Neural Science for Engineers
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Lecture - 47
Movement: Role of Cerebellum

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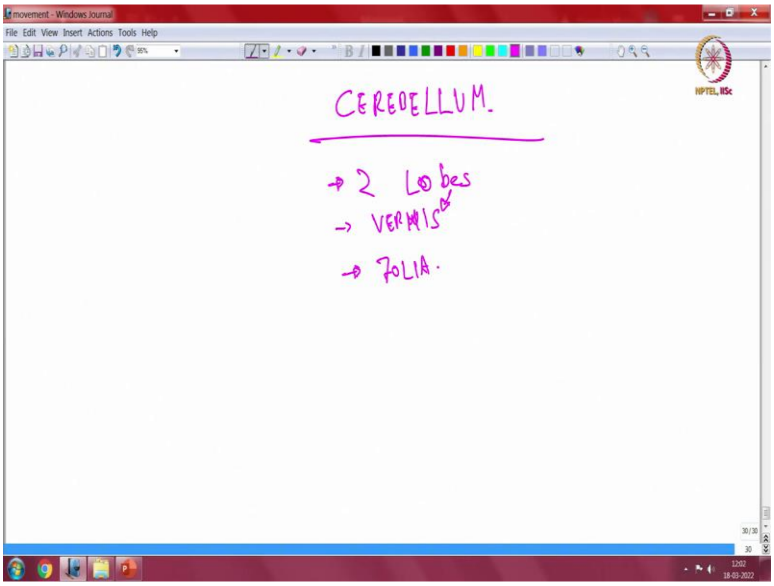

We proceed to a more interesting topic Cerebellum. So, cerebellum is located somewhere over here, I have explained in anatomy again how to recognize that in image, how it looks like. You have two lobes, and you have the vermis in the centre. So, two lobes, vermis; lobes are connected to the vermis.

So, the central part of it is the vermis and then you have two and the convolutions on the surface of the cerebellum are called folia. There are big fissures which split it into multiple parts visually, but functionally you have a different kind of arrangement. So, these are certain things which you need to be aware.

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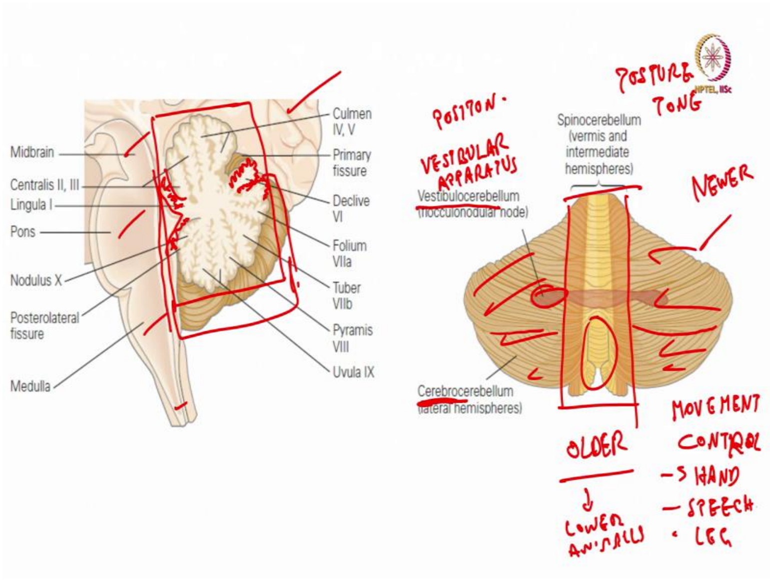

So, I will go back to the pictures. So, that is the cerebellum, cut section of the brain. So, this whole part is the cerebellum this included. Cut section, so you have this leaf like you know this one, each of which is called as the folia. Now, this is the midbrain, Pons, medulla, spinal cord, occipital lobe and to give you an understanding they have got the fourth ventricle over here and there are things which connect the cerebellum into the spinal cord and to the brain. So, they are called as the peduncles.

If you look at it from the back, from the surface of the brain you see it like this is something called as the primary fissure which is over here. Structurally we look at it in a different fashion I think I should explain a little more.

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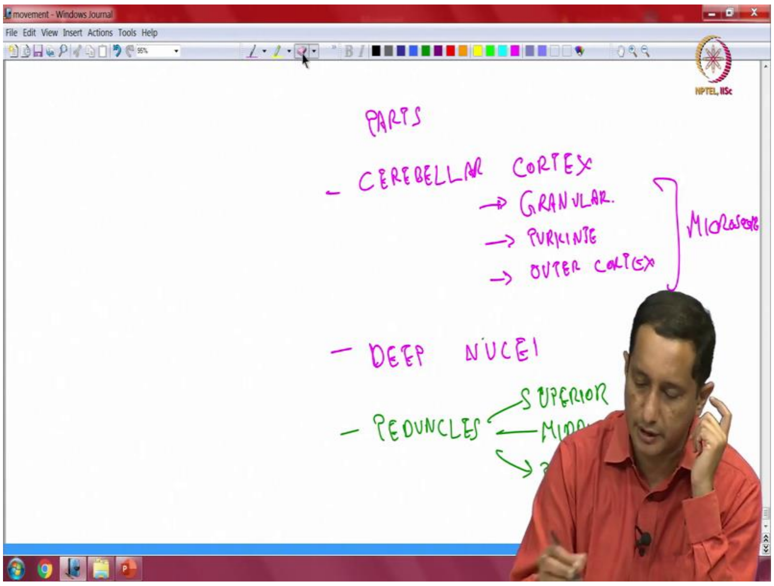

You have the cerebellar cortex and then you have the deep nuclei, the input and output are through peduncles; superior, middle and inferior. So, up, middle and lower down, so that is technical stuff. The cortex as such has multiple layers, granular, then you have the Purkinje cell and the outer cortex.

We will look into this in a little more detail, lot more detail actually. So outside there are two lobes, central vermis then within each lobe you have the cortex which contains multiple other layers. Now, you see under the microscope, you would find these layers. I think this is wrong I will correct it in the picture.

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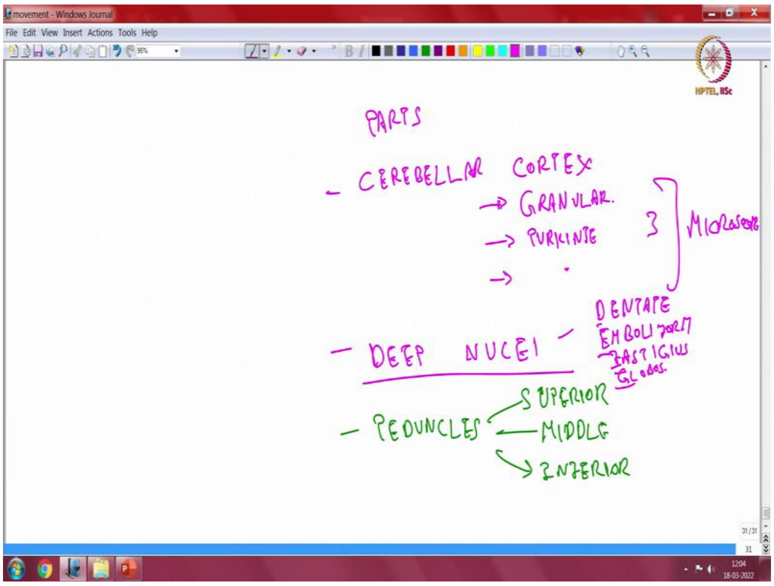

So, three layers, then you have got the deep nuclei which is sort of replicates the anatomy of the cerebellum in which you have got cortex and basal ganglia. Only here it is called deep nuclei, you have got dentate, emboli form, fastigius and globose. So, that is how you remember, these are just for mentioning not something which you need to remember because they are you know structural names. So, they do not actually correlate with function.

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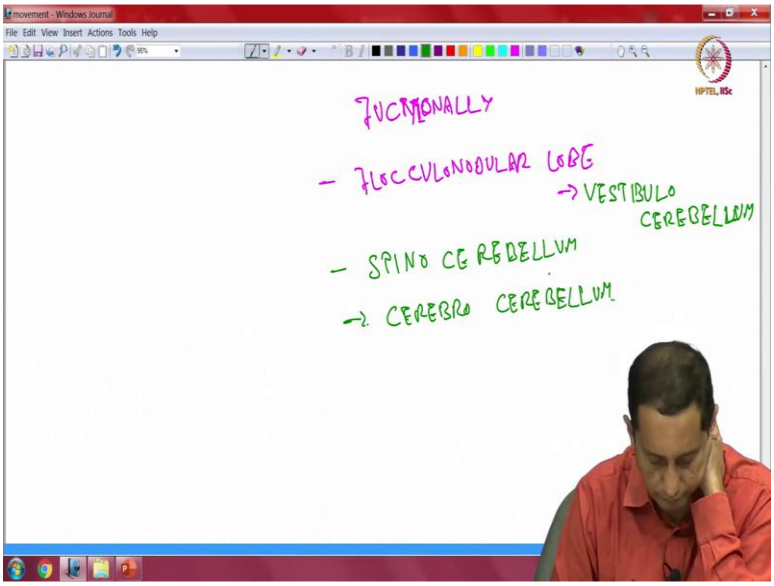

So, functionally you have flocculonodular everything in anatomy is a mouthful. So, that is vestibular cerebellum then spino cerebellum and cerebro cerebellum. Flocculonodular node is part of the lower part of the vermis and the little bit of the deep grey.

The spino cerebellum is the intermediate part and everything lateral is the cerebro cerebellum. Basically, indicates that it is connected to the cerebellum, the cerebral cortex and there is a lot of communication which happens. And obviously, the larger areas are connected to the larger part of the cortex. A brief description, vestibular cerebellum is basically with the vestibular apparatus.

So, that would be in position, spino cerebellum is posture and tone, this is for movement control. Control can be anything, hand, speech, leg, all those things. Movements of various kinds are controlled by the cerebellum and we have been able to demarcate these locations to be responsible for these actions.

So, there are descriptions of again topological organization within the cerebellum, but they are not in conventional teaching. So, again not very well defined as you would see in the sensory homunculus or in the motor homunculus, but there are maps within the cerebellum.

So, the central part of the cerebellum is the older part in the sense that these are there in lower animals also. This is higher so newer, higher animals in the sense that you have a higher amount of cerebral cortex where this connection is relevant. So, that is about the you know structure of the cerebellum.

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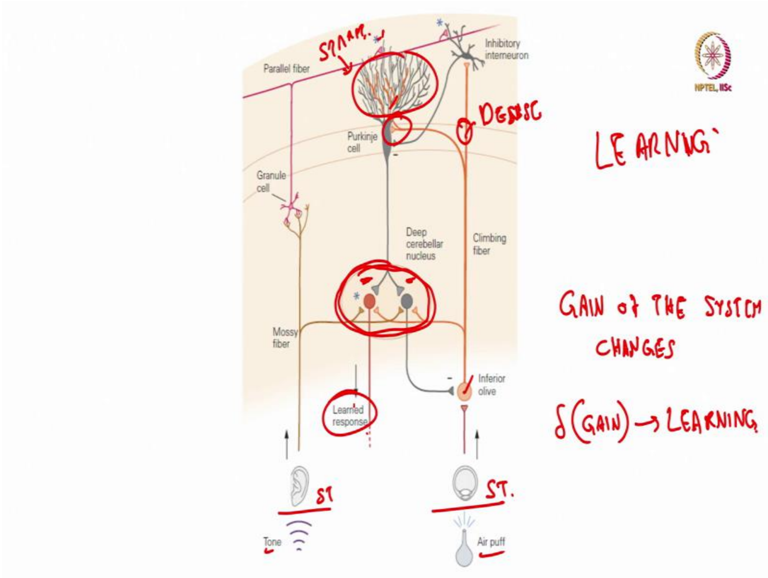

What is more interesting are these three layers of the cerebellum.

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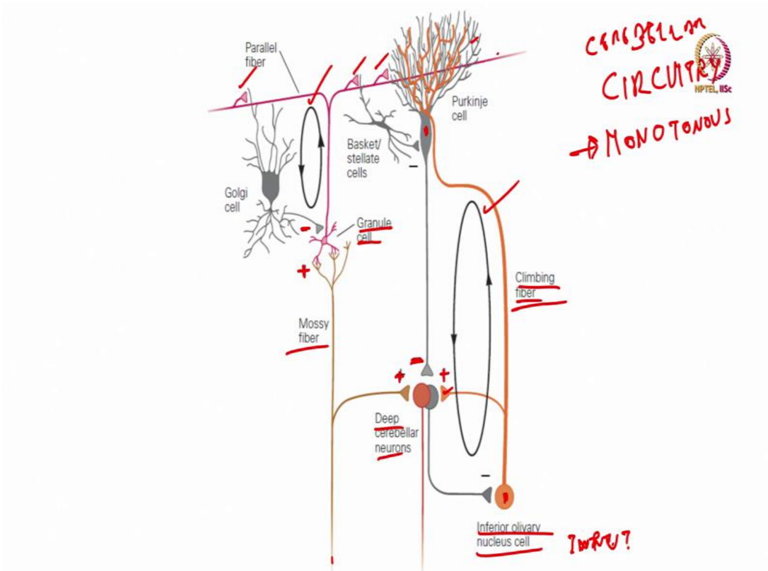

And that is something which I have to show and explain to you. So, we start cerebellar circuitry. My first impression of it is it’s a monotonous circuit. You know you see a section of it gets replicated all across the cerebellum. So, what I mean to say is that you know what cerebellum does for the speech would be exactly the same stuff it does for movements. So, the kind of function which is the servo mechanism which is performed by the cerebellum remains the same across various kinds of task irrespective of the nature of the task.

So, speech is regulated in the cerebellum, movement of the hand, limbs is also regulated in the cerebellum in almost same fashion by the same circuits, which I am about to show you. I will be going back and forth, so please do bear with me on that. I spoke about three layers in the cerebellum.

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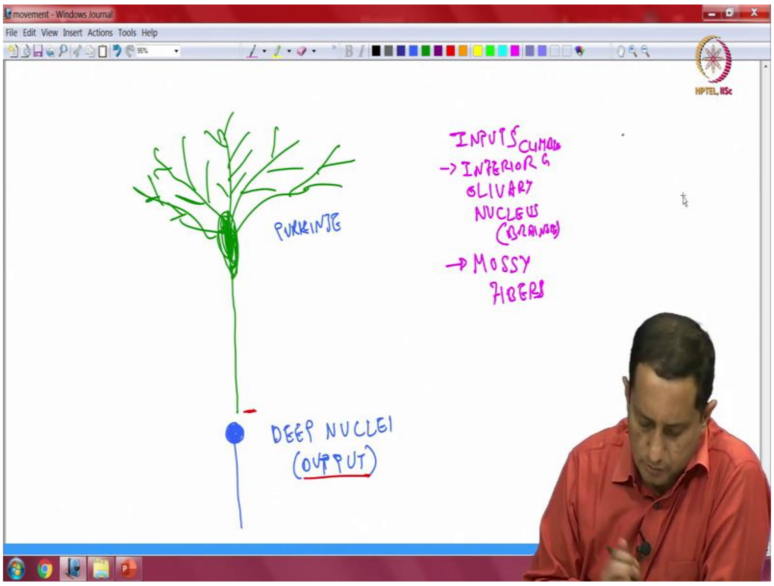

So, the major cell in the cerebellum is the Purkinje cell. So, it is a pretty large cell it has got a dedicated layer for itself, it is a large cell it is got multitudes of branches. So, very large number of branches and the Purkinje cell is like a tree. The Purkinje cell synapses on a single deep nuclei, so the deep nuclei is the output. So, Purkinje deep nuclei and that is the output, so Purkinje cell basically is inhibitory over here. Now there are two kinds of inputs. So, we discuss about the output, so what about the inputs.

Now, inputs into this cerebellum come from two sources, one of them is called as the inferior, olivary nucleus which is in the brain stem and then you have got fibers which there are two kinds of fibers; so they are in turn called mossy fibers. Anatomical names are peculiar, and I have difficulty remembering this stuff, I do understand the concept, but please do forgive me if I am making mistakes in terminologies and naming.

Now, the fibers which come from the inferior olivary nucleus are called climbing fibers. So, there are two sets of this fiber, so we will remove the inferior olivary nucleus for that purpose. We will just keep it simple and quote climbing and mossy fibers.

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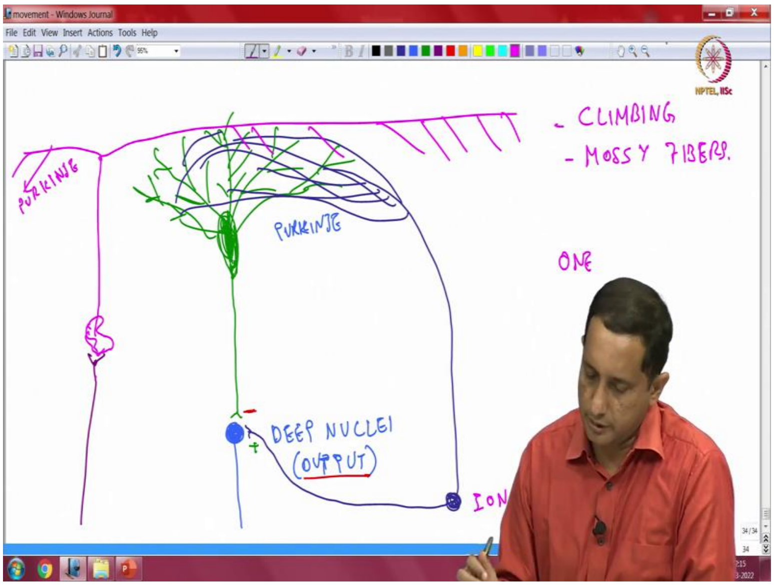

Now climbing fibers are interesting because they come from the inferior olivary nucleus. One single fiber would go and branch multiple times synapsing on a single Purkinje cell. So, it also sends another this one to the deep nuclei and that is positive. So, you have got a negative there and the positive there. Now mossy fibers on the other hand I need colours.

Mossy fibers go into the granular layer and then they synapse into something called as a granular cell. The granular cell has an interesting method, so it sends fiber up goes all the way over here and synapses with multiple Purkinje cells.

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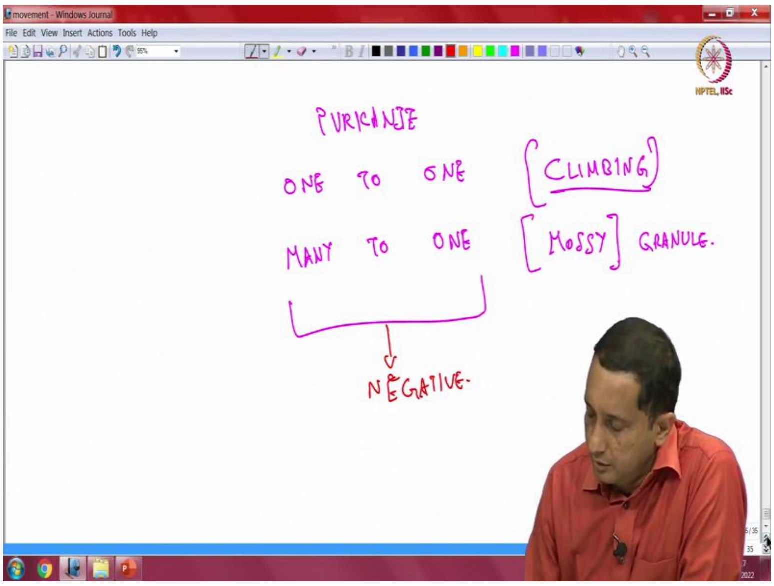

So, one signal is distributed. If we look at it from the Purkinje perspective, one to one for climbing fiber, many to one for a mossy fiber. One to one is climbing fiber. So, climbing fiber one fiber goes to one Purkinje cell whereas, mossy fiber goes to a granule cell and one granule cell would synapse on multiple Purkinje cells conversely, one Purkinje cell gets information from multiple granule cells.

So, the net output is negative. So, this kind of mechanism in which you know you get information from two sources, one goes specifically to a cell, makes it you know reduces the input. The other one spreads you know there is a local spread in that region because wherever this fiber goes on it gives a little bit of stimulation to the Purkinje cell. So, there are two sources which converge onto the Purkinje cell, it averages the signal. So, averages spatial averaging for the mossy fiber.

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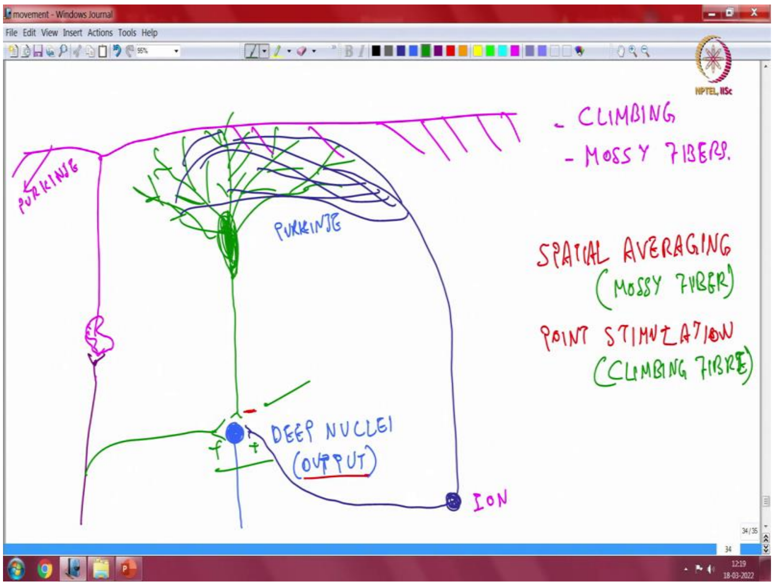

And I do not know how to terminate. So, you have point stimulation from the climbing fiber. Essentially it compares two sets of information and generates an output, the output of the cerebellum in turn goes into the deep nuclei wherein it gets information from other sources also. So, two positives and one negative and the sum of all of these things is the output.

Describing this network is a very idiotic process, ideally somebody should model the whole thing, but there are models of computational neuro biology of Purkinje cell. So, quite some time, but the apparently the modelling is very complex they there I would invite people in the audience to model it in a simpler fashion taking some assumptions. I am pretty sure that there is a Nobel movement in the cerebellar network which is just there for the taking.

So, the diagram I come back to the diagram. So, this is the climbing fiber which I was telling, coming from all the way from the inferior olivary nucleus. Remember there are two sets of output from the inferior olivary nucleus within the cerebellum yeah sorry its input. So, this is an input.

So, climbing fiber goes to one Purkinje cell. So, this is one nucleus, one Purkinje cell and then it modulates that activity, reduces the output of the cerebellar, deep cerebellar neurons whereas this is positive. So, one single neuron generates a positive and a negative response on the output nucleus.

Now, if you look at the other fibers this is another set of information comes to the granule cell then goes to multiple parallel fiber. So, multiple parallel fibers go across to multiple Purkinje cells and then that produces a change in the negative stimulation where again this is positive, and this is negative.

So, there are two sets of data which go into the cerebellum, one from the mossy fiber and the other from the climbing fiber. The information is sort of compared and then you have an output which is negative compounded with inputs from the input nuclei into the output nuclei and I think it makes it more confusing.

But what is important to note here is these two loops which are there. So, these two loops are responsible for a lot of the interesting mechanism which the cerebellum does. Now what happens if the cerebellum is not functioning.

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So, reaching particular object. So, this object is in free space you can execute the task, but there is a tendency of overshooting. So, if I were to say a standard testing cerebellar function is do this finger object test. So, instead of this there would be the examiners finger and the person has to do this fast.

I am able to do this fast, but in a patient with cerebellar dysfunction it would do this, go back touch somewhere else, go near but overshoot, either you overshoot or undershoot to target. So, conversely the cerebellum ensures that reaching a target is you know it accurately does it for all of us. So, this particular network which I have shown here is responsible for the job.

Now, apparently you can develop a learning model also, learning model it’s not developed it is there within you. So, how learning happens in this cerebellum is somewhat like this. So, you have an air puff and a tone. So, this is condition reflex, you must have heard of Pavlov’s reflex.

So, inferior olivary goes into the Purkinje and that reduces output over here, mossy fiber, which is from the ear goes over here, stimulates here. Again, negative here and then changes the output over here. So, after a certain level of stimulation through these pathways the gain of this system changes and that is learning in the cerebellum.

So, you repeat a task, these parameters change in the output nuclei due to these various networks and you achieve a steady state. So, that steady state is reflective of the maps which I was telling you. So, this is the task map. So, a task map being represented in terms of synapse values. So, the more the synapse gets stimulated the more neurotransmitters are released and then it achieves a new equilibrium.

So, a particular signal generates a particular amount of neurotransmitters and synaptically as the signal increases the synapse output increases, until you reach a new steady state. So, the specific state function of the set of synapses would constitute a mechanism of learning and the association is here. So, you associate one stimulus to another stimulus and then that causes a steady state change in this output nuclei which is the learned response.

So, that is how one of the mechanisms of learning and how cerebellum contributes to learning. I have also discussed how tasks are smoothened, so the smoothening happens in two mechanisms, all of that in this Purkinje. One through this single input, high dense signal and the other one is through the sparse signal. So, this is a dense signal, this particular thing is a dense signal, and this is the sparse signal.

Sparse because multiple granule cells impinge, give a small signal to the Purkinje cell. So, the Purkinje cell averages both of this. So, the dense signal and the sparse signal and then outputs it into the deep nucleus which in turn gives the final output of the cerebellar computation.

So, please do feel free to read about this topic, I do not know if I made justice of it because what is written in medical textbooks is just about like this, unlike many other topics which I have dealt with I did not know how to simplify this any further than saying point A, point B and stuff like that.

But as I have highlighted in the section on mission and some other sections it is a very important network actually, I feel it is very easily codable also. But somebody should actually look into it the outputs which you would get from coding a network like this would be really very interesting.

And I think I take leave at this place completing the topic on movement, the pathways involved, the mechanisms which we understand as of now. And a brief description of the cerebellar function which I have highlighted over here, see cerebella function is the key point in the whole thing all of it is how of it is. Not the how of it, how the path exists?

And which part of the brain or the nervous system is involved in coding for individual components. What is shown in the cerebellar network is a very interesting mechanism, I have not found an engineering equivalent in which data of this kind you know sparse and dense, and you know you have got an average and then you blend altogether in the deep nuclei.

So, I no idea of anything which resembles the cerebellar pathway, but its importance is highlighted by the fact that it’s a very monotonous system. So, you have got the entire cerebellar cortex looking exactly like this, it repeats, but it does anything from learning music to driving cars to speaking properly.

Thank you.