Artificial Intelligence
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Lecture No. - 15
Optimization Ii (Genetic Algorithms)

Let us go back to nature today, and remember we are doing optimization. So, does nature to optimization?

Student: Yes sir, yes sir, n colony optimization.

Somebody said yes. Yes, but we are not going to say n colony optimization, that is an algorithm that if you, may not get time to look at the today probably in the next class essentially, what is it, what is optimization happening there?

Student: Natural selection.

Natural selection, which is different from n colony optimization.

N colonies are known to is very good at finding food, if you leave a anything which edible you know, a biscuit or lump of sugar then, you can be sure that you know, within some time ants would be there, somehow they find it, you look at that in the next class may be I think, we will go to natural selection.

So, you can think of, of course, many of us considered human beings to be the pinnacle of life forms. So, we can say, we have come through a process of natural selection which of course, is attributed, the theory is attributed to Charles Darwin and you must have heard about the well known phrase, survival of the fittest, but what is nature doing essentially.

So, let us set of step back and see what is it trying to do? So, we can say it is trying to design live forms essentially. So, we have whole wide spectrum diversity of life on earth starting with cockroach, not starting with a cockroach, starting with you know, some amoebas, and ants, and birds, and animals, and so, we think that we are on top of it. What would be the objective of this design process, what is it trying to designed?

I mean if of course, we are trying to sting by sting nature is like thing to design something. Have you heard, how many of read anything by Richard Dawkins? Which one, which book have you read?

Student- The God delusion.

The god delusion, that is one of his most recent books I think, in which he says that he is kind of anti institution of religion, but any way his one of the earlier books was called the blind watch maker, it was quite a well known book, it quite a hit in that time. The argument in the western society was whether or not there was a god who created the universe and the earth and human beings at the center of earth.

And the argument was that, you know that everything is so perfect, the world is so perfect, we just have the right amount of oxygen in our air and we have everything that we need, we have water flowing and we have day and night and all this kind of stuff, that there must be a watch maker. If the universe functions so perfectly like a Swiss watch for example, Switzerland is known for its mechanical watches then, it could not have come out of random.

So, this is an arguments against Darwin. Darwin said that we came out of evolution. So, people would aghast at the notion that we have evolved from apes. Sometimes I think that the apes might be more aghast at this notion. The idea was that, such a perfectly functioning world must have a maker behind it of the watch maker, like a watch maker.

But Dawkins and Darwin, they are all on the same side, they say that there is a built in ratchet mechanism. In a sense that if you find some improvement somehow then, that improvement sticks around essentially. So, there is a ratchet mechanism, if you by mistake or by some chance event designed something which works then, it has a tendency to persist.

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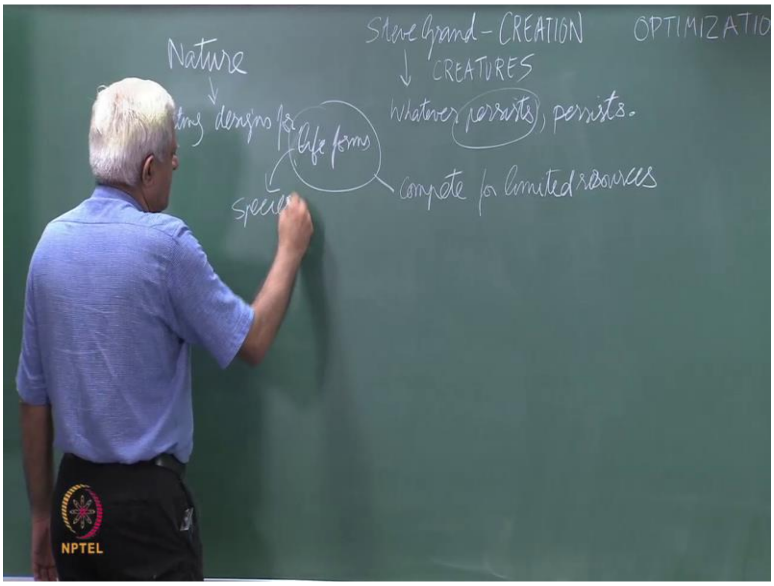

There is a person called Steven grand is somewhere in the UK, he wrote this book call creation, which the institute has one copy which is with me at this moment. If you want to have a look at it, you can come and borrow it I think. You know I have heard about creatures, these are computational ((Refer Time: 06:00)) of people.

Life forms that you create in the so called cyber world, artificial fish, artificial this thing, artificial that, in the creatures I means. So, the term creature, if you just look up creature on the on the net, you will find some sites, one of them is maintained by Steve Grand. So, he is the, in this book that he wrote, he wrote something very profound at least I found it profound and it is that whatever persists.

Just imagine a random world where there is no watch maker, there is no creator, he says that see this is at this is a kind of tautology whatever persists, persists. Obviously, I mean that is what we say well, this is the fundamental thing behind how life has emerged out of chaos I might say essentially. I mean after big bang I suppose there were chaos for the lot of time and so, if you follow what Steve grand is saying then the, you can say an equivalent statement at the goal of life.

So, if life is you know some driving force or something is to live, and by live essentially e mean persists essentially. But there is no, one cannot describe some external high level goal to life, it just happens at we happen to persists so, we are their essentially, a goal of life is simply to be there essentially. Now, you can say that nature is experimenting, I do not really need to say.

Nature is, again when you say nature we do not want to anthropomize again, nature is not like god or some devata or somebody we doing something. Nature is some term that we use for everything that is around us. A set of creating different designs for life forms. At least we can ((Refer Time: 09:01)) like that nature is doing it, see very often people for the sake explanation describe a design motive behind things which are happening.

So, why did we develop a neocortex? Because you know, it helped us reason at a symbolic level I think like that essentially, but of course it is not, there is no motive behind it. It just so happens that we walled a cortex which allowed us to do thinking so, we are thinking essentially. So, which is what Steve grand says? Whatever persists essentially. And this a basic mechanism behind nature's effort to design life forms, and the goal of this life form is nothing but to live, to persists essentially, and that is our ((Refer Time: 09:56)) instinct to persists.

So, if you what walk out of this building and you see somebody with a gun pointing at you, the first thing you do is ((Refer Time: 10:07)), that is our inbuilt nature to persists essentially. And if you think of it in combination with what is Steve grand say just imagine that in the initial chaos there were only atoms floating around then, molecules form then, molecules combined into forming bigger molecules.

And then, eventually organic molecules came into being which has this tendency of surviving and sticking together and then, of course making copies of themselves and so on and so forth. Things which happened, happened and those things which survive, survive which is what Darwin called as survival of the fittest essentially. Of the many things that you are trying out, some things survive and they are the fittest essentially.

So, when you say survival of the fittest, one has to you know look at it from a careful perspective, there it is not as if your first determining fitness and then talking about survival. It is a other way around fact essentially. When you say survival of the fittest, what we really mean is that, the once who survives are the fittest essentially.

Now, these life forms compete with each other. What do they compete for? They compete for whatever resources that they need essentially, material resources, primarily material resources like food and so, on. And there is a limited amount of food and remember that food is a building, food provide just a matter for building our bodies essentially. So, if a child grows up it is by eating food and you know having that food transform into various things inside his system.

So, they compete for resources which mean that, some life forms succeeds and some life forms fails essentially. Just imagine that there is a bunch of people in a room, let us say there are 50 people in the room and there are only let us say 20 cakes or something like that, and of course you cannot divide the cake such you know.

Then, there is some mechanism by which people are given cakes. So, some 20 people will get cakes and 30 people will not get a cakes and to be taking a next game point of you the is a very extreme you, but in some time what is happening in the nature especially that different life terms are like different species.

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And nature is experimenting again I would like to set of question that we say nature is experimenting it, nature is a not a like a person setting of a there is a experiment and these things a happening on their own and making view them as experiment essentially.

So, how is nature doing? It is nature is doing generate and test. It is searching in, remember that we started off by saying for the basic paradigm of search algorithm that we had look at this generate and test. Generate a candidate and test, you know the candidate, the solution that we had a smaller problem, nature does not have a goal.

So, we do not have a goal test function, but by testing we mean something else here. So, what do you mean by generate? So, there was a French poet, I do not know remember his name unfortunately right now whose ((Refer Time: 14:03)) he said this process that a world, this process of evaluation is that one makes up the combination and the other chooses.

So, there are two forces which are applying, one is which is making up the combination, which we will call as generate, and test is basically other chooses. So, these are two things essentially. What you mean by the other chooses? Listen that there is a force with natural selection which says that it will select some people who will survive and will not people some creature will survive and some which will survive essentially.

So, there were, there were selection happening which is like a text function and there is a process of generating, creating new features is happening. And so, just imagine this world in which new creatures and by creatures I mean individuals, I been created all this time. And each of them is competing with other creatures, they may be from the same species or they may be from the different species.

But everybody is competing for food essentially. So, at the fundamental limit, I mean that is so strongest basic urge is to eat essentially, and that, where that we cannot survive essentially. How does these combinations come out? Let us talk about other chooses before we do that essentially. So, just imagine that there is a rabbit o there is species of rabbit and there are these rabbits on field and they are being chased by foxes essentially also let us say on the same field. So, there is a relation between them, the fox species and the rabbit species. And I will use this as a, which denotes the positive influence on the population essentially.

So, this is like some people call influence diagrams. How does the population of rabbits influence the population of foxes? We say that there is a positive influence, beside the more the rabbits are there out there, the more the foxes will get to eat them and therefore the foxes will survive essentially. So, the more, there is no famine nor ((Refer Time: 16:54)).

And of course there is a negative influence of the population of the foxes and the rabbits essentially. There of course there is this whole eco system out there. So, when you have foxes then, you have let us say tigers, when you have tigers you have let us say bacteria.

And ((Refer Time: 17:24)) familiar with this necessity you know. The birds help pollinate the flowers and there is the dependence, the whole eco system there, it is a stable eco system then, which every population is having some influence on other population essentially.

So, now a day's people one hears that is suddenly bees vanish from this world, you might have heard some news item. The bees vanish when it will affect certain food chain which means we stop getting things of a certain kind. So, we have this stable eco systems, but we also have catastrophic on the way essentially.

So, like 60000 years ago or whatever when the predominant life form was we ((Refer Time: 18:20)) so on. And mammals were you know small smelly creatures hiding from ((Refer Time: 18:25)), but suddenly something happened and we do not quite know what happened. And ((Refer Time: 18:30)) became extinct and mammals become prominent and then, human of course the most prominent of those all essentially. So, we are talking about competition.

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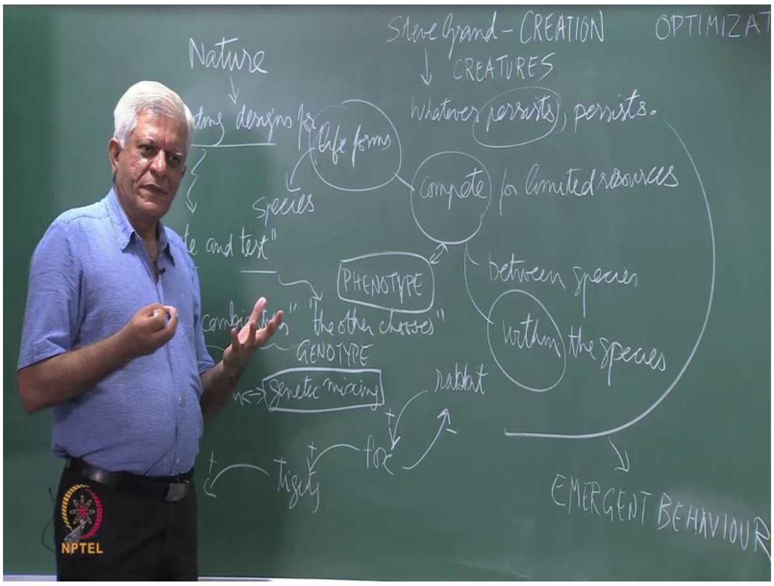

Thus competitor competition between species. So, let us say we have rabbits and cows and goats and sheep, all trying to go for some ((Refer Time: 19:03)), I do not know whether the rabbits eat grass, but at least cows and goats and sheep all competing for grass essentially so, there is a computation between species. And there is also a competition within the species. So, we are going to focus on this, competition within the species. What do you mean by this? So, just imagine again this bunch of rabbits on this field and let us say 2 or 3 foxes come running and the rabbits all run away.

Or more likely if you have watched some ((Refer Time: 19:39)) it is some set of bunch of deer and one or two lions come running then, all the Deers are running away. And the lion catches a in some sense of weakest one essentially, the one which cannot run away fastest so, the lion catches the weakest one and the fastest deer they escape essentially.

To ((Refer Time: 20:02)) leave to tell let us say another team. So, there is competition within the species. So, if there is a prey and the age of species which is preyed upon, there is competition within the species to escape or to catch ((Refer Time: 20:22)) essentially. So, again the strongest lions will be able to catch deer, by strongest we mean fastest so, whatever is the good quality, the fastest rabbits will be able to escape.

So, fastest is just a, just a actually that I am using it, it is not necessarily fastest, it could be something else, cleverest or you know something which can disguises itself very well or any kind of things that nature adopts to. So, there is a constant battle between the predator and the prey essentially, both are involving.

How are they involving? Because within, the competition within the species is selecting better and better individuals, which are propagating there propagates in some fashion to the next level essentially. So, that bring us to one makes up the combination. So, what is the combination that nature has adopted? It is of sexual reproduction and what is it lead to it? Leads to genetic mixing, this is a key. How does nature experiments with different life form?

It mixes up genes of individuals. So, every creatures is at least from this earth has born of two parents and inherits the genes from both the parents. And there of course there is this whole theory of which are the dominant ones and which are the recessive once and that kind of stuff. But eventually there is a experimentation with newer or newer combinations of genes that life is doing.

So, we are, we up, we use the term genotype for this. Nature is experimenting with the genotype of, so, genotype is like the design of a creature. So, of course you know amongst human being we say that this child has inherited the height from one parent or both parent or something like that essentially or colour of hair or colour of eyes, all kinds of things that you have inherited from parent.

So, you inherit some from one parent some from another parent, and within a human family one sibling may brighter than another sibling and things like that because they have inherited different things from different parents and so on. So, we have this whole churning of the genes which is happening then with the genotype.

And at this other level which we call as a phenotype, it is competition is happening. It is a physical creature which is competing on the, in the real world essentially. So, what is this we have to do with the optimization? We want to look at a method of optimization which is kind of takes inspiration from this world of natural selection.

So, this whole idea here is that of emergent behavior and the idea of emergent behavior is that you put together simple parts to give you a more complex things essentially. So, nature is, it is this building blocks of life, which are called the genes that we have, which is trying out with different combination of genes and letting them loose in the world. And if they survive, they survive.

So, they are competing for food they are competing for mates, they are competing for shelter, the once who manage to win they will pass on their genes to the next generation and in the process we will have in some sense fitter population. So, the population of rabbits becomes faster, again I am using faster just as we are talking about it. As they evolve they become faster, at the same time foxes are becoming faster. So, there is a sort of war going on between them essentially. So, emergent behavior is this approach to optimization, it says let us try to do this so called random mixing of genes.

So, again this is a randomize process, and see if we can somehow keep track of the best one. So, what is the basic idea? You allow for random mixing of genes and you have a mechanism for keeping the best. So, this thing, one makes up the combination and the other chooses. So, there is this two processes, one is combining things which generates and test, one is combining things to produce a new creatures and there is some mechanism which is judging. So, which creatures are good and which creatures are bad and allowing them to survive essentially. And in the process, we want to see if we can improve upon the designs and come up with the optimal design, whatever optimal means here.

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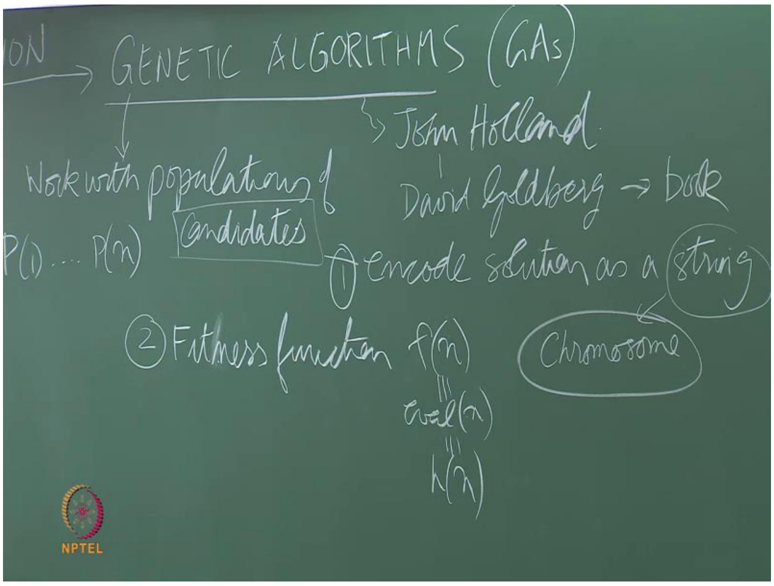

So, this idea of optimization is called by the known name of genetic algorithms, also called GAS for example. And they were devised around 1980 or so by John Holland, and one of his students call David Goldberg is still very active in this area. And in fact, he has written a book which is called genetic algorithms or something like that, which is a very popular book on this topic essentially. So, the idea of the genetic algorithms is that they work with populations.

So, the first thing of course is you have to first appears to encode. You are working in the solutions space so, you have to encode a solution as a string so, I just used a term string. But if I were to be from this community, instead of string I would say chromosome. So, it is a chromosome which start of contains the design decisions that you are going to work with, but will tend to think of it as a string essentially. So, the first thing is to encode the solution as a string. So, the simplest example that we can think of is the sat problem where the solution is just a bits string essentially or TSP can be encoded as some sort of string.

And for any kind of a problem that you want to solve with GAS, you have to encode it as a string essentially. So, this population is a population of strings essentially. So, this population p 1, p n let us say we have n population of n elements inside it essentially.

Then, the next thing you want to do so, the first thing is to encode.

Candidate solutions are string essentially so, essentially what are we trying to do that we will work with the population of initial randomly generated candidates. And then, try to mix up the strings to produce new candidate which will hopefully be better essentially. And how do we decide better?

So, we do not let loose this things in to the designs in to the real world as nature does. We devise something call a fitness function, it s a f of n which is the same as what we call eval of n which was the same as what we call of a h of n start with.

Remember that we came to this world of optimization by starting with a heuristic function and that we said the evaluation, we call it the evaluation because that is what the optimization community calls it. And in particular the genetic algorithms can be calls it a fitness function essentially. So, with every candidate we have a fitness value, which tells us how good that candidate is essentially. I have to see how much time we will have. So, there are, there are 3 basics steps to a genetic algorithms so, we start with a initial population P.

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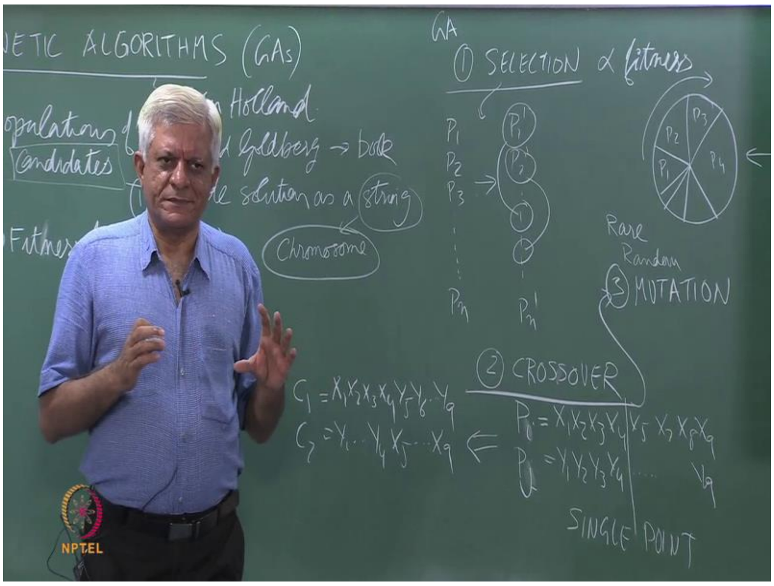

And then, the first step is the so, this is the preliminary what we are doing designing the system, but the algorithms itself, the GA algorithms has 3 steps, the first step is called selection which is proportional to fitness. So, unlike the real world, genetic algorithm does cloning essentially so, just creates copies of candidates.

So, what we do? We have these candidates p 1, p 2, p 3, p n and for that each of them we have a fitness function, and we reproduce this population, clone this population by clone individuals in this population, in proportion to their fitness which means we will make more copies of fit candidates and less copies of unfit candidates, less meaning 0 essentially or more could be 1, 2, 3, 4, anything.

How do we do this? We create, it is a similar process to how do we create this whole random process. We can think of it as a ((Refer Time: 33:34)) in which we assign sectors proportional to their fitness in is p 1, is p 2, is p 3, is p 4 and so on. The amount of angle they get is proportional to the fitness value so, p 4 is very fit so it gets a large angle, p 3 is and so on and so forth. And we just sort of rotate it randomly and we have a some pointer, where ever it stops that candidate gets to reproduce once.

So, we rotate it let us say P 4 it stops at P 4. So, remember that this is something which can rotate and we give it a random rotation like ((Refer Time: 34:26)) and observe where the needle is. We do this n times and generate n new, a population of n new elements. So, let us call it P 1 prime, P 2 prime, P n prime. So, this is the first step, selection. We are just making copies of the original, but which the difference that everyone does not get to make a copy.

Fit members have a greater chance of making more copies that you can see there is very lightly that P 4 will stop at, the P 4 will be created, will stop at this, at this arrow more than once essentially. So, P 4 may get more copies, this thing whatever it is here will probably get 0 copies or something like that. But of course it depends upon chance, the randomized algorithm, we cannot say deterministically what will come about it. All we are saying is that these rule wheel we will spin n times and whichever names of the candidates appear against the needled we will create a copy of that.

So, we will create a new population of n candidates and you can see that this population, the fit members will have a greater chance of appearing more than once, and unfit members may get the wheeled out essentially. So, it is a little bit difference of what happens in nature, we do not create the final thing, final individuals and out, and send them out to compete.

We allow them to clone in proportion to how good they are essentially and they can get to clone more than once. After that is the second step is called in ((Refer Time: 36:18)) of the j a community, it is called cross over. And what we do here? We randomly pair this population.

So, for example, we may pair P 1 with some other one, P 2 with somebody else and so on and so forth. We randomly pair of these elements of this new population and we randomly mix up their genes, that mix up of genes is called cross over and that is just a term that we use. So, the idea is something like this for example, let us say P 1 is a made up of let us say gene which we call x. Let us say that there are 9 components to this.

So, for example, if it is a sat problems with 9 variables then, there will be 9 bits essentially. So, we are just calling them x 1 to x 9 then, P 2 so, let us say p 1 is been paired with p 2, or you can call it P i and P j. Since, I am using, that is a P i and P j and let us call this y 1, y 2, y 3 up to y 9.

So, where these 2 parents so, p 1 and p i and p j are the two parents which have been mated together by this random process of mating. We just randomly made two elements and then, we wanted to the mix up their genes. So, one way of doing it to just draw line somewhere and generate new children. So, c 1 is equal to we take x 1, x 2, x 3, x 4, from here and then, y 1, y 5, y 6, y 9, from this essentially. The other child get the other genes so, this will get y 1 to y 4 and x 5 to x 9.

This process of mixing of genes is called cross over, and you can see why it is called cross over is that you know some genes are crossing over from one candidate to the other and vice versa policy. This particular cross over is called single point cross over, but you can devise other cross overs, I mean there is no, nothing ((Refer Time: 39:17)) about this single point of a, just to illustrate we have done that.

So, we will randomly choose a point here and everything on one side will go to one child and the other side will go to the other child and likewise for the other distinguish. So, we can imagine a sat problem in which you get first 4 bit value from one candidate, one solution and the, and the next 5 bits from the other parent essentially, in likewise for the other child essentially.

So, you can see this 2 components of it talked about, one makes up the combination is being done by the cross over part, and this the other chooses is being done by the selection part essentially. And we basically put this in to a loop essentially. You take a population generate a new ((Refer Time: 40:11)) population, do cross over and go all over again.

Now, for the sake of completeness that sometimes a population may be lacking a gene essentially. So, how do, new kind of species emerge out of this process essentially? We have a third step so, the first step is selection, the second step is cross over, and the third step is called mutation. And by mutation we mean random and not only random it is a rare event. Every once in a while you change one gene randomly in one individual so, we had this whole population of n elements here which is reproduced according to fitness then, we do cross over to make sub genes. And then, we make some random change in one candidate.

So, this is a just to allow for new genes to come in or if a so, for example, if you have a population of this sat problem let us say these 9 variables sat problem and you have a population of 50 candidates and it so happens that all 50 of them have their 3 rd bit as 0 essentially. Now, we can see that if all 50 of them as a 3 rd bit as 0 then, however much we do this churning the 3 rd bit will remain 0. Because both parents are going to have the 3 rd bit as 0 and this cross over operation will result in the 3 rd bit means 0 in both the children essentially.

So, you have lost that 3 rd bit in some sense. To create it to something like that, we have a random change somewhere in mutation, but we do it very rarely essentially. These are just for the sake of completeness. So, the primary processes is selection and cross over, but there is a process which once in a while we do which we make some change in some candidates essentially or random change in some candidate.

So, when we talk about sat we are talking about bits, but otherwise we have to do this encoding in to the production in a low careful fashion. And then, we have to because you know one bit is nice, but most, for most problems you cannot have a components represented by 1 bit, you will have a chunk of bits. Then you have to devise a algorithm to move around chunk of bits rather than you know just single bits and then, you have to be careful about mutation that you can change mutate something in to something meaningful and not something which is not meaningful ((Refer Time: 43:12)).

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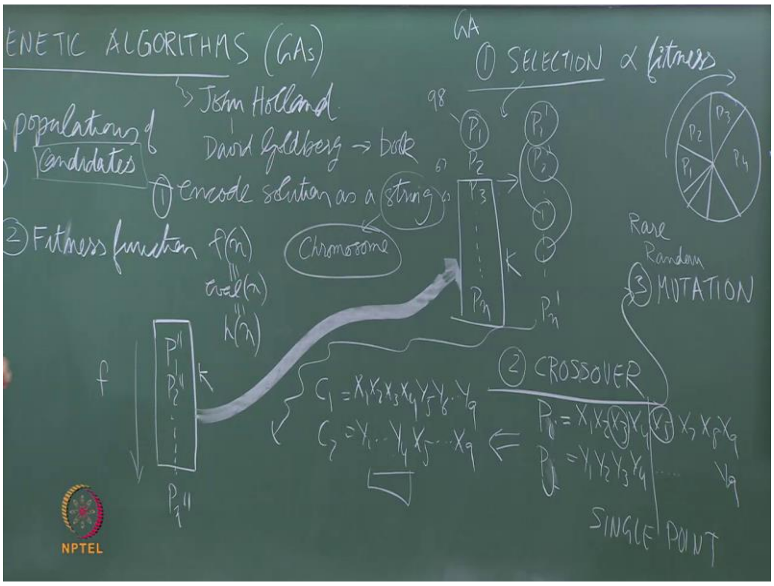

So, from this we get a new population let us call this P 1 prime prime, P 2 prime prime, P n prime prime. So, the first P prime population we got by cloning and this P prime prime population we got by cross over essentially and let us say mutation has been taken into0 account here essentially.

Now, there are variations to what people do at this stage, if I assume that these are sorted on fitness values then these are the best on the, just for the sake of processing, these are sorted, the most fit numbers are here and the least fit numbers are here. So, what one might do is that, one might take the most fit k elements where k is a little bit smaller than n and we place it in the original population by the least fit k elements.

So, what are we doing here is that we started with this population of n elements, and let us assume that they are sorted according to the fitness here just for sake of allowing me to draw this diagram. We clone the entire population to get a new population and when I say entire population, it means that you get representation in proportion to a fitness value.

A very fit member will get more copies, and a very unfit member will get less copies or 0 copies, some will have to have 0 copies then, you do this cross over, mix up the genes, took arrived at this population which is now mix up the genes of the old ones. Now, some people would argue that what if there was a very good candidate here. This P 1, let us say its fitness value is 98 or something like that, and everything else let us say began with 67 and 65 and so and so forth. Are not you losing your candidate with fitness value 98 essentially?

To, create it to this, one way to devise this, is that you take the most fit to most fit candidate in this new population and add them or substitute this least k fit population with this worst k fit population. Then, keep those few top from the original population here, we just design question.

You can say k equal to n and that is what really happens in nature essentially. I mean nature does not allow one to live in definitely essentially. If you want read some of these work by Goldberg in fact this book by Goldberg then, he goes on to study as to how should we design these encoding scheme so, that good genes in some science have a tendency to stick together and carry forward essentially.

So, let us say if we have this some or let us say this sat example with 9 genes or 9 variables. And let us say some good values we have found in some candidate where let us say x 3 and x 4, we have found what should be the value in the ultimate solution. How do we kind of make sure that, they stick around together essentially. So, Goldberg talks about things like cluster of jeans and so on which will so, he calls, he has a some notion of saying that if you have gains which sort of a design kept together then, they will stay together. They are more likely to be not split, broken up essentially.

Essentially one of the things with this genetic programming or genetic algorithm community is concern with is that is there some way we can ensure that when a candidate has good genes, we can ensure their good genes stay together essentially. And they do not get broken up and divided in because in this case as we can see, it is a very clear cut exchange of genes essentially.

Every genes of parent for example, if x 3 is a good gene, it will go to exactly one child in this way, in this scheme of thing because c 1 will get x 3, but c 2 will get y 3 essentially. So, it is not as if, as it, as it happens in the real world, their good gene can go to both the children, in this case it will go to only one child.

So, if x 3 and x 5 for example, happen to be good genes, how can we sort of ensure, how can we ensure that you know good genes stay together? It means they stay in one candidate only essentially. So, this is a kind of stuff that Goldberg has looked at, you will not go in to those details here, but you can see that this scheme of things where we select the k best and replace the k worst with this k best is in some sense trying to keep the good candidates still alive essentially.

Of course this even prime prime which is a totally new candidate because it is got generated by the cross over. It could be P 1 cross over with some other elements is totally different then, it could in fact be better than 98 it is quite possible essentially. That is a hope that as we mix up genes, the candidate with the good genes will propagate their genes more often and we are showing this by the process of selection which is proportional to fitness essentially.

So, I think I will stop close to here, if there any question you can answer them. In the next class when we meet, I will take up an example again from Goldberg’s book to try and give you ((Refer Time :49:55)) behind genetic algorithms. But I also wanted you to think about our, not our, the community’s favorite problems which is the travelling sales man problem. How can we use genetic algorithms for solving the travelling salesmen problems? So, either way outside let me say that because the way that we have encoded TSP so far is that let us say we have 9 cities.

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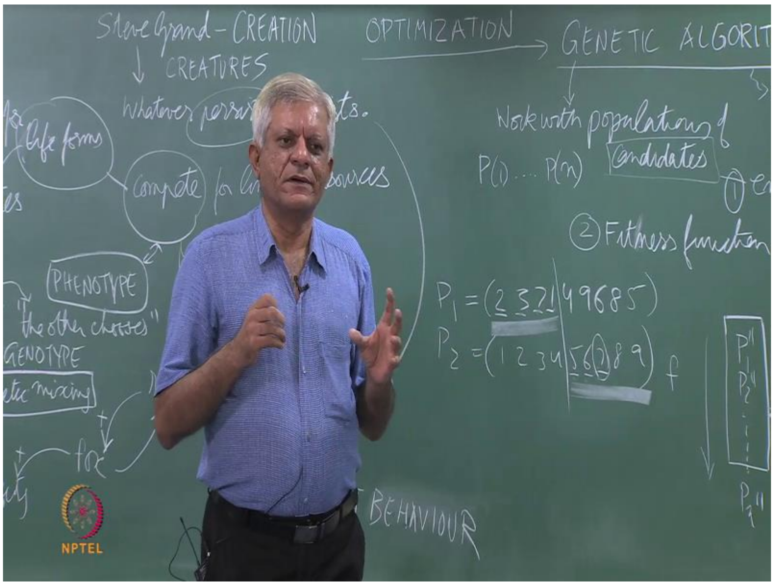

So, let us say parent 1 is 1, 2, 3, 7, 1, and parent 2 is let us say 1, 2, 3, 4, 5, 6, 7, 8, 9. I have these two parents which means I have these two towards. So, here you go from 2 to 3, 3 to 7, and 7 to 1, and 7 and so on. Here you go for 1 to 2 and 2 to 3 and so on so forth. You can see that the single point cross over will not work here because if I just take a random point let us say here after 4 cities then, what I am doing? I am going from 2 to 3 to 7 to 1 to 5 to 6 to 7, you can see I have closed the loop even before, I am not allowed to that.

In a travelling sales men problem, the solution must be a permutation of the cities, but if I do, if I do this single point crossover and say this is, I will take this cities from here and this cities from here. What I get is not really a candidate tour because this tour has a loop inside before.

So, again from 2 to 3, 3 to 7, 7 to 1 then, you are going to 5 to and then to 6 and then, you are coming back to 7. And you are never visiting some cities, you never visiting 4, you never visiting 8, you never visiting 9. So, that is not a candidate solution. What we want is a population of candidate solution, and what is a candidate solution? In which every city is visited exactly once and then, which means basically it is a permutation of the number 1 to 9 and this sequence of numbers that is not a permutation because 7 is repeated and 4 is missing essentially so, it is not a permutation. How can we devise cross over operators for the TSP essentially.

So, this has, this question is in two parts. Can we think of a different representation of that candidate solution, and can we think of different operators essentially, different cross operators? And there is been a considerable amount of work done in trying to experiment with different kinds of cross over operators.

So, we generalize the notion of cross over to say that you take two parents, and you must somehow get two children which are generated from those two parents essentially. So, these two things we will do in the next class to start with. Look at the example of genetic algorithms for a simple problem and then, we will look at how TSP can be solved using j s and I wanted to give some thought to at before come to the next class because we will stop here.