

An Introduction to Evolutionary Biology

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Evidence for evolution 3: Descent with modification Part 2

Hi, so in the last discussion we started by looking at evidence for descent with modification. And we looked at taxonomy/phylogeny. So, now we will continue with that discussion. And the first thing that we are going to talk about will be the universality of the basic organization of life. Now, what do I mean by that? So, for all known surviving organisms, genetic information is always encoded as nucleic acids. Mostly, it is DNA, but for some viruses, it can be RNA.

This genetic information in the DNA, and even if it is in the RNA, remember it has to be reverse transcribed to DNA. This genetic information from the DNA is then transcribed into what is known as messenger RNA. This information in the messenger RNA is then translated into amino acids, you know. which are amino acid polymers that are essentially proteins.

And then the process of translation always uses ribosomes whose structure is highly conserved. Now, think about it. We have millions of organisms known on this planet. And in all those organisms with all that tremendous diversity that we have, you have exactly this process going on. How is that possible? What exactly can lead to such a thing? Now, one way of looking at it is simple, which is descent with modification.

We say that the last common ancestor of all life forms, the so-called last universal common ancestor, LUCA had all these properties, and because they are so fundamental, therefore after that things have basically remained unchanged. However, whenever you talk about an explanation, you should also think about alternate explanations. Now what could be the potential alternate explanations for this? One potential alternative explanation is that this may be the only way to make life. There is no other way to make a life. Now, unfortunately, this is a negative statement.

There is no other way to make life, and that is why statements like these are logically very, very difficult to prove. In fact, they are unprovable. So if we ever end up locating life on another planet, or if we ever end up locating a different kind of life on this planet, Then we might end up saying that, okay, there is, you know, another way of doing it. But until we find such a way, we will never be able to prove conclusively that there is no other way of making life. Incidentally, if we end up finding a different way of making life.

Then that will say that multiple ways of making life are possible. And yet only one way of making life is what is here. That will essentially become a very, very strong support for descent with modification. So we actually need something that is ideally very well conserved. but not so well conserved that we cannot even say that hey alternates are possible.

Do we have such a thing, and it turns out that there is indeed such a near universality? For which, again, alternatives are also known, and that is known as a genetic code. Now, when I talk about the genetic code, you know how I ask students. Many of them simply say, "You know the fact that the information is coded in the sequence of nucleotides ATGC on the DNA." But that is not what the genetic code refers to. The genetic code refers to it.

The genetic code is the set of rules that determines which codon in the mRNA maps to which amino acid in the polypeptide chain. So, as we know that there are 64 triplets, we

know that the codons are based on triplets. Three nucleotides at a time, and there are 64, four into four into four, 64 triplets possible given that there are only four nucleotides. We know that there are 20 amino acids, and we know that 3 of those triplets do not code for anything; they are stop codons. The remaining 61 are assigned to 20 different amino acids, as per the table that I am showing you on the right-hand side.

Now, here is the interesting part. If you have 20 amino acids and these, you know 61 codons and 3 stops. Then there are 10^{84} possible alternative code tables. If each one of those 20 amino acids needs to be assigned to at least one codon. No, 20 amino acids and the stop codons need to be assigned to at least one codon.

Now this number 10^{84} is such a number for which we do not really have any reference. It is a large number you can think about, but how large is it? Do you know how large it is? Turns out that the estimated number of atoms in the observable universe is supposed to be between 10^{80} and 10^{82} . which means that the number of possible tables that we are talking about is between 100 and 10,000 times larger than the number of atoms estimated in the observable universe. So, without putting too fine a point on it, that is a very, very, very large number, and yet out of that extremely high number. It is just one code and one you know a few little variants here and there that we see across all organisms.

So, again, the question is: where did this arise? How is it possible? So, people have obviously given multiple possible, you know, reasons for this. So, one possibility is that there is some kind of chemical constraints because of which only one code is possible. So, for example, some people have ended up saying that, you know, if you have a codon on this side, and you know. The tRNA, on the other hand, has the amino acid, and then that amino acid has to interact with the codon. And maybe there is some kind of stereochemical interaction.

Because of this, you know that only certain combinations of amino acids and codons are possible. Now, number one, we do not know of any such thing. Number two, and more

importantly, if you remember the structure of the tRNA, you have the codon on one side. And the amino acid actually is on the other side of the molecule. So it is pretty far away from the codon.

So there is no possibility of some kind of stereochemical interaction happening between the two. So, people discounted very early, but what happens if there are other kinds of chemical constraints? Unfortunately, we have found none, and people have looked for it very, very seriously. In fact, what they have ended up finding is actually the other way around. There does not seem to be too much chemical constraints. So, for example, if you look at ciliates, these are, you know, single-celled organisms like paramecium and all.

In those cases, one stop codon, the UAA stop codon, actually specifies glutamine. Which suggests that there is nothing very universal about UAA, due to which it has to be the stop. Similarly, experiments that have been done have shown that you can actually, through different chemical techniques, reassign a codon in an organism to a completely different amino acid. Including synthetic amino acids that do not even exist on this planet. So just to give you one example there is this codon called UGG. If you look up that genetic code table, you will find that it codes for tryptophan.

Now in 2015, Hosel et al. actually used some techniques to change that codon. To code for a synthetic amino acid called thienopyrrole-alanine in *E. coli*. So, in that particular organism, every single protein that had the tryptophan and all those proteins for all those proteins. The tryptophan was actually replaced by this particular synthetic amino acid on its own. Basically, they produced synthetic *E. coli* that was able to do that. Similarly, you know the same thing was done in 2017 by Han et al. in mice. So *E. coli* is a simple organism; fine, you know *E. coli* can do many crazy things, but we are talking about a mouse. It is a mammal, and even in that case, they were able to completely replace, or rather reassign, one codon to another amino acid. So I am giving you the corresponding references; if you're interested, you can look them up on your own. However, the primary message here is that there do not seem to be any major chemical constraints in the genetic code.

So, what is the other possibility? One other possibility was that, okay, maybe there were many, many genetic codes that arose, and unfortunately, the one code. What we have now is the most optimal code for whatever reason, and because it is the most optimal code. that has been selected and everything else essentially has been selected out. So, they are invoking natural selection as the primary reason. So, now you know the question is, you know, optimal according to what? Now we know that in the genetic code, the third base has what is known as a wobble, which basically means that You can change the third base in a triplet in a codon, and in many cases, not all, but in many cases.

You will still have the same amino acid being incorporated, which essentially means. There is some redundancy in the code, which is very important. Because mutations keep happening all the time, and if there were no redundancy. Then you would actually lead to, you know, the expression of the mutation all the time, which is bad. So, this robustness is actually against mistranslation.

And the hypothesis is that we have the code, which is absolutely the most robust. So, how do you test for this? So, obviously, it is very difficult to do it experimentally, but people have done all kinds of theories where they have asked that. If we have other kinds of codes, you know, well, nobody could have studied all the 10 to the power of 84 . but some other codes then are they going to be as robust as our code Or are they going to be more robust, or are they going to be less robust? In other words, is the code that we have the most robust code possible? Actually, although our code is pretty robust, it is by no stretch of the imagination using whatever metric you want. By no stretch of the imagination is it the most optimal code.

And whatever way you look at it, there are billions of codes that are expected to be much more robust than the one we have. So, this suggests that the theory that the most optimal code is what has been selected is probably also not correct. So that goes. So what remains? Of course, what remains is the simple explanation of descent with modification from the last universal common ancestor. In other words, this code is not

very special.

It just so happened that this code was present in the last universal common ancestor of all life forms. And therefore, this is the one that got frozen in the entire life, you know, amongst the entire life of the world. Now, here I have to take a quick digression. So if you remember, I have been saying that life has originated once or maybe a few times. And not more than that; I never really explained why I said so.

So that is coming from arguments like this, particularly related to the genetic code. So, as we pointed out, the probability that The code that we have arose multiple times in different organisms by chance alone is very, very low. Why? Because the total number of possible codes is extremely high, Therefore the possibility that the same code arose twice is actually going to be very very small. However, the issue is that I cannot really give you a figure for how small it is, right? Therefore, lots of people say you are saying it is very small, but I am not convinced that it is very small. Therefore, for such people, you have to say that, okay, suppose it did not arise once, but suppose it arose twice.

So the probability that the same code will arise twice given the extremely high space is even smaller. The probability that it will be three times smaller is even smaller. So the more times you propose that it has arisen independently, The smaller the probability will be, and at some point, whatever your criteria might be. At some point, you have to say it is 0 or extremely close to 0. So that is the reason for which, for purely theoretical philosophical reasons, we have to say that.

Life has probably arisen one time or, at most, a few times, not multiple times. However, from a very practical point of view, given the fact that the total number of codes is 10^{84} . No one is going to be surprised if the, you know, last universal common ancestor that we have was just one. and not multiple last universal common ancestors. This is just a mathematical point, nothing else.

None of the arguments that we are making will change because of what I just said. So

anyway, there is much other evidence of the fact that there is a fundamental conservation in life. So, for example, you know if you take the gene that induces eyes in a mouse, a gene called Pax 6. and you put it inside Drosophila eggs or Drosophila cells. Then the resulting fly that comes out of that egg is actually going to have, you know, eyes developing in its legs.

So, for example, that is exactly what I am showing you over here. These are the things that you are seeing over here; these are actually eye cells. which are coming out of the legs in a Drosophila, which basically means that this gene makes eyes in mice. Even if you put it inside something as, you know, primitive as Drosophila, something as small as Drosophila, something as different as Drosophila, is still capable of making the eyes. Now, although this is a very eye-catching example, if you think about it closely, you know Bt cotton.

The fact that you can express human insulin in bacteria is significant. And that is what has brought down the cost of insulin for millions of diabetics all over the world. Pretty much every single miracle of recombinant DNA technology. All of which is possible because you can take the gene from one organism and express it in another. All that, think about it: what kind of miracle it is going to be if life were to originate separately, right? But the fact that it is still happening shows us that life is fundamentally conserved.

And the best explanation for why life is conserved is actually descent with modification. So, those are two lines of evidence. Now, we are going to talk about another major line, the so-called Darwinian homology. Now, in most books, you are simply going to see this term as homology. but I will explain why I am calling it Darwinian homology in a minute.

So, suppose you have two organisms. Let us say we have a whale and a shark. So, the one on the top is a whale; the one on the bottom is a shark. Now, both of them live in the water; both of them swim in the water. Both of them need to move against the friction that is caused by water. And therefore, one can argue that the fact that their bodies are

very similar to each other is simply because of the function that is, you know, that they are performing.

The fact that they are living in a similar environment is what is dictating the similarity in their body shapes. So, this is what is known in biology as analogy, which is similarity in structure explained by similarity in function. However, suppose you have a situation where the structure is similar, even though the functions are very, very different. That is what used to be called homology in Darwin's time. Of course, Darwin didn't call it Darwinian homology; he simply called it homology.

But that was the definition of homology in Darwin's time. The structures are the same, yet the functions are very different. However, nowadays, the term "homology" has taken on a slightly different meaning. In modern usage, homology refers to the fact that certain traits or characters are related by ancestry. Now, why am I making this distinction? Because right now, what is it that we are discussing? We are discussing what the evidence is in favor of descent with modification. Now, if we end up using homology in terms of ancestral relationships, Then that means that we are taking descent with modification as a given, right? Because ancestry and succession essentially come from the concept of descent with modification.

So, if we use this modern understanding of homology and show you those things, Then we cannot really claim that to be, you know, proof or evidence in favor of descent with modification. That problem did not exist for Darwin because he used homology in a very different way and in his honor. We are going to call it Darwinian homology, which is basically similarity in structures but difference in function. So, what I am showing you here, This is a very classic textbook example of Darwinian homology in, you know, the four limbs of vertebrates, specifically tetrapods. So, if you look at the early tetrapods, the amphibians, and all, So their body and their four limbs have a certain structure, or a certain way, or a certain plan.

So, this bone is known as the humerus. So, after this bone, there are two bones over here; they are known as the radius and ulna, and after that, there are a bunch of bones. These

are known, as you know. First, you have these bones; these are known as carpals, and then you have these bones. The ones that form our palms are known as metacarpals, and then we have the fingers, which are known as phalanges. So, if you look at the limbs of all tetrapods, then different tetrapod limbs are performing different functions.

So, the limb of a seal is, you know, used for swimming; it has a flap-like limb. The limb of a horse is used for running, so it has a rod-like structure; the limb of a human is used for grasping. so you know its hand looks like the way my hand looks, The limb of a bird is used for flying; the limb of a bat is used for flying. So, all these limbs actually have very, very different purposes.

Yet, if you look at their structure, they are always the same. One bone, two bones, multiple bones, multiple bones, multiple bone-humerus, radius-ulna, carpals, metacarpals, phalanges. Look at this: seals have the same plan; horses have the same plan. Now, here it is very interesting. So, if you look at the horses, you have the humerus.

Let me do this; you have the humerus, sorry. You have the humerus, you have the humerus, you have the radius, and the ulna. But after that, if you look at this, there is one bone that seems to have become the longest. This is the third digit, this is the 3 over here. The other bones have either become smaller or, in many cases, they have completely disappeared but this is in a fully grown horse. If you look at when the horse is developing, you are actually going to see every single bone that it has in the tetrapod limb. Some of these bones actually disappeared during certain stages of development. Which is why you have to say that you know all tetrapods have limbs with at least 5 digits at some stage in their development. Similarly, if you look at the birds, you see that it has digit 1, it has digit 2, it has digit 3; 4 and 5 are not there. But if you look at when the bird is developing, 4 and 5 digits are actually there which at some point essentially simply, you know, regress and disappear. So, here is the question: why should organs that have very different functions still have the same underlying structure? Now, think about it: if they have come from different sources, they originated separately and were put together separately. Then, from an engineering perspective, you do not really expect all of

them to have the same structure. Yet, biologically, when we see them, they do. So, the simplest way of explaining them is that you know the same thing that we have been doing for everything else. You can simply say that, hey, look, there are no other ways of making limbs.

And in this particular case, we definitely know that is not true. Why? Because tetrapods are not the only ones with limbs. You also have insects with legs, spiders with legs, centipedes, and millipedes; all of them have legs. You know, even octopuses have legs, squids have legs, and all those limbs have a very, very different structure. Therefore, saying that you cannot make limbs in only this way—there is no other way—is completely wrong, right? Therefore this explanation goes. So the only other explanation that remains is the explanation of descent with modification which suggests that the ancestral form had this plan and that subsequently the plan was not changed, It was simply modified to become something different. So, now we come to one of the strongest proofs, you know, in favor of descent with modification, which is the fossil record. So, actually, in the context of the fossil records, there are multiple lines of proof. Now remember, descent with modification is saying that these forms have essentially changed from one form into another.

The other form has changed into another, and so on and so forth. So if this is the case, then for all the existing species, Since they have come from other pre-existing species, you expect to find some fossils, okay? So, for all the existing animals or organisms, you expect fossilized forms of their ancestors. And more importantly, whenever you are having, let us say, one group transitioning into another group, you expect. You know, although today they are very distinct. So, for example, let us say you know reptiles are very distinct from birds today. But recent modifications suggest that this change was probably not a one-step change.

There probably was a slow change, and therefore you expect intermediate forms. So if that is the case, you actually expect those transitional forms to be there in the fossil record. Now, although this expectation is correct, practically speaking, it is very difficult

to get fossil records. Why? That is because the process of fossil formation requires extremely special conditions. First of all, the organism has to die, and normally what happens when an organism dies is all kinds of you know parasites and insects and everything else they just eat the body and very soon the body is completely decomposed and no trace remains of it, right? So, obviously, in those situations, fossilization is not possible.

So, first you need the organism to die. and then for whatever reason the dead body needs to get preserved extremely fast so that nobody else is able to eat it. Then the organism has to die somewhere near water because. It is only then that you expect the entire thing to be covered by sediments. Or, you know, maybe lava or something like that, and only then is it going to be preserved. And even when it is covered with sediments, all kinds of special conditions of temperature and pressure occur and you know minerals, etc., need to happen for a fossil to be formed. So, first of all, this means that fossil forms of, you know, that are, sorry, Organisms that are dying away from water are unlikely to get fossilized. and therefore you know that leaves a relatively smaller amount of space where fossilization can happen. The other important problem is that fossilization typically happens for the harder body parts: the bones and the teeth. The softer body parts are very, very difficult to fossilize, right? And that also puts a lot of restrictions on what gets fossilized and what does not get fossilized. So, taken together, the formation of a fossil itself is a rare event, and after the fossil is formed.

It is going to face all the forces that are operating in the Earth's crust and, in many cases, you know, under the deep ocean. all of which are also you know can in principle end up breaking and disintegrating the fossil itself. So, although theory tells us that the theory of descent with modification indicates fossils are supposed to be there, Practical constraints tell us that although they are likely to be there, they are unlikely to be found, at least not in very large numbers. In spite of that, after Darwin, a lot of effort has been put into paleontology.

Paleontologists have actually ended up discovering lots and lots of fossils. And a lot of

this happened because of Darwin's strong claim that, you know, at his time, fossil records were sparse. But he was so bold that he ended up saying that if you look closely and carefully, you are going to find a lot more fossils. And you will be able to patch up a lot of these gaps, and this prediction has actually been extremely well borne out. Today we have fairly good records for many organisms.

So, for example, this is again a textbook example of the fossil lineage of horses. So, horses actually started with much smaller animals with five toes, and over time, So, I do not know if you can see this. So, this has more toes. So, this is already a form that has 3 toes, and then you can see that. One toe is becoming larger, and the two toes are becoming smaller. So, by the time you come to *Pliohippus* and *Equus*, this is the modern form; you can see only one toe remaining.

Similarly, there are, you know, gradations in the skull itself, the structure of the skull. Now, typically, when you see this diagram, people end up thinking that Oh, *Mesohippus* led to *Merychippus*, *Merychippus* led to *Pliohippus*, and *Pliohippus* led to *Equus*. That is not what this is supposed to show. The descent with modification is still a web-like, tree-like structure, like the kind of tree that we saw. It is still a structure like this.

We have some of the nodes from these trees, and those nodes are these. So, that is what I mean by saying it is not a linear sequence of events. But still, we actually have many of the intermediate forms going from the five-toed horse-like ancestor. All the way to the one-toed horse that we have today. So, this is about one lineage.

Again, as I said, there are many, many more lineages available to paleontologists today. And the other thing that I said was about transitional forms. This is perhaps the most well-known transitional form that we have, that of *Archaeopteryx*. which is a transitional form between theropod dinosaurs and birds, telling us that You know the birds and these dinosaurs had a common ancestor at some point, like this. So, this fossil actually has some proper properties that are bird-like and many properties that are reptile-like.

The other major way in which fossil records help us is by providing evidence of past life forms. In proving descent with modification, it is in terms of the order of at least the major groups. So, you know that we can date fossils, right? We can date fossils in two ways. We can date them in terms of the layer in which they are found, which is a geological layer. Nowadays, you can also directly do radiometry and other isotope tracing techniques. By which you can figure out, roughly speaking, what the age of the fossil is and around what time it died.

So, this actually allows us to date and reconstruct the order of the major groups. So, this is roughly what it looks like for the class Vertebrata. So, here what you see on the y-axis is time, and these are the various, you know, time periods. Cambrian, Ordovician, Silurian, Devonian, Jurassic, Triassic, Cretaceous, and Tertiary, and so on. Now, here this shows, roughly speaking, at what point the various groups branched off.

So, for example, if you look at this, this suggests that birds branched off from the—let me use this. So this suggests that birds branched off, you know, from the reptilian lineage somewhere around the Jurassic, right? Whereas if you look at mammals, they branched off from the reptilian lineage. Somewhere around slightly before this period. Similarly, it tells you that, let us say, amphibians branched out from the fishes somewhere around the Devonian-Silurian period. So, looking at this, what are you getting? You are getting an order in which the groups arose based on fossil data. Now remember when we created those phylogenetic trees, we were also getting an order of which group deviated or which group branched off from the parent groups, roughly speaking, earlier, and which groups branched off later. So from that, we know that the amphibians were the first to branch off, okay. The reptilians branched off after that.

So, you have an order over there. We know that mammals ended up branching maybe a little before the birds. So if you get an order from there, you get an order from here. These two orders need to match. If these two orders do not match then we have an issue right. And the best part of it is that, at least for the major groups, these orders match extremely well. You are unlikely to find, and I am unlikely to find, in the sense that to

date nobody has ever found a mammal which, let us say, is, you know, older than an amphibian, or which, let us say, branched before the amphibians branched off. You do not have a mammal present in the period before amphibians branched. So, the orders that you are getting from these branchings are actually corresponding extremely well with whatever orders. We are getting from our phylogenetic trees, which, remember, is coming from a very different set of information. And this again allows us to put a lot of credence in the theory of descent with modification because both these things You know there are two different manifestations of descent with modifications, both of which lead to the same information.

So, what other observations do we have that are consistent with descent with modification? Actually, the number is extremely large; you know we have already spent about two discussions on it. So, what I will do is quickly talk about two or three major lines of evidence. If you look at some of the references that I will share with you, you know. You have many more pieces of evidence, many more lines of evidence for this. So, one of the lines of evidence comes from our study of anatomy, those of what are known as vestigial structures.

Now, traditionally, vestigial structures were defined as organs that do not have a purpose in the body and are non-functional. But the problem is that if you say that something is non-functional It is extremely difficult, if not impossible, for you to prove that it does not really have a function. And what you think today does not have a function, tomorrow somebody else might show that it has a function. So, for example, you know this appendix in humans.

For a long time, people thought that the appendix is a completely vestigial organ. has no function, and it was in the textbooks as a prime example of vestigial organs. I mean I read it when I was in college; I was reading the appendix as a vestigial organ. A few years back, they ended up showing that the appendix actually plays a very important role. What it does is let you know that inside our gut we have all kinds of bacteria, the so-called gut bacteria. So, it turns out that the appendix serves as a repository, a bank of those gut

bacteria, such that Due to some infection or maybe due to some antibiotics that you have taken, If all the gut bacteria in your gut die off, they can be recolonized from the appendix and people are obviously still debating this thing; they are still studying whether this is correct or not. But preliminary evidence looks like that organ is not a vestigial organ at all. So, nowadays you have a more modern definition of a vestigial structure or vestigial organ. which says that it is a less elaborate or non-functional organ, either less elaborate or non-functional, whatever That is structurally or developmentally similar to a more elaborate organ in other organisms. So, sometimes it is non-functional; sometimes it might be functional.

But definitely, it is a much smaller, much less fancy version of something else that exists in another organism. So, just to give you an example, this is the undersurface of a snake, a boa constrictor to be more specific. I do not know if you can see this or not, but let me show you what you are seeing: the legs. And these are the legs. Can you see them now inside those blue circles? So, of course, a snake is a reptile, but to be more specific, you know it is a reptile that is not supposed to have legs. It is a legless reptile, but developmentally speaking, the legs are very much there, and if you actually cut open this leg.

And if you study its structure, you will find that entire, you know, 1, 2, the humerus, radioulnar, carpal, metacarpal. That entire structure is actually present inside that small nub. That you find on the underside of the boa constrictor. Similarly, goosebumps appear on human skin. So, you know that when we are shocked or when we are really aroused for whatever reason.

Then we get these things, you know, these spots on the skin which are known as goosebumps. And why does that happen? That happens because we have these arrector pili muscles, which are at the base of every single hair on our skin. Now, in birds and in many primates, whenever they are, let us say, threatened or anything, then these muscles They end up, or whenever they are cold, for example, they end up constricting, and the hair ends up standing, you know, on itself. So basically, the size of the fur and the depth

of the fur increase quite a bit.

That can increase the body's insulation. So it helps as a mechanism to fight colds. That can also end up making it look bigger, you know. It is used as an aggression-related thing to, you know, frighten off potential predators or something else. However, in humans, where the fur has been reduced quite a lot, none of those things is possible. Even if the hairs on our hands stand up, they do not really give us warmth. Yet the muscles are still there, and that is why when we suddenly feel cold or when you suddenly feel threatened, The muscles still contract, and it does not lead to anything else apart from these goosebump-like structures.

You have similar non-functional elements at the level of your genome. So, there are certain non-protein-coding DNA sequences. whose structures are actually very similar to those of functional protein-coding genes in other organisms. These are known as pseudogenes. So, for example, human beings and other primates cannot really manufacture vitamin C, which is why you know. Whenever you have a cold, the doctor tells you to take vitamin C tablets.

Because if you could make it on your own, you would not have needed to do that. Yet the enzyme that is required to make vitamin C is very much present in our bodies. This is the enzyme L-gulonolactone oxidase; I cannot pronounce it forever: L-gulonolactone oxidase gene. And this is the chief enzyme that is needed here. We have the gene, but it is not activated in the sense that it has many mutations.

Because of this, it cannot produce any protein, which means we cannot make vitamin C. Much more critical is our inability to break down uric acid, and by the way, we are not the only ones. even other close relatives of ours all the apes they cannot break down uric acid. And many of you might be aware of uric acid, or rather the deposition of uric acid, you know, inside our joints. Due to a high level of uric acid in the blood, this is what leads to an extremely painful disease called gout. So, it turns out that the enzyme responsible for breaking down this thing, This so-called urate oxidase, we very much

have that gene, like many of our other ancestors.

It is just that it has lots of mutations that have ended up inactivating the gene. So, we will give you one more example like this. This is from the field of developmental biology. So, in giraffes, there is this nerve called the recurrent laryngeal nerve. It is the fourth branch of a big nerve called the vagus nerve.

So, this nerve, actually, I do not know if you can see it. So, this nerve is a laryngeal nerve. So, it is supposed to arise from the brain and go to the larynx, the place where the voice box is. So, it is supposed to start here and go here, which is great except that the path that it takes is what you are seeing in this black thing; it goes all the way like this. And then it comes back up like this, which is about 4 and a half meters, which is about 13 or 14 feet of nerve. So, this thing, instead of going straight like this, comes down like this.

The neck of a giraffe you can imagine makes a loop over here around the aortic arch and then goes up again. Why, in God's name, does it do that? Turns out that the giraffe is not the only guy who has this problem. We have similar things in humans. So, in humans, this thing is supposed to start from here. This thing is supposed to start here and just go there.

This is our larynx, but it does the same thing; it, you know, first goes down and comes close to the, you know, sorry. It first goes down like this, comes close to the aorta, takes a loop, and then goes back again to reach over here. Why? About 2 feet of extra nerve, what is the purpose? We have no idea. Now, by themselves, these two observations seem to defy all logic. Why does the organism have such a design? And yet, the reason for this design becomes very clear when you look at the ancestral state.

So, this is a diagram that I made. Sorry for the extremely poor quality of the diagram, but unfortunately, when I am using this pen on this pad, you know it is very difficult to control this pen, but still, I have tried my best. So, this is what happens in the fish; this is

the ancestral form. So, in the fish, you have the dorsal aorta, which is one of the blood vessels on the dorsal side. This is the ventral aorta; this is the blood vessel on the ventral side, and you have connections between them.

So, there are six such connections: one, as you can see over here; one, two, three, four, five, and this is the sixth one. Now, this vagus nerve is in this position. This is the first branch, this is the second branch, this is the third branch, and this is the fourth branch. And this fourth branch is actually going behind the sixth arch, right? So, this one. Now, in the fish, this is a direct straight line, absolutely the least path.

However, due to evolution, what has happened is that this sixth thing exists in both humans and giraffes. This has actually traveled down a lot, and this is now forming what is known as the aortic arch. This is forming something near the heart in this region. Now, with all these organisms, the giraffes and the humans, we have not really been able to modify the position of the nerve.

So, the nerve is coded in such a way that it still follows the aortic arch. and makes a loop, coming back to the equivalent of the larynx. And therefore, instead of this short, straight path that you find over here, This actually makes the entire detour and comes back. This is what we know because we have seen this happening developmentally. Now, why exactly should there be? Now, if you think about descent with modification, the term in which I explain this entire concept, then this is explained very trivially. However, it turns out that many people think that evolution has not really happened.

Because the fantastic amount of, you know, complexity that we see can only happen if there is an intelligent designer. So, if you remember, we talked about William Paley, right, when we were looking at the historic idea? Who argued that if you find a watch, you assume that there has to be a watchmaker? Therefore, if you find that the bodies of organisms are so complex and so well made, That automatically implies that there has to be a designer. Otherwise, how do you get such perfect, you know, plants? How do you get perfect, such perfect things as a well-made organism? What these examples show you

is the example of the pseudogene and the example of the, you know, vestigial organ. The example of this extra nerve in the giraffe is that, in many cases, organisms are not really designed very perfectly. Organisms have all kinds of oddities that make no engineering sense.

Which is actually costly for the organism in many ways, right? I mean, think about it; for example, in human beings, our testicles hang outside. And if you have ever participated in a fight and you are male, You know what kind of a disadvantage that damn thing is, right? However, in spite of that, that thing is still there because that is the way evolution has made us, right? That is the way the descent with modification has taken us. So, all the imperfections in the human body can be explained extremely well. If you look at what happened in the ancestral forms or what kind of other benefits you are getting from those structures. However, intelligent design cannot really explain most of these oddities.

Most of these apparently purposeless features of organisms, which is why this entire line of evidence exists, you know. Coming from all these imperfections is a very important set of evidence in the context of descent with modification. So, until this point, we have talked about all the general lines of evidence for descent with modification. Now, please appreciate that for each one of these general lines that we talked about, Taxonomy, the fossil record, etc., you have many specific cases for various groups of organisms. And therefore, it is not that we have one proof of descent with modification. You have proof of descent with modification in the context of mammals. You have proof in the context of humans, in the context of horses, or in the context of, you know, any other set of organisms. So, it is probably a good idea for you to take a look at one group of organisms. And in the context of that group of organisms, look at everything—the various lines of evidence that we talked about.

Now, that is something that I am not going to cover in this lecture, but it is very much a part of this course. So, for this, I will refer you to a video related to one such group of organisms. namely, the cetaceans, or the whales and the dolphins. So, this is the YouTube video that you need to watch. It is a very nicely made video, with lots of, you know,

pictures of fossils, etc.

And this is the end of this particular discussion, and we will meet again in the next discussion to ask the question that. You know, in spite of all these lines of evidence, a lot of people still tend to have objections. Related to one aspect of evolution or another. What might be the reasons for those objections, and what are the counters to those objections directly? What are the scientific mistakes that people often make? While examining all this evidence, what are the ways to counter it? See you in the next lecture. Bye.