Neural Science for Engineers
Prof. Vikas V
Department of Electronics and Communication Engineering
National Institute of Mental Health and Neurosciences (NIMHANS), Bengaluru

Lecture - 02
Biological Information Systems

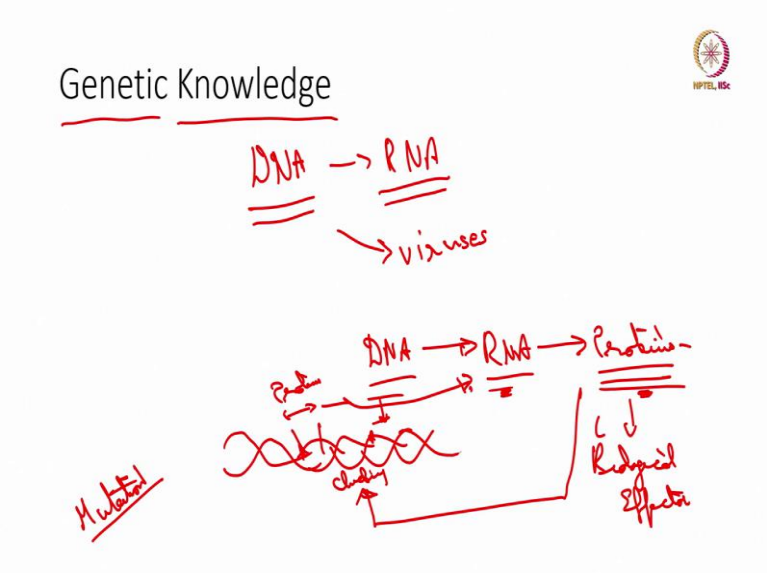
We start today with Biological Information Systems. Now, all of us who have read computer systems we start from information theory as to how information exists, its stored, transmitted and used. So, biological information is a kind of information. Meaning biological information, the basic necessity is living beings need to process information. So, when you need to process information, it can start from basically as to where food is available and human beings where phone is available.

So, various classes of organisms need information for their existence, survival and to ensure that they propagate in the real world. So, information systems have evolved over millions of years, and they are very robust. They have survived so many mass extinction events. So, unfortunately for us we do not understand them in their complete sense.

So, within this class I will try to introduce you to how information is processed by various discrete entities. Of course, I am focusing on humans because that is the group of organisms with which I have been trained on. So, there are areas which I am not aware of, and I would not make a generalization to that extent, but I try to give you a flavor of the topic.

So, this is the overarching information theory; overarching biological information theory which says that how information is acquired, stored, processed and transmitted. So, that is the idea of this discussion.

(Refer Slide Time: 02:18)



All of us are familiar with genes. So, genes basically consist of proteins which are called DNA and RNA. So, the basis of life; so, the DNA molecule is thought to be the basis of life and organisms which contain DNA are known to be organisms which had life at some point in time.

Now, there is also a necessity of mentioning RNA because though when we conventionally call as life we call as all organisms which we are very familiar with the exception of viruses. So, viruses have slightly different kinds of mechanisms and in fact, they can be the easiest representation of alien life on the planet. We confine ourselves to conventional DNA.

So, information is stored in genes, and we as yet do not have a clear understanding of how much of information is stored. To give you the understanding of both the richness and diversity of the genetic information you must be very familiar with people saying that you have a smile you have you look like your forefather, grandfather, grandmother, aunt, uncle.

Now, if you look at this statement saying that you have a smile like your aunt you have a smile like your uncle or like you laugh exactly like your dad, how exactly? What constitutes that? So, first you need to have facial muscles which are very similar to your parents or aunts or uncles then you need to have activation functions of those muscles in exactly the same pattern as that was there in the parent or uncle or whatever.

Now, that much amount of information has been bundled into genetic material and has been transmitted across through the family. So, that is the kind of information density which is there within the gene. And we as yet do not have any clear understanding of how that goes on from one generation to another generation. There is a lot of work. We as surgeons deal with a lot of genetic information to treat tumors, but there are lots of limits and for which reason we are not able to get a handle on it.

Now, what is important to know is that this is an important method by which information is stored in nature and biological information is transmitted from one generation to another within a species and this species propagates to maybe even generate newer generations of species and various biological entities. Say trees and plants are very different from animals, human beings, and things like that, all of them have a genetic basis.

So, genes consist of these DNA molecules; so, how information transfer occurs is that DNA is transmitted to RNA and that is converted into proteins. Now, proteins form the executor entities. So, proteins can be anything from material which constitutes the cell surface to say actuators within the cells such as muscles and it can also be sensor proteins which we will go in greater depth in the later part of the course.

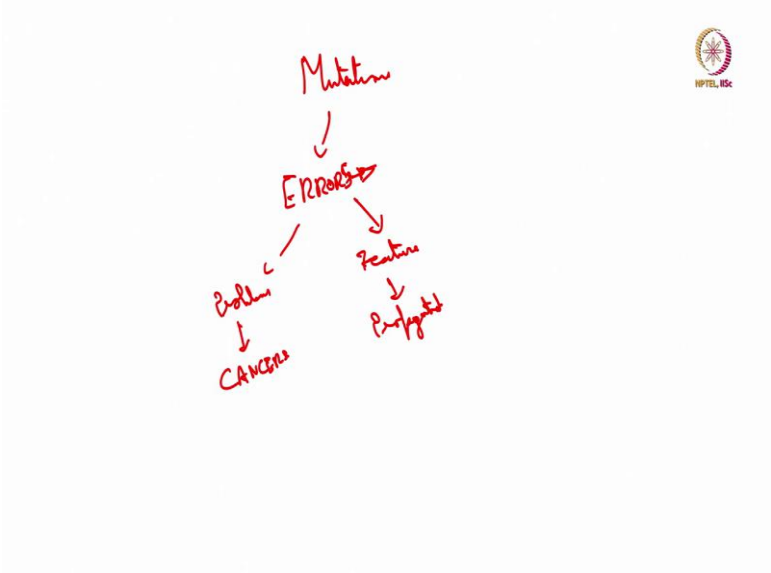
So, all this information is compactly packed within the DNA. So, we have DNA transmitting to RNA and then to proteins and these are the biological effectors. So, proteins are biological effector systems and there are diverse kinds of proteins which provide various kinds of biological functions.

A little more to be talked about DNA. So, DNA as such consists of this double stranded nucleic acid sequence and it has to be transmitted into RNA. So, RNA requires that a particular segment of the genomic sequence be translated. So, there is a specific area of interest which is translated through multiple proteins. So, these proteins in turn produce the RNA and in turn produce the protein.

So, even the repair mechanisms of DNA are through proteins. So, DNA synthesizes RNA to proteins which in turn do the error checking. So, very diverse mechanisms are there for error checking within the DNA molecule so that there is fidelity of the information which is transmitted from one to another and when you lose that fidelity that is called as a mutation.

So, mutations are abnormalities which are generated. There are natural mechanisms of mutations. Mutations have their benefits and also cause problems too.

(Refer Slide Time: 07:52)



So, we are discussing mutations. Mutations can be thought of as errors. There are various kinds of mechanisms of mutation. Again, it would not be of interest to non-medical students, and it is a separate topic in itself. So, when errors are generated, they can be part of problems. Say you have diseases such as cancers which are based on mutations, they can also be a part of evolution.

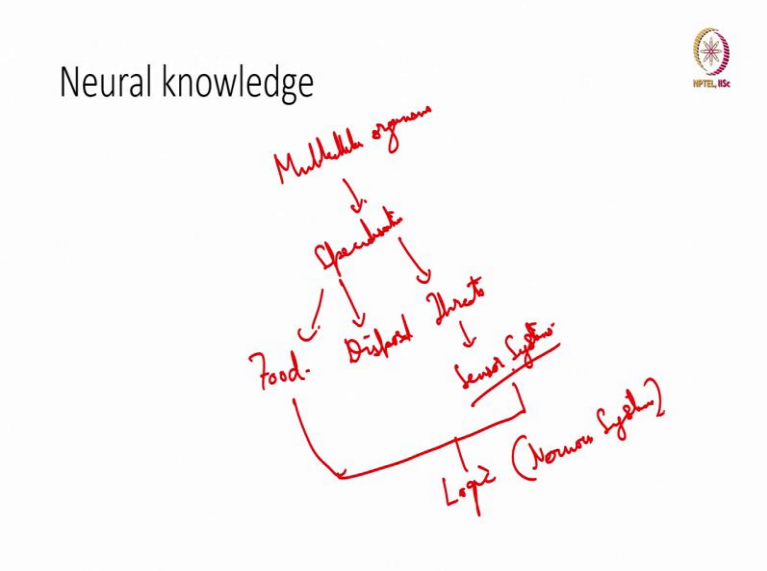
So, you generate an error which actually forms a feature and if the feature is good, it gets transmitted on to the propagation propagated to the next generation. So, what happens with mutations is it is both good and bad. So, you have entities which benefit from mutations and then there are diseases which are based on mutations.

Cancer is the easiest because it is something which most of us know. So, to give you an example of the depth of the system you can have errors within DNA, you can have errors within RNA, and you can have errors within protein. Of course, all starting from the DNA part of the story. So, you have DNA error which gets transmitted onto an RNA error and then which gets transmitted onto a protein error.

So, any of these parts can be faulty and then you would have a disease process which is related to the over expression or under expression of different kinds of proteins. Now,

that is the kind of genetic knowledge which is available within living organisms and that forms the basis of all living entities. Now, we go on to neural knowledge.

(Refer Slide Time: 09:41)

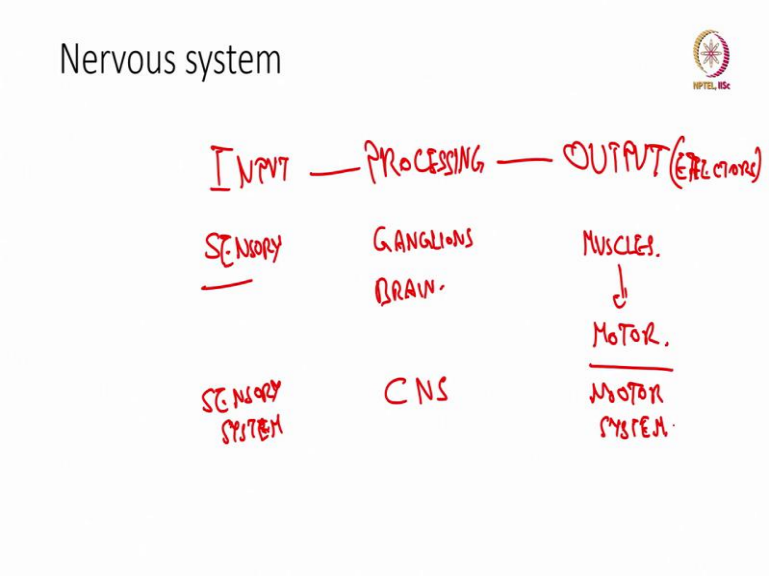


Now, the nervous system as such started much earlier in evolution after multicellular organisms started evolving. So, when multicellular organisms started you need to have specialization because each cell would not like to do the same stuff which all other cells are doing, it becomes inefficient for the organisms. And that is why there was a necessity for some parts of the organisms to diversify into different functional entities.

So, say for example, you have parts of cells which are processing food. Food which is the energy source for the organism which needs to be acquired and processed by the organism and that is necessary for food. So, basically that also necessitates a disposal system. Now, when you have food acquisition and disposal you also need to be aware of threats.

So, threats require sensor systems. So, there are sensor systems and then when you need to acquire food, we need to have something which connects the sensor system to logic. So, you need to have food and sensor systems going directly to form logic and then we have what forms in our system.

(Refer Slide Time: 11:28)

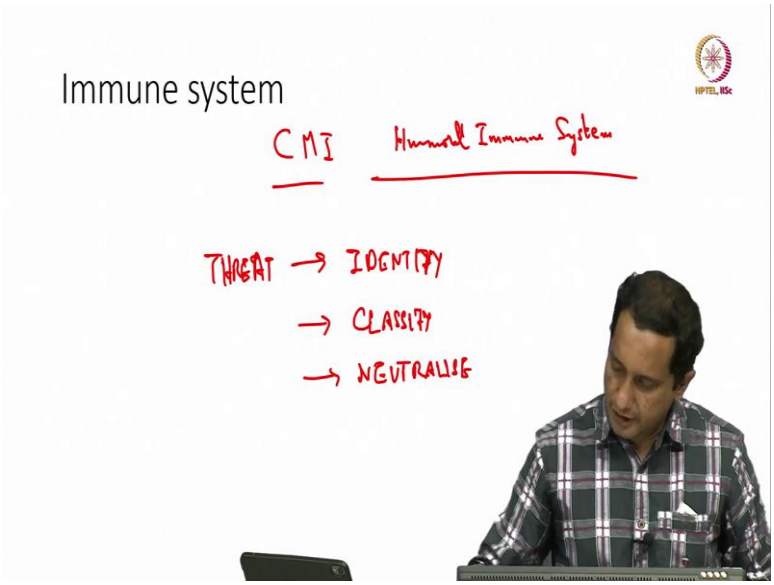


So, if we compare the nervous system with conventional computing system you have input, then you have processing, and then you have output. So, if you look at the nervous system terminologies, we would call input as sensory system. Then you have processing which is called by various terms. You have ganglions and then you have brain. Of course, we will discuss that in greater things and the output effectors are the effector systems.

So, effectors are muscles. For the time being we will consider only muscles. Now, muscles as such are called motor. So, we have sensory and motor systems, and then the brain, which is the central nervous system. So, if you look at; if you look at biological methods of study, we have sensory system to be studied then the central nervous system and the motor system.

So, these are the classifications by which we analyze the nervous system and its functions and try to understand what is happening within the nervous system.

(Refer Slide Time: 13:05)



Of course, we are going to deal with it in greater detail. So, I am not going to go in great depth into that as of now. The immune system is not something which people are very familiar with. Of course, now with Corona virus everybody knows what a cytokine storms and antibody titers and things like that are. Now, some things which have to be told about the immune system is one of the most fantastic systems for the defense of the body.

You have skin, you have the immune system, you have various kinds of membranes which protect the body from outside attackers. So, to give you an idea of how the immune system works you need to have an understanding of what constitutes the immune system. So, fundamentally there is something called cell mediated immune system and then there is the humoral immune system. So, these are the biological side of the story, humoral immune.

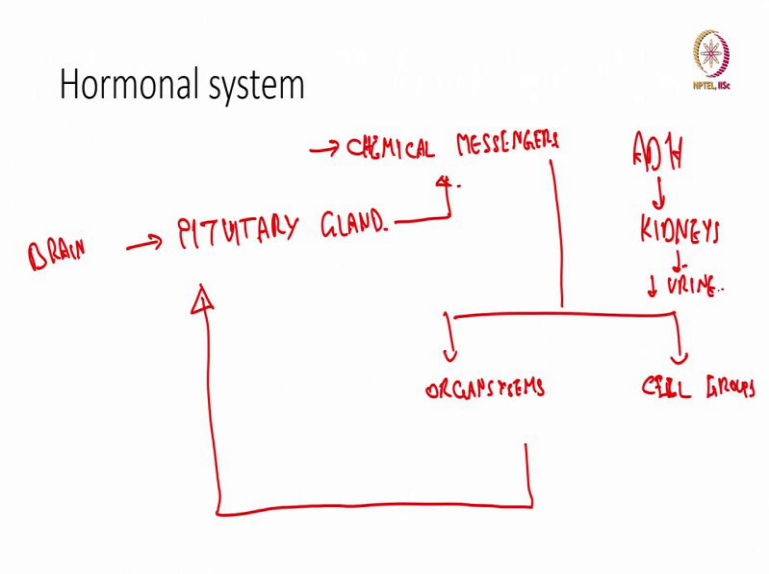
So, these are just to give you an idea that there are biological entities which we discuss. So, cell mediated basically means that there are cells which are dedicated for taking care of these foreign entities. Foreign entities mean bacteria, viruses, any kind of foreign body which enters into the body which is perceived as a threat. Humeral is something which is present within the blood, and they react with outside entities that is bacteria, viruses, foreign bodies, etcetera.

And the interplay between these forms the immune system. Now, why did I discuss this information or knowledge biological information systems? Because if we look at what is a threat, so you need to identify the threat. If I identify the threat, then you need to classify the threat and then you need to neutralize the threat right.

So, this is the function. So, if you look at any kind of security systems in engineering on the engineering side, they would essentially form the same thing. So, when you put a finger on a biometric sensor there is sensing which is basically the identity. So, you try to identify whether this person that the fingerprint is legitimate to be a fingerprint and then you try to classify whether the person is within the limits of the database.

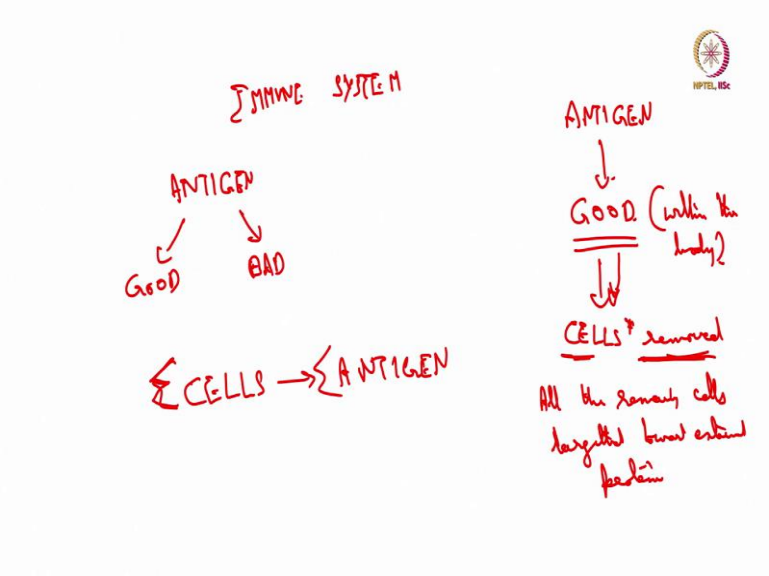
In the sense that the person can be classified as a safe person or not a safe person. And of course, you do not neutralize in a biometric sensor. There is a door which either opens or remains closed. So, that is the neutralization part of it. So, it is a similar philosophy which is there, but it is much richer. So, how does the immune system take care of this is something which I should explain to some extent.

(Refer Slide Time: 16:20)



Now, the beauty of the system is that it is done up front. Up front how do you do that?

(Refer Slide Time: 16:30)



So, before birth when the immune system develops, we need to know that any protein is something called as an antigen and all of us are now aware thanks to Corona virus, there is hardly anybody who does not know or never heard of the term antigen. We are all familiar with the term antigen and antigen is a protein which is either good or bad.

So, you have good antigens, and you have bad antigens. So, how can for all the multitudes of proteins which exist in the world how does a person who is not born understand whether it is a threat or not a threat? So, it is done in our bodies in the following way. So, you generate cells for every antigen. So, the cell has a reacting surface which will detect a given antigen and then you get an individual cell for all kinds of antigens.

Then once you develop a particular antigen you expose it to all the good antigens that is within the body. So, when you expose all the good antigens you ensure that those cells are removed. Cells with the good antigen are removed. What does that mean? All the remaining cells are targeted towards external proteins.

So, you imagine that the body generates proteins of different kinds of varieties and then each of these proteins have specific protein entities called antigens, a part of the antigen which forms epitope for these various kinds of cells. Now, in the bargain you have cells which generate immune response which can attack a normal cell as well as abnormal cells.

Now, the body as such does not have a knowledge of all the proteins which can come into the body, but all kinds of foreign proteins which can be generated are generated to actually provide a training set for the immune system. Now, at the end of this training you have cells which can attack normal cells and which you have cells which can attack any kind of foreign proteins.

So, that is the result of the first level of so-called learning. At the end of this level of learning these cells which have antigens towards the body they are all recognized and killed. So, what remains is cells which can act towards foreign antigens and that is how the immune system is geared up for any particular foreign entity whether it be a virus, whether it be a bacteria or whether it be. Of course, it needs to be within certain limits of protein detection.

You cannot have these are protein-based information systems and so, you would have protein limitations as the input to the system. So, at the end of the entire training system you have cells which can detect very small amounts of antigen which are introduced into the body. And these antigens can trigger an immune response which is amplified within the body. So, it is very different from the nervous system.

See unlike the nervous system which is basically a management system of the entire body this is a complete defense mechanism. So, the defense mechanism is ready towards any foreign entity as opposed to you know you do not need a fresh foreign entity to come. So, when a fresh foreign entity comes it is checked against the library of all foreign antigens that the body has.

When there is a map based on the prior exposure of the foreign entity in reference to the library there is an immune response which is generated through common pathways. So, that is the beauty of the system. So, that is the reason I put it up in biological information systems is it is very rich. As I told you it is a threat perception, detection and elimination system, it is very different from the nervous system in this one.

All of these are connected hypo at very high levels in the human body and that connection is what we call as homeostasis in which each system acts independently but it acts as part of the hole in harmony. Now, to give you what actually goes wrong with immune system, is you must have heard of autoimmune diseases. Say for example, Grave’s disease and several kinds of muscle disorders.

So, what happens in this is the good cells good antigens that is the body antigen cells are not destroyed. You know I told you that they are removed. So, what happens if they are not removed is you know you have cells which are reacting towards your own body, when the person grows up or at a later point in life. So, these cells start destroying parts of normal body and that causes a defect in function.

Say for example, Grave's disease causes defect in the thyroid and that is a problem. So, there are thyroid cells which are part of the body, but the immune system thinks of it as foreign and tries to attack the cells and produces the disease. So, that is how the immune system is.

Again, as I told you it is a brief introduction. I do not think I can go on more about the system with this current course it is a separate topic in itself. Hormonal system I included for multiple reasons. Now, hormones basically are chemical messengers. So, chemical messengers in the sense they are produced by various entities within the body, but it is more in the context of a small gland which is called as a pituitary gland.

Now, the pituitary gland is directly connected to the brain, and we do operate on diseases of the pituitary and brain. So, the brain is connected to the pituitary gland and the pituitary gland produces chemical messengers and these chemical messengers have very diverse actions on multiple organ systems and cell groups.

So, they are one single point of production and very diffuse and very temporally long. Meaning there is a long period of action of these hormonal systems and of course, there is feedback. So, the organ systems in turn tell the pituitary as to when more hormone is required or when less hormone is required and that is how the normal mechanism.

So, there are several mechanisms built in which tell you. One of the most important and very regularly strictly controlled system is with reference to fluid management and sodium management which we will come to later. So, when there is a deficiency of water within the body the pituitary gland secretes a hormone called as ADH. Now, ADH acts on the kidneys and reduces urine formation.

So, over a period of time that again triggers different parts of the brain you have sense of thirst, and you take in more water. So, the system is it is an internal server system. It is very general where there is some amount of specificity built into the kind of target

systems and the kind of cells which produce the chemical messengers. But it is a very rich system which extends throughout the body, and it is responsible for actions almost through life.

So, there are various parts and parts of life at which different hormones play a role, but I am including it into the discussion of information systems because these are not systems which are very generally aware. You know when people hear about hormones, when they hear about the endocrine system, they think of more in terms of diseases. They do not look at it in terms of an information system which is its own beautiful server systems very quick response systems very long action durations of action and things like that.

So, the idea was that to incorporate all these into biological information systems. Biological information systems that way is you know are very rich in their domain. So, when we look at genes, we are looking at millions of years of time spans in which the genes have shown their influence. You know starting from dinosaur single celled organisms to us we have seen the effect of genes how they manifest, how the genetic system preserves its fidelity.

You know you all human beings are almost similar to each other. There is a very high amount of sanctity in the genetic code which is transferred from one human generation to the another. And also with various kinds of organisms and many most single celled organisms. So, many single cells organisms have remained the same for the past couple of billions of years since life has evolved and that gives an idea of the richness of the system, you know the robustness of the system, the error checking mechanisms which are there within the system.

Nervous system is something which you are all interested in, but it has come at a later stage of development. It started as a necessity of having a system which is completely necessary for managing the organism in the environment. So, in the real world how does the organism interact with the environment to its own profit to its own survival and to its own propagation. So, that is the message of the nervous system.

The immune system is beautiful because again it is not conventionally thought of as an information system. So, I gave you an example of the biometric because that is something which most of us are familiar with, but that is almost exactly the mechanism and to imagine that this system is far more robust.

You know it not only recognizes proteins, bacteria, viruses and several other things, but it is built from de novo and the mechanism is simply too good to not be characterized as an immune system. The hormonal system is an add on to the whole system because the hormonal system is basically if you look at it in engineering terms it is like hyperparameters.

So, the entire hormonal system is a very high level of hyperparameters which tune various parts of the body. You know it acts. Say for example, it acts on different parts of the body. Say for example, the thyroid hormone acts on the nervous system. It ensures that the fidelity of messages which are passed between different parts of the nervous system is intact and that is how when you have low levels of thyroid during the growth of the nervous system it results in mental retardation.

So, that is the kind of influence which the system has. So, what I have shown you in this discussion is that various kinds of biological information systems, their scope, their influence and a brief introduction to their functioning. The idea is to make you sensitize to these kinds of information system which are there and the different kinds of functions which they execute and what they are able to do in different scenarios.

So, with that I think we close this session.

Thank you.