Artificial Intelligence for Economics

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Lecture - 37

Lecture 37 : Agent-based Modeling for Economics

Hello everyone, welcome to this course on artificial intelligence for economics. We are now in the last week of this course, today is the lecture number 37. So, right now we are dealing with some of the more specific or specialized topics of how AI based methods can be used for economics. So, today we will be focusing on a new kind of like computational tool or computational framework which has like potential for a lot of economic applications. So, today we are going to talk about agent based modeling. So, like here today the concepts we will be covering are agents and rules, after that we will talk about simulation and emergent phenomena.

We will talk about like the some concepts of physics based applications and finally, we will come to how the model parameters can be estimated in agent based models. So, first of all let us start with what agent these agent based models are. So, an agent based model we can say it is a highly distributed computational approach where the focus is on individual units of a complex system. So, like these agent based models is not it is not specific to economics, but it can be used in various other disciplines in like ecology, epidemiology.

many others, but basically the when we have a large number of individuals who like behave according to some patterns and they are sometimes can interact with each other also like then it is a suitable case for application of these agent based models. So, like for example, these individuals can be persons in a society or they can be birds in a flock or fish in a soul. So, these are typical examples of modeling in ecology or it can be something like say vehicles in a traffic system and so on. As you can understand these are all like very complex systems involving a very large number of individuals who behave and interact with each other in some ways. So, here we reach of the individual will be referred to as an agent, each individual can execute an action from a from a set of actions or from a given space of actions at every time step and these actions are usually quite straight forward not very complicated actions.

Say like it can be like moving from one location to an adjacent location like this is especially true for like applications like the movement of birds in a flock or vehicles in a traffic system and so on. And furthermore we consider that each individual has what is known as bounded rationality. That means, whenever they like as I said at every time step they can take an action. So, from a space of actions now the action which they take is likely to be locally optimal that is they may be taking the action according to some like or what whichever action seems most suitable to them at that point of time. It may not be good in the long term of them, but so that is why we say that it they are not fully rational agent, but they have bounded or limited rationality.

So, like so this agent based modeling this is also like so why do we use agent based modeling in the first place. So, like we use it in such situations where the overall dynamics of a system is very hard to represent using some kind of mathematical models or mathematical representation. Because it is a very complex system with lots of individuals which may behave in simple ways or may interact with each other in simple ways, but the overall dynamics of the system is I mean it is very difficult to express in mathematical terms. So, in such situations like we may think agent based models is a fit case to like it is a fit case to use agent based models. And agent based model it is like we can consider it as a bottom up distributed computing framework.

Why bottom up? Because we are focusing on the individual elements of the complex system. We are not focusing on the system as a whole. The dynamics of the whole system is of interest to us, but we are not directly studying that rather we are studying the dynamics of every individual element in the system which in this case are the agents. So, furthermore these agents they behave independently I mean not when I say independently it is not like identically I mean every agent can behave according to their context which may be dependent on other agents also. So, in that sense it is not independent, but what move one agent takes.

Like we can actually do like it is like simulate that movement of every agent at every time step in a distributed way. So, like just consider this kind of a social network. So, we have some persons in this social network. So, an age between two person let us say it means that they are friends or they know each other. So, the system of state is that is represented by this situation that is let us say an adjacency matrix or something like that.

So, we know that like for example, this lady is a friend of this couple and these two couples are friends of each other, this man is a friend of this couple and so on. Now, let us say this situation evolves as they continue to interact with each other. So, it is possible that the social network evolves that is new edges are created and maybe in some cases old edges might be deleted also. So, for example, from here to here you can see that a new edge some new edges got added as maybe new people came to know each other through common friends. Like for example, this lady these two ladies they did not know each other earlier, but this lady knew this couple and this couple knew this lady and these couple two couples they knew each other.

So, maybe through them like and like at maybe at some social event they got to interact with each other. Similarly, this man and this couple they became friends and so on and so forth. So, the structure of this social network like it keeps evolving. However, it like we are not specifying the overall dynamics of the of the social network that is it is not that we are defining some kind of a. equation dynamical equation on the adjacency matrix of the social network, but rather like for every agent we are seeing at every time step with whom they may be interacting and so on.

And as a result the adjacency matrix may be getting updated. So, this is what I mean by this bottom up distributed approach. So, every agent here they can have some attributes example their location I mean where exactly that person is located and where else they can move their age their savings and all that. Each agent is programmed to perform some simple actions and these and there are certain rules by which they choose which action to pick. So, these actions may be deterministic or probabilistic there it like it may be that if certain conditions are satisfied then the agent perform some particular action if some other conditions are satisfied then they perform some other action and so on or it can be thatthey have a probability distribution over the actions, but the weights of the probabilities theyfor of the different actions they may change depending on the context.

Now, what I exactly do I mean by context? The context may mean the agents own status I have already mentioned each agent has its attributes. So, like if as the attributes change the agents actions or the their I mean their tendency to perform different actions, their probability distribution over different actions may change according to their own status and also the status of other agents. So, like we know the like if we can imagine ourselves to be individuals in a society the actions which I will take that may depend on my own situation what I want to do given my current situation or it may also depend on my social surroundings that is the attributes of the other agents. May be not all other agents, but only say neighboring agents or those agents who somehow have an influence on that particular agent at that particular point of time. Now, these different agents may perform simple interactions such as exchange of information and these attributes of the interacting agents may change according to some rule or probability distributions.

That means, according to my current attributes or the attributes of the other agents I may choose what action I take at this point of time and because of that action again my attribute may change or the attributes of the other interacting agents may also change. Now, this is the model. So, what do we use this model for? So, we can use it mostly for simulation of the complex system and observation of emergent phenomena. So, let me explain this step by step. So, an agent based model is usually it is run over many iterations which are discrete time step.

Now, as I said at every point a step in time the agents perform some actions or interactions and as a result of that their status or their individual attributes can change. Now, we may specify some initial conditions of the system that is we like initialize the attributes of all the agents we specify the set of rules for all at the beginning of the simulations. And then keep like simulating the whole thing that is at every point of time we decide like we will we visit every agent and see what action they are going to perform. like either sequentially or parallely. So, this is known as the simulation.

So, at simulation that the like at every step of the simulation the entire system gets updated as a combination of these individual updates to each of the individual agents. Now, why do I do this simulation? My aim is to see how the system evolves and looks after a particular period of time. I have already specified how it looks at initially, but I want to see how it looks after some steps like for example, consider this social network. So, like initially this was the adjacency matrix I may like I may let these agents interact among themselves for a like let us say fixed point of time and I am interested to see if finally, all of them come to know each other that is if it becomes a complete graph or not. So, like I at every time step they may or may not interact according to some rules and as a result some edge may or may not be put according I mean between every pair of these agents.

I want to see if this goes on like for a particular period of time then will all the all every pair of agents become connected with an edge or maybe two specific agents will get connected by an edge or something like that. So, like that is this is what I want to observe and that is why I learnt the simulation. Now, what is an emergent phenomena? An emergent phenomena is some characteristics of the system which are observed if we run the simulation, but they are not specific or they are not obvious from the model specification. That is I may not have like programmed the model or that is when I like set the attributes of the different agents or specify their rules of actions or interactions. I may not have anticipated that the whole system will show some kind of dynamics, but it happens that way.

So, like let us now see a few examples of these agent based models. So, the simple agent based model is the predator prey model. So, let us consider a toy ecosystem which has some amount of grass available on which sheep graze and there are also wolves which attack the sheeps. That is the sheeps are the predators for the grass and the wolves are the predators for the sheep. So, now the population of the sheep and the wolves that will depend on how much food they have that is if there is like too much I mean if there is too little grass that is if there are too many sheep compared to the grass available then some of the sheep will starve and hence they will die off or they will just migrate to somewhere else.

So, on the other hand if there are too few sheep left then the wolves even if they are present they will not have enough adequate food. So, again their population will also decrease. But on the other hand if see the population of when there is a dearth of both kinds of predators then the grass will grow and as a result we can expect that more sheep will come in from other places and they will start eating the grass. And as a result the wolves from other places may also be attracted. So, like this system is characterized by certain equations that is how the number of sheeps evolve or how the number of wolves evolve.

So, there is some system of equations called the Lotka Volterra equations. So, those are equation based models which basically it shows which it allows us to track the number of the population of sheep, wolves as well as the amount of grass present. So, you can see the curves here. But if we so if we simulate this kind of a system according to the by drawing analogy from the Lotka Volterra equations. So, here what you are seeing is there are cells each cell is either green that is it can be green depending on how much grass is present in each of the cells.

And here you can see some circles which indicate the sheep and there are also some triangles which indicates the wolves. So, the sheep are located in some places. So, the every sheep will try to move to a place the nearest green square where it so that it can eat the grass there. And similarly every wolf they will try to move to the square which already contains a sheep so that it can eat that sheep. Now, if a sheep eats up the grass present in a square that that that square will become red that means, that no more grass is left.

So, that sheep will have to move to somewhere else similarly as the sheep moves the wolves will also move. And now if there is a sheep which is which is surrounded by red squares and it does is not able to move to I mean it is not able to find grass to eat then it may just die off. So, it goes off the system. And similar fate also befalls the wolves who which do not find any sheep in the neighborhood. So, here like according to the what the dynamics which I specified.

So, note that every sheep and every wolf is actually executing a very simple equation or simple rule. It is just trying to search its immediate neighborhood and wherever there is food for it, it is going there. If it is not finding food, then it will die and so on and so forth. So, like according to this we are seeing the like how the population of sheep or the population of wolves and the amount of grass how it changes. And as you can see or as you can expect from what the story that I told you there are continuous peaks and troughs and like peaks like when there is a peak of the amount of grass that is that is that typically happens when there are very few sheep left.

And, but when the grass peaks then immediately the sheep also start coming up. The same thing happen the same dynamics is observed between the populations of sheep and the population of wolves. Another interesting case is the like epidemiological models. So, during the COVID pandemic it became very like in this agent based epidemiological models became very useful for many policy planners. So, in a case of epidemiological models we consider that every agent has a health state which is susceptible infected or recovered.

So, initially a few agents are infected now as they interact with the other agents they may infect some other people with some probabilities. So, we can expect that the number of infected people that will gradually increase. So, like as you can see here this green curve this indicates the number of infected people. So, initially very few people were infected, but then as the interactions go on the number of people interacting increases the number of infections also increase. But it reaches typically a peak where a large number of people are infected, but then from there the people infected people start recovering.

So, the number of infected people keeps falling because once someone recovers then they cannot be infected any further. So, like the important thing here is the peak that is typically at the maximum how many people are going to be infected at a given point of time after like and when that peak will be reached and what will be the value of that peak. Once that peak is reached then the number of infections can come down. Now, of course, in case of a real pandemic like COVID this was certainly not the case because we had multiple peaks and not I mean someone could easily be reinfected also and so on and so forth. So, this is a simple epidemiological model after which of course, a lot of sophistication can be done.

So, like here the emergent phenomena is that the epidemic may peak as I am showing here or it may just quickly die off. Maybe the epidemic will never peak only as like the certain number of people who are initially infected. If they do not interact with others, then maybe the infection will not spread at all and after some time they will all recover. So, the epidemic will never really take place.

So, that is an emergent phenomena. So, like during COVID as I said lots of such detailed agent based models were developed mostly to model the interactions between different groups of people and to see how the COVID the I mean the infection can take place as a result of these interactions. So, like the I am showing an example paper Covasim this is a very famous agent based model for COVID dynamics. So, like as you can see the agents here are the residents of a city. So, their interactions and their their their attributes their interactions and interactions were described in a very granular level. So, here like So, bias attributes we are showing which like every agent which household they belong to where they go for their work or where they go for school or where they go for other community activities and so on.

So, like based on that we know that which agents can come close to each other and as a result which agent can infect the other one and so on. So, like basically we have some kind of a interaction graph between the different agents that is what is indicated here and like as the interactions proceed then the number of infections that can also keep growing as a result. Now, these agent based models of also can be used in economics. So, some of the economic questions it might be or the agents in an economics like we can consider every person in a society or every firm in a market they can be considered as agents and the attributes here is their role. I mean whether they are a buyer or a seller or what is their bank balance in case of persons or stock value in case of companies, what other assets they have which they can trade and then what are their targets what what is it that they want to achieve and various other demographic and behavioral features they can also be attributes now what kind of interactions now obviously in an economic system the main kind of interactions which we are interested in is the transfer of money or assets between two agents Now, the nature of the interactions between any two agents will of course, depend on their attributes.

So, if one if someone is a buyer and the other is a seller, then typically the assets the seller can pass on some of their assets to the buyer and the buyer can pass on a part of their bank balance to the seller. So, that is a simple like simple kind of an interaction. or it may be related to like two two companies or two firms in a market they have some dealings with each other in which they share some of their revenues one one company shares part of their revenue with each other in exchange of some other favor. So, like these are the types of interactions which we can consider. So, what are the emergent phenomena the way the prime in most economic applications we are interested in understanding the wealth distribution in the society or the market.

So, initially there is I mean wealth is understood in terms of both money and assets. So, like initially there is some I mean there are some rich agents and some poor agents and we want to see how this wealth distribution changes like if the if they are led to allowed to interact according to a given set of rules. And like there is in fact a branch of economics which is known as a econophysics in which the in this kind of interactions between the agents it is modeled according to the laws of statistical physics. where like we have particles interacting with each other and when two particles collide they I mean some there can be a transfer of momentum from one particle to another. So, like so these are all represented by mathematical equations in statistical physics.

So, in econophysics some of these kinds of equations are used to model the interactions between the different agents. Now, what is the entire purpose of this kind of agent based modeling? I mean as I one purpose of course, is to understand the emergent phenomena that is we run we allow the system to run and we observe its dynamics and we see if anything interesting is coming up, but then what? So, one important thing is intervention analysis that is suppose like one is to observe how the system is going to behave, but the other is how I can make it behave the way I want to. So, for that we use what is known as intervention analysis. So, there is a truism in the modeling of physical system that is all models are wrong, but some models are useful. So, why do I what do I what does it mean all models are wrong means a model is basically some kind of an abstraction it is a simplified representation of the world around us.

So, a simplified representation is by definition wrong and it all depends on how much simplification you are making if it is too simple more simplified it is the more wrong it is. they can some models can be useful if like even if they are wrong or even if they do not actually represent the world exactly the way it is like you can still make it behave like the world especially when you make some interactions or some kind of interventions on the model. It is then that a model becomes useful, then you will I mean by making an intervention on the model like the its behavior is somehow is reflected in the behavior of the world. So, role of the agent based modeling is to see the possible impacts here of the different kinds of interventions which we can make on the system. So, what is an intervention? An intervention on an agent based modeling is typically done by like altering some of the actions or interactions which are available to the individual agents.

So, like it might be that we may restrict the set of actions available or the type of interactions available between for any agent or any pair of agents. or we may alter the rules of some of the actions. So, this is typically the kind of interventions which we do like in case of epidemiological modeling like one interventions which we can consider is like if we restrict the interactions among the agents. So, the like we know that a two people I mean an infected agent can infect another agent if they interact. So, what if they are prevented from interacting like consider the paradigms of physical distancing or lockdown as we saw during the COVID pandemic.

So, like I want to understand that if I impose a lock down that is if I somehow prevent the agents from interacting then will it reduce the I mean the infections or not. Similarly, in an economic system we can understand like we can we want may want to see if the wealth distribution can change if the transactions are somehow regulated that is if more than a particular amount of money or like a given quantity of asset they cannot be exchanged. They I mean whatever interactions take place or whatever transactions take place they can be only limited. If such limits are imposed then will we see that the wealth distribution still like changes as much as it did in the in unrestricted case or will we see that the in such situations the wealth distribution more or less remains at the initial stage itself. Or like for example, if the poorer agents if they are provided some benefits that is if they are losing or out on money or assets then we then some external agency tops up their bank balance.

So, in such a situation will their wealth distribution change and so on. So, like there are some pretty interesting work. So, this is a paper which came out in a conference which I attended recently. So, can poverty be reduced by acting on discrimination and agent based model for policy planning. So, this is basically the same as what I was just telling that is study of the wealth distribution.

So, the plots which you are seeing here they are plots like they are showing the guinea index indices of the wealth. of the agents in different cases. So, Gini index is a measure of inequality the low value of Gini index it means that like there is less income inequality that is there I mean the poorer less poor compared to the rich and high value of Gini index means that I mean the I mean there is a lot of disparity between the rich and the poorer agents. So, here like this like these 6 plots which you are seeing are a result of different 6 different kinds of interventions. So, they have listed the kinds of interventions here like for example, some in some interventions can be like aimed at helping the poorer agents like you see like providing them with some minimum vital income and so on and some other like some other interactions or some other interventions they may be aimed at punishing the poor by making them let us say pay a fine when you sleep on the street or something like that.

So, like they are showing that for certain sets of policies we can reduce the guinea index and achieve greater equality in the society and for some other different set of policies we can have more inequality in the society. So, this is a typical use case. Now, we can build any kind of model, but then the question arises how we can validate the model. Now, this is a typically a very difficult task on agent based model. It is very difficult to verify if an agent based model is accurate at the level of the individual agents, but validation may be possible by comparing some aggregate statistics of the system with the actual observations.

And like here we have to like typically we would like to consider multiple aggregate measures. I mean aggregate measures is like I mean you have the attributes of the different agents. So, from that you calculate some aggregate score I mean like for example, in case of the SIR model. So, every individual agent will have its own health condition whether it is susceptible, infected or recovered, but the aggregate statistics might be the total number of susceptible people, total number of infected people and so on and so forth. So, that is something which can be like measured from the agent based model and as well as from the real world system which we are trying to represent through the agent based model.

So, in case of covid modeling like people try to validate their agent based models using these kind of plots. So, like they have some measure of daily infections through the testing which they do. So, they may have plot for that and their model is also predicting how many people are going to be infected every day. So, they simply plot these two they I mean they compare these two plots and if the plots are more or less coinciding with each other as you are seeing here then we say that the model has been validated. So, like for intervention analysis also we can do something in the similar.

So, like here you can see that three different kinds of interventions has been considered that is the lock down starts from the first day, but it it ends on day 21 or it continues till day 27 or it continues to day 41 and so on and so forth. So, in each of the cases like they like they have the they plot the number of interactions infections as simulated by their models and then they try to match the these plots with the actual number of interventions and then they understand like which is a better best idea and so on. So, like so now when we are having a model we obviously, have a number of parameters. So, how to estimate the parameters? So, like we have discussed a lot about parameter estimation in our earlier lecture. So, which set of the question here is which set of parameters do the ABM simulations resemble the observations most closely.

I mean if I choose the parameters in a certain way the gross statistics may or may not I mean resemble the actual gross statistics of the observations. So, I may want to change my parameters. The question is if I change the parameters in a particular way will I still manage to align my I mean the models gross statistics with the observed gross statistics. and if that is so if such parameter values do indeed exist then how I can find them. If no such parameter values exist then we will have to conclude that our model is wrong that is under no circumstance will the model be able to reflect the situation in the like what is observed in the world.

but if there is a set of parameter values then finding that set is also difficult because typically we cannot use optimization techniques. We have discussed many optimization techniques earlier in this course, but those may not be applicable unless the agent based model can be expressed as some kind of a differentiable function of the parameters which is usually not the case. So, in that case we may usually need to carry out grid search over the space of parameters and for each candidate parameter value we run the simulations, we calculate the mean aggregate measures on the simulation results and compare them with the actual observations. If the comparison is favorable then we accept that candidate parameter value and if not then again we continue searching the space. and like the other parameter values they can I mean the which do not reflect what was the observation they it is not that they are useless those parameter values can also be useful because they give us a what if scenario that is the these parameters they somehow specify the ways people act or interact.

So, now it is now suppose I find out what are the suitable parameter values in which the system in which my simulation resembles what is observed in the world. So, then we can say that those are those parameter values they somehow reflect the actual behaviours of the people. but the other possible parameter values they are like hypothetical scenarios that if instead of behaving in such and such ways what if people behaved in in such in some other ways in that case how would the system dynamics be. So, like that is the kind of what if analysis which we can do by varying the parameter values. So, to conclude agent based models can represent complex systems involving many autonomous individuals, agent behavior and interactions are represented by simple rules of probability distributions, simulation leads to observation of emergent phenomena at the system scale, the parameters can be estimated by limited comparisons in terms of aggregate statistics with the observations.

and the impacts of interventions can be estimated by changing these kinds of action or interactions rules or by which may be done by changing the parameters. So, with this we come to the end of this lecture we will continue some discussions on some more specific more specialized topics in the next remaining lectures of this course. So, we will see you again stay well and take care bye.