Computer Aided Applied Single Objective Optimization
Dr. Prakash Kotecha
Department of Chemical Engineering
Indian Institute of Technology, Guwahati

Lecture - 18
Artificial Bee Colony Algorithm

Welcome to the session, we will now take the same example that we have been taking for all the other metaheuristic techniques, the spear function. The so he will take the spear function with four decision variables ok.

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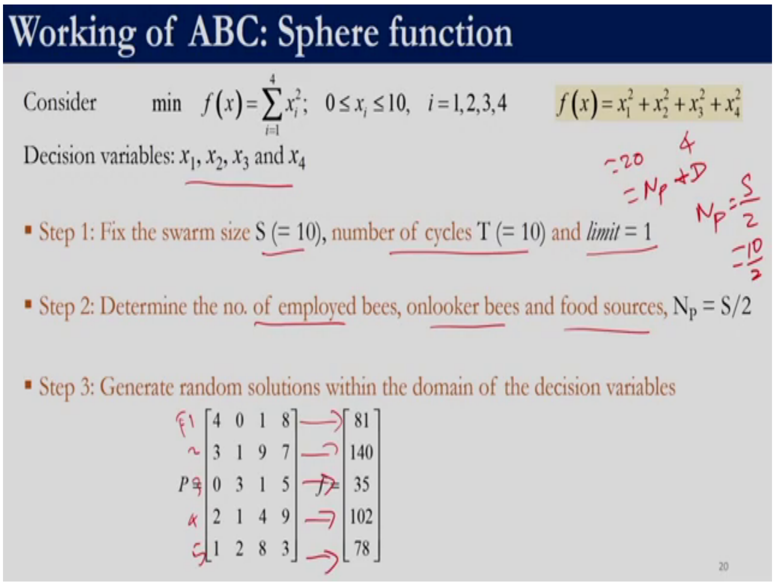

So, the spear function if you remember, it is the summation of square of all the decision variables. So, the first step is to fix this swarm size the number of cycles and the parameter limit right. So, the number of swarm size will tell us the number of food sources, number of employed bees and the number of onlooker bees right. The number of cycles will tell us when to complete our procedure, and the parameter limit helps in determining as to when the scout phase is to be implemented.

So, the limit parameter we should have ideally taken it as to be N P into D right. So, N P in this case will be S by 2 which is 10 by 2, so N P should have been taken as 5 and the number of decision variable is 4 right; so we are working with this four variable a problem. So, it should have been taken to be 20, but if we had taken the limit to be 20, we would have had to perform a large number of iterations in order to encounter the scout phase, but since motivation here is to show all the phases we have taken a very small value of a limit right limit equal to 1.

So, the next step is to determine the number of employed bees, onlooker bees and food sources. So, as we just discussed it is S by 2 right, so 10 by 2 the number of food sources is 5. The next step is to generate a random population right, so these are our food sources. So, we have five food sources a food source 1, 2, 3, 4, 5 and these are their corresponding objective function values right. So, these values are obtained by plugging these solutions into the objective function x 1 squared plus x 2 squared plus x 3 squared plus x 4 square.

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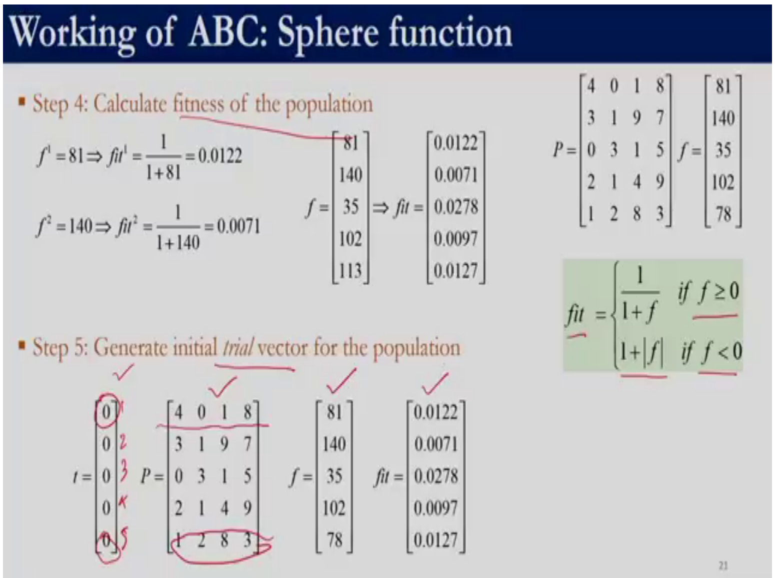

The next step is to calculate the fitness of the population. Remember that in the other metaheuristic take techniques which we had discussed, the objective function was the fitness function value. Whereas, here the fitness function is to be determined using this particular formula that fitness is equal to 1 by 1 plus f; if the objective function is greater than or equal to 0 or it is 1 plus absolute of f; if the objective function is less than 0. So, now we need to calculate the fitness of all the solutions right. So, if we calculate the fitness of all the solutions, this is what we would be getting right. So, now we have the initial food source or the initial population, we know their objective function values and we also know their fitness function values.

So, the next step is to generate the initial trial vector right. So, initial trial vector so the number of elements in the trial vector is equal to the population size or the number of food sources. So, here we have five entries over here, so each entry will correspond to the number of failures encountered by that particular solution. So, if the solution 4 0 1 8 fails in any of the phases, we will have to increase the value of the trail by 1, for this first variable right.

If this particular food source fails to generate a new solution 1 2 8 3, we will have to increase this particular counter right, right. So, now we have the trail vector, we have the food source, we have calculated the objective function value and we also know that fitness function value right. So, the next step is to perform the employed bee phase. So, in the employed bee phase if you remember, all the food source get an opportunity to generate a new solution.

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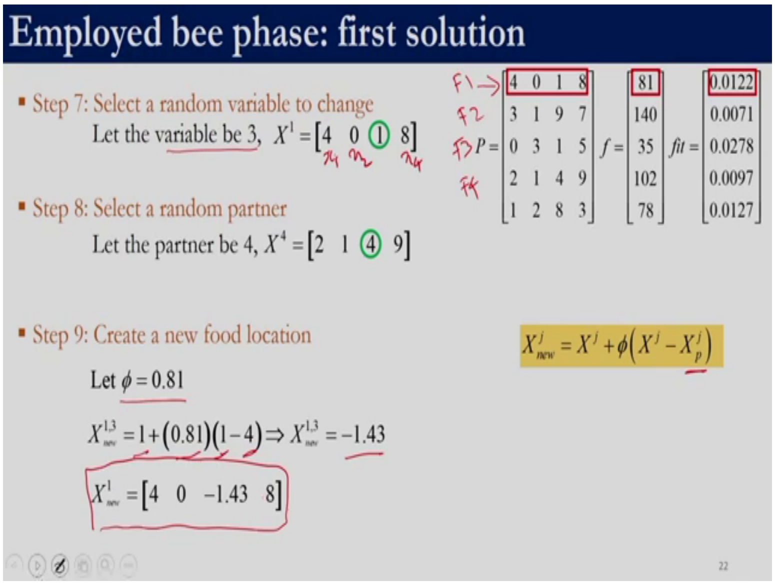

So, every solution has to undergo the employed bee phase. So, first in this case the first solution is entering the employed bee phase, so that is 4 0 1 8 right. So, in the employed bee phase we need to generate a new solution. So, to generate a new solution, we need a partner solution and which is to be randomly selected from the population, and we also need to randomly select a decision variable which we are going to change. Remember in ABC algorithm we are not changing all the decision variables, but we would be changing one only one of the D decision variables. So, even if there are a hundred decision variables, only one variable is to be change.

So, in this case let us take the variable which we are going to change is the third variable right. So, in this 4 0 1 8 we are going to change this 1, 4 0 and 8 that is the first decision variable x 1, x 2 and x 4 will remain the same; only x 3 will get modified right. So, now we have randomly selected the variable to be change, now we will randomly select the partner to be change. So, in this case let us assume that we are selecting the fourth partner. So, this is the first food source, the second food source, the third food source and this is the fourth food source; so 2 1 4 9 is the fourth food source.

So, here also we are going to select the only the third variable, because that is what we have decided that we will randomly change the variable 3. Now, that we have the random partner, we have the random variable to be changed, we will require this phi value, remember phi has randomly taken between minus 1 and 1. So, if we take 0.81, if we plug into this equation, so X j is 1 that is from the current solution right; 0.81 is the phi value which we have chosen, 1 is again from the current solution, this 4 is from the partner solution right; so if we evaluate, we will end up with this minus 1.43. So, the first solution is undergoing the employed bee phase right, so we get 4 0 minus 1.43 and 8.

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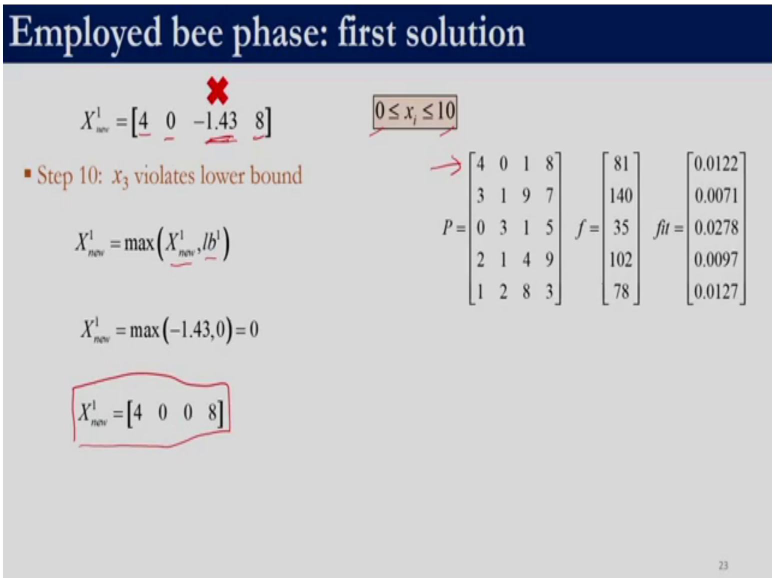

So, the next step is to check for the bounds of the decision variable right. So, I do not need to check the bounds of these decision variables, because they are the same we have modified only x 3, so we need to check the bounds of only x 3 over here right. It is minus 1.43 and for this problem the bounds were to be between 0 and 10, so the lower bound is 0.

So, now if we see this solution actually violates the lower bound, so we need to bound that solution. So, we take the maximum of minus 1.43 and the lower bond which is 0, so if we take that we will get a 0. So, the new solution is 4 0 0 8 right, the solution which generated 4 0 0 8 is 4 0 1 8 right. So, as we see this solution is only slightly away from the solution 4 0 1 8, because we had changed only one decision variable right.

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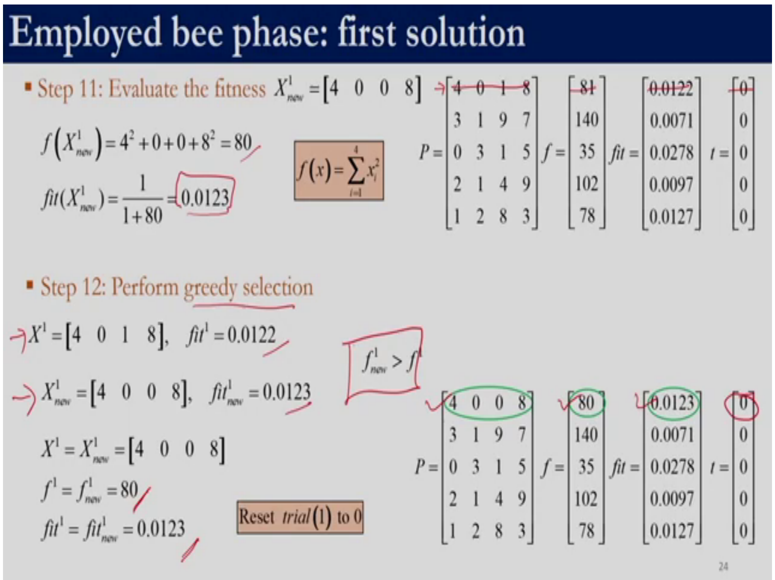

So, now we have this solution, the next step is to calculate its objective function value. So, the objective function value as you know, it is the sum of square of all the decision variables, so that will turn out to be 80 in this case. And then we need to calculate the fitness, because in ABC we work with the fitness of the solution and not the objective function. The fitness is nevertheless calculated using the objective function right, so the fitness value is 0.0123 for this solution right.

Now, we need to perform a greedy selection right. So, we will perform a greedy selection that is the solution, which was used to generate is the first solution and the solution which we have generated is this X 1 new. So, among these two solutions we are supposed to select one of the solution right. So, we will do that on the basis of the fitness function value. So, the fitness function value if we see that for the newly generated solution, it is better than the solution which was used to generate, so this 0.0123 is greater than 0.122 right.

So, what we will do is we will eliminate the first solution right and we will include the new solution right. So, when we say eliminate the solution, so we should not only eliminate the decision variables, but the objective function, the fitness as well as the trial counter right, because this is a new solution which is coming into the population. The new solution is updated right, the objective function value is updated.

So, the objective function value of the new solution is 80, the fitness of the new solution is updated and the trial is to be reset to 0 right. Since it is the first iteration, we may not be able to realize this particular step right, but had it is been any other value this had to be reset to 0, because a new solution is actually entering our population right, so that completes the employed bee phase for the first solution.

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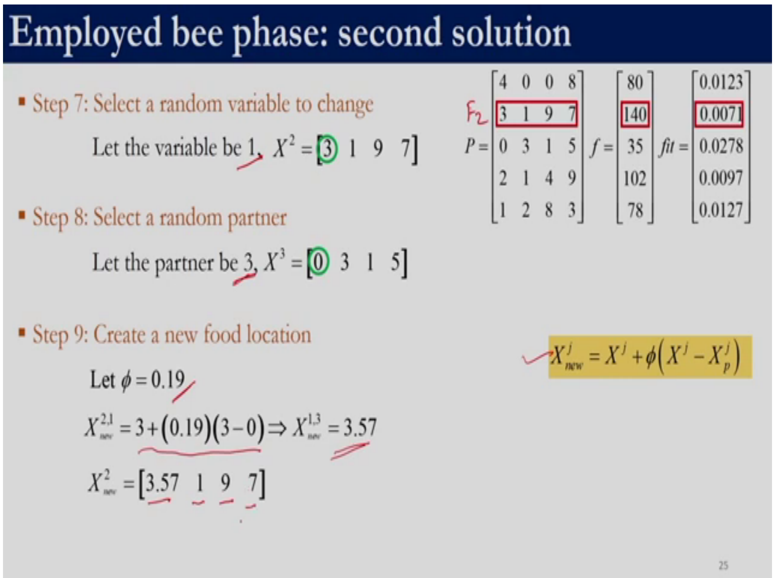

So, now we are supposed to perform the employee bee phase for the second solution. So, the second solution F 2 is 3 1 9 7 right, let us take the random partner to be 3 right; let the random variable is 1 and the randomly selected partner is 3 uh. So, based on these two solutions we are again going to generate a new solution. So, again for this equation we require phi between minus 1 and 1. So, if we take phi value to be 0.19, so this 3 plus 0.19 into 3 minus 0 based on this equation will give us a value of 3.57 right. So, the new solution is actually 3.57 1 9 and 7.

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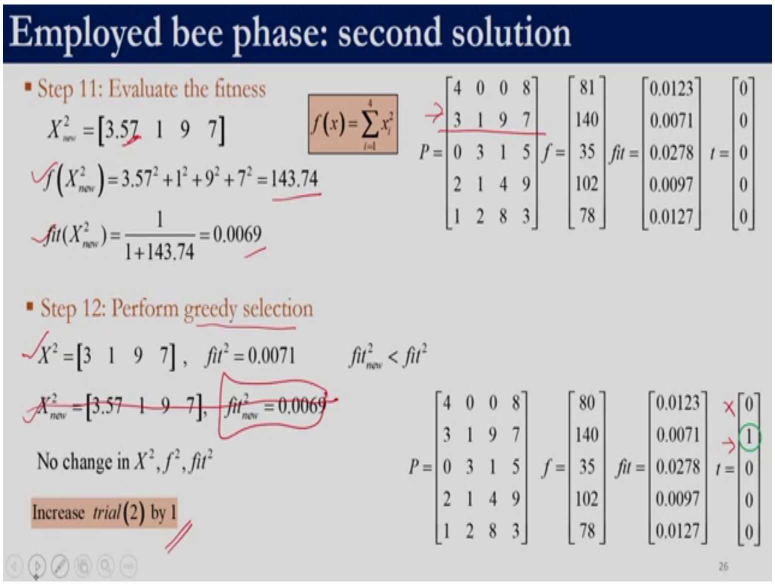

In this case, it happens that the solution is already bounded right our bounds were 0 to 10, so this is within the bounds of lower and upper bound of 0 to 10. So, then we need to calculate the objective function value. So, in this case it comes out to be 143.74 and then we need to calculate the fitness using the formula that fitness is equal to 1 by 1 plus objective function value. So, the fitness turns out to be 0.0069 in this case right.

After this, we have a new solution now. We have evaluated its objective function as well as the fitness. So, now we are ready to perform a greedy selection right. So, we will perform a greedy selection as in we will compare the solution which was used to generate the new solution that is this X 2 this solution, and the newly generated solution right. So, the newly generated solution is 3.57 1 9 7 right.

So, between these two if we see, the new solution is actually having a poor fitness right. So, this has a poor fitness this value is lower than this value, remember fitness function is inversely related to the objective function right. So, this value is lower so we need to discard the solution right.

So, since this solution is discarded 3 1 9 7 fail to generate a better solution. So, now we will increase the trail counter of the second solution by 1 right. So, here you see we are increasing the trial counter only of the second solution right, we are not changing 1 or any of the other, because it is this solution 3 1 9 7 which failed to generate a good solution. So, since that failed we are increasing the trail counter by 1, this completes the employed bee phase of the second solution.

So, remember the first solution helped us in generating a solution which was actually better right. So, we took that inside the population where as in the second solution, it did not help us to create a better solution right. So, we discard that solution we retain the same solution right, but increase the trial counter by 1.

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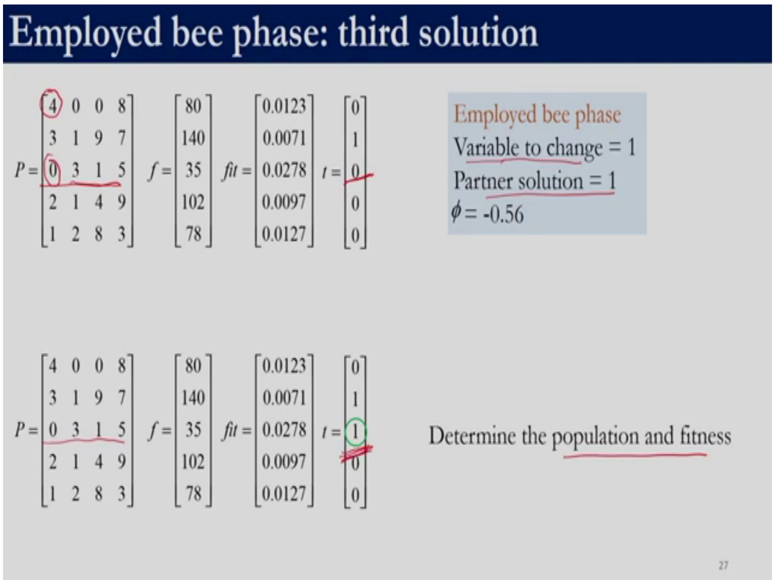

So, similarly we need to perform the employed bee phase for the rest of the solution, since the procedure is similar we will not show the detailed calculation, you can try it out yourself right. So, variable if we select the variable to be changed, randomly if you take the first variable and the partner solution also has to be the first partner right. So, this is the partner 4 0 0 8 is the partner solution and we are selecting the variable 1, and the third solution. So, the equation is to be applied between 0 and 4, the rest of the three variables 3 1 5 will be retained right.

If we generate the new solution, we need to check for its bound; if it is within the bounds, well and good; if it is not within the bounds, we will have to bound it, evaluate its objective function, then we will have to evaluate it fitness function value and then we will how to perform a greedy search right. So, depending upon the fitness you will have to perform a greedy selection and then update the population.

So, in this case if you do all those things, if you see that the solution 0 3 1 5 is actually rating. So, what does that mean? That means, with the new solution which was generated is actually inferior to this right, so that is why it has not been incorporated into the population, but it has been discarded. Since, this third solution failed to generate a new solution; we increased the trial counter by 1. So, here it was 0, so here we increase the trial counter by 1 right.

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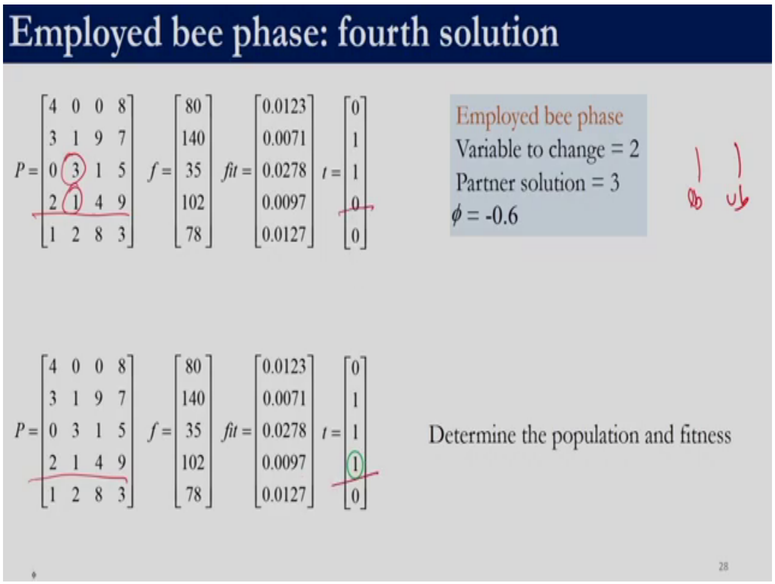

Similarly, you can perform for the fourth solution right. So, for the fourth solution the variable that you should change is the second variable right, four solutions second variable is this one, this one and the partners selected is again 3 right, so this one. So, if you apply the equation, the new variable would be 1 plus minus 0.6 into 1 minus 3 right. So, if you apply this equation, you will be able to calculate what is the second variable.

So, the new solution would be 2, whatever you are calculating over here and 4, and 9 right. This solution you will have to check whether this variable is within bounds or not, so this will be X 2, because we are changing the second variable and this is the new solution. You need to check the bound of this; if it is in the bounds, we do not need to bound it; but if it is not in the bound, we need to bring it back into the bounds and then evaluate its objective function and the fitness function value.

Once we have evaluated the objective function and fitness function value, we will have to employ a greedy selection strategy and depending upon that we will have to either update the population or either update the trial counter. So, in this case if you determine the new solution and fitness. You will be able to see that the solution is again the same that means, we encountered a failure and we have updated the trail counter.

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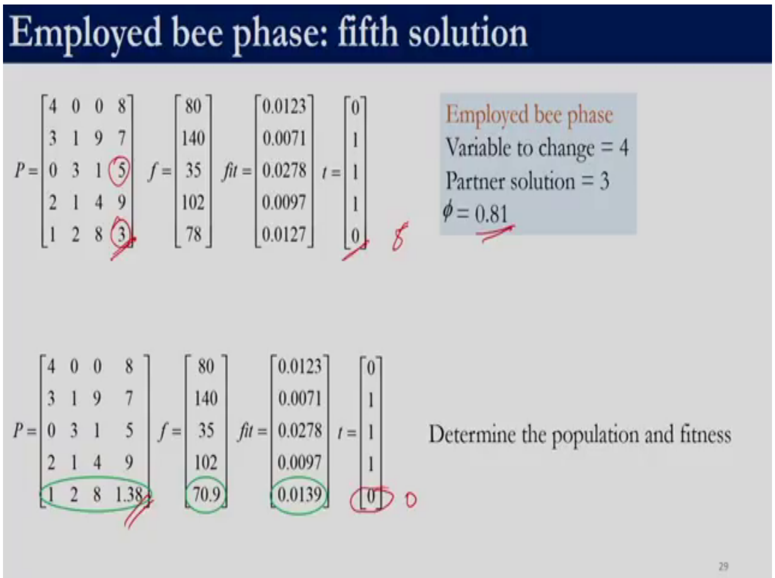

Similarly, you have to perform it for the fifth solution right. The variable to be changed is fourth variable, so this is the variable to be changed the partner solution is third right, so this one. You need to apply that equation with the phi value of 0.81 and calculate the new variable. If the new variable is within the bounds good, otherwise you will have to bound evaluate the objective function, the fitness function value and then perform a greedy search right.

So, in this case if you see this fifth variable has been changed, so that indicates that we had encountered a success right. Since we had encountered a success, this trial value has to be reset to 0. It happens that it is 0 over here already, but assume at some stage it was 5 and this 1 2 8 3 three actually let us to the solution 1 2 8 1.38 which was actually better. Then this phi had to be reset to 0, because 1 2 8 3 underwent employed bee phase and was able to generate a better solution and since the better solution is being incorporated in the population we will have to initialize the trial value to be 0 right, so that completes the employed bee phase for all the five solutions.

So, here we have basically tried to generate five new solution. If the solution was good, we include at in the population; if the solution was bad, we discarded it. One major difference between other algorithms and over here is that whenever we encounter failure we keep track of the number of failures right, so that completes the employed bee phase. Before going to the onlooker bee phase, we need to evaluate the probability associated with each solution.

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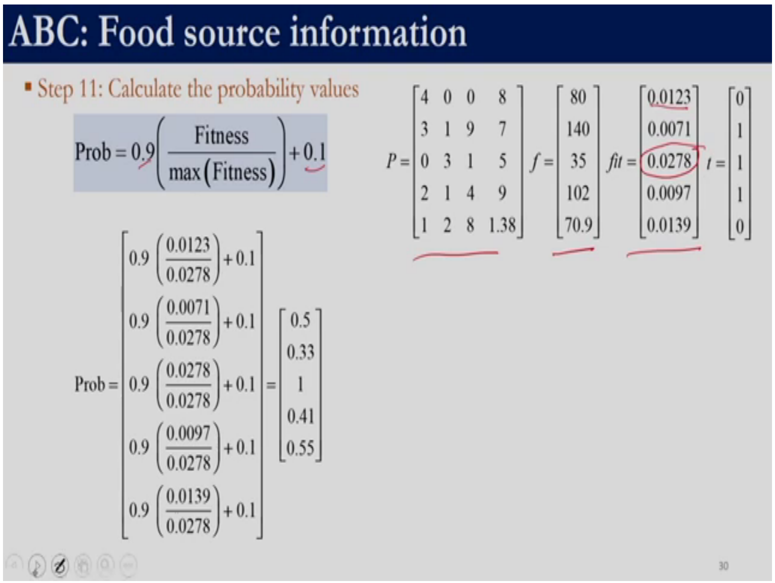

So, this is our current population right and this is our current objective function value, and this is our current fitness value. To determine this probability equation, we are required to find out the maximum fitness. So, the maximum fitness is 0.0278, so we can calculate the probability for each solution right. So, first solution we will have 0.9 into 0.0123 divided by 0.0278 plus this 0.1 right. So, we will end up with this probability values for all the five food sources right.

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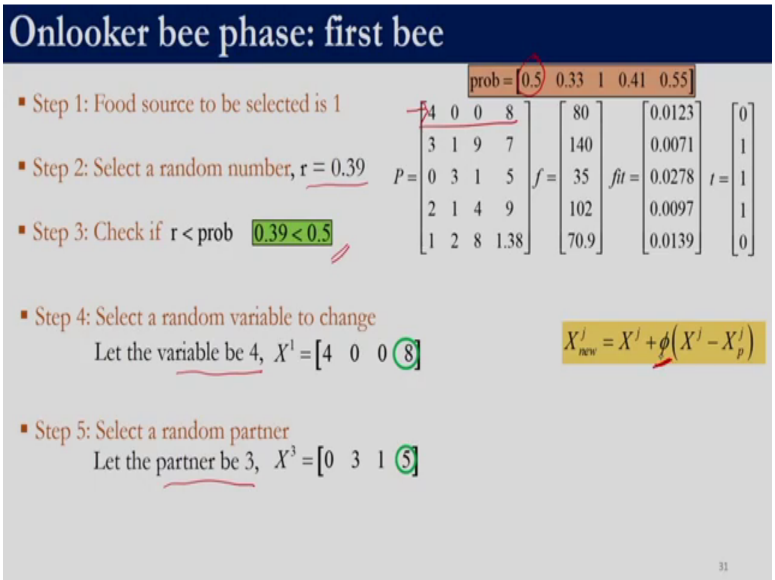

Now, we have the probability value we can actually implement the onlooker bee phase. So, the first onlooker bee will decide, whether it will go for the first food source or not right. So, far that we need to generate a random number right, let the random number be 0.39, so is this random number less than 0.5 right. So, the probability associated with the first food sources 0.5, so that is why we are comparing this 0.39 with 0.5. Since this condition is valid right, we enter the loop for creating a new solution.

So, creating the new solution is the same procedure, it is the first solution that we need we are considering as of now first food source which is being considered right. So, this 4 0 0 8 we need to use that to generate a new solution, so to generate a new solution we need to decide on a variable that we are going to change. So, let the variable be 4, again this is randomly selected we need to decide on a partner.

So, let the partner be 3, so again the partner is randomly selected. So, the third solution is 0 3 1 5. The fourth solution is 4 0 0 8 and we have decided to modify the fourth variable, so 8 and 5. Now, we need to again employ this equation a with a particular phi value to generate the new solution.

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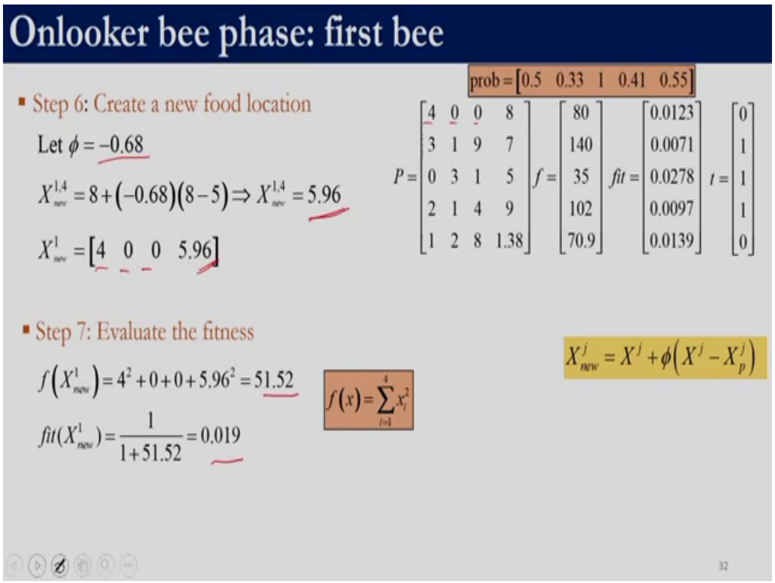

So, if you take a value of phi to be minus 0.68, we will end up with this 5.96 right. So, the first three variables x 1, x 2, x 3 will remain the same, because only one variable is changed in ABC. So, this is the new solution this solution happens to be in the bounds right. So, we can calculate its objective function right, so 51.52 is the objective function and then we need to calculate its fitness value. So, once we have calculated the objective function and the fitness value, we are ready to perform a greedy selection right.

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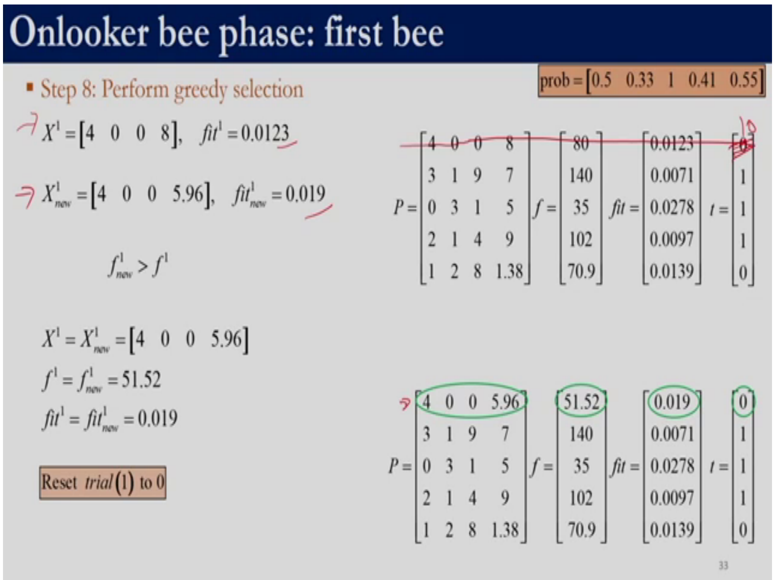

So, the solution that is undergoing onlooker bee phase is the first solution, this is the new solution which we have generated, so we need to check this condition which is better. So, if we compare these two values, we can see that the new solution has a better fitness value 0.019, when compared to 0.0123, so we are going to discard the first solution right.

So, we have replace the solution its corresponding objective function value, its fitness function value and the trial again it has to be reset to 0, immaterial of what is the value is over here? It has to be reset to 0. Even if we had a value of 10 over here in this case it had it should be replaced, because we have generated a new solution which is better and that has entered the population right. So, this particular member has not got to chance to generate new solutions so far. So, its trial has to be set to 0, so that is the onlooker bee phase of the first bee right.

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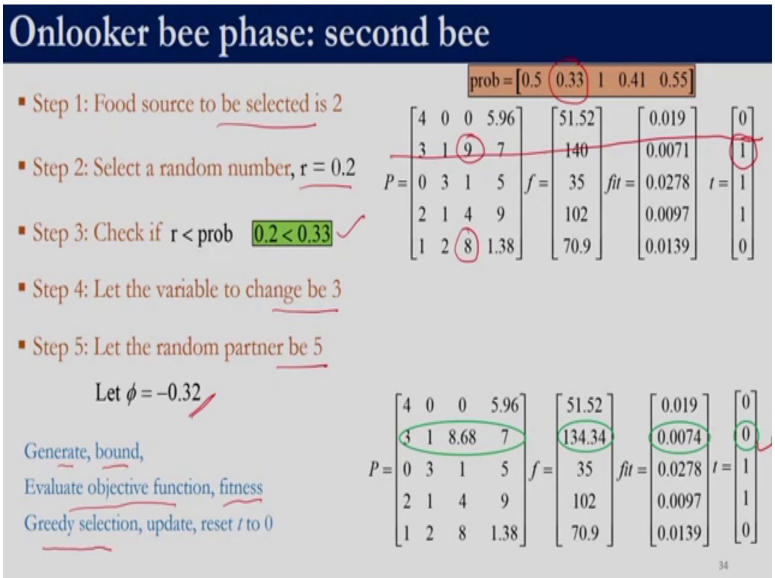

Now, we need to go for the second bee. So, now we will have to select the second food source right. So, again we need to generate a random number, let the random number be 0.2 we need to check this condition right the probability of the second food source is 0.33, so this condition is satisfied right. So, again we need to employ the same procedure we will not give the detailed calculation here, but you can perform that let the variable to be changed to be 3 and the partner be 5 right; so the third variable and fifth is the partner. So, right now the second solution and the variable, which we are talking is the third variable right. So, this 9 and this 8 right both of them have to be used to generate a new solution.

So, once you generate a new solution, you will have to check for its bounds; if it is in the bound, it is we do not need to bound it; else we will have to use the corner bounding strategy, then we will how to evaluate the objective function and the fitness function value right. Once we have the fitness function value, we will we are supposed to perform a greedy selection.

So, if you do the calculation you will see that you will end up with this value 8.68 right, and it happens that this newly generated solution is better than 3 1 9 7. So, this solution is to be eliminated and the new solution is to be included right, whenever a new solution is included in the population its trial has to be set to 0. So, both the first bee and the second bee gave us a new solution which is actually better right.

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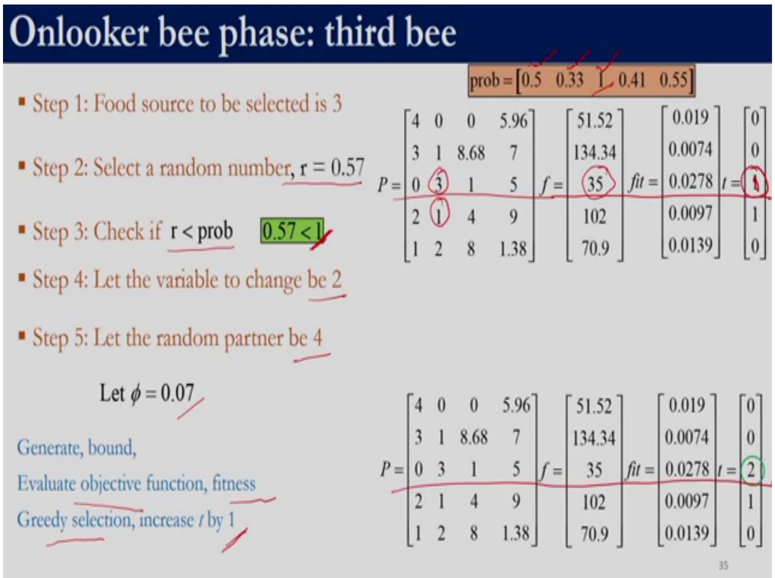

So, for the second solution if you see the trial was initially 1 right, now it is being set to 0, because we have replace that particular solution right. So, this completes the onlooker bee phase of the second solution right. So, for the third solution if we perform so now the first food source has been exploited, the second food source has been exploited, so now we need to consider the third food source right.

Third food source has a probability of 1 right, so for the third onlooker bee whether we it will use the third food source or not depends upon a random number which is to be generated between 0 and 1. So, if the random number let us say its 0.57 right, in this case it will satisfy this condition right; if it satisfies this condition, we need to generate a new solution.

So, let us assume that the second variable will be change with the help of the fourth solution. So, right now second variable so this 3 and this partner is fourth. So, we can generate a new solution and then we have to check for it bounds; if it is in the bounds, well and good; otherwise we will have to bound it, then we need to evaluate the objective function and the fitness function value. Once we have evaluated the objective function value and the fitness function value, we can perform a greedy selection.

So, in this case it happens that the solution that is generated is not better that is why if we perform a greedy selection, we will see that this solution 0 3 1 5 is actually being retained, which indicates that the solution which we generated actually was inferior to this. So, in that case what we do is we increase the trial by 1. So, trial it is already 1 over here when we started right, so now it encountered a failure. So, we are increasing the trial from 1 to 2 right.

So, this completes the onlooker bee phase for the third bee right. So, for all these three cases if you see this condition was valid that whatever random number we chose was less than the probability value right. And whenever we generated a new solution, we reset the trial counter to 0; and when we do not get a better solution, we increase the trial counter by 1 right, so that is what is happened. So, we have exploited all these three food sources right.

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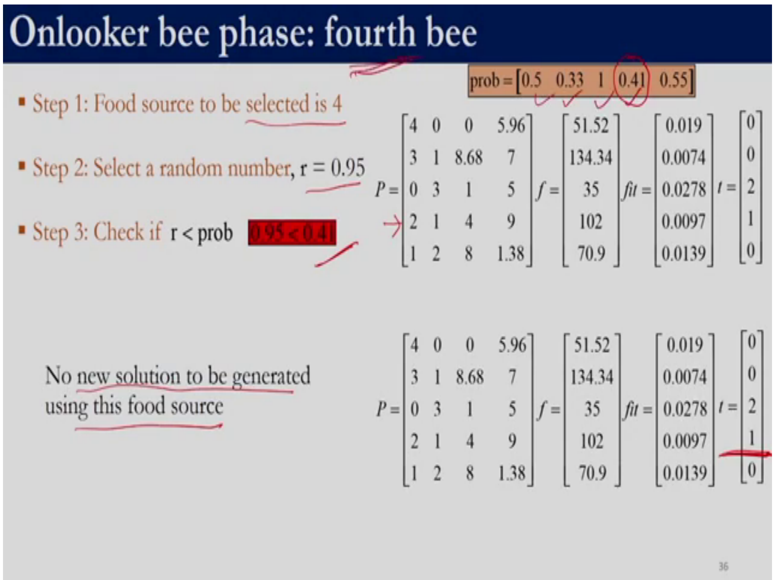

So, now we need to go to the fourth food source right. Let the random number be 0.95, since we are working with the fourth food source right, this 0.95 has to be compared with this 0.41 right, so this condition does not satisfy. For the first three bees this condition was satisfied and hence we generated a new solution, in this case this condition is not satisfied, so we will not be able to generate a new solution; so no new solution is to be generated using this food source right.

So, remember the fourth bee which is now undergoing this onlooker bee phase did not get an opportunity to generate a new solution, I should neither reset it to 0 nor I should increase it by 1 right. We will increase it by 1, only when it has generated a solution and it has met a failure; we will reset it to 0, if the new solution is actually better right. In this case, 2 1 4 9 was not even able to generate a solution, so we should not update the trial vector right, we should neither update increase it by 1 nor reset it to 0. So, now this four food sources have been exploited right and fourth on looker bee has not completed the onlooker bee phase.

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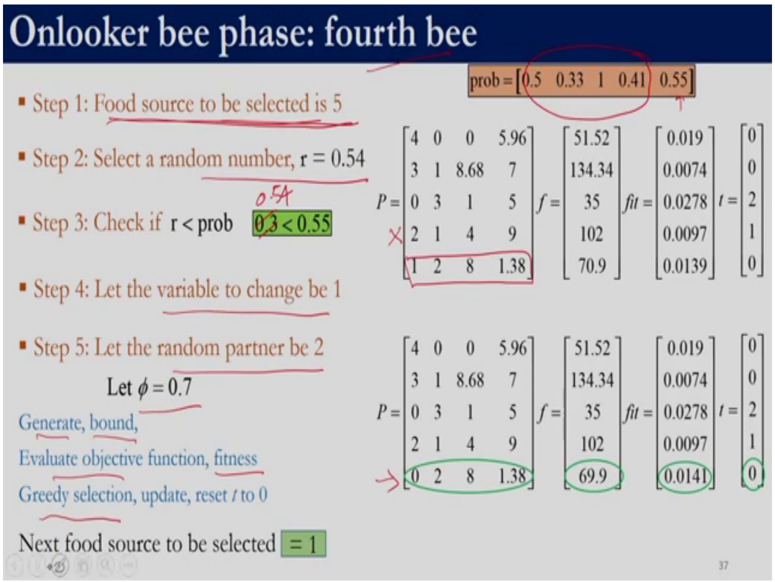

So, what we will have to do is, the fourth bee will now undergo the fifth source, because the first four food sources have been exploited right. So, we again generate a random number let us say, it is 0.54, here we need to again check right. So, this should be actually 0.54 not 0.3 it has to be 0.54, because that is the random number that we have generated, so this 0.54 has to be compared with 0.55 right. So, since the condition is satisfied, we need to generate a new solution. For generating a new solution, we need to decide on a partner, we need to decide on the variable that has to be changed.

In order to perform the calculations, you can take the variable to be changed as 1 and the random partner as 2 and a phi value of 0.7 right. So, if you take that you will be able to generate a new solution right, bound that solution if it is out of bounds, evaluate the objective function, evaluate the fitness function value, employ a greedy selection over there and if it is better update.

So, in this case if you see the fifth food source right. Remember it is the fourth onlooker bee, but it is the fifth food source that we have selected, because only for the fifth food source that condition was satisfied; for the fourth food source it was not there. So, now we are working with 1 2 8 1.38 and not 2 1 4 9, because the food source we have selected is 5 right.

So, now if you see that solution has been updated right, we had got a better solution over there. So, we have updated the solution and the trail counters since it is a new solution which is entering the population the trail counter is set to 0. So, now if you observe all the five food sources have been exploited. However, only four bees have underwent the onlooker bee phase right.

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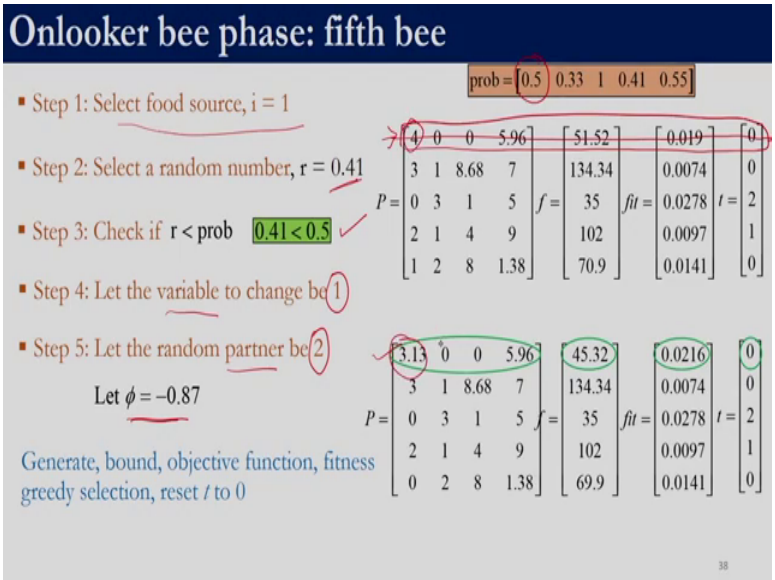

So, for the fifth bee we need to start from the first food source. So, the food source to be selected is 1, now we will have to decide whether the fifth bee will exploit food source 1 right, so food source 1 again we are working with this solution right. So, for that we need to again generate a random number, let the random number be 0.41 right. So, if the random number is 0.41 this condition satisfies that 0.41 is less than 0.5 ah. So, we need to generate a new solution for generating a new solution, we need a variable that has to be changed and the partner that has to be used to change it right.

So, if we select the first variable and the second solution as partner with a phi value of minus 0.87. If you perform the calculation, you will see that you are you will be generating a solution, which is actually better than this solution right. So, since it is better than that solution, this solution is discarded and this solution is included right. So, since we are changing only one variable only this x 1 has changed. So, this completes the onlooker bee phase.

Remember the difference between the employed bee phase and the onlooker bee phase. In the employed bee phase, all the food sources were used to generate a new solution; whereas, in onlooker bee phase a food source may or may not generate a new solution that depends on the random number which is selected for a particular onlooker bee, as well as the probability of the food source. In this example, the fourth food source was never used to generate a new solution right.

Now, that we have completed the employed bee phase and the onlooker bee phase, now we need to implement the scout phase, remember scout phase may or may not be encountered in every iteration right. So, first we need to check whether we need to perform scout phase or not, so that decision is taken on the basis of trail vector right.

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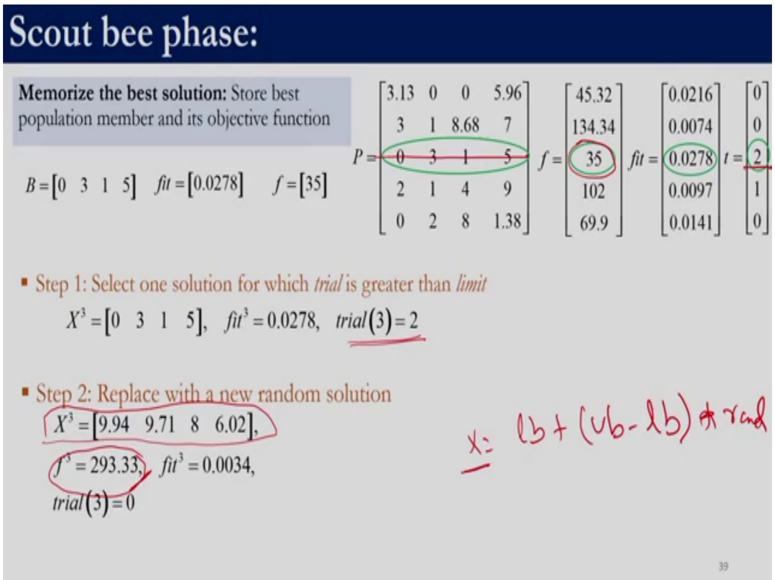

So, if we see this is our trial vector and if you remember the limit that we started was 1 right and this trial vector has a value of 2. So, this particular solution 0 3 1 5 got an opportunity to generate two solutions right, and in both the cases it failed to generate a solution better than itself right. So, in this case what we will do is, we will have to discard this solution from the population and replace it by a randomly generated solution. In employed bee phase and in onlooker bee phase, we used two solutions to generate a particular new solution; whereas, in scout bee phase the entire solution has to be discarded and a randomly generated new solution has to be included right.

So, solution which will be discarded in this case is this one, because it has a trial value of 2, the third solution has a trial value of 2. So, we need to generate a random solution, so let the random solution will be a this one. So, this random solution is again generated by using X is equal to l b plus u b minus l b into random number right.

So, remember all the variables have to be changed, in employed bee phase and in the onlooker bee phase we were changing the value of only one decision variable whereas, here this entire solution is to be discarded 0 3 1 5, all the four values are to be discarded and replace with randomly generated values right. So, let us say I generated this value and let us say the objective function value of this solution is 293.33 right.

So, now if you compare the objective function value of this solution and of this solution which we have decided to discard, the solution which we are discarding has a better objective function value right. Despite that fact, we will still discard this solution that is the difference in scout bee phase. In employed bee phase as well as in onlooker bee phase, we did employ a greedy selection strategy right.

Over here, there is no selection strategy, so a solution has to be discarded which solution will be discarded depends upon the trial value of that particular solution and irrespective of the value of the objective function, the new solution is included in the population right, so that is a fundamental difference between scout bee phase and employed bee phase and onlooker bee phase right.

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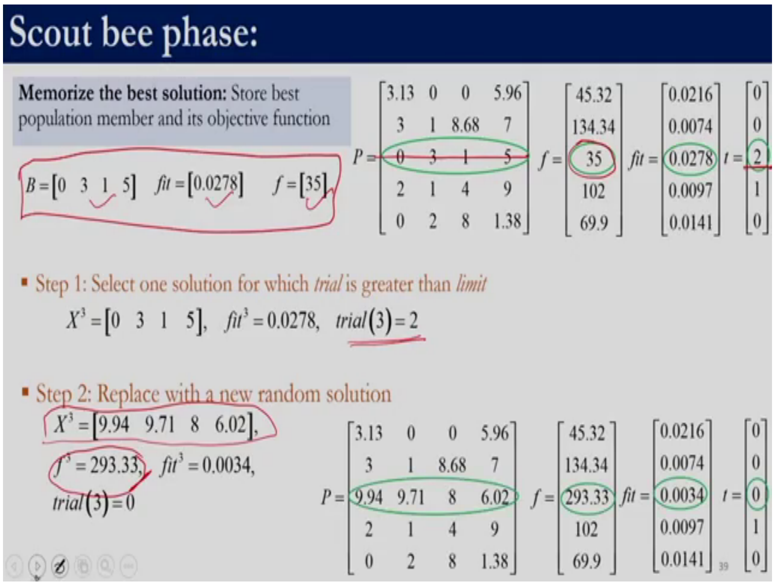

So, our new solution would be this one, so this solution is removed and this one is there. So, now if you compare this population, we did encounter solution of 35 right, but since we updated it, it is lost. And all of this solutions are actually bad, then the solution which we have discarded right, so this can happen in scout bee phase. In scout bee phase, a solution which is very good can get discarded right. To avoid this, what we will do is we will store the solution before discarding right. So, these values are stored the solution, its fitness function and the objective function value are stored separately and it is discarded.

Next time when I am discarding a solution, let us say we progress and then in subsequent iteration again I am going to discard a solution in scout bee phase, so that time I will compare that solution with this solution right. So, if this solution still remains the better solution, I will not update these values; but if it happens that the other solution is better than this solution, then we will update this.

So, basically what we are saying is that when before entering into the scout phase, you will have to check if the solution that is going to be discarded is actually the best solution that you have encountered so far. If that is the case, store the solution separately though it may not be present in the population, it is to be stored separately right.

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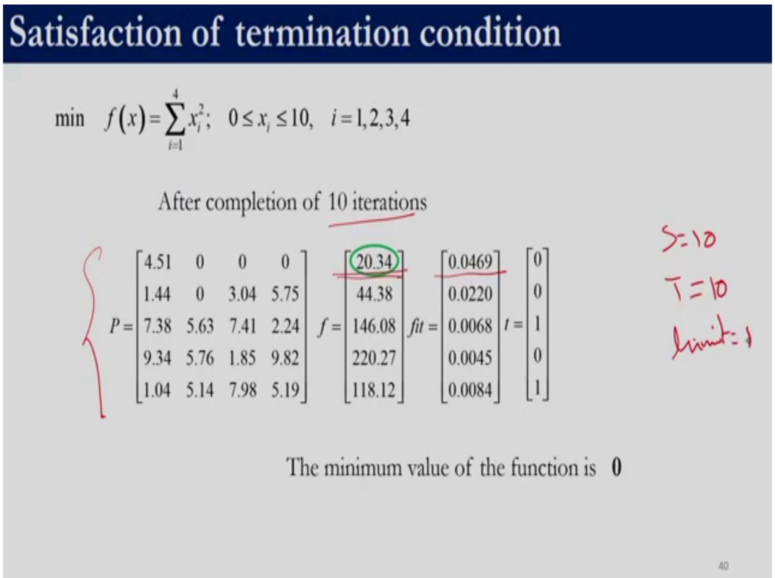

So that completes the scout bee phase of the first iteration right with the same settings if you continue to perform, 10 iterations or 10 cycles right. The solution that we end up is given over here; these are the value of the food sources at the end of 10 cycles or 10 iterations. So, the best value obtained is 20.34 this is the least value in terms of objective function.

If you are compare in the in terms of fitness function, this will have the highest value, because objective function as well as fitness function are inversely related in ABC algorithm right. So, here if we see that the best value we obtain at the end of the 10 iterations is 20.34 right. So, with a swarm size of 10 right and with 10 cycles with the limit of 1, this is the optimal solution as determined by ABC algorithm.

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The inventor of ABC has a home page for the ABC algorithm. On the home page of ABC, you will be able to find MATLAB codes, C codes, JAVA codes, C sharp code, R code is also available over here right. So, R code is available over here for ABC implementation, they have also provided these two software right to understand the working of ABC, ok.

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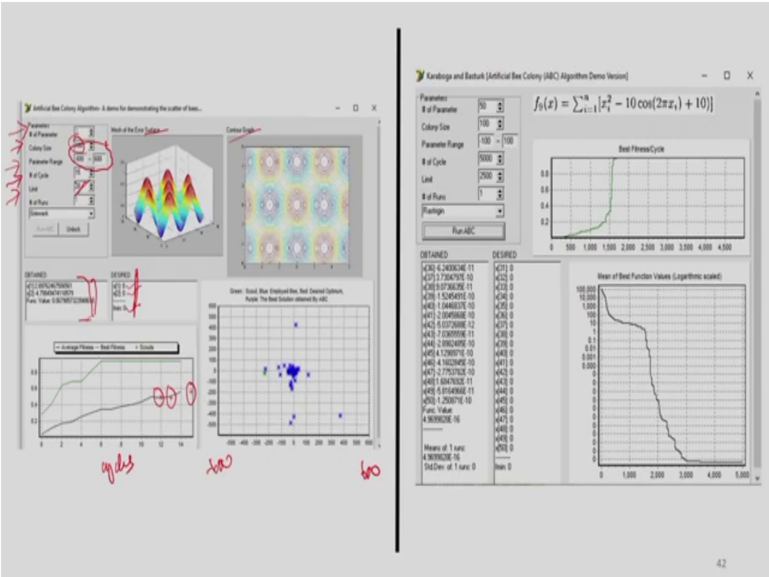

So, let us have a quick look at those two software's right. So, this is the first one where in the number of variables are restricted. So, it is just a two-dimensional problem, so this value is locked, number of parameters is 2. So, the colony size we can fix right the colony size is nothing but the swarm size which is twice the number of food sources right.

The parameter range we can fix the upper and lower bounds of the two decision variables can be fixed with these two values, the number of cycles that we want to implement in ABC can be set over here. We can also change the limit right, so the limit parameter can be given over here. Over here there are a few functions which are given, I think so there are four functions in this software right.

So, this shows the surface plot of this Griewank function right. So, the variation of objective function with respect to the decision variable, this is the surface plot and they also have a contour plot for this problem right. So, as x 1 and x 2 vary, how do the contours look can be seen over here and here the global optima for this problem is given its a two variable problem.

So, the global optima is x 1 is equal to 0, x 2 is equal to 0 and the objective at x 1 equal to 0, x 2 equal to 0 is 0. This portion indicates the solution that has been obtained by ABC, this one shows the search space right. So, for example the decision variable the lower and upper bound for the decision variable were minus 600 and 600, so this is minus 600, this is plus 600 right, same thing for the other variable. So, this shows the location of the food source right.

So, with various color they indicate what is the global optima, what is the best solution that has been obtained by ABC so far, whenever a scout is encountered it is plotted with a green color right. So, this shows the movement of the food sources during the search process. So, for every cycle we will be able to see how, how the food sources are moving.

This plot shows the cycles on the x-axis and the fitness function on the y-axis right, so the line on the top shows the best fitness. So, in that cycle what is the best fitness that has been achieved so far right, so that is shown over here. And the second line shows the average of the fitness at that particular cycle right and this marks show scout has been discovered in that particular cycle right, when we execute this program for 15 cycles, 3 times the scout phase was encountered right.

So, this 20 the limit of 20 was hit thrice, remember since the colony size is high right the colony size is 100. So, the number of food sources 50, so they are working with 50 solutions and the limit is set as 20 right. So, there are solutions which hit the limit value right, so for 20 times a particular solution is not able to improve itself. So, in that case that solution enters the scout phase and it is eliminated right, so with this we can understand the working of ABC better, let us have a look at the software.

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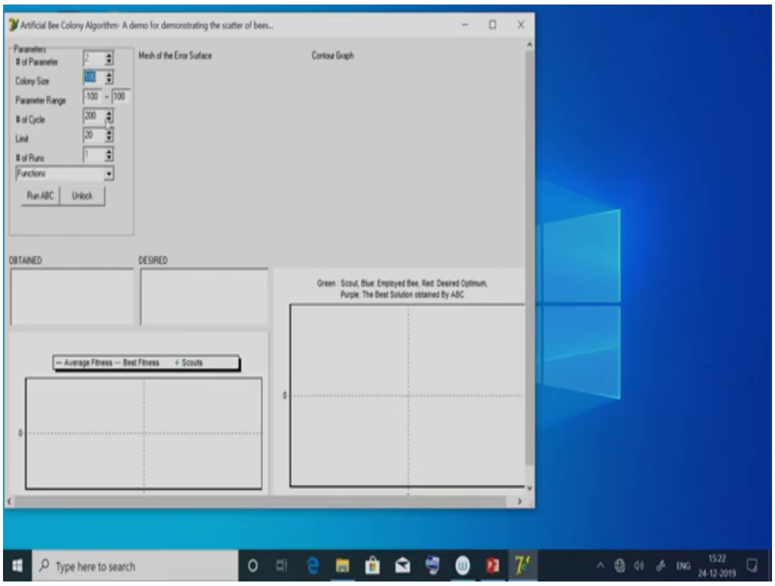

So, the this number of variables cannot be changed, because they are plotting contour plot and mix surface right. So, if I select they have four functions over here; the Sphere function, Rosenbrock function, Rastrigin function and Griewank function.

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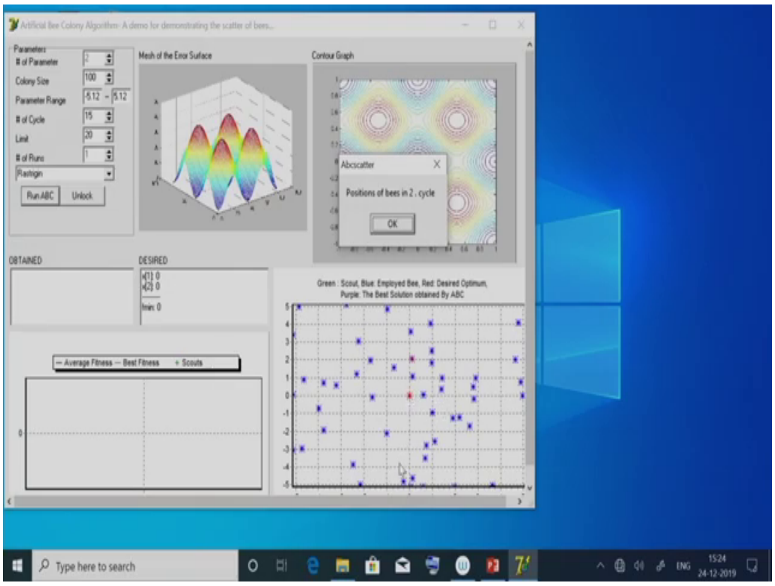

Let us select the Rastrigin function right. So, this shows the surface plot and this shows the contour plot of it. Here the decision variables are between minus 5.12 to 5.12 right. So, let us just perform 15 cycles, so let us see how it works. So, if I give run ABC, so let me just move this over here.

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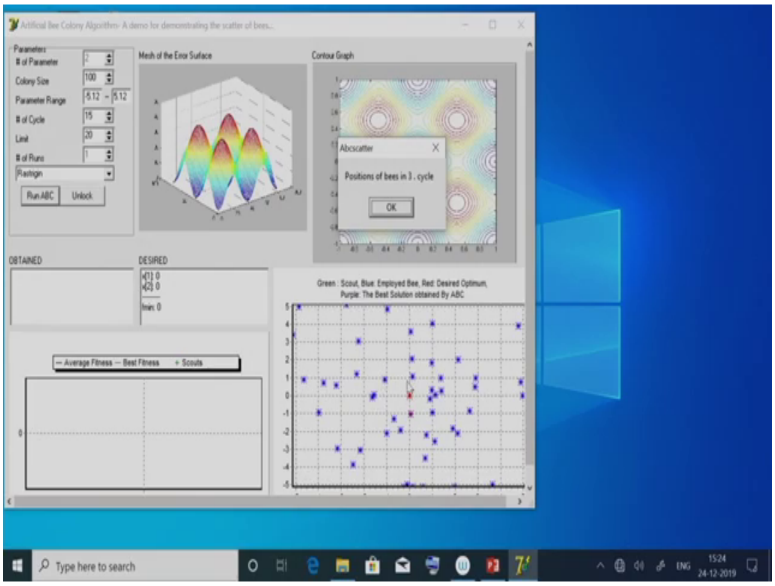

If I click on ok, it will show me the positions of bees in the first cycle right. So, these are the positions of the position of the bees in the first cycle right, so this is the global optimal solution. So, right now if we see the solutions are in pretty much they are scattered everywhere, so if I click on ok, this is the positions at the second cycle right.

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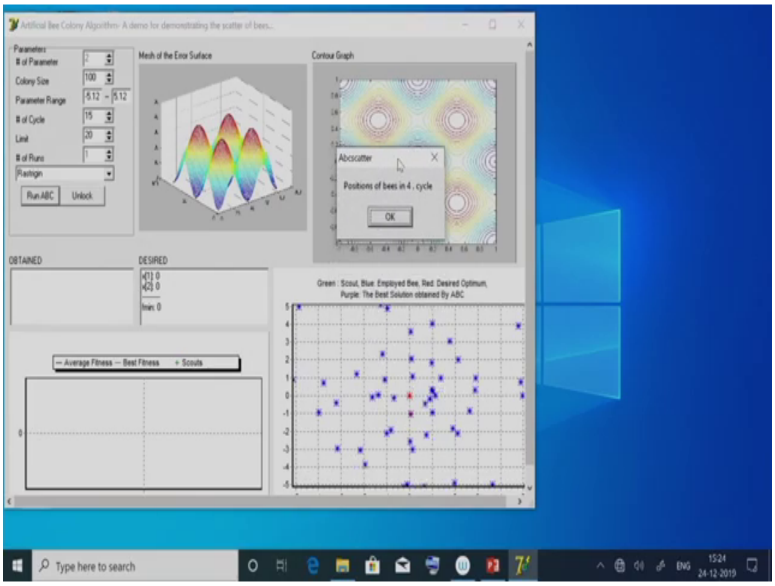

At the end of second cycle, positions at the end of third cycle.

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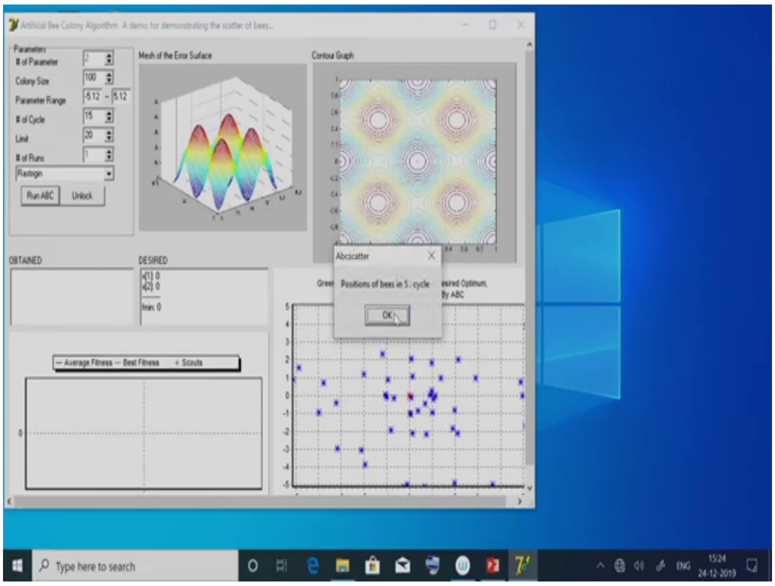

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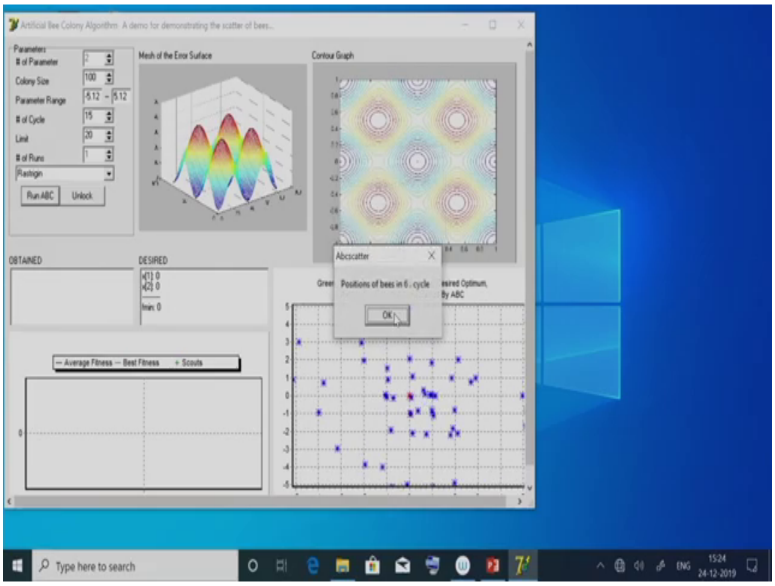

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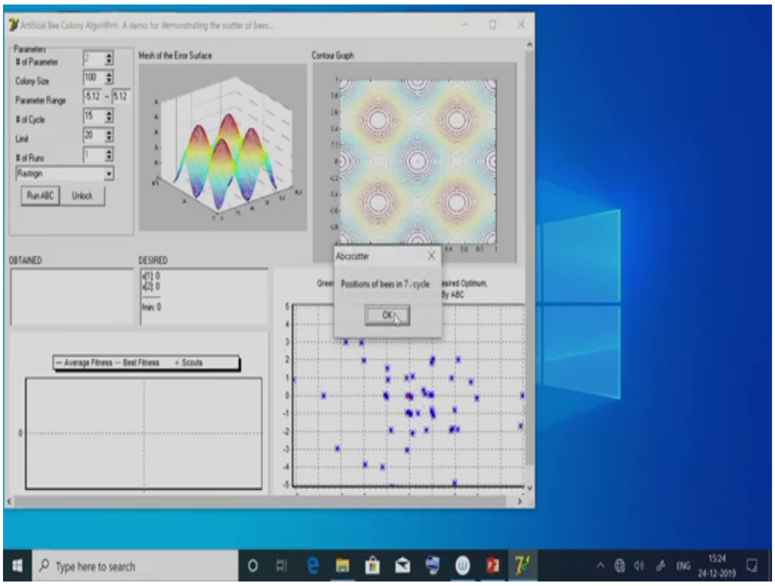

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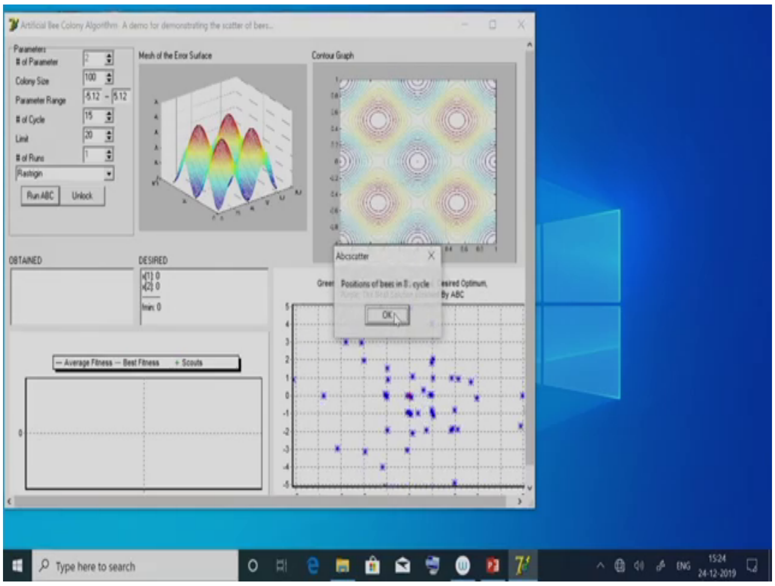

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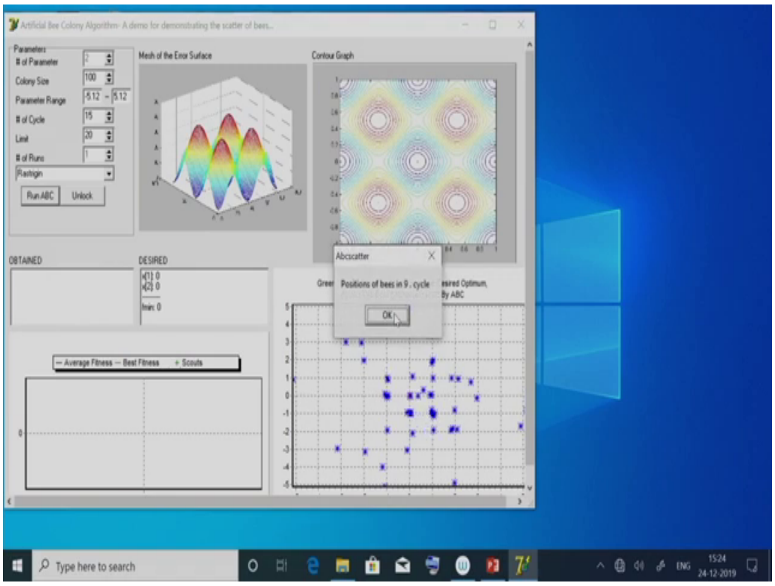

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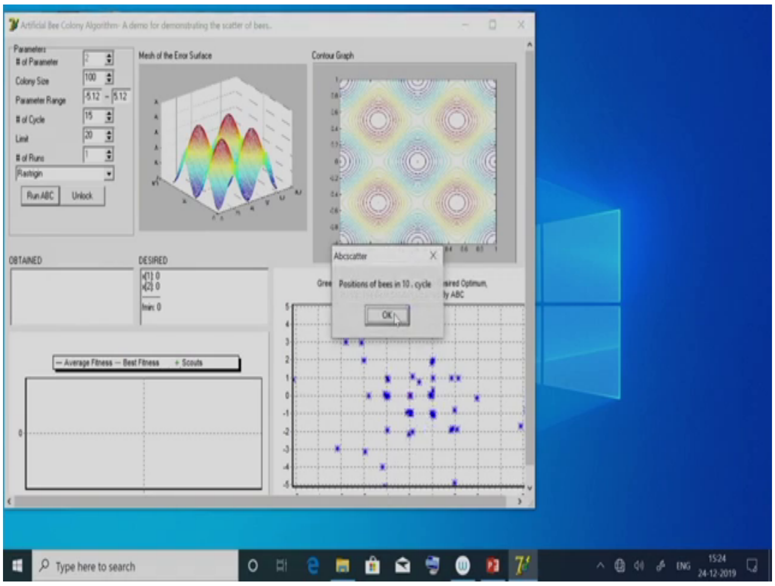

At the end of fourth cycle, so as we see the solutions are slowly moving towards the global optima right.

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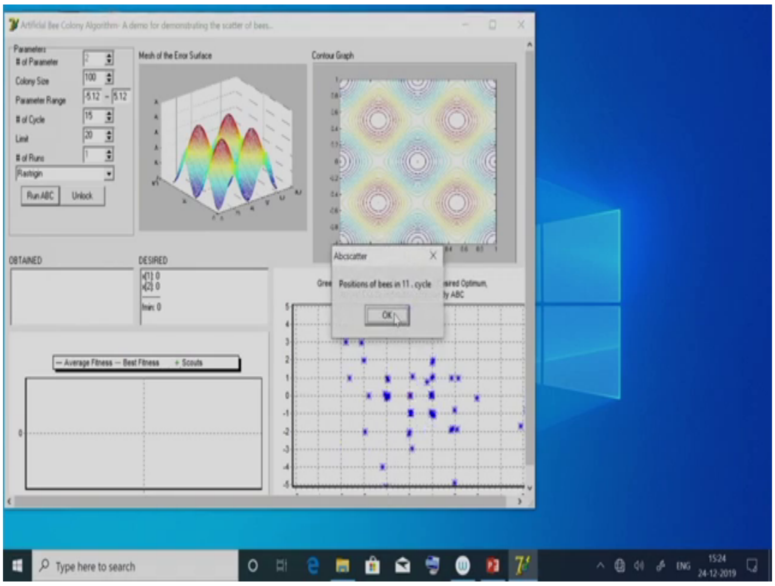

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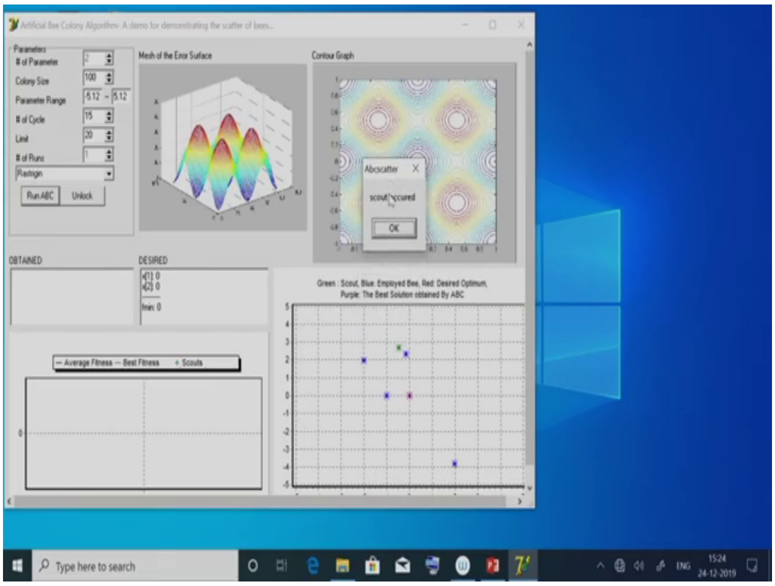

Let us see if we encounter a scout yes. So, in this cycle a scout was encountered right, so that will come up in this plot also right. We can actually see in what was the cycle number in which the scout phase was encountered right.

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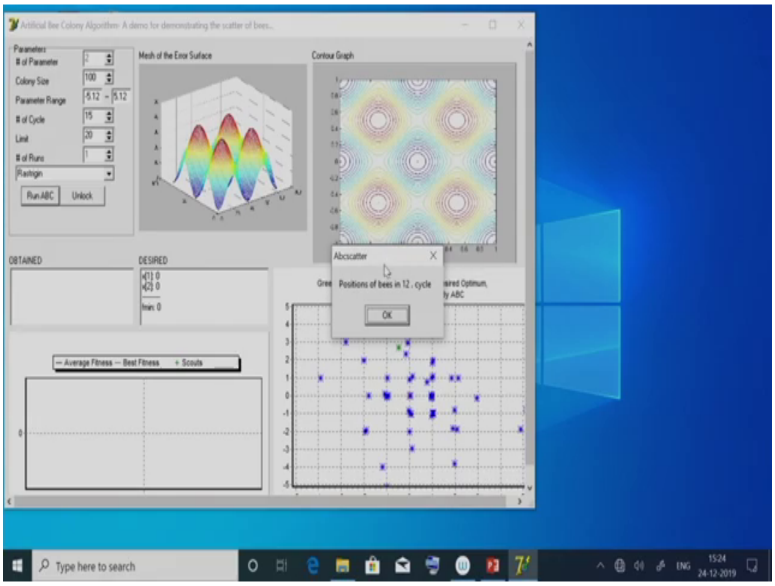

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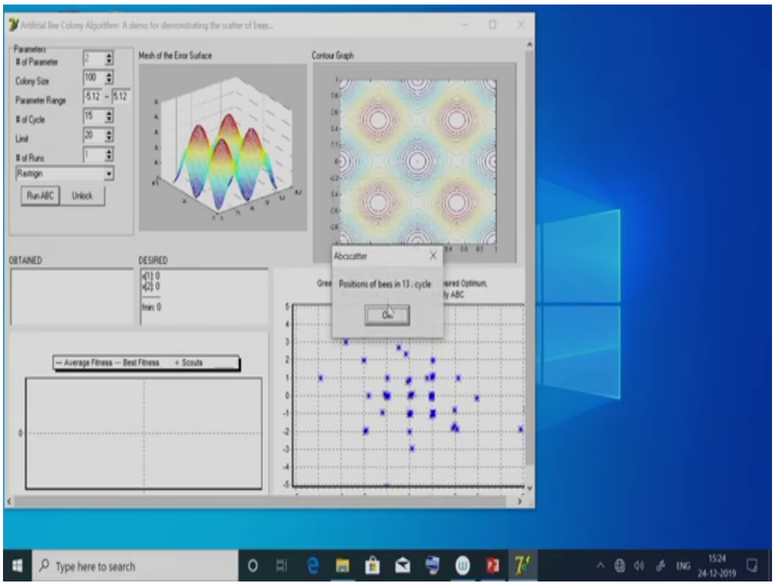

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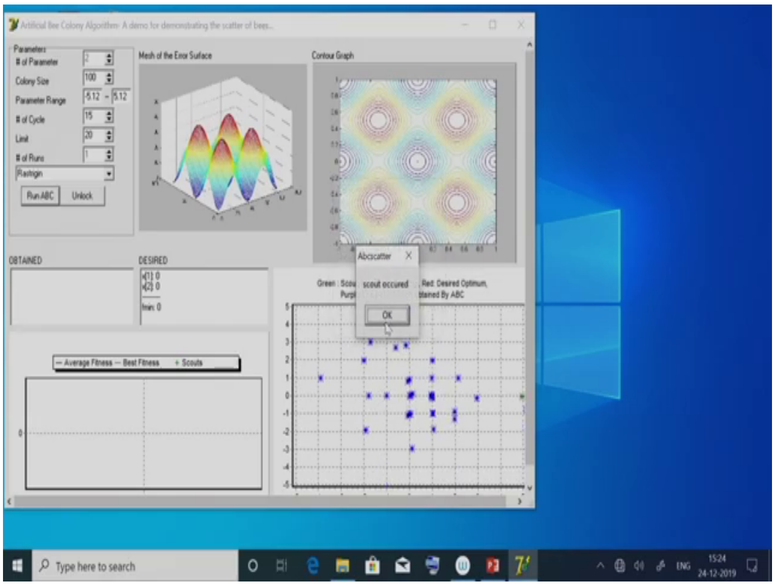

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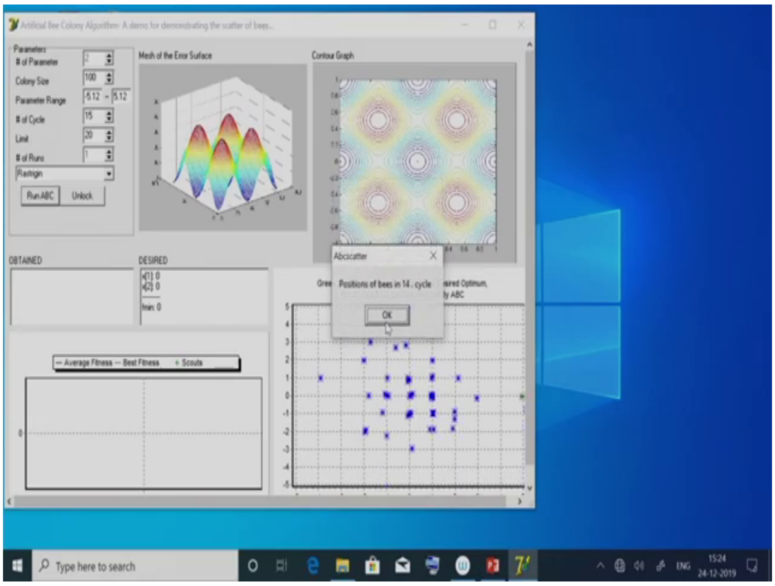

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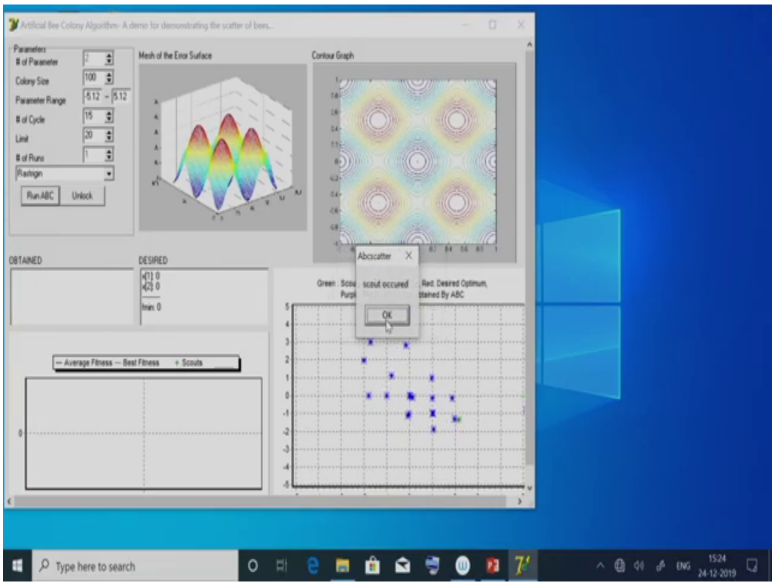

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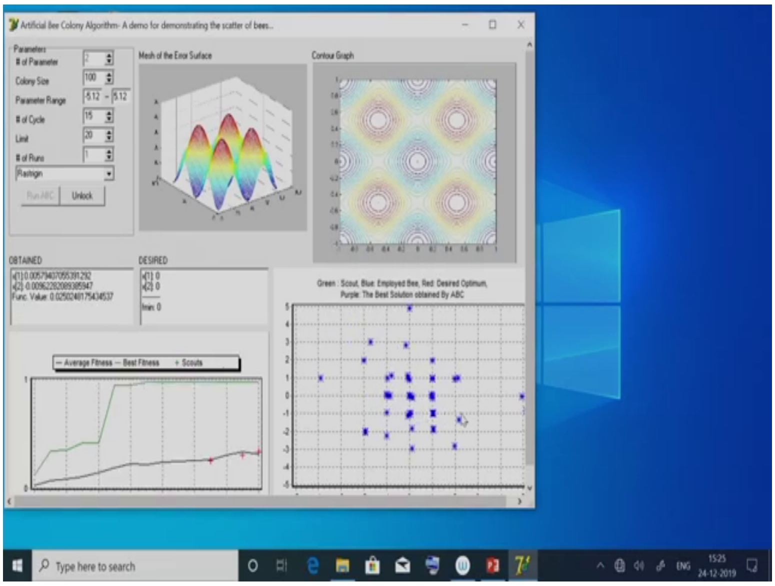

So, if I keep doing this right, so as you see the solutions are slowly moving at the end of 20 cycles, this is what we have right. So, this shows the average fitness value, so it is close to 1, the average fitness is close to 1. Remember this is not the objective function value, the objective function is inversely related to this, this is the average fitness of the population. So, the scout phase was encountered three times at probably the 11th cycle and the 13th cycle and the 14th cycle. So, the scout phase was encountered three times, they can similarly perform for any other problem right.

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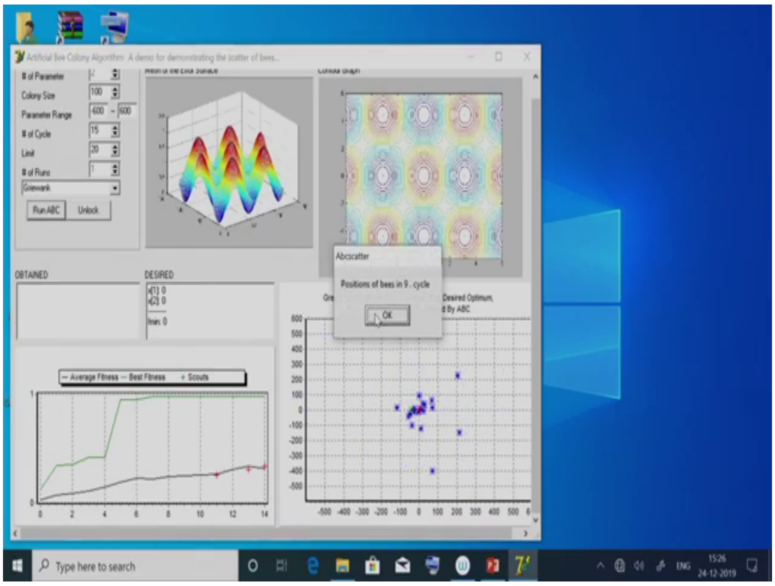

So, far Griewank, let us say this is unlocked and then if we run it, so let us see how it happens for the Griewank function right, so whether it is able to converge.

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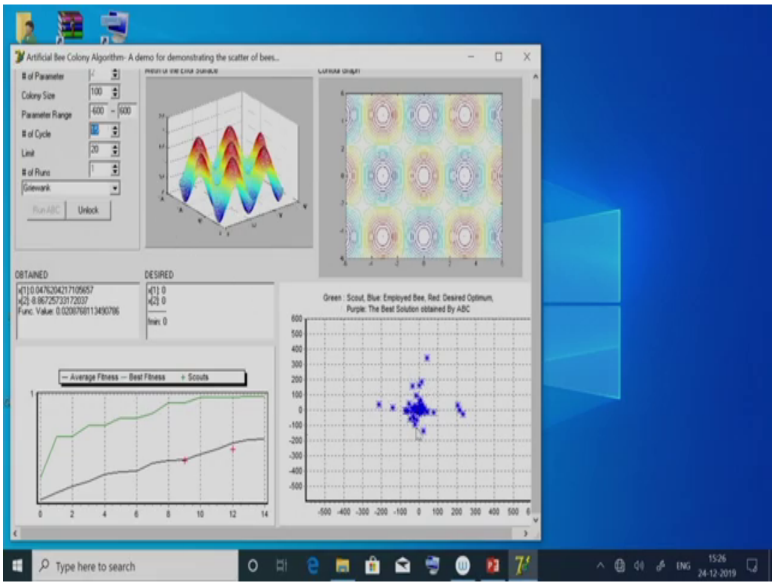

So, the solution seem to be moving towards this thing. So, if we increase the number of cycles right, so you will be able to see that these solutions are actually converging to the optimal solution, this software helps us to visualize the movement of the solutions right.

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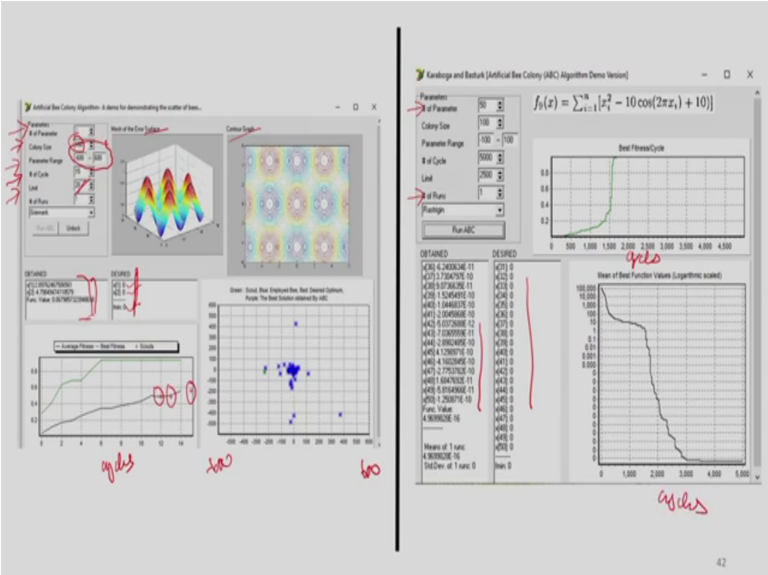

It also has this another software right, where in the number of decision variables are not fixed right. So, here it was fixed to just two variable here we can change the number of variable and here we can run for multiple runs right, we need not restrict to one run we can run for multiple runs right.

So, this is again the desired global optima, this is the solution that is reported as the optimal solution by ABC algorithm right. So, the x-axis in this figure is cycles, so how does the fitness function vary with respect to the cycles and this one shows the average fitness. Since, we are implementing multiple runs in each run the best fitness function value is different. So, in each cycle across all the runs the mean of the fitness function values are taken and that is what is plotted over here right.

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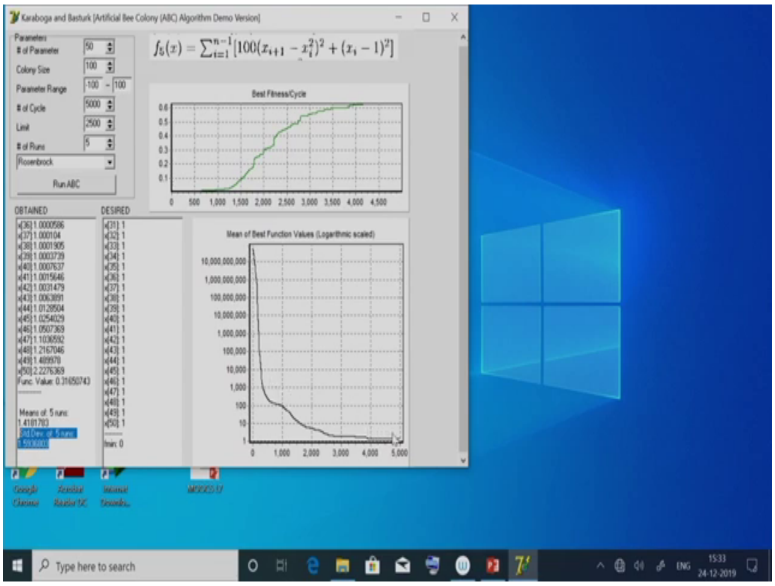

So, here also the x-axis is cycles. So, let us have a look at this particular software. So, here we can change the number of decision variables, let us take the Rosenbrock function and the let the number of decision variables be 50. So, Rosenbrock function is a scalable function right. So, let us keep the number of runs to just 5 right. So, you can perform with larger number of runs right. So, let me for demonstration purpose let me just take 5 runs and let me just execute this ABC right. So, it will take a little bit of time, so it reports the 50 decision variable and the objective function value obtained at each run.

So, here if we see that the values of all the 5 runs are given right. So, in the fourth run, it obtained an objective function value of 3.69, in the last run it obtained an objective function value of 0.31 with these as the decision variable right. So, the optimal solution for this function occurs at all the 50 decision variables taking a value of 1 right. However, here if we see some of the variables, so for example variable 50 is 2.22, 49 is 1.48.

So, in each run we had obtained a objective function value, the mean of this is given over here right and this is the standard deviation across the 5 runs right. The y-axis over here is the objective function value whereas, the x-axis cycles, over here the x-axis is cycles in this plot and the y-axis is fitness, so that is why it is inversely related. The fitness is actually increasing whereas, the objective function is actually decreasing. One thing that you need to notice, we had calculated the probability using this equation right.

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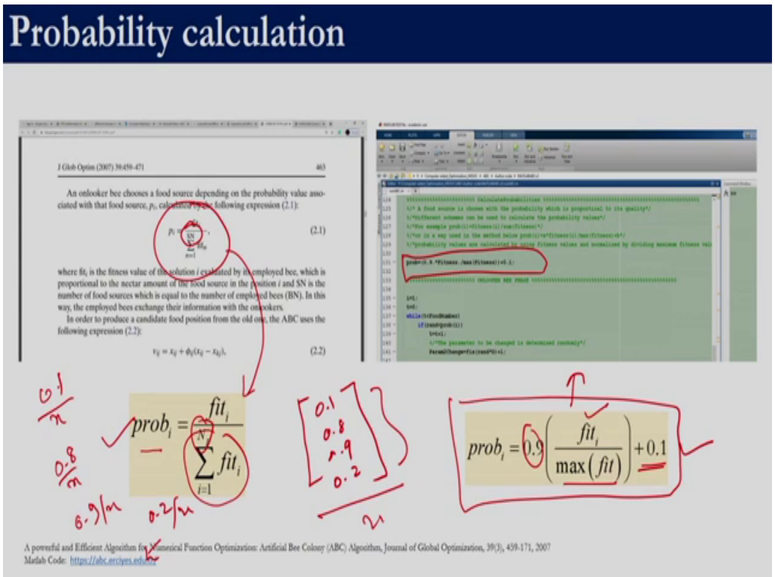

So, if we have N P members the fitness of the i th member divided by the maximum fitness into this 0.9 plus 0.1 right. This expression we have actually obtained from the MATLAB code which has been given over here by the authors themselves right, but if you actually look into the paper of artificial bee colony optimization, this is how probability is calculated. So, it is fitness of i divided by summation of fitness of all of the members right.

So, if we have let us assume the fitness to be 0.1, 0.8, 0.9 let us say 0.2 over here right, so this is the fitness of four members. Let us say we have four members and this is the fitness right. So, this denominator is nothing but summation of this four values right. So, for first member, it will be 0.1 divided by whatever summation; so let us assume the summation to be x. So, for the first member the probability is 0.1 by x, for the second member it is 0.8 by x, for the third member it is 0.9 by x and for the fourth member it is 0.2 by x. So, this is how probability is to be calculated as per the paper right.

So, over here this is the expression that expression we have just changed it into our notation, there they use S N, but since we are looking at multiple algorithms we thought that we would stick with the consistent notation, so that is why we have used N p right. So, this we have demonstrated to you how to calculate right. So, this is a minor difference between what we are using and what has been reported in the paper right, but even in the code of the authors, this is what is used right.

So, probability equal to 0.9 into fitness divided by maximum fitness plus 0.1 right. So, if you go back and read the paper you will find this discrepancy, but this discrepancy is because inherently there is discrepancy between what the author has reported in the paper and what they have used in their code right. So, if you want to use this, you can use this everything else remains the same, it is just the way that we calculate probability is different.

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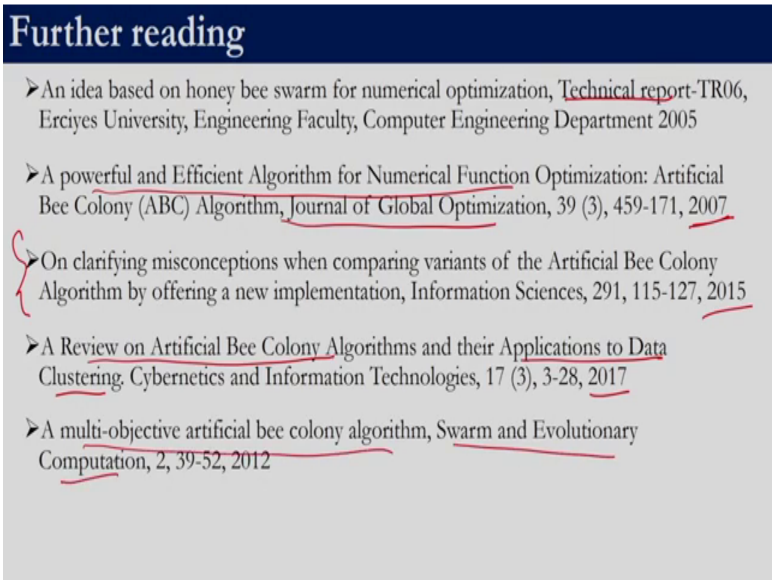

So, if you are interested in further reading on artificial bee colony optimization right, you can look into this technical report. So, there they explain in much greater detail particularly the motivation of artificial bee colony optimization. So, this is the paper in which ABC was first reported, it is in the journal of global optimization right, again wise would strongly recommend you to look into this paper right.

So, artificial bee colony optimization came up in let us say in 2007 right, 8 years down the line they had to publish another paper. Just to show that many of the researchers who have been using artificial bee colony optimization between 2007 and 2015, not all of them were implementing the original ABC as proposed by their inventors.

When you use these algorithms, now that we have seen the five algorithms; when you use this algorithms, you need to be extremely careful right. Particularly if you are comparing multiple algorithms, then you need to be very careful that the termination criteria is identical for all the algorithms right. So, the number of iterations cannot be a termination criteria. So, as we have seen previously given a specified number of iterations, different algorithms consume different number of functional evaluations right.

So, you can look into this paper right. So, recently there was a review of artificial bee colony optimization and particularly their applications to data clustering right. So, you can look into that review paper also. If you are interested in multi-objective artificial bee colony optimization, you can look into this paper which appeared in the journal swarm and evolutionary computation right. So, with that we will conclude the session of artificial bee colony optimization. In the next session, we will look at the implementation of artificial bee colony optimization using MATLAB.

Thank you.