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Prof. Jatindra Kr. Deka
Department of CSE
IIT Guwahati

Module IV: Temporal Logic

Lecture IV: Syntax and Semantics of CTL – Continued

So in last class we have introduced a temporal logic called CTL, computational tree logic. So what happens we have seen what is the syntax of CTL and we have discussed how to define the semantics of those particular CTL okay.

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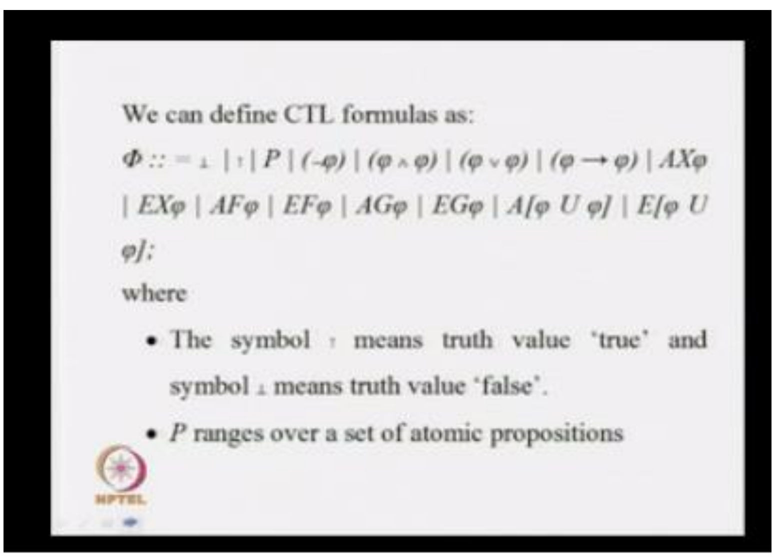

So what happens in syntax we have seen that if P is the atomic proposition or set of atomic proposition then all atomic proposition will be treated as your CTL formulas along with the truth values true and false. And we have already seen that if we are having your logical connectives like your AND, OR implication with all those connectives we can again form CTL formula for whether ϕ is a CTL formula.

On the other hand we are having four temporal operators basically we have discussed about four temporal operators NEXT state, FUTURE state, GLOBAL, and UNTIL. So with this particular four temporal operators we can form CTL formula in conjunction to it your path quantifier A and E. So we are going to get this particular eight different forms of your CTL formula. AXϕ, EXϕ, AFϕ, EFϕ, AGϕ, EGϕ, Aϕ U φ and Eϕ U φ okay.

Now what will happen in last class we have seen how to define the semantics of those particular your logical connectives. Today we are going to discuss about the semantics of those particular temporal operators along with your path quantifier A and E, and already I have mentioned that in CTL we are going to deal with state formula that is temporal operator preceded by your path quantifier then it becomes a state formula.

We are going to define the truth values of temporal formulas with respect to state of a model. Now how we are going to define the semantics already I have mentioned that.

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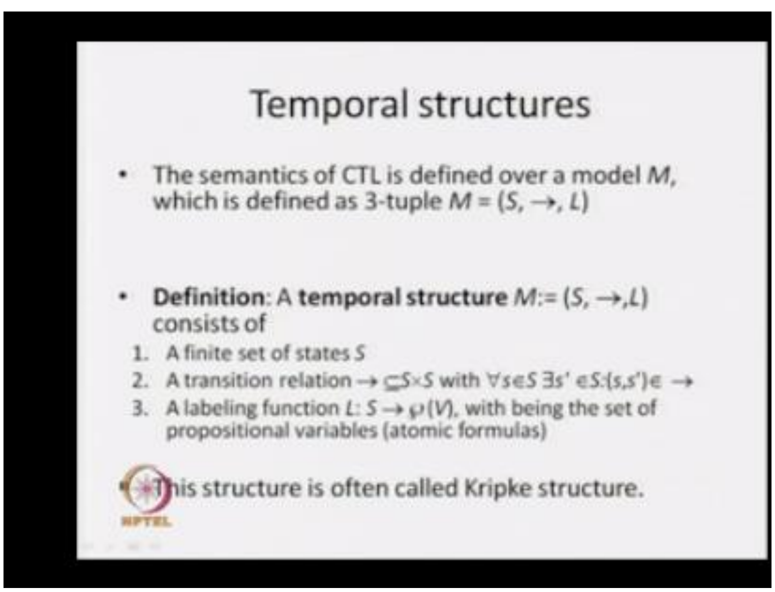

To define a semantics we need a model we call it CTL model or temporal structure or Kripke structure, because it is having three components set of states, a transition relation and a labeling function. Already I have mentioned what is labeling function it is basically related to your atomic proposition which are true in that particular state and we are going to level those particular state with α those particular atomic proposition. Now we are going to see how we are going to define the semantics of our temporal operator.

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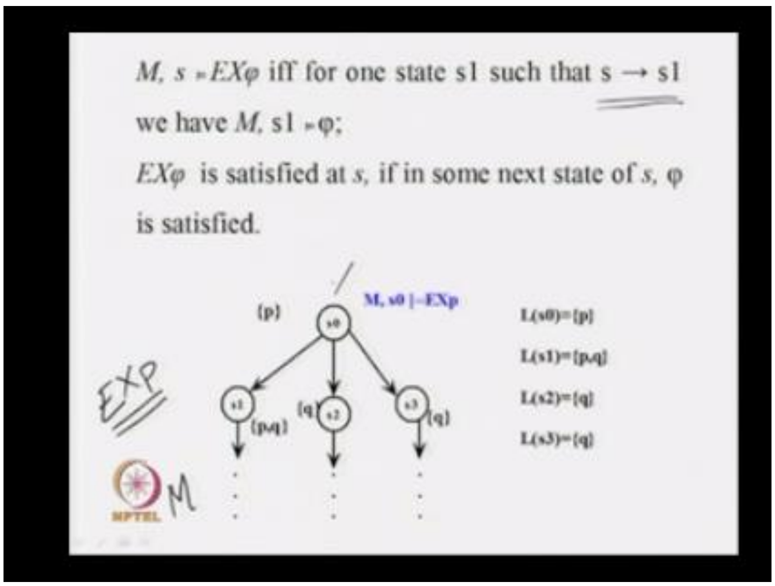

Now first we are going to consider AXφ this is you are in all part in next state φ holds and we are going to define it in a state, in a model M state S. We are going to say that N as models AXφ if for all S1 such that we are having a transition from S1 to S1 we have M S1 models φ. So you just say that we are going to consider one particular state S, we are going to look for all next state as 1 and such that this 1 in S1 φ holds.

So in next state operator what will happen we are going to see next state what something holds or not if it holds then we are saying that AXφ holds in this state. So AXφ is satisfied at S if all next state of S φ is satisfied, so we just look into this particular models and we are going to look into this particular model and these are the labeling functions say L as 0 is P that means you are having a set of atomic proposition P where I'm having PQR these are the three atomic propositions.

So we are having that labeling function, so we say that in S0 P is true in S1, P and Q is true in S2, Q is true and S3 Q is true. Now we are going to look for formula AXQ, so what does it means in all part in next state Q holds or not. So we are going to look into this particular state S0, we will see come to our S1 this is our next state SQ is true at the particular state, because it is labeled with Q.

If you come to S2 again you will find at Q is also true about here similarly in S3 Q is also true. So we can say that in S0 AXQ is true, so you say that M as 0 models AXQ. So this is the way that we are going to define the semantics of our formula AXφ so the semantics the meaning is defined with respect to our model. Now the next operator is your EXφ that means there exist a path in next state φ holds.

So it is similar to your previous one, but here we are going to concern about any path not all path. So if for some state S1 such that there is a transition from S to S1 and we have M S1 models φ that means we are going to get at least one transition S2, S1 that means S1 is the next state of S and if you find that in S1φ holds then we say that Male Speaker: models EXφ. So that is why I said that EXφ is satisfied at S if in some next state of S is satisfied.

So similarly we are going to look into this particular model M we are having the same labeling function LS0, LS1, LS2 and LS3 and atomic proposition are PQ only two atom goes and you are having PQ. So here we will say that from S0 we are having a condition to S1 where K holds again S2 again S3 all the places Q holds but here P holds in your S1. So we are going to look for the formula EXP whether there exist a part in next state P holds.

If we are looking into a condition from S0 we will see that there is a state called S1 where this particular formula P holds, so we say that in your state this particular S0 the EXP holds, so we wrote it that in model M state S0 EXP holds that means EXP is true in this particular state S0. So this is about eh behavior of our next state, so we are having two operator in temporal logic one is your AXφ and second one is your EXφ.

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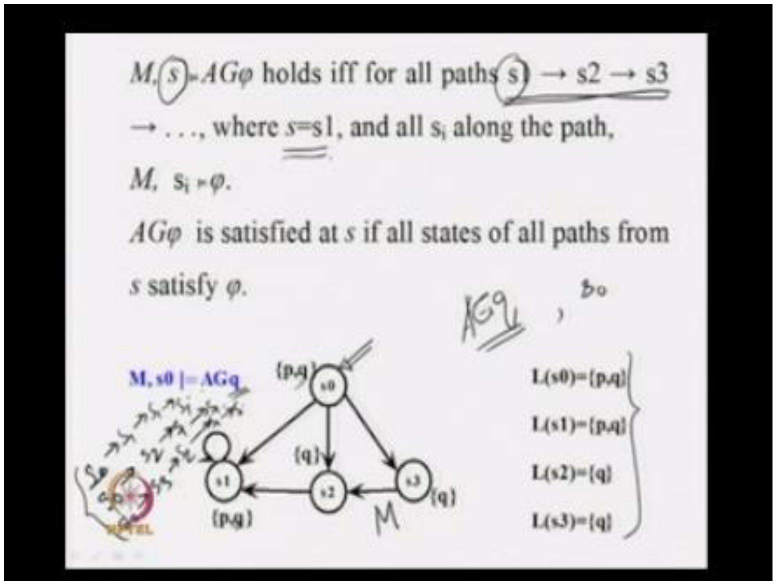

Now next formula that we are going to look into our logic is your AGφ G is a global operator and AGφ it says that these all part globally φ holds on that. So we say that if it is true in a particular state we say that in model M state as AGφ holds. So when we say that AGφ holds if all parts that we are going to consider all part like that we are having a condition from S0, S1 to S2, S2 to S3 and like that we are having a sequence of states where we are going to say that S=S1 that means we are concerned about this particular state S.

And we say that in all parts that typing state S0 is equal to your S and all Si along the part and now we are going to consider all Si all other states along the path such that M in this model M Si model is φ that means φ holds in this state Si and what is this Si, Si is the all states along the part that means what it says that AGφ will be true in a state provided in all states along all the paths that φ holds.

So we say that AGφ is satisfied at S in all state of all paths from S satisfied φ. Now again come to this particular model M we say that this is our model M we are having four state S0, S1, S2 and S3 along with this labeling function well we are having that atomic proposition P and Q. Now we are concerned about this particular formula AGQ and we are going to look into state S0. Now that means when we concentrate this particular state S0 we will see the path.

So it is having three different conditions, so we are going to the three different path starting from this S0 1 will go something like that from S0 to S1 then S1, S1 like that second one will go from S0 to S2 and from S2 it will go to S1 then it will remain in S1 like that. And another path we are having it will go from S0 it will go to your S3 from S3 it will go to S2 and from S2 it will go to S1 and like that it will remain at S1.

Now these are the three possible execution states that we are going to get in this model. Now we are going to look for all such that we plot S1, S2, S3 like that where S=S1. Now my S is your S0, now from here we are going to see all the possible state and then find that all those state S0 and S1 that Q is true it is labeled with Q. When you come by this particular path S0, S2, S1, S1 it is having a self node so it is going to come S1 to S1.

In all the states we are going to get that Q is true about here. And in third part again we are going to get S0, S3, S2, S1, S1, S1 like that and in all the states we are going to get the Q is true that means all possible state in all parts we will see that or we have seen that φ is true or Q is true in this example so we can say that AGQ is true in this particular state S0. So we say that in model M in state S0 AGQ holds. So this is the way we are going to look for the meaning of your AGφ.

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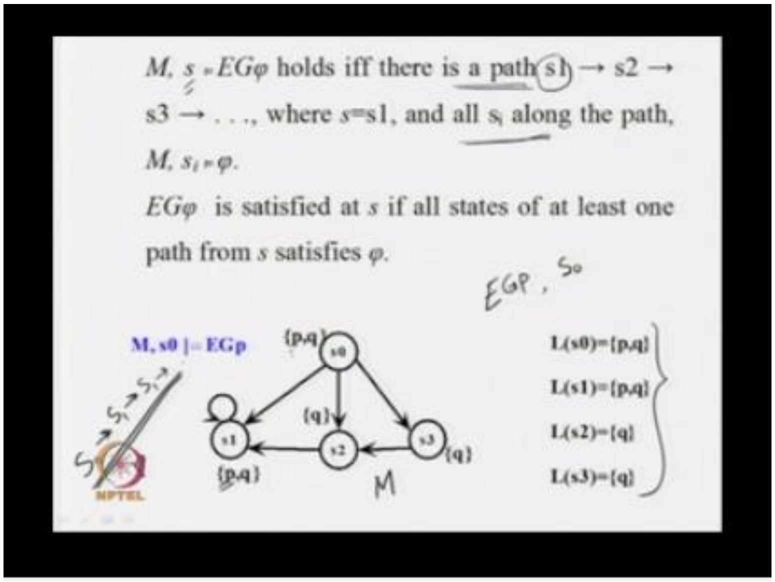

So next formula that we are going to get is your EGφ, so it is again the global path but we are having the path quantifier as your E that means we are concerned about any path, we are not going to look for all the path, so that is why you say that in model M instead S it models EGφ that means you say that EGφ hold if there is a path. Now we are going to look for any path such that it is going from state S1 to S2, S2 to S2 like that where S=S1 that means the φ state of the path is by the state that we are looking for.

And all Si along the path that φ is true, so M Si models φ where Si is your all state along that path. So that means if we are going to look get the path wherein all states φ is hold and we say that EGφ holds in the states starting state of this particular path that means S. So which are that EGφ satisfied as S, if all states or at least one path from S satisfy φ. Now again just look into this particular model M okay, we are having this particular labeling function LS0, LS1, LS2 and LS3 as PQ, PQ, Q1Q.

Now we are going to look for this particular EGP such that S0 that means there exist a path globally P holds. Now again like the BSK we are going to get these three different path S0 to S1, S1 to S1 and like that, again S0 to Q, sorry, S0 to S2, S2 to S1 and it will remain in S1, again S0 to S3, S3 to S2 and S2 to S1 and it remains in S1. Now we are going to look for EGP, now when we start from S0 we are getting path to your S1.

In S1 we have seen that P is true that means when we are going from S0 it is your P is true then we are coming to S1 again P is true, then it will remain in S1 like that all the path if you see here in this execution phase from 0 to S1, S1, to S1, S1, to S1 here p is true. But if you look into this second path S0 to S2 to S1 we will find that state S2 where Q is not true, so that means in this particular path globally P is not true.

Similarly if you go for the path S0, S3,l S2, S1 then instead S3 and S2 that P is not true that means in this two path P is not true globally, for at least we have got one path S0 to S1 from S1 to S1wherein all the state P is true that means we can say that in this particular state S0 that formula EGP is true, so we say that in model and state S0 that EGP holds, so that is why M S0 models EGP.

So we are getting at least one path where EGP is true globally and that is why we say that EGP is true instead S0 okay. So this is basically GLOBAL operator that means in all state it must be true.

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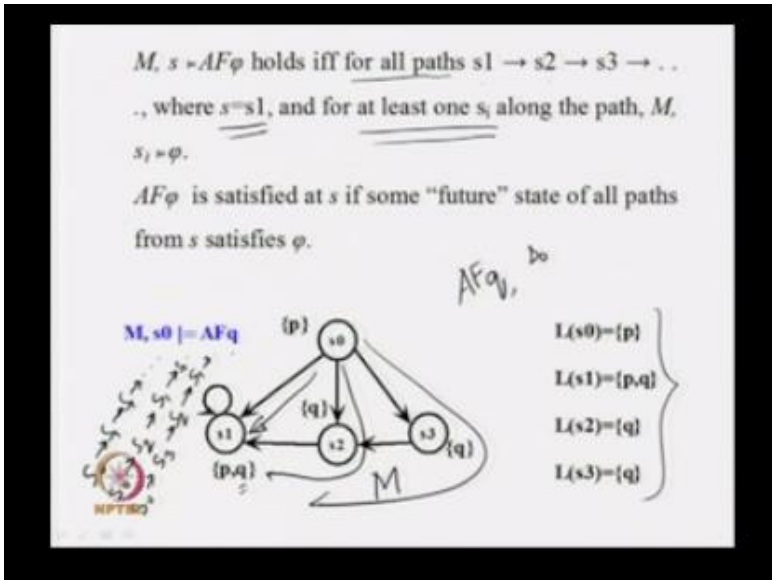

Now the next temporal operator is your F future already we have seen that in some future state or eventually something must have. So we say that in model MS it models AFφ or AFφ holds in that particular state S provided for all parts. Now since we are going to have this particular path quantifier S, so we are going to look for all such that provide going from S1 to S2, S2 to S3 like that where S= S1 that means the such things that of all those path is the states of our concern that you are looking for this particular state S.

And for at least one Si along the path now we are saying that at least one Si along the path M Si models φ. So you just see that we are going to look for all paths, in all paths we are saying that eventually φ must true that means we are going to look for some state where the φ holds about here or not. In that case if this is going to happen in all parts then we are going to say that AFφ holds in this particular state S.

Now again look for this particular model M okay we are having four state S0, S1, S2 and S3 and this is the labeling function of this particular four state S0, S1, S2 and S3. Now we are concerned about this particular formula AFq in state S0. Now again we are going to get the path S0 to S1, S1 it will remain in S1 because you are having a self flow. Similarly we are going to have S0 to S2 and we are having a condition from S2 to S1 and S1 like that.

Again in another path from S0 this is going from S0 to S3, from S3 you are having a condition to S2, from S2, S1 like that. So these are the three possible paths. Now we are going to look for EAFQ that means whether we are going to get a future state where Q holds. Obviously you see that when I go by this particular path we are getting a state S1 where Q is true. When I go by this particular path again we will find that in S2 Q is true.

Again if we follow this particular path we will find that again Q is true in S that gets in all three parts in some future state we are going to that Q as true. So future is appeared it happens to be in the very next state, but it may happen that in next state if it is not true, but in some future state it is true then we are going to say that in all path in future Q holds. So we say that N has zero models AFQ.

So we are going to look for this particular formula Q which is true in some future state along all the paths okay.

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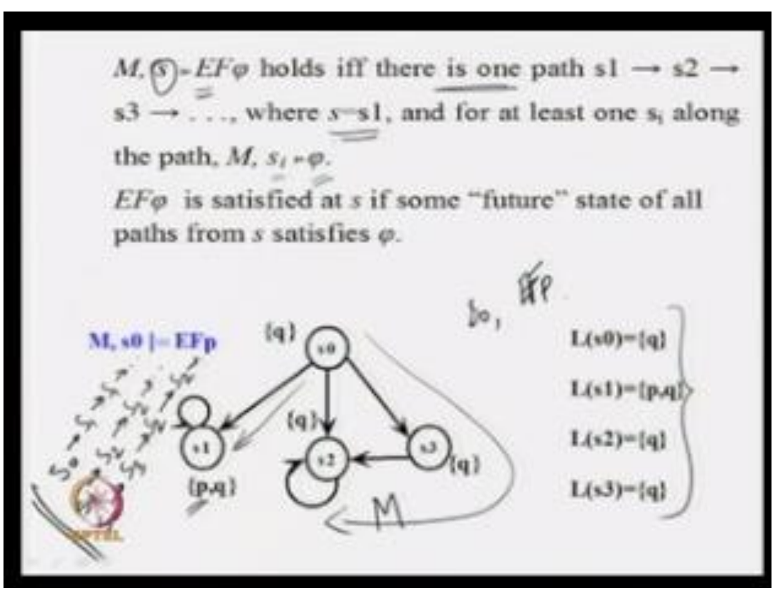

Now next formula again we this future operator, but in this path quantifier it defines where exist a path in future φ holds. So again with the similarity basis we are going to concern about any one part we are not going to look for all the path, but if it is true with any one path then we are going to say that EFφ is true. So again we will say that we are going to look anyone from goring from S1 to S2, S2 to S3 where S=S1 that means starting state of the path is equal or is the state of our concern S and for at least one Si along the path N Si model φ, that means φ holds in some state Si along that particular path.

In that particular case we are going to say that EFØ holds in that particular state again look for this particular model M and my state of concern is your S0 and that formula is your EFp here exits a path in further p holds and this is the leveling function that we have qpq in your state S1 in S2 q is 2 and S3 q is 2 now you just say that again we are having those particular part S0 to S1 to S1 like that we are having an sequence.

Second path is from S0 to S2 from horizon transition from S2 lighted I have slightly sense the model now again third path we are going to get S0 to S3 from S3 your having a transition S2 then we are having a transition from S1 to S2 to like then these are the 3 possible paths that we are going to get from this particular state S0.

Now if you look this two path say from S0 to s2 and it will remain in S2 so we are going to get this sequence as S0 S2 from S2 to S2 like that in non of the further state p is that means in this particular path we are going to say that p will be true in further similarly the path S0 S3 S2 if we consider this particular path again we will see that we are not going to get any further state where p is true.

But if you follow this particular path S0 to S1 to S1 like then that S1 is marked with your p that is p is to over here that means we are going to get at least 1 further state where p is true so due to this particular path we say that in S0 EFp is true so this way that we are going to defined the true values of EFp.

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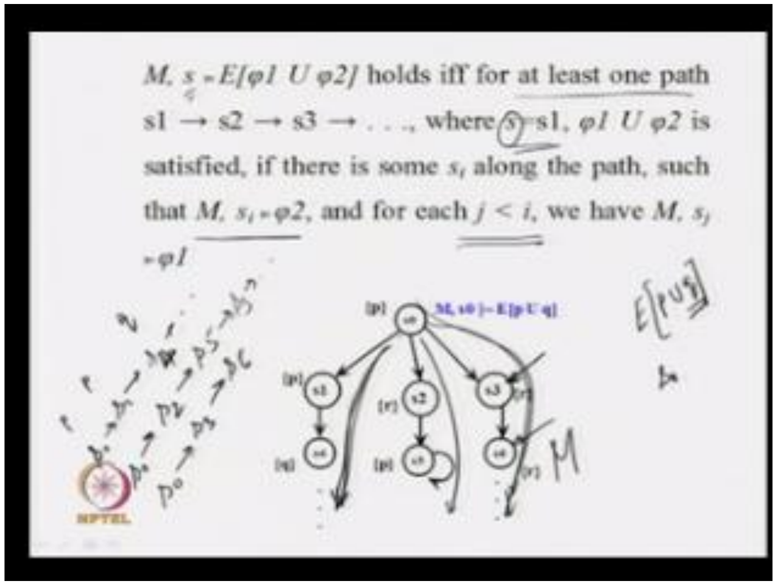

Now the next operators is your until because already I have mentioned that the 3 operator that we have next state qsr and global these are urinary operator it works with one particular formula but until is a binary operator so it works with two empower formulas so we are going to say that Ø1 until Ø2 and this until operator must be proceed by path quantifier either A or E in case of your CTL so that is we are going to do wither this particular formula AØ1 and until Ø2 that means in all path Ø remains to until Ø becomes true.

So we say that these formula holds in a state S of model M provided for all such type of paths that we are going to do having a transition from S1 to S2, S2 TO S3 where this particular steady state of the path S1 is = the state that we are lo0oking for and we say that Ø1 and Ø2 is satisfied if Di is some Is along the path okay now we are going to look for those particular path such that M of Si models Ø 2 that means we are going to get some state Si where Ø2 is true and for each J is less than I so we are going to get one particular state Si where Ø2 is true.

Now look for all other state Si where Sj where j is less than I we must add NSJ models Ø1 that means Ø1 must be true all those particular state Sj now just consider this particular model M over here and we are looking for this particular formula A p until q instead S0 now in this particular case you will just see that if I am having just now excision phase something like that from S0 it is coming to S1 from S1 we are coming S4.

So we are having an excursion phase S0 to S1 S1 to S4 like that it is infinite path second one we are looking for this particular path S0 is having a transition to S2 S3 is having a transition to S5 in S5 we are have a set proof so we are having a transition to S5 like again we are having another path from S0 this is your S0 is going to your S3 and from S3 we have a transition to S6 and it is have path from F.

Now if you look into this your concern about A p until to that means we have to loop for all this three paths and we are going to look for further state where Q is to now in this particular first path we are going to say that q is 2 in your S4 and in that particular case if q is 2 in some state then we have look for all proceeding state of those particular state in that particular path and we have seen we have to see whether p holds of what they are not so we will find that p is 2 in S1 and p is 2 in your S0.

That means in this particular path p until q is slow with the similar rejoining you can look for other two path also S0 to S2 S2 to S5 we will find that p remains to true until q becomes true in this particular path and similar in third path also we will find that p remains to until q becomes true so we have seen in all these three path p until q is true that means we can say that we use that this three paths are coming out form this particular state S0 so we can say that in state S0 of model MA p until q is true.

Okay so this is the way that we are going to look for the true values of formula A Ø1 until Ø of A p and until q so similarly now we are look for the last formula where it is with until operator at the path quantifier E that means we are concern about any path here exits a path so that Ø1 until Ø2 holds form this particular in a particular state S again in this particular case what will happen we are going to look for at least 1path such that we are going from S1 to S2 To S2 to S3 where S= S1 that will starting state of this particular what is our concern state s such that Ø1 until Ø2 is satisfied.

In this particular what does it means that means we are going to get a state Is where Ø2 is 2 and all the proceeding state in the path from this Si Ø1 must be true that means for each j is less than I n Sj models Ø1 so this is similar to your AØ1 until Ø2 but here we are concern about one particular path any particular path that is why we say that there exists a path so again just look for this particular model M we are having this particular level this is with respect to your level in function,.

So we are going to look for the formula E p until Q instead So again similar to all PPSk we are going to get 3 path S0 to S1 to your S2 and S0 sorry this your S4 then S2 then it is going to S5 and it remain in as third path is your S0 to S3 then from S3 to S6 now we are going to look for p until q so if you look into this particular path at least since the but we are not getting any state where q is true similarly if we look for this particular path.

So this again from SØ to SØ so there is no possibility that we are going to get state where Q is true so here we many get some where q is true but in this particular state if your state that p is not true at least here p is true so if you look into this particular path we will find that we are getting S4 where q is true and it is having tow proceeding state S0 and S1 so in this preceding state p is true so that means we are getting this particular path where p until q is true but in other two path p until q is not true.

Here it is obvious that p until q is not true because we are not getting any state like you will be true but since in this particular path we are showing an infinite sequence that means in power behind you may get a state where q is true but at least you will find this particular state where p is not true secondly S6 p is not true that means p will not remain to until q becomes true so it is also avoid that in this particular path we do not in it is not going to satisfy Ep and Eq so the in this particular case at least we have got 1 path.

So from that we can complete that in this particular state S0 p Ep until qw is true okay so this is the way that we are going to defined the meaning for our CTL formula now till what we have discussed we have seen one particular temporal logic which is known as your CTL computational free logical general these are two value are temporal logic is defined of a model which is having transition and states.

But in case of CTL basically we have all ready said that this particular model can be unfold to three and the semantics is basically refined on a tree sop we are saying that this is your computational p logic and we have seen the 4 temporal operator that we have along with 2 path quantifier A and E we are going to get 8 different possible temporal operator in case of CTL and all temporal operator must be preceded by a path quantifier and due to that reasons the formulas of CTL becomes our state formula.

So defined a truth a value of that formula with respect to a state and this is due to the presence of this particular path quantifier.

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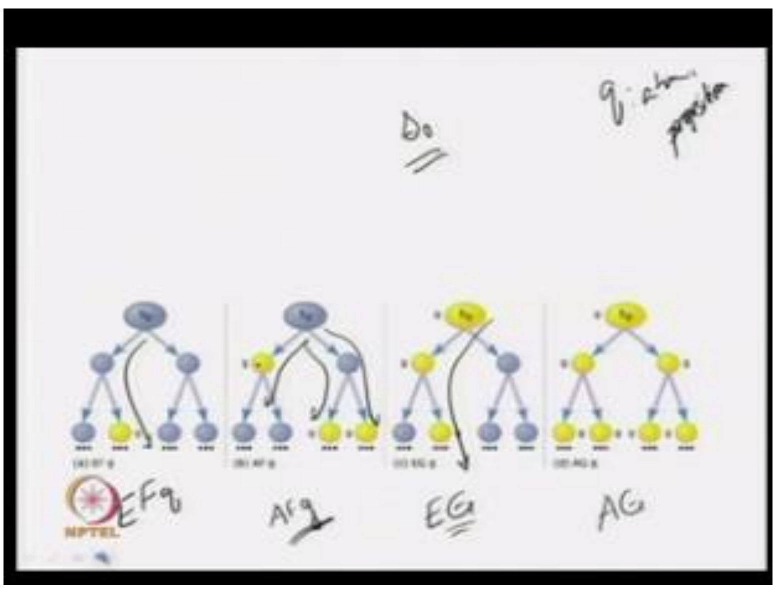

So now just see that what will happen thus I am showing here one diagram that we are looking for some formulas showing pic so really so we have concerned about this particular state S0 we are having that atomic proposition q is an atomic proposition now in the past diagram three we have look for there existed path in further q holds where q is 2 thus we have colored with yellow so we will find at least one path where in further q is 2 in second 1 I will say that AF this sorry so in this particular we find that whether in all path in further used one.

So we again looking for this particular path it is staring from we are getting one state where it is true and other two path we having this as so in further we are getting this particular p is true so we consider AFg is true third is your there exists a path whether globally something whole or not so this is the path where everything is marked with yellow that means this property is true in all this particular state of this particular path so we can say that pg is true and 4 is your AG all path globally that means this particular formula is true all the state if it is marked like that then we can similar say that Ag is 2 over here because in all path globally something is true that particular j is true so that is why it is marked like that so by looking into this particular tree structure very well we can say whether a particular formula is true in a particular state or not here.

We are going to look for this particular state S0 stating state of this 3 so like that you can see whether particular formula is 3 true in a particular model or not now after defining the syntax and synthetics of CTL Formulas now wew ill see some example to make it more clear okay before proceeding further because we will be knowing now just see that consider this particular model M.

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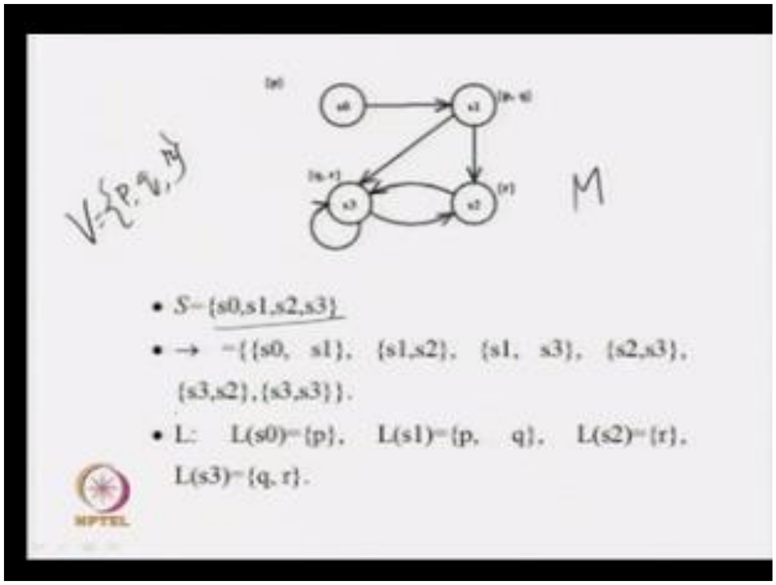

Okay so it is a model but this model is having 3 components basically first one is state of states second one is the transition relation and third one is your leveling function so in this particular model L say s is a state of states so we are having 4 particular state S0, S1, S2 and S3 and this transition relation how many transition relation we have 1, 2, 3, 4, 5, 6 so total 6 transition relation we having.

So first one is having a transition from S0 to S1 then S1 to S2 S1 to S3 then S2 to S3 from S3 to S2 and we are having a self look S3 to S2 state and if we see that we have having one more condition where we say that transition relation must be complete what does it means it says that every state must have successors state if you look into this particular model you will find that all those particular 4 state are having successors state because from all the state we having at least 1 outgoing as S.

And this is the leveling function now what will happen in this model we having the state of atomic proposition E as your p q and r these are the state of atomic these are the atomic proposition that we have now the leveling function says that L S0 p what does it means that means that atomic proposition p is true in S0 and in the remains that atomic proposition q and r false in this particular state s0 similarly in S1 the leveling the function say that p and q that means the atomic preposition p and q is two in your S1.

Leveling function S2 say that r that mean it say the r is true in this particular state S2 and leveling function of S3 says q and r that means the atomic proposition q and r is true in S3 but atomic proposition p is also false, if it is false we are not directly marking it but in the diagram it say that q is false so now we are concern about this particular model and these are the 3 components now we will see some examples over with respect to this models.

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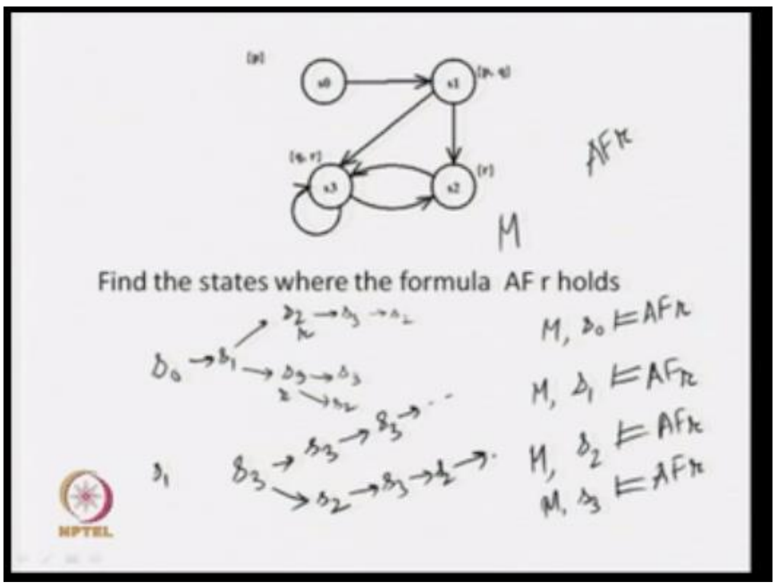

Now the first question I say that find a state where that formulas AF r holds that means in all path in further are holds okay now we have to say it is state formula now we are going to look for the state S0 and that side this is my model M so in S0 if I go for S0 it is having this particular path only path is everything and we are getting that S1 going from S0 to S1 and from S1 I'm having 2 possibilities at I am going to S2 and S3.

Now if these are the and again from S2 it is going to S3 and from S3 again it is coming back to S2 like that and from S3 it will remain in your S3 or it may have another one also it may go to S2 lighter, but now user select in all part in future whether holes are not so if you see you for all those particular path we will find that in one future step this s2 are holes and we are going to get one future step are holes that means you can say that the in this model M S0 that in all path and future are holes.

Now similarly you look for the state S1 if you look into this particular state S1 when you find that it is having two paths and in future path in future step R is true so in S3 R is true and S2 also R is true, so in all possible path in future we are saying to state where R is true, so you can say that in this model M S1 AF R is true, similarly when I come to your S2 than we will find that from S2 it is going to S3 where R is true.

Coming back to S2 and again going to S3 that means all part we are going to get step in future R is true so again you can say that the M as true it models AF_R now when you come back to this particular step S3 so basically what will happen from S3 we are having a transition 2S3, S3 like that or we can have that from S3 you are going to S2 coming back to S3 again going to S2 like that, so you will say that in all those particular examples in future step.

R is true so we will say that in model M in S2 it also model F Re in all path in future R is true, so now individually you have gone to each and every step and we are on that this formula AF_R s true in all those particular four steps, so this is the width and we have to look into it because in a CTL formula or step formula that true values of CTL formula is defined with respect to a state ON, okay.

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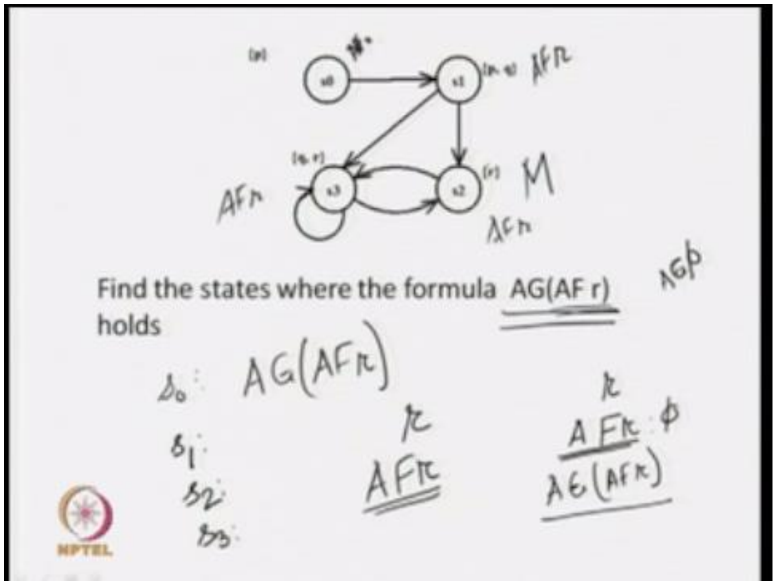

Now this is the same model I am having over here and now we are going to see the formula find a steps where the formula AG(AF r) is true or not okay, what does it means in all part in future are holds and it says that in all part globally whether this particular formula words or not, so what we can say that R is an atomic proposition so we will say that R is a CTL formula so we know that truth values of R in each and every step this is with respect to your level in function.

Then F is a temporal operators so AF r it says that in future are holds are not and A says that whether in all part in future are holds so this is AF r is also CTL formula so you can say that this is your Ø is your CTL formula, so if Ø is a CTL formula then we will find that AEØis aloe CTL formula so that means AE(AFR) is a CTL formula now we have to say whether this CTL formula is true in all steps are not.

Or whether it is true in some steps or all steps in this particular case on so now basically are said at when I am coming to that state S0 now we will see that from S0 what are eight holes in all possible states in all possible direction along no those are let us go back to my previous example so in previous example what we have seen that this AF, r is true in all those particular four step we have seen over here.

Now what does it mean, since AF r is true in all step that means I can level those particular state with this particular formula AF r so now we can say that in step S0 AF r is true in state S1 AF r is true in state S2 AF r is true in step S3, FRR is true now it says that in all part globally AF r is true now from S0 if you go in all possible direction in find that AF r is true so we can say that in S0 in all path globally, AF r is true so with similar logic what we can say that then you start from S1 then we loop for all possible part all possible combination and wherever I will go I will find that AF, r is true everywhere.

So we can say that AE(AF r) is true in S1 also with similar logic you can say that it is true in S2 as well as it is true in state S3 also that means in all those particular fours state of this particular model and AE(AF, r) is true so what we are going to loop for the truth values of a particular CTL formula first of all we have to know the truth value of its sub formula, so basically here if I consider this particular formula.

AG(AF r) it is having two sub formulas one is R we must know the truth values of R in this all steps the another sub formula we are having AF r before going to AE(AF r) we must know the truth values of AF, r in each and every step then only you can loop for the truth values of the given formula AAG(AF r) so after analyzing this particular model we have found that AG(AF r) is true in all those particular four step.

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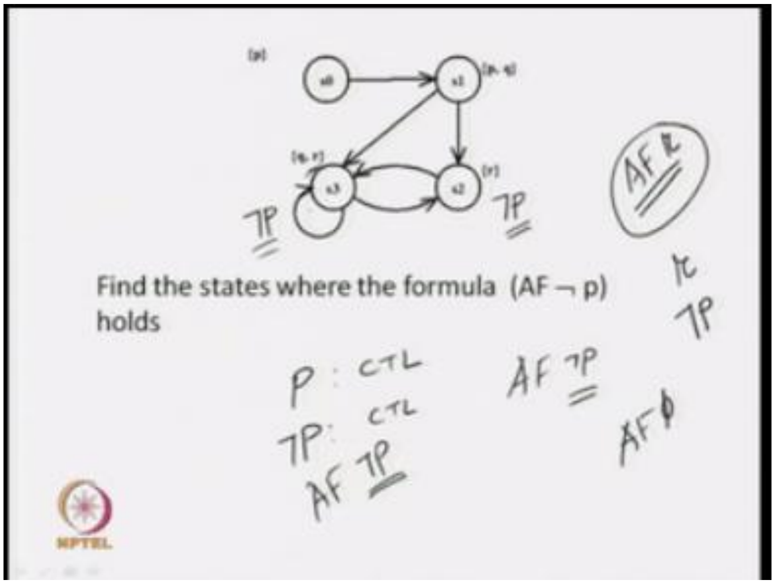

Now this is simple one that I am again saying now we are going to look for AF ˥P so this is similar to our AF, r on the just we are saying that it is not of P know, how I am going to look into it, it is say p is a atomic proposition so P is a CTL formula because its atomic proposition is a CTL formula, now if Ø is a CTL formula then ˥Ø will also be a CTL formula, so we can see that ˥P is also a CTL formula, okay.

Now if we are having any Ø as a CTL formula then we will say that AF, Ø is also a CTL formula, so we will get the AF, ˥P is also a CTL formula, now what about this particular ˥P, we are going to get the truth values of ˥P from our level in function all day, if it is not level to a particular level atomic proposition we will say that these particular atomic proposition is passed in that particular state.

Now you just see that in your S0 P is true so P remains true over here, in S1 P and Q is true that means p is true over here in S1 P and Q is true that means P is true over here, in S2 it is level it R so what does it means it says that Q and R is not true over here so we can say that ˥P is true over here similarly in S3 Q and R i9s true it is leveled with 2NR so it is not level with Q so we are going to say that ˥P is true over here.

Now you just see that already I have analyzed this particular formula in all path in future R is true or not when we have analyzed this particular formula we have founded in all those particular step AF, r is true because in QSR we are going to get one step when R is true, so this is the same behavior we are going to get say in S2 R is true similarly ˥P is also true in S3 R is true here also ˥P is true, so the behavior of this model is same with respect to your diatomic proposition R and ˥P.

Since AF, r is true in all the ports of this particular model similarly we can compute that ˥AF, ˥P is also true with all those particular four steps of this particular model, so this is the width that we have to see whether some CTL formula in true in some models or not.

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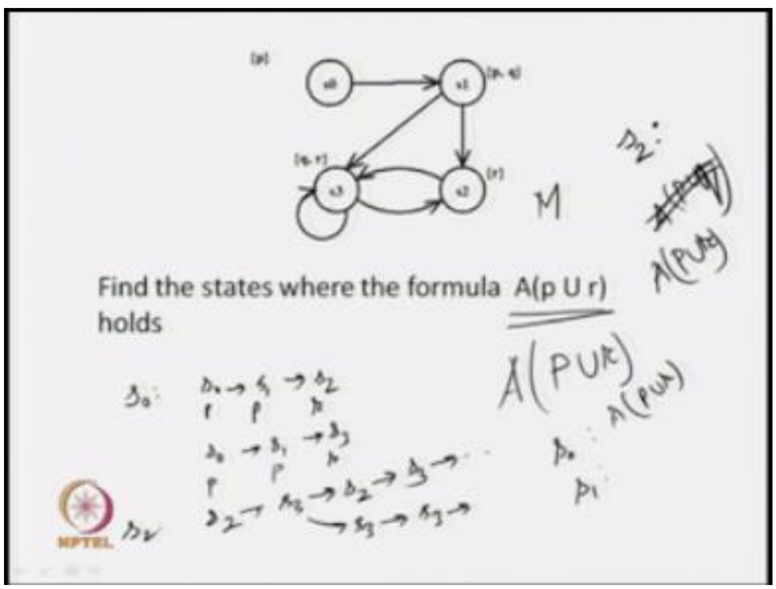

Now so slope for this particular model again this is the model M and we are consigned about this particular formula A(P U R) P remains to until R becomes true, so again we have to see all the states so from SO what will happen it will go S1 saying S0 P is true then S1P is true, then we are going to get S2 where R is true this is one execution path similarly another path we are going to get S0, S1 and S3.

So again in S0 P is true, S1 P is true and S3 R is true so we are getting some step in future where R is true and in all the precedence state of this particular part all those particular part P is true so we can say that in S0 that A(P U R|) is true similarly if I look into S1 it is simpler than the previous one because S1 we are getting two state S1 and S3 where you are R is true and the preceding step in S1 P is true so we can that, that in S1 also PUR is true.

Now we look into state S2 so it is going from in S2 if you say we are having a path from S2 to S3, S3 to S2 and S3 to S2 like that we are having this particular path along with that when I am coming to S3 again it remain in your S3, S3 like that, so these are the possible execution twist, okay, now when we go for your S3 then from S2 I am getting these are the execution twits from S3 we are getting these are the execution text.

Because one is sub set of whatever we can said this is the subsequence of this particular part from S2 now what will be a truth values of you P A(PUQ) if you look sorry we have function about in all part P until R this is the formula, now what is the truth values of this particular formula is step as two and S3 if you look into it, it will simply said at P is not worded is true in all this particular part.

So now part will be the truth values of your A(P U R) in step as S2 and S3 I will express after express some more things to you we will see what will a truth values of A(PUR) in state S2 And S3, so I am not saying anything whether it i9s true or false at that particular moment. I will come back to it.

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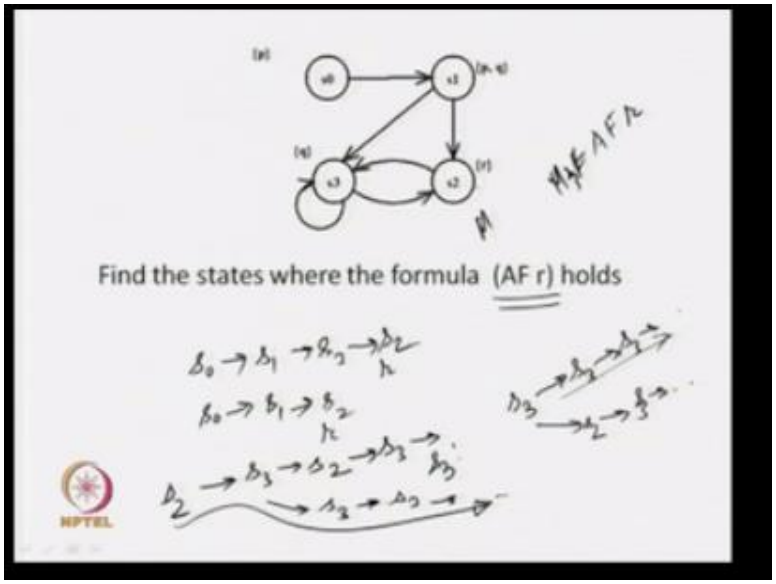

Soon will that next formula again you see that I am talking about in all part in future are holes are not, now here I have slightly sends the leveling function in S3 I am having only EQ okay so we are talking about AF r now again similarly if you say that this is the same model slight difference now if I come to this particular point AF r them you will find that from S0 we are going for all execution part and we will find that in some future step we are going to get R is true.

Because this is part where R is true this is another part where R is true out so basically S0, S1, S2, S3 so R is true over here or s0, s1 then S2 so R is true over here so we are getting two possible path and increases that RA so similarly from S1 also it is sub part of this are part coming out from S0 so again we are having that it is true over here, now what will happen in this particular case see if I am going to look for S3.

So we are going to get the part from S3 it will remain in S3 like that or maybe it will go from S3 to S2, s2 TO s3 like that so if you go this particular path you will find that in future R is not true so that means this particular formula AF r is not true it ion model M in step S3 it does not model

AF r because you are getting one part where R is not true, now when you start from this particular state S2 the what will happen.

From S2 we are getting going to S3 then we are going to S2 again S3 like that or maybe it is having that bit is from S2 we are going to S3 then it will remain in your S3 okay, so here users see that in that particular part somewhere again you are coming back to S2 and R is true over here but if you go this particular part S2 is not true, so in this particular case what happens, I am not going to whether you can concrete that whether this AF r is true in S2 or 1.

Because we are getting this particular part where in future we are not going to get any future step where R is true but I am going to say whether AF r is true at that particular state S2 or not I will come back to you like that previous example I have said that I am not going to say anything after the truth values of that particular formula in state S2 similarly for AF r I am not going to talk anything about now truth values of this particular formula in S2. But I will come back and see what will happen now.

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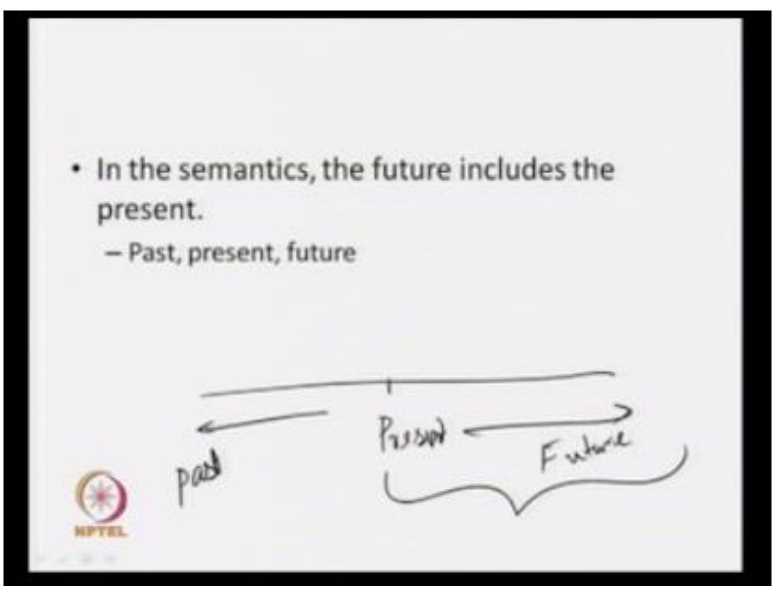

Now in this particular case now what will happen now we are going to talk about a timing behavior of our system now if you look into the time line basically we are having three particular tenses past, present and future so if we are in a present state then we can listen about what is what happen in earlier state or past or we can try to listen our that what is going to happen in future but now I am at a present state.

Now what will happen now we are having three these things past present and future but that way we are defining the semantics of CTL it says that the future increases our presence that means if you look into this particular time line if this is my your present state these are my past and from present I am going for future then what will happen the way the that we have defined a semantics of CTL it says that the future includes the present.

That means the present state only included in the future behavior, this is the because of defining a syntax that we have defined a syntax so that means we having on the two norms one is past behavior and one is future behavior in future behavior the present is included, now see why it happens.

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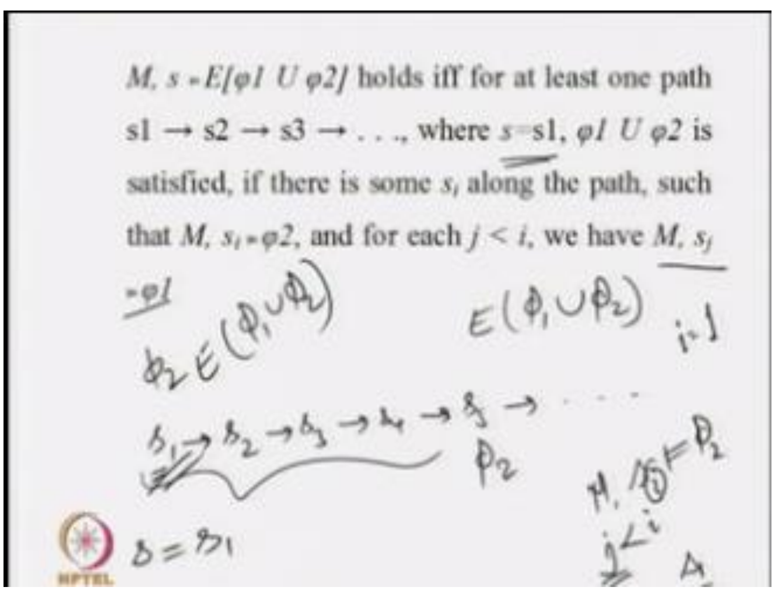

One simple example I am going to say that we are going to look into that EFQ how we have defined this particular EFQ or EFØ so we going to look for the transition S1 to S2 to S3 like that we are going to look for one congestion part and where looking for one particular step S and what you say that S = S1 that means our state of concern is S and we are saying that this is S = S1 that means starting step of this particular part.

And for t least on sn now we are going to look for one si where m si models you φ now we are going to loom for one si but in this si we are not excluding this particular one so I may where is form now one two three like that all possible values can part is because we are not excluding this particular one over her so what will happen that we are getting m s1 if it is models φ then what will happen so for this particular definition ms models this particular EFφ.

So according this two particular definition m1 also models EFφ so this is due to that definition of the symmetry so if a particular formula holds in step will said that EFφ holds in that particular step also so similarly EFφ also holds in the particular step if I holds in the particular step okay because this is the way we have defined a symmetry because we have not excluded this particular s1 from this particular any si.

So this is the way that we have defined so that is why the presence that also includes in the future behavior now see the another one that E φ1 ᴗ φ 2 again what happen we said that w are going to take any excision pairs s1 s2s3s4like that s5 now what we are saying that we are concern about the particular step s and we are saying that s = s1 the starting step of this particular part we are saying that 1.

And what we are saying that φ e φ 1 and φ 2 will hold in this particular step[s over that we are going to get some si which model your φ2 just say that here in this particular φ 2 models and all j les than I we should have msm models φ1 okay so φ1 must be true in all those particular step now what is this particular j you just say that j is all presenting step of this particular part we are not excluding s1 from here you are not saying that all j apart from s1 is true.

So in this particular case what will happen oh sorry it I not over here but we are going to talk about this particular I when I am talking about I we are not excluding one from this particular iers also so I maybe one.

So in this particular case what will happen in s1 if φ holds at the particular step then what will happen? You will find that s according to this particular definition of particular symmetries E φ1 ᴗ φ 2 holds in this particular step s1 also such say that means if five 2 hold in a particular step we said that E φ1 ᴗ φ 2 holds over here similarly f E φ1 ᴗ φ 2 holds in the particular step.

So this is because of the definition of the symmetry so those symmetry that we have defined over here says that the presence that includes ion a future behavior also but if we want to exclude the present behavior from the future then accordingly we have to defined a symmetry now you just take it as tusk or it is a homo and you just try to defined a symmetric of this CTL formula where the future behavior is going to exclude the present behavior.

Okay just see it is simple now w re have to explain over here because where I = 1 we have not excluded it so what will happen if I = 1 then it says that this s1 if s2 holds then will get that the five 1 until five one holds in s1, now I have given you talks what you have to do try to defined the symmetry of ctl formula in such a way that that means thee behavior excludes the presence scenario okay. So how to define the future or symmetric for this CTL formula this simple talk you can go it.

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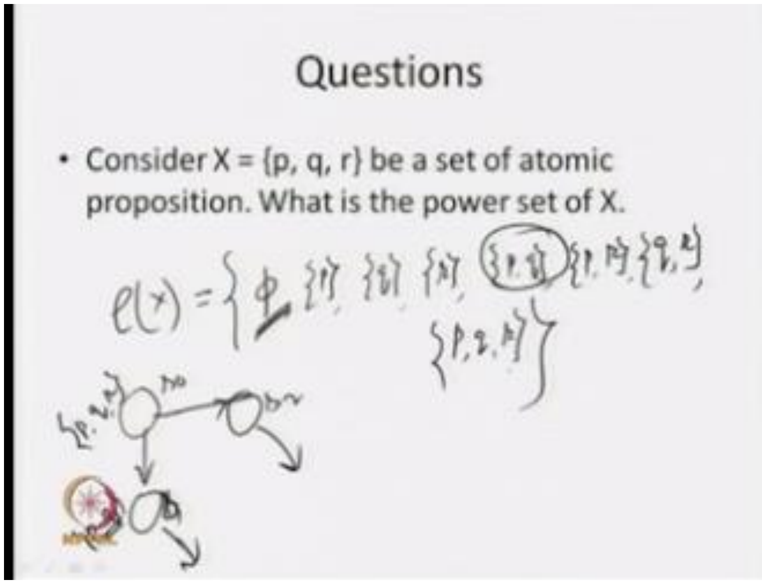

Now in this particular lecture we are going to see some question simple question I am going to consider the first question I m saying that consider a state of your atomic portion x where we are having here form proposition pq r okay so this is the set of atomic proposition now where saying that what is the power set of x why you need it because the leveling function we are seeing that the state will be level by the member of the power set of our atomic proposition so it is very simple.

Now if x is your pqr then power set of x will remain elements will have I think you know it is very well that we are having 8 element o one I you are the null set then only p only q only r or maybe pq pr or ur and the complete set pqr, so this is the power set of x 12345678 so these are the all possible combination and we said that this is the power set of x, now when we look for any step say if we have step in this term say s0 to s1 s1 to s2 like that done.

If I said that particular 1 is leveled which sy p and q so what does it means that atomic proposition p and q is true in this particular step s1 but r is not true so what is the p and q it is the member of this particular part that means the steps will be level by the member of power step about or given atomic step. So at this st of atomic proposition p q what so these are the component of this power set and the leveling set is going to become my member of this particular power step?

Because it says that these are the atomic proposition prove in this particular step say if s2w if sy that it is not mark to it or any atomic proposition that means work in that we are going to take this particular member of five it says that it is null set none of them atomic proposition in this particular step s2. And if says that pqr I provide in as a says that all the atomic proposition is true over here.

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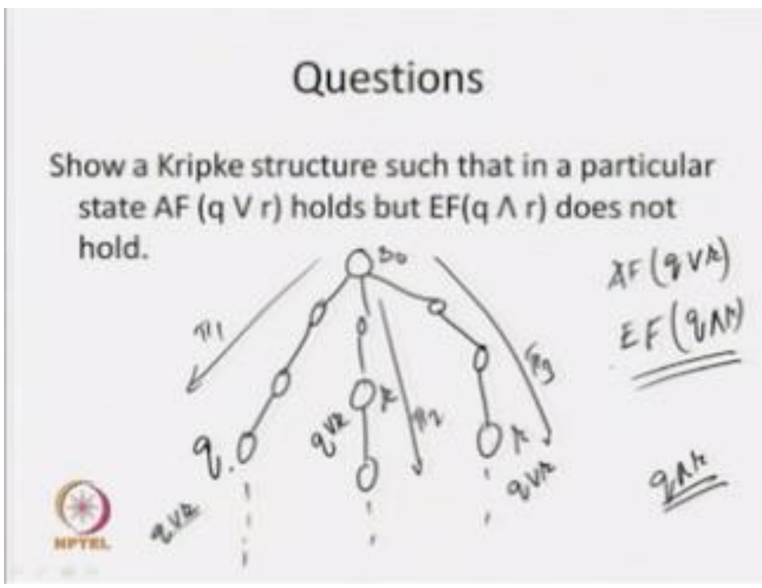

Okay next question what I am saying show a keep guest structure starts that in a particular step exp or r hold one but ex pq and r does not holds that means what we are looking for say they are the exits stet r in next step either q or r hold or I am saying that one we are exist the part in x that q and r is not hold so this is very simple so I can say that this is the state s0 since it is your next state we have to look for one particular next state only okay.

If I said that it is leveled to it q and it is leveled it to it r then what will happen we are exist the part in x the r q and r hold so if you said that since q is true over here what we can say that qr r is also true over here so we can said that at least we are getting one step so in s0 we are exist the part in next step qr r is true. But if you look in to this particular next step it is q is true but r is not true in this particular step r is true but q is not true so q and r is not true in anyone of this particular step.

So what happens in this particular model in s0 we are exist a part in x that r in this not true so we are saying that show a keep gust structure such tht in a particular state in all part in future qr r is true but here exist the part in future q and r is not true so what we are saying that in all part in future you are r is true. But we exists a part in future q and r is not true let us look for this particular model.

Say s0 ay we have a pre possible hold part now here if you see this particular tens what will happen we having three excision traces form s0 this is past part say five 1 this is the second part and five 2 say this is the third part five 3 now if you follow this particular part we are getting one state in future of where q is true so can say that q r r is true in this particular step.

Similarly in five 2 also we are getting once that we are r is true so in this particular state I can say that qr r is true over here similarly in the third part five 3 you are getting one step where r is true I can say that q and r is also true over here so in all three performance s0 and s3 possible flux so in three parts we have seen that we are getting one future that q where is r is true so we can said that in s0 ef q or ro is true.

Now look for the second formula that we are exist the part in future q and r is true if I am having this particular leveling then and you will find that none of this particular part in none of the steps u and r is true so that means you are not getting any part where in future q and r will be true so that is why I say that this particular formula e we are exist the part in future q and r is fale in this particular step s0.

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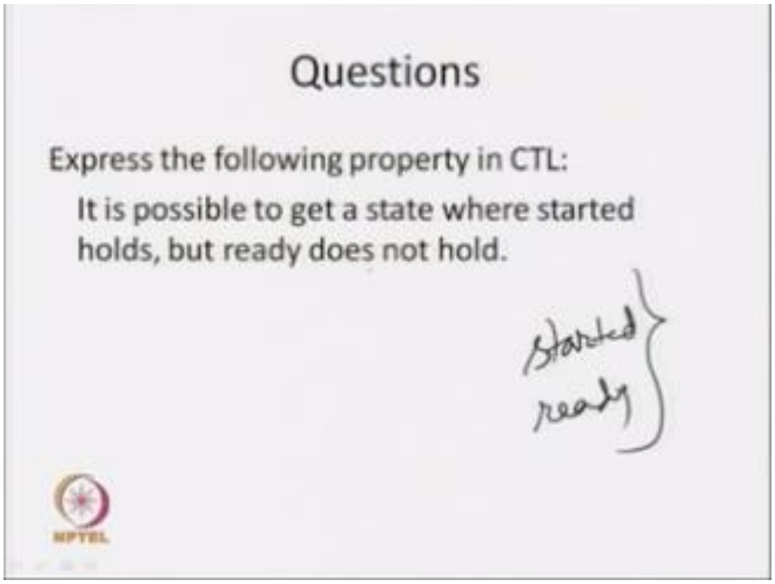

Now just look for another way of looking in to the CTL formula what I am saying that express the following properties in CTL is it possible to get a state where started holds but really does not holds so if you look in to this particular step what will happen from here we can capture quip awls one is your started and another one is ready that means what we can say that these two are my atomic proposition.

So we can have some signals in my systems where the fellow of this signal maybe either 0 or 1 if it is 0 we can say that it is true if it is one we will y that if it is 2 we can sy that 0 we that it is false so these are two signals we can thing in my system that means you can map this two as my atomic preposition of my system, now we have to said that if it is possible to get a state where started holds but ready does not holds.

That mean we can think something like that we have design a system and after that it I going for operation now we have started a machines but it is not going to the ready step okay, so it is we have started it but it I not going to the ready step so whether we have to region about uh them a property now whether this property can be express in a CTL or not. So is it possible to get a state where started holds spot ready or not hold.

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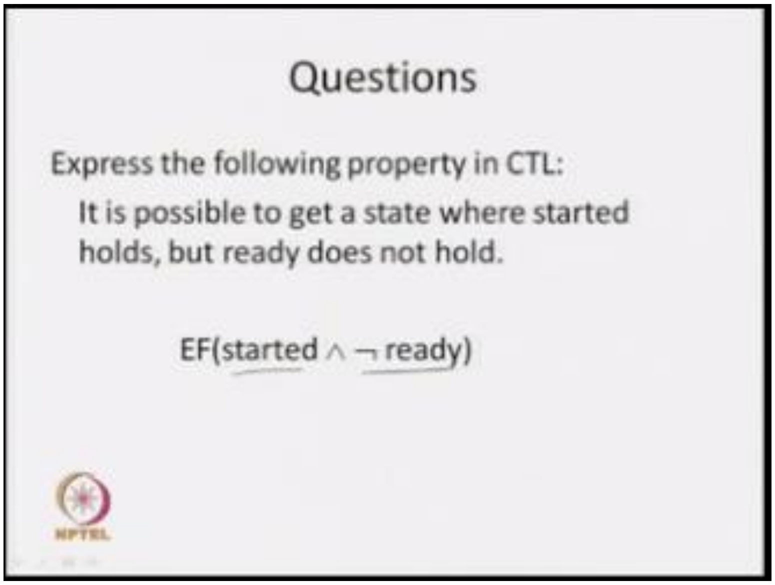

So in find that you can express this property in CTL something like that they are exist the part in future whether started is true but maybe is not true so this property we are going to capture in CTL like that we are exist the part in future started is true and ready is not true so this is way we can capture now if we are having a model of the system now we are going to look for the two models of this particular formula and will see what are the steps that formula I true and what are the step this formula is false.

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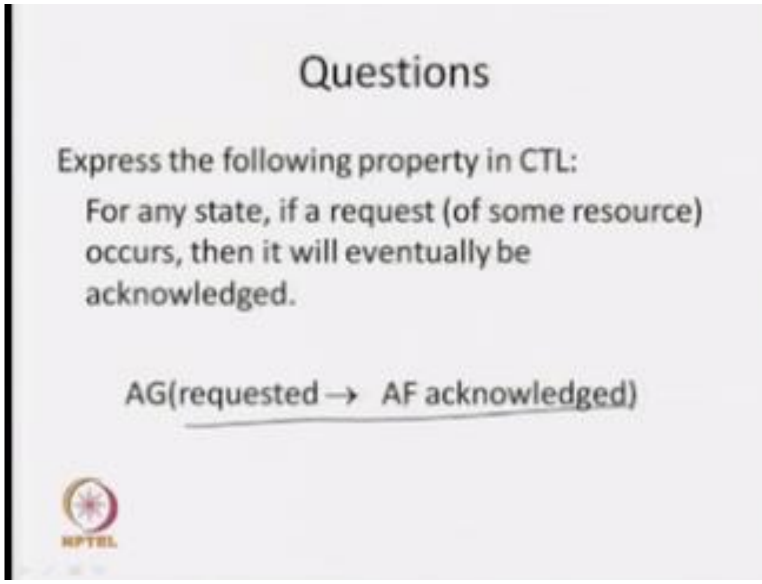

So another property are see that express the following property in CTL the property says like that for any step if I request of some resource occurs then it will eventually be acknowledgement now if we are going to look for your distribute a system or maybe confidence with them what will happen same resources will be shared by fine process so what we are saying that if we are requesting of a particular resource it may be sad memory or it may be something else also it may be some of the devices also.

If we are requesting from some resources then it will eventually b acknowledgement because if say if I am going to a this as a sad memory eventually i should get it then only I can progress if I cannot get it done what will happen I will go in to the start system now once we design a system that system must be satisfy such type of property now this is we know the meaning of this particular property.

Now when we are going to formula verifies someone we have to capture it formally now we are going to see whether this property can capture in CTL or not now again you consider here we are having two key word one is your request and second one is your acknowledge that means we can said that some process or some process might be raced or request we said it this is signal f it is based or request then you have go to rectify and if it is not requesting it then it is accept low.

So request can be determine is a atomic proposition this fellow is either true and false, when it is that resources gutted to the process then what will happen we can say that it has been acknowledge then either you can see that acknowledge is a signals it fellow either 0 of 1 o we can say that this also the atomic proposition in my system or my model so we are getting two atomic proposition request the acknowledge.

Now with the help of this two signal we will defined this particular property in CTL now what we can see that if somebody has request the pump some resources that should implies that in all part in future with must get the acknowledgement and these properties soot hold globally in the system so that is why I am saying that in all part globally if it is requires that can it should say that it should get that it should get an acknowledgement what about the system.

So that is why I am saying that in all part in future it should get the acknowledgement okay so in all part globally it must be 0 so if in a particular step if requested happen then formed a particular step where ever you go in all part in future you should get the acknowledgement her some part were we are not getting the acknowledgement then what happen if i follow that particular part let us see system is going to get start passion because it is not going to get thee resources.

Now this is the way that we have to look for the properties about system and we have to express in your CTL and we have going to use loop for the foot fellows' particular CTL formula in our system. Say why did this is true or not okay so this is about our one particular class of logic tempo logic call CTL compaction of free logic we have to seen how to defined a what is the syntax of your CTL how to defined it and what is the meaning.

We have seen the symmetry of those particular CTL formulas and secondly we have seen how to defend a syntax this is respect to s model and second we have seen in that the CTYL formula are basically step formulas if the true whether it defined over a step of a model okay so with this I am stop here today in next class we are going to see some of the notable equivalent about CTL formula which will help us for verify node system. Thank you.

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