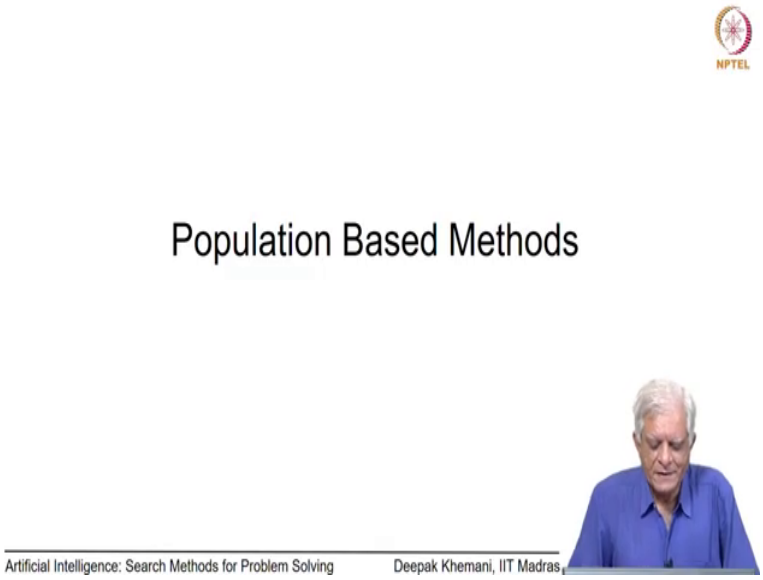
Artificial Intelligence: Search Methods for Problem Solving

Prof. Deepak Khemani
Department of Computer Science & Engineering
Indian Institute of Technology, Madras

Chapter - 04
A First Course in Artificial Intelligence
Lecture – 29
Population Based Methods:
Genetic Algorithms: Survival of the Fittest

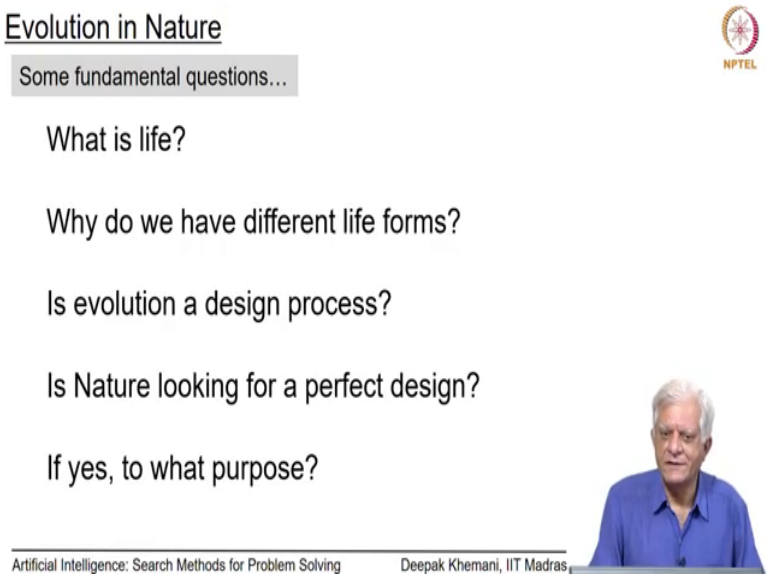
(Refer Slide Time: 00:14)



So, welcome back. Let us continue our study of stochastic local search algorithms. Remember that we arrived at this place because of the fact that our search spaces can be humongous and the simpler approaches that we saw may not always succeed essentially. And, we also saw that we since we came to Hill Climbing and then moved on to simulated annealing that we have converted the problem into one optimization problem.

And, today we want to look at population based method which is very popular in the optimization community and this is the method which has taken inspiration from nature because nature has also one can say embarked upon a journey of improving life forms. So, we know that different species evolve continuously and we want to take motivation from that.

(Refer Slide Time: 01:27)



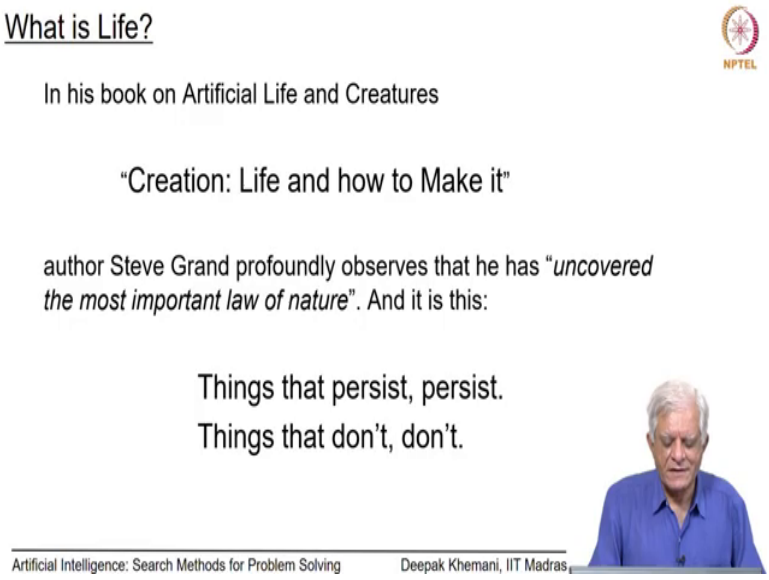
So, let us start with some basic questions. So, the kind of questions we want to ask is what is life? Essentially if you look around you find all forms of life coexisting and we are, but one example of such a life form.

So, what is life, how did it come about, what is the goal of life if any and so on. So, these are some of the questions that we want to very briefly look at. Why do we have different life forms essentially no. So, you have millions of species now to speak of the individuals which belong to each of those species. Is evolution a kind of a design process? Is nature doing some

kind of experimentation to see which are the life forms which are good, whatever good means here?

Is nature looking for a perfect design essentially ok? But, the question that arises is if yes, then what is the purpose of designing these life forms. Why do we have life in the first place how come we have life in the first place? And, secondly, why do we have. So, many different life forms and what is going on in the world essentially?

(Refer Slide Time: 02:49)



So, let us start with this question what is life and I will draw your attention to the fact that over the last 15 – 20 years or may be a bit more people have been involved in creating what they called as artificial life.

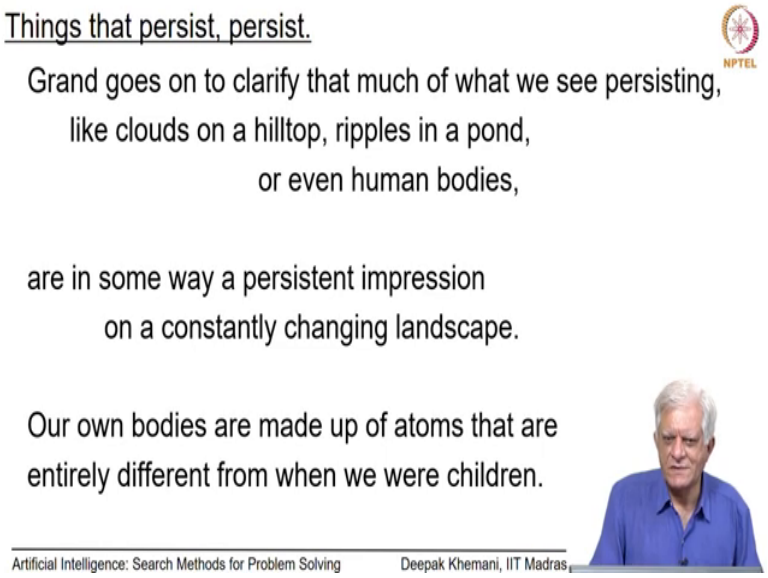
So, basically artificial life is something which kind of mimics or looks like natural life except that it exists inside your computers on your screens and so on and in many ways they tend to behave like normal life forms. So, in many countries in the world artificial pets became very popular many years ago and so much so that for example, people would get attached to their artificial pets and you know rush back home from office saying that I want to feed my I have to feed my pet and so on essentially.

So, one of the earliest people who was involved in this was this British computer scientist called Steve Grand and he wrote this book on Artificial Life and Creature. So, creature is a name that one gives to these artificial life forms that populate your screens essentially. So, the book is called creation with the subtitle or subtext that Life and how to Make it.

So, Steve Grand very profoundly observe that he has uncovered what he calls as the most important law of nature and the law is this, the things that persist, persist. Things that do not, do not. Now, if you want to go through his book this book Creation I think around page 40 or 39 or 40 or something you will see an explanation of this law as he calls it things that persist things that do not do not.

Now, on the surface of it looks like a tautology like obviously, things which persist will persist and obviously, things that do not do not. But, if you think a little bit carefully about what he is saying you can see that this is a genesis of life forms because life is a form of persistence essentially.

(Refer Slide Time: 05:33)



So, let us take that up he says things that persist, persist and he goes on to say that what we see as persisting for example, you see clouds on a hilltop ripples in a pond or even human bodies I mean human bodies are collections of large collections of atoms which together somehow stick and persist in the form of a human body. He says that in some way a persistent impression that all these things that clouds on a hilltop.

So, for example, in his book he describes that if you want to go on a hilltop, where you see a cloud which seems to be hanging on top of the hilltop when you go there you will see that there is a tremendous amount of breeze there. So, it is not as if the cloud is physically stationary on the hilltop, the breeze is kind of flowing over the hill, but as the moisture rises to the top of the hill it condenses and as it moves on it loses its condense form.

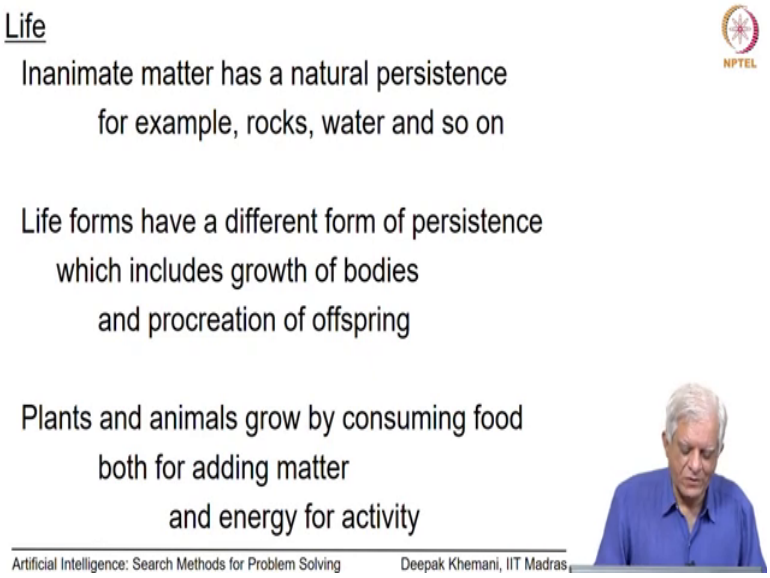
And, what we see is a cloud which is stationary on top of the hill whereas what really happens is that there is a lot of moist air blowing over the hill and some of it temporally appears like a stationary cloud. The cloud itself appears stationary, but the wind is moving.

There is a similar phenomena in ripples in a pond you see ripples it appears as a ripples are moving, but the water is not really moving. It is a wave of energy which is moving and he says that even human bodies are like that the impression they that what you call a human body is a persistent impression of a constantly changing landscape.

So, he says that our own bodies are made up of atoms that are entirely different from when you were a child. Now, obviously, you know that human bodies grow out of a single cell level egg being fertilized by a sperm and then out of that egg and sperm the union of that the whole body grows essentially. So, obviously, our bodies are made up of atoms and atoms keep changing.

So, the example that one gives is that the atoms in our bodies keep changing, but somehow the notion of our body, the notion of our cell so, notion of a person is persistent essentially. And, so, what persist is this notion not a physical bodies physical atoms that make part of their bodies.

(Refer Slide Time: 08:33)

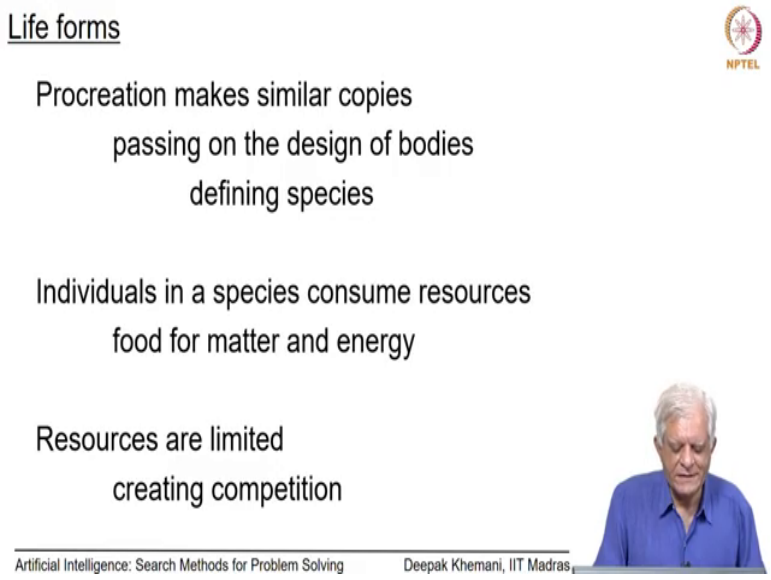


Now, inanimate matter has a natural persistence for example, rocks and water and so on. They just exist and they continue to exist and so on. But, life forms because they are more structured, they are more complex have a different form of persistent which includes for example, the growth of the bodies all animals, all trees, all plants, all humans everything grows and all life forms one can in fact, say that you can distinguish life forms from inanimate matter by the process that they procreate and create copies of themselves and you know, therefore, propagate the species and so on.

Now, plants and animals they grow by consuming food in some form or the other. And, this food is used both for adding matter to their bodies in the sense a body is grow and also for energy for any activity that they do. If you see a dog running around in your garden the energy

that it needs for doing that comes from the food that it eats and likewise for all life forms essentially.

(Refer Slide Time: 09:46)

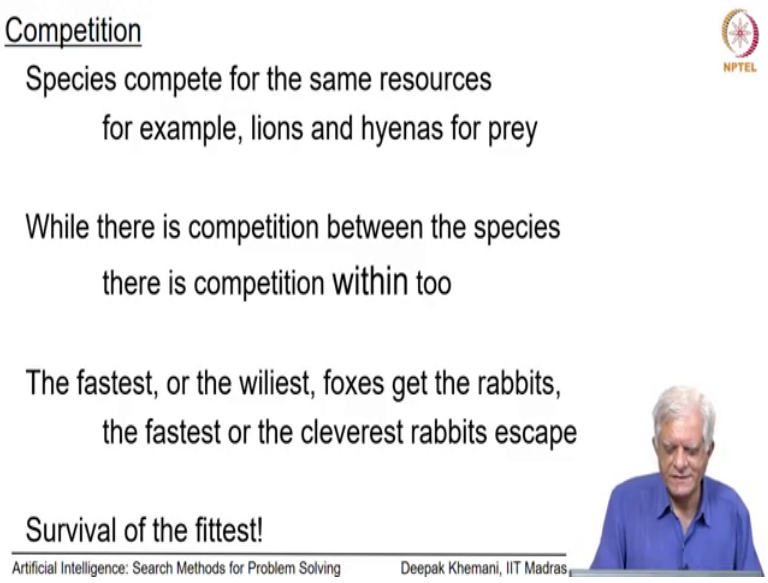


Now, the question is why do we have so many different kind of life forms? Now, the act of procreation makes similar copies. So, dogs produce baby dogs, deer produce baby deer, human produce baby humans and so on and so forth. In some sense we pass on the design of our bodies and in the process we define the species that we belong to.

So, the species exist as a concept is a class as a group of individuals which kind of propagates itself, but it is a individuals in the species that consume resources. So, each physical entity whether it is a dog or a cat or a deer or a mouse they consume energy to sustain themselves to survive and so on. But, the resources that they consume are limited. So, this introduces competition for the same resources.

And, we know that Charles Darwin introduce this notion of survival of the fittest and so, what we can understand from that is that there is competition amongst individuals or resources. The individuals comes from different species and whichever species has a better design to go ahead in this competition that species does better in this world essentially.

(Refer Slide Time: 11:25)



So, competition is at one level between the species that species compete for the same resources for example, lions and hyenas may compete for some deer in a forest, but it is not just between the species that competition exist more interestingly for us because that is the basis of evolution. There is competition within the species as well.

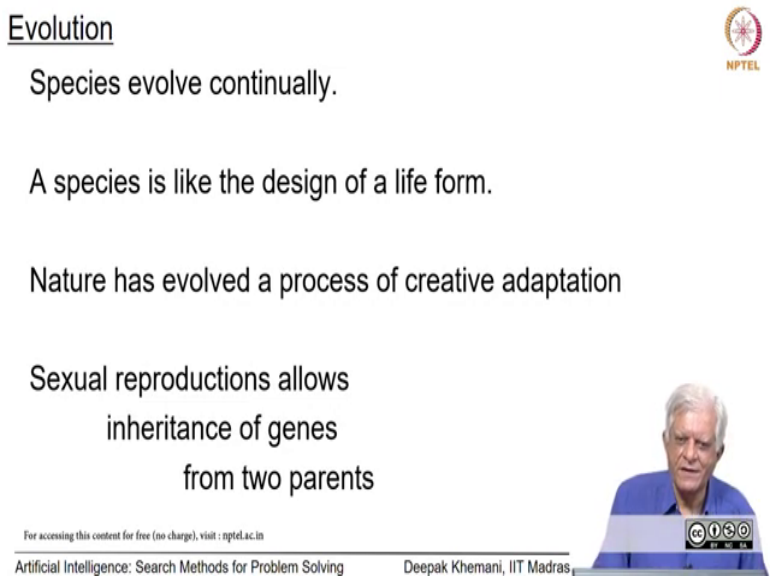
So, for example, the individuals in a species compete for many things the fastest or the wiliest foxes gets the rabbits and the fastest or the cleverest rabbits escape I mean this is just an

example that I am giving here, but essentially that within the species the fitter ones in some sense survive and the unfit ones may not survive essentially.

Why is that important? Because the ones that survive are the ones which get to propagate their genes and in that sense it is a genes of the individuals that survive that get propagated more than the genes of the individuals which do not survive and in this way the nature kind of you know tries to continuously improve upon the design of each species essentially.

So, it is not as if the species is constant, we keep evolving all the time essentially I mean.

(Refer Slide Time: 13:01)

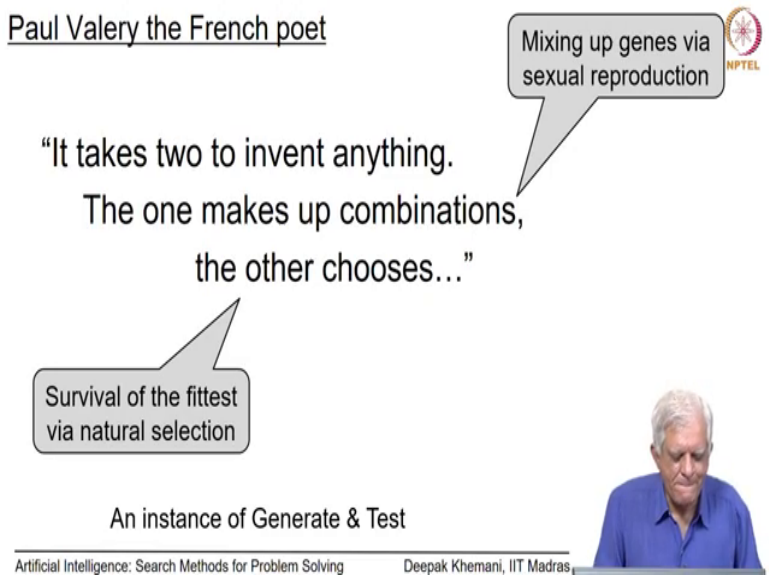


So, species evolve continuously because you know as I said the fastest foxes will get to propagate and the fastest rabbits will survive and get to propagate. So, it is like a design of a life form and nature has evolved a process of creative adaptation.

How does one improve upon ones design? So, what nature does is a kind of search in a population of candidates and it has this novel mechanism of sexual reproduction which allows inheritance of genes from two parents. So, every child in most forms of nature of course, there are some forms of nature where there is cloning, but typically those are very simple life forms and they do not evolve too much.

But, in all other life forms it is always that we combined the genes from two parents to produce a child. And, that child goes through a process of competition and the one's that survive are the other ones who will propagate the genes further. So, that is the process of trial and error search that nature have adapted. This is called survival of the fittest or by natural selection.

(Refer Slide Time: 14:23)

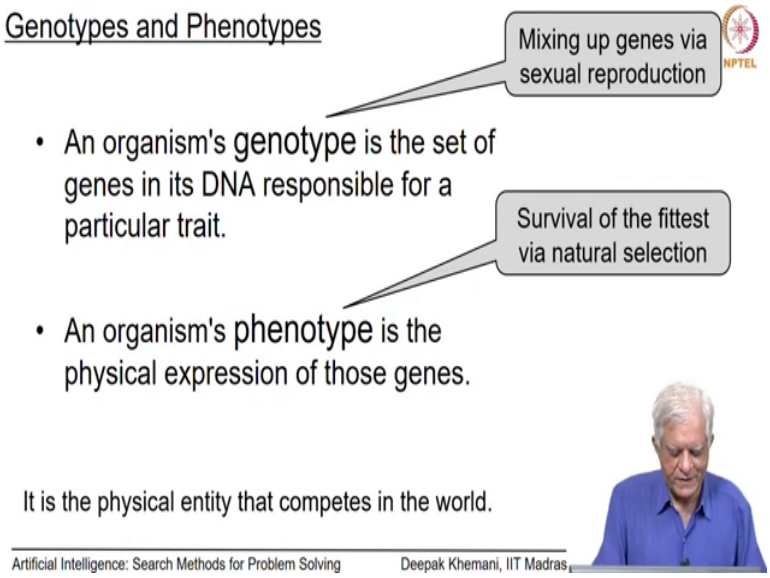


So, the French poet Valery said very creatively that it takes two to invent anything. The one makes up combinations and the other chooses. So, what he is saying here is that evolution or improvement of a design is not a process in which there is only one kind of activity going on, but in a sense that there is one aspect to it in which you try to improve upon designs. And, there is another aspect of it which judges upon the new designs and says this one is better or this one is not as good and so on and so forth.

So, in nature the two forces that he is talking about are essentially the mixing up of genes is what makes up the combinations this is done through sexual reproduction as we just mentioned. And, the other chooses and other is in some sense nature itself and I mean we do not want to think of nature as an entity or as a designer or as something which is conscious entity which is you know doing the world.

But, rather that the process of persistent which Steve Grand out line that whatever persist and whatever does not creates this process of selection because it is only that persists which can compete for the resources and so on essentially. So, you can think of this as an instance of generate and test in the sense that nature is producing new designs and testing them out in the real world to see if they survive or not essentially.

(Refer Slide Time: 16:17)



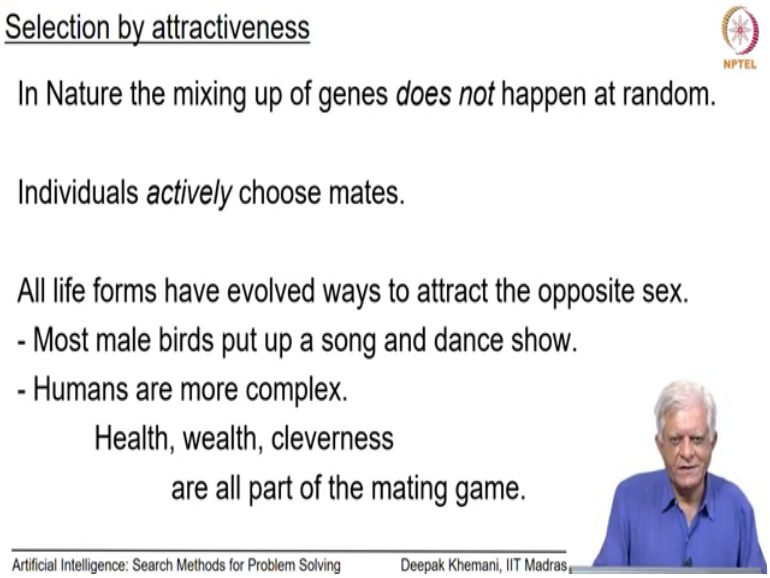
Now, if you look at the biological aspects of things we can distinguish between two ways of describing the same entity. One is called the genotype which is the set of genes in the DNA responsible for a particular trait. So, for example, you know people might say that you have genes for black eyes or you have genes for blue eyes and things like that.

So, traits that we often look for a human beings can they trace back to some genetic makeup of the individual and the total genetic makeup of the individual which is expressed in the genome of the individual is known as the genotype.

The organisms phenotype is a physical entity or physical expression of those genes, it is a actual physical creature which the genes have resulted in or express themselves in the form essentially. So, if you look at these two things then mixing up of genes takes place at the

genotype level and the competition happens at the phenotype level because it is a individual which goes out in the world and fights to survive essentially.

(Refer Slide Time: 17:43)



Sexual reproduction which results in the mixing of genes does not happen randomly in nature it is not that you just arbitrarily take two individuals and you know they produce their offspring.

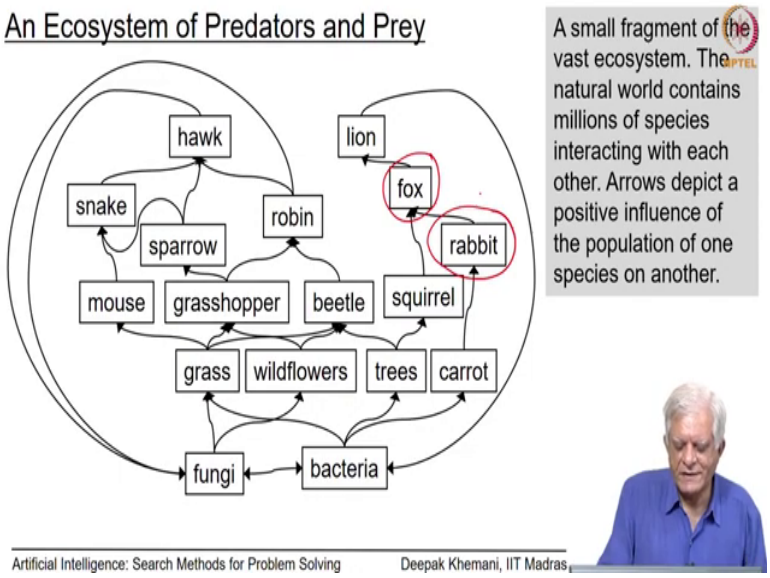
In nature individuals actively choose mates essentially. And, in fact, a competition that we are talking about is not just for resources like food and energy, it is also for mates and this is within the species that in some sense we are designed to look for mates which we find attractive and the whole notion of attractiveness is such that we are attracted towards members of the opposite sex who we innately feel or intuitively feel or subconsciously feel will result in better offspring essentially.

So, all life forms have evolved ways to attract the opposite sex. For example, in the birds you often see that the male are always or almost always most colorful and they have to go through an elaborate process of trying to attract the female of the species. And, it is a male who for example, often goes and constructs an nest and tries to invite a female to come and occupy that nest or it is a male peacock for example, which does the song and dance show which is designed to attract the female.

So, it is an active process the selection of mates is an active process and amongst humans of course it is much more complex. In fact, there are people who say that the human brain evolved not so much to compete with other species, but to compete within the species that you know humans try to impress the opposite sex by showing their mental proudness by showing their good at music or art or dance or whatever the case maybe.

And some people speculate that we have developed this huge brains simply to be able to attract more healthier mates essentially. So, health wealth and cleverness are all part of the mating game in humans essentially.

(Refer Slide Time: 20:28)



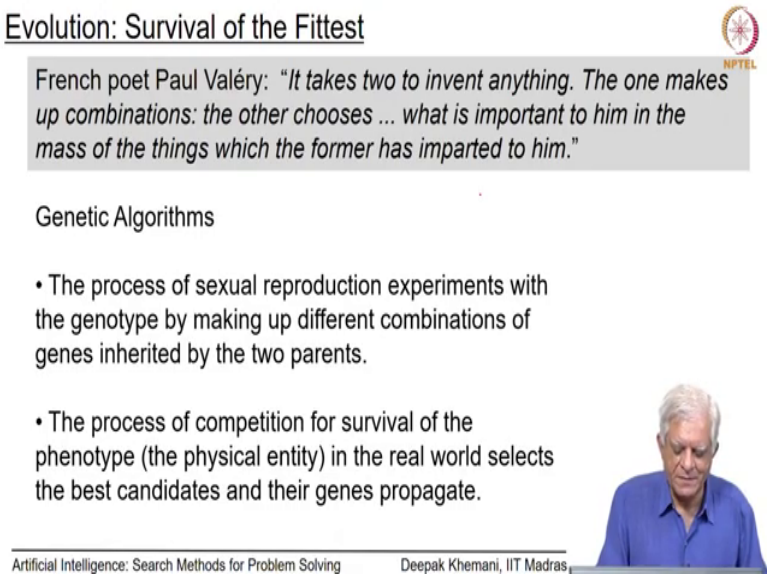
Now, if you look at the world there is competition going on between various species, but as a same time we have an ecosystem which kind of exists in a Cauchy stationary form in which each species is evolving. So, like we said the fox which is dependent upon the rabbit for food. Let us assume for simplicity the fox is eats only rabbit and squirrels that the population of foxes will be dependent on the population of rabbit.

So, what this diagram kind of shows is the positive influence of one population on another. So, if there are more rabbits then they will support more foxes and therefore, the number of foxes will increase. So, the population of rabbits has a positive influence on the population of foxes. The population of foxes in turn may have positive influence on the population of lions and so on and so forth.

So, nature exist in a fairly stable ecosystem. But, nowadays of course, people are started worrying about whether it is going to be so stable after all because of the fact that human activity seems to have overtaken everybody else's activity and you know one hears constant stories about one species dying out here another species dying out here.

The shortage of sparrows in cities and all kinds of things and there is a fear that the collapse of some species may result in a catastrophic event in which a whole subset of this ecosystem will just get destroyed essentially. So, for example, if there are no butterflies or bees to pollinate flowers then flowers will not survive, and you know there could be a chain reaction that kind of a thing.

(Refer Slide Time: 22:37)



So, going back to what Valery said it takes two to invent anything the one makes up combinations, the other chooses and the other chooses what is important to him in the mass of

things which the former has imparted to him. So, the other will choose not based on a total evaluation of the former in the sense that it is like designer offering many different choices to customer let us say, the customer will choose based on what the customers own preferences are essentially.

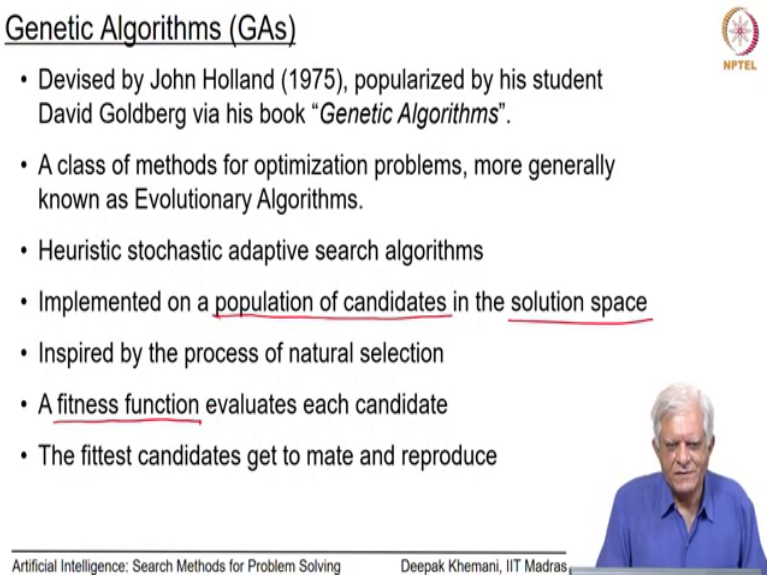
Now, in nature and we have already said that this happens to the process of mixing and matching of genes and survival of the individuals which are expressions of those genes. So, the process of sexual reproduction experiments with the genotype by making up different combinations of the genes inherited by the two parents.

So, even if we take a pair of siblings or pair of human siblings you see often that they are very different from each other, unless of course, they happen to be identical twins in which case very often they are very similar and almost indistinguishable. But, for most siblings they have they are different from each other. How does the difference come? The difference comes because each child has inherited a different set of combination of genes from the parents and therefore, each child is different in that sense.

Of course, we know that the human species is more than 99 percent similar that all of us have identical genes which are more than 99 percent same. It is just that a small thing here and there makes a difference between different individuals and that small thing is what eventually counts into resulting in different kinds of individuals which go and compete in the real world.

So, we said that the process of competition for survival of the phenotype in the real world selects the best candidates and then their genes propagate essentially. So, this is nature's way of going about it. Mix up genes, let the phenotype out in the world and let it fight for survival and those which survive will propagate their genes further.

(Refer Slide Time: 24:56)



So, genetic algorithms is a branch of optimization which kind of takes motivation from nature. Genetic algorithms are devised by John Holland in the University of Michigan in 1975 or so and was popularized by his student David Goldberg in his book called genetic algorithms.

So, it is a class of optimization methods for optimization problems more generally known as evolutionary algorithms. So, if you talk about evolutionary algorithms, one of the way that things can evolves through this genetic algorithm which involves the mixing up of genes and then looking at things.

So, this is a heuristic stochastic adaptive search algorithms. They are heuristic in the sense that you know they are driven by the fitness function, they are stochastic because there is random

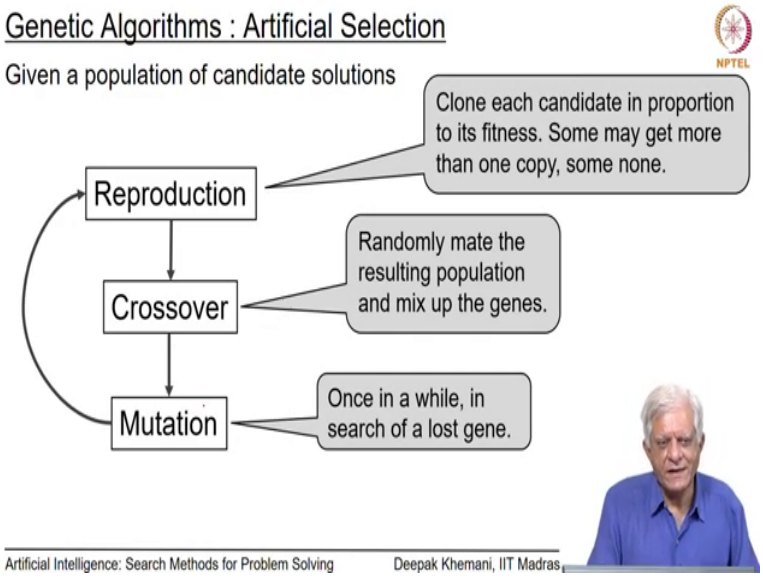
mating as we will see and they are adaptive because you know as they you go along the population keeps changing.

It is implemented in a population of candidates. So, remember that we are searching in the solution space and only thing now is that we are working with the population of candidates and these candidates exists in the solution space, instead of working with one candidate we are working with the population.

It is inspired by the process of natural selection as we have just said and what we do in genetic algorithms is that we impose a fitness function which evaluates each candidate. Now, in nature fitness is in fact, defined by survivalibility that in some sense whatever survives is fit, but in genetic algorithms we turn this upside down. We impose an external fitness function and then we make sure that the fit candidates they get to propagate more essentially.

Because our goal is to optimize some function which is sometimes called the objective function or the evaluation function or the heuristic function in our case or the fitness function in the case of genetic algorithm and we want to maximize the value of that. Nature's goal we can hypothesize is persistence and therefore, it defines fitness in terms of persistence. The fitness candidates get to mate and to reproduce essentially.

(Refer Slide Time: 27:23)



So, given a population of candidate solutions the genetic algorithm has is a three stage process. First there is a stage of reproduction, unlike in nature reproduction is done by cloning that you make copies of each candidate and you make as many copies as the candidate is fit.

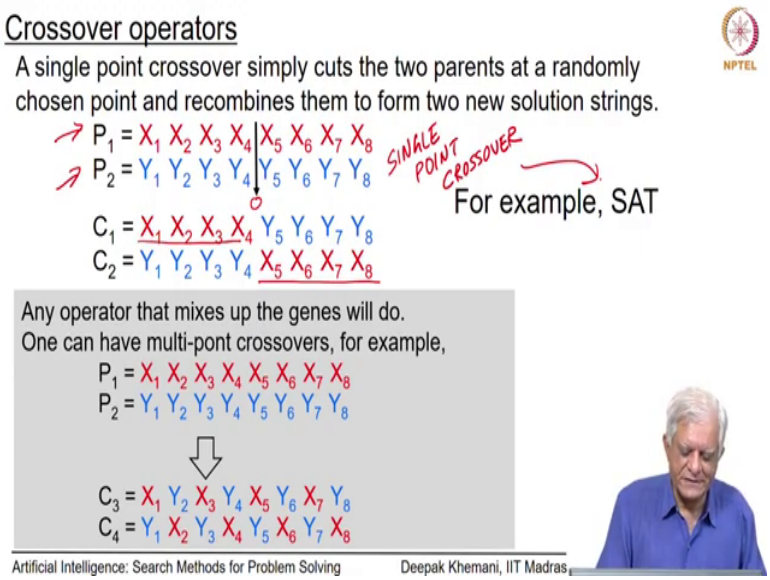
So, fit candidates get more than one copy, unfit candidates may simply die out essentially. So, you maintain a population of let us say n candidates, you start off with n candidates the first step is reproduction in which you make copies or you can say you clone them essentially.

The second step is the mixing up of genes and in the context of genetic algorithms we call this is a cross over operation and what we do in cross over is that we randomly mate the resulting population that is obtained by cloning and then we mix up the genes. We will see cross over operation in a moment.

The third stage is also kind of inspired by nature and this is mutation which says that once in a while change some gene in some individual and this happens in nature that you know suddenly some gene goes mutation goes through a process of mutation.

And, the goal of introducing that in genetic algorithms as you we will see in an example is to make sure that that if sometimes the gene has been lost, maybe it can regained through a process of mutation or sometimes when a mutation happens then it becomes beneficial for individual and then it starts propagating and so on.

(Refer Slide Time: 29:09)



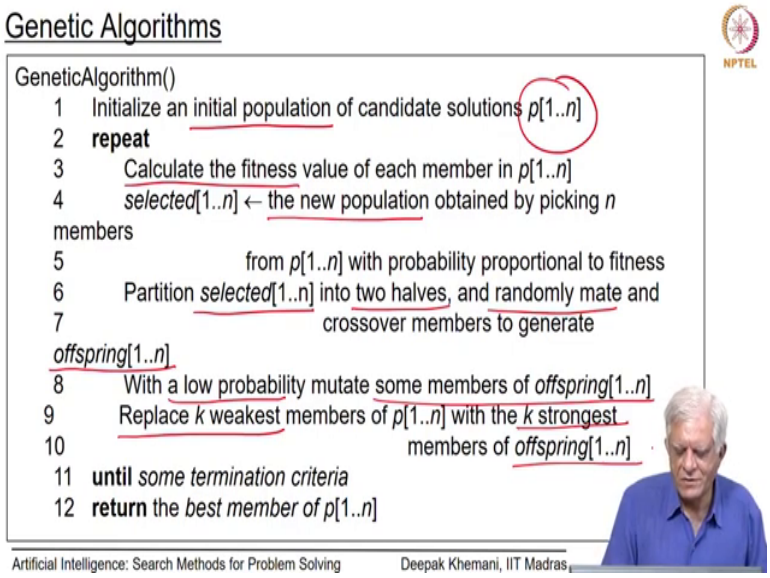
So, the cross the cross over operators that we are talking about are simply saying that you take up the genes of two parents. So, remember that we have we first produced in the

reproduction phase set of clones, then we randomly picked two parents. So, let them be parent 1 and parent 2 and let X 1 upto X 8 and Y 1 upto Y 8 be the genes of those that parent.

Then, in something a process of mixing up genes one simple approach is simply says that you take half the genes not half you choose a random cross over point here and then take one side into one child and the other side into the other child and likewise for the other two parents. So, this kind of a cross over is called as a single point cross over.

There is no sanctity about this. It is just that it is easy to implement and very often we try something like single point cross over and you could do it for example, for the SAT problem remember that a candidate in SAT is a sequence of bits. As I said single point does not have any sanctity and below you can see that there are other ways of mixing up genes for example, you take alternate genes from alternate parents and you could get another way of producing the children.

(Refer Slide Time: 30:52)



So, this is the genetic algorithm at a high level. We start with the initial population of candidates and we calculate the fitness of each member selected; then we produce a new population by a process of cloning which is in proportion to the fitness of each candidate.

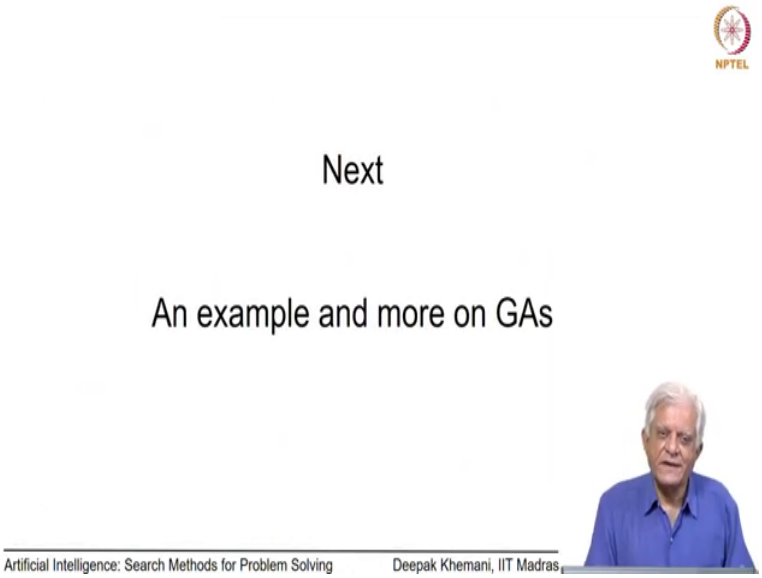
Then, this selected population we partition into two halves and randomly mate them and apply the cross over function that we have to the members over this thing and we produce a new population called offspring. Then with a low probability make some members of the offspring mutate some members of the offspring so that you know you may do this and this is typically done very rarely.

Then, for the original population which is p 1 to n we replaced there k weakest members of this with the k strongest members of the offspring. Of course, some variations of this they replace the entire population. So, the entire population p 1 to n is replaced by the entire set of

offspring 1 to n, but this desire to keep a few very good ones sometimes helps in some problems and people just try this out experimentally.

And, we just repeat this process under till some termination criteria that either some kind of stability has been achieved or we have according to the competition resources that we have and then we return the best member from this ok.

(Refer Slide Time: 32:42)



So, in the next video we will look at an example a little bit more detail example and look at this notion of cross over and survival of genes and this thing. And, then we will move on to trying to look at how t the TSV problem, the travelling salesman problem can be solved using gas which is quite an interesting application.

So, see you in the next session.