

An Introduction to Evolutionary Biology

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Darwinism

Hi, so in our last discussion, you looked at the HHMI video about how Darwin and Wallace came up with the theory of evolution through natural selection. So, in this lecture, in this discussion, we are going to look at Darwin's logic, what Darwin was trying to say in a little bit greater amount of detail. Now, although very often we talk about Darwin's theory or you know Darwin's evolution and so on, what Darwin gave was not really one equation or just one statement or anything. What Darwin gave was essentially a bunch of observations, and based on those observations, A few inferences and a few hypothesis and Darwin's theory essentially is the sum total of all these things taken together. So, the video that you saw of course, it gave you an overall picture of what Darwin was trying to say, but what we are going to do over here is a lot more formal examination of Darwin's position. So, as I said Darwin starts with a bunch of observations, and his first observation is that if you take any organism, any species, then typically they produce quite a large number of babies.

So, for example, you look at let us say fishes, Each fish with over its lifetime will produce, maybe depending on the kind of fish, Anything between a few thousand to a few million offspring. Darwin famously did some calculations to show that Even if you take the slowest breeder on earth which at that point he thought were the elephants, And then you plug in their rate of reproduction, Then over a period of only 750 years, starting from just one pair of elephants, You expect to get some 19-20 million elephants. So,

obviously, that means that any organism produces a lot more number of babies than what is required to replace itself in the population. Along with that, a second very interesting observation is that the resource levels on which these organisms sustain themselves, Food or rain or whatever, generally these resource levels tend to remain pretty stable.

So, if that be the case, then you expect that lots of offspring resource levels remaining roughly stable, You expect the population size to increase greatly, you know, exponentially. And yet what we normally see is that population sizes on an average remain stable. This is not to say that it does not change from year to year, of course, it does. There are certain years, let us say, when there is a major famine, the population size will maybe crash. There are certain other years when let us say there are lots of crops, You know lots of fruiting has happened, the population numbers can go up.

But these are small localized changes. Over longish time, in general, population sizes of different species tend to remain roughly around an average. Now, if you have these three observations put together, Then you realize that if I have lots of offspring being produced And yet the population size is remaining by and large stable, That means that somewhere all the offspring that are being produced, They are not really reaching to adulthood or not all of them are able to reach to a breeding stage, Which essentially means that given these three observations, One, there has to be a lot of competition that is happening across the organisms, What Darwin put as struggle for existence. Now, this concept that if resource levels are limiting, then there is going to be competition across the users of these resources. This Darwin takes from the work of the famous British economist, Adam Smith.

Similarly, this thing about organisms tend to produce at a higher rate than what can be sustained, That observation comes from Thomas Malthus, a very famous again British economist. Now, so competition is something that you expect to happen across organisms in nature. Now, Darwin takes two more observations. One observation is that if you take pretty much any trait in any given species, then, typically, you are going to see that the organisms vary with respect to that trait. So, for example, suppose we are talking about

skin color.

Skin color in organisms typically is going to vary quite a bit for any species. Similarly, say we take you know height in humans Or we take the length of the leg in, say some deers or rabbits. Very often, you are going to see that these traits are going to vary across the individuals in the species. This is an observation that we have already made, right? When our alien came from outer space, this is one of those observations that the alien made. However, there is one very interesting thing, another interesting observation, which is that this variation in the trait, at least some part of it is inheritable, which means organisms are able to pass them from you know to their offspring, to their babies.

In other words, if you have let us say tall organisms, very often their babies are also tall when they become adults. Now, of course, this is not something that happens all the time. There is a it varies from trait to trait. Certain traits the inheritance is very strong, which means you know, let us say tall parents leading to tall offspring. In certain other traits, the inheritance is not that strong, but this is an observatio.n That is generally true that parents tend to pass on their characters to their offspring, at least to some degree.

Now, based on these two observations and the fact that competition exists, Darwin makes a very very interesting inference. He says that let us assume that these traits or at least some of the traits, they actually play a role in terms of the struggle for existence that the organism is facing. What do I mean here? So, suppose we are talking about say leg length in deers and let us assume that if you have longer legs, then the deer are able to run faster. Now, what will that mean? That will mean that such deer, which have longer legs, They have a greater probability of escaping the predators, right? Now, if they have a greater probability of escaping the predators, Their probability of living slightly longer is greater and of course, if their probability of living longer is greater, then their probability of being able to pass on that you know information to their babies, the longer long leg character to their babies, that also goes up, right. Therefore, Darwin comes to this inference that Given trait variation and given inheritance, and given that some of these traits, The values of the traits are going to be associated, are going to correlate with the

struggles for or their success in the struggle for existence.

Then all the trait variations, all the values of the trait that increases their ability to survive, their ability to reproduce, those are going to be passed to the next generation in greater numbers. And therefore, in the next generation, the favorable trait variations, their frequency is going to go up, and similarly, the non-favorable trait variation, in this example, let us say short legs, their frequency is going to go down in the next generation. Now, Darwin, since he was you know trying to get an analogy for this, He got an analogy for this from the practice of breeding. Now, remember, human beings have been breeding animals, Human beings have been breeding crops you know for like thousands of years, probably ever since they started domesticating plants and animals. Now, what exactly happens in breeding? Breeders, they look at all the animals that they have and then they choose what is the character that they would like to propagate.

And accordingly, they allow animals which have those characters to reproduce and all the animals which do not have those characters or all the plants which do not have those characters, They are not allowed to reproduce. And this act of selection by the breeders, this is what then you know when done generation after generation Leads to the production of varieties or breeds that we see today. So, for example, if you remember in our first discussion, we were looking at various breeds of dogs And we know that all these breeds of dogs have actually arisen from some ancestral wolf-like animal, Which, at some point, got domesticated And then different breeders in different parts of the world ended up choosing for different characters based on what they wanted. So, some chose for large size, some chose for you know very ferocious guarding instincts, These are the ones that became guard dogs, Some chose for small you know less ferocious cuddly you know pet kind of things which you know led to, For example, the Chihuahua and the Pomerians and all those. There are others who chose for you know dogs which will run extremely fast, To be used as hunting dogs and so on and so forth.

And therefore, the fact that different breeders chose to select for different traits over time led to an enormous diversity in terms of how you know what kind of breeds we have

today in our hand. So, Darwin said that a similar process is happening in nature. However, instead of some kind of a human having some you know requirement of what they want in their animals, all we have is nature working blindly. And what is the process by which nature is working blindly? Nature is simply making sure that those organisms which are able to survive better, their genes, or I am sorry, I should not say genes, their characters get more represented in the next generation. Those organisms which have traits which do not survive that well or do not reproduce that well, the frequency of those traits in the next generation is going down.

Therefore, Darwin said that this process is exactly equal to the artificial selection that human beings have been practicing forever and since this is something that is being done by nature, He calls it natural selection. Now, note over here that Darwin explicitly framed this in terms of competition, and struggle for existence and survival of the fittest, but today we know that these conditions are not necessary conditions for natural selection to happen. So, when we look at the you know topic of natural selection, then we are going to discuss in what other ways natural selection can happen, but right now I am just sticking to what Darwin was saying. So, now once you have the inference of natural selection, then what happens when this process is continued across generations? When this process is continued across generations, let us say we are going back to our you know deer and leg length example, what will happen? The first time this selection happens, the frequency of long legs, Long legged individuals in the population will increase a bit. Then in the next generation that frequency will increase a bit further, And this will keep on happening till the point everybody in the population will have long legs, At which point you are going to look at those population those deers and you will say aha these guys have long legs Which allows them to escape their predators, Thus, they are uniquely adapted to the ability to survive the predators right.

So, remember one of the observations that we had was that Organisms are very well suited to the environment in which they live, and Darwin said that natural selection happening over many many generations is going to lead to exactly that outcome. So, adaptation to environment follows naturally as an inference from natural selection, but

Darwin did not stop there. He said that if this process which he said is going to be a very very slow process, if this continues for many many many generations what will happen? At some point, we are going to get a bunch of organisms that have a very different set of characters Or which look very different from what they started. So, for example, if we are talking about leg length in deer at some point after many many generations We are going to find deer whose legs are so long that we will say that for all practical purposes, these are new groups, These are new species and therefore, this process continued over long time is what will lead to the origin of new species. Now, note that nowadays when we talk about species, we typically think about species as you know groups of organisms which cannot exchange genes, cannot reproduce vis-a-vis other groups, but that is not the way in which Darwin is thinking about species.

Darwin is thinking about species in terms of organisms, which look very different from the ancestral group from which they started. Now this particular conceptualization that if you have small changes happening in something and then these small changes accumulate over a very long time to lead to what looks like very large changes, this conceptualization actually Darwin borrows from his you know contemporary Charles Lyell. Now Charles Lyell was a geologist and he came up with this conceptualization in the context of You know phenomena like deep river valleys or canyons and so on. So Charles Lyell's thing was that look suppose you have let us say a river or let us say wind and let us assume that it is eroding rock at a very you know small rate, let us say some 0.01 centimeter per year or some small value.

Then, if you are just watching that thing year to year to year you are not going to see too much of a difference. However, if you are watching it over millions of years then obviously you are going to see a huge difference. You are going to see deep canyons and deep valleys, which have actually come about by very weak forces, simply because those weak forces have operated over very very long time. In other words if you see a big change then you do not necessarily need to have a large action force to create that change. Maybe that change has come about due to small actions integrated over very long periods of time.

So, this is the principle of uniformitarianism. And Darwin borrows that from geology and puts it in the context of you know formation of species. And then here comes Darwin's major you know fifth inference. He says that probably if we think about the entire process like this, Then, suppose long back we had just one or two you know original species, original groups And then these original groups they started changing in the way that We are talking about you know the origin of new species, But then this new species some of them will find themselves in one environment, Some will find in themselves in another environment And then in these two different environments they will then adapt very differently And therefore, there is going to be divergence. So, he thought about it in the context of a diagram like this.

So, suppose let us say you know if you can see my cursor, this is point where one let us say this is where they originated And then through the process of natural selection over long long time they became something else something like this. But then this group some individuals of this found themselves in one environment, Another set of individuals found themselves in another environment, a third set found themselves in another environment And in these three different environments they evolved very differently, they changed very differently And therefore, this set you know of individuals they you know formed one species, This set formed another species and let us say this set formed another species. Now again if you look at this you know one, this group of individuals, some of them found themselves in one environment, some others found themselves in another environment. You do not need to posit different mechanisms for the creation of the entire biodiversity or for the creation of species. Now, note how this is very different from what Lamarck was trying to say.

Lamarck said that there is some kind of a plan, Nature's plan or whatever, and accordingly, organisms are linearly becoming more and more complex, right. So, there is a goal, goal-driven evolution, but Darwin is not saying something like that. Darwin is saying that species are simply branching out and why are they branching? They are branching because different set of individuals are finding themselves in different

environments, Each one of them is responding to their given environment and then they are essentially becoming that, You know, the changes that are occurring in them are becoming guided by the said environment. And therefore, since at any given point many many different environments are possible, Different individuals from a given species, Different groups are getting formed and therefore, new set of species are being formed. So, here one has to note that Darwin was very careful.

Remember all this is happening in the backdrop of lot of other you know controversies that have already happened and therefore, Darwin very deliberately keeps himself very vague about the origin of life. He essentially implies that existing life forms have originated from one or very few ancestral forms, without necessarily talking about how the origin happened. In some sense, you know some people have even argued that Darwin was perfectly ok with the origin of life being an act of God. But what he said is that once you have the origin, then the rest of the biodiversity has been formed by a process like this. And the most important implication of that is that all life forms that we see today, all of them are connected with each other through various degrees of ancestral relationships.

So, life forms that look very similar to each other or have properties which are very similar to each other, they have relatively recent ancestors. Whereas those life forms which look very different from each other, they have ancestors which are far far you know back in past, But end of the day all living organisms are related to each other through what Darwin called descent with modification, essentially, a relationship that looks like this. Now, there is a very important point that I need to mention over here. Whatever I told you in the last two slides, they are merely a description of how Darwin framed his argument, right? As I told you, this is not how we understand the process today. In fact, as we go along this course, you will understand that Darwin got many things right, He also got many, many things totally wrong and frankly did not have any clue about a large number of other things, right? So, over the next 150, 170 years, many people have worked on Darwin's ideas, and have figured out which are the ones, concepts which are right, which are the concepts which are not correct.

Now, why am I making such a big deal out of this? The reason I am making a big deal out of this is because in the minds of many people, Evolutionary theory is equal to Darwinism, what Darwin said, right? And therefore, you will get these brilliant essays and brilliant books saying, Oh my god, Darwin was wrong, and therefore, evolution cannot be correct. If you want to know in how many ways Darwin was wrong, all you have to do is to speak to an evolutionary biologist. They will give you a complete laundry list of ways in which Darwin was wrong, and things that Darwin could not say anything about. But just because certain things that Darwin said did not make sense does not mean that everything that he said was wrong. And one of the things that we are going to do over the course of this particular discussion, This course is that we will explicitly examine what are the things that Darwin said.

What he got right, and what are the things that people after him said And what is the situation with the subject right now. In fact, we will get into this in our very next lecture to some extent. When Darwin's thing came out, there was obviously an enormous reaction to his book in 1859 And part of the reason for that was that there were a very large number of observations, that were actually getting explained by Darwin's theory. Many of these observations we have already made. So, for example, as I told you, the tremendous diversity of life forms which our alien would have seen, Darwin explains it based on his theory of descent with modification over long long time.

Similarly, as I told you, the environment-specific features, adaptations, Darwin's theory of evolution by natural selection has an automatic explanation for how adaptations are happening. You remember in the last discussion we talked about the observation that many comparative anatomists in the middle ages were making that there seems to be various degrees of similarities in anatomical structures across species and what Darwin said was, yeah that is obvious. So, if you have let us say two species which had an a common ancestor relatively recently in past then that means they are going to share lots of features with each other. Whereas, if you compare say let us say this species with let us say this species Which had a common ancestor much you know earlier in time, Then

obviously they have had more time to change, They have had more kinds of environments to adapt to And therefore, their features are not going to be as similar as let us say this one and this one. And you can actually extend this argument over the entire tree and all the both the differences and the similarities get explained based on these ancestral relationships.

Then of course, the observation that Cuvier and other paleontologists were making many of the extinct species are similar to existing species. And Darwin said yeah obviously because think about it again, let us say this is one species, this is one species. Both of them have a common ancestor and let us say this species went extinct, this species stayed. So, obviously, these two guys they are going to have very similar features to each other simply because they came they arose from the same ancestral group. Why do we typically find similar species that is species with similar traits close to each other? Again same thing Darwin is saying that look both these guys they have arisen from one common ancestor. So, obviously this common ancestor is you know at a particular geographical location and therefore, the evolution that has happened the change that has happened has to happen geographically close to each other. And therefore, there is a high chance that when you are looking at them today they are generally geographically close to each other. Of course, there are some small you know exceptions here and there. Some species you know, particularly the mobile species, they might have moved a you know bit, Some other species may not have moved at all.

So, there will be some degree of slop here, But on an average you are going to expect based on this kind of a branching relationship that, Similar species will be found close to each other. And then of course all these interesting patterns of distribution of life forms. How do you explain that? Again, Darwin's explanation is that this entirely depends on from which branch of this kind of a tree they have originated And after that, how exactly they have moved. So, for example, if you remember the video about Wallace line, so you have two different groups of organisms. One has arisen from the marsupials of Australia, another has arisen from the placentals of Asia.

The placentals of Asia have moved like this, you know, southwards. These guys have moved more towards the west or north-west. And at some point, the two groups of organisms have met and this point or this front is your Wallace's line. So, similarly, any other distribution patterns like this can be reasonably explained in terms of from where from which node on this tree the corresponding species have arisen and how they have moved over space. So, these are just the patterns that we saw we have been discussing till now. That does not necessarily mean that these are all the patterns that are explained by Darwin's theory.

Actually there are many many many more right. So for example Darwin himself talks about you know things from embryology developmental biology. Similarly there are stuffs from physiology and this is just stuff that is happening at Darwin's time. If you look at what happened after that as we are going to do in probably our next discussion, this list of observations that are explained by Darwin's theory actually becomes extremely extremely large. However, they were not everything that Darwin's theory could explain. So, what are the things that Darwin's theory could not explain, and more importantly, how exactly was it received? Because, as you saw, what Darwin was saying was very very different from what rest of the people were saying.

Darwin's theory essentially buying the origin part does not really invoke God at any place, It does not require the hypothesis of God. So, obviously, people who were you know believing in creation by some kind of a deity, they were obviously in lot of pain. So, how exactly did they react? And more critically, what happened after that? That reason more is what we are going to do in our next discussion. Let us see.