

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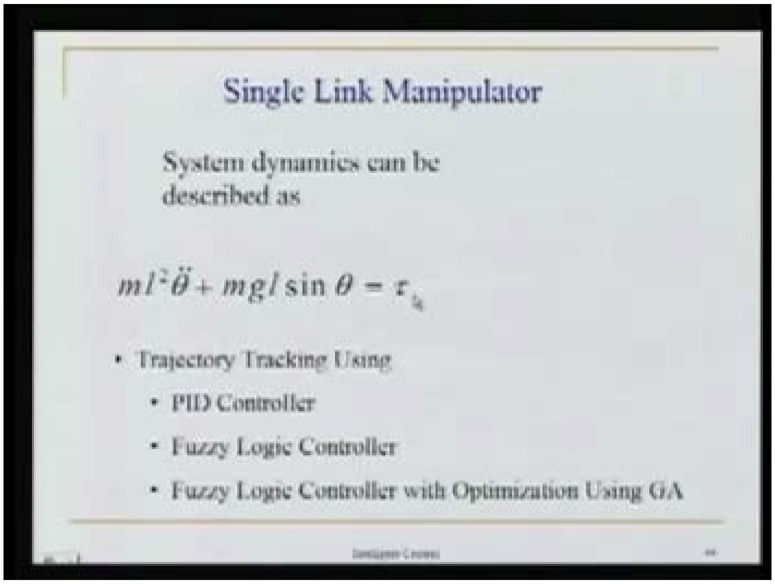

You see that because of this sin theta term the system becomes non-linear. It does not follow the superposition principle. We will be designing all these varieties of controllers; PID controller, fuzzy logic controller. We will use also genetic algorithm, how to optimize fuzzy logic controller? These are the insights; the description of the course model that I am now making so that you are very well aware of what we are going to cover in this course .

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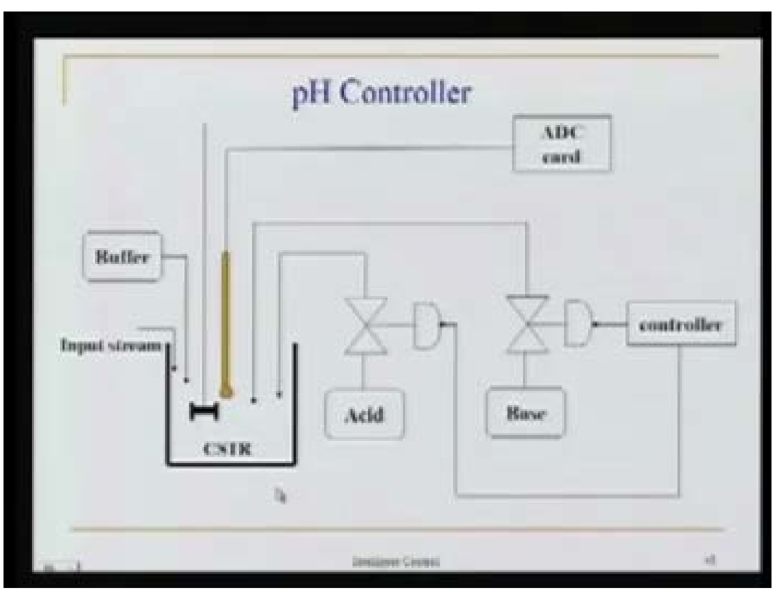

Here is the pH controller. You can see that this is a continuously stirred tank reactor and there are three things entering into this particular container. Buffer is a substance and then acid as well base. These are various kinds of liquid that enter into this container based on their pH level. The objective is that we want to maintain the pH of this container constant and what we normally do is that we control only the base flow; from the plant, wastage or something like that. The various things enter into this and this waste product has to be discharged to the environment. But if the pH value is more likely acidic or more likely alkaline, accordingly this will have a very drastic impact on the environment. To avoid that, we want to neutralize the pH value. Normally the neutralized value of pH is 7. How do we inject either base or acid into this system such that this pH remains constant? Although this looks like a very simple system, the dynamics becomes non-linear. I will show you in detail as to how to solve this control system design for this system. Actually, in our practical system we have already done.

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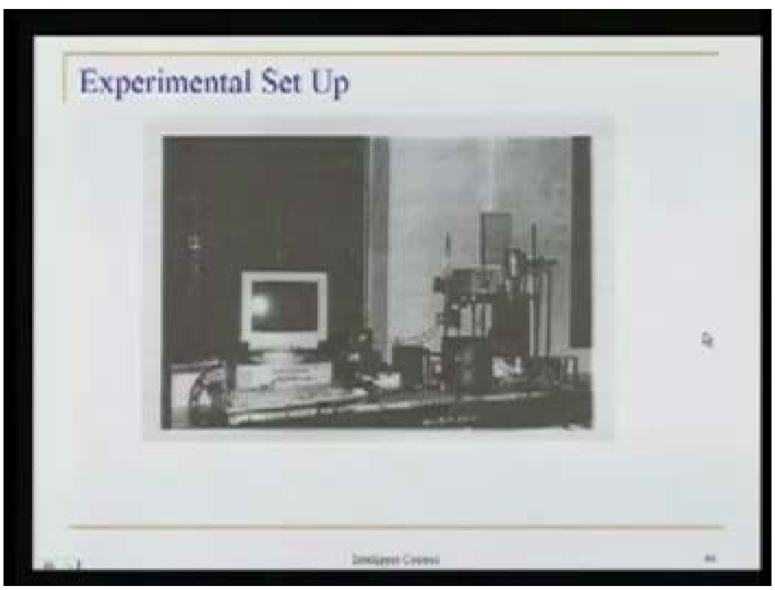

We have synthesized a pH reactor and we have actually applied fuzzy logic controller to this pH reactor. This we will take in detail.

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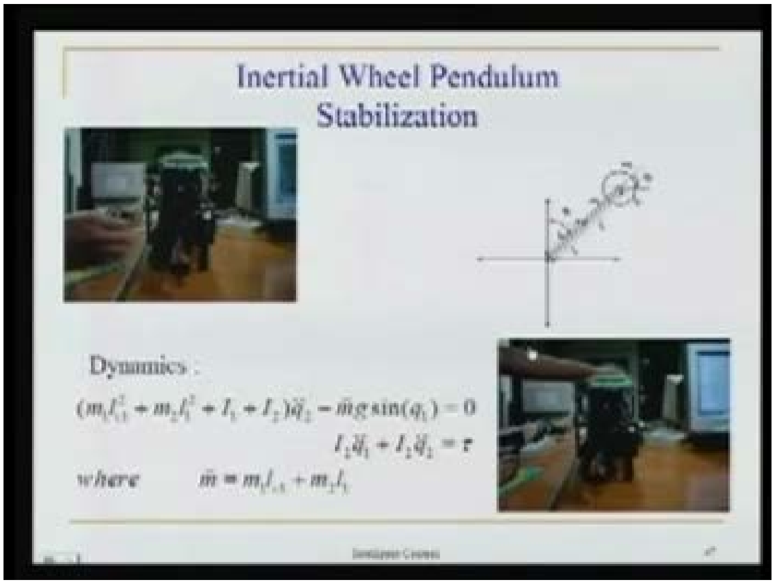

Here you can see the inertia wheel pendulum. What you are seeing here is the pendulum attached to the disc here. This is the pendulum rod and then there is a disc. The objective is to bring this pendulum to the top position and that is done using certain concepts of non-linear control; we say swing up control and balancing control. This we will discuss in detail and we will show how we can design for this also, fuzzy logic controller. The other controllers we will design and we will demonstrate in terms of the application of neural networks. Here are certain systems that we will discuss in this course.

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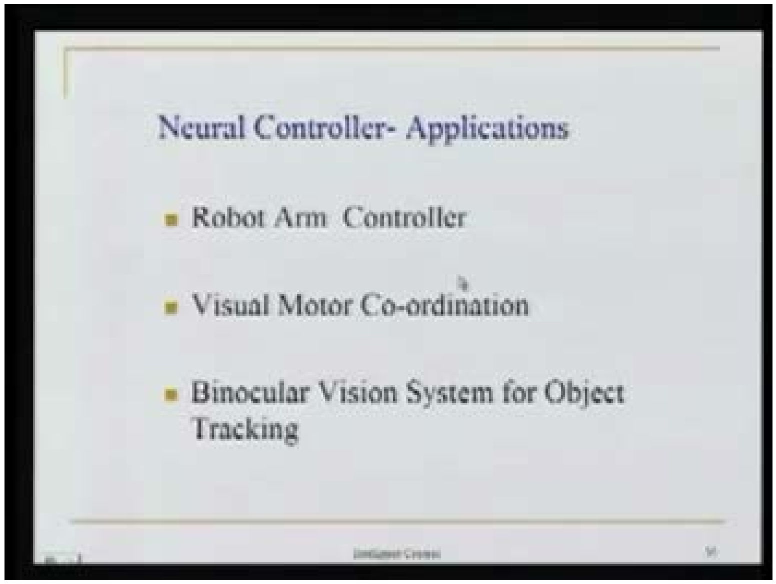

One is a robot arm, visual motor coordination. This is hand-eye coordination, just like when I pass a ball to my fellow player there is enough coordination that takes place between hand, leg and eye. Similarly, when I try to exhibit any skill with my hand, then for manipulating certain environment around me, then there is also a certain degree of coordination between hand and eye. This is called visual motor coordination and we will solve this problem using neural controller. Similarly, binocular vision system for object tracking.

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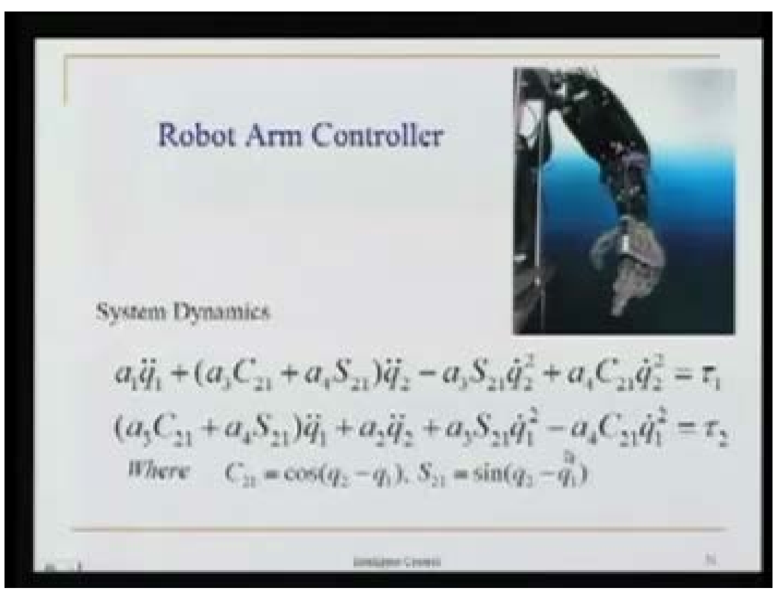

This is a typical robot manipulator. You can see this is a gripper and this is one link and another link. This is the base and this is dynamics of this robot manipulator.

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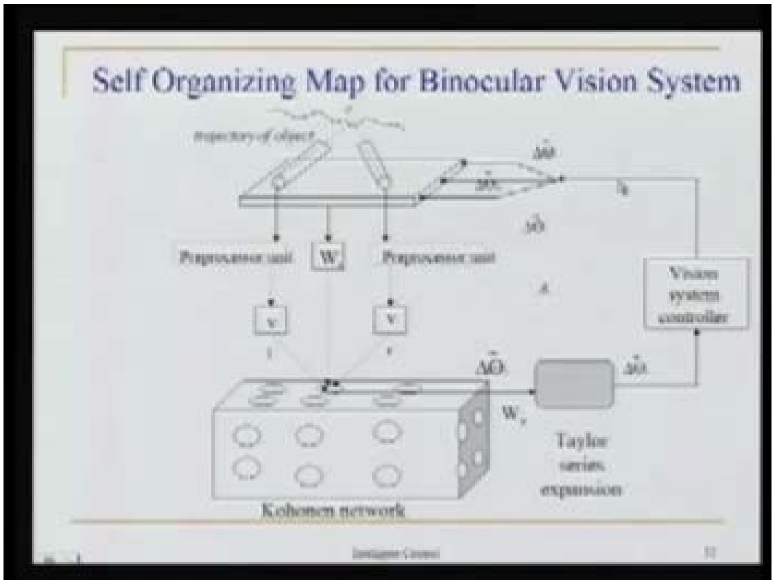

This is a binocular vision system. These are two cameras. These two cameras are tracking certain moving objects. This is a pan. This pan can move upward, downward in certain angle and accordingly, also this camera here and here can also turn in a circle. As for that we can actually see that this camera is looking at a point here. This is point p and this is the trajectory of my moving object and as the object moves I want to focus the object. How do I exactly orient towards the object? This is called a binocular vision system. This is called visual navigation also. We will also discuss this kind of problem and we would like to solve using neural network.

What I gave you today is what we are going to learn in this course. We did not tell what it is in detail. We learnt and just highlighted some of the things that we are going to learn in this course on intelligent control. While saying that let me conclude this lecture in a little philosophical manner. We talked about intelligent control, but after learning this course or taking this course, probably we may still enquire about after all what is intelligence?

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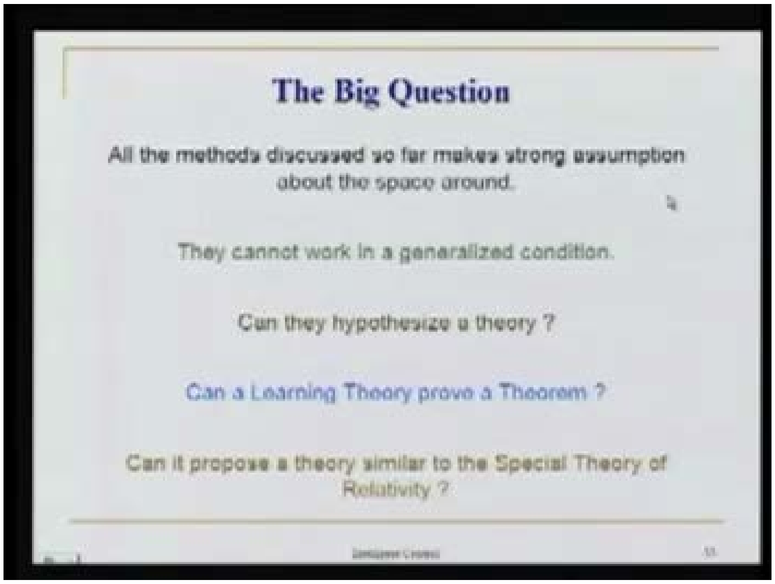

All the methods discussed so far makes a strong assumption about the space around; that is, when we use whether a neural network or fuzzy logic or …. and …. any method that may have been adopted in intelligent control framework, they all make always very strong assumptions and normally they cannot work in a generalized condition. The question is that can they hypothesize a theory? When I design all these controllers, I always take the data; the engineer takes the data. He always builds these models that are updated. They update their own weights based on the feedback from the plant. But the structure of the controller, the model by which we assume the physical plant, all these are done by the engineer and also the structure of the intelligent controller is also decided by the engineer. We do not have a machine that can hypothesize everything; the model it should select, the controller it should select, looking at simply data. As it encounters a specific kind of data from a plant can it come up with specific controller architecture and can it come up with specific type of system model? That is the question we are asking now.

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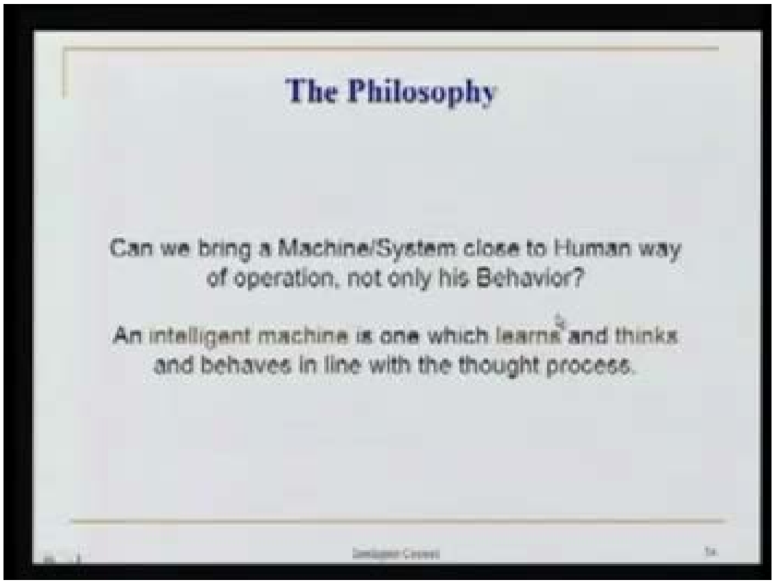

Because we are talking about learning systems, in this course we will be talking a lot about it, again, we can ask the question: can a learning theory prove a theorem? Can it propose a theory similar to special theory of relativity? Can it become an artificial Einstein? Like that we can always become little philosophical when we actually try to understand the importance of the word intelligence. Finally, can we bring a machine or system close to human way of operation and not only his behavior?

You will see that in the entire course we will be discussing various tools. They will only be dealing with these two things; behaviour. These tools are actually developed by mimicking the human behavior, but not the human way of working. An intelligent machine is one which learns, thinks and behaves in line with the thought process. That we would like but we are very far from it. At least, at the moment, we are very far from this target of achieving real intelligence. Finally, I would like to tell you, a very important aspect of intelligence which is perception. Why I am saying is that as you go through this particular course, you will see that we will not be addressing this issue, but these are the issues that make the concept of intelligence very exciting. What I am talking here about is the role of perception. We showed a brain and you look at this brain; the various location of this brain - we have visual cortex, we have auditory cortex. We have various locations in this brain and they perform various actions. These things, we have already verified using various studies in neuroscience; you can say anatomical and neurophysiological evidence.

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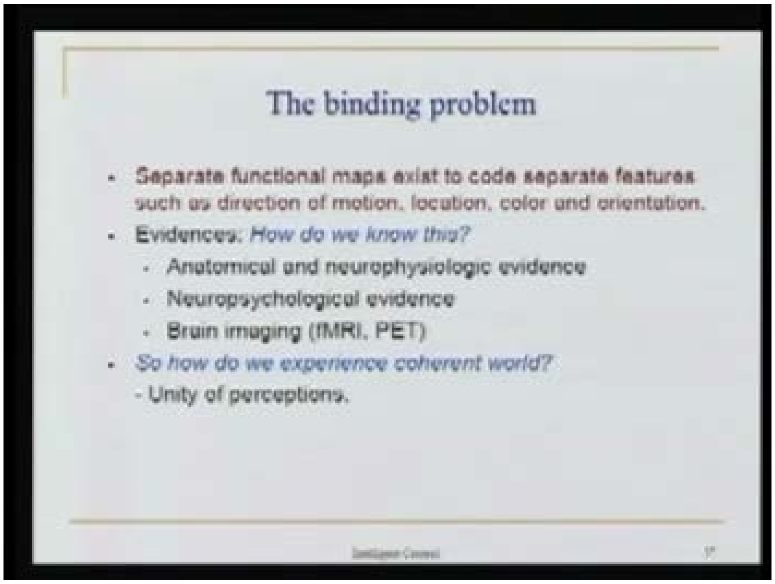

Neuropsychological evidence, brain imaging; these are various methods by which we know the various parts of the brain and their functions; they do different functions. But when we have a perception of the world, we have a unique perception. That is, how do we experience a coherent world? Whenever I perceive, I do not perceive that my visual cortex is processing vision or color and my auditory cortex is processing sound and so forth; we do not. We perceive the environment in a very unique way, in a coherent manner. This is called unity of perception and intelligence has also something to do with this unity of perception, awareness and certain things are not very clear to us until now. But nonetheless, still you will say that this intelligent control course will be very interesting, because some of the new concepts we can learn about and we will learn how to apply these new concepts like neural network, fuzzy logic, fuzzy neural network and genetic algorithms and how to apply these principles in control theory.

Thank you very much.