Estimation of Signals and Systems

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Lecture - 23
System Identification: Introductory Concepts

We will today start our last module and system identification. And will discuss some introductory concepts today, before looking at the algorithms.

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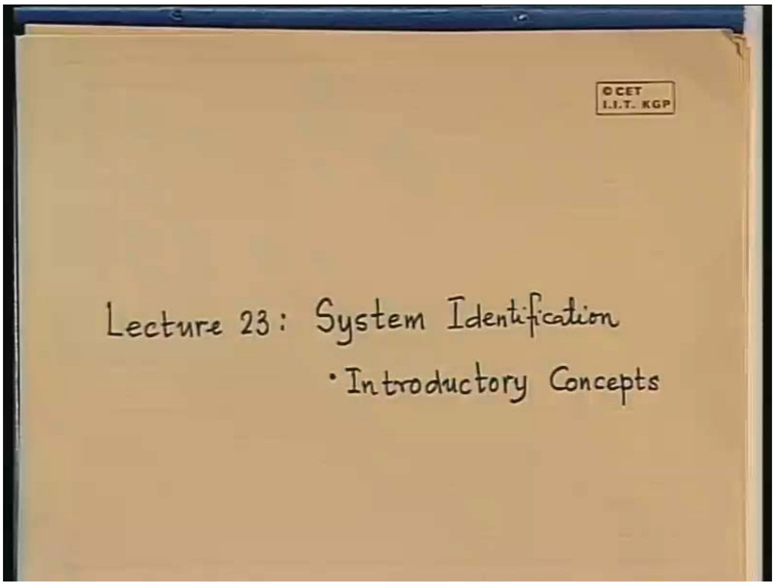

It is important to you know anything, before you really take a detail look; it is good to take a but x i view and the big picture. So we will start from right from systems and models, modelling, product involves, what are the factors that affect it because system identification is basically about building models for systems from data. So if you do not know the model of a system, so far or in our in in all our state estimation and filtering chapters that we have covered lecture that we have covered; we have almost always assumed except of course in it is like winner filtering, that that the that the model is known, right. Now now some you have to somehow obtain the model. So in this last module we are going to look at, how to obtain models of systems.

So taking rather, you know system is a is probably one of the most used and abused word in the at least in the technical dictionary. It appears to me, I mean it means hundred different things to two hundred different things. And and everybody use it.

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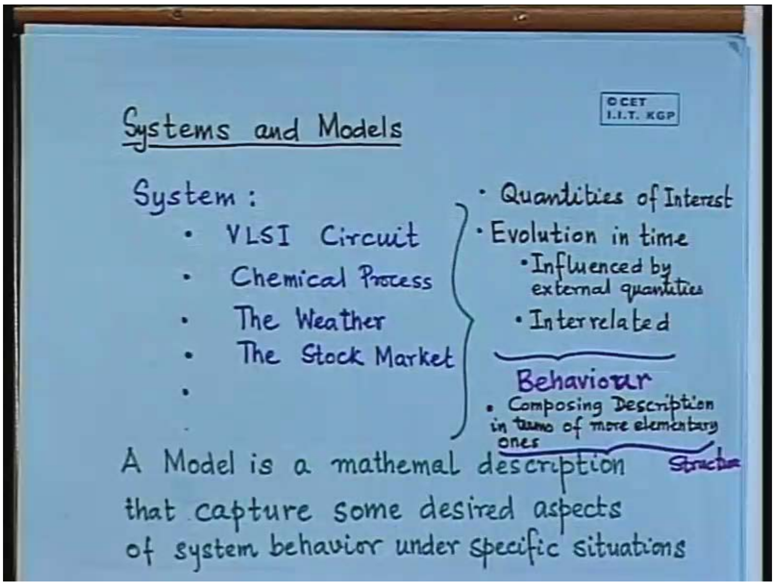

So it is I would not try to define a system because you all know, what it is but but rather I would like to give some examples, I like to start with some examples. For example a VLSI circuit or a circuit; VLSI or not in a system a chemical process could be a system, our global weather is a system, even the stock market is a system. So do we able to get an idea of what we mean by systems, to be able to arrive at you know and and an abstract definition; you must distil out the common features in these.

What is the common feature? Let there are related to each one of them, there are some quantities of interest; for VLSI circuits it will be be voltage is an all for any circuit, it may it may be voltage is on currents signals or their properties, for chemical process it will be some you know chemical compositions, temperatures, pressures. We are interested in them for some reason, economic, social, technical, natural, environmental or otherwise. Similarly if you have the weather, here also we are interested we are we are we are we are very much interested in; there are some quantities of interest and we would like to we would like to predict them, we would like to understand how the change, so so it is also a system.

So we always have a some quantities of interest which we want to study or predict or control or whatever; and typically these quantities changes with time, the evolve in time, right. And this evolution is their their evolutions depend on each other's evolution; so they are interrelated. And sometimes there influence by external quantities, very often, you know what is internal and what is external? When we when we look at something for some purpose, we in general intuitively we fix, what is known as kind of you know we we imagine a boundary, right.

This is the table everything is so all that is here are internal to the table system, while you are external to the table. So in that sense very fundamentally speaking associated with every system that is a boundary and whatever is, I mean the things of interest within the boundary are are supposed to be internal to the system and you I mean you want to study that in great detail, that is your object of study; everything else which influenced to it or external to it are not called its environment. So turns out that these these quantities of interest of the system which evolve in time or not only interrelated among themselves; they were also influenced by external quantities which are across the boundary.

And this this evolution in time is typically called, the called the systems behaviour. You know in related with system there are two terms which are used; one is called it is structure, another is called its behaviour, so anything, right. So structure in a sense, why we use structure, because we we use structure because we can you know, we are we always look for nice and efficient methods of dealing with complex systems.

So we have quickly discovered that; if you break it up and if you describe the overall system, complex system in terms of small small things then it is useful. It is it is easier to understand. Using using the same set of small models, you can build hundred different types of systems. So in a sense its uniform, I mean makes knowledge uniform. So so we so basically a structured description of a system is is where you try to describe a system in terms of smaller system. So when you so these these smaller systems are typically called its components, right.

So if you are interested in describing, how a circuit is made of let's a smaller sub circuits then you are looking at its structure; while without looking at that, if you are generally interested in how things change in that circuit then you are interested is behaviour, right. So in a sense after all how is that smaller circuit described? It may be described in terms of still smaller circuits. In this way you will go down and down and down and then finally you will come to a point, where where describing it in terms of smaller things is not useful. So at that point of time, you would like to directly describe without saying that it is made up of smaller things.

So finally very simple objects only have behaviour, they do not have structure. There structure is actually trivial but when you deal with complex object then you would like to compose new and new behaviour using elementary behaviour and then composing them. So you describe complex behaviour in terms of simple behaviour, using structure concepts, right. I mean that is the that is the issue of structure and behaviour of system. So so what I am trying to say is that in a way structure is also come down to behaviour, finally, eventually.

So we are, what are we interested in? We are interested in because we want to because we want to understand behaviour, we want to influence it, we want to predict it. So so we want to first of all to be able to do anything like that; you need an unambiguous description for the structure. You need to, everybody needs to understand it in the in the same manner and and and that is where I mean mathematics comes in.

So so you need to to be able to understand such complex system, you need to put it into a mathematical framework. See you need to describe the structure or rather the behaviour. So model is nothing but a mathematical, and try it a the problems of a will it be a minority left. A model is a mathematical description that captures some desired aspects of system behaviour under specific situation. So these are important things, so basically a model is a mathematical description of behaviour, but it that it it may not describe the behaviour under under all situations. So you may like to because, we in general you I mean the the the thumb rule in engineering is, keep things small as small as as it as you can serving your purpose.

So you may not be interested in constructing a grenade mathematical model which describes the system under all situations, you may be concerned with very special kind of situation. So you build a simple model for that and then you you may not even concern, we we concern with for example; when we first learn circuits, in many cases we are not concerned with, what is the I mean what is the power loss. So we simply model them as ideal elements. So if you are interested in power loss for some reason, you will model it. If you are interested in power loss you will not model it. So you only model those aspects which are of your interest and you model them under the situation that is that you are likely to encounter in your goal, not so so so so in a sense a model is a partial description of behaviour; it is not a total description, right.

So here what what I what I what I try to say,

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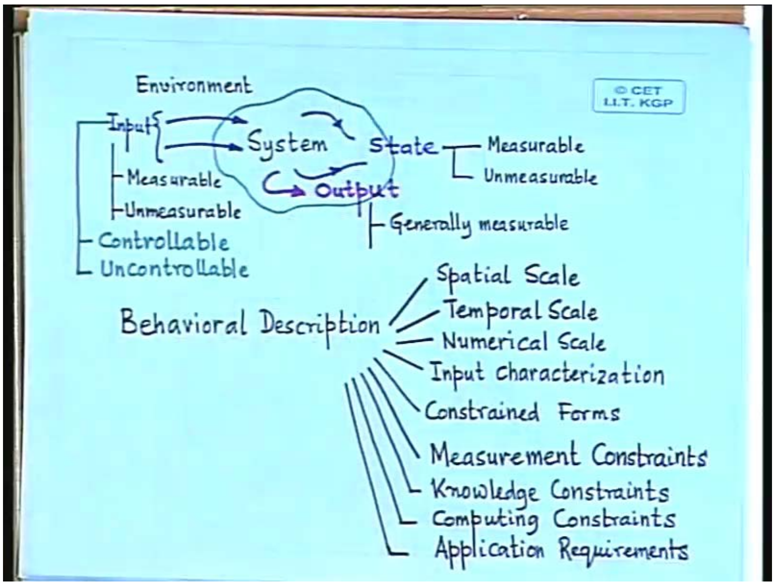

I have try to describe that, this is the system it has the boundary; and it is it is influenced by quantities outside it, such quantities are called inputs. And inputs may be either measurable or un-measurable, that is you may be aware of its existence but in a given situation you you may not be able to measure it. In another situation you may be able to measure it, but that for purpose on which you are building the model, in that situation you may not be able to measure some input. For example, you if a machine is running, you may not be able to measure many things inside it, if you if you happened to stop it and then take it a part, you may be able to measure so many things.

So it may be measurable or un-measurable and not only that, it may be controllable or uncontrollable and it can happen in any combination. So it can be in general if it is if it if it has to be controllable; in general it should be measurable, it is unlikely that that something which is un-measurable can be controlled but something which is uncontrollable can be either measurable or un-measurable. For example, disturbance in a system it may be measurable or it may be un-measurable depends on whether you are willing; to sometimes we I mean is is is not a question of physical measurability, it is a question of whether I mean is not that whether whether whether really globally technology exist or or whether it is possible to measure it.

It is question of whether you have, whether the facility of measurement exist or not in that given situation; due to some reason you might have chosen not to measure it because it because may be it involves more money. Whatever it is but but in a given situation there be measurable or un-measurable and controllable and un-controllable. Similarly, the we define typically we define two other quantities in relation to systems; the first one of them is the state, actually the state is nothing but the quantities of interest, things which you are interested in, things which affect the evolution of the quantities of interest in time.

So such things are called state, they may be measurable or un-measurable. And in general depending on our purpose some of the elements of these states or some direct functions of state we just choose to define as as output. So generally output which one will be a output is a matter of definition; when you can define this one as the output and and that one not an not as output, right. For example, you can say that in a motors in a given situation speed is the output, if you are trying to do speed controls suppose you are doing a machining application then for a motors speed may be output because you say that, that is the prime thing that I am trying to control, that is what is my main object of interest.

For the same motor in in another situation position may be output, angular position. Suppose you are having an having an actuate, that you are precisely trying to position something then speed is not so much in.. speed affects position of course; position if we integral a speed but you may choose not to define speed as an output or directly even control it, right. So output is generally a matter of definition, it is generally measurable while state may or may not be measurable. For example, in our last day’s lecture, we acceleration, velocity, position all were states; acceleration and velocity were not measurable while position was measurable by this thing, right. Why we are saying all these is that, all these as you see affects modelling of systems and they will also affect model building; you have to remember it though if if you directly plunge into into algorithms many of these things will not be clear, that is why in the first lecture it is it is good to stop and take a look at these things.

So incidentally, so basically we are concern with this behaviour constructing a mathematical behavioural description and this mathematical behavioural description is affected by so many things, I mean what kind of description you will choose? There are so many kinds of descriptions possible for the same object. It depends on many many things; for example, it depends on this spatial scale of an object, that is for example suppose you you are trying to model the the temperature in this room, are you interested to really capture the difference or variation in temperature in that corner to this corner? If you are interested then you have to build one kind of model.

On the other hand, if you assume that no no there is there are there are enough number of fans running in this room; so the so the so the temperature distribution is always uniform. So I do not need to really model what is what is this corner and that corner; that is not of interest to me. There will be slightly different, that is known but what how much different is not known to me, so I will take measurement at any point and then I just assume for my purpose that, it is the that the whole room is is in that temperature. If you do that then you will have to build a different model. So so it very much depends on spatial scale whether you are interested in modelling.

Similarly it depends on temporal scale. For example, if we if you have clock digital system then we are not really interested, we are only interested in the state of the system at certain points of time. For example, in a in our in our discreet time model; we are only saying x k plus one is equal to A x k plus B u k, so this model describes the system behaviour only at certain points of time, k t k plus one, what happened in between them? We are not interested, why we are not interested because we know that, the that the interval is so small that it is definitely going to a somewhere between k and k plus one and k at k and k plus one itself at very close.

So if I can find out x k and x k plus one in between it is going to be somewhere in between and I do not need that kind of resolution, that is why you have chosen to use that model. If you had that is why you have chosen to use that sampling time and sampling time is an is an integral part of the model because, it appears in the parameters; for any system the sampling time appear in the discreet time model parameters, you must have seen it when when when you try to construct z transforms with sampling time.

So the model you choose depends on the temporal scale at which you want to examine phenomena, very much. Similarly it depends on the numerical scale at which you want to, you see the temporal scale is actually the x axis. You are generally interested, if you are not interested, if you are interested in you are generally interested in evolution of a thing in some dimensions. So here I have covered three dimensions, here am covering the fourth dimension time. And then finally you have to you have to also see what is the value of the variable, what these dimensions.

So so so there also you may be interested in very in in various case; for example, do you think that a that a logic gate really does not exist at at at any other voltage value other than zero and five volt? It does. It very much does, how can it is suddenly transform itself from zero volt to five volt? When it goes from zero to five, it actually goes to all the voltage value, but when we deal with logic gates; we do not at all bother about that we treat them as zeros and ones, why? Because of the fact that, the that in its overall life cycle the the amount of time in which the in which the logic gate lives at a voltage let us say; between point four and three point two, within that band is infinite decimal. It either always is below point four or point six or point two whatever and it is and it is always above the three point two, three point four. So ninety-nine percent of its life time, it remains in those two voltages.

So that is why you have chosen to ignore, that that other one percent and you have decided. So you have at just at your your numerical scale of values, you have the whole scale from zero to five which could be model by a real number, you have chosen to describe by two integrals zero and one, right. And that as you can see completely change is the model of the logic gate, right so so depends on numerical scale. It also depends on various properties of the inputs that you want to consider. For example, we we will typically built d c models, see for a transistor we build either high frequency model or a low frequency model which are quite different; why because in one case we assume that it will take high frequency signals input, another case we assume that it will take only low frequency signal input. So we characterize the so the model we are selected based on the input characterization, correct.

Similarly; there are there are there can be various kinds of model forms, I mean we can we can we can we may constrain our model selection just by various conveniences. So for example, we always look for linear models, why? Things are not linear but we sort of force them into when I, even if they are non-linear we would find all kind of excuses to do to do a linear modelling, why? Because for further purpose, since we know the linear theory that you know you can construct a grand non-linear model with which you can do nothing or you can construct an approximate linear model with which at least you can progress, you can may be you can design a controller.

So that is why because looking at the future usability of the model, you would like to a priory constrain; that know I am only going to build a linear model whatever it takes, I am not interested in building non-linear models even if the system is this not linear or even if it could be described better by non-linear models. So so we might like to for for for for various purposes, we might like to constrain the model form, right. Similarly there may be several other factors, there may be there may be measurement constraints that immediately decide between which and which variable, it it is useful to build the models. If you want to use the model, you must generally build it between two measurable quantities.

Similarly, you may have knowledge constrains or you may have knowledge advantages. For example, you may already know that the there are system is stable. So if it is if you if you happened to know it to be stable, this is a this is a I mean I am calling it a knowledge constraint; because constraint means in in in mathematical terms, it means that it will that it will define a smaller space than the overall space. So so if you are if you already know that the system is stable then you will only look for stable models, you will not look for unstable model.

So you will have to device an algorithm which will automatically reject unstable model, because you already happened to know that this stable; I mean it is not a constraint in the sense that it is a disadvantage, it is actually an advantage. So so you will have to sometimes you call it as a priori knowledge; that is before we start looking for a model, whatever what do we know, what is our experience, you should be able to use it.

Then there may be computing constraints. For example; in a given situation, if you ask an Air-space engineer he will say, no no no no do not give me complex, I mean particle filtering algorithms. You know recently them this thing signal estimation that is an approach which is in which which is receiving a lot of the attension; it is it is said that it can produce better estimates than usual Kalman filtering things like that. So people have now doing lot of research on that, but if you ask a practicing common I mean Airo space engineer, he will say no no no no what is this Kalman, what is this a a particle filtering; it may be very grand but my my on board computer cannot perform this every cycle, every guidance cycle. I I cannot accept it.

So you must use a Kalman filter, you must use.. you must use a corresponding models. So here it is the computing constraints which restrict you to choose a model, right. So there are plus there are various cubic, various kinds of applications requirements also. So what I what I wanted to say, is that the model of a system is not absolute it is actually a decision, it is actually a, it is actually you know it is like; you are you will have to look for a model but while looking for a model, just like you shop for a thing in a market similar to that, but while you do that there are various other consideration which will guide you which may be related to your situation or which may be related to your purpose either of them. All of them are either related to the situation given to you, about which you cannot do anything. And or it will be related to the purpose that you want to put the model to, right.

So so that is what, I wanted to say that so many things will finally determine what kind of model you have to look for. And then satisfying these thing; you have to look for a good model, probably a probably you will have to look for the best model in some sense. So that is, how to do that is a system identification. So first of all naturally you consider that, we have I mean I mean a I am talking a very general term; rather general terms but so we will have we will we will have to define before we actually describe algorithms, that what what do we decide for these at thing, am I looking for a symbolic model or a we will have to we will have to define our scope in which we are going to study because model building is a very very vast subject.

So, in this small setup of six or seven lectures; we are going to cover only a small part of it. So we will say which which part we are going to cover, in our lecture. Before going on to that there is there is another concept. This is this is this something which I really like to explain; there is the same quantity, the same thing the the the same physical thing, may you may choose to model it in five different ways. In fact people for the same thing, there are there there are different sets of people who actually modulating five different ways for their own purposes.

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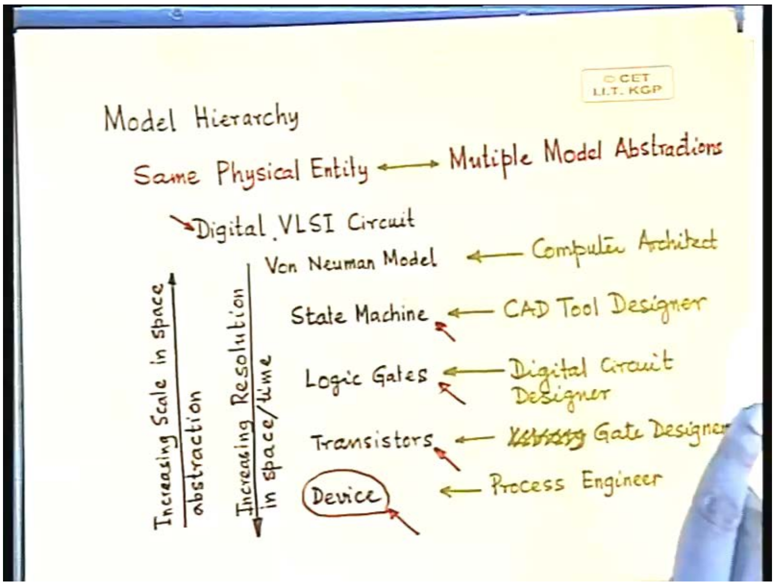

So for example, this this is my set example that you take a take a digital VLSI circuit; suppose you take a signal consider chip from t i, it is the device, what is it made of? So in this case it will not be Wanna Iman model, it will probably be Harvard architecture. So when you look at the signal processor, you you it contains millions of transmittance. So obviously you first say that, it is a it is a device, it is a system, how does it work? What is its model? So if you if you say that, it is for for for general purpose computers like a P C. You will say that, it has a Wanna Iman model; somebody say that, it has it has a Harvard architecture, signal processes typically do not have have have Harvard architecture.

So what what do you mean, that this cheap has has has Harvard architecture? You are obviously trying to describe its behaviour and it's working at some level, using some pre-defined concept. So the Harvard architecture has been defined using other concepts. So you are looking at it as a device of Harvard architecture. What is the Harvard architecture somebody asks? So then you can may be this step may be too too too abroad, you may be you may be defining a Harvard architecture in terms of lower level devices A L U, I am not very familiar with the Harvard architecture. So you may come down to you know small small computing units which are which are computed in a particular way, that is called Harvard architecture.

So how are they made? So if you ask somebody, will say that, it is how does it function. What its behaviour, each module? For example one of the one of one of the one of the important components in a signal processer is the multiplier; that is why signal process are so fast because they have they have a Harvard multiplier. So how does the multiplier function? What is it behaviour? So you say that, it is a state machine, it has certain lines. It is it is a it is a sequential circuit, typically described as a finite state machine.

So so at that level you think it is a finance state machine, what is the finance state machine? It is a model for any circuit which is made of Logic gates. So now you come to Logic gates, what is the Logic gate made of? It is made of transistors, what is the transistor made of? You know remember, I heard a story where an an an ancient lady scholar called Gorgy, it was it was not a lady, it was the it was the stage called jaguvulgar; who kept as in a Gorgy actually kept a asking jaguar work about, what is this made of what is that made of what is that made of and then finally I mean it was becoming very abstract people becoming very deep. So you see from from a digital V L S I circuit, we are from transistor if you say what is what makes transistor, you will have to say electrons and volts. Then if you say what makes electrons and volts then you go to sub atom in physics, about which I know nothing.

It is the same object, now why should you now now tell me that now you will find that everybody is interested in this model, somebody is interested in each level. For example, the the person who is designing the process for making that; the actually semi-conductor manufacturing process, he all the time looks at it like this. On the other hand the the suppose when when when you design a when you design a digital circuit, you do not bother whether it is made of transistors, do you? You are only bothered weather its truth to you, but the person who has designed the gate he had to really bother about; what are the transition time, how fast does it tries.

So he had to really look it look at the same gate as that as the non-linear transistor circuit for his purpose. So the so the gate designer, who has design the gate which you used, he he never looked at the gate as as the as the as the truth teller; he looked at the other non-linear differential equation, coupled, representing that transistor circuit. On the other hand, you always look at it as logic gates, somebody who is suppose somebody who wants to design software for using their processor may be internal software; he does not even bother about the logic gates, he is only a bothered about its abstract behaviour. So he looks at it as a state machine.

And finally the the computer architect may not be even interested in in the state machine, because it will be it will have millions of states, he may be interested in higher level models. And it is a same digital wheel as I said. So that is what I wanted to say that, is that the the same physical entity can be modelled as multiple model abstractions. And you you may need to do, is not that you need to always model it at one abstractions; it it it totally depends on your purpose. And so you must decide that at what abstraction level, you want to model the system? That will you know give you answer to all these questions, and then focus your search for models, right.

So what having said all that, let’s let’s let’s focus our what are we going to look at? So we this is just you know kind of a taxonomy of models; just this just describes, what are, this is incomplete you could have various other cases or categorization. So here I have defined models as laughened symbolic,

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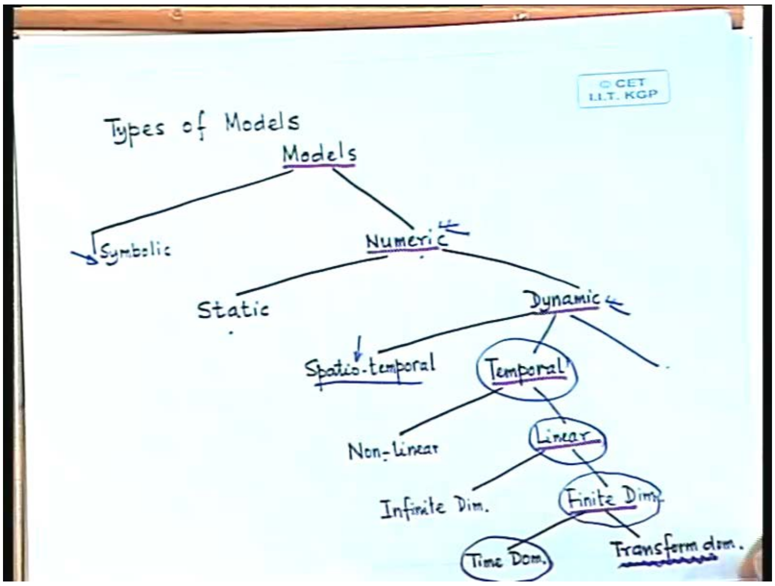

you may have for example, a a digital circuit you are you are calling as made of zeros and ones; those zeros and ones are not numbers, they are they are not to materialize integers, they are actually nothing but symbols, okay, so this so so the digital circuit is symbolic model.

On the other hand you may you may have numeric models and we are interested in the numeric models. Now numeric models could be either static; where where the value at a given point of time depends on other values but at the same time there is no extension of time towards the past or it could be dynamic, we are interested in the dynamic model. It could be

Spatio temporal that is, in in in how many dimension you are talking about? Actually I mean arbitrarily speaking, that is why I wrote it here; the there could be is is not necessary that, that I mean everything has to take place in four dimensions, it can take place n dimensions, in general because all all systems are not physical, right.

So for example, that is precisely why I stated the, I gave the example of the stock market it is not a physical. So so so but we are we are concern with generally concern with physical objects, so it could be either Spatio temporal; where you you you are you are you are interested in studying the variation with time and with space or it could be only temporal, we are interested in only temporal. A temporal dynamics can be either linear or non-linear; for most purposes will be concerned with linear, because of simplicity.

A linear system could be finite dimensional or infinite dimensional; for example, e to the power s t is the is the infinite dimensional linear system. So we are generally interested in finite dimensional system; if you construct a a states space description of it, it will have a finite number of states. So we are interested in finite dimensional systems. Finite dimensional linear systems could be treated either in timed domain or in transformed domain, sorry we are not going to take it in transformed domain; we are mostly going to take it in time domain because basically because of the fact that, then you can directly use signal values.

You could go further down, for example linear finite dimensional time domain model could be could be either time varying parameter or or timing variant; it could be either single input or it could be multiple input. There are so many other categorization, but suffice it to say here that we are interested in generally interested in linear finite dimensional; actually single input single output and actually though it could be varying, but generally interested in timing variant model. So we will treat, that the that the bottled parameter is generally keyed, that the that the system model parameter is constant, but unknown.

We have to find it but it does not change all the time. So that is that defines the; you see so after telling such a big story, I have come down now finally to the right. So so this is what we are going to consider in this lecture.

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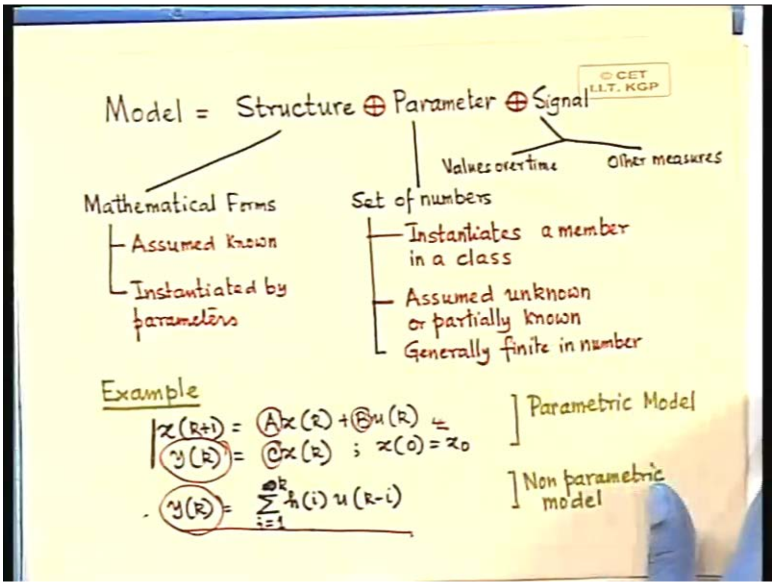

Now we will search models, now now we are now we have to come we are gradually selling down the business. We want to identify we want to look at find out a good model. So what is the model made of? What are the all the things, that we have to find out. So model is typically made of structure, parameter, and signal values; these are the three you know entities which make a model. So what is the structure? It is the it is the particular mathematical form; for example, if you have x k plus 1 is equal to A x k plus B u k; this mathematical form that that that this is the vector, that this is the n by n matrix, this particular mathematical form is called its structure. That is that is how things affect one another, right.

Then you have so basically when you when you tell a structure, you are defining a class of models. So this is a class of linear, finite dimensional, time variant systems; you are not talking about a particular model model of this circuit, you are not saying that, you are you are talking about a set of models all of which can be described by that structure, right. And now you have to you are in generally interested in building a model for something. So once you defined a set that set search like a bag; now in that, bag there are there there are there are so many bags of models. So so in how many bags,you will you search? So you are defined that, no no no I am going to search from from the systems in this bag. So when you are define defined the model form, you have defined that now.

In that bag you have to pick out the particular model. So so so how that bag characterizes in is terms of the parameter values, this is a matrix. What is the exactly, what are the exact elements values in that matrix? They are called parameters, so a model set which is characterize by the mathematical form of the structure is instantiated by the parameters; if you put the parameter values, you get a particular model of that structure and then finally to complete the model, after all it is a relation of signal values. So you have to add the signal values, so you have to have x k and u k, that gives a model, right.

Now generally we say, sometime so all models we as I have described all models are called parameters, I mean all models have parameters that is the fact. But still some models are sometimes called non-parametric models and some models are called parametric models, why? Because generally, we we have we we we you know, always finite that finite descriptions are good; remember that we we we wanted to have algorithms where as you as time k goes up, you have to describe or if you have to compute all signals from zero to k then you are in trouble because k goes on increasing. So every time your work increases, your memory increases. So in general we are interested in those model forms which have a nice set of finite set of parameter by which you can characterize the model.

On the other hand there are some systems, some model form, some mathematical forms in which there are still parameters; but those parameters are very large in number and the the so so so they are not really called parameters, so such models are called non-parametric models. For example, the same system is either described like this or described in terms of its impulses models. Now the impulses response is obviously is of it very could very well be of infinite duration, it does not come to zero. See in which case, this model the same model here also y k, here also y k with the same u k. This is describe by an infinite set up parameter as k goes on, for this is always described by the elements of A, elements of B and elements of C, which are obviously, finite.

So that is why this kind of models are called, parametric models while this kind of models are called non-parametric models; because here the parameters that is too large, you know to be conveniently use those parameters, we are we will be generally interested in parametric models.

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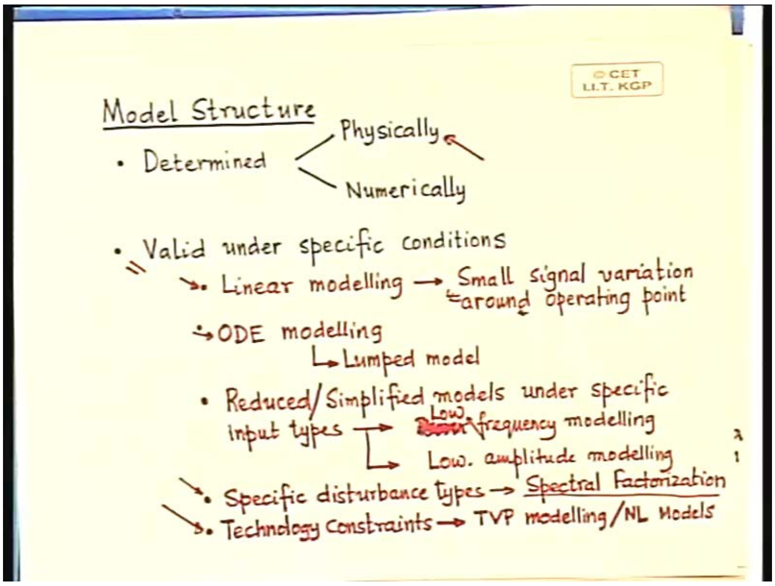

Now in many cases, we will assume for for for most of the lecture we will assume that the model structure is you know kind of known; at the end of at the end we will spend one lecture to see, how we can even choose model structure but generally we will mostly assume some model structure and then find out that, that given that model structure how to pick out a good model? So how do you determine model structure, if you are given a circuit; if you have given a circuit diagram, let say R L C circuit, how will you know whether whether it should be of second order or or third order? Are you going to do better error or no? You are going to look at the circuit; you are going to write the equations, you know as many as many energy storing devices and many states.

So if it has two inductors, if it has two capacitors, you will immediately know that it will have four states even before I did not know equations and probably the exact model structure; you will be you will write the basically the K V L, K C L equations and from there you will get the model structure, such a model structure you have determined physically. That is from physics, again that means you have you have employed its structure; you know you have you have the the you have got the got the I mean sort of deducted, reduced the model of the compose system in terms of models of inductors and capacitors which you have learned in college, right.

On the other hand, the same higher c circuit, if it is given in a box to you and said that these are two terminals, these are two terminals; it is a linear system please find the model structure. Then you do not know what inside, you do not know the circuit; so you cannot do it physically then you have to do it numerically and there are methods of doing it. So a model structure may be determined either physically or physically means; based on physics based arguments, based on the device physics or the system physics or numerical.

And we we must remember again and again I am telling that it is valid under specific conditions; for example, when when we are doing a linear modelling, it is in many cases valid under under small signal conditions, where there is an operating condition which the circuit people called called the called a bios. If you are if you are a consistent amplifier design and you will called d c bios on which you have small signal variations. And the other hand, the chemical engineer will call it operating point, around which he has signal wets signal fairy.

So in any case signal must be small for that model to be varying. So this is the case for example, if you are chosen to chosen ordinary differential equation model; it means that you are you are ignoring spatial distribution, otherwise you would have gone for a partial differential equation point.

Similarly low frequency, low amplitude model, low amplitude is here even low frequency and high frequency models as we describe. Or models, sometimes you will have to construct, also utilise models for disturbances even some times for un-measurable disturbances, right. For example, you have you have already done that in your Kalman filter, you have used a disturbance which is un-measurable in your model. So you have so I mean how do you know that the disturbance acts like that? So it will act, it it will be there only is there are certain mathematical conditions; for examples, only when the power spectrum of the disturbance can be spectrally factorized.

So and there were be several kind of technology constraints; something may be measurable, something may not be measurable. So the model structure we will inherently depend, can be determined but it but we must after we make an assumptions on that; we are not going to look back then we are going to look for our system in that bag, but we must remember that the bag selection is done somehow and it is valid under certain conditions. So if if if those conditions are are invalidated, those parameters will not work any more.

Now even in that bag, now we are gradually coming to how to choose even in that bag there will be big models and then will be small models. For example, if you if you specify depend you know, it is always like a Russian doll. So so there will be a bag inside a bag inside a bag, right. So first you define a big bag or linear finite dimensional model, there is a linear final dimensional models of order n, right. So there you may like to say, okay okay linear finite dimension, I am I am going to look it look at it in the bag of linear finite dimensional models, but the of of what order? So which bag in that bag? So we must, so it is

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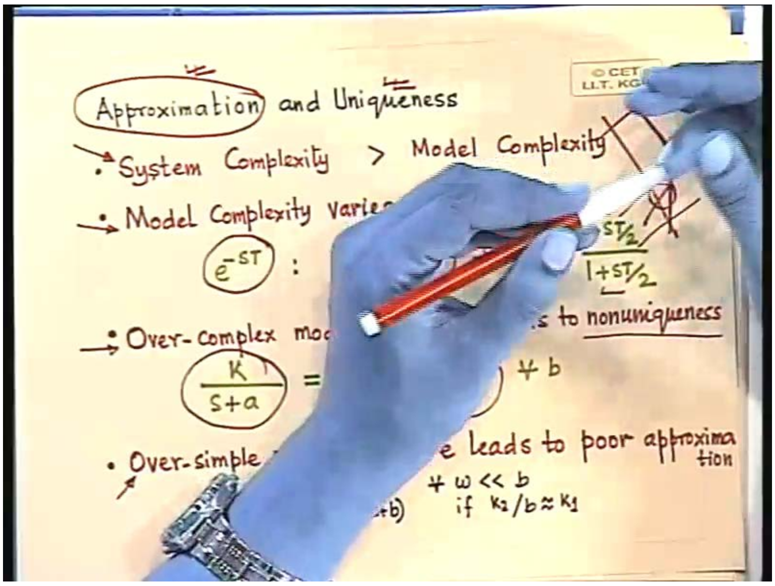

it is important to be able to decide the, the appropriate model complexity. After all we want to keep things the simplest, for our purpose. So we we will choose the simplest model based on two considerations; first consideration is that it should be able to approximate the system, even that situation reasonably accurate, right.

And another thing is that, since you are looking for sometimes; we say that since you are looking for and looking for a modelling in an in an in an automated manner, you know it helps us to to to find the situation where we will always convergent one model. If it turns out that, there are five different models anyone them could be picked up then it is so happen, that my that my algorithm, if it is especially; if I am looking at the model on line then my algorithm may by just wonder, sometimes we are in there or it will shift such things may happen, so uniqueness is important.

Now what I wanted to say is that, so so I will make some comments about this this approximation and uniqueness. First thing is that, we must remember this is this is a thumb rule; based on which the whole field of robust control is based is that, system complexity is always greater than model complexity. So the model is bought an approximation of system, there is always some un-model dynamics, always I mean almost always. Similarly model complexity varies, I mean it is a matter of choice; for example this e this e to the power minus S T, give a model either as 1 by 1 plus S T or as 1 minus S T or as 1 minus S T by 2 by 1 plus S T by 2, within certain frequency ranges; these are all valid approximation of e to the power minus S, which one you will choose, depends.

Similarly, now so so you have to choose the now you cannot choose two complex models, because they will lead to loss of uniqueness. For example, if the system data is really generated from a system like these which has the trans function, okay; k by s plus a then remember that, if you are looking for second order models then we will get we will we will get so many choices, because this second all such second order models for any value of b will actually fit the system.

So the solution highly non unique, there are infinite number of second order system which will fit this first order system. It it, why it does it happen, because you are unnecessarily considered a model which is too complex, it will not necessary. On the other hand, if you if you if you choose an over simple model structure then you will not be able to approximate; for example, if the if if the system board a plot, if I mean if you model a system by a first order board a plot, then then you will never be able to model, you will be able to model after this may be but if the system has the has has another pole here, you will never be able to model these thing, if you are if you always choose a first order model.

So if you are, depends depends on the input spectrum. If your input spectrum only stretches up to this, it is fine. If it is stretches up to this, you will you will never be able to fit a first order model, there you are chosen a over simple model structure. So I will stop you just by defining, what is systematic definition? So basically, given a set up process signal values over time; given an assumed modelled structure which will be based on so many considerations that we described today.

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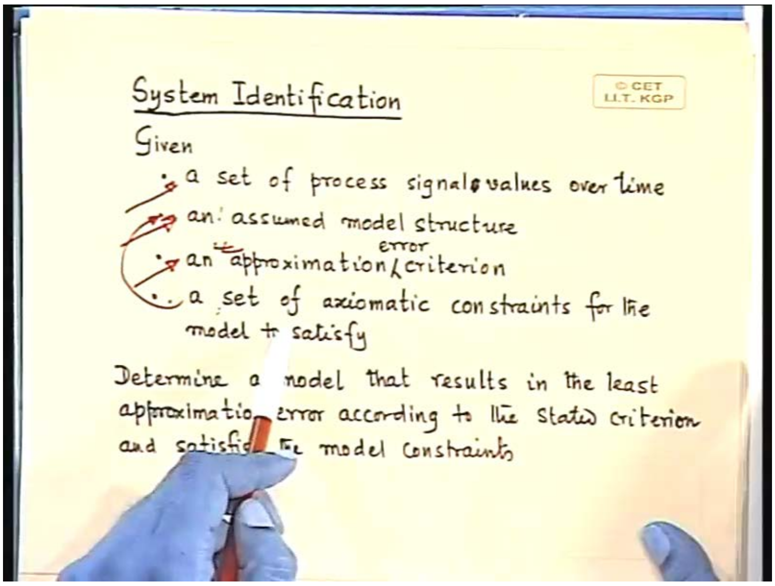

So now we have defined the bag, in that bag we have to pick a good model. So what do we mean by good? So we have to define an an some measure of goodness which is an approximation error criterion and we may you may also; actually this is this is also you know some actual these two together define the bag, so you may also also say you may not only say linear finite dimensional, you may also say linear finite dimensional stable.

So when you are saying stable, you are further define further dividing the bag and and obviously now if you want to find out the the poles and zeros of the system, you are going to look into left half minute. So you are using a priori knowledge to to first get to the smallest bag and then in that bag, you will have to pick out the best model according to this approximation error criteria; this is the problem of systematic defecation.

So determine a model, that results in the least approximation error according to the stated criterion and satisfies the model constraints; that is the problem which we are going to handle from tomorrow, thank you very much.