Artificial Intelligence: Search Methods for Problem Solving
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Chapter – 07 and 10
A First Course in Artificial Intelligence
Lecture – 66
Means-Ends Analysis

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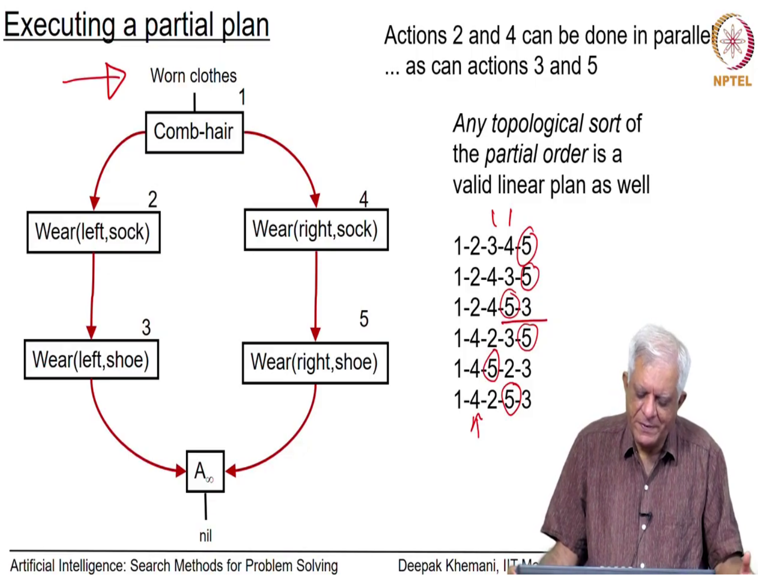

So, welcome back let us wind up our discussion on plan space planning now, or partial order planning as it is called. And, remember that the output the solution plan that is written by partial order planning or plan space planning is a partially ordered plan essentially. This is consistent with the fact that it is a least commitment strategy that unless you want to impose an order for some reason you do not do that essentially.

So, this is another domain from everyday world. Supposing, during your childhood days you had to get ready for going to school and you had been taught how to get ready, so you had a plan in your head of how to get ready.

And this is a segment of that plan. This segment begins after you have achieved the major objectives which is to wear your clothes, so you have got your school clothes on and your bag ready and everything. The last thing that remains is to wear your shoes and comb your hair.

So, this is this partial plan says that after you have done the rest of your getting ready job which means the condition worn clothes has become true, and when that peak condition is true then the action comb hair can be executed. And I have not shown the effects here because they are some somewhat difficult to model, but you can imagine there a partial plan like this.

That after you have combed the hair then the left hand side of the plan shows that you have to wear your left sock and you have to wear your left shoe. So, clearly they have to be done in that particular order you have to first wear the sock and then you have to wear the shoe. And on the right hand is the same thing for wearing the right sock and wearing the right shoe essentially.

Now, when you execute such a plan a partial plan and this is very similar to the plan that we produce for the blocks whole domain it is a partial order and we are talking about how to execute it. Now, how you execute it will depend upon what are the capabilities of the agent who is executing these plans.

If you are very skilled for example, then it is possible that you can do actions 2 and 4 in parallel which means you put both your socks simultaneously and then you put both your shoes simultaneously. So, in 3 times steps. The first time step was used for combing your hair you could have finished your job of getting ready.

But if you were working in a more relaxed situation and you did not want to let us say use both your hands at the same time, you could still have valid plans and it turns out that any topological sort of the partial order that we have is a valid linear plan as well. So, all the sequences that I have listed here are valid sequences.

So, you can first comb your hair which is the action 1, then you can do 2 and then you can do 3, then you can do 4 and 5 which means you first wear your left sock, left shoe, and then the right sock and the right shoe.

But you could also do as follows that you first comb your hair you wear your left sock, then you wear your right sock then you wear the left shoe and then you wear the right shoe or you could wear the right shoe first as this is the case here and the left shoe afterwards any topological sorts.

So, remember that topological sort is says that you can take a partial order and convert into a linear order and that process is called linear order. And the linear order must be such that it respects the ordering constraints in the partial order. And all these linear orders respect that. Basically, it says that action 5 must always action happen before action 4. So, if you look at all these sequences you will see that 5 is sorry action 5 should happen after action 4.

So, you can see that in all these sequences 5 is happening somewhere and 4 is happening before that essentially. So, 4 is happening here in these sequences and here and here in these two sequences. So, they respect the ordering of the partial order and any linearization which does that is a valid plan. So, you can produce a partial order plan and execute it sequentially. There is no stopping you from doing that. You do not have to execute it in parallel.

And this also kind of emphasizes the fact that we are using a least commitment strategy, because there is no way at least we have no reason for saying that you should wear the left sock first or the right sock first. We say that this is a plan you wear the left sock you can wear the right sock in any order and the only are other condition is that you wear the corresponding shoe after you have worn the corresponding sock. And you can do things in any order.

So, perhaps there would be some other considerations which would finally, ask you to you know do things in a particular order which you can try and imagine, but the plan the planner is not committing. So, in that sense it is a least commitment planner.

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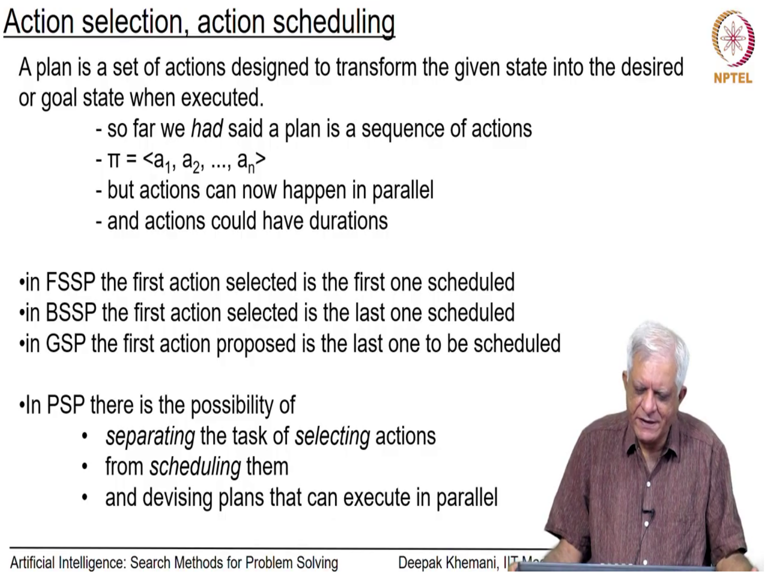

So, we have been talking about planning in general and we have been talking about action selection and action scheduling. So, just to do a very quick recap. A plan is a set of actions designed to transform the given state into the desired or the goal state when it is executed. When we started looking at planning we had said that the plan is a sequence of actions that you know you have to do action a 1 first, then you have to do a action a 2, and then so on up to a n essentially.

When we moved to plan space planning, we said that action can now happen in parallel as well which means that the planner says that, certain there is no order between certain actions.

So, for example, wearing left sock and wearing right sock you can do them in any order essentially.

And actions could have durations also we have not talked about temporal planning here because we do not have enough time in this course, but you can imagine plans which have duration. So, maybe wearing a sock is faster than wearing a shoe because you have to tie a shoelaces and so on.

Then, the whole thing could have a total amount of time that is spent in executing the plan. In our world, which is the simplest possible world? We have said that actions are instantaneous and therefore, we only measure in how many times steps do you to complete a plan essentially and that we have called as a (Refer Time: 07:36) plan.

Now, in forward state space planning the first action selected was the first one to be scheduled. In backward state space planning it was the opposite the first action to be selected was the last one to be scheduled.

In goal stack planning, the first action proposed which was done in the backward fashion was actually the last one to be selected and scheduled as well at the same time essentially.

So, we had said that goal stack planning constructs a plan in a forward manner which is sound, but search is for the actions in a backward fashion. But in all these 3 algorithms it was pre decided where the action would be scheduled in the plan it means that the order of actions was decided by the planner as and when it found those actions

Now, in the case of plan space planning as we have just seen there is a possibility of separating, the task of selecting the actions from the task of scheduling them. So, this is how we often do planning as humans. And we will see a little bit of origins of this shortly.

And we also saw that in plan space planning there is a possibility of devising plans that can execute in parallel because if two actions do not have an orderly link between them then in principle it means that they can also be done in parallel. So, if we have the means to do them in parallel, then the planner can go ahead and do that.

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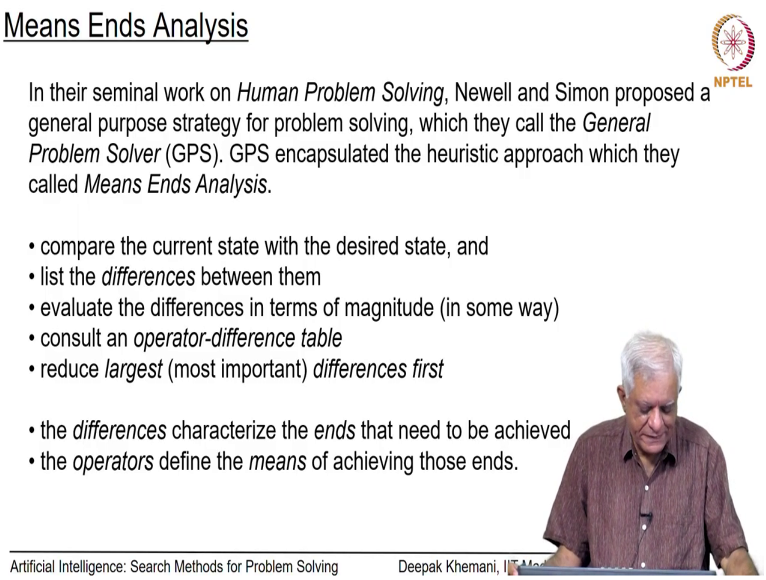

So, I was saying that the origins of this kind of planning or the plan space planning can be traced back to heuristic called means ends analysis which was given to us at the very beginning of AI development. Remember that we had talked about the Dartmouth conference, and two of the people who were there in the Dartmouth conference which happened in 65 or so, were Allen Newell and Herbert Simon.

And they in their seminal work which is and there is a huge book called human problem solving, they proposed a general purpose strategy for problem solving which they called as general problem solver. The program that is based on that it is called the general problem solver. And this program encapsulates a heuristic approach which they called as means ends analysis. And this is a technique that we often refer to even in modern strategies for solving problems.

So, the basic idea of means ends analysis is as follows that you compare the current state with the desired state and that is what the task of planning is right, to transform somehow the current state into the desired state. Now, this is taking an in some sense a removed on a distant view or a global view of the problem and says, ok, what is the current state and what is the desired state and list the differences between them.

So, you know certain things may be may or may not be the same. So, for example, the current state maybe that your plate is empty let us say you are going to a buffet or to a canteen where you can pick up food that you want, and the desired state maybe that you want certain things in your plate.

So, you maybe you want a little bit of biryani, maybe you want a little bit of raita, maybe you want some salads, maybe you want the sweet dish. So, all these are things which are differences, that that which are not true in the not true in the current state and you want them to be true in the desired state.

And what the general problem solver strategy or the means ends analysis says that look for ways to reduce those differences, ok. So, evaluate the differences in terms of some magnitude in some in some manner that which difference is more important to be reduced, and then address that difference first essentially.

You can imagine that there is something called an operator difference table. We will see an example shortly, which tells you as to what are the operators available for reducing what kinds of differences.

So, for example, again going back to your eating plan. If you want to have some soup or you want to have some soup, let us say on your lunch table, then that operator would be you pick up a bowl and then you go and pour soup in that and put it in your plate or carry it along with your plate or whatever the case may be.

That for every kind of difference which exists between the start state or the given state and the desired state there would be some operator and you have to choose from one of those operators to reduce that difference. And we assume that there is some sort of a difference table available to us or some kind of a database which tells you what other the operators used for or reducing what kinds of differences.

And the means ends analysis strategy says that reduce the most important differences first, and then look at the smaller differences. And the reason why I am introducing this here is that as human beings we often reason in this fashion.

We do not necessarily reason in forward state space planning level or in the backward state space planning approach. We often think of the problem as a whole and see what all needs to be done to solve the problem and address those difference in the order of importance or the order of magnitude if you want to call that.

The differences characterize the ends that need to be achieved by the planner and the operators define the means of achieving those ends. So, means ends analysis essentially says that look at the means available to you, look at the ends that you want to achieve and order the ends or order the differences in some order and use the means to solve your problem essentially.

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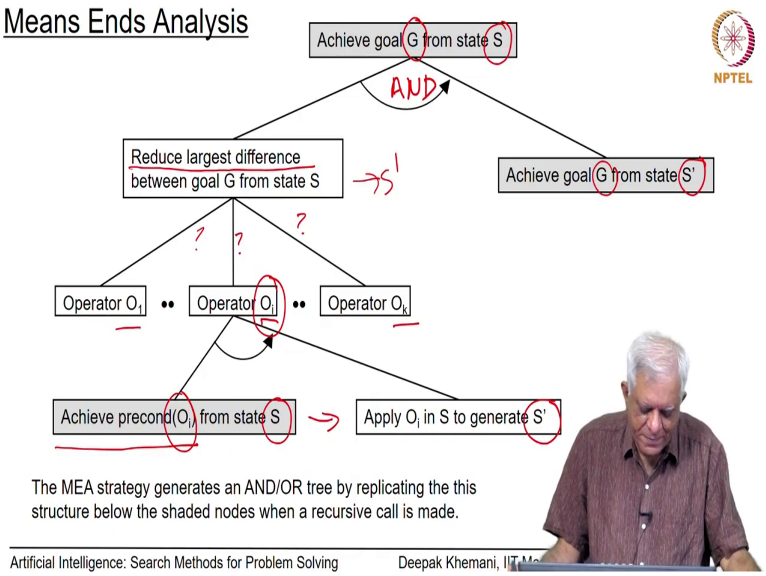

So, essentially the means ends analysis breaks down your problem solving thing into an and or tree. So, essentially it is goal based reasoning, a little bit like goal stack planning, but a little bit more explicitly because of here, ok. So, if your main goal is that you want to achieve goal G from the state S or situation S, means ends analysis says that reduce the largest difference between goal G and goal S.

After you have reduced the largest difference and your gone one to a new S which will take you to a state called S prime then you achieve the goal G the same goal that you wanted to achieve, but in this new state S prime. What is the S prime? S prime is the state after you have reduced the largest difference. How do you reduce the largest difference? Maybe there is a set of operators available to you O 1 and O 2 and O i and O k. And let us say you have chosen a operator O i in this case.

So, now, you are saying that to apply operator O i, so this you can see has this flavor of plan space planning here which says that to be able to achieve to be able to apply operator O i you achieve the preconditions of that operator O i in the given state S. And once you have achieved the preconditions of that operator you would have gone into a new state.

And once you have applied the operator, so you achieve the preconditions then you apply the operator and you are into a new state S prime and then you go and solve the rest of the problem from S prime. So, you can see that this is an AND, OR tree, because you are saying you saw the main difference and you solve the remaining differences, but we address the main difference first.

And it is AND, OR tree because you have choices here, should we do this, should we do this, should we choose operator 1 or operator 2 or operator k n so on. And then recursively we do again means ends analysis. So, you can see that you want to achieve to apply operator 1, we may have to do some kind of a solving.

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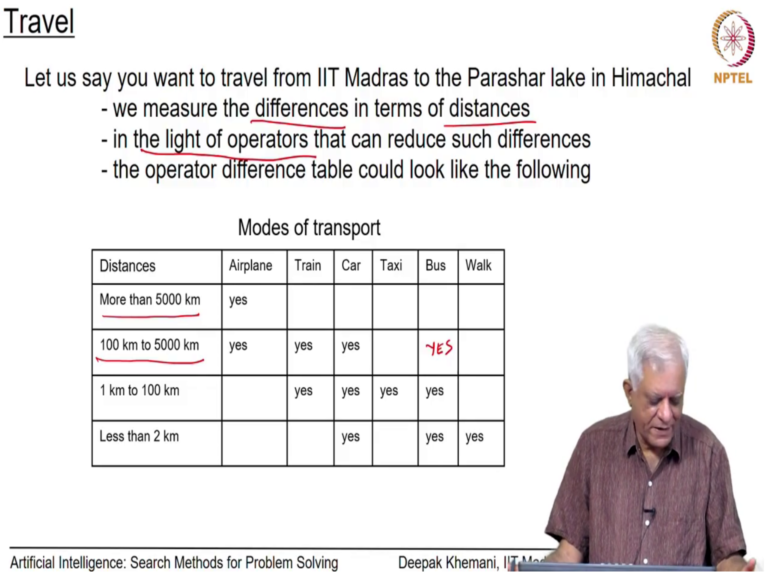

So, let us look at this my favorite example because the differences here are easier to characterize and let us say that you happen to be here in IIT, Madras and you want to go and visit the Parashar Lake in Himachal Pradesh, ok. And we want to find a plan for doing that. Now, you can imagine that forward state space planning would start saying that, if you are at IIT, Madras you I mean I am ignoring the fact that you may have to book tickets and so on.

But you go to the gate somehow then you maybe you wait for the bus or you take an auto or something like that and we will come back to this business of how to get to the station in the next class a little bit. But you might plan in this fashion that, ok, what is the first action, what is the second action, what is the last action and so on. Or you could do things in the reverse order that you want to be near Parashar Lake.

So, you would say that the last thing I need to do is so maybe take a bus from Mandi town and or maybe take a taxi from Mandi town or something like that and then walk backwards from there. But means ends analysis says you reduce the largest differences first. So, here you are sitting in IIT, Madras in the south of the country and Parashar Lake is somewhere in the north which is in Himachal.

And what are the largest differences? Clearly, the largest difference is that somehow you were to go from south to north essentially and then you worry about you know the finer details of whether you will go by taxi or whether you will take a bus and so on. So, the strategy is that reduce the largest differences first. In this particular problem which is a geographical travel plan problem, the differences can be measured in terms of distances. So, it is easy to characterize what our largest differences and what how they can be solved.

Now, obviously, you do not measure distances vaguely, but you can only measure them in the light of the operators that are available to you. So, for example, if you were to planning a trip from Tamil Nadu to Himachal, then you would basically say, first thing is how do I get to Himachal and that is the largest difference, that you are in Tamil Nadu and you want to be in Himachal. And then you worried about the remaining smaller things essentially.

Now, an operator difference table for a problem like this could looks like something like this that differences are characterized by distances and if the distance is more than 5000 kilometers which of course, is not the case in India but in general then the only means that you can use is an airplane essentially. But if it is let us say between 100 and 5000 kilometers then you could depending on the distance you could take a flight or you could take a train or you can if you are adventurous enough drive all the way essentially.

Shorter distances 1 kilometers to 100 kilometers you can take a train, a metro train or suburban train for that matter car or a taxi or a local bus or something like that. And you are assuming that shorter distances you will either take a bus or a car or walk essentially.

Maybe I should add a bus here as well because we often take buses for distances which are more than a 100 kilometers, typically we do for example, Chennai to Bangalore is 365 kilometers and so on. So, this is the operator difference table.

It says that depending on what is the distance that you are talking about, you will first think of that mode of transport and the distance is ordered from top to down the largest one is on the top.

So, the very longest distances you can only cover by flight. So, if you wanted to go for example, from here from here to IIT, Madras, so let us say Technical University at Munich essentially which is in Germany then clearly if you do not have the means to take a flight from here to Germany, then you can never make a plan.

So, no point you know me doing the rest of the detailed planning as to how you will get to the airport and stuff like that. First thing you want to address is can you reduce the largest difference, if you can, then you go ahead and reduce the next largest difference and so on.

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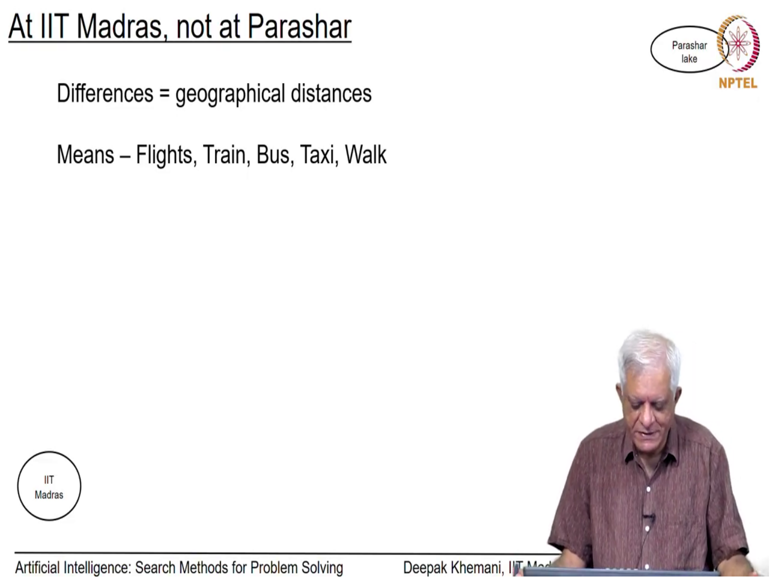

So, in our problem where you are at IIT, Madras and you are not at Parashar that is the difference between the two things, and the operator difference table as we have just said are geographical distances and the means are flights, train, bus, taxi or walk. Let us assume that these are the options available to you. Then we said reduce the largest difference first. So, maybe this is what you would typically do.

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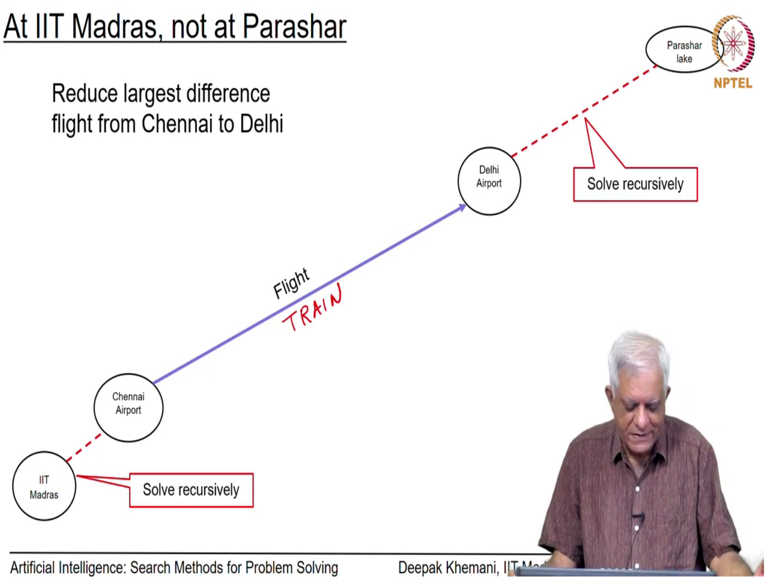

Nowadays flights are becoming more common and more popular. But you could have done this by train as well, but that does not matter. The distance from the Chennai to Delhi is about 2000 kilometers and either would work essentially. I mean I spent a lot of time traveling between Chennai and Delhi in the Tamil Nadu express, it takes 2 nights to get there, in a flight you would do that in about 3 hours or something like that.

So, obviously, it depends on how much leisure time you have available. Train journeys can be fun, but you should have the time to enjoy them. So, this is the largest difference that you have said that, ok.

Now, you have sorted out that you will not be that that you are not going to be in Chennai, but you will be maybe at the Delhi airport or maybe you can take a flight to Chandigarh or something like that. But this is one possible way of solving it is that one large difference that you have reduced is to take a flight from Chennai to Delhi.

This is how humans tend to plan essentially, right. That is what I am trying to also illustrate. And then of course, you recursively solve the problem as to how do you get from IIT, Madras to Chennai airport and the other problem which is a slightly larger difference which is how do you get from the Delhi airport to Parashar lake essentially.

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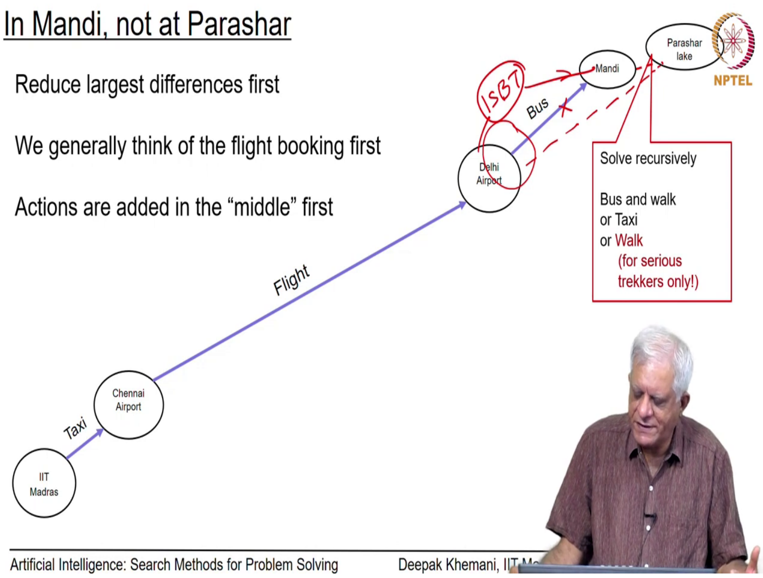

So, our strategy has been to reduce largest differences first. So, maybe this is what you do that this difference between Delhi airport and Parashar lake maybe there is not direct way of going there, of course you can hire a taxi from the airport directly to take you to Parashar.

But most people would say let us first get to Mandi town which is close to Parashar, and then we will worry about how to go to Parashar. And popular way of getting to Mandi which is used by many of my colleagues from my IIT, Mandi is to take a bus from the Delhi to Mandi.

So, I have not, I have kind of ignored the part that you have to go from Delhi airport to IBST, and then from IBST actually that you take the bus. So, this is not the real plan. The real plan should have been that you figured out how to go from Delhi airport to IBST, and you first decide that you will take a bus from IBST to Mandi and then you figure out how you will get from Delhi airport to IBST which thankfully the transport system in Delhi has improved so much in the last 10 odd years that you can take a metro and get to IBST.

Anyway the flavor of this whole planning exercise is that you reduce the largest differences first, and then you in some sense address the remaining problem, whatever remains and solve that in the same fashion that remove the largest differences first.

So, you are at Delhi airport you want to go to Parashar, the largest difference you can think of is that you should be in Mandi and not in Delhi airport. And then you decide that you will take a bus from IBST to Mandi and then of course, later on you worry about how you will get from Delhi airport to IBST. And likewise something similar from IIT, Madras to Chennai airport.

From Mandi to Parashar the typical options would be you take a bus, there is the bus which goes once a day from Mandi to Parashar. And then walk from there or you hire a taxi which will take you to Parashar or if you are adventurous and this is only for serious trekkers that you walk all the way from Mandi to Parashar. It is a walk of about 26 kilometers.

The strategy that we have been talking about is reduce the largest differences first and that is what we wanted to illustrate with this example and that is what we get out of this means ends analysis strategy given to us by Herbert Simon and Allen Newell essentially.

When we do such planning we often think of the largest differences which is like, how will I, what is the main thing I want to do that I want to book a flight from here to Delhi or here to Chandigarh or here to Darmashala or here to Kullu as the case may be and then worry about the smaller details essentially.

The interesting thing here is the first action that we choose which is taking a flight in this case from the Chennai to Delhi was an action somewhere in the middle of the plan. Whichever way you look at the plan, it was in it was not by the means the first action it was not by any means a last action, but it was an action which reduce the largest difference first. Let us say and that is something which we get from means ends analysis and which is a way that we as humans often use to solve problems.

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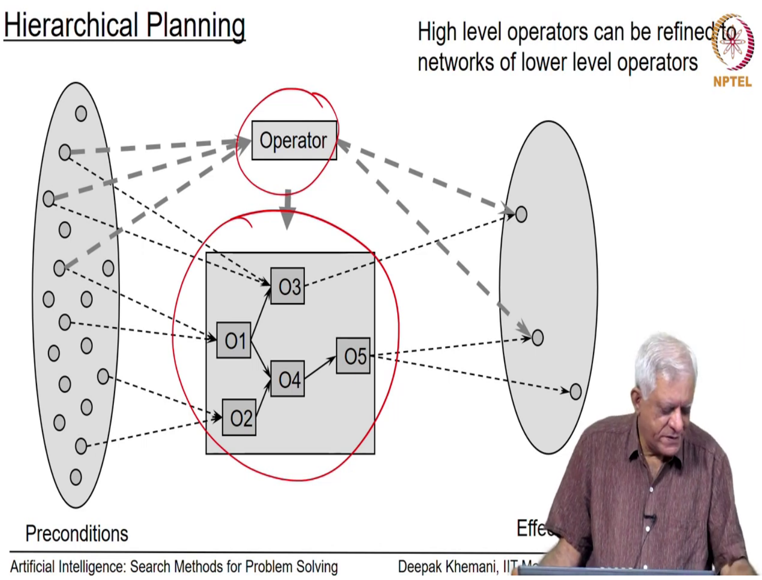

Now, this whole business of looking at largest differences first and then the smaller ones later, is also nowadays captured in this approach to planning which is called hierarchical planning. So, if you are making this travel plan, then you would say that planning is done in a hierarchical nature in the manner in which an operator can actually be refined into a set of smaller operators essentially.

So, I said that for example, the operator could be could be to say, let us say one of the operators at some level is that you want to take this flight from Chennai to Delhi. Now, taking this flight as inserting it into a plan can be a high level operator, but the lower level break up of this plan would be to maybe in this day you go to some travel booking site, and investigate what are the different flights available, choose the flight which is convenient to you, then book the flight, pay for it, print your ticket, all these are sub actions of the larger action which says I will take a flight to Delhi.

Also, of course, you need to include those other actions like that I will go from here to the station to the airport and then I have to plan for that and so on. So, means ends analysis just kind of characterizes what we are doing in hierarchical planning. In the hierarchical planning I have just say, I am planning holiday from I am planning a visit to Parashar lake from IIT, Madras.

And then to do this plan then I would say, ok, I will need to take a flight from Chennai to Delhi and a bus from Delhi to this thing and so on and we gradually break it down into smaller and smaller actions. The lowest level contains actions which are actually executed and the highest level are actions which are kind of abstract actions or which we use for planning. Unfortunately, we do not have too much time to delve into hierarchical planning, though it is a very important aspect of planning.

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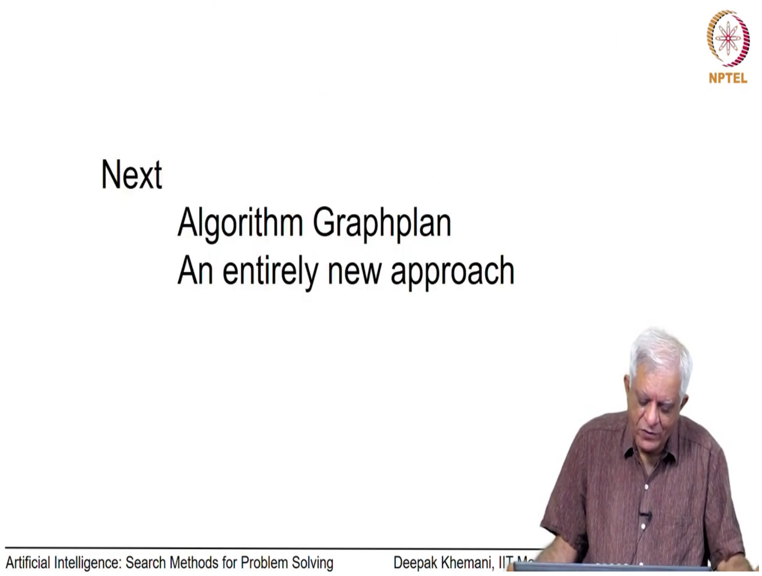

What we will do next is shift our attention to an entirely new way of planning which came up in the mid-90s, an algorithm called graph plan which revolutionized planning in some way. Because up to that time all the approaches that we have seen in planning they could produce short plans, the plans of 10 steps or 15 steps or 20 steps and so on. That of course, was partly because of the fact that computational resources were less in those days.

But also partly because of the fact that the planning problem is a hard problem and we are facing this thing combinatorial explosion or exponential growth whichever way you want to express it. And those methods were essentially getting caught into that explosion. What algorithm graph plan does, and its quite interesting. And this is the last thing we will do in planning; is to somehow compress those different possibilities that you want to explore into one compact structure which they call as the planning graph.

And in fact, this gave rise to a whole series of approaches in which planning was done in two stages, that you create some intermediate representation, and then solve the planning problem on that intermediate representation.

So, we will do that in the next session. See you then.