An Introduction to Evolutionary Biology

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Introduction to Selection

So, last week we looked at variation and how it is generated and how mutation acts as a weak evolutionary force. This week we are going to look at perhaps the most important topic. And definitely the most well-studied evolutionary force, which is selection. However, before we talk about that, we need to think slightly about one term that we have already used. But we haven't really defined it properly, and that term is "trait" and its distribution. So, what exactly is a trait? Any observable or measurable feature of an organism constitutes a trait.

So, for example, if you are looking at me—my height, my body size, the fat content of my body—all these are my traits. Now, for evolution to happen, you realize that there has to be variation in the traits, which essentially means Since we study evolution at the level of the population, that means. We need a distribution of the traits, trait distribution as we call it. The whole point of looking at the effect of selection or microevolution.

Is essentially looking at how this trait distribution is changing. Now, why am I making this point so clearly? The reason is that we normally think of evolution in terms of the entire organism. However, when you study evolution, it is very difficult to look at every feature of the organism together. And therefore, one of the things that Darwin did was, since he was coming from his experience in breeding, He put the focus on looking at the trait and its distribution. And therefore, even today, when people study evolution, particularly microevolution, they generally talk about a particular trait.

Some people talk about two or a maximum of three traits and how those are changing simultaneously. So, essentially, the focus needs to be slightly altered from looking at the organism as an entirety to looking at the trait. More importantly, since we are looking at the level of the population, we are also looking at the distribution of the traits. So, now that we are done with this, what do we have to say about selection? So, remember, we looked at Darwin's logic about natural selection, which said all organisms produce too many offspring. However, the amount of resources that we have is stable; the population sizes are generally stable.

This implies that there is going to be competition for the limited amount of resources. On top of this, Darwin made two more observations: A. Traits vary within a population. And B. Some of this variation is actually inheritable, which means that it can be passed from the parents to the offspring and based on this, Darwin came to the conclusion that. Favorable or non-favorable inheritable variation will increase or decrease in frequency over generations. And the process by which this is happening, that is what Darwin called natural selection. Now, we think of the same process in slightly different words. which slightly changes the way we emphasize on the concepts.

So, in today's parlance, one should or one can define selection as the differential reproduction of individuals due to variation in inheritable traits. Now, this way of looking at selection straightaway tells you That the difference between natural and artificial selection is actually rather well, "quote unquote," artificial. So, basically, when Darwin was constructing his arguments, He was coming from the perspective of breeding, which was obviously an artificial thing. So, you know, keeping parity with that artificial selection. He made the point that a similar process is happening in nature and therefore, he called it natural selection.

However, as far as the details of the process are concerned, They are pretty much the same whether it is being introduced; you know, the selection is being done by nature or by humans. Therefore, nowadays, many books do not even make this distinction. Or many times, you know, they say natural selection when they probably mean, You know, selection due to, let us say, human activities or something else. So, very often, people go back and forth between these two topics. Generally, in the context of this course, we will use the term selection.

However, sometimes, due to historical reasons, we might also end up using the term natural selection. Now, what exactly is natural selection, and why am I calling... What exactly do I mean in terms of differential reproduction, and so on? So, let me just break it down to its constituent parts.

So, in a nutshell, natural selection states that if three conditions are met, then natural selection will definitely occur. Now, what are those three conditions? There has to be a variation in the context of some trait in the group, a breeding group, you know, or populations. Why does it have to be population? Because remember, microevolution is always studied at the level of the population across generations. So, the first condition is trait variation in the population. Second condition is that, due to this trait variation, there is a difference in the reproductive output of the individuals.

In other words, some individuals produce more babies, while others produce fewer. And this is due to their having differences in terms of traits. And finally, if at least part of the observed trait variation is heritable, then if these three conditions are met, Then natural selection is going to operate, right? Now, what exactly does that mean? Very often, that means the trait distribution will change. It will either mean that the mean will increase or decrease, or the variation will increase or decrease, or some stuff will happen. However, this is the interesting part: it is not essential that The trait distribution and the properties of the distribution will always change under the effect of selection.

There are many situations where actually going from generation to generation, The trait distribution is not changing, yet natural selection is operating. Which is why we define natural selection in terms of the conditions that must be met. If these three conditions are met—variation, inheritability, and reproductive differential due to the variation— If these three are met, then we say that natural selection is occurring. Now, if you are thinking about it this way, then there are two major points that you need to consider. Point number one: selection is not evolution.

I am paraphrasing this from a very, very famous book. Yeah, I think I have this book over here. It is this book. So, this is "The Genetical Theory of Natural Selection" by R.A. Fisher. Actually, this is reputed to be the second most important book in evolutionary biology, next only to Darwin's "Origin of Species." And the first sentence of this book is, "Yeah, natural selection is not evolution." Now, what exactly is meant by that? So, selection is one of the many forces that can cause changes in the composition of a population. Either in terms of the phenotype or in terms of the allelic distribution to change. And this change is what we call evolution, right? And therefore, natural selection by itself can sometimes lead to evolution; sometimes, due to selection, evolution will not happen.

Sometimes evolution will happen, but that is not happening due to selection, and so on. And overall, the thing to keep in mind is that evolution is equal to change; natural selection is One of the ways in which the change can happen, but it is definitely not the only way in which it can happen. So, we have already looked at one force. Remember, we said that if there is mutation, then the allelic distribution also changes. The allelic, you know, composition of the population can change; the frequencies can change, and that will qualify as evolution.

In the subsequent discussions, we will look at two or three more such forces. But this is definitely true that natural selection is one of the most important and strongest forces of evolution. The second point is that, in order to appreciate this, let us see what exactly is happening due to selection. So, let us assume that we have two genotypes in a population and that both of them are in equal proportion, so, 0.5 and 0.5 are their frequencies. Now, let us assume that one has a growth rate of 1.01. So, it is growing at a rate of 1%. The other has a growth rate of 1.02. So, there is a very slight difference, in the second place after the decimal in terms of the growth rate. What happens to their distribution? In other words, in what ways does the proportion, which starts with 0.5, 0.5, change? And if you do some simulations, very easy simulations, then you will see that The proportion of the genotype actually increases even if there is, you know, a slight difference in terms of its growth rate. So, in this particular case, you can see that within about 200 generations, it goes from approximately 0.5 to somewhere around 0.9. Now, the point to be noted here is that in this particular case, there is no competition happening. Both genotypes are surviving during this process, okay. Yet, what is happening is that the relative proportions are changing, and because of that, evolution is occurring. Now, you can see the same thing if you increase the growth rate difference slightly more, let us say, 1.01 and 1.1. And you can see very quickly within about 40 to 50 generations, yeah, within about 50 to 60 generations or so. It goes from the proportion of one type, you know, of genotype 2. Which has a higher growth rate goes from 0.5 all the way to 1. So, the basic point I am trying to make here is that normally, when people think about, you know, evolution due to natural selection, They are always thinking in terms of the struggle for existence or survival of the fittest, right? But that is not really what is happening here.

So, if you think about it, in the first case, the 1.01, 1.02 case, the left panel, both of them are there; they are surviving. They are not competing with each other, or at least that competition is not a necessary condition at all. And yet, the relative frequencies are changing, and that frequency is changing because there is a difference in their reproductive output. Therefore, selection is happening; evolution due to natural selection is occurring. So, similarly, you know there is no concept of you know survival differential necessarily. So, if you look at it at the end of 200 generations, both groups are there, and yet selection has happened; evolution has happened. So, these two conditions—survival of the fittest and struggle for existence—which lots of people think are synonymous.

Evolution by natural selection is actually not considered to be, you know, necessary conditions for selection anymore. The necessary conditions for selection are the three things that I told you about. Competition is just one way in which selection can happen; certainly, it is not the only way. So, given these two features, we are going to talk about many other features of selection as we move forward. What we will do is have a quick look at examples of natural selection, and we will examine them from many different areas.

So, the first two examples are going to be from nature, and in both of these cases, I am actually going to lead you towards some videos. So, the first video that you should see is the action of selection in the Galapagos finches. So, this is the HHMI link that I want you to visit and watch that video. There are hundreds of videos available on the internet, many of which are very good. But there is a reason for which I want you to look at this one and the next one.

So, in this particular case, the reasons are as follows. Number one, this is one of the most famous pieces of work in evolutionary biology in the 20th and 21st centuries. So this is the work of, you know, Princeton biologists Peter and Rosemary Grant. So they went to the Galápagos Islands and studied the Galápagos finches for 40 years. When this video was produced more than 50 years ago.

And they made several extremely interesting observations. Many of which form the cornerstone of what we understand about evolutionary biology today. So, one of the things, for example, which they are going to tell you in this video is that prior to that, everybody thought that. Evolution, at least in nature, is very, very slow, and yet this was one of those cases where they ended up showing that. Evolutionary measurable microevolution happens within the space of just one year in one generation in these Galapagos finches.

So, although this particular video, the primary question they are asking is in terms of, you know, how new species are formed. The reason I want you to have a look at this one and the next one is that. They very nicely spell out the conditions that are required for selection, very properly done. And therefore, you know the three conditions that I talked about; you can very easily. Experience those conditions for yourself nicely in this video.

The second thing is that the above HHMI page not only contains the video, but it also has some very nice fun activities. I strongly recommend them to you. They won't have anything to do with the evolutions, but they are only for your enjoyment. Thirdly, there is a brilliant book written by, you know, Jonathan Weiner, called The Beak of the Finch. This won the 1995 Pulitzer Prize for writing, and it's a brilliant read.

Absolutely superb read and one of the best non-technical introductions to the work of Peter and Rosemary Grant. Therefore, I will again recommend this book for anyone, even if you are not trying to become a biologist. This book is a nice, you know, introduction not only to evolution but also to how exactly one can go about doing science. Again, it can't be recommended too highly. And finally, although this video is at an introductory level, you have to realize that the work being shown over here is Extremely rigorous and extensive, it has tons and tons of data and, as I already said, spans over more than 50 years.

So, one strong recommendation is needed. The second video that I want you to look at is the action of selection on the pocket mouse. This is the work of a bunch of people: Michael Nachman, Hopi Hoekstra, and others in New Mexico. And again, a very nicely short video, with very nicely explained concepts. However, before you head off to the videos, as I said, please remember these three prerequisites for selection that we talked about. The three necessary conditions, and try to see for yourself whether you can identify these things when you are watching the videos.

That is the main reason why I want you to go there. Now, of course, these are nicely shot, beautifully short videos. But you do not really need to go off to the Galapagos or New Mexico to see good examples of changes due to selection. As a matter of fact, we can see them all around us all the time. So here are a bunch of examples from breeding and other human activities. So, for example, most of the crops that we have around us are actually products of some kind of breeding or another.

But one of the major examples of that is the evolution of maize. So the maize, or corn, is, you know, what looks like what we are seeing below in this panel. However, this was actually derived from a relative of wild grass called teosinte, you know. and it was domesticated in Mexico about 9,000 to 10,000 years ago. And then, slowly, by the process of breeding, Mexican farmers ended up bringing it from teosinte all the way to maize.

But, very interestingly, even today, some of the teosinte maize can interbreed. And therefore, you can have teosinte-maize hybrids, as you see in the middle. You can see it is intermediate between the two forms. Now, this is by no means the only example. Remember we have already looked at the examples of cabbage, cauliflower, broccoli, and kale—all of them, actually, you know being derived from some plant in the Brassica family within human history. Similarly, one of the major things that we have talked about again and again is antibiotic resistance arising. You know about the spread of antibiotic resistance, but the one that really matters is you know. It makes it difficult for public health professionals and for agricultural workers due to the emergence of pest resistance. So, here I am showing you the cumulative number of insect pest species that have evolved resistance to five classes of insecticides over the last 50 years or so. So, this data is only up to 1990. We are sure that you know the total number is far greater than what it was 35 years ago. But as you can see in the 1940s, that amount of resistance and number of resistant species was close to 0. Whereas in a span of about 50 years, this total number has risen to above 500.

So, this again tells us the relatively fast pace at which these things end up evolving. The other example we already talked about is when we were discussing industrial melanism, and we said that. The moment they introduced pollution control laws, the soot deposition level started going down. And when the soot deposition level started going down, the black forms, the so-called melanic forms of the Biston betularia, emerged. They were no longer being favored, and their numbers started decreasing.

What I had not done was show you the way it decreased, and that is what I am showing you over here. So, on the x-axis, you have, you know, 1960 all the way up to 2000. So, the 1960s is when those pollution control laws were introduced, and these, you know, blue, red, and green symbols. They show the relative frequencies of the melanic form, the black form, at three different locations in England. And as you can see, within about, you know, 10-15 years, the frequencies had started falling and by the time you hit 2000, which is about 30-35 years later, these frequencies have actually gone very, very close to 0. In other words, things are almost back to normal. The light form has again become the most common form. Now, obviously, these are pretty spectacular, but if you really want to see the spectacular effects of selection, Then the best place to see them actually is experimental evolution studies under lab conditions. Many of them you know are superb, but I am going to give you two examples, both are from India, both are in the field of Drosophila.

So, the first example is from the lab of Professor Amitabh Joshi at JNCASR, Bengaluru. So he works on the effects of accelerated development in Drosophila. So normally Drosophila at about 25 degrees Celsius takes roughly speaking about 10 days to develop. But what Professor Joshi's group did was select the top 10% or so of flies every generation. the earliest developing flies and only allowed them to reproduce to the next generation and killed off everybody else.

So, obviously you know in order to contribute their gene to the next generation, these flies had to be in the top 10% of developers in their population, and this process continued over several hundred generations Today has led to a reduction of 34% in the development time. In other words, instead of 10 days, they are developing in about 6.3 days. So, 34% reduction, you know, just to give you a context.

So, human beings, our babies take about 9 months to develop. So, 34 percent is roughly 1/3. So, we are talking about the context of human babies coming out in about 6 months of development time. Now, of course, the consequences of that, and you know why they did that exactly. And what are the insights that they got from those studies? Those are things that we are going to look at in a different study. But the main point here is that in another study, they ended up showing that It looks like these faster-developing flies are going towards incipient speciation.

In other words, the initial stages of separating into different species have actually set in in these flies. I will give you one more example; this is from our own lab in Pune. So here what we do is study the effect of, you know, selection for dispersal abilities. So what we do is take lots of flies in this container; we call it the source container and here there is no food; there is no moisture. Therefore, these flies are under a lot of stress. So these flies, you know, move around when they get stressed out, and very soon they find, you know, This hole over here is right at the top, and then some of them, not all of them, decide to move. The ones that decide to move or disperse enter into this pipe that we call the path. And some are able to traverse the entire pipe; some are not. Those who are able to traverse the entire pipe reach this thing, this other container called the destination.

Only the flies that reach the destination are allowed to breed for the next generation; everybody else is killed. So, this process continues from generation to generation. And after every few generations, all we do is increase the length of the path. In other words, we add a little bit of extra length to the path that is connecting the source and the destination. And what has that led to? Well, that has led to many things, but what I want to show you is that When we started our experiment, you know that these flies, on average, could move about 4 meters.

Therefore, we started our experiment with what you are seeing in front of you: a path length of about 2 meters. Then, after a few generations, we had to increase the path length, even increasing the path length. And the path length became 10 meters, at which point it looked something like this. So let us see. So this is what a path length of 10 meters looks like, and here are two undergraduates from our institute just for scale.

And this is what the entire process looks like. So these things that you are seeing are the destinations, and let us see if you have a close-up. These are the sources from which the flies are starting to migrate. So this was a path length of 10 meters, and after some time, we had to increase the path length even further. Space ran out in the lab, so that is when this is what we used to do: we used to coil them like Formula 1 racing tracks. And we had to put them in, you know, special enclosures like this to ensure uniform lighting.

So this was a path length of 20 meters, and then this process continued and continued and continued until today. The path length has become 104 meters, so we do not have the ability to, you know, make a formula for one coil that big. So we have to make multiple layers of coils, and then those coils are stacked on top of each other, which is what you are seeing over here. So remember when this guy started, the average distance that the flies could move was 4 meters. And now the path length itself is 104 meters, which is about 26 times what it started with, 26 times.

Now, why we did all this, what the result was, and all those things are different, but the point I am trying to make is that. Selection can actually lead to a massive magnitude of changes in the populations, something that you know is It is very difficult to get with any other thing; there is something called macromutation that might lead to this. But otherwise, in terms of its effect on the population, selection is a very, very strong force. So, how exactly does selection affect variation at the phenotypic and allelic levels? So, that is the question that we are going to discuss in our next meeting. See you then. Bye.