An Introduction to Evolutionary Biology

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Week 7 Lecture 35

Why sex?

Hi, so last week we discussed how evolution explains one of the most intriguing patterns in the whole of biology, that of aging. This week we are going to discuss another very, very interesting thing on which evolution sheds a lot of light, namely sex. Now, what exactly does one mean when one says "sex"? In common day-to-day language, "sex" can mean many things. One usage, of course, is in terms of gender—the role that an organism plays in its society, particularly. In the context of human society, it can mean the act of sex, which a certain Sheldon Cooper would call coitus or intercourse. But when a biologist talks about sex, the way they think about it is slightly different.

And in order to understand what exactly a biologist thinks in terms of sex, One first needs to understand what the various ways are in which reproduction happens in the animal or rather in the living world. So, of course, when it comes to reproduction, we are talking. About one organism producing babies or offspring of its own species. And when this happens, there are two major ways.

One way is reproduction in which there is no mixing of genes among individuals of the same species. So, think about bacteria. When it divides, it does not really need to mix genes from other bacteria, and that is what is known as a part of asexual reproduction. Or, for example, when a hydra buds or a yeast buds. In contrast, you have another scenario where individuals need to explicitly mix their genes.

In order to produce the next generation, this is what is known as sexual reproduction. Now this mixing of genes happens in terms of what are known as gametes, right? These gametes can be of two kinds, or rather, there are two situations in which you can find the gametes in terms of size. And these two situations are when the gametes have the same size; this is what is known as isogamy. Or you can have a scenario in which the gametes are of unequal sizes, and this is what is known as anisogamy. Now, as far as we understand, almost all the reproduction that we have is primarily in terms of the fusion of two gametes.

And if we are talking about them being unequal in size, obviously we are talking about one being large and the other being small. The smaller gametes are known as the male gametes or the sperm. The producers of the male gametes, or the smaller gametes, are known as males. And the larger gametes, typically known as eggs, are produced by the larger gamete producers, known as females. So, in this context, biological sex is simply a system of classification.

It is the system of classification, binary classification of anisogamous organisms as either males or females; these are the potential. Producers of the small gametes or females who are the potential producers of the few large, resource-rich gametes. Now, the person who put this very, very nicely and very, very pithily was a famous evolutionary biologist named Joan Roughgarden. And what she said was very simple. She says to a biologist that male means making small gametes and female means making large gametes.

By definition, the smaller of the two gametes is called a sperm, and the larger an egg. That is it; that is all there is to sex for a biologist. Now this is all good, but when it comes to the strategies of reproduction, you know, between sexes and Sexual and asexual reproduction turns out that the living world represents an enormous amount of variation. Now this amount of variation is so large that there is no way I can give you a proper listing in the next few minutes. So, all I am going to do is just show you a few random examples of these kinds of strategies.

So, for example, as I talked about in the context of asexual reproduction, you can have hydras simply budding off, as shown. Here in this particular figure, or in slightly higher, more complex organisms, you have vegetative propagation in Biophytum. So, this is a very common plant in, you know, many, many gardens or even in You know, on balconies where people put simple tubs, they use these simple pots. Here you can see that on the edges of the leaves, there are these small, spall bud-like structures, and from these structures They have root-like structures coming out, and each one of these buds, if you put it in the soil, will form a whole tree. So, as you can imagine, this propagates extremely fast.

Then you have, you know, amongst animals, asexual organisms that are typically a little rarer, particularly among vertebrates. But this is a very interesting example. This is a lizard known as the whiptail lizard, and there are many species. Of this particular genus, Aspidoscelis, 13 of those many species are all females and reproduce only asexually. So, how exactly do they reproduce? So, they reproduce through what is known as parthenogenesis, where their unfertilized eggs can develop into offspring.

And of course, these are unfertilized eggs, which means that they are genetically a complete clone of their mothers. Now, the interesting bit about these species, these asexual species among all the Aspidocelis genus, is that they All of them have arisen due to hybridization events at different times between ancestor species that were bisexual. And scientists have shown in all these cases that the arising of the asexual lineage has happened in a single generation. So, this is fascinating because, of course, the amount of difference between asexual and sexual reproduction is one. expects it to be huge, but you can go from a sexual mode of reproduction to an asexual mode of reproduction in one generation Within one generation of hybridization, that is something that I have always found to be mind-boggling.

However, this is just one scenario; we are still within the realm of the asexuals. But sorry, this is the group that is the largest known collection of unisexual vertebrate species. As I was saying, this is, you know, one example of asexual reproduction. But you actually, amongst animals, have a tremendous variety in terms of reproduction; well, not only animals, also plants. So, for example, here I am showing you the strawberry.

Now, as you know, strawberries normally reproduce by asexual reproduction. So, like grasses, they send out runners, and you know that from one place the plant will send out runners. And at another place, another plant will grow; they will be connected internally, you know, under the soil. But the strawberry can also reproduce sexually. So, sometimes, somewhat rarely, they can.

And they do produce seeds, and then you can take those seeds and just plant them, and you will also get a plant. So, here you have a scenario in which both kinds of reproduction are in the same organism. An even more extreme case of this is the clownfish, the Finding Nemo fish. So in this particular case, all these fish, when they are born, are all males, but The largest of them all ends up changing its sex to female. In this particular case, you can see one of them is large; the other two are small.

The large one is the female; the other two are the males. Now it turns out that if you remove this female or if the female dies for whatever reason, Then whichever is the largest male among these will develop into a female, and the others will now start mating with it. So a scenario where, depending on the environment, the adult can change its sex from male to female. Of course, then you have this particular scenario: earthworms. So here, the same individual has both male and female reproductive organs.

So, such organisms are known as hermaphrodites, as you know, and this, of course, leads to a conundrum. What is it? Because if you have the male sex cell and the female gamete in the same organism, in principle, they can end up fertilizing each other. In other words, you can have the next generation coming simply by self-fertilization, and self-fertilization is a thing. It does happen in many plants, but when it comes to earthworms, it does not happen. Why does it not happen? Because earthworms have evolved something known as protandry.

What is protandry? So, here the male reproductive organs of the organism mature earlier than the female reproductive organs. which is why there is a prevention of self-fertilization and the geometry of the organs is such that it is very difficult for them to bring the male and female organs together. So, you know sexual reproduction in earthworms actually involves two worms exchanging gametes, which is what you can see over here. You know they basically orient themselves in the opposite orientation. So, head to tail in this direction for one, and you know head to tail in the other direction for the other, and then Their male parts and the female parts superimpose on each other, and they exchange the male and female gametes.

And then, of course, you have guys like this. So, this is the famous rainbow agama. In this particular case, the sex is determined entirely by the temperature that the embryos experience during development. So, if it is slightly colder, 26 to 27 degrees Celsius, then it will develop into a female. If it is higher, it is actually 29 degrees Celsius; that is a type over there.

So, if it is around 29 degrees Celsius or slightly higher, then this will develop as a male. So, as you can see, there is a bewildering variety of strategies for reproduction among organisms. Now, of course, this leads to the question of what exactly determines how an organism should reproduce. And at the fundamental level, the question is when an organism should be sexual and when it should be asexual. Now, how do you answer this question? So the simple way of answering this question is to figure out what the merits and demerits of asexual reproduction are.

And what are the merits and demerits of sexual reproduction? So what we will do is start with one of these, which are the demerits of sexual reproduction. And when we do that, what are the demerits of sexual reproduction? And it turns out that there are quite a few. So let us start with perhaps the biggest one: let us take a toy example. So, suppose you have two populations, both of which have a sex ratio of 1:1. And each one of the females, on average, produces 2 babies.

Now let us assume that the first population is sexual, which means that a 1:1 sex ratio indicates that, on average, you have One male and one female are going to produce two babies; one of them will be male, and the other will be female. So, in this case, what is happening is that you start with 2 individuals and you end with 2 individuals. And the same thing happens in the next generation; again, you end up with 2 individuals. In other words, the population size remains constant, right? I mean, you can think about it, right? If the female is producing 2 babies, one of them is a male and one is a female, and the males are not reproducing. So, the female, in essence, is just producing one female.

Obviously, the population size is going to remain constant. Now think about the other case, the asexual case. Of course, here you cannot have males and females; here both of them are female. First, one female is producing two babies; the second female is also producing two babies. So what is happening? From 2, you get 4; the next generation, 4 becomes 8.

So obviously the population size in this case does not remain constant; the population size is constantly increasing. Now, this is a toy example in which we assume that the sex ratio is 1:1. But suppose the sex ratio is not 1:1; let us assume that the sex ratio is, say, female-biased. On average, it is producing more females than males. Even in that case, as long as in both cases the number of babies that are being produced is the same, The rate of growth of the sexual population will be far smaller than the rate of growth of the asexual population, I mean, you can; you do not need any math for this; you just think about it logically. If in both cases, the sexual and the asexual, the number of babies per individual per female is the same, But in one case, there are at least a few males being produced in the sexual case. Then those males are not going to reproduce; they are not going to produce more babies. Therefore, the overall growth rate of the population is going to be lower in the sexual case. And this is what is formally stated in this way: that as long as the reproductive output and the progeny survivorship of sexual If asexual females remain the same, the population size of the asexuals will increase at a faster pace than that of the sexuals.

And this is what is known as the cost of sex or the cost of males. So, this is the technical; both of them are technical terms, essentially meaning That if you have sexual reproduction, then the population growth rate will be lower. And this concept was introduced by the famous British evolutionary biologist John Maynard Smith in 1971. Now, I need to give you one more term, which is known as the twofold cost of sex. What is that? In the example that I gave you, if the female produces offspring in a 1:1 ratio, which is exactly the example that I took, That indicates that the female is investing an equal amount of resources in making males and females.

That is what a 1:1 ratio is all about. If that is the case, then the per capita birth rate of the asexuals will be twice that of the sexuals. From a population dynamics perspective, if you compute the birth rates of the models, The per capita birth rate of the asexuals will be twice that of the sexuals, and this is what is known as the twofold cost of sex. This is another term that you are going to encounter in the literature quite a bit, that the cost of sex is twofold. And that is a special case of the cost of sex that we talked about in the previous slide, under the assumption that the sex ratio is 1:1.

That is about it. It is basically referring to the same phenomenon under a specific scenario. Now, this cost of sex that we talked about is by no means the only cost that sexually reproducing organisms have to pay. There are many others, so I will just give you a quick listing. For example, what is known as the cost of meiosis. As I said, if you are having sexual reproduction, then two gametes have to come together and fertilize.

Now, that means that sexual reproduction is always associated with meiosis and a reduction in division. If you do not have a reduction division, then the chromosome number will keep doubling every generation. And very soon, the chromosome numbers will become infinitely large, and of course, the species identity will get lost. Therefore, every generation, a sexually reproducing organism has to undergo a reduction division. But the moment you undergo a reduction division, you pass only 50 percent of your genes to your gametes, and hence to your next generation, which means in terms of how genetically related you are. A sexual organism is only related 50 percent of its genes to its offspring, to its babies. On the other hand, an asexually reproducing organism is essentially reproducing clonally. This means it is passing on 100% of its genes to its next generation, barring a few mutations here and there. And therefore, the relatedness that it has to its offspring is 100%, right? So, in other words, if you are asexually reproducing, you are not able to pass all your genes to your next generation.

You are able to pass only 50%. Then, of course, you have the cost of sexual selection. The moment you have sex, two sexes, then one sex can end up choosing who to mate with, and the moment this choice comes in, The sex that is experiencing the choice, the other one, basically, can and is often forced to evolve all kinds of. What are known as secondary sexual characteristics? So, take, for example, the tail of the male peacock. You know that it has this very beautiful, nice, long train of feathers, which looks awesome; the females like them. The female peacocks, but it is actually extremely bad for the male peacocks because it severely hampers their ability to fly.

And yet they have to evolve it; otherwise, they are not going to get mates. So, this is something that we are going to talk about in great detail, not in the next discussion, but in the discussion after that. But as of this moment, just keep it in your mind that there is a tremendous cost of sexual selection that not all. But many, many sexually reproducing organisms have to pay; the asexuals do not care.

Then, you have the massive cost of sharing a genome. What do I mean by that? Again, think in terms of peacocks. Now, suppose you have a male peacock that has evolved to have this nice long tail, which gets it more mates. But when the peacock is reproducing, this same gene that is responsible for this tail, That same gene is also being passed to its female offspring, right? Now, what happens when this gene expresses itself in a female? Inside a female, if it ends up producing a nice long, colorful tail, then that actually does not help the female at all. That is actually detrimental to the female because it prevents her from flying properly, but at the same time, it does not attract her mates. So, the same gene that is good when it finds itself in the body of a male can actually be extremely bad for the bearer.

If it is found in the body of a female, and you know the opposite also happens, this is what is known as intralocus sexual conflict. And this is a cost that many sexually reproducing organisms end up paying. Again, asexuals completely avoid this cost. The fourth thing that we are going to talk about, of course, is something I am sure many of you might have experienced yourselves, is the cost of mating. If you need to mate, then you need to find yourself a mate. And in order to find yourself a mate, sometimes you need to search a lot. Sometimes when you have found a mate, you need to signal, right? I mean again, think about the peacock, how much energy it needs to expend to create that massive tail of its; a lot, right? And then courtship, peacocking, and dancing; when you are dancing, you are extremely appealing to the female. But you are also attracting the attention of the predators; you might get killed, right? So, all these things—searching, signaling, courtship, and even, you know, population—are pretty energy-consuming activities.

So, all of these are very costly in terms of energy and time. And this becomes a particularly thorny issue when the population size becomes small. Because then you have to spend even more time and even more energy doing this. Asexuals do not care, they want to reproduce, they reproduce, right. As long as the resources are there, they will be able to reproduce; they do not need to undergo all these things. And then you have the cost of inbreeding; you have the cost of hybridization.

So, as we have already discussed, you know that inbreeding can happen in small populations. Sexually reproducing organisms sometimes, if they are not able to identify mates of their same species, By mistake, they end up mating with individuals of other species. It is known that it keeps happening. In most cases, if that happens, the hybrids typically end up having either, well, In most cases, the hybrids are not even formed. When the offspring are formed, in many cases, The offspring actually have either reduced survivorship or are not able to reproduce, and so on.

So, all these situations actually lead to reduced fitness among the, you know, sexuals.

Asexuals as usual do not really care, they do not have to pay this cost. And finally, this is actually pretty big: the cost of sexually transmitted diseases. Humans are not the only species that pay this cost. All species that reproduce sexually can potentially end up paying this cost.

So, as you can see, I listed quite a few. I listed a total of seven causes here, and you will be surprised to know that even this is not the complete list. So, if you want to know more about the costs of sex, here is a review that you can look at. Of course, you know this is just for your own edification. This is the rest of what is presented; the extra information presented in this review is not part of this course. So, given that sexual reproduction is so expensive, there are many ways in which you know sexually reproducing individuals.

Having to pay these extra costs, it stands to reason that sexual reproduction should be one of the rarest things. In the world, in the living world. So, what does the data tell us? And it turns out that if you look at all the organisms, sexual reproduction, particularly among eukaryotes, is extremely common. Among prokaryotes, such as bacteria, most of the time they reproduce asexually.

But among eukaryotes, it is extremely common. Now, that is a vague statement. What do I mean by extremely common? How common? So, just to give you some idea, about 99.9% of the approximately 1 million known animal species are sexual. Among the plants, the majority of the higher plants are sexual. It is also extremely common among simple eukaryotes, including fungi, algae, and protozoa.

And to make it even, you know, give you a better understanding of everything in general. Maynard Smith states that about 1% of all species are asexual, which means that 99% are sexual. And these asexual species typically tend to represent evolutionary dead ends, which basically means that In most cases among eukaryotes, these asexuals have arisen from previously sexual populations. And after becoming asexual, they have not really gone back to producing sexuals after that. So, essentially, they have become asexual and then they have stopped further branching on the phylogenetic tree.

Now, here I must make one thing very clear: when we say that a species is sexual, We mean that it undergoes sexual reproduction at least at some point in its life. This does not mean obligately sexual species, whereas asexuals do. When I say, for example, here that 1% of all species are asexual, I mean obligate asexuals. So, we are really differentiating between obligate asexuals, obligate sexuals, and non-obligate sexuals.

In other words, 99% of all species are either obligate sexual. Or they are experiencing sexual reproduction at least in some phases of their lives. So, this observation is actually pretty puzzling given what we discussed about the various costs of sex. So, this leads to the famous question: why is sexual reproduction so common? Which biologists do you know that make it even simpler? They ask the question, "Why sex?" So, when biologists are asking this question, "Why sex?" that is what they mean: why is it so common? And it turns out that this is one of the biggest unsolved problems in biology. I am not exaggerating here; you can actually go to the Wikipedia list of unsolved problems in biology. And you will find this question over there: why is sexual reproduction so common? By the way, you will also find the question of aging, which we discussed last week, on that list.

Now, obviously, if this problem is on the list of unsolved problems in biology, That essentially means that at the end of the day, I cannot give you the reason why sex is so common. Turns out that there are many hypotheses, and these hypotheses have different degrees of validation. But as of this moment, we seriously do not know why it is so. So, I won't be able to give you a proper answer, but we are definitely going to discuss some of the major aspects of this question. Or major tentative answers to this question, and that is what is going to happen in the next discussion. See you then. Bye.