Course Name: I think Biology

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Week:2

Lecture:7

W2L7_Numbers and Scales in Biology - Part I

Hello and welcome to this lecture as part of the I think biology and NPTEL. course. This is week 2 and we are discussing the process of science. As part of that process, we are going to look at numbers and scales in biology.

So I thought I would motivate my lecture by showing you this painting. The title of this painting is Science is Measurement. The painting looks a bit funny but it's trying to make the point that if you need to know something in detail as part of a scientific investigation you need to be able to measure it.

And seen in the picture is the skeleton of an adjutant stork. A man, presumably a scientist who is trying to find out more about the anatomy of this bird is measuring various parts of that skeleton. And I should remind the viewers that it is just such careful measurements of the anatomy of the human body that have allowed us to know so much more about it and which we now make use of in modern medicine. But the larger point remains that numbers, counting or measurement are central to science all branches of science and especially to biology. So in this lecture, I will discuss different scales, especially the log scale.

Then we will talk about spatial scales in biology, essentially the sizes of different things. Then the temporal scale of biology, so what are the timings of different events? How to read a graph with different scales and then we will think of an estimation exercise as part of the lecture. So shown here is a very standard linear scale, we would all be familiar with this from our school days with the plastic rulers that we used to use. A linear scale is very easy to understand, it is an additive scale so you are going from 0 on the left-hand side to 100, then you add 100 to get the next major division which is 200, and so forth, then you go to 300, 400, etc.

So a linear scale is additive and the blue dots show certain points that are marked on the scale they are quite easy to read because between 0 to 100, you have 10 divisions so the first point which has been shown is 0, then you have a 10, then you have 25, then you have 100, then you have 270, then you have 1000. So that is a linear scale. But in biology, we often make use of a log scale. And so what is the difference between a linear scale and a log scale? So a log scale tends to be multiplicative which means that if you are going from one major division to the next shown here is 10 to the minus 5 on the left which means that is 0.00001 to 10 to the minus 4 which is the next major division so I have to multiply this by 10 so I get 10 to the minus 4 so it is a multiplicative scale and then so on so then from 10 to the minus 4 if I multiply that by 10 I get 10 to the minus 3 etc. And so if I move to the right I will come to more familiar parts of the numbers which we carry in our head I have 10 to the 0 which we know is 1, then the next major division is 10, then I have a 100 which is 10 to the 2 and then I have 1000 which is 10 to the 3. And so now if I want to read numbers on this scale it is slightly different as compared to a log scale. So again in a log scale, you will have 10 divisions between the two major divisions and then you just read off which division your point is located on so for instance in this case I am looking at the region of the scale which is between 10 to the 2 or a 100 to 10 to the 3 which is 1000 and so this point would be 2 into 10 to the 2 which is 200 and so that is how you read a log scale. So now if we look at these blue dots which are shown on the log scale this first point here would be 1, 2, 3 so that is 3 times 10 to the minus 4 this point is 10 to the minus 1, and this point is 10 to the 0 which is 1 then you have 10, so again this point here is the third division so it is 3 into 10 equals 30 and then this point here is 3 into 10 to the, 10 raised to 2 which is 300 and then the last point shown is 10 to the 3 which is 1000 so we immediately see the benefit of using a log scale because it allows us to represent numbers across a very wide range so I am going from 10 to the minus 4 to 10 to the third so you could say I am going up in 7 orders of magnitude because I am using the base 10 for this scale.

So that is the major benefit of using a log scale is that it allows you to represent numbers across a very large range which is much needed when we are talking about biology. So then coming to an actual scale, the spatial scale in biology as is shown here so before we talk about the various objects shown, let's try and get some conversions out of the way. So for instance I have 1 nanometer shown here and so 1 nanometer is 1 billionth of a meter so it's 10 to the minus 9 meters. Then I have 1 micrometer here which is 1 millionth of a meter and then I have 1 millimeter here which is one thousandth of a meter so we just need to be aware of what are known as the prefixes to the meter. So nanometer, micrometer, and millimeter.

And of course, then we have centimeters, etc. So then let me start on the extreme left. So if you are talking about atomic scale then really we are talking about one tenth of a nanometer. We are going down below 1 nanometer if you are talking about atoms on this scale and then atoms come together to make up larger molecules, especially in biology. We have a lot of micromolecules so your proteins or your lipids will be on the order of on average between 1 to 5 nanometers if you have a protein that is about 5 nanometers that's very large actually.

So that's something to remember. Then you have viruses and that has been shown at the 100 nanometer scale so again that would be a very large virus viruses typically would be between 30 to 100 nanometers so let me show for proteins I would say between 1 to 3 nanometers would be a good size for proteins. So you are going from proteins to viruses which are collections of nucleic acids and proteins and they would be on the order of between 30 to 100 nanometers The next one is a cell, a bacterial cell, and shown here is an *E.coli* cell. *E.coli* and this cell size is very easy to remember because the width is about 1 micrometer and the length is about 2 micrometers So this is something that we should all know as students of biology what is the size of an *E.coli* cell and suppose we need to make a quick calculation we can even assume the length to be about 1 micrometer because we won't be far off from the actual size the other thing to note is that a cell organelle that we all know which is the mitochondria is on the same order as an *E.coli* cell and that's a question that we should think about why is the size of mitochondria equal to that of a bacterial cell. Moving on then we go to animal and plant cells and it has been shown here at the 10-micrometer scale but I should tell you that cells occupy a very large size range so it's good to think about cell sizes between this range between 10 to 100 micrometers Typically plant cells tend to be larger than animal cells and at the far end of the scale which is 100 micrometers you have the largest cell in the human body which is about 100 micrometers. Another cell that you should know about in the human body is the RBC and we know that this is a disk-shaped cell without a nucleus and it's a very large cell and it's a very large cell. It's a large cell without a nucleus and its size is about 7 microns in diameter the size of an RBC, the most abundant cell within our body So again, just as I asked you to remember the size of an *E.coli* cell it's good to remember the size of an RBC and so if you can't remember the number 7 it's easy to remember the number 10. So you could say it's approximately 10 microns So then moving on from the larger cell sizes which will be on the order of 100 microns or slightly larger we enter the realm of millimeter scales and so between this 100 microns to 1 millimeter we also start to see many different kinds of organisms. Primarily we can have certain protists or we can have many kinds of insects which will be in the size range So insects will occupy this size range. You can have protists that are there in this size range and then from there, we start to enter a length scale that is probably more familiar to us because we can see it easily with our eyes and this is the length scale on the order of millimeters to meters. And many of the objects now daily lives occupy this length scale.

Whether it's reptiles, amphibians, birds, species, or all the human beings that we see around us. At the end of the scale would be humans so we could say that humans on the whole occupy a length scale of between 1 to 2 meters. Most humans would be found within this size scale of 1 to 2 meters. And then larger than this would be certain other biological objects. We have chosen to show here two man-made objects just to make them more familiar to us.

But of course, we know of certain whales and other fish, like the whale sharks which are on the order of tens of meters. And then on the order of hundreds of meters or up to 100 meters, we have certain very large trees like sequoias or redwoods or even certain species of eucalyptus which are on this size scale. So this is the complete breadth of biology going from atomic scale to the scale of say whales or certain large trees. And you need to remember certain landmarks across this size scale. For instance, at the lower end, I could ask what the DNA molecule's width is. Or what is the size of a protein we would all know, say like hemoglobin? So this is something for you to find out and look up and just keep a few of these numbers within your head.

Or say what is the size of the COVID-19 virus which would be something we should be familiar with? And then I mentioned certain cells that we should be familiar with like the *E.coli* cell or the size of an RBC or the human egg, the size of the human egg. And just try and keep these landmarks in your head as you deepen your study of biology. Another reason to know these sizes is because biology works on kind of a hierarchy of levels. So you go from cells which is the unit of biology and cells come together, different cells come together to make a tissue. Shown here is the same kind of hierarchy for plants or animals. So if you look at a leaf or a leaf cross section you will have different kinds of cells which make up different tissues in the leaf. Then the leaf we can consider to be an organ. Then it will be part of an organ system which consists of tissues that photosynthesize or tissues that carry nutrients or water in both directions.

And then these organ systems make up the whole organism. So if you are talking about a tree it will be from the roots or the shoot or the tips of the shoot. So if you are talking about sizes the thing to note would be that these cells which are on the order of tens of micrometers to hundreds of micrometers somehow go on to make these pipes which we call xylem or phloem which carry water and nutrients within an organism which can be on the order of millimeters, centimeters, to meters, to even tens of meters. So how is it possible for these cells to do that? So that's one way to kind of motivate this question of scale or size. And the same thing could be said for an animal.

Here are some more figures for human cells. The human cells shown are the average volumes for different kinds of human cells. This is taken from a book called Bionumbers where you will find many kinds of numbers related to biology. But more than that what the website is trying to do is trying to promote a more quantitative way of thinking in biology. So I do urge you to look up this website called Bionumbers. Shown here, What's interesting to me is in this table, the smallest cell is the sperm cell with an average volume of a 30-micrometer cube.

And the largest cell is the human egg or the oocyte with a volume of 4 million micrometer cubes. So the difference in these two cell sizes which fuse to make up all of us is almost 5 orders of magnitude. And then we can do things like look up what is the average across the size range. So that would be somewhere near the HeLa cell which is a cervical cancer cell line or these hair cells which we find in our ear. So it's between 3000 to 4000 micrometer cube.

Shown here are two HeLa cells that are being caught in the process of cell division. And you can see what is the length scale for this cell line. The HeLa cell which is a cell line that is used widely in biology comes from a patient whose name was Henrietta Lacks. You should look up the history of this cell line and how it came to be used in biology. So I will just put down the name of the patient from whom this cell line was taken. So HeLa comes from the first two letters of the first and the last name of this patient. So do look up the history of this cell line.

Moving on to a temporal scale what is the time at which certain events in biology happen? Shown here is a very simple model of such a scale. So we could say that going from the molecular level to the ecosystem level, the important time scales tend to change.

So on the molecular scale, the important time scales are on the order of nanoseconds. So we are talking about say the tumbling of molecules or the rotation across bonds or certain reactions happening. Then moving up in the subcellular regime, we can talk about the transport of certain molecules or diffusion processes happening. So those could happen between microseconds to milliseconds. And we can build up going from the cell level to the tissue.

And then at the ecosystem level, we would talk about things happening across a year or multiple years or decades or even a century. So the thing to note here is that the kind of scale that you use depends on the kind of question that you are interested in. And to make it more real, we could think about a human scale or a human temporal scale. For instance, if you think about human reflexes, they occur say from 100th of a second to say 1/10th of a second. So 0.01 to 0.1 second.

So approximately from microseconds to millisecond time scales. Then we can think of certain physiological processes. So for instance our heartbeat and approximately 1 per second. Then we follow a circadian rhythm and that's over 24 hours.

So one day we have an ovulation cycle. So that's about 28 days. That's approximately a month. We have a gestation cycle. That's 9 months. We can say it's 3 quarters of a year. You have a human lifespan. So between 70 to 80 years. So you can say it's approximately 1 century. So I was able to construct a very simple temporal scale for humans. And we could think of doing this for any kind of organism or any kind of process that we are interested in.

The main point is that both your spatial scale and temporal scale change depending on the question you are asking or what are you motivated by. So it doesn't make sense to talk about centuries when you are interested in enzyme dynamics or turn over of certain molecules within a cell. So the tools you would use will change depending on the question you ask and the scale at which you are asking that question. An obvious point but it bears repetition.

Then we come to graphs. If we have numbers we need to have ways to represent them. So shown here are two kinds of graphs. On the left is a linear graph with a linear scale and on the right is a graph with a semi-log scale. The process that has been shown here is cell division and growth.

So you are going from one cell to two to four etc. So if you look at the graph on the left it appears flat in the first part of the graph and then approximately at 200 minutes. So over here, maybe it's 210 minutes. The graph suddenly starts to shoot up. So the semi-log scale which is shown on the right allows us to represent the whole range of numbers that we have in a way that we can establish certain relationships. So in a semi-log plot, we have on the x-axis a regular linear scale so time is shown in minutes, and then on the y-axis is the log scale so that's the multiplicative scale that I was talking about earlier.

So you are going from 1 to 10 to 100 to 1000 and that shows the number of cells. And so you immediately see that plotting it this way you can see that the number of cells, the relationship with time can be marked with a straight line and the slope of the line is the doubling time for this cell line. How much time does it take to go from 1 cell to 2 and 2 to 4? And so putting things on a graph like this allows you to see these kinds of relationships. So I will end this part of the lecture here and in the next lecture we will talk about estimation and how to go about estimating things knowing the sizes of certain objects in biology and we will also talk about the use of these kinds of plots in a study of biology called Allometry. So I will see you in that class. Thank you.