Evolutionary Dynamics

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Week 01
Lecture 04

Hi, everyone. So the goal of today's lecture is to discuss the various elements of the theory of natural selection. There are three essential constituents that comprise the theory of natural selection. And the plan for this video is to go through each one of these and understand how it operates.

So imagine a population. Let's say we have a population of individuals. And we add population. So let's say we have a whole bunch of populations. If this is a population of bacteria, it's asexually reproducing individuals, or if it's a population of complex organisms such as us, it's sexually reproducing organisms.

But the principles of natural selection hold for whichever case we want to discuss. Now, one of the terms that we need to learn here is called a phenotype. By phenotype, we mean a physical manifestation of some trait, a physical manifestation. So, for instance, if we look at our bodies, my height is a phenotype, my weight is a phenotype, the number of fingers I have is a phenotype. Every physical manifestation that I have, the color of my eyes, the color of my hair, every physical manifestation that I have is a phenotype.

So, in this imaginary population that we are talking about, these individuals also manifest different phenotypes based on whatever their physiology is. And let us imagine that we are interested in some phenotype X. We'll keep this phenotype X abstract for the time being, but after we are done with this discussion, we'll discuss concrete examples of how natural selection can operate on these phenotypes, and that's when we will give concrete meanings to these phenotypes X. So, what I'm going to do is measure this phenotype in this individual. Let's say the value of this phenotype is X1. And if it helps you imagine this better, let's just imagine that we are measuring the weight of each individual.

So this individual's weight is X1. I measure this individual's phenotype. That's X2. That's X3, and so on and so forth. So if there are N individuals in this population, their weights will be X1 to XN.

And what I'm going to plot now is a plot that I want everybody to understand. This is something that we will keep repeating over and over throughout the duration of this course. And this is called a frequency distribution of some trait in a population. And in this case, the distribution that we are interested in is of this particular phenotype X. And what we are plotting is this particular distribution. On the x-axis is the value of the phenotype X, and on the y-axis is the percentage of the population corresponding to each value of X. So let us say I choose a very small interval, 0 and delta.

And I ask myself, in this population of n individuals, how many individuals had their weight between 0 and delta? And this is really small. So maybe there were no individuals between 0 and delta. So the percentage of the population that lies between 0 and delta will be just 0. Then I ask, how many individuals have their weight between delta and 2 delta, and maybe there are 3 individuals.

So the percentage will be 3 divided by n multiplied by 100. This will be the percentage of individuals who have their weight between delta and 2 delta. So I plot that percentage here, and then I keep repeating this by counting the number of individuals between 2 delta and 3 delta, and so on and so forth. And as you can imagine, I will get a distribution like this. And this distribution is the first and most important consequence of the theory of natural selection, which is that in a population, variation must exist.

So, variation must exist. If all individuals weigh the exact same amount, then this graph that we have just made is going to look like the following. Let us say all individuals weigh between 6 delta and 7 delta. Then our graph is going to be 0, 0, 0, 0, 0, 0, and then 100% of the population here, and then again 0, 0, 0. This means no variation exists.

For natural selection to act, there must be variation in a population, and that's the first element of the theory of natural selection: that this variation must exist. So, I hope that this is clear to everyone, and that's the first and most important principle of the theory of natural selection. The second idea of natural selection is that this variation exists in the population. This must be linked with differential success in reproduction. What that means is that now I have this population in which variation exists in this trait.

So, this is the distribution that exists for the imaginary trait X that we are talking about. Now, this variation must not be. So, this is X. This is the percentage of the population. This variation that exists in the population has already been established in the first step of natural selection. This variation that exists must not be irrelevant when it comes to the differential success of reproductive success of these individuals.

And what we mean by that is that because of this variation in this hypothetical example that we are discussing, let's imagine that individuals with a greater value of X are able to produce more offspring. So, they have more children, and individuals with smaller values of X produce fewer offspring. If this was the case, what we are saying is that variation in the trait is very closely linked with offspring. Reproductive success of the individuals in that population: some individuals, because of this different value of X—higher value of X in this case—are going to produce more offspring, and some individuals with smaller values of X are going to produce fewer offspring. So, as an example, I want you to guess: let's imagine if this was the case that greater X meant more offspring. What is the next generation's distribution in X going to look like? And what you should realize is that because these individuals are producing more offspring compared to this.

So even though their initial frequencies, or their initial frequency or percentage in the population, might be the same. But now let's imagine these two extremes, or let's look at these two extremes. And even if. These two extremes are the same frequency in this particular generation. In the next generation, these individuals will produce more offspring.

These individuals will produce fewer offspring. Hence, the percentage of individuals with this value of X will decrease, and the percentage of the population with this value of X will increase in the next generation. So the next generation's distribution might look something like this. Because the parents of these offspring produced more children, their percentage in the population has increased with one generation having passed, whereas these individuals' percentage has decreased with the passage of time. So this is the second necessary condition for natural selection to operate: that only variation will not do.

Variation has to be relevant as far as the reproductive success of the organism is concerned. I hope that makes sense to everybody. Finally, the third element of natural selection is that the trait on which selection is acting The trait on which selection is acting must be hereditary. And what we mean here is that imagine we have a population distribution of X like this.

This is the distribution of the population that we have in one generation, and these individuals give birth to offspring such that in the next generation, the distribution looks like this. The smaller values decrease, and the higher values increase. So maybe this is what the distribution looks like in the next generation. What is important is that this trait must be hereditary.

That means it must have a genetic basis. Higher X value parents, their offspring their offspring must also be higher X. Which means the offspring of these individuals must be these individuals. And that will be true if the trait is genetically inherited from one generation to another. If this was a trait that was not genetically inherited, then the offspring of this individual would be everywhere.

And then natural selection wouldn't know how to act because this is just a random trait variation that occurs in a population. It's not linked with the genotype of the population. So this is the third important element of the theory of natural selection. The traits in which variation exists and traits which are relevant for reproductive success must be hereditary. That must be inherited from one generation to another.

They must be passed on through some chemical basis, which, of course, Darwin didn't know. So again, I'll summarize these three points because they are just extremely important to understanding how the theory of natural selection works. The first point is that variation must exist. Variation must exist in some trait associated with the population, and we saw that this variation can look something like what is mathematically represented as sometimes a normal distribution.

So this could be my trait X, and this could be the percentage of the population. So that is the first element of natural selection. The second element of natural selection is that variation. Now we have already established that variation exists. So this variation, which does exist, must be linked to

differential reproductive success. That means if I'm looking at the number of individuals, the number of offspring that individuals with different values of X have, this individual is going to have N1 number of offspring, this individual is going to have N2 number of individuals, all individuals in this bar are going to have N3, and so on and so forth. And these Ns are all different. So depending on the value of X, you have a different number of offspring associated with a particular parent. That's variation must be linked with reproductive success.

And the third bit is that this trait must be inherited. And what that means is that now what must be true for natural selection to act is that these individuals which were at this value of X and had N1 offspring. These N1 offspring must also be at the same X value in the next generation. So this is the inherited trait. You acquire the trait from the parent.

So if it is a bacterial population, then this is a uniparental inheritance because you only have one parent. If this is a sexually reproducing organism, then it is a biparental inheritance. And very often the value of the offspring's trait is simply the mean of the two parents' trait values. So, offspring of these individuals with this X naught value of that trait must again be at X naught. Offspring of these individuals with X n trait value must be at X n. If these three conditions are satisfied, then we have all the raw material necessary for natural selection to act.

But before we go any further, it is important to realize how this will break down, how natural selection cannot act if one or more of these conditions breaks down. So let's relax one of these three conditions one at a time and see how natural selection will then fail to work. First is that variation must exist. So if variation does not exist, that would lead to a scenario where the distribution in the population just looks like this. 100% of the population is at the same value X naught.

And then there is no evolutionary change that can take place because everybody is going to produce offspring which is also at X naught, which is also at X naught. So, through generations, the trait value will never move. And if the trait value is not changing, then the population is not evolving with respect to that trait value in that environment in that population. So if variation doesn't exist, then there is no raw material for natural selection to act on. So what is often said is that variation is the raw material for natural selection to act.

The second idea is that this variation, so we understand why natural selection will not be able to act if there was no variation in the population. Let's now relax the second condition. That now let's say that this variation is there in the population, but it's not linked with differential reproductive success. What that means is that Your reproductive success as an individual in this population is not dependent on the value of the trait that is here.

So even if you are X naught, you produce N1 individuals. If you are at XN, you produce an N number of individuals. If you are at X1, you produce N2 number of individuals. And all these ends are equal. Basically, you produce an equal number of offspring, and the number of offspring you produce is independent of the value of the trait.

So, if everybody produces two offspring in this population, in the next generation, this graph is going to look exactly like this. Again, evolution is the change of the mean value of the trait as we move across generations. And if this variation is not linked with differential reproductive success, then the mean value will not change, the distribution will not change, and the distribution of the trait will remain as we are seeing it now in the picture. It will remain like this, and no evolutionary change is taking place. So, hence, variation could exist, but if that variation is not linked with differential reproductive success, we do not have evolutionary change taking place.

So natural selection can't act if variation is not linked with reproductive success. Let's now relax the third element, which is that the trait must be inherited. Let's assume what happens if the trait is not inherited. If the trait value is is not inherited.

Basically, if an offspring is born, so in this case, let's try to work this example here. This is the entire range of X that I have. And in this scenario where the trait value is not inherited, let's say this individual has an offspring. So this individual's value was Xi, but it has an offspring. Now, if the trait was inherited, the offspring's trait value would also be Xi.

But because the trait is not inherited, it could be anywhere. It's completely random. So while variation exists, it is linked with reproductive success. This trait is not inherited, so we cannot say that higher X values will keep on increasing in frequency in the population because the individuals with higher X, when they have offspring, the offspring's value could be anywhere in the population. And as a result, reproductive evolutionary change will not take place as we go through this process.

That sort of summarizes our discussion of what the three core elements of the theory of natural selection are. And these are basic principles, and we'll discuss them with some examples in a few minutes. An important thing to realize is that natural selection, to act, needs variations. Along with the other two conditions. But it needs variation in a trait that is inheritable and is linked with differential reproductive success.

So it needs variation. But what's going to happen is that in a trait like that. If X is that trait and this is the percentage of the population. And this is the variation that exists in the population. As we move forward, what is going to happen is in the next generation, the frequency of this phenotype will increase because these individuals will have more offspring compared to these individuals.

So the frequency of these individuals will decrease. Similarly, it can be worked out that this will decrease, this will increase, and this will, for the time being, stay more or less the same. So in the next generation, the distribution might look like this. And you should realize the evolutionary change that is taking place: these two used to be equal, and in one generation's time, this has reduced, but this has gone up. These two used to be equal, which means this, but now in one generation, this has reduced, and this has increased. And if this process is allowed to propagate for n number of generations, evolutionary change is slow, and it takes several generations for it to show up.

What is going to happen is that these frequencies will keep on increasing, these frequencies will keep on decreasing, and there will come a time in a relatively few number of generations, that this frequency will become zero, the second one will become zero, the third will be small, the fourth will be there, and the fifth one will be the highest frequency. And if we propagate this cycle even more for a few more generations, then what will happen is that the first four frequencies will become zero, and 100% of the population will occupy zero. This phenotype at the highest value of X, and this is going to be 100%. So what has happened here is that the takeaway from this discussion about natural selection that I want you to take is that natural selection needs variation, and in this hypothetical population that we are talking about, this variation did exist.

And hence, because this variation existed, natural selection acted. When natural selection acted, it made the frequencies change in a fashion that is consistent with the rules of natural selection, which is that less fit individuals decreased in frequency, and more fit individuals increased in frequency. And this process, when it was allowed to propagate for many generations, led to this observation that all lower fitness individuals were gone. And the only surviving phenotype in the population was just this highest phenotype, which we can call XN.

So only individuals with phenotype XN survived in the population when this was allowed to propagate over evolutionary time. But in that process, what I want you to realize is that as natural selection progressed, all variation was lost. So, if we go back to our previous slide. We just said that natural selection needs variation to exist so that it can act. But when it acts, it actually removes the variation from the population and only selects the most fit phenotype in the population.

So, this leads to an interesting problem that natural selection needs variation, But it consumes that variation as it acts on a population. We started with phenotypic diversity in the population and ended up in a scenario where all that diversity was lost and only one phenotype survived. So this leads to a curious question: if this is the case and this is how natural selection operates, then what preserves diversity in a population? If we look around us, diversity exists in every trait associated with all living organisms.

Hence, there must be other mechanisms that preserve this diversity in populations. And we'll discuss these themes as we move ahead in the course. Thank you.