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

Lecture - 12
Architecture of the Nervous System

So far, we have been discussing parts of the neuron and within a cell. And I have shown you how computation is done across the cell, in various parts of the cell, how computation is done across cells from across the synapse and how electrical activity can result in mechanical activity. The potentials of that, how information, how actuation is coupled with information so, that is the biological variant of information and actuation coupling.

So, what we now discuss is higher level stuff. So, far I have been discussing very elementary issues, but without discussing the elementary issues it is not possible to go into the higher-level stuff. So, it is necessary to have a thorough understanding of the concepts which have been dealt so far.

So, each of it would have merit in its own, to know how the biological system works and as I had highlighted in the previous session, there are certain very novel things which the nervous system has to teach us of course, there are several of it but which, may have ready implementation in for several of you who are sitting and watching the course. Now, I have termed this talk as Architecture of the Nervous System.

So, why I did not use the term anatomy is because anatomy sort of is you know, it just says that what is there and what is it and what is something in relation to something else. It is essential for us in the biological sciences to study material in this fashion because we need to have an understanding of how things are situated at an independent level.

For the course I am not putting it like that as I had promised in the beginning, term it as architecture because we will look at how things are in relation to each other, both in terms of structure and as well as function. So, there is going to be a lot of mix there. Once the architecture is completed, I think we will go lot more into the function and then build on stuff at as we progress further.

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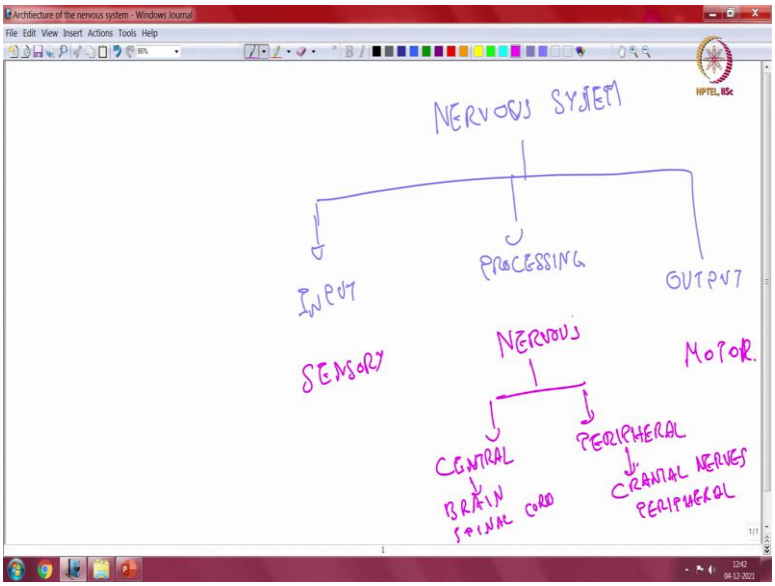

So, when we speak about the nervous system. We generally think of in terms, I think I have highlighted this before, input, output and the CPU processing. So, in biological terms it is called Sensory, Motor and the nervous, which in turn is divided into central and peripheral, central as in what is at the core and peripheral as what is distributed.

So, central obviously, is brain and spinal cord. You have a peripheral as in the cranial nerves, peripheral nerves. There are so many other things. So, you got plexuses, then there is also this system of autonomic nervous system. I think autonomic nervous system is something which we have to talk about.

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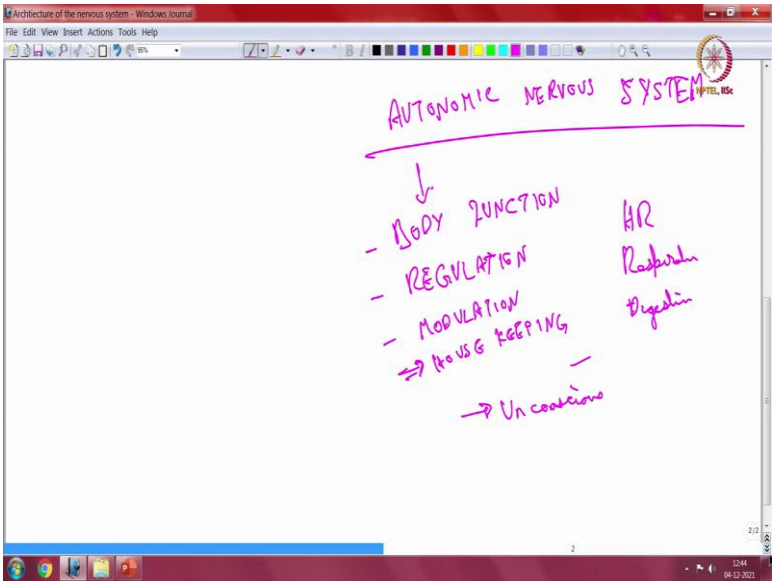

So, Autonomic Nervous System regulates body functions. So, it is regulation, modulation and in general housekeeping. I think that is the easier word, housekeeping. So, yeah something like heart rate, respiration, digestion and so many other stuff, which you know as housekeeping for the body is taken care of by the autonomic nervous system.

It basically works at an unconscious level. So, it's sort of possible, you cannot of course, movies do show it to be very easy, you cannot generally control your heart rate and several of these things. So, you cannot hold your breath beyond a certain point of time of course, I think that is a wrong example.

So, autonomous nervous system takes care of all of this. So, central nervous system is what we will be discussing in greater detail because autonomous nervous system is basically a biological medical topic.

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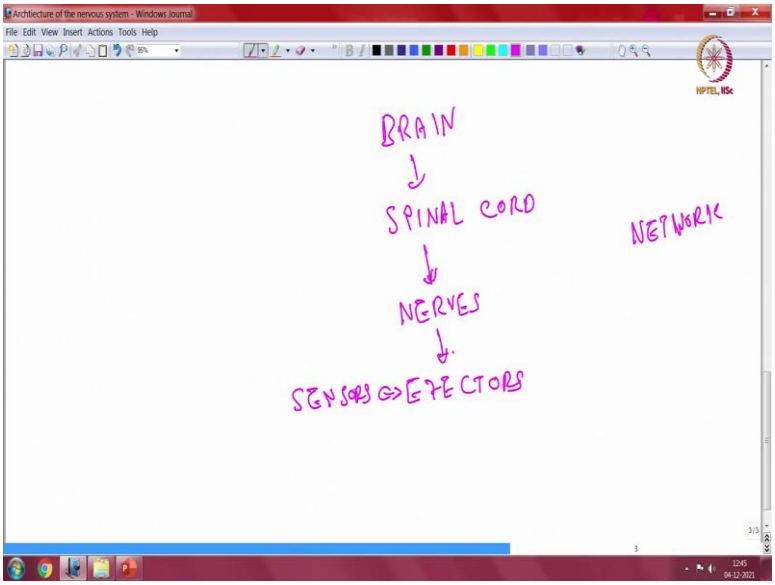

So, when we speak about nervous system in common terms, we think of it in terms of brain, then spinal cord, nerves and effectors and sensors ok. So, I have done it as a top down approach because it is easier to understand, but please do remember that it is all a network and it there are multiple layers in the network and these layers are integrated within that particular layer and as well as with our top down.

So, I think whatever terminology works fine, its fine. So, now the brain continues into the spinal cord and then it continues into the nerves and the nerves are in turn are connected to effectors which can be muscles glands, or it can take in data from various parts of the skin mucosal membranes, eyes, ears and things like that.

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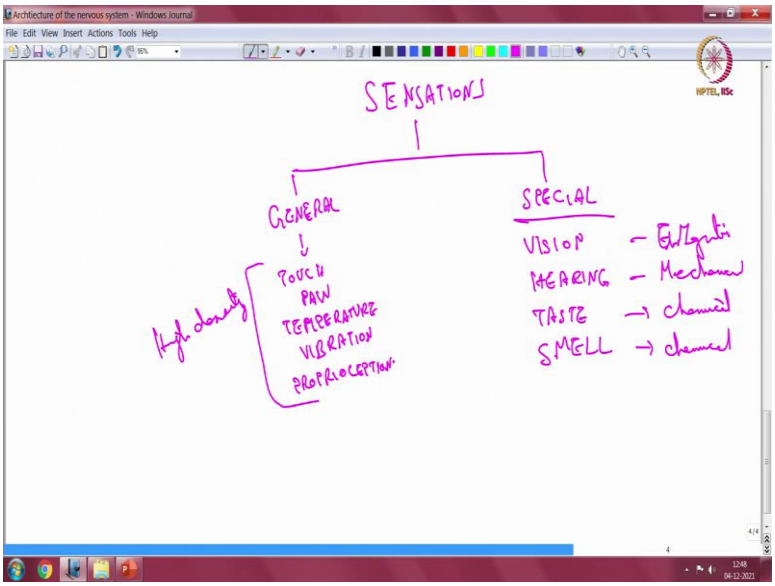

So, sensations, there is some classification. I think I will just note the general which is touch, pain, temperature, then vibration and something called proprioception and there is special vision, hearing, taste, smell.

So, it is high density. Basically, every square millimeter of your skin is covered, it has a lot of these sensors and the sensation the density differs, but it is pretty high density, very incomparable to any kind of electromechanical device which we have as of now.

Special sensations are very evolved senses in which there are definitive organ systems which are dedicated for particular sensation, obviously, eye for sight which processes photons, the visible electromagnetic spectrum, hearing auditory spectrum, sound waves, taste is chemical, and smell is chemical olfaction, that is what you call, not vaporized. Gaseous this one for smell and taste is liquid.

You need to have liquid base to have taste. So, these are chemical. This one is auditory mechanical. Vision is electromagnetic, auditory is mechanical magnetic, taste is chemical, and smell is chemical. So, the this is the sensory architecture.

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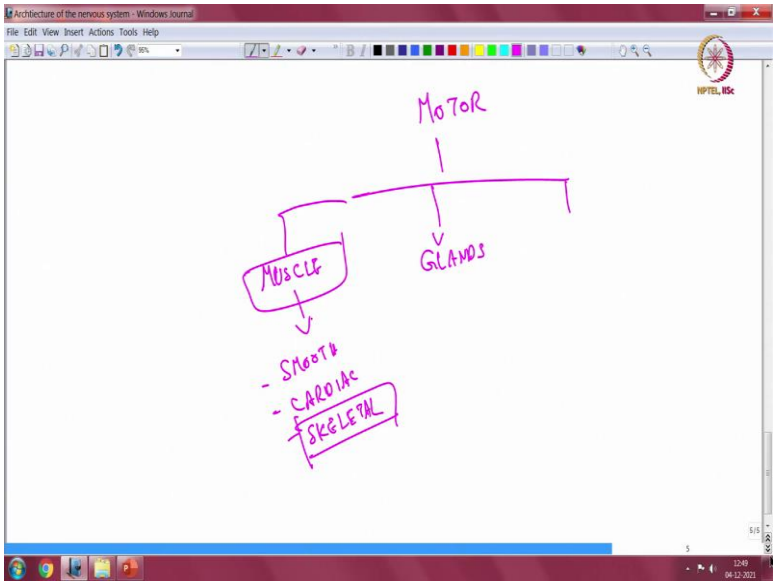

I have already spoken sometime earlier about the motor side. So, motor is you have muscle and glands. Glands can be anything, say salivary glands, glands within the GI system, many other kinds. I am not boring you with the detail. Muscle, you have smooth

muscle, then cardiac which is in the heart and skeletal, which is what we will be dealing with in greater detail.

So, when I would be discussing muscle for this topic, we will be discussing generally skeletal muscles. The other muscles I am not including it in discussion neither are the glands. So, we finish the sensory system and the effector system. We come to the nervous system per se. So, there are multiple other hierarchies within the nervous system.

So, if we look at how the nervous system evolved, we started with single cells which could actually detect some change within the environment and say mostly chemical, you have noxious chemicals which the cell had to go away from and the cell had to go towards food and so, there are very elegant experiments which have been described, photo taxis and so many other kinds of taxis in which cells move towards and away from various kinds of stimuli.

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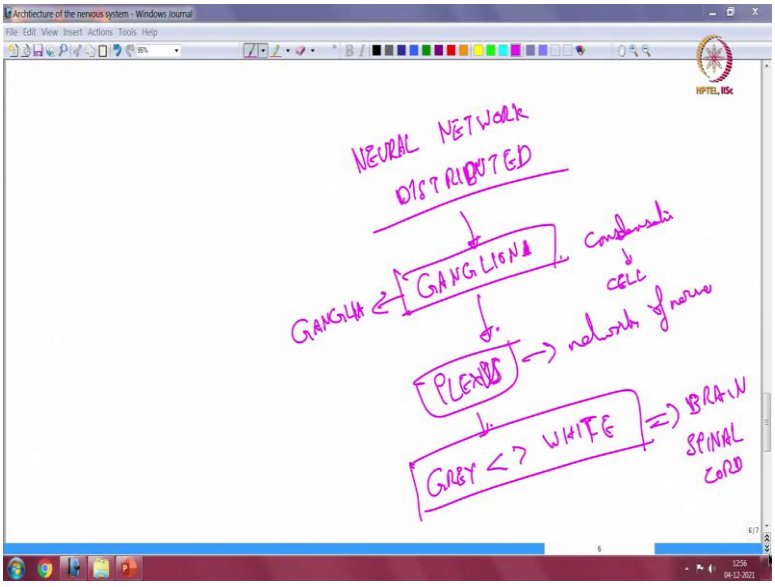

I spoke to you about higher organisms having Neural Nets. So, Neural Net is distributed organization of nerve cells which do not have a central control, but you know they function amongst themselves to generate. I have forgotten the organism, some eight cells or something which act as a nervous system. So, there is nothing like hierarchy. It is nonhierarchical. All neurons have equal powers and this one.

Now, going above that, you have nerve cells aggregated into something called ganglion which even we have. So, the ganglions are condensations of cell bodies. We spoke about the various parts of the neuron. One thing which I have not highlighted there is generally dendrites are in close approximation with the cell body whereas the axon can have very long lengths.

So, as I told you I think I have expressed earlier, there are long axons which span all the way from the tip of the toe to the brainstem, which is situated easily about 5-6 feet length of one single axon. The synapse occurs only in the back of your head. So, that is the length of an axon, one single axon. So, there are multitudes of such axons which pass through the spinal cord intact without having this one.

So, there are cell bodies in the back which give out single axon and it takes up information from the various sensations from different parts of the body. There are also cell bodies within the spinal cord which gives out axons which go all the way into the muscles. So, they are also again single axons. So, one axon goes and meets several individual muscle cell groups and that is something called as a Motor Unit.

So, we have coming back to this discussion. So, we have ganglion, then we have something larger called plexus. Plexuses are networks of nerves. They do not have cell bodies within themselves but there is a lot of intermingling and, that is what I was discussing about architecture.

So, I do not know actually the cause of why plexuses exist, but you know the mapping of various muscles to various parts within the spinal cord and brain, they may be handled by the plexus. So, there is a lot of intermingling. So, there is something called cervical plexus and there is something called lumbar plexus.

So, these are, these mediate information transfer from both the limbs, upper limb and lower limb into the central nervous system. So, that is the idea of plexus. Then we have grey and white matter. What I am trying to showcase or highlight is to introduce you to certain concepts which we may use subsequently in very daily terms.

So, you should have an idea that these terms exist one and at least some idea of what they mean. It is not necessary to know in very great detail about what they are, the

precise definitions and things like that because it's not very relevant to the point under discussion. So, we have grey and white matter, white matter is gone.

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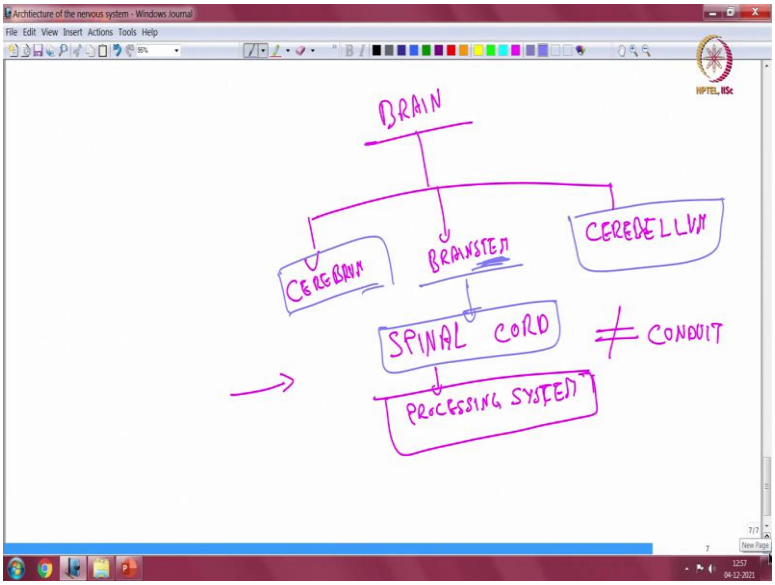

So, when we speak about the brain as such, we have the brain in turn has so many other different parts. I will not bore you with the technical details of the individual parts which are biological, but you would need to know cerebrum, then you have brainstem, then you have the cerebellum.

So, from the brain sort of is the spinal cord, but you should not think of the spinal cord as just a conduit. It is not a conduit. It has its own independent processing system. So, which we will be discussing to some extent because it is important to understand that it is not that the spinal cord is just a mode of transferring information between the brain and this one.

So, going back to the previous slide, I have highlighted how the networks evolved. So, you had very unorganized networks. You had organized networks which form ganglia and these ganglia in higher forms condensate into this grey and white matter and which in turn forms the brain and spinal cord.

So, yeah, so coming back to the brain, we have this gross entities which need to be remembered. So, cerebrum is this whole stuff. So, when you cut open the skull, what you see in above your eyebrows is just about the cerebrum.

Brainstem is somewhat behind, deeper part it's basically a stem because it's a single cylindrical entity which continues into the spinal cord in its in continuity. Cerebellum is somewhat on the back and the architecture is different so, cerebrum, brainstem and cerebellum. We will go into a little more detail into each of these things.

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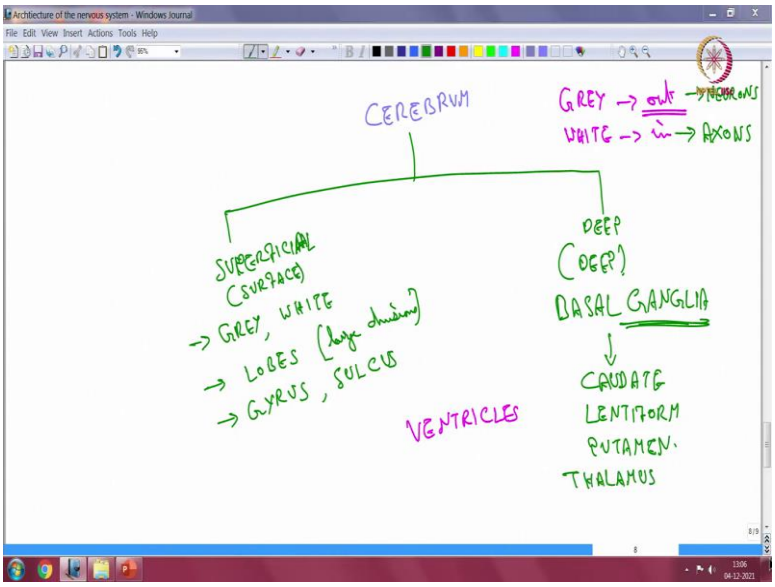

So, the most interesting of it is Cerebrum. So, you should remember this stuff that is grey out, white in. So, outside the surface of the cerebrum and the cerebellum, incidentally has grey matter outside and white matter inside right. In the spinal cord it's just the reverse. So, white matter on the outside and the processing in the inside.

Grey is neurons and for our understanding we put white as axons. We will not complicate issues with that, but it's not so simple. So, the grey matter is basically a lot of neurons, billions of neurons compactly placed in close to each other. You can imagine server farms you know.

So, maybe the body optimize it because you know supplying blood to the grey matter is more of a priority than white matter and it is easier to send high density nutrients to the compacted stuff rather than to the distributor.

You have one cell body and one white matter close to each other, you may have sub optimal delivery of nutrients maybe that is one logic. I have no idea of whether there are any theories to the effect of why this happened. Of course, there may be embryonic

theories, that this gene caused that and all that, but if you look at why compaction has to happen, it should be due to some other reason.

So, you have condensation of this material in different parts. So, cortex has grey matter and then deeper down is white matter. Majority of the stuff is actually white matter. So, it is the conduit which is forms a major part of the brain. The grey matter is the small, thin outer part in which all of computation happens.

Now, cerebrum in turn has a superficial, which is on the surface, and deep. So, the superficial architecture is grey and white. That is one thing. Second thing is it is also divided into so called lobes and so, lobes are larger divisions, and then you have the structure in terms of gyrus and sulcus. So, these are things which you should know.

So, you have grey and white matter distributed like the way I have described, and you have got lobes which are sort of artificial, semi artificial divisions between various parts of the brain. We will look into it in greater detail. I am not going to explain anatomy like this.

It is going to be in a separate class, and I am going to spend time on that. This is just to make you familiarize. So, when I start attributing names to a part you should at least have heard the name that is the idea.

So, superficially we have this stuff which is grey and white and then you have deep grey matter which consists of something called as basal ganglia. So, ganglia are basically an aggregation of the cell bodies of neurons and these are located towards the so called base of the brain and that is one of the reasons you, so this is constitutes of caudate lentiform putamen.

So, there are several other kinds of nuclei. I am just listing out these important structures. There is also this entity, fluid filled entity called as ventricles, which are there within the brain.

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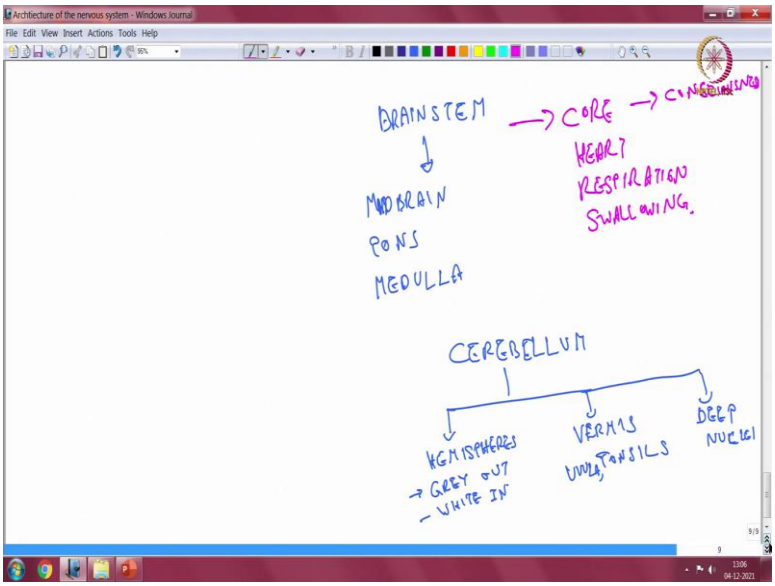

So, when we go into the brainstem so, its top-down hierarchy. So, midbrain, pons and medulla then in the same context we have cerebellum. This is behind the brainstem. So, cerebellum has parts, hemispheres, then you have the vermis, and sort of related are tonsils and uvula, uvula.

So, hemispheres in turn, right and left with the same architecture, grey out, white in. Then there is also these deep nuclei. So, deep nuclei are dentate, emboliform and dfg, not relevant, I think even I am not able to get those things so I am not burdening with additional stuff.

So, if you look at the architecture of the cerebellum and the cerebrum, the there are similarities and dissimilarities. Similarities are both have outer grey inner white; they also have this concept of outer grey and then deep grey.

So, there are deep nuclei which take in stuff, information fibers from outside and then it goes back out into the cortex and then that is how, in fact, information is processed, but similarities sort of end over there because the cerebrum has diverse functions.

It is the net integrator of all signals, the pro generator of thought, generator of action or the modulation of actions, everything. Everything is controlled by the cerebrum. Cerebellum is basically a huge server control system which modulates any kind of output.

So, modulation of physical movements hands, legs, head turning, sitting, standing, walking, speech. So, the way in which speech is modulated, not the generation of speech, how speech is modulated is controlled by the cerebellum.

Brainstem is core functions, heart, then respiration, swallowing, the most important consciousness. This is basal ganglia and you also have thalamus over here which we have conveniently forgotten. Now, both thalamus and the brainstem are responsible for consciousness. That is separate discussion.

So, this is how the brain is organized in very simple terms we will delve into a lot more detail subsequently, but for the time being I would want you to understand this rather than mug up stuff, how the architecture is there, how things are similar between the cerebrum and cerebellum. The brain stem is sort of continuity. So, there are similarities between the brainstem and the spinal cord, both in terms of outer white, inner grey, being cylindrical.

There are similarities between the cerebellum and the cerebrum, outer grey, inner this one, the cerebrum has gyri and sulci and cerebellum also has gyri and sulci but their arrangement is completely different. So, this sort of gives vanilla understanding of the nervous system architecture, just naming parts, I have just named the parts we will go into a lot more detail and structure and function in subsequent classes.

Thank you.