Game Theory and Economics

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Module No. # 05

Extensive Games and Nash Equilibrium

Lecture No. # 02

Strategy and Equilibrium

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Welcome to the second lecture of fifth module of this course game theory and economics. So, before we start this lecture, let me take you through what you have been discussing in this module. So, this is a model about, this is a module about extensive games. Extensive game is a part of this this category of games called non cooperative games.

So, in extensive games, the thing that is different from the strategic games is that here the decisions are taken one after another. So, things are moving sequentially instead of simultaneously, and therefore, what becomes important is the structure of the sequences how the people are moving one after another. And at each stage, what are the actions that a particular player can take, that also becomes important.

And typically it will be seen that, as people move, their actions that are available to them. Those actions also keep on changing. So, this is the basic difference of this games which are known as extensive games from simultaneous move games, which we have discussed before.

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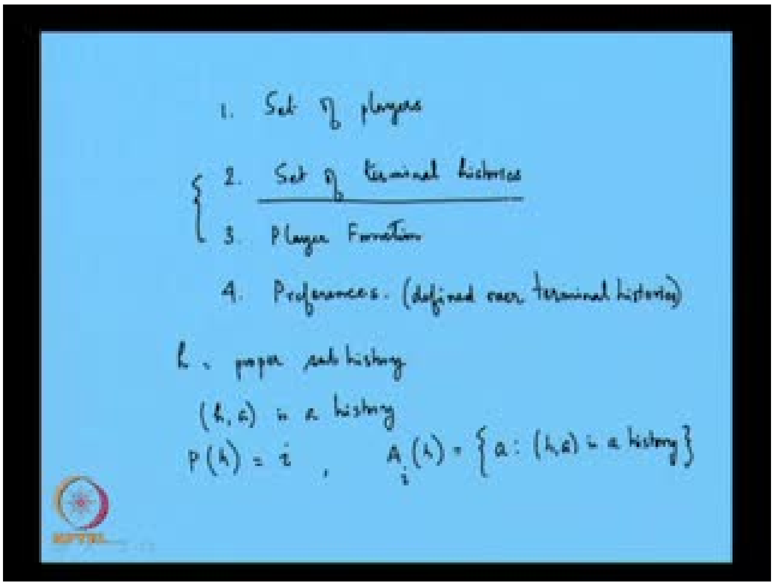

We have seen in the previous lecture that in extensive form game or extensive game, there are basically four elements that are needed to be known, if we want to pin point a particular game and this four elements are the following - one is the set of players; two is the set of terminal histories; what a terminal histories? Well, terminal histories are sequences of actions, and in this set of terminal histories, the sequences must be such that no sequence should be a proper sub history of any other sequence. If we have a proper sub history, then it is not a terminal history because that sequences, that sequence is ending somewhere in between. It is not reaching the end of the game; it is not reaching the terminal.

Thirdly, what we need to know is the player function. Basically, what it means is that, at each stage of any terminal history, if the terminal history is not ending, then I need to know which is the player who is going to move now, whose turn it is to move. And so, player function is defined over a proper sub history. It is not defined over the complete terminal history, because if we have the complete terminal history, the game is a ending, and if the game is ending, there is no other player a two make a move.

So, player function is defined over sub history, proper sub history, and notice that from these two informations, that is, a two and three, we can find out what is this action set our particular player at a particular stage, because so far we have not defined that important component of action sets, because, if you remember in strategic games, one of the three components - important components - defining the game was the set of actions.

Here, we are not talking about the set of actions, but what I claim is that from two and three, we can figure out what is the set of action of a particular player at a particular stage. And it is done as the followings suppose, a's, this h is a proper sub history suppose, and h a is suppose is also a history and suppose this p p is the player function; p of h is suppose i which means after h has happened, it is now player i's turn to make a move. Then we say that the action set after h has happened and who is the player? Who is making this action? Who has these actions? It is a, sorry, it is i. His action set after h has happened is defined as a - where h a is a history.

So, if I have the information that after h, it is now player i's turn to move, and if I have the information that a is an action, which happens after h and h a is a history, valid history. Then, action set of i after h has happened, will consist of all such a's - where h a is a history. And fourthly, which the important component of an extensive game, which was there in case of strategic game also, is the information about preferences and this preferences are defined over terminal histories.

So, after a game has reached its, its, final conclusion, the players must be able to say how much they like that kind of, that outcome after the game has reached its final outcome. And this outcome is nothing but the terminal history. All players have, all players were involve with the game, have taken their decisions and we have reach the kind of finality, and if the game has reach it is finality, people must be able to say whether how much they like that, that, sort of outcome and that is what we meant by preferences.

So, these are the four important components of any extensive firm game. They define an extensive firm game. The important thing to note is that, in the definition of terminal histories is what we say that, is that it is a sequence of actions. Now, if it does not rule out the fact that, that, this sequence can be an infinite sequence. So, those things are included. In particular, if game has the longest terminal history with a length which is finite, then we said that the game is finite horizon game. The length of the longest terminal history is finite.

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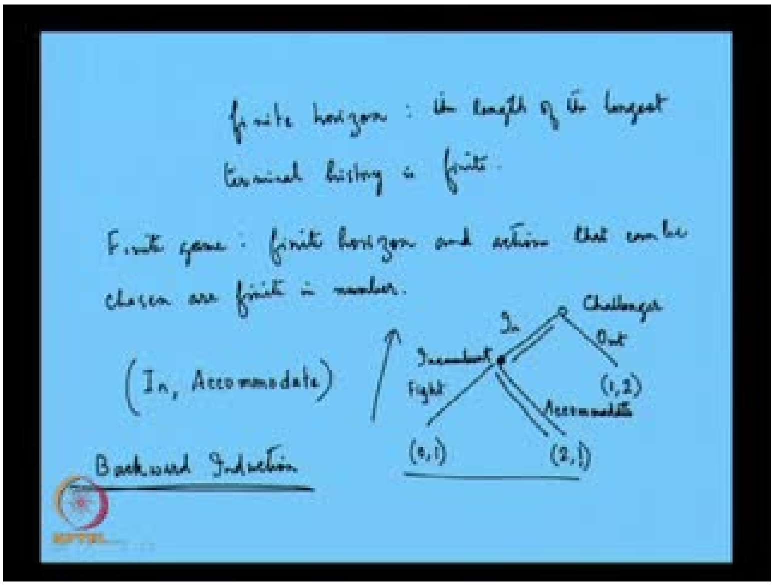

And so, if the length of the longest terminal history is not finite, if it is infinite, then the game will be called an infinite horizon game. Second point to note is that, if the actions available to a player is infinite in number, the action set is infinite, then, and then, there is a problem. Then, we the kind of game strategy we have seen before. For example, we have talked about chess for example; in chess, after every move, after every move by the rival any player has a finite number of moves.

So, if a player has not infinite number of actions to choose from but a finite number of actions to choose from, and if the horizon is also finite, then the game is called a finite game. So, finite horizon and actions that can be chosen are finite in number. So, if these two conditions are met, then we call that the game is a finite game. What could be the case where the actions could be infinite? For example, people can choose different prices and those prices can be within a particular range. For example, price could be between 20 rupees and 40 rupees. Between 20 and 40, there are infinite numbers of points. So, in that case, the action set is not finite; it is an infinite set. In that case, the game will not be called a finite game.

We have also seen that a particular extensive game can be represented in terms of what is known as a as a game tree. In particular, we have seen that it is done as the following. Suppose we are talking about this entry game, then this is the challenger; he can take two sorts of actions - one is in; the other is out. If he chooses out, if he does not compete, then the game is ending there. So, we are reaching a terminal history. In that case, the challenger is getting 1. And there is this incumbent his rival who will get 2 in that case.

If the challenger chooses in, then the game progresses a far further. If we chooses in now, it is the incumbents turn to make a move, and he has two options - one is to fight with the challenger and the other is not to fight to accommodate. So, if fighting takes place, it is bad for both of them. We shall assume that 0 0. If accommodation takes place, then the challenger is benefited; he gets 2, incumbent gets 1, because he is basically being forced to share the market.

So, this is worse than the case where the challenger stays out. So, this is how a game tree is strong. Now, the obvious question to ask is, if this is how a game looks like, then what is this solution of a game, of a particular extensive game? How can we predict that this is the, you know, sequence of moves that will probably take place. What is going to be our prediction? So, by solution, we mean what is the lightly outcome or particular game. What are the actions that will be taken? What is the terminal history that is going to come out of the game?

So, if we examine in the game carefully, it is stands to reason that the solution of the game will be the following that the challenger gets in and the incumbent does not fight the incumbent accommodates. Why I am saying that this is going to be the solution. What is the rational? The rational is that, challenger is the first mover in this game; he is making the first move.

Now, since the structure of the game is known to him, so this is an important point, the structure of the game. How the actions can be taken and what are what are the sequences of actions. Those information’s are known to everyone both the challenger and the incumbent know them.

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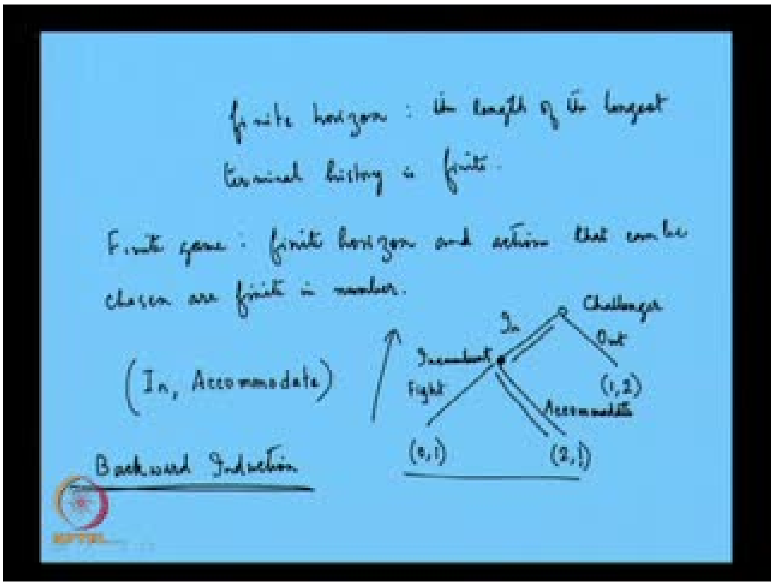

Now, if the challenger knows the structure of the game, then he can figure out that, if he gets in, then the incumbent will have to move and the incumbent will then look at fight, and if the incumbent looks at fight, he sees that he will get zero in this case by fighting, where as if he accommodates, he gets 1.

And by the theory of rational choice, we know that this accommodation will, will, have a preference over fighting because 1 is greater than 0. So, by, by thinking, by thinking, by putting himself in incumbents position, that challenger can figure out that, if he gets in, then incumbent will accommodate; the incumbent will not fight. So, this is going to be the action of the incumbent by going by the theory of rational choice.

Then, for the challenger, the choice is really between two and one, because, if he gets in, the incumbent will accommodate, which means that the challenger by taking the action in will get 2, where as if the challengers stays out, is getting 1. So, again by going by the theory of rational choice, 2 is greater than 1. Therefore, the challenger is going to get in, and if he gets in, the incumbent chooses accommodate.

So, that is why I am saying that, this in accommodate seems to be the solution of the game. And this sort of thinking from the last players point of view, putting yourself in the shoes of other player and thinking from his point of view and then figuring out how the game will evolve from backwards from this point and going upwards, going in upward direction. This is known as backward induction.

So, in backward induction, the mover, the mover, who is not making the last move puts himself in the shoes of the last mover and sees what is the optimal decision for the last mover. And by figuring out, he goes backwards and then he calculates what is this optimal action. In this case, in is the optimal action. So, that is known as backward induction. We shall talk more about the backward induction in subsequent discussions but, the, there is some problems with this backward induction logic and how it can be applied. For example, if I change the numbers a little bit, suppose instead of zero, I have one here. Then it is not very certain whether the incumbent will fight or accommodate, because the payoffs from both this actions are same.

Therefore, the challenger will not be able predict for sure what action the incumbent will take if the challenger gets in. So, in this case, backward induction does not have that predictive power. So, here, backward induction fails to an extent. Backward induction also fails if for example, the game is an infinite horizon game. There are the largest; the longest terminal history goes to infinity. In that case also there is no final stage, and if there is no final stage, how can you go backward.

So, here the idea is that you start from the final stage and come backwards. But, if there is no final stage, backward induction logic does not apply. So, that is again another problem of a applying backward induction, and also suppose the players are un-aware of the moves of the other player. In extensive game also, we can have such situations where the, for example, the incumbent and the challenger are not aware of each other's decisions and they take the decision for example simultaneously.

And if they are taking their actions simultaneously, then again you can figure out that, it is not certain whether the incumbent will choose fight or accommodate. And again so, challenger is not able to predict which action will be taken by the incumbent, and therefore, which action he himself will take.

So, there are certain problems with backward inductions; there are certain situations. In which it cannot give us some clear cut prediction. And therefore, what we shall do is that we shall start with the idea of nash equilibrium? And from there, form there, we shall try to see what are the solutions that we can get. And we shall see that in nash equilibrium in case of extensive games. There are some weaknesses of that concept it needs to be corrected a little bit, and from there, we shall see that one of the ways in which it can be corrected is backward induction. So, nash equilibrium is a more generalized concept. And from there, we shall try to trace to backward induction.

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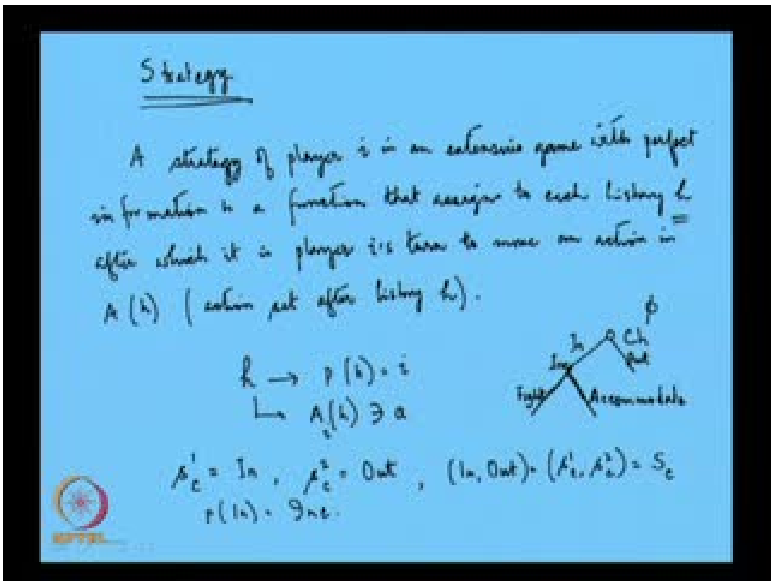

Now, if in an extensive game nash equilibrium has to be defined, what first step has to be defined is what is known as a strategy. Now, strategy is a important and a little complicated idea in extensive game. What it means is the following. Let me write the definition first and I shall explain. (No audio from 23:00 to 24:42)

So, this is the definition of a strategy. Now, what is important is that, how is a strategy defined. A strategy is defined for a particular player. And how is a defined a strategy of player i then extensive game with perfect information is a function that assigns to each history h. So, it is defined for a player and over a history. After which, it is player i is turn to move and action in a h - where a is the actions set which is available after history h.

So, h is there. From h, I know by the player function that, suppose it is player i is turn to move. From h, I also know what is the action set - the set of actions, which is available after h and this actions are obviously available to player i. What is strategy will tell me is that, which action? Suppose this action is a will be played after this history h.

Now, obviously player function we know is defined only over histories which are proper sub histories but the game is not ending. So, this h that we are talking about here is a proper sub history; it is not a terminal history. That is the first thing. And secondly, the games that we have seen before, just now we have talked about this entry game. There each player had just one history after which he moves. For example, here, the challenger, suppose c h is moving; here the incumbent is moving. So, he, this challenger moving, is moving after a particular sub history, which is the sub history after which the challenger is the moving. It is phi. Phi is also, the null set is also sub history, and which is the sub history after which the incumbent is moving? The incumbent is moving suppose this i and c incumbent to distinguishing from the action in and this is the action out. So, the incumbent is moving only after the sub history in.

So, there are, as I just said that for each player, there is just one sub history after which he or she moves and a particular player has to specify which is the action that he is going to take. So, in this case, if i have to specify a particular strategy of challenger so in general, smallest will be used for a strategy, and see for the challenger, it can be in right. So, this is one strategy. He is saying that, after null has happened, I will take the action in, but this is not the only strategy that he can take. He has another strategy which is out. So, we shall say that, this in out which is s 1 c, s 2 c. This is the strategy set which we are denoting by capital S and there is the subscript c, c for the challenger.

So, this is how strategy set is defined. Within the strategy set, there are different strategies. A particular strategy will tell me what is the, what is the action the player. C is going to take after the history a phi. Similarly, what about the incumbent? So, this is fight; this is accommodate. I am not writing the, the, payoffs because they are not relevant that much here.

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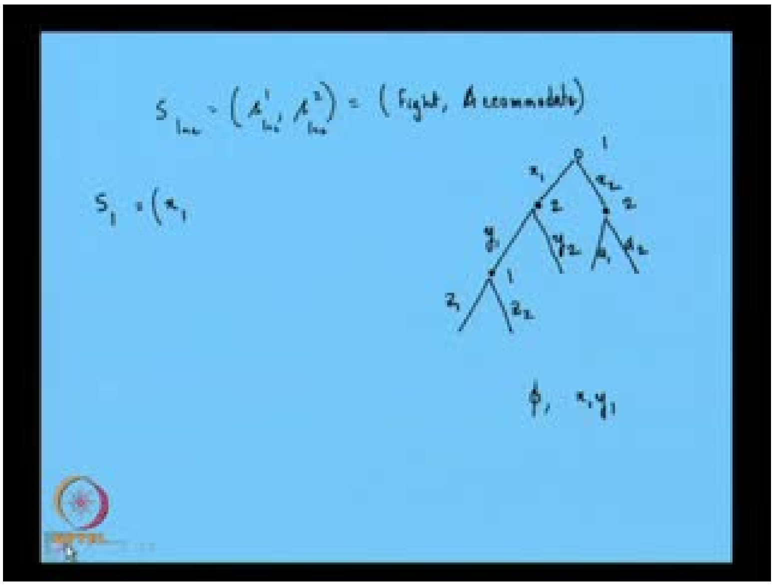

Now, similarly, here the incumbent is moving only after one history. The history is in. So, I know the following in is incumbent. Now, how many actions the incumbent has in his action set after it has happened? He has two actions - fight or accommodate. So, like before, like the case of challenger, his strategy set is the following; just call it s 1 and s 2 with the superscript 2, one minute, sorry, the convention is different. So, this is incumbent.

The subscript is standing for the identity of the player and the superscript is denoting the number of, the serial number of the strategy. So, how many strategies he has? He has the two strategies - fight and accommodate. So, his strategy could be fight. So, that is a strategy or his strategy could be accommodated. So, that is another strategy, but the point that I was trying to make is that it is not necessary that the players have a just single history. After which, it is his turn to move. Let me give you the following example. Suppose this is player one. He has two actions - suppose x 1 x 2. If x 1 happens, suppose it is player turn to move, player two's turn to move and suppose the actions are y 1, y 2 and then, suppose, again it is player one's turn to move. And they are suppose, z 1 and z 2.

Now, what we are seeing here is that there are two histories. After which, it is player one's turn to move. And I can complicate the story further by putting 2 here. So, this, these actions are suppose, a 1 and a 2. So, the game is the following - in the first stage, a player one moves. If player one takes the action a 1, x 1, then it is player two's turn to move and player two now has two actions to choose from y 1 and y 2. If y 2 is played by player two, the game ends there. There is no further move, but if two takes the action y 1, then again it is player one's turn to move. So, this is from this side, from the left hand side. From the right hand side, if player one takes the action x 2, player two has to move now and player two has two actions to choose from at o a 1 and a 2.

Now, in this case, suppose I want to write the strategy set of player one. Then how will it look like? Now, here, unlike the case before, there are two histories, after which two sub histories after which player one gets to move. They are phi and the history x 1, y 1. So, these are the histories after which player one moves.

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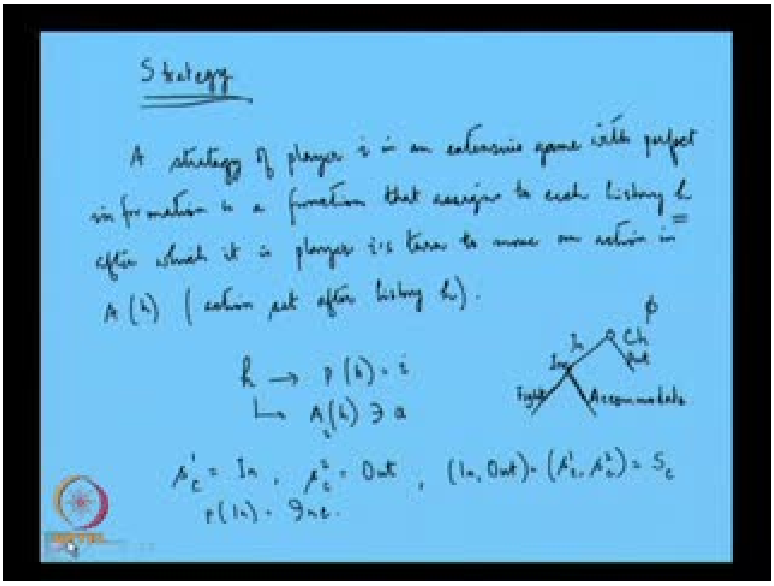

So, a strategy must specify which are the actions the player one will take after these histories. So, that is what a strategy is. So, it can be x 1. What does it mean? He is saying that after phi happens, I will take the action x 1 but that is not the end of it. He also must specify what is the action he is going to take after x 1, y 1 has happened, because if you remember, that assigns to each history h, after which it is player i is turn to move and action in the set a h.

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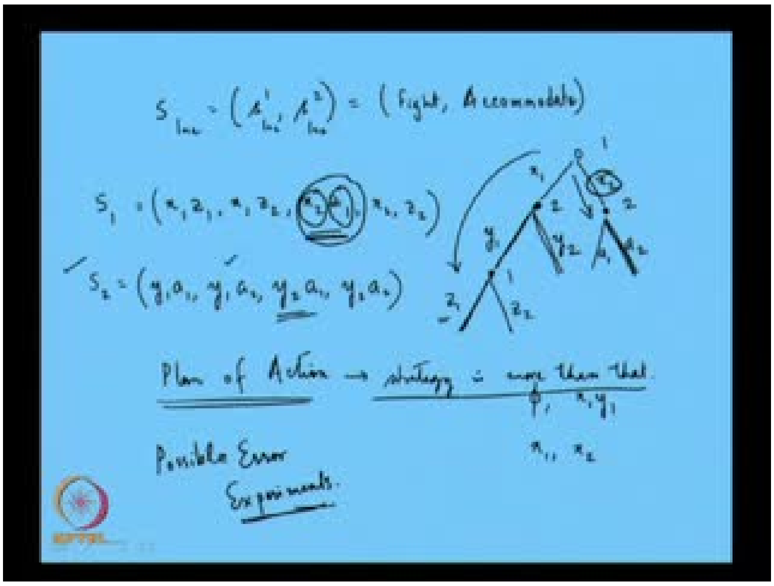

So, now, if x 1, y 1 is the history, he has to say which action he is going to take. So, it can be z 1. That is possible. It could be x 1, z 2, is saying that, first, I will take the action x 1, and if x 1, y 1 happens, I will take the action set two but that is not the end of it. He can also say that I will take x 2, and interestingly if x 2 is the action that is taken by him, then also he has to mention what is the action that he is going to take if the history is x 1, y 1. So, he has to say either this or this. So, this is the strategy set of player one. Before I shall elaborate a little bit about this second the last two strategies, but before that, let me write down the strategy set of player two. Strategy set of player two is more simple and here also we will strict to the definition of strategy. What is a particular strategy?

Now, like the case of player one, player two gets to move after two histories. If the history is x 1, he moves, or if the history of is x 2 again he moves. So, here also in each particular strategy of player two, there must be two components - one should specify what the action of player two will be if the history is x 1 and the second component will tell us what is the action of player two if the history is not x 1 but x 2. So, here also I have to combine these actions y 1, y 2 with the, these second set of actions a 1 and a 2.

So, these are the strategies. Each of them is a possible strategy of player two. And what is the interpretation? Let us take this y 1 a 2. Here, player two is saying if x 1 is the move by player one, I will play y 1. If player one is going to play x 2, I am going to play a 2. This is his strategy. Now, and similarly, for other strategies for example, y 2, a 2, here he is saying that if player one is taking the action a 1. I will take the action y 2. If player one takes the action x 2, I shall take the action a 2.

Now, while looking at the strategy of player two, it may appear that what is the strategy? It is a plan of action. He is just saying that after each contingence, what is the action that I will take. In particular, if he is not there, if he just writes down his strategy suppose, he writes down the strategy y 2, a 1 and on a piece of paper and gives it over to some other player, then that other player will be able to play according to the a plan of player two. So, player two need not necessarily be in the sight of action to take the required decisions. So, in this sense, it means appear. The strategy is a plan of action, but what we are saying is that strategy is not merely a plan of action; it is more than that. And this fact that the strategy is more than a plan of action can be seen from this, this, example. Here, player one is saying that x 2 z 1 is the, is my strategy.

Now, what is x 2, z 1? A player one if he plays x 2, then the game moves in this direction. So, there is no chance that the game comes here at this node, and if the game does not come here, there is no reason why a player one is specifying that I shall play z 1. So, if I had stuck to the definition, the strategy is a plan of action; then there is no necessity for saying z 1. I could have just said x 2. That is the end of it; because I know that after x 2, z 1, there is no chance that z 1 will be considered. But, still I have to mention z 1 or z 2, because going by the definition, what is the definition - is a function that assigns each to each history h after which it is player i is turn to move and action in h.

So, does not matter if x 1, y 1 this history happens or not, and in fact, it is going to be ruled out if the action is x 2. So, it is in material whether this history materializes x 1, y 1 history materializes, that is, in material. Player one has to mention. What his action is going to be if x 1 y 1 is the history. So, this kind of strategies entirely valid. In fact, that is what we are have we have to specify that after each possible history, after which it is i is turn to move; i has to tell us what his action is going to be.

So, in that sense, strategy is more than a plan of action. It is tell it tells us more than that, but, if one has to consider it, one has to visualize it that I can understand that by going by the definition, one has to specify z 1 or z 2 also; even if I am saying that x 2 is going to be plate, but what is the logic of it? I mean why one has to mention the action after x 1, y 1 history?

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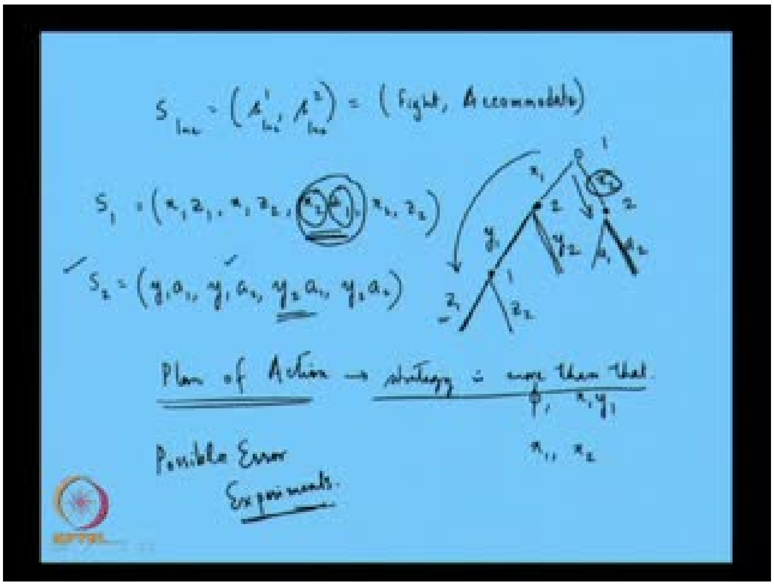

So, one way to rationalize it; one way to justify this kind of writing down of strategies could be the following. That player one is saying that, I am going to take the action x 2, and still he is saying what he is going to do after x 1 and y 1 happens because he may make mistakes. There might be error in his carrying out of the action. So, though he is saying that I am going to play x 2, maybe he makes a mistake plays x 1, and if x 1 is played, there is a chance that x y 1 will also be played. So, x 1 y 1 could be a history and if that is a history, then one has to specify what his action is going to be after that is to be x 1 and y 1. And that is why, he is saying that, look z 1 is going to be my action is if x 1 y 1 is takes two.

So, one way to justify or rationalize this sort of writing down of actions is that you might make mistakes or it could be justified as the following. So, one is error, possible error. The other way to justify this sort of writing down of strategies is that players can make experiments. What we mean by this is the following that, player one is saying that he is going to take this action x 2, but from time to time, he may take a chance and intentionally can do some experiment and play x 1.

And by this strategy therefore, we mean that if we does and experiment, so we come to this second node and player two takes the action y 1. Then here, if the game comes, then one is going to take this action for example, z 1.

So, this, these are the, these are the actions that the players are specifying in case of all possible contingences. Even, if that contingency is still being ruled out by his own specifications of actions here. So, that is it. We shall see that this idea that people are specifying their contingences is going to be important when we develop the idea of nash equilibrium in subsequent discussion and also how the idea of nash equilibrium is not so robust in case of extensive games and one has to refine the idea of equilibrium. In case of extensive games, one has to be away from of the idea of nash equilibrium.

So, that is what is meant by a strategy to. So, this is, since this idea is important, the idea of strategy in extensive games. Let me just once again very briefly go over it. Strategy for a particular player must tell us what his action is, what is action is going to be after each history, after each possible sub history after which it is his turn to move.

So, it tells us the all possible contingencies. It may very well happen that those contingencies are basically ruled out by his own strategy. Those contingences may not happen by the specification of his own strategy, but nevertheless one has to mention what the actions are going to be after all possible sub histories, possible sub histories.

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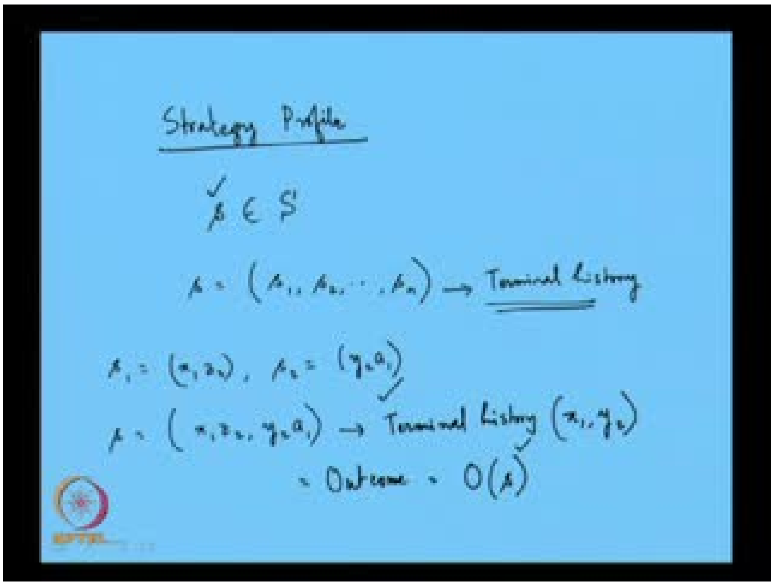

So, this is the strategy, and now, we talk about what is known as strategy profile. So, strategy profile is like an action profile. It is a list of strategies of different players. So, it is a collection of strategies of different players. In particular, I shall write it as small s a particular strategy profile. It belongs to the set of strategy profiles which is capital S.

So, small s could be like this. If there are n players, small n players, small s 1 is the strategy of player one; small s 2 strategy of player two, etcetera, etcetera. So, the last strategy is strategy of player n. So, this is a collection of strategies of different players and this collection is being called a strategy profile. What is important to notice that, if I have got a strategy profile, then basically I am tracing out a particular terminal history.

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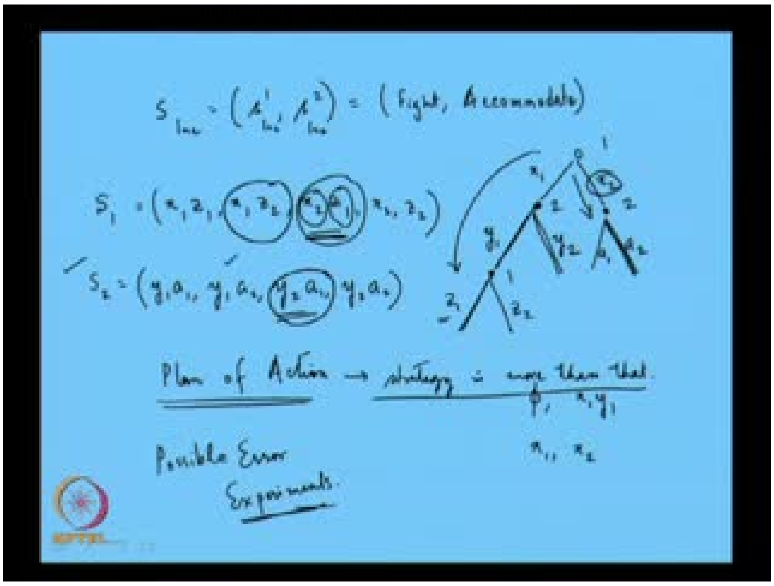

So, a particular strategy profile will give the definite terminal history. How is this possible? Let us take particular example. For example, let us take this game. Suppose for player one, I choose this strategy, and suppose for player two, I choose this strategy, any two arbitrary strategies.

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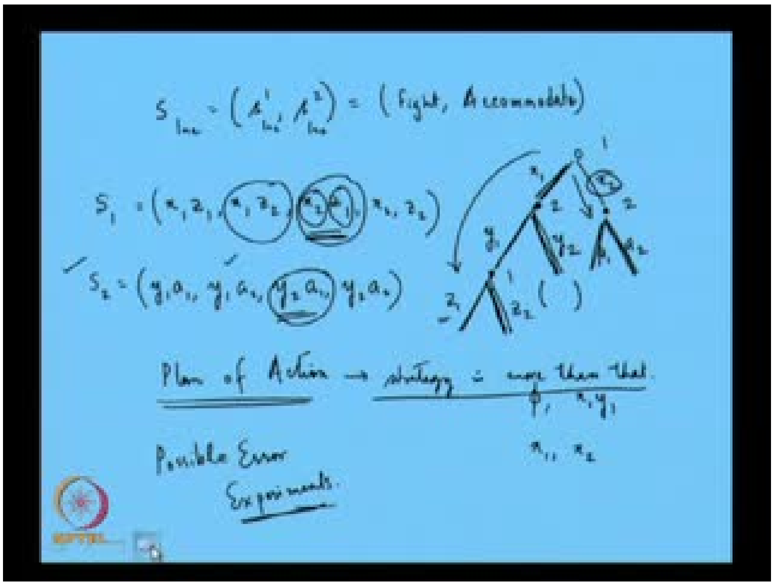

So, s 1 here is x 1 z 2 and s 2 here is y 2 a 1. So, small s is this x 1 z 2, y 2 a 1. What I am claiming is that, from this strategic profile, I can trace out a particular terminal history. Let us see how it is happening x 1 and z 2. So, this is what player one strategy is and player two is saying that y 2 a 1.

Now, if I combined this this with this this, what I get is this. So, that is a terminal history, because the game is ending there. So, this is how from a particular strategy profile, I am getting, I am tracing out a particular terminal history. And in this case, just giving me the terminal history x 1 y 2. And this is also known is the, as the outcome. So, outcome or o is a function of a particular strategy profile.

Now, so, there are different stages of it. Each player has a strategy. By combining the strategy of all the player, we are getting a strategy profile, and from a strategy profile, what we get is a terminal history and that terminal history is also known as outcome and we write it as o of s - o standing for outcome and small s standing for the strategy profile.

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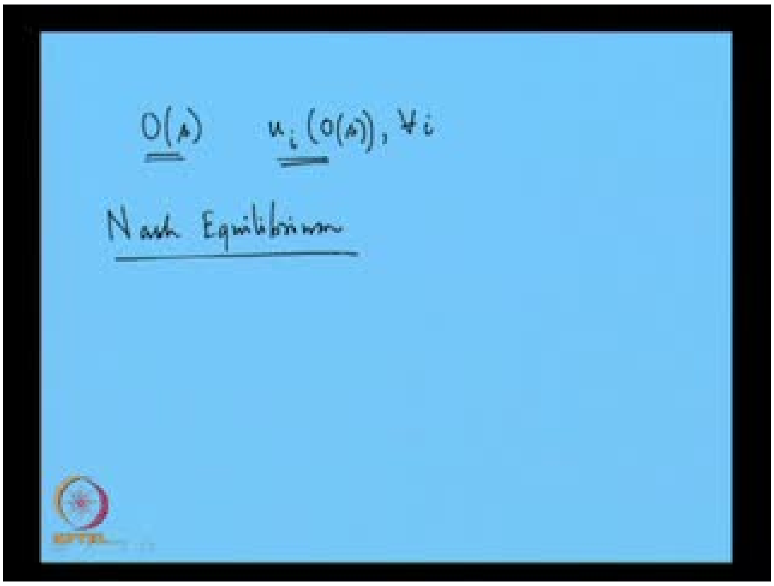

Now, if I am getting a terminal history, then remember terminal history is also give me what is known as the preference of the players, the payoff of the players. So, related to an outcome, one gets what is known as y i's for all i. So, the thing is becoming more structure now. For each player, I have a strategy. Combining the strategies, I get strategy profile. For each strategy profile, I get a terminal history or an outcome, and from that outcome, I get what is known as the payoff of each player from that outcome. I shall write it as o s. And this payoffs will be important, because if we want to define nash equilibrium, what is important is that players compare between different payoffs and they choose that decision which maximizes their payoff. So, one has to do some kind of optimization, and to do that optimization, this idea of payoff has to be brought in some up.

So, now, before we end this lecture, just little bit discussion about the nash equilibrium therefore. So, nash equilibrium in extensive firm game now can be defined as the following: that it is defined over the set of strategy profiles and each player will like to choose that strategy such that the resulting strategy profile gives him the maximum possible payoff given what are the strategies chosen by the other players right.

Given the strategies chosen by other players, my strategy should give me the maximum payoff. So, that is the idea which we are going to develop in the next class because we have a more structured story now. We know that there are players. They are going to choose their strategies. Depending on the strategies, there is a strategy profile. From a strategy profile, we get a history - terminal history, and from the terminal history, I know what is the payoff that I am going to get. So, by changing, by moving around with my strategies, I am going to maximize my payoff and this happens for every player, and therefore, we can apply the idea of nash equilibrium. So, this is what we are going to do in the next class. Thank you.

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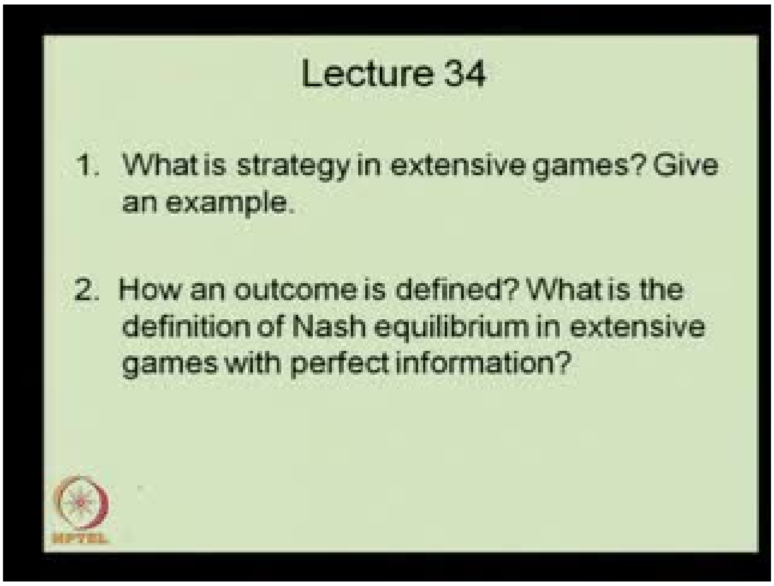

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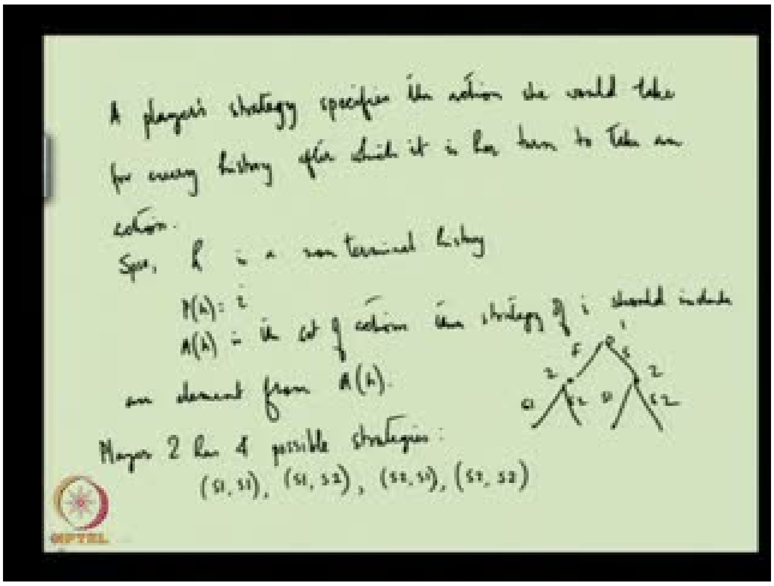

What is strategy in extensive games give an example? So, what is a strategy? A strategy belongs to a player. So, a player strategy what does it is say? It specifies the action she would take for every history. After which, it is her turn to take an action. So, for each player, he should specify if after some non terminal history, he as to make a move what move he will make.

So, suppose h is a non terminal history and suppose p h is equal to i and suppose a h is the set of actions after history a h has happen. Then strategy of i should include an element from a h. So, he should say after h has happen, what action he will play taking that action from this set a h.

So, let us give an example. Let us take the example of a batsman and a bowler. So, one is the bowler - he can bowl a fast ball or a slow ball. Two, player two is a batsman. He can play shot one or shot two. Now, what are the strategies of player two? Player two has four possible strategies. So, which are the strategies? It can be s 1, which means he is saying that, if f occurs, I will play s 1. If s occurs, then I will play s 1 or it can be s 1 s 2. Here, he is saying that if f occurs, I am going to play s 1, but if s occurs, I am going to play s 2. So, likewise, we have other two strategies. So, there are four possible strategies.

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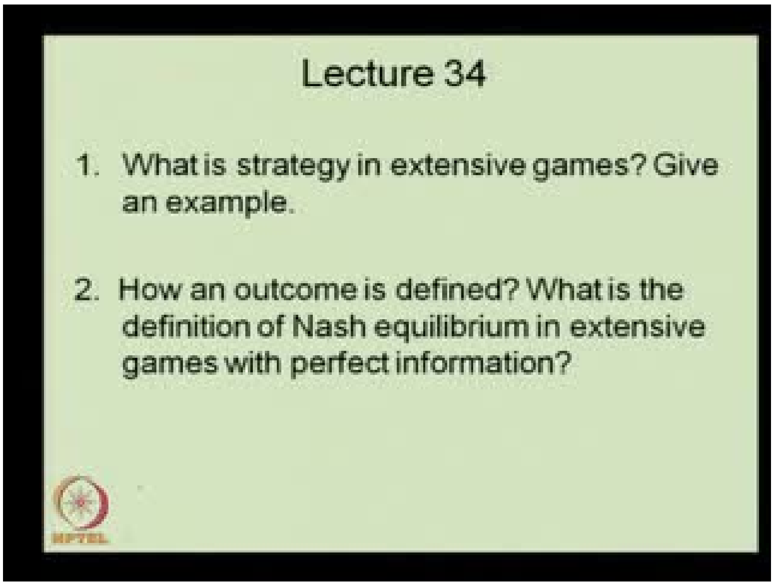

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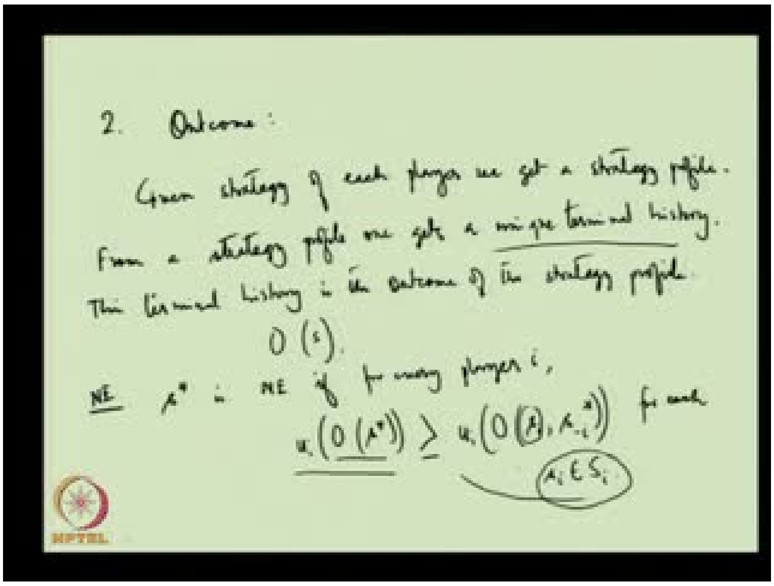

How an outcome is defined? What is the definition of nash equilibrium in extensive games with prefect information? So, first, what is an outcome? So, given strategy of each player, we get us strategy profile. Basically, which is a combination of all the strategies of all the players?

Now, from a strategy profile, one gets unique terminal history, because in a strategy profile, every player is specifying - I am going to play this; I am going to play that, and depending on that plan of action, we can trace out a unique terminal history. This terminal history is the outcome of the strategy profile. So, it is written as o s; s is the strategy profile; o stands for outcome.

Now, the second part of the question was what is the definition of nash equilibrium in extensive games with prefect information? Nash equilibrium, s star strategy profile is nash equilibrium if the following condition is satisfied if for every player i u i. So, here, s star is a specific strategic profile. From the strategy profile, we are getting o s star outcome, and from that player, i’s getting u i o s star. This payoff must be either greater than or equal to the payoff if player i deviates and chooses something s i from his set of strategies. This deviation is not beneficial for him. It can give him either equal payoff or less pay off. Thank you.