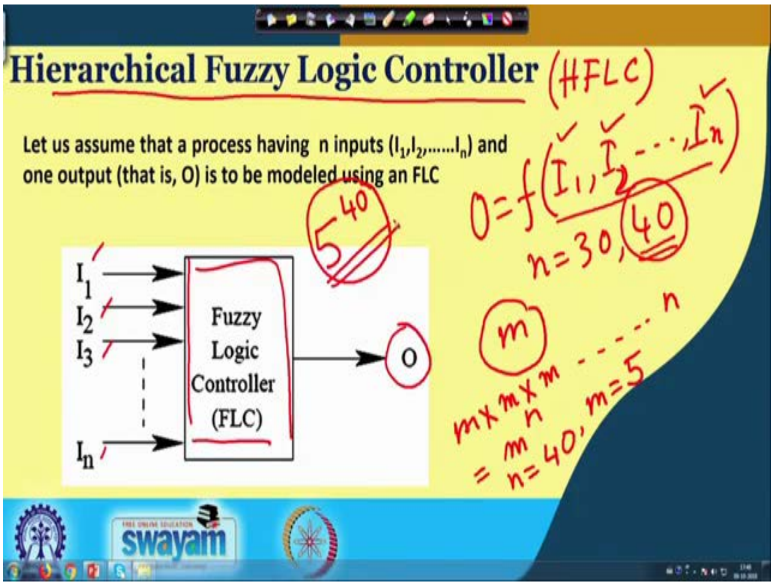
Fuzzy Logic and Neural Networks
Prof. Dilip Kumar Pratihar
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 12
Applications of Fuzzy Sets (Contd.)

Now, we are going to discuss the concept of Hierarchical Fuzzy logic Controller.

(Refer Slide Time: 00:20)



So, in short, this is known as HFLC. So, let us try to understand the reason behind going for this particular the HFLC. Now, let me assume a very complex real-world problem, supposing that, the problem is related to say weather forecasting. Now, if you see the problem of weather forecasting,whether there will be a rain or not after say 2 hours or 3 hours.

So, that particular prediction depends on a large number of parameters. Now, supposing that I am going to use a fuzzy reasoning tool as an expert system just to predict whether there will be rain or not. Now, if you see that particular process, it depends on a large number of input parameters and the output, that is a function of a large number of input parameters like your I_1, I_2 up to your say I_n, a large number of parameters. Say, might be n is equal to 30 or 40 and so, then how to predict and how to design and develop the knowledge base for this particular the fuzzy reasoning tool.

Now, to design this type of the fuzzy reasoning tool, actually we are going to face a major difficulty and difficulty in the sense that we will have a large number of rules. Now, here, if you see say, if I consider like n number of input parameters. So, this is nothing, but your fuzzy logic controller and it has got n number of inputs like your I_1, I_2, I_3 up to I_n and supposing that n is equal to 40 and supposing that, I have got only one output. Now, what should be the number of rules and what is the maximum number of rules, which I will have to design?

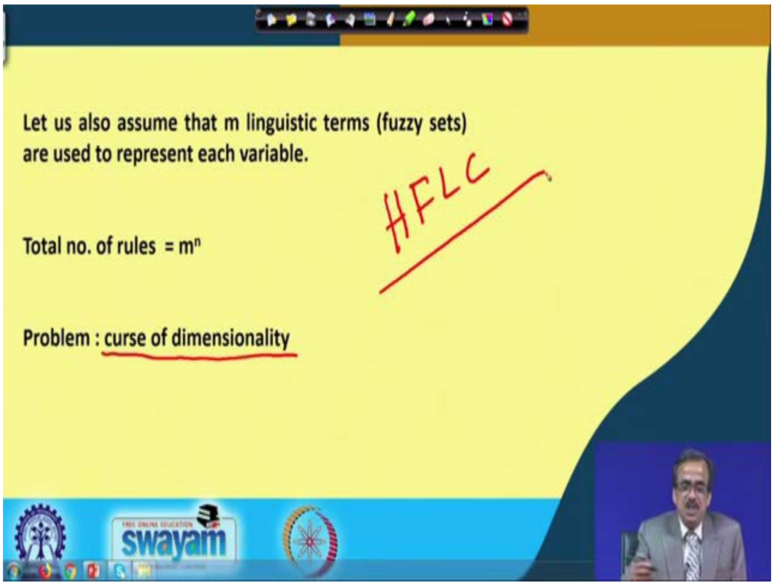
Now, to represent each of these input parameters like I_1, I_2 up to say I_n, supposing that I am using say small m number of linguistic terms. Now, if I use small m number of linguistic terms to represent each of the input variables like I_1, I_2 say I_n, and if there are n such input parameters, then what should be the number of rules?

Now, the maximum number of rules will be how much? So, that is nothing, but your $m \times m \times ....n.terms$, because we have got small n number of input variables. For each input variable, I have got small m linguistic terms and this will give rise to your m^n and this is actually will be a very high number.

Now, let us just try to put some numerical value, supposing that n is equals to your say 40. So, small n if I put that is equals to say 40 and supposing that I am considering the small m is equals to say 5; that means, I am using 5 linguistic terms to represent each of the variable. So, the total number of rules that will become your m^n that is nothing, but is your 5^{40} now, this 5 raised to the power 40 will give rise to a very large number. So, many such rules we will have to design and so, many such rules we will have to consider, while determining the output for a set of input parameters.

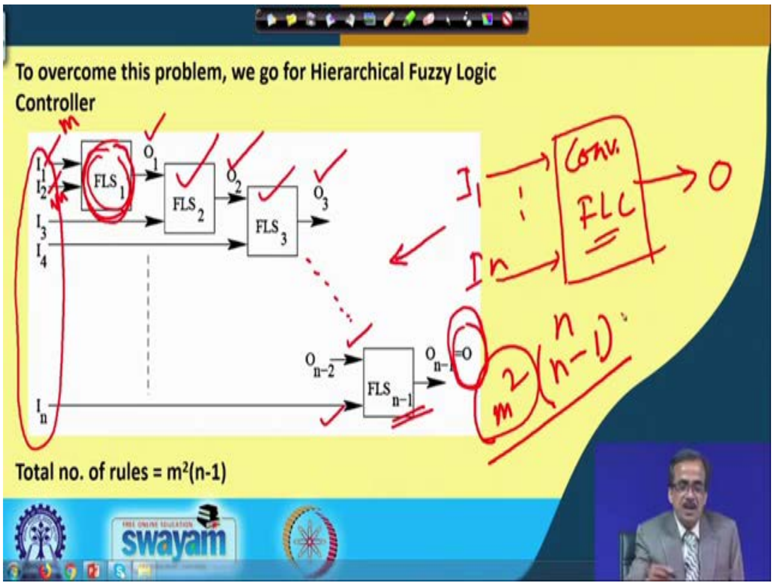
So, it is bit difficult in terms of computation and as the number of input variable increases and as the number of linguistic terms used to represent each of the input variable increases. So, what will happen to the number of rules? The number of rules is going to increase like anything and computationally, it will become very complex. Now, let me summarize whatever I have discussed. Now, supposing that I am just going to handle a real-world problem having a large number of input variables and if I use say 4 or 5 linguistic terms to represent each of the input variables. So, we need a very large number of rules and as the number of rules increases the computational complexity of this fuzzy logic controller is going to increase. So, this is not desirable. And, this particular problem is actually known as the curse of dimensionality.

(Refer Slide Time: 05:42)



Now, if you see the literature, people are using this particular term, that is, curse of dimensionality. So, the fuzzy reasoning tool or fuzzy logic controller is suffering from this particular drawback and that is nothing, but the curse of dimensionality. Now, how to solve this particular problem? To solve this particular problem, the concept of your HFLC, that is your hierarchical fuzzy logic controller has come into the picture. Now, let us try to understand the working principle of this particular, say HFLC.

(Refer Slide Time: 06:24)



Now, to understand the working principle of this particular figure. Now, here actually what you do is, we have got say the same problem like I have got small n number of input parameters and I have got only one output and previously, I was using only one fuzzy logic controller. So, I have got a large number of inputs here say I_1 and this is say I_n and I have got one output. So, this is actually the conventional FLC. Now, to replace that so, what I am doing is, I am just going to use the concept of HFLC or your hierarchical the fuzzy reasoning tool or fuzzy logic controller. Now, the structure wise it is very simple. So, what you do is, out of these n input variables so, we try to find out which are the most important ones.

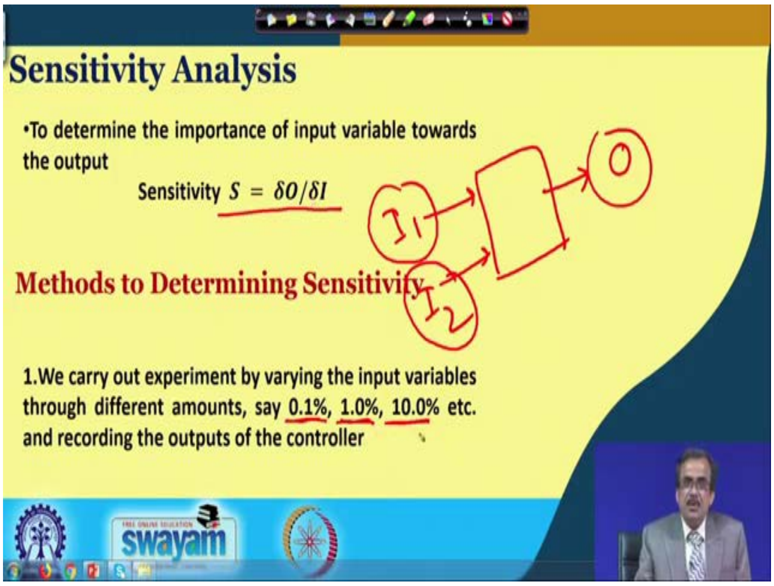
Now, supposing that I_1 is very important; that means, I_1 is having some significant contribution towards the output, similarly I_2 is another very important input variables. So, what you do is; so, this I_1 and I-2 so, these two input variables we consider for the first fuzzy logic system and whatever output we are getting from the first fuzzy logic system, that will be used as the input for the second fuzzy logic system and another input is also coming from here, say I_3 is coming here and these two inputs are entering to the second fuzzy logic system and it will give rise to an output that is nothing, but O_2 and this particular O_2 is going to enter the third fuzzy logic system FLS_3 and another input is coming say I_4 and here, I will be getting the output that is O_3 and the same process will be continued and the last fuzzy logic system that will be like this.

So, here O_{n-2} is going to enter as input and the last input that is I_n is also going to enter and on the output side, we will be getting O_{n-1} and that is nothing, but the final output. Now, here actually what you do is, the conventional fuzzy logic controller is replaced by a number of simple fuzzy logic systems and this fuzzy logic systems are put in the hierarchy confession. Say, might be in the series this, particular thing support and by doing that, actually we are getting one advantage. Now, let us try to understand, what type of advantage we are getting. Now, here if you see, say if you concentrate on the first fuzzy logic system.

So, there are two inputs, supposing that for I_1 say I am using m linguistics terms and to represent I_2, I am using say m linguistic terms. So, what should be the number of rules? The number of rules will be nothing, but m^2, multiplied by m, and this particular fuzzy logic system is going to tackle only m^2 rules and similarly, how many such fuzzy logic system we have got? We have got n minus 1 small fuzzy logic systems. So, what should be the total number of rules which we are going to consider? That is nothing, but $m^2(n-1)$.

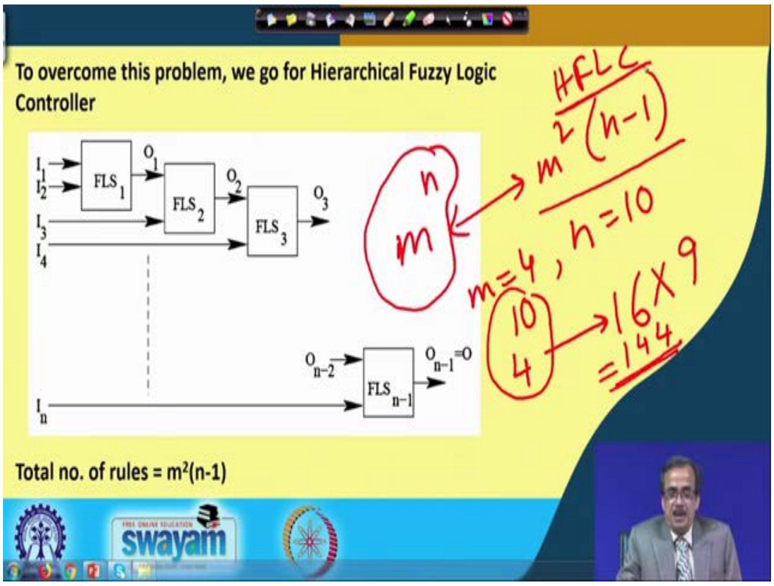
Now, you see the advantage of this particular HFLC.

(Refer Slide Time: 10:38)



So, previously in the conventional fuzzy logic system so, we had the total number of rules like your; total number of rules like your m^n.

(Refer Slide Time: 10:50)



And, now actually in place of that we have got $m^2(n-1)$. So, in the conventional fuzzy logic controller, we had this number of rules that is m^n, and now in the HFLC so, we have got only m square multiplied by your say n minus 1. Let me take a very simple example, let me put some numerical value will understand like if I put say m equals to say 4 and if I consider say n equals to 10.

So, in the conventional FLC, we had the maximum number of rules like 4^{10}, which is a very large number. And, in place of that so, here I am getting like your m square that is nothing, but 16 multiplied by n minus 1. So, that is nothing, but is your 9 and this is equal to your 144. So, in place of so, 4^{10}, I am actually using only 144 rules.

So, this is actually the advantage of using this HFLC, that is, the hierarchical fuzzy logic controller. Now, to conclude actually, what will have to do is, for a problem having a large number of input variables, we generally go for this, your the hierarchical fuzzy logic controller. Now, here so, this is the merit, this is the advantage of using HFLC, but it has got one demerit also.

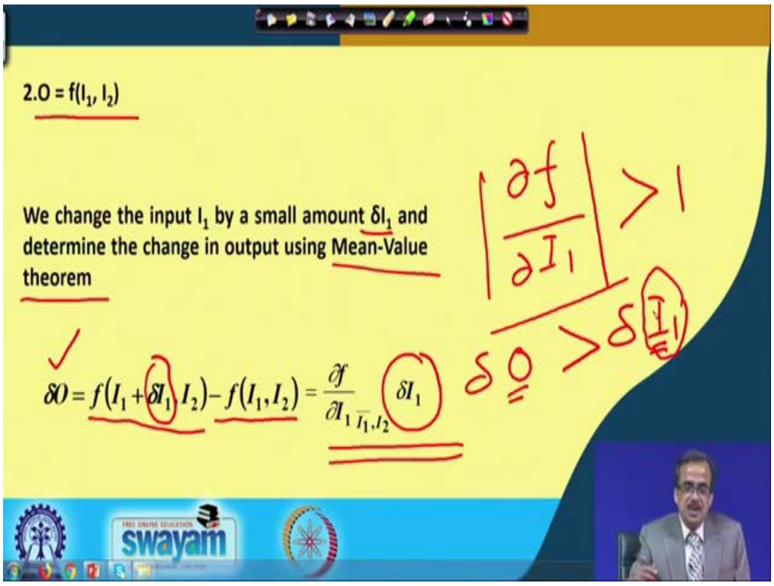
Now, that particular demerit is actually as follows: like we may not get the actual level of accuracy, which we get in the conventional FLC. So, we will be getting less accuracy in HFLC in comparison with that of your conventional FLC, but computationally, it is faster HFLC is faster compared to your conventional FLC. So, these are the relative merits and demerits of conventional FLC and HFLC. Now, we are going to concentrate on another thing that is called your the sensitivity analysis of a fuzzy reasoning tool or fuzzy logic controller. Now, let us try to understand the meaning of the term: sensitivity.

So, by sensitivity actually what we mean is, actually the change of output to the change in input. So, sensitivity S is nothing, but the change in output to the change in input; that means, for unit change of input, what should be the amount of change in output, that is nothing, but the sensitivity. So, supposing that I have got one FLC, which is used to model a process having say two inputs I_1 and I_2. So, here I have got one FLC having two inputs, say I_1 and I_2 and have got only 1 output.

Now, my aim should be how to find out the rate of change of output with respect to your this particular I_1 and rate of change of output with respect to this your I 2. That means, if I make unit change in I_1, what will happen to the change in output and if I make unit change in I_2, what will happen to the change in output? So, those things actually, we are going to find out. Now, how to determine this? So, the change in output to change in input so, what you do is, so, we vary the input variables by different amounts. For example, say we increase by say 0.1 percent then 1 percent, and then 10 percent and we try to notice what should be the corresponding change in the value of the output.

Now, if I change the input by say 0.1 percent 1 percent and 10 percent and if I can find out what should be the change in output. So, I can find out the sensitivity of this particular fuzzy reasoning tool. Now, this is a very crude method, we are doing; now mathematically also, we can find out this particular sensitivity.

(Refer Slide Time: 16:06)



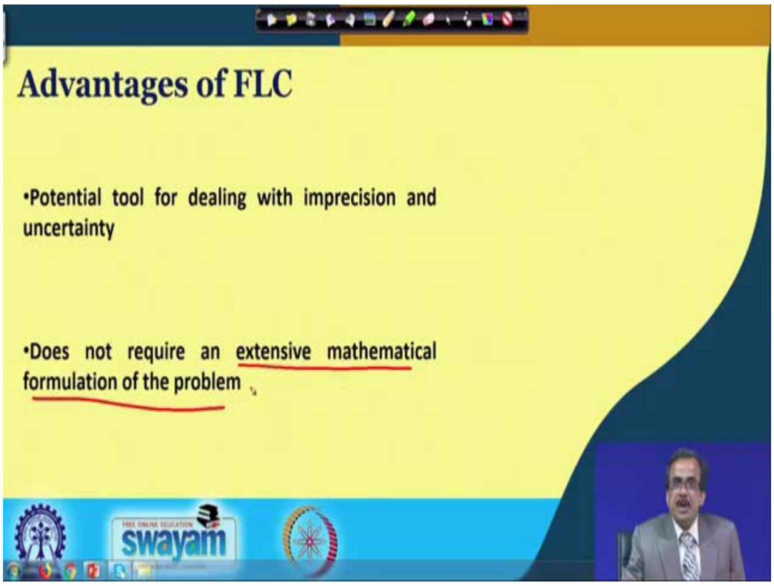
Now, let me concentrate on a fuzzy logic controller, which is going to determine the output for two inputs, like I_1 and I_2. So, the output is a function of the two input parameters I_1 and I_2.

Now, what I do is, we just change input I_1 by a small amount say δI_1. So, what you do is, we try to find out the change in output that is your δO and that is nothing, but $f(I_1 + \delta I_1, I_2)$. So, the change in I _is nothing, but this amount δI_1. So, we try to find out $f(I_1 + \delta I_1, I_2) - f(I_1, I_2)$ and this is nothing, but the change in output that is your δO and that is equal to the $\frac{\partial f}{\partial I_1} \times \delta I_1$.

So, this is the way actually we can find out, in fact, the change in output using the mean value theorem. So, by using the mean value theorem, we can write down and we can find out this. Now, supposing that the mod value of this particular your partial derivative of f with respect to your I_1 is coming to be greater than 1. So, we can write down that your change in output is greater than your change in input; that means, your if I change this particular the input by a small amount, I will be getting more change in this particular output. So, this I_1 is actually very significant. So, we can carry out the sensitivity analysis by following this particular method.

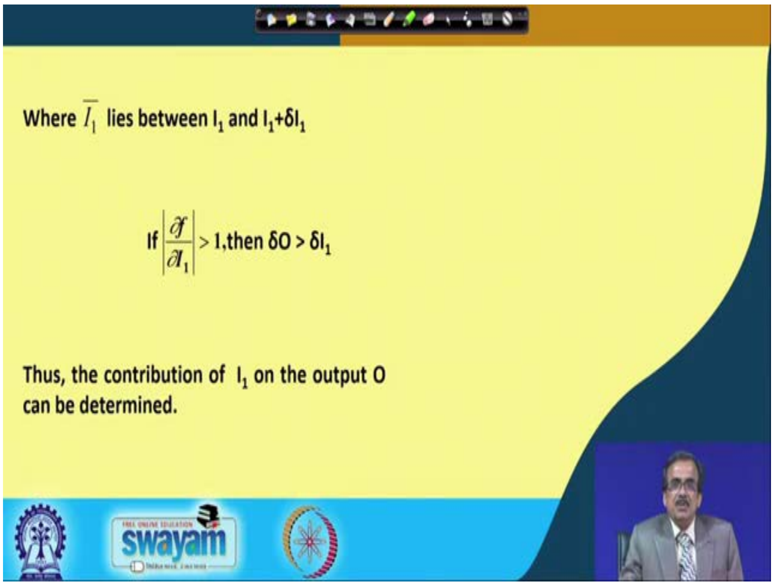
Now, in place of I_1, I can also carry out the sensitivity analysis for I_2 and if you carry out the sensitivity analysis for I-2 by following the same procedure, I can also find out what should be the change in output corresponding to the unit change in your input, that is your I_2. So, sensitivity analysis can be carried out both for I_1 and I_2 separately by following the same procedure, which I have already discussed.

(Refer Slide Time: 19:08)



Now, this is actually what you mean by the sensitivity analysis of the fuzzy reasoning tool.

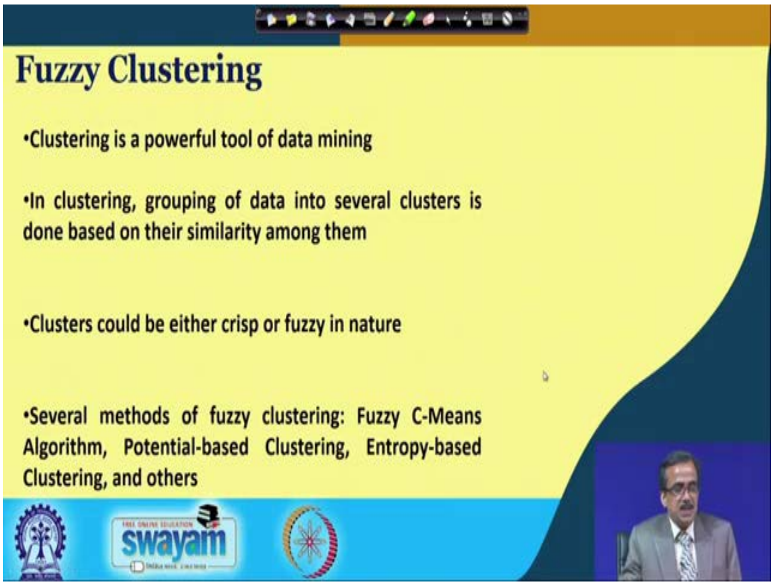
(Refer Slide Time: 19:10)



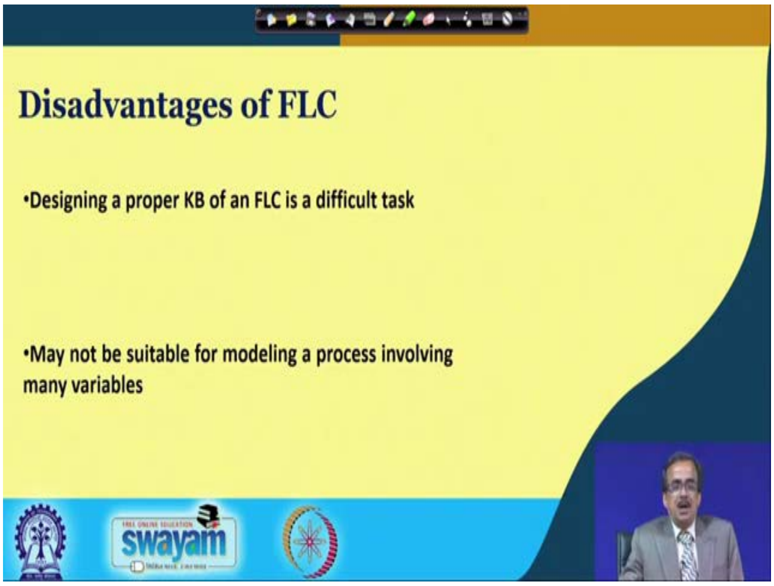
And, we can find out the contributions of the different input parameters or the input variables towards its output and we can find out the sensitivity analysis.

Now, I am just going to discuss the merits and demerits of this fuzzy reasoning tool or fuzzy logic controller. The 1st point, which I am going to make here that fuzzy reasoning tool is a potential tool for dealing with imprecision and uncertainty. So, this I have already discussed several times. The 2nd merit or the advantage of FLC it does not required an extensive mathematical formulation; that means, your if I you if you want to find out the input-output relationships, we need not go for the differential equation and its solution. And, if the designer has some information of the process to be controlled or the process to be modelled so, he or she can design the rule base, the database, that is nothing, but the knowledge base of the fuzzy logic controller and once that particular knowledge base has been determined, if we just send one set of input parameters, there is a possibility. So, we will be getting the output. So, it does not require the extensive mathematical formulation of the problem, and one fact we have already discussed several times that most of the real-world problems are very complex and those are bit difficult to model mathematically. And, that is why, this type of fuzzy reasoning tool or fuzzy logic controller is going to help us a lot, particularly for tackling or solving the complex real-world problems. Now, I am just going to concentrate on the demerits.

(Refer Slide Time: 21:24)



(Refer Slide Time: 21:26)



So, here to discuss the demerits actually, what I do is so, we try to say that the performance depends on the knowledge base and how to determine this particular optimal knowledge base; that means, how to determine the database, how to determine the optimal rule base? So, that is a difficult task, the fuzzy reasoning tool, in fact, does not know anything, it does not have any in built optimisation tool.

So, what we will have to do is, we will have to optimise or you will have to train this fuzzy reasoning tool with the help of one optimizer and the known input-output data; that means, we will have to design and develop the knowledge base of this particular the fuzzy logic controller or fuzzy reasoning tool. And as I told determining the proper knowledge base is not an easy task and in fact, we will be discussing like how to design and develop the optimal knowledge base of a fuzzy reasoning tool or a fuzzy logic controller, so that it can perform in the optimal sense.

Now, the next point may not be suitable for modelling a process involving many variables, this problem we have already discussed, like if there are large number of variables like the problem of weather forecasting and so on, say very difficult problem real-world problem. And, for this particular problem, there will be a very large number of input parameters or the input variables and consequently, the number of rules is going to increase like anything and the computational complexity is going to be very heavy and that is why, for a problem having a large number of input parameters or the input variables, our recommendation should be, we should not go for this type of fuzzy reasoning tool or your are the fuzzy logic controller. And, to solve this type of problem or to tackle this type of real-world problem, in fact, we have got another very powerful tool that is your artificial neural networks. So, those tools and techniques will be discussed in details, after sometime.

Thank you.