Bioengineering: An Interface with Biology and Medicine

Prof. Sanjeeva Srivastava
Department of Biosciences and Bioengineering
Indian Institute of Technology – Bombay

Lecture - 03
Life Processes & Cell

Welcome to the MOOC NPTEL course on bioengineering an interface with biology and medicine. In the last two lectures, we discussed various issues and try to understand why biology is required for engineers, in which way the discipline of bioengineering has made huge impact. Today, let us start with some fundamentals and discuss about life properties and processes.

Some of the properties and processes which are associated with life but let first start what is life? So in very simplest manner we can say that life is what living people do, we see their activity and we can identify easily that what is living and what is dead. At the cellular level, their various biochemical pathways which governed the production of energy which is a chemical energy obtained from the food molecules.

And then this energy is required for the life processes to happen. Living world has so much diversity and complexity. How to make sense of them? So let us look at some properties of life and I will provide you some illustrations for various properties by showing one illustrative organism. All these pictures are taken from the Campbell book which is the recommended book at IIT Bombay for this undergraduate course.

The figure numbers are also referring to the Campbell Version 10th edition. So you can follow this book and you can also follow these legends and details from this book.

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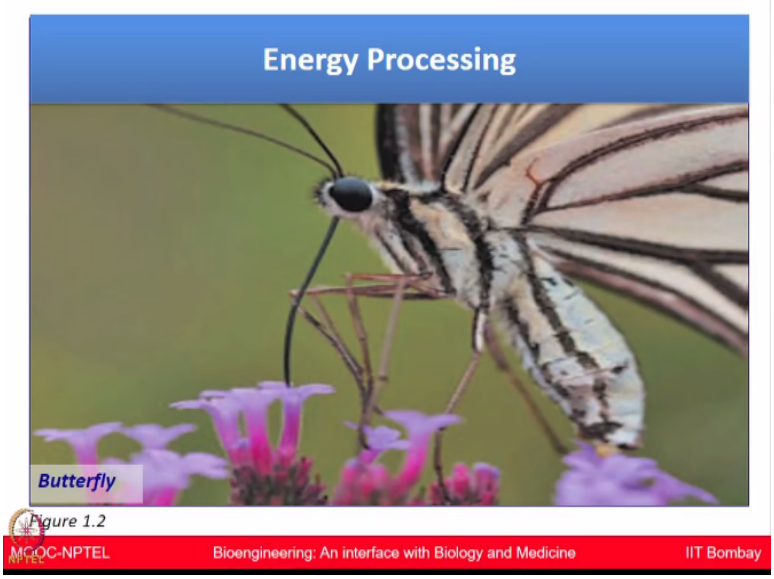

Let us first start with energy processing. As you can see in the image, the butterfly is shown is trying to obtain the energy from the nectar of the flowers. The hummingbird can use this chemical energy which is stored in its food and now it can power the flight and other words.

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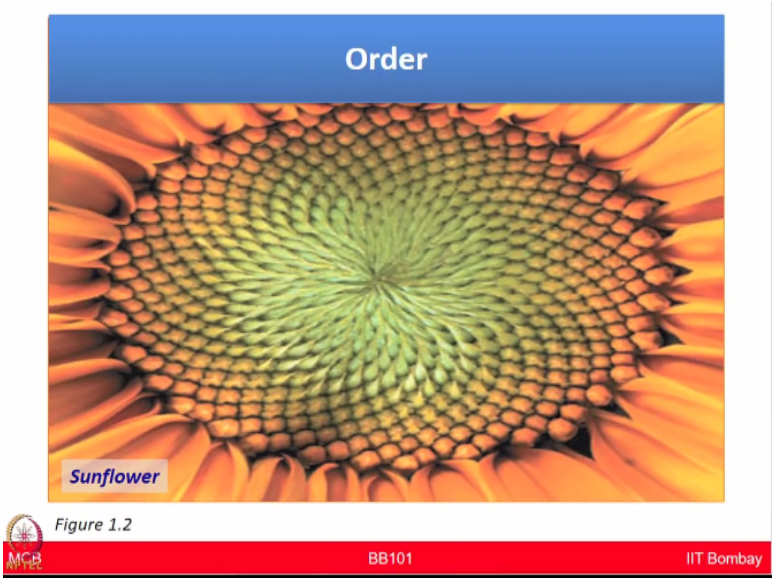

Let us look at the sunflower. How much orderliness we have in this flower, it illustrates you know very beautiful example of the symmetrical structure which characterizes life.

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Now let us look at the Jack Rabbit which illustrate the regulation. How the blood flow is regulated in the blood vessels and even the ear in this case helps to maintain the constant body temperature and you know when the rabbit is running fast it generate lot of heat, so now the ear exchanges those heat exchange in the surrounding air and try to maintain the body temperature.

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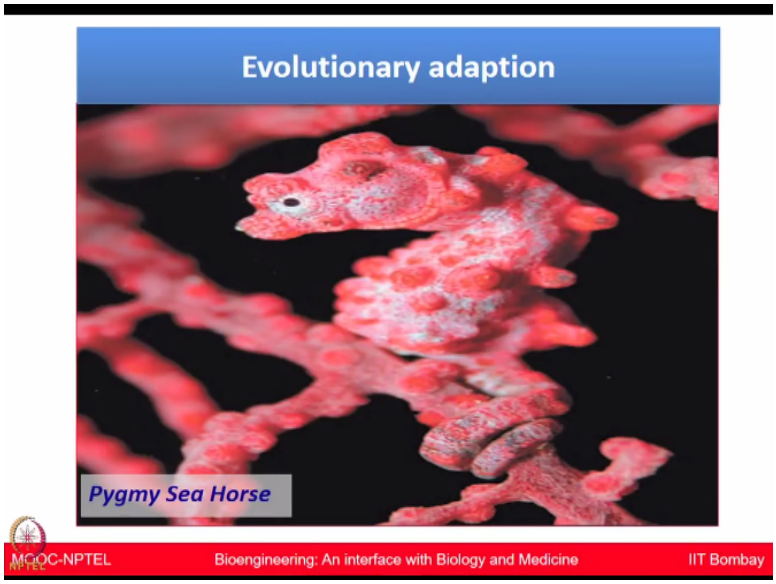

Let us look at this pygmy seahorse which provides example for evolutionary adaptation. The appearance of this pygmy seahorse is pretty much camouflaging the environment which is you know you can see in the red color and such adaptations evolved over the many generations will actually you know probably become part of the hereditary.

And that is something which you know which is part of the Darwinism which we will talk later on as a part of the evolution that how many of these you know positive changes which we have to adapt can actually you know best suited to the environment could actually become part of the hereditary and may pass from the one to the next generation.

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Let us look at this oak seedling, one of the examples of a plant which shows the growth and development which is required for all of us. This inherited information in the plant will be continued to the next plantlet the seedlings and then it is required for the growth and development of organism.

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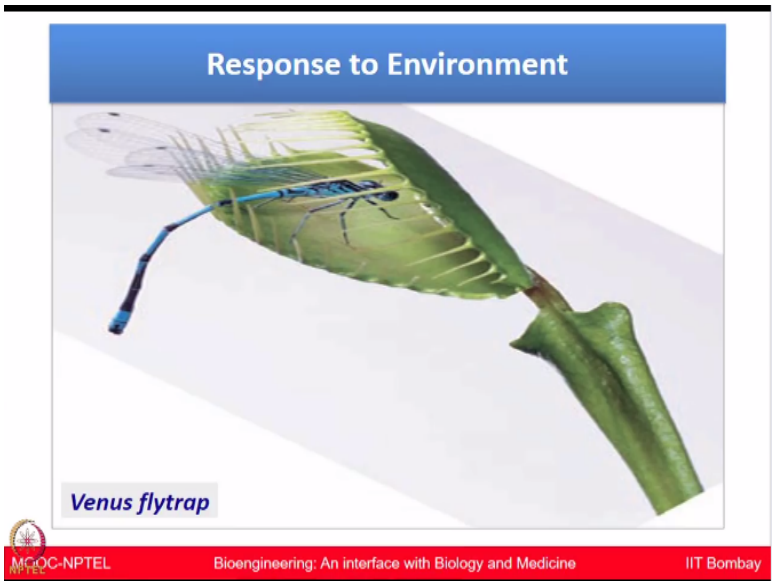

You can all see this Venus flytrap and it is interesting example that how in response to the environment this trap is rapidly you know getting its stimulus and we know gets closed as

soon as it sees the damselfly which lands on this predictor trap. So in response to environment it can make those immediate quick action and now it can respond to that environmental condition.

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Let us now talk about you know the reproduction which is one of the organisms living thing. In the example you can see the giraffe but that is pretty common to every living being where a baby giraffe is standing close to its mother, it illustrates that reproduction is such an essential process for the life alright. So now let us talk about the unifying themes of life. How we think about the life forms?

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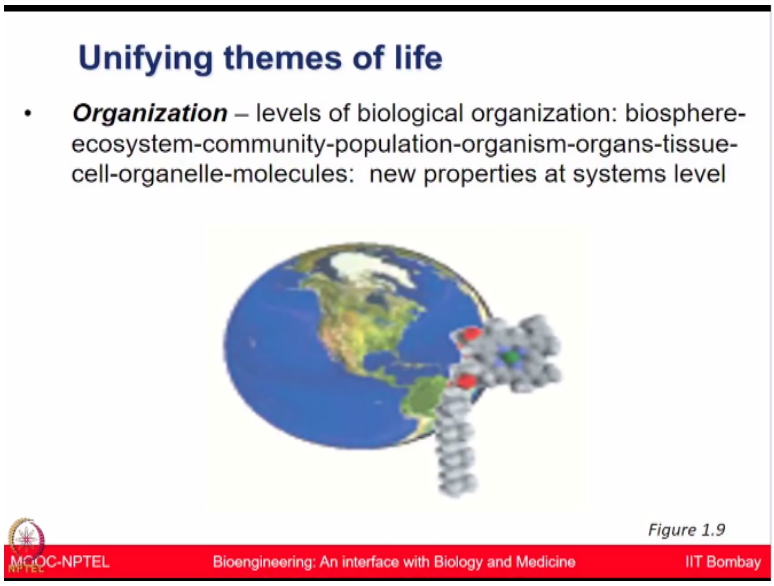

So much bigger organization let us start with that. So the level of biological organization is starting from the biosphere, ecosystem, then community, looking at the population organism,

then organs, tissue, cells, organelles and the molecules. So all of these properties are you know governed at a systems level and much bigger biological organization is required for the life forms to actually occur.

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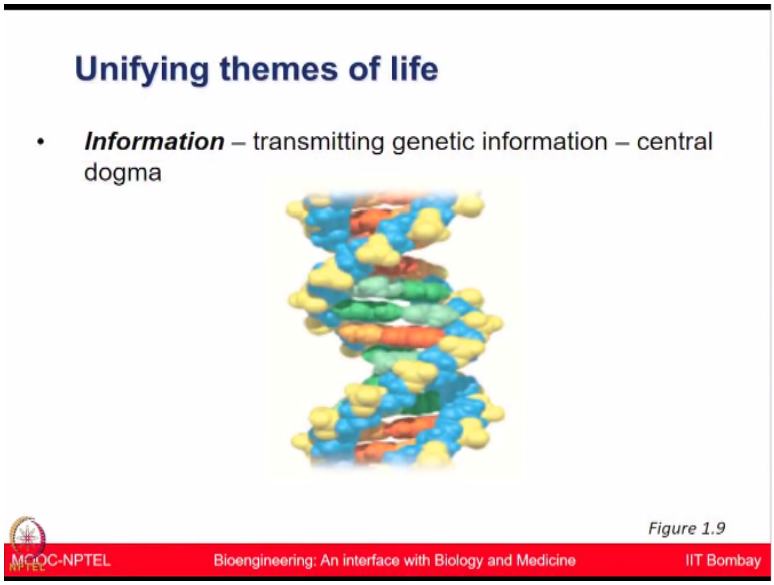

And this information then has to transmit from one to the next generation and in the process which is the central dogma is one of the fundamental concept where the information from DNA is transcribed to the RNA form and then being translated to the proteins which form the central dogma for the information to flow. Let us now look at energy and matter.

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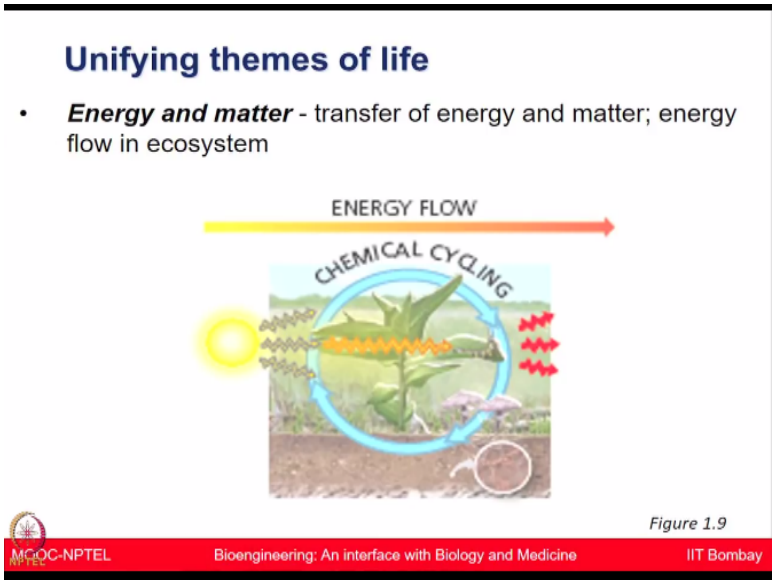

The transfer of energy and matter is very crucial because how energy flows in the ecosystem is governed with intricate relation of various processes which are involved in this chemical cycling.

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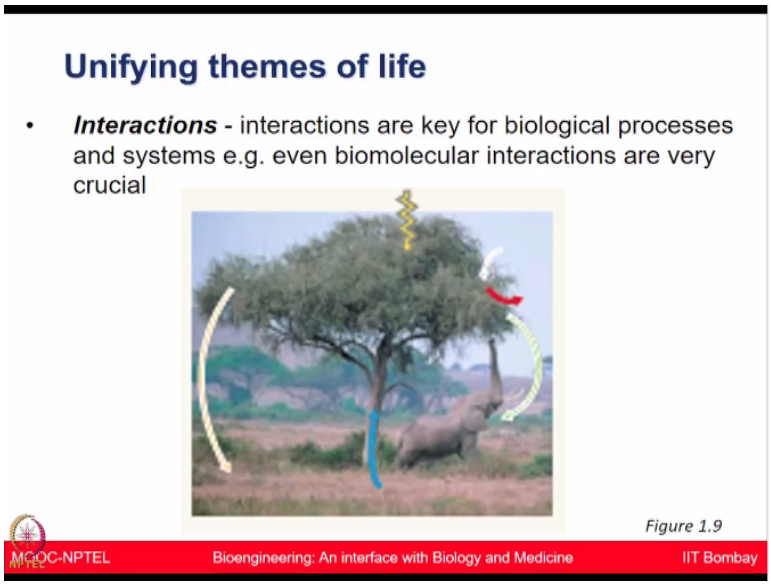

Interactions are of course very key for the biological processes, the life forms to happen both at the environmental level with organism and as well as even at the biomolecule level various type of biomolecules how they interact is very crucial for the life forms to govern.

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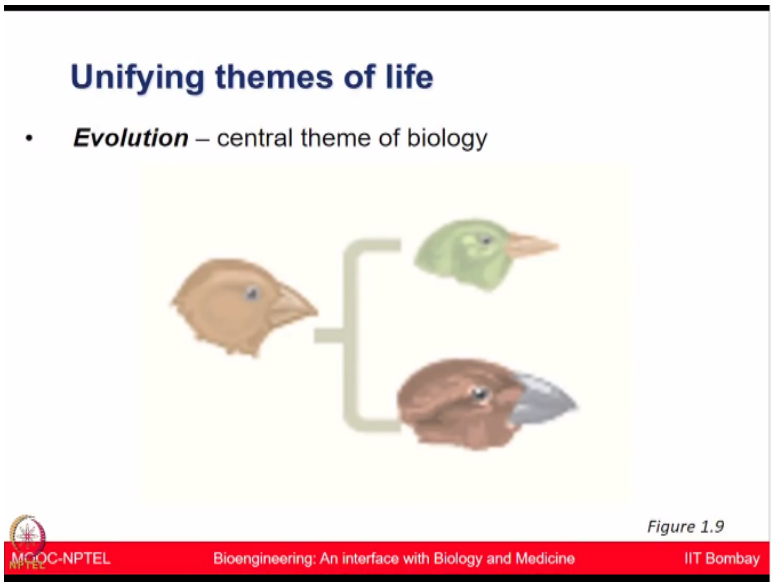

Let us now think about evolution which is one of the central theme of biology, a very interesting concept and as we go along in the lectures we will see that understanding these you know the biochemical properties and knowing these biomolecules and then finally trying to relate that at evolutionary level provides very interesting and standing of the central theme of biology which is evolution.

So organisms have very distinct morphology but they have a still very much commonality at the biochemical level.

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So on the screen I am showing you one image. Can you identify what this particular organism is? Alright, so you have mentioned right, it is the bacteria which is Escherichia coli. Now let us look at the next image.

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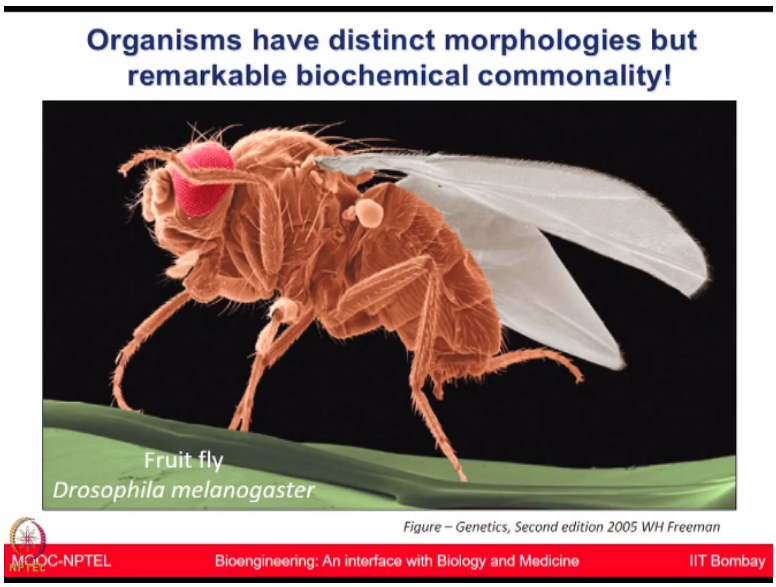

This is fruit fly Drosophila melanogaster. Let us look at now this plant image.

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This is Thale cress or Arabidopsis thaliana. Let us look at this worm.

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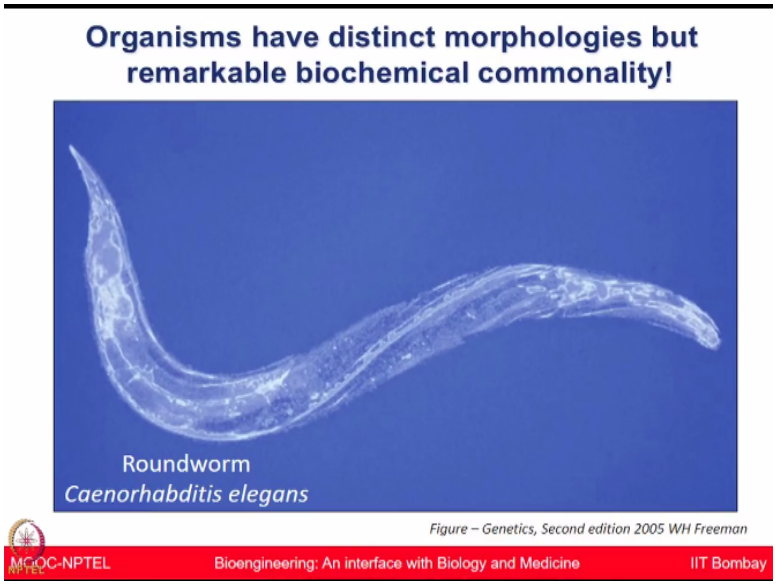

What is this one? This is a round worm or C. elegans.

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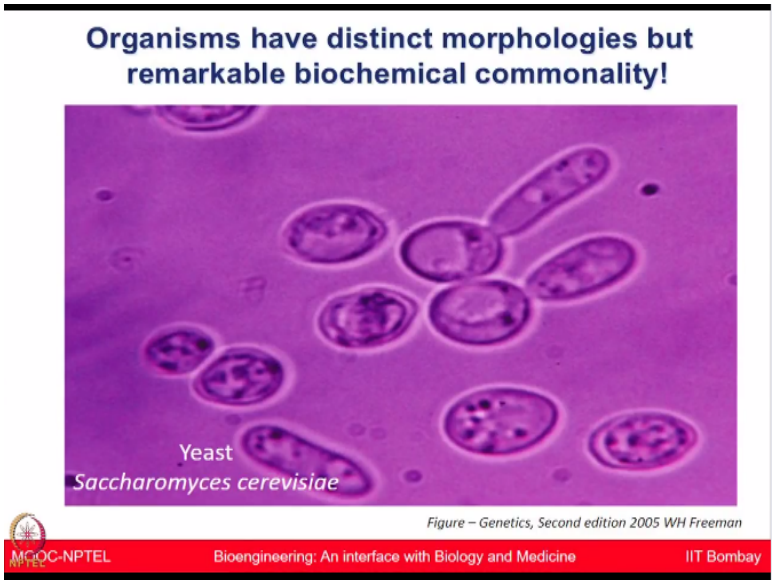

What is this image? This you know small microscopic thing you know something looks like those are yeast saccharomyces cerevisiae.

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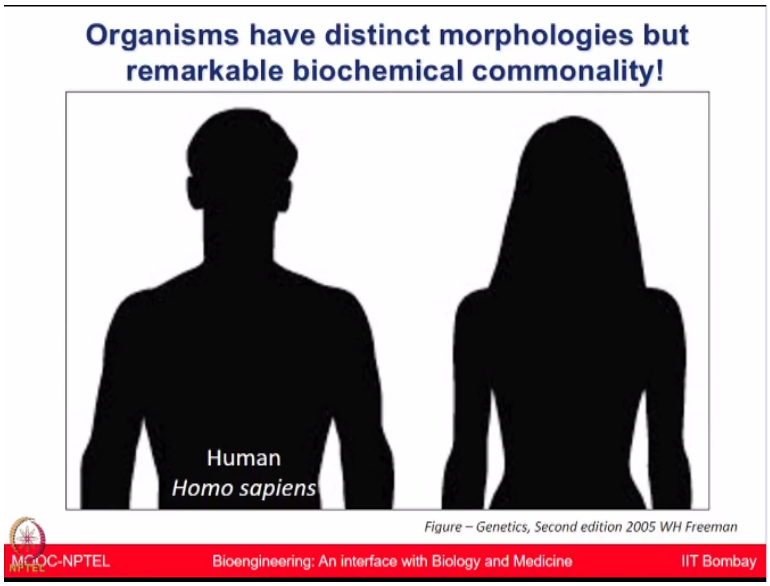

And of course you know human which is Homo sapiens. So if you look at them at the morphological level, they are very different, very distinct right but when you go to their DNA level, RNA and the protein level at the biochemical properties you will find you will be surprised in fact to see that how remarkable uniformity we have at the molecular level. So then that probably indicates that we have all arisen from some common ancestor.

So let us now come to the fundamental part which is cell and let discuss about what is a cell? Let me first try to gauge you in the discussion and try to find out your understanding about a cell. It is one of the structural and functional unit of life. There could be more definitions of

cell. It is an organism's basic unit of a structure and function. It is fundamental to living systems of biology like you know the way you define atoms in the chemistry field.

And it is one of the simplest collection of matter which can be alive. So in many ways you can define the cell but fundamentally it is defining a living system of biology. We have billions of cells in our body and just imagine those billions of cell has to really work in a very orchestrated manner together to govern many of the life processes and what we are studying right now just one cell and how that cell, different organelle and their properties how they are regulated.

You just imagine that you know the living system is so complex and how beautifully it is governed that you know billions of cells have to perform in a very obedient manner otherwise if they start performing you know in this regulated manner that may add up to or that may cause some diseases right.

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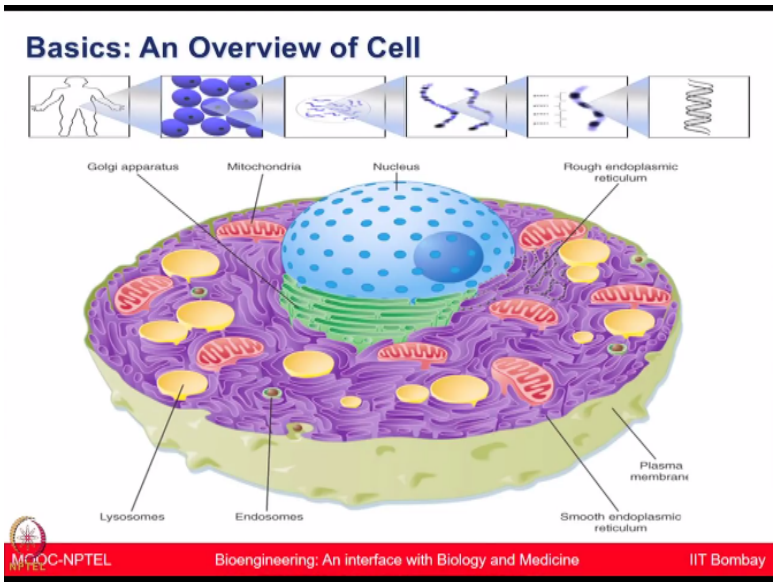

So what I have shown you here is you know from human body, there are billions of cell possible and now if you look at one of the cell nucleus which has all the nuclear content, it has all the chromosomes then we are looking at the DNA segments and then we are defining that with genes we are interested to study for example. So how you know small units we are talking if you think about starting from human.

Now just you know analogous to that like a cell if you think about you know a complex machinery like an aeroplane or like a car, the way you have you know a lot of circuits and intricate the wirings inside these machines inside these you know the car or aeroplane.

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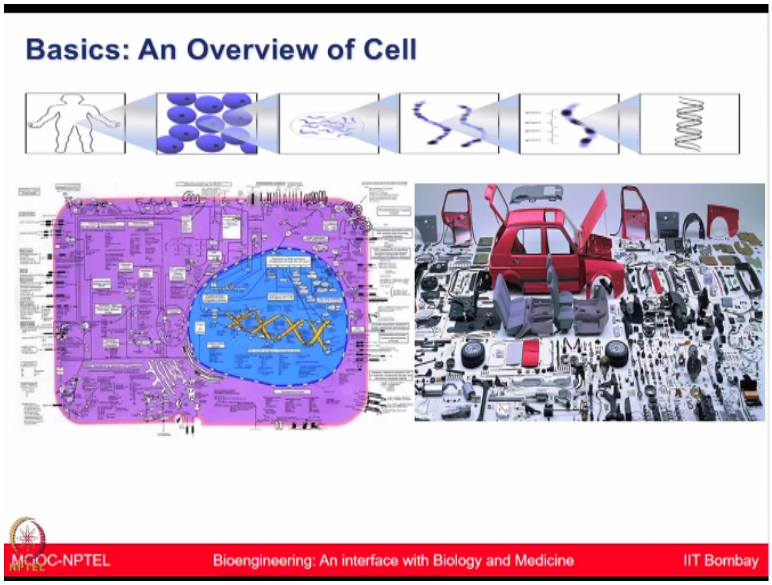

Similarly, in the cell even to communicate from one to other organelle, the information to pass from one to other level all of this requires lot of coordination and it is no less than in a circuit which you can see in the car on the right side but says the circuit shown in the left side for this cell and there are in fact you know the scientists who are trying to understand the cell more like in a circuit in which way by changing the one component to other component how that can hamper or how that can accelerate different type of functions.

So that is something you know an interesting area where lot of engineering people want to study the cell like you know in the electrical manner to see that you know how different circuits are governing these kind of life functions.

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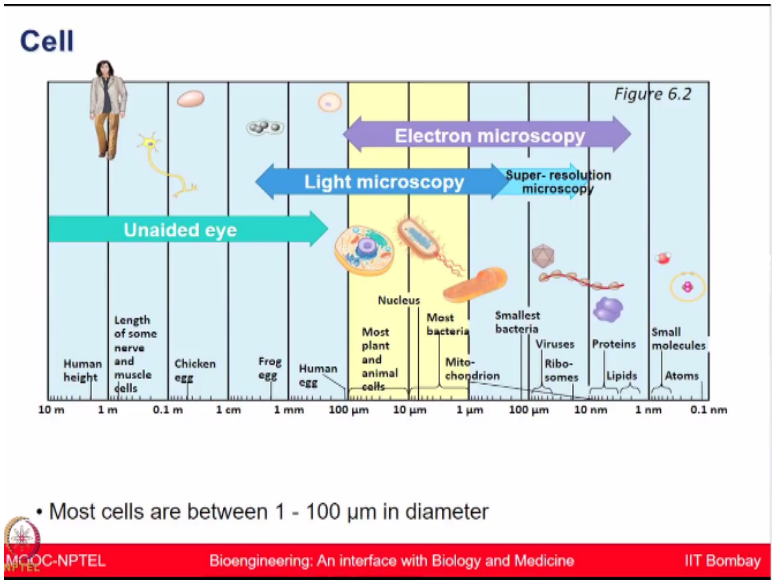

So if you not think at the cell at the structural level, most of the cells are found in the diameter of 1 to 100 microns and of course you know the bigger cell like you know the when you go to take the chicken egg those are visibly you can see from the naked eyes but when you want to start looking at the smaller cells then you need the light microscope when most of the plant and animal cell you want to see can be seen with the light microscope.

And then if you want to look at their ultra-structural details, different type of organelle or you want to study bacteria or viruses, those things you have to see with the electron microscopy. So for studying cells what I really you know made a big revolution in biology is the you know various type of advanced microscopy.

Our ability to know about the cell about different cell organelles and looking at their ultra-structural details was only possible because of various advancements which had happened in the field of microscopy. So we are not going to talk in much more detail right now about you know various type of microscopy but I have illustrated an image here on the screen which shows you various sections taken from different cells and different type of microscopy which is used to obtain those images.

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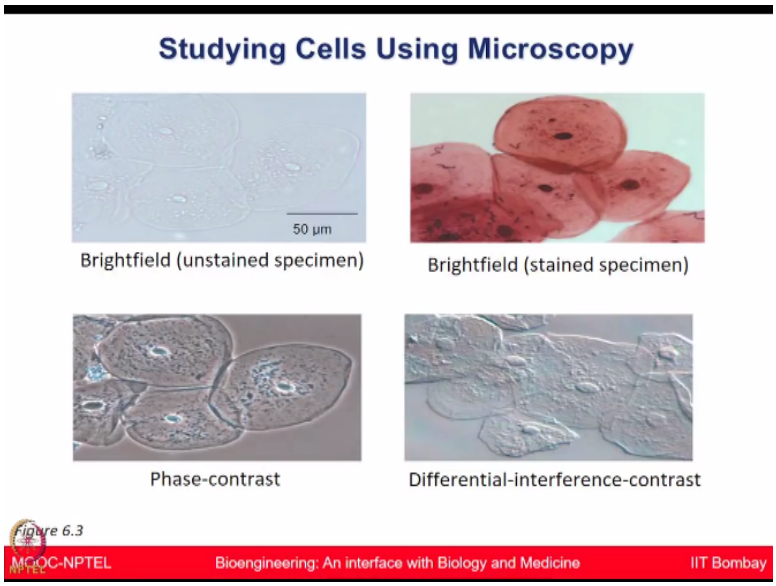

For example, from the left if you see the bright field image for the unstained specimen is shown and then on the right side of that is stained specimen image is shown. Then, the next one is the phase-contrast image and then we have differential-interference-contrast image shown.

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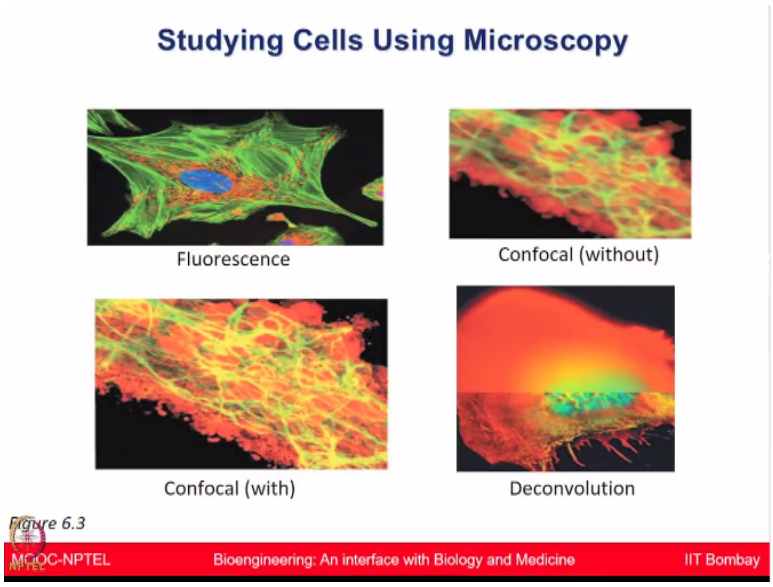

Then, we have the fluorescence image, then on the right side of that we have a confocal without and then the next one is confocal with image and then we can see the deconvolution image on the right-hand side.

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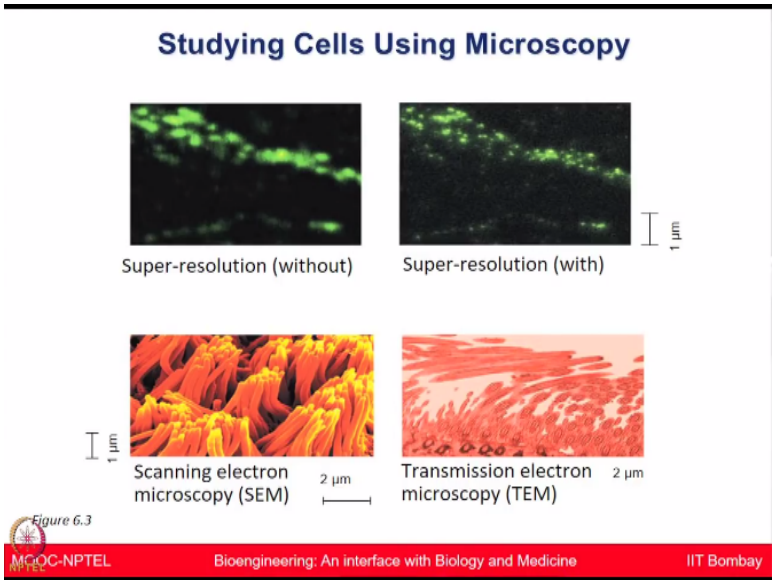

And that is the super-resolution; again we have the you know the changes of that variant form in the right hand side. Now you look at the third image which is the scanning electron microscope or SEM and then we have the transmission electron microscopy or TEM. I am sure you must be wondering now that you know there are many type of microscopy available and how they are you know able to provide these informations.

So actually all the variants of the light microscopy are being shown here except the one like scanning electron microscopy and transmission electron microscopy which is a part of the electron microscopes, rest everything is light microscopy. Light microscopy is going to allow you to image a live cell whereas the electron microscopy you can only study when you have the dead cells because you have to make the sections when you are looking at the ultra-structural details.

So just kind of broadly it gives you some sense and feel that if you want to look at the life cells you have to use the light microscopy and its variants. If you are looking at the ultra-structural detail then you have to fix the cell, you have to make the sections, you have to you know the cell will be dead in fact and then you can use different type of scanning our transmission electron microscopy alright.

So now let us come to various type of cells and on the screen I am showing you one image can you recognize what this image is?

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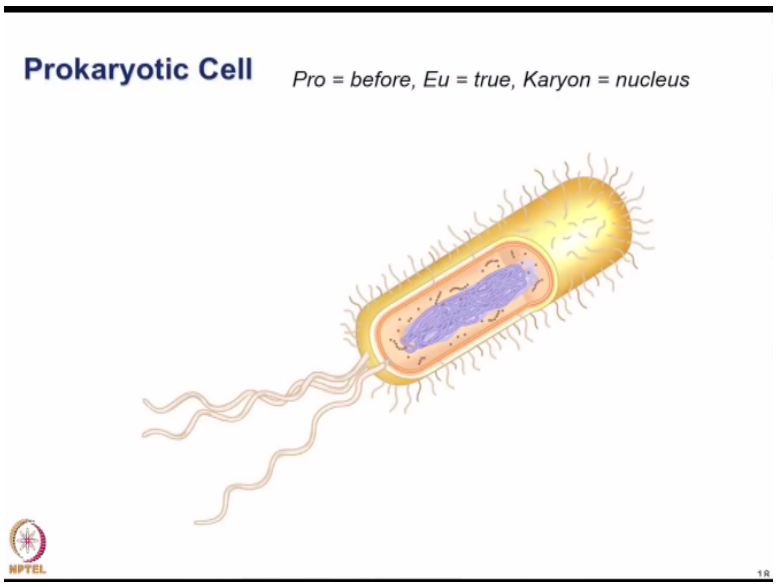

What type of organism this particular image is illustrating? Alright, so you are right, it is the bacteria, it is the prokaryotic cell and when we say prokaryote, it means pro means before and karyon means nucleus. So this does not possess a very true nucleus right. So let us kind of I am showing you some arrow and you have to now guess from your previous studies and previous understanding of a bacteria that what organelles are there shown on the screen.

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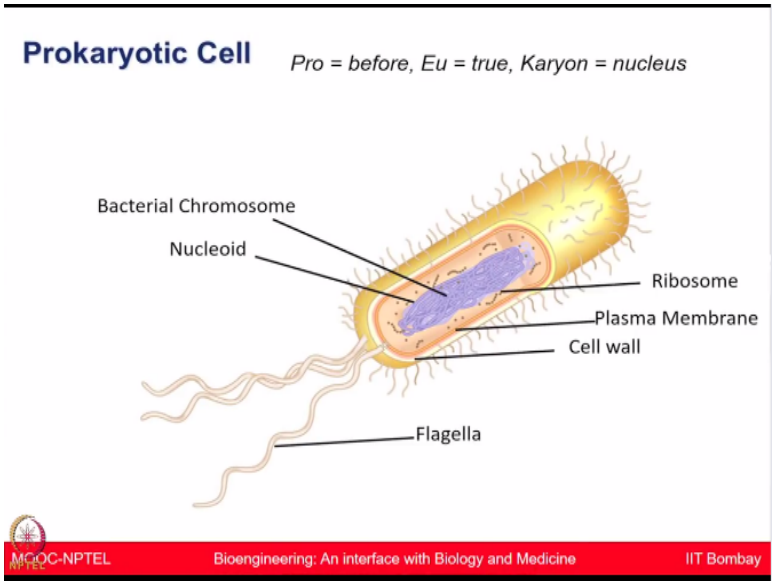

So this first one is a nucleoid. Now what is shown here is a bacterial chromosome, yes you are right it is flagella and then move on to the cell wall and now you can see the plasma membrane. Then, we have ribosomes the tiny particles and nucleoid is you know the major component of the bacterial DNA which is actually free-floating in the cytoplasm; it is not enclosed inside a nuclear membrane which kind of you know makes a distinction between the prokaryotes with the eukaryotes alright.

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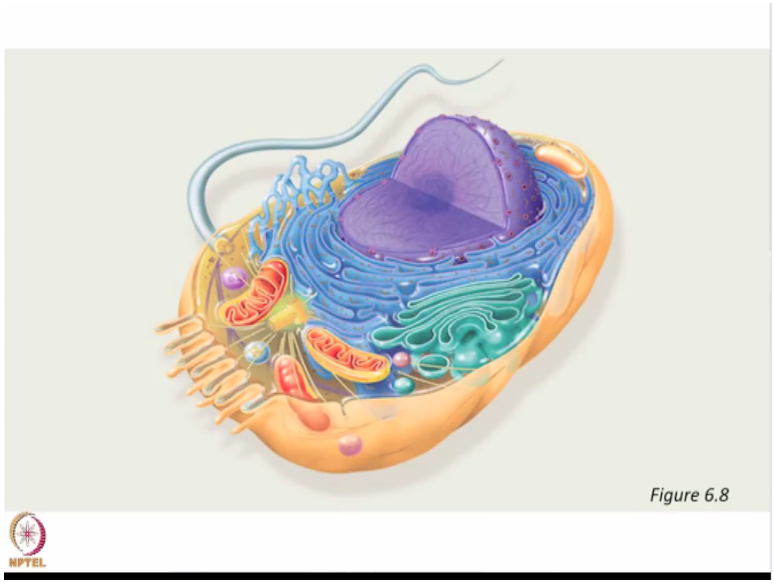

So now let us look at this image and can you guess what this particular you know cell is? Okay this is an animal cell coming from eukaryotes. So now let us again go to the arrows and try to find out the labels for them.

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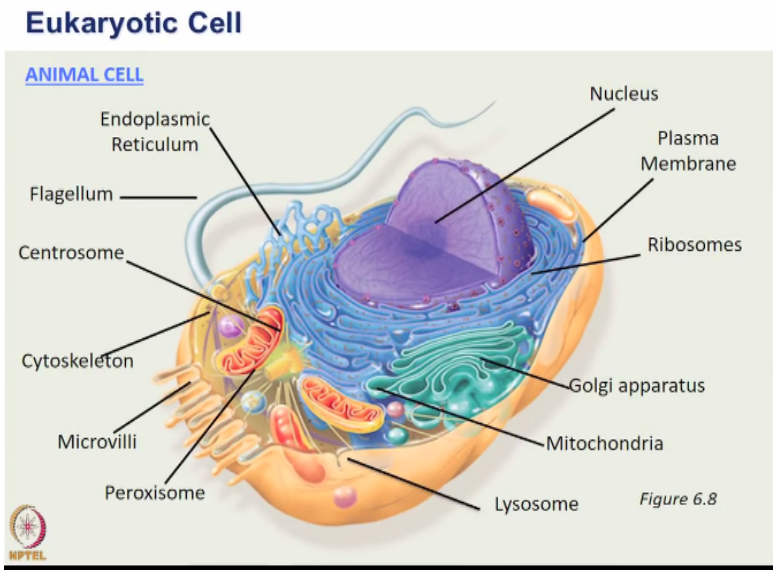

So the very first one is you are right it is nucleus. So what is the role of nucleus? Okay welcome to the role of each of them in much more detail in some time but ideally this you know all the genetic information is stored with the various nuclear contents which are found in the nucleus you have DNA, RNA, these material there and this information has to then move from the various other organelle which are surrounding to them to pass on from one to the next cell.

And then there lot of you know intricate communication is actually involved within the cell and from one to other cell as well. So we will talk about these things but let us kind of continue trying to guess about, now the next arrow which is the plasma membrane. Then, it comes the tiny particles, which is ribosomes and then we have these, the green colored ones what is shown is the Golgi apparatus.

Then, we have mitochondria and peroxisomes. This one is microvilli. These are cytoskeletal elements and now we have centrosomes, finally this is a flagellum and we have endoplasmic reticulum shown in the network over there, we have then lysosomes. So it just kind of refreshes you about you know what you have studied in the past regarding the cell and their different organelle.

We will again talk to you about their function in some time but let us kind of try to get you know morphological uniqueness from the prokaryotes to different type of eukaryotic cell.

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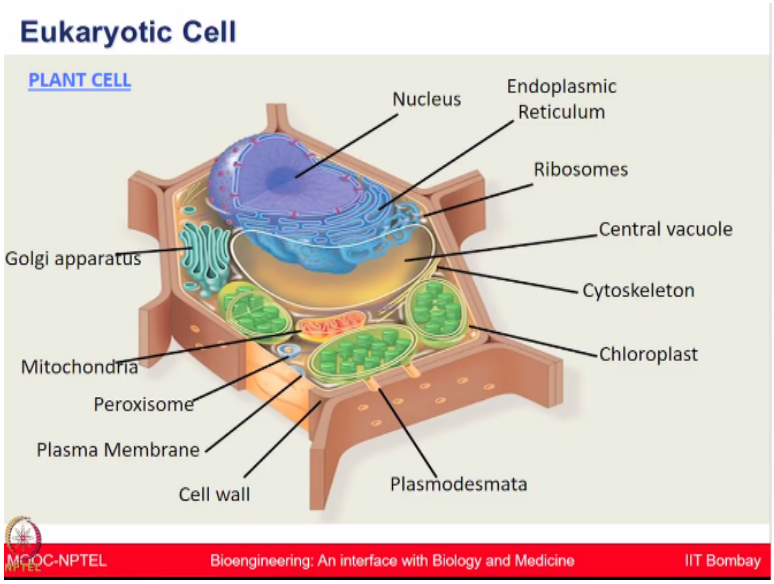

And now let us guess what is this image shown on the screen for this eukaryotic cell. So this is a plant cell and now let us move on to look at you know the different components of these plant cells. Yeah, so in the arrow what is shown now, it is a nucleus and now we have endoplasmic reticulum, then ribosomes, there is something which is very different than the animal cells right which is a much larger volume a central vacuole.

Then, we have cytoskeletal elements. Now we have chloroplasts which is again you know one of the distinguishing feature of plant cells, plasmodesmata. Then, we have a cell wall a

very thick one and a plasma membrane. Then, these are peroxisomes, mitochondria, Golgi apparatus. So many of these organelles are common in both plant and animal cell but there are certain unique organelle which gives plant cells more adaptability for you know for them to live in the open field in the environment.

And do many processes which they are doing different than the animal cells. So we will talk about the functions in some time but let us now move on again thinking about the broad categories of prokaryotes and eukaryotes. So broadly as we discussed pro means primitive and karyon means nucleus and eu means advanced. When we have a distant boundary of the nucleus then we say this is the eukaryotic cell whereas if it is diffused found in the cytoplasm then that is a prokaryote.

So the diverse organisms they could be divided into 3 fundamental groups.

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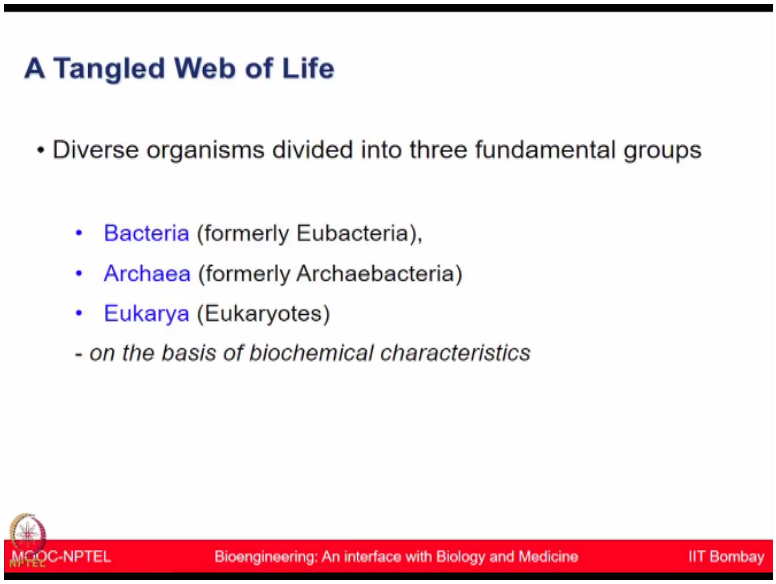

The bacteria, they formerly known as Eubacteria or Archaea which is formerly known as Archaebacteria and Eukarya which is a eukaryote. This distinction can be made on the basis of their biochemical characteristics as well as this fundamental groups are known as domains. A scientist Carl Woese, he suggested to group these organisms into 3 domains on the basis of their 16S ribosomal RNA properties.

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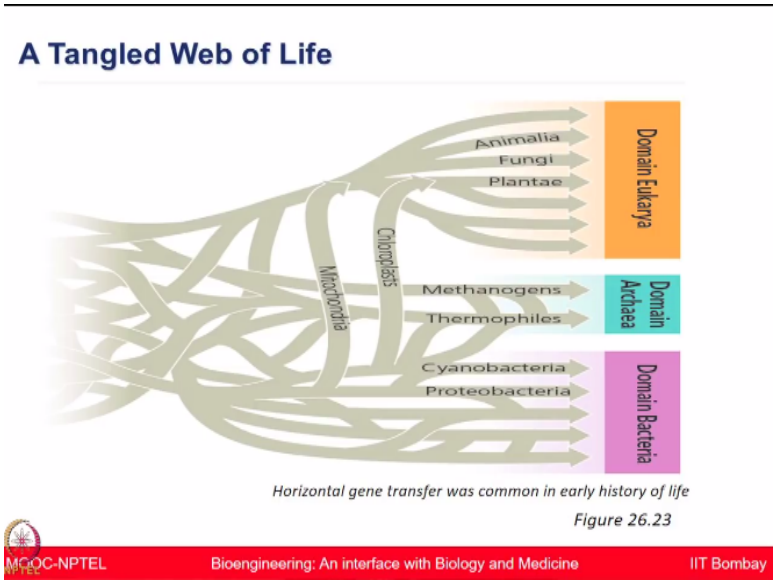

What is shown on the image here is a tangled web of life. It shows the domain Eukarya, domain Archaea and domain bacteria but it also shows that you know from the proteobacteria and cyanobacteria when it you know the more Archaea and the Eukarya were generated especially the methanogens, thermophiles, animalia, fungi and plantae. Then, we have you know the some of the horizontal gene transfer was seen and probably chloroplasts and mitochondria played an important role in that process.

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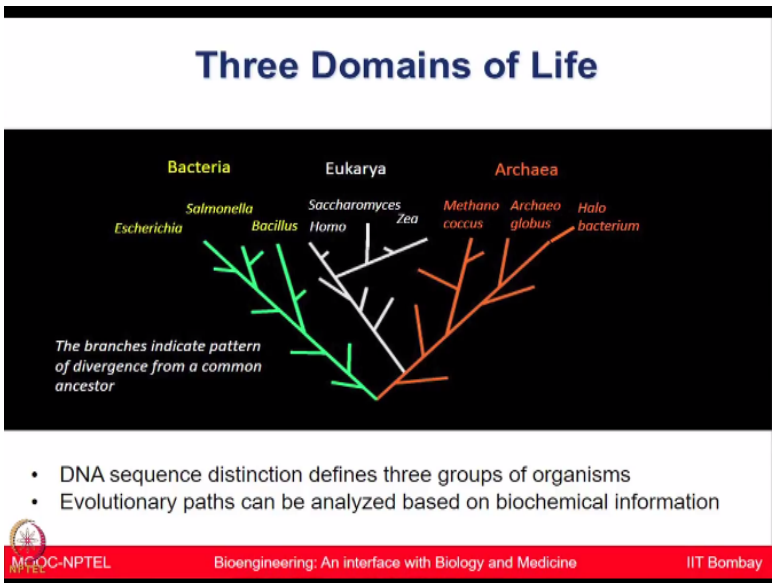

So broadly when we are thinking about 3 domains of life, we have bacteria, couple of examples are shown Escherichia, Salmonella, we have Bacillus. In case of Archaea, we have examples like Methanococcus, Archaeoglobus and Halobacterium and in case of Eukarya we have examples like Saccharomyces, Homo sapiens and Zea mays. So these branches indicate the pattern of divergence from the common ancestors.

And the DNA sequence distinction defines that these are the 3 major domains of life. The evolutionary path could actually be analyzed based on their biochemical properties. Let us look at one of the classes of you know these 3 domains of life Archaea in some more detail, we will be talking about the you know more functional details for both prokaryotes and eukaryotes you know in subsequent lectures but let us kind of you know briefly discuss about Archaea.

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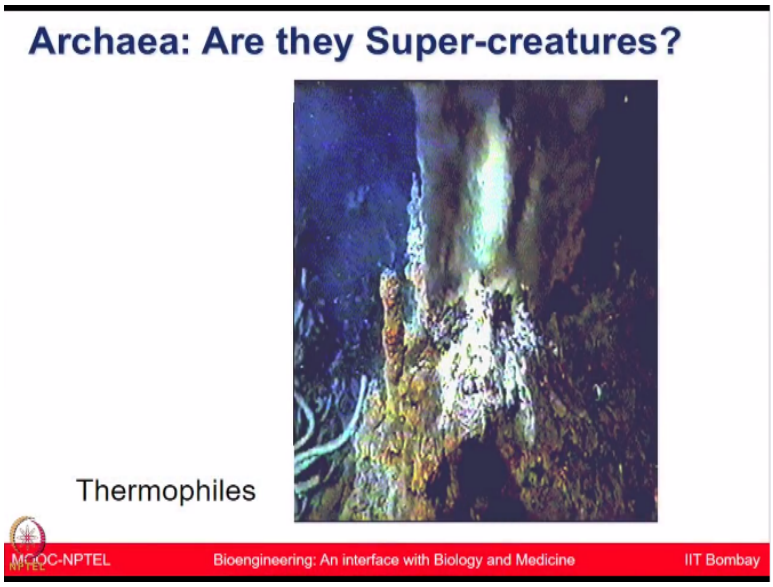

What the Archaea's are? Are they super-creatures because they can live in the very hot environment which is like a thermophiles.

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They can live in the salt fields.

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They can also live in the methane gas environment or known as methanogens. So these are you know very extreme environmental condition and the organism to survive in those conditions have to really adapt those and then only they can you know survive with those conditions. So this Archaea are actually prokaryotes which are distantly related to the bacteria like organisms.

Their cell membranes have some chemical properties which makes them different from both prokaryotes and eukaryotes. It means they have certain uniqueness like their cell membrane does not contain fatty acid but it contains some branch molecule which is known as isoprenes, so looking at them it looks like they are not the prokaryote but rather they had certain you know uniqueness which gives them some unique identity.

And just imagine biologically why it is important for us to know about these kind of organism and why we have to study these kind of extreme conditions. Just imagine that you know when people are observing the nature and looking at even the extreme nature conditions, what kind of organisms can grow and survive those can provide us lot of clues which can be really translated back into the actual day-to-day life conditions.

For example, the invention of polymerase chain reaction or PCR just happened because Kary Mullis, he observed that you know the one of the bacteria which lives into the hot spring, very hot weather, hot conditions, it can survive in that type of you know hot temperature and

then probably its physiology is meant its enzymes are meant in such a way that it can withstand very high temperature.

So Thermus aquaticus was the organism which he isolated and then he obtained the enzyme which is Taq polymerase which is now being used for doing the polymerase chain reaction or PCR. In this manner, just imagine that you know this entire molecule biology which is you know one of the fundamentals to use the PCR polymerase chain reaction is so much depending on this enzyme.

And that was not possible to obtain if somebody has not made close observation that there are some group of bacteria which could live into these kind of hot condition. So it is important for us to make these kinds of observations from the nature not only the normal condition but also what is found in the very adverse conditions.

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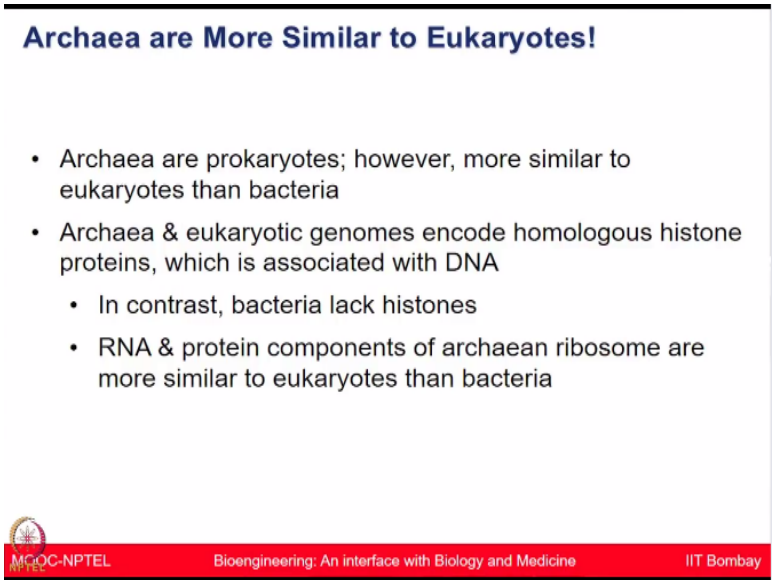

So Archaea there actually if you look at their biochemical behavior they are probably more similar to eukaryotes, although they have similarity from the you know prokaryotes as well but they have more similarity to eukaryotes than if you think about you know their similarity with the bacteria.

Both Archaea and eukaryotes their genome they encode for the homologous histone proteins, which could be associated with DNA and which is not the case when you think about the prokaryotes because bacteria they lack histones. Even RNA and protein components of these

Archaea and ribosomes, they are much more similar to the eukaryotes as compared to the bacteria.

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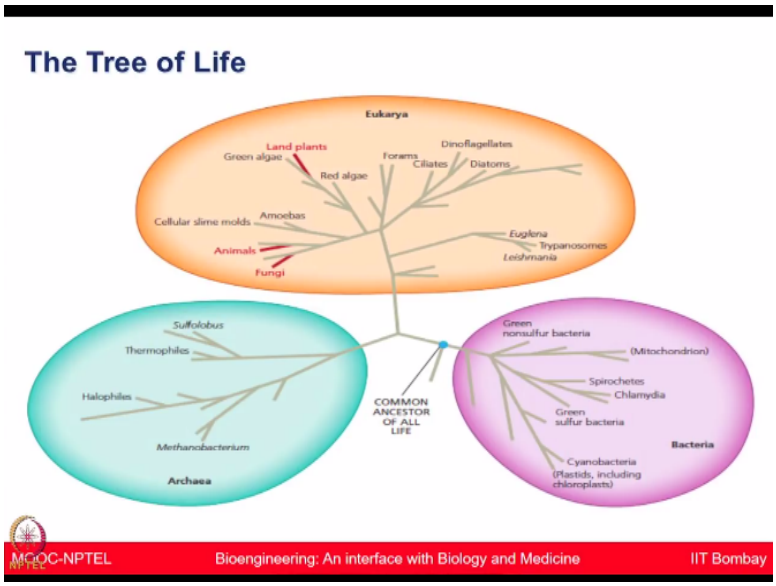

Now this again summarizes the tree of life which we have been discussing. We have the prokaryotes, we have the bacteria and we have Archaea and probably there was one common ancestor of all life-forms which has given rise to these kinds of tremendous diversity.

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Let me explain you this in more detail in the following animation.

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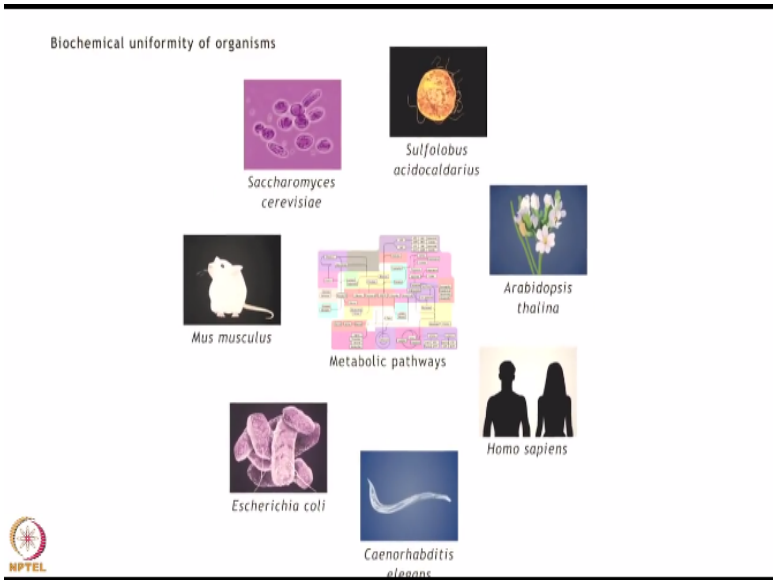

All living organisms from various periods of evolution have been found to exhibit remarkable similarity at the biochemical level. Genetic information is stored in the form of DNA or RNA. The same set of 20 amino acids form the structural elements of proteins. Similar metabolic pathways and several proteins with structural similarity have been found to have similar roles in different organisms.

All of these point towards the existence of a common ancestor from which various organisms evolved at different points of time.

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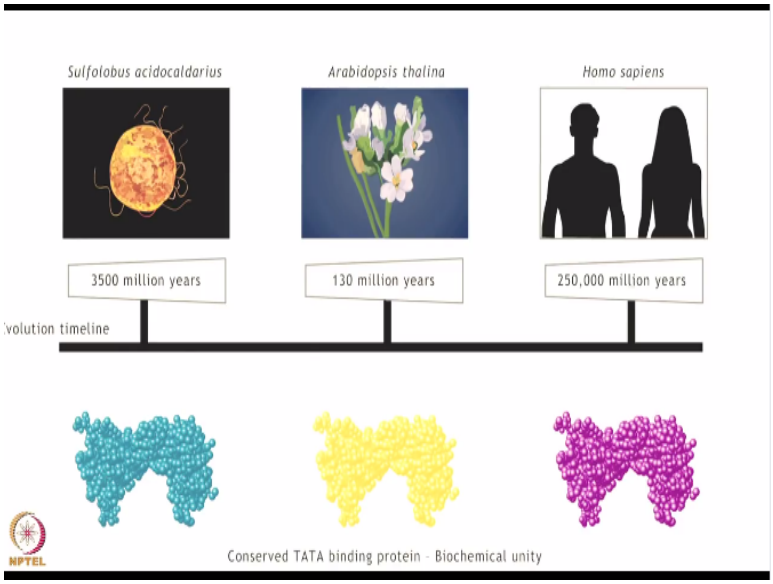

Several proteins have been identified that possess similar three-dimensional structures and perform very closely related functions in organisms that are separated in evolution over

billions of years. One such protein is the TATA box binding protein which plays an important role in gene regulation.

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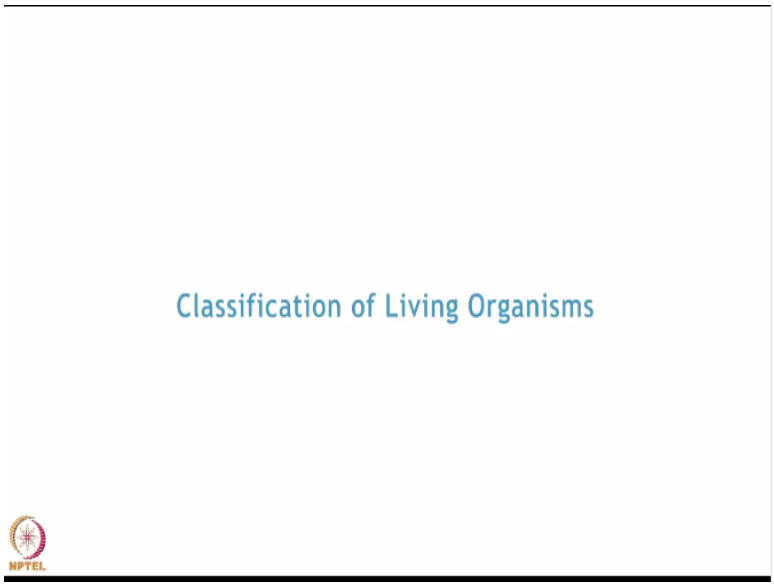

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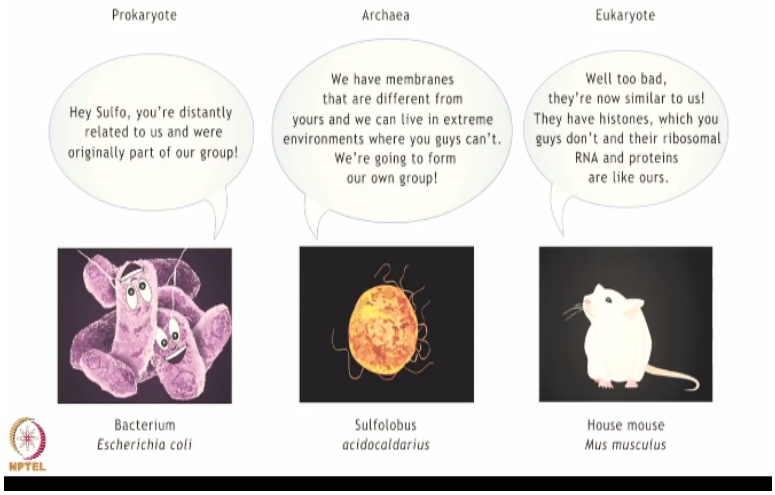

Archaea are a group of prokaryotic organisms that are distinctly related to bacteria like organisms. They are however more similar to eukaryotes than bacteria. Both Archaea and eukaryotic genomes encode homologous histone proteins which are not present in bacteria. The ribosomal RNA and proteins or Archaea closely resemble those of eukaryotes; however, Archaea are capable of growing in extreme environmental conditions such as high temperatures, salt concentrations, etc.

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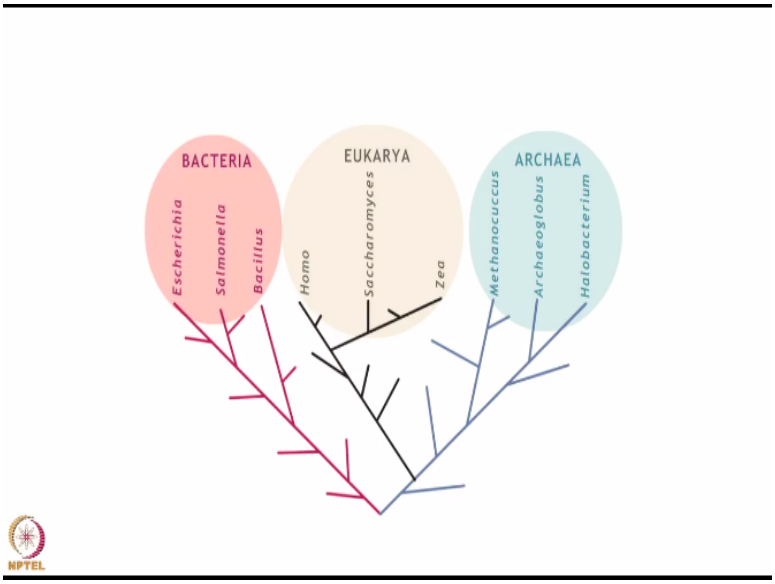

One of the most recent classifications of living organisms is a 3 domain system consisting of bacteria, Eukarya and Archaea although, Archaea were originally considered as bacteria. They were later classified into their own domain due to several differences in their metabolic pathways and genetics. Eukaryotes are believed to have evolved through several endosymbiotic relationships between various bacteria and Archaea.

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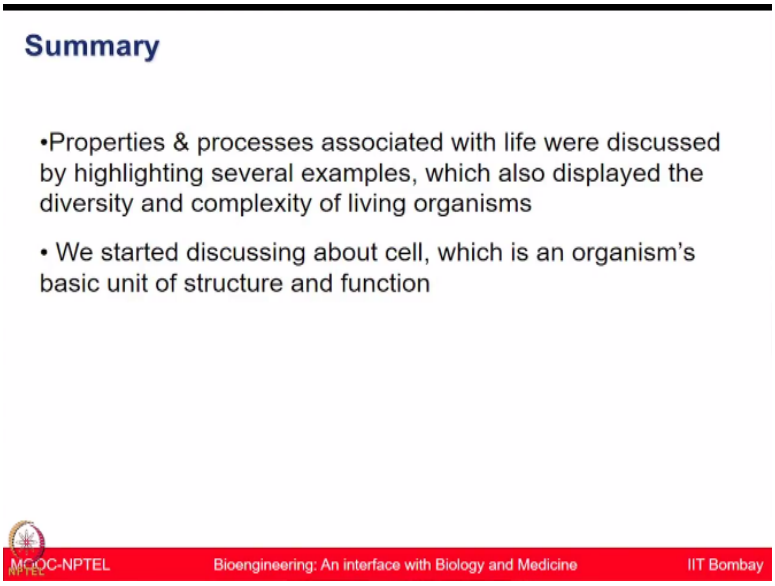

So today in the starting with the life-forms we started discussing about processes and properties which are associated with life and we highlighted various examples to discuss about it which could actually display the kind of diversity we have but it is still lot of you know a unifying theme we have because we are still sharing lot of you know common properties and those are governed in different you know animals, different organisms and those properties are shared.

Then, we started discussing about the cell and you know the at least an overview of the cell, a distinction between prokaryotic and eukaryotic cells and then try to give you the feel of how different you know the major life forms or the tree of life has originated especially from the prokaryotes, eukaryotes and the Archaea and some of their you know the basic distinct features of Archaeal forms.

We will continue our discussion about the cell and its properties looking at the structure and function for various cell organelle and how they actually govern different you know cell processes. Also, we will talk about how cells communicate to each other and how communication also happens within the cell. So let us discuss these points in the next lecture. Thank you.

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