**Artificial Intelligence: Search Methods for Problem Solving**
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**Chapter – 04**
**A First Course in Artificial Intelligence**
**Lecture – 33**
**Population Based Methods: Ant Colony Optimization**

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We in looking at randomized algorithms, then we looked at Population Based Methods, we have looked at stochastic behavior. All this kind of again comes together into our next algorithm which is also an algorithm for optimization, but it takes inspiration from the way that ants operate in this world essentially. And the lesson that we would like to learn from ants is that cooperation is now good strategy.

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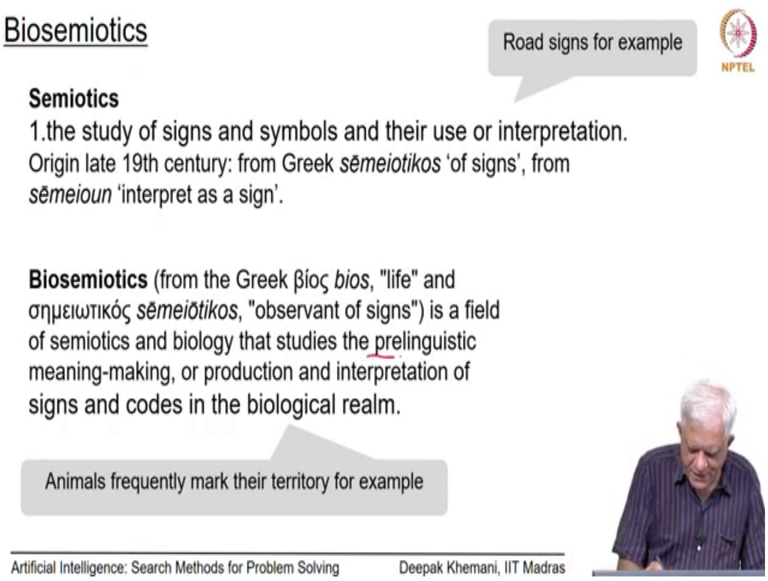


So, let us see what we are talking about here. Let us first talk about communication because cooperation requires communication and there is this whole field of bio semiotics which looks at biology and communication. And we start off with two definition. There is this field of semiotics which is the study of signs and symbols. This is the dictionary definition and their use or interpretation.

So, for example, you would have seen road sign which says that u-turn is allowed or school ahead or various kind of symbols which we use to communicate essentially. You know in IIT, Madras for example you can see symbols which say animals crossing and so on. So, there is a whole field of semiotics which studies how symbols can be used for communication.

And if you think a little bit about this you will see that the language that we have evolved, the characters for example, in English from a to z, which form words and then sentences and so on, these are just complex semiotic systems where you know the symbol stand for something and we learn to communicate via those symbols.

The field that we are currently interested in is called bio-semiotics. This is at the intersection of biology and semiotics. And it studies what? Some people say it is a pre-linguistic meaning making which means that we are not looking at it at as that as linguistic symbols or pre-linguistic symbol. We are trying to see how real world chemicals can be used for communication and interpretation of science and codes and so on.

So, you would have seen for example, animals frequently mark their territory, you might have seen a dog raising an raising a leg somewhere and marking authority or saying now this is my territory and other animals especially predators they do quite a bit of this essentially. So, that is a notion of bio semiotics.

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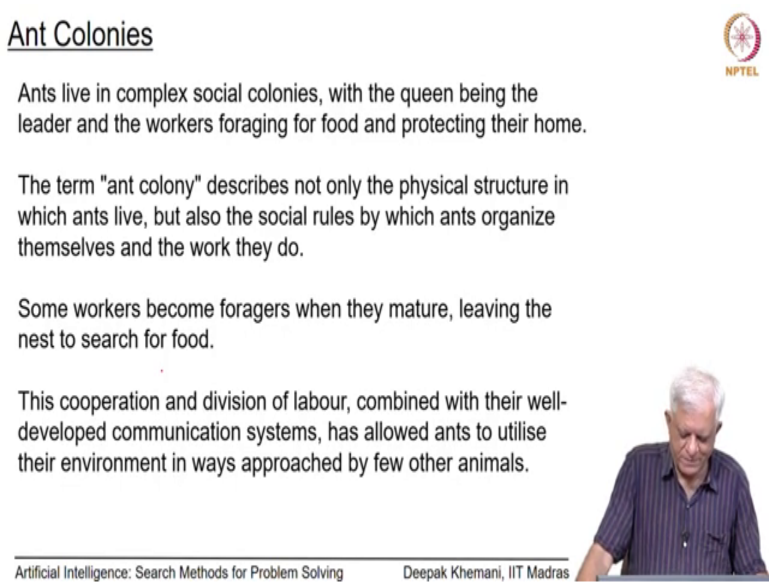

Now, let us talk about ant colonies. Ant colonies are complex social structures. Ants live in complex social colonies and they have a hierarchy you know virtually a caste system amongst them, the queen being the leader and then there are drones and workers, and all kinds of other this thing. They basically do all the work. And they go looking for food and they protect their home from predators all kinds of things.

The term ant colony describes not only the physical structure in which the ants live. So It is not just like a like a housing colony that we often refer to amongst humans, but also the social rules by which the ants organize themselves and the work that they do.

So, we have just been talking about emergent systems in the last class. And here we are looking at a real world example of a complex system which emerges out of these simple creatures where each ant is a very fairly simple creature. Now, some workers become foragers and when they mature especially and then they are allowed to or then they have to go out of the nest in search for food essentially.

This cooperation and division of labour combined with their well developed communication systems has allowed ants to utilise their environment in ways approached by few other animals. Of course, human beings are also a shining example of such cooperation because in fact, we lived in much more sophisticated social structures and we also have different human beings which have not evolved, but they learn different rates.

For example, you have carpenters making doors for us and you have farmers growing food for us, and so much so that this entire cooperation has resulted in so much produce that we can feed or at least hopefully we can feed the entire human species and it still lives time for other activities which we can sometimes called as creative activities like arts and music and so on.

So, we have you know people who spend their entire lives creating music for us or there are people who you know spend their entire lives hitting a piece of leather or a ball with a page of piece of wood and a bat and we have the entire nation watching them do so. All this is possible because of the fact that we lived in evolved societies where because of cooperation many different people can specialize into different things to the benefit of all essentially. Ants do it in a simpler way.

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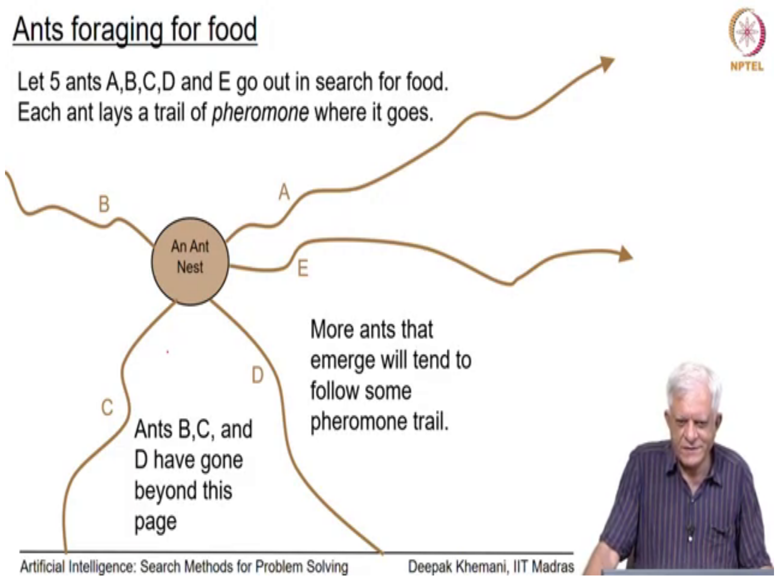


So, let us consider this possibility of a what happens how do an ant colony look for food essentially. Now, I am sure especially living in a tropical country like India you would have at some time or the other found that you have left a piece of food somewhere and after some time you see there is a whole trail of ants coming and happily taking part of your whatever you have left carelessly around.

How does that happen? How does how do ants invariably find the food that you leave around which is accessible to them essentially? The process is basically starts with search, the kind of search that we are talking about. So, you can imagine that each ant is going out looking for food. And remember we said that we have workers ants which have the task of going and collecting food for the ant colony.

So, each ant goes and looks for food, but that would not have been amounting to much except for the fact that when they do find food, they bring it back to the nest and they also communicate implicitly through biosemiotics to other ants as to where to go and look for food. And this little bit of cooperation results in a massive success for the ant colony.

See this kind of signaling is common in other creatures also. For example, bees are known to signal to other bees about where the nectar is and through their dance in the air and that kind of thing. And all these creatures they are not thinking creatures like we consider ourselves to be, they have evolved to communicate through chemicals or bio-semiotics and in the process they have built successful societies.

So, let us see what happens when ants are foraging for food. And so, let us say that we have this ant nest and a bunch of ants have been sent out to go and look for food. And let us assume that for simplicity that there are five ants which we will call as A, B, C, D and E, and each of these ants they go out in search of food.

So, each of them you know kind of randomly goes off in some direction based on whatever little cues they have and we have named these ants as A, B, C, D and E, and as you can see they are kind of randomly going off in some direction essentially.

And the important thing is that as they go they leave a trail which is called the pheromone trail. The pheromone is a chemical substance which the ant drops wherever it walks essentially. So, it goes somewhere and it leaves the trail that this is where I am going or this is where I have been and so on. And this trail itself is an very interesting consequence, that if another ant were to encounter pheromone laid by the first ant then it would have a tendency to follow the pheromone.

So, this very simple means of saying that this is where I have been through a chemical that it leaves results in ants kind of communicating with each other implicitly essentially. In our diagram, some of the ants have gone off the page, so we cannot draw them and more ants will emerge eventually and follow some of the trails that we have seen here.

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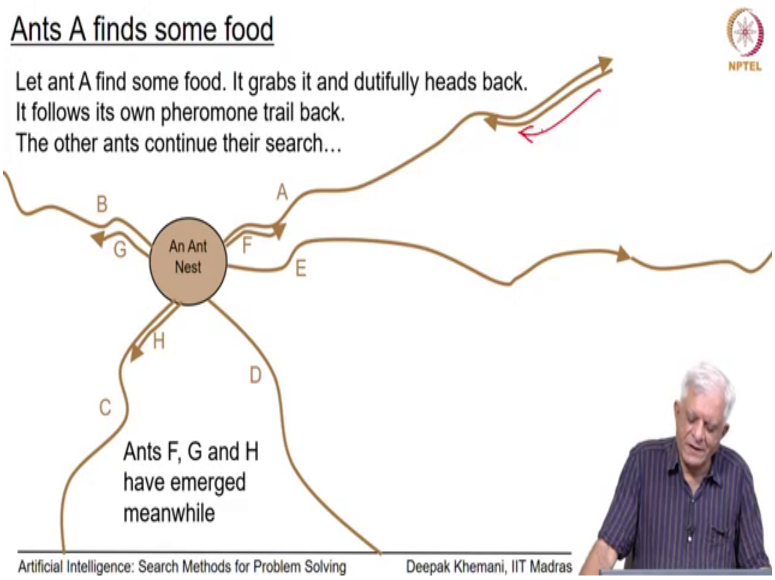


So, let us assume that let us say that ants, ant A finds some food and when it finds the food it immediately starts back essentially, going back to the nest with the food these are very cooperative creatures and you know it is not that it would just sit and start eating the food, it will just takes it and goes back to the nest essentially.

So, that we have depicted here by showing that it has started going backwards. How does it go back? It simply follows the trail that it had laid itself and that tells you, that tells it as to where it came from. So, just follows the trail back and goes towards the nest.

Meanwhile, other ants would have emerged. In this case we have shown them as F, G and H and they kind of randomly choose one of the trails that they see going out and ant A has found some food, it is heading back and the other ants continue their search in whichever direction they were going essentially, ok.

Now, you see we said that ants have this habit of leaving pheromone wherever they are traveling. So, you can see what is happening with what ant A is doing. Ant A is going back on the trail that it came from, but in the process it is also depositing pheromone again on the same trail. So, the trail becomes stronger, the amount of pheromone on that particular trail becomes stronger.

And this kind of process repeats, and then it goes into a positive feedback kind of a cycle that the stronger the trail the more the ants are likely to follow it. And this results in after some time you find that all the ants are going in along one particular trail essentially, that was formed originally by ant A essentially.

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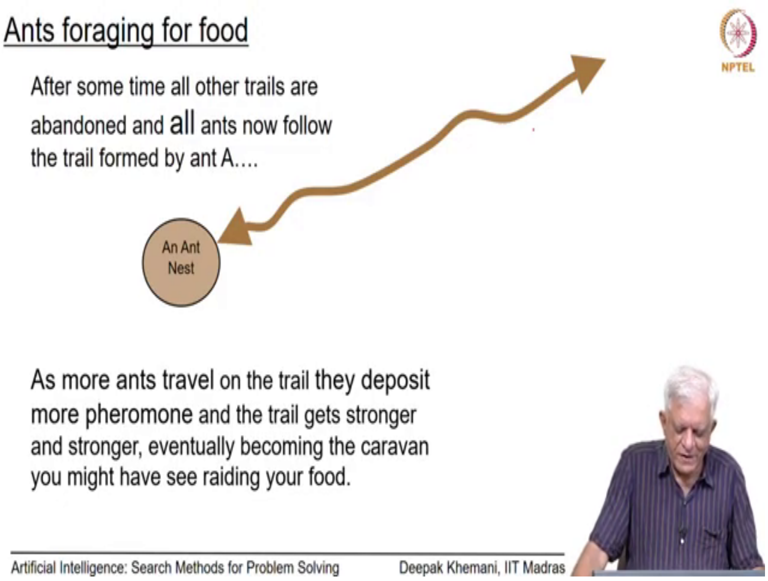


And why is this happening? As we just said, as more ants travel on this trail more pheromone gets deposited on the trail, the trail becomes stronger and therefore, more ants travel on the trail and so on and so forth, until a stage reaches where you just see one caravan of ants going back and forth along the trail happily making away with your food, ok.

So, not only do ants cooperate in this fashion and solve this problem of finding food, they also find the shortest paths in the process.

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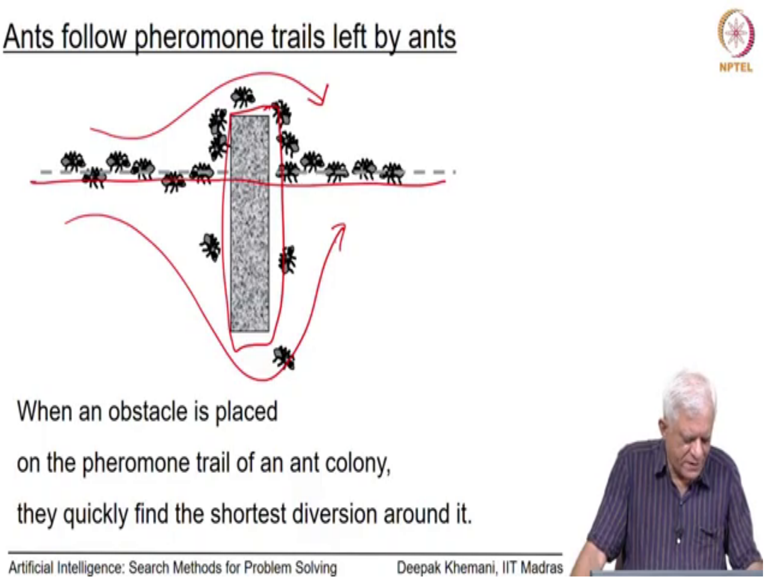


So, we can illustrate this by saying that supposing these ants were going along this trail that we have here, going and fetching food and if you were to put this obstacle suddenly on the way and they cannot obviously, go on the trail because obstacle stops him from doing that, so some ants go this way and other ants go that way. So, you can see that there are two paths around this obstacle, the top path is the slightly shorter path and the bottom path is the slightly longer path.

Now, ants will try both the paths. But because the ants which are traveling on the shorter paths they will find the food first, and they will return back on the shorter path again the trail will get stronger and stronger and eventually you will find that all the ants have started following the shorter trail essentially. So, in that sense they do what we are interested in very often which is to find shortest paths in some kind of a problem structure which is typically a graph.

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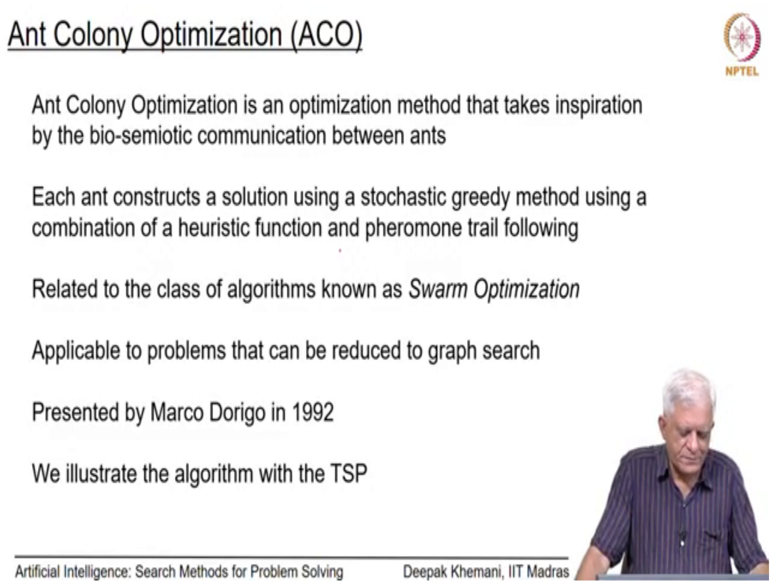


So, the ant colony optimization algorithm is basically motivated from this behavior of ants and it is an optimization method that takes inspiration from the bio-semiotic communication between ants and each ant as we will see constructs a solution using a stochastic greedy method.

So, it is stochastic because there is an element of probability as we will see and it is greedy because it only looks at its surroundings and makes a decision based on that. So, just as we have greedy algorithms like hill climbing or other algorithms, this is also a greedy algorithm, but it is a stochastic element to it essentially which is a little bit like what we did in simulated annealing.

So, it uses a combination of heuristic function which is you know estimate of distance and the pheromone trail that its sees here, and in some manner it constructs the solution essentially. This is known, as and there is a wider class of algorithms which has emerged since ant colonial optimization was introduced, and these are often called as swarm optimization because you know there is a whole population of agents working together and this swarm is the term that we use for example, with bees and so on.

These kind of problems are applicable to these kind of methods are applicable to problems which can be reduced to graph search. They were first presented the ant colony optimization was presented by Marco Dorigo in 1992 and became very popular subsequently. And as he did we will also illustrate this algorithm with the traveling salesman problem essentially. So, just imagine that you have to solve the traveling salesman problem. You have a set of N cities and you want to find the shortest tour. Each edge has the associated cost.

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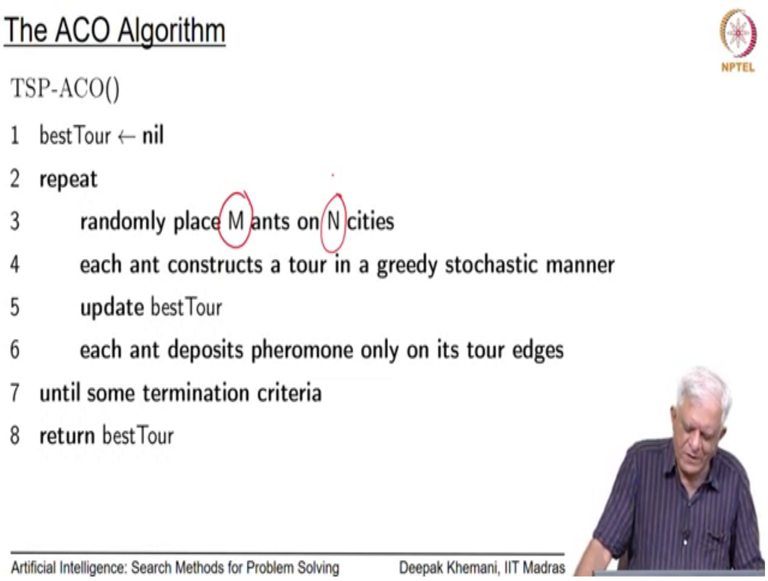


So, how does it work? This is the high level algorithm and we are looking for the best tour which we initialize to nil, and we somehow choose a population of M ants and we place them randomly somewhere on the N cities essentially, And then each ant constructs a tour, in this greedy stochastic fashion that we will again describe in a little bit more detail shortly.

But essentially what happens is that each ant constructs the tour independently of the other ants. It is not like a distributed system which is kind of communicating directly, but it is like a system which is communicating through bio semiotics through pheromone trails that whatever ants did, other ants did in the past result to ant which is doing something at the moment. So, wherever it sees pheromone it has a tendency to go towards that and we will you know make this more specific shortly.

Then of course, in all such algorithms you have to keep track of the best tour. So, we update the best tour. And after the tour has been constructed by each ant then each ant deposits pheromone. So, it is unlike in the real world, in the real world the ant goes around depositing pheromone where it goes, but in our algorithm it deposits pheromone only after it has completed the tour. And as we will see shortly the reason for that is that the amount of pheromone that the tour the ant will deposit will depend upon the cost of the tour it has found. So, we would like ants which find shorter tours to deposit more pheromone and ants which find longer tours to deposit less pheromone. So, it is for this reason that ant deposits tour only after it has completed a tour.

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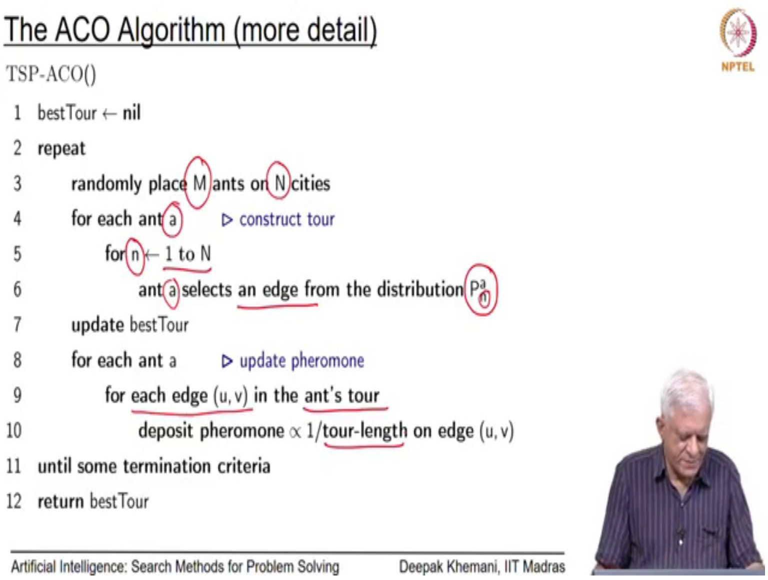

Here is this slightly more detailed version of this algorithm and this is all thanks to Baskaran who has been helping me with this course. So, I asked before we place this M ants on this N cities and then for each ant A it visits N cities one by one.

So, N is the parameter that we are using here and it goes from 1 to N. And at each stage this ant A selects an edge from a distribution that it is available to it. So, at each stage N, it will have some cities that it is allowed to go to and from these cities it will pick one city in a probabilistic fashion which we will again describe in a moment.

Then, of course we update the best tour. And after it has after this process has gone through then each ant deposits pheromone on each edge u, v that is in the ants tour essentially. And how much pheromone does? It deposit it deposits pheromone which is inversely proportional to the tour length essentially and it deposit the same pheromone on every edge that it has traversed.

The amount of pheromone does not depend upon the length of that edge, it depends upon the cost of the tour that the ant has found, the complete tour that the ant has found. And we do this until some termination criteria till we have reach stability of some sort or we have pre-decided that we will run the algorithm for so many cycles as the case may be.

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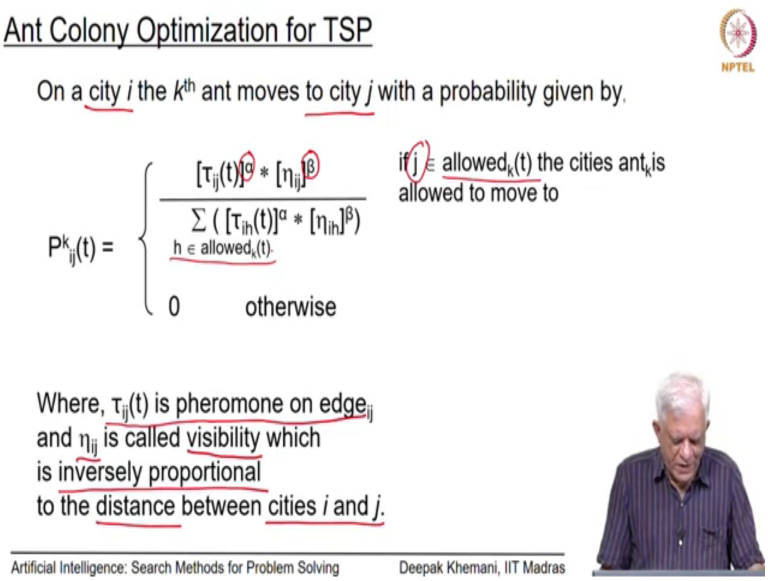


So, how does each ant construct a tour? So, let us say that we are talking of the kth ant and it is moving from city i to city j essentially. And it will move from city i to city j with the probability which is given by this expression, the probability of ant k going from city i to city j at time t is given by this expression which is tau ij at time t and eta ij which is independent of time essentially.

So, tau ij is a amount of pheromone on that edge ij and as you will see it depends on time because you know ants deposit more pheromone eventually and pheromone also has this property of evaporating. So, it is a thing which changes dynamically essentially and so, pheromone is the function of time t.

Eta is called visibility and it basically inversely proportional to the distance between cities i and j essentially. So, the closer the city, the higher the value of eta and that will influence the probability of going to that city j. Also the more the pheromone on this edge ij, the more the probability that this ant will go on that edge.

So, it is a combination of how much pheromone that we have and how much how close the city is. There are two parameters alpha and beta that we can use to control the effect of the two components here, how much importance we want to give to pheromone and how much importance we want to give to the distance.

This city j must be belonging to the set where ant k is allowed to go at time t and this is simply saying that you cannot move to cities where which are not part of a valid tour. So, you cannot create a sub tour for example, you cannot go from city a to b and back to a or you cannot go from city a to b to c and then back to a and things like that.

So, only from the cities that are allowed you can choose this and the ant chooses this using this two components which influences probability. So, it is proportional to the amount of pheromone and it is inversely proportional to the distance essentially.

Now, since this is a probability value we must normalize it, and normalization is done over all allowed cities and we simply sum up this expression for all cities and divide and use that in the denominator, so that we get probabilities which all sum up to 1.

So, these are the probabilities for all the cities where the ant is allowed to go and if j is something which is not an allowed city then it will not go there, so probability is 0. So, it will only go to one of the cities that it is allowed to go. And it will go it will choose a city stochastically with a probability which is proportional to two things, one is the amount of pheromone on that edge and the second is how short that edge is essentially, ok.

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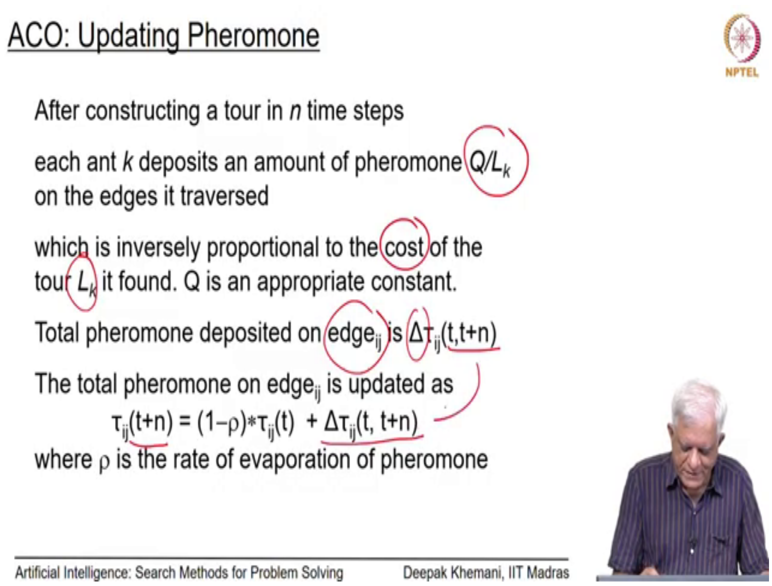


So, having constructed the tour the last thing that remains for us to see is how does it update the pheromone essentially. So, every ant will construct a tour in n time steps because it has to visit n cities. And each ant k will deposit an amount of pheromone which is given by Q divided L k on the edges that it has traversed. And this amount Q by L k is as you can see inversely proportional to the cost of the tour which is L k, and Q is some appropriate constant that we use for adjusting the value of the this expression.

Remember that, L k is the length of the tour. So, 1 by L k will be very small, so we just choose an Q as an appropriate constant. The total pheromone deposited on edge ij will be the sum we will denote as the delta tau ijs, how much new pheromone has been deposited from the time t when they started ant started constructing the tour to the time t n t plus n when they finished constructing the tour. And this is the sum of all the pheromone deposited by all the ants on this particular edge ij.

The total pheromone on edge ij is now updated as that at time t plus n we have this new pheromone which has been deposited that we just mentioned here and we had the old pheromone which was tau ij at time t. But some of this has evaporated away and we have this parameter which we can use to control the rate of evaporation row and that determines how much of the old pheromone stays essentially, ok.

So, this is a brief description of the ant colony optimization which is a optimization method which is population based where it is the population of agents which is each acting independently in a greedy stochastic manner. But communicating through signals which is pheromone in this case and in the process is the fairly good optimization method.

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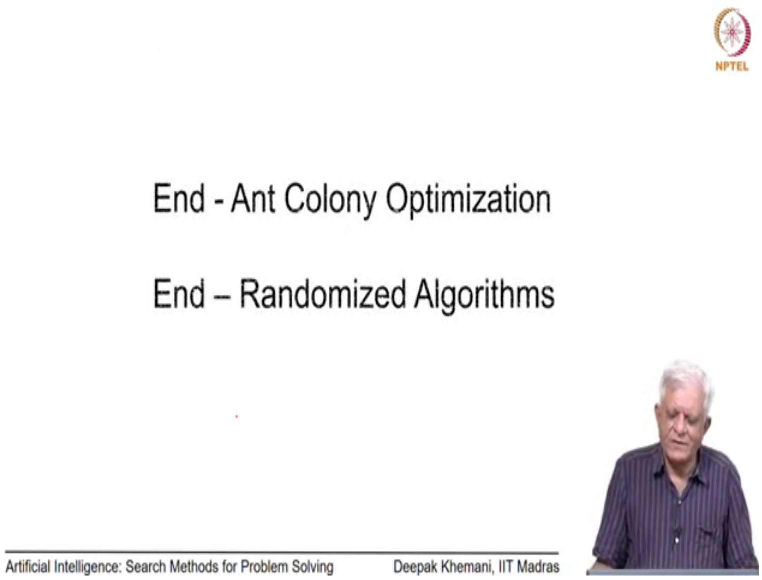

So, with this we will come to an end of our randomized algorithms and in particular to the ant colony optimization method. We will move back to deterministic methods from here and we will look at some very well known algorithms for optimization or finding shortest paths and there is an algorithm called a star and then we will look at other kinds of problems that we would want to (Refer Time: 25:33). So, see you the next time.