Foundations of Cognitive Robotics

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Lecture – 07

Good morning students, welcome to the class of Foundations of Cognitive Robotics. We are looking for the neural networks inside the brain in the 2nd week lecture. And now we will look into the basic system that actually builds this network. That means, we will look into the configurations the characteristics of the building block of the brain and the central nervous system which is the neuron concept. So, today our focus will be on neuron.

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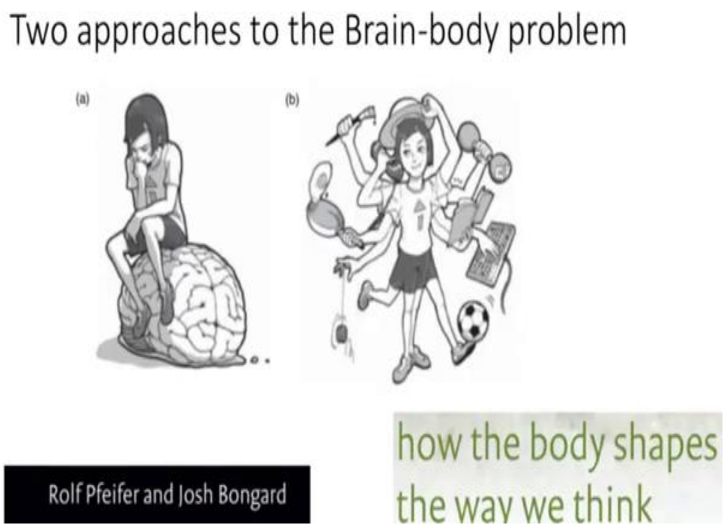

When we have discussed earlier we also told you that there are two approaches to the brain body problem. In one approach we say that the brain is the fundamental of all the processing's and the cognitive behavior; hence, the focus has to be on the brain. On the other hand, we have also talked about another group of thought where it is the periphery it is the dynamic systems that constitutes the body and that actually influence us influences the brain that was the thought process.

Now, one thing that is common between both of them is that in both the cases the answer is in terms of the neurons and their formations of networks. So, before concentrating on any one type of these systems we have to understand about these fundamental building block or the neurons of living system.

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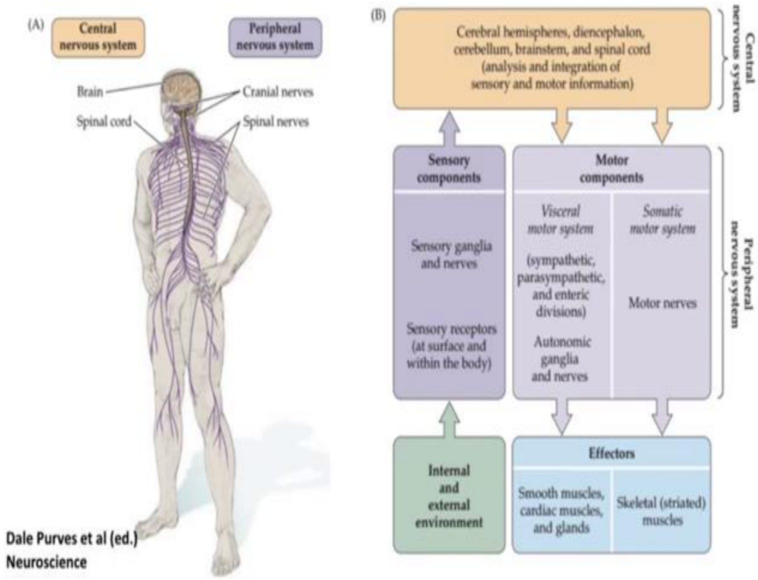

Now, when we talk about neurons; if you remember that we have talked about central nervous system and peripheral nervous system. We have talked about that how the brain and the you know spinal cord itself so how these are the regions that are the part of the central nervous system the brain and the spinal cord. And how the other parts are like the part of the peripheral nervous system for example, the spinal nerves the cranial nerves etcetera.

Now, in one thing that is common in both the central nervous system and peripheral nervous system is the neurons. Of course, the neurons are having different characteristics in these different systems. So, that is what we are going to have a look into it.

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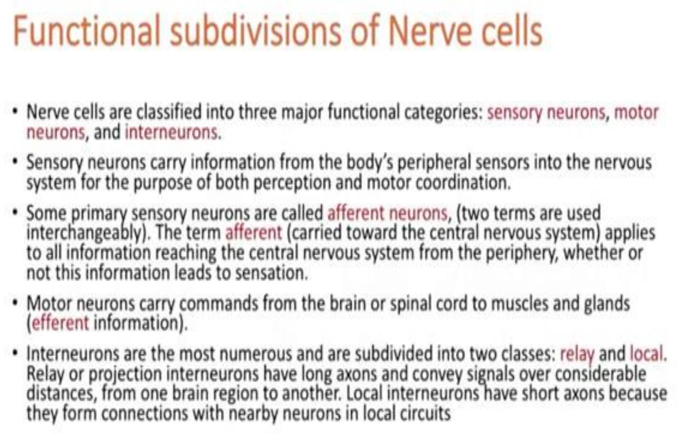

So, when we try to subdivide neurons in terms of the nerve cells. There are actually three major functional categories under them; the sensory neurons, the motor neurons and the inter-neuron's. Now, sensory neurons actually carry information from the body's peripheral sensors into the nervous system for the purpose of perception motor coordination's etcetera.

So, if you just go back to the slide you would see that these are the things from which the sensory neurons are bringing these sensory feedbacks and they are putting those things into the nervous system into the central nervous system so that is the sensory neurons.

Sometimes we also call them as the afferent neurons. Afferent means something which is carrying towards the central nervous system then it applies to all information that is reaching the central nervous system from the periphery whether or not this information leads to sensation.

Now, the other one that is from the brain to the muscles these are actually you know functionally these are something which the motor neurons take care of and these are the efferent neurons. So, afferent neurons and efferent neurons afferent means going inward and efferent is coming back outward. So, they carry the comments from either the brain or the spinal cord. So, if you look back again that either the brain or the spinal cord sends back the comments in some of these nerves and these are the efferent nerves which are the motor neurons.

Now, there are some which are neither at the receptors or nor connected to the muscles they are in between. And they actually make connections sometimes between the sensor to the motor neuron sensor neuron to motor neuron or may be sensor neuron to another sensor neuron or motor to motor so these are called interneurons. And they are in fact, the most numerous and they are subdivided into two classes the relay type and the local type.

The relay or the projection interneurons they have long axons and convey signals over considerable distance from say one brain region to another. The local interneurons they have short axons because they form connections with nearby neurons in local circuits. So, these are the four sensory neurons, motor neurons and interneurons.

So, now that we know functionally that there are these sensory neurons, motor neurons and interneurons; we would like to see that what is common in all these neurons. And we would like to see that in all these neuronal structures; what are the issues that one has to look at?

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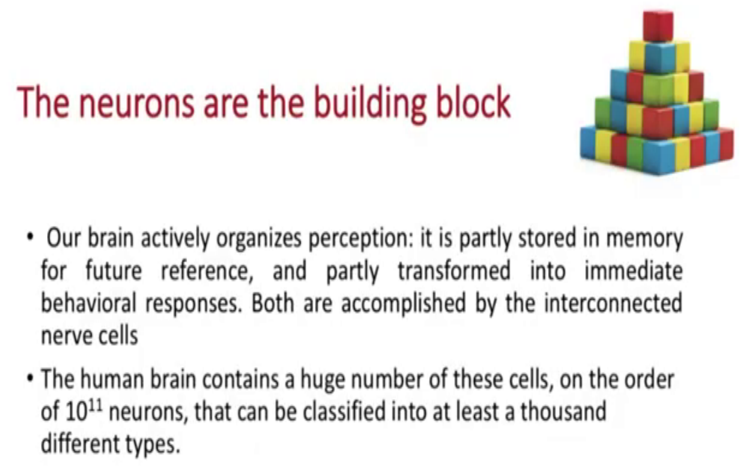

As neurons are the building block our brain actually organizes all the perceptions be it in terms of storing in the memory or be it in terms of immediate behavioral responses and these are accomplished by the neurons itself. And there are very large number of these neurons that are presented in our brain which is in the range of about 10 to the power 11 neurons. So, you know these are these are huge mind boggling numbers of this neurons and they are of different types at least a thousand different types of neurons you will find in the brain itself.

These neurons as I have just now told you that there are a huge number of neurons that are present in the human brain itself. And if you look at it in different types of species starting from the lower order species to the higher order; you would see that one of the thing that distinctly distinguishes between the species or as we are actually upgrading the species. And that is in terms of the total number of neurons that is one and the second point is in terms of the number of connections or the synaptic joints that these neurons make.

So, let us look into it how this number of neurons or the synaptic connections they actually change as we take our journey from the lower order systems to higher order system.

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Brain Neurons from Lower to Higher Order

Name	Neurons	Synapse
Roundworm	302	7500
Jelly fish	5,600	NA
Snail	11,000	NA
Fruit-fly	250,000	10,000,000
Frog	16,000,000	NA
House mouse	71,000,000	~1×10^{12}
Flinch	131,000,000	NA
Parakeet	1.096×10^{9}	NA

https://en.wikipedia.org/wiki/List_of_animals_by_number_of_neurons

If we look into the brain neurons from lower to higher order let us say we start with the roundworms; it has about 302 neurons and about 7500 synapses. If you think of jelly fish it is you know sub order of magnitudes higher about 5,600, for snails it will be about 11,000 neurons, for fruit fly it is huge 250,000.

For frogs now we will be talking about in terms of millions about 16,000,000 and for a house mouse it will be about 71,000,000, when you come to a bird for example, flinch this is about 131,000,000 so this will start to go towards the billions. And the same thing is true for the parakeets also that this will be also having in terms of about a billion or so.

So, you can see that how as we are going from the you know lower order to the higher order you can see that how these you know as the order is actually becoming higher and higher order the number of neuron is actually increasing number of neuron has a increasing trend.

And that is also true for the number of synapses because you can see that for roundworm there is only about 7500 synapse whereas, for fruit fly you know already it is so high and then for a simple thing like a mouse it is even higher. So, the synapses also actually increased as the number of neurons increase the synapses also increased.

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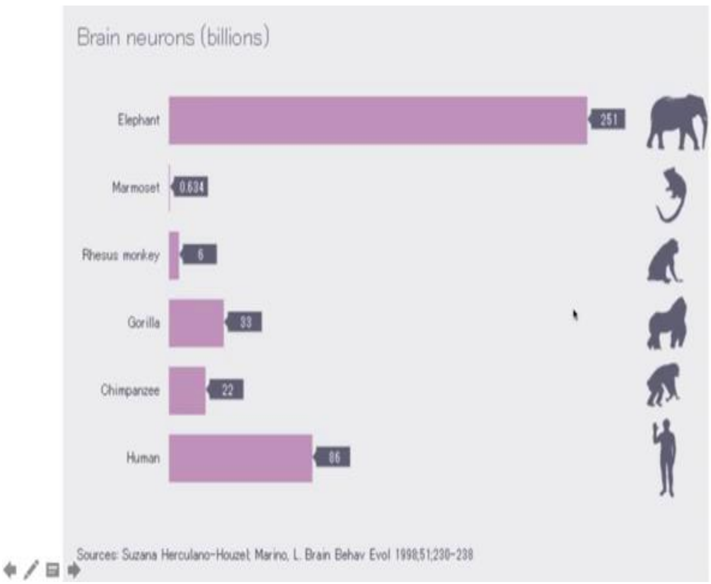

If you look at even higher animals let us say if you look at elephant for example, you would see that this will be having about 251 billion brain neurons. If you look at say for example, marmosets it has much less total number of neurons, monkey is about 6 billion, gorilla is about 33 billion, chimpanzees about 22 billion and for humans they are having 86 billion.

Now, one interesting thing to note is that; the total number of neurons for a human is much less in comparison to the elephant. This is you can see that this is 86 billion for human the total number of neurons whereas, for elephant it is 251. Of course, you have to consider that the size of an elephant is much bigger than the man.

So, it is not just the total number of neuron that would actually signify the level of intelligence for that you have to measure the number of neurons in the cerebral cortex itself.

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In the cerebral cortex elephant is having only 5.6 billion neuron. Gorilla is having about 9.1 billion neuron and human beings are having about 16.3 billion neuron. So, it is this high presence of the neurons, you can see it is very very high it is the highest. So, it is a high presence of these neurons in the cerebral cortex that actually signifies the intelligence in the system.

So far, we have discussed about the total number of neurons, their presence in terms of different types of living systems. And now we will focus into each single neuron in a system. When we look into these we will see that there are certain important aspects of a neuron that we need to look into.

Now, not all the issues we will be covering in this lecture, but I will first make you aware of the issues that are related to these neuronal single neurons you know what are the issues that are important point.

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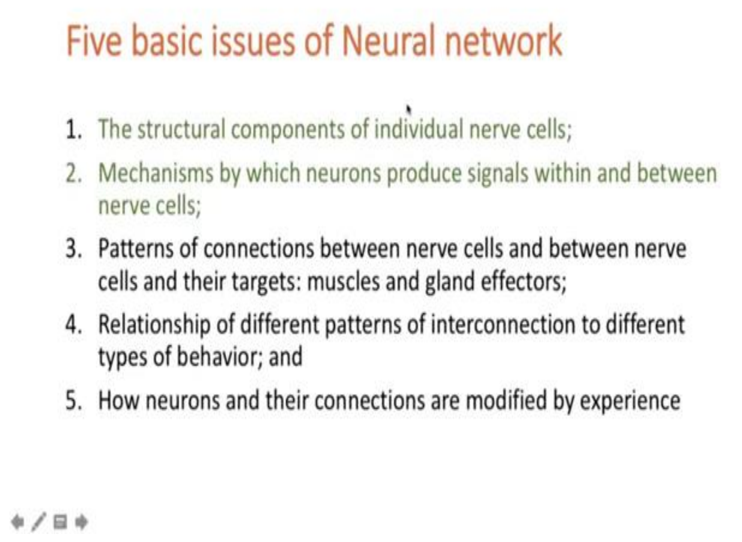

There are five basic issues of a neural network; the structural component of an individual cells, then the mechanisms by which the neurons produce signals within and between the nerve cells, the patterns of connections between nerve cells and between nerve cells and their targets, muscles and its gland effectors, relationship of different patterns of interconnection to different types of behavior, and finally, how neurons and their connections are modified by the experience, different experiences that will gather how it is.

Now this is a vast subject of it is own. So what we will be covering basically right now is the structural components of individual nerve cells and also in the subsequent lecture the mechanisms by which neurons produce signals within and between the nerve cells.

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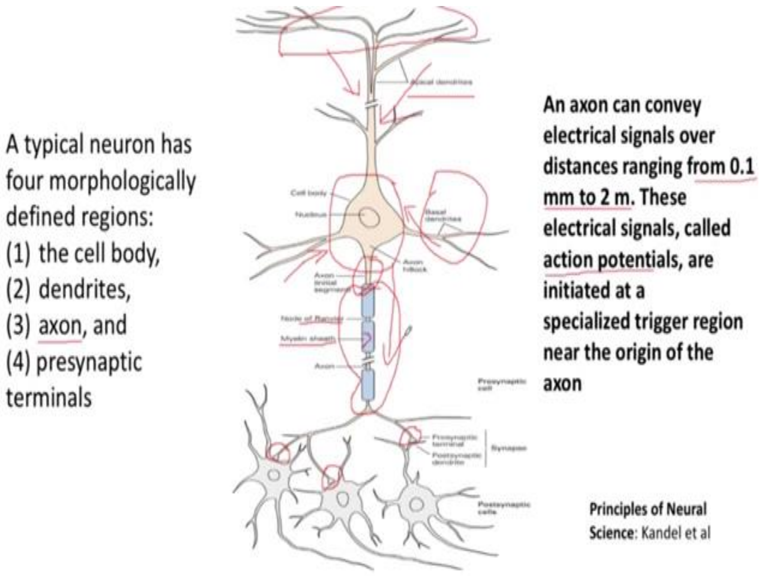

If you look at a typical neuron; you would see that it consists of four important parts. What are these four important parts? So, I will first of all there is a cell body and secondly, there are these regions which are the dendrites. There are two types of dendrite some dendrites actually go out from a process and then these are the apical dendrites. Some dendrites are directly from the cell body or the soma then they are called the basal dendrites.

Now, then we have the most important thing that is the axon so this is where is the axon region that is the axon region. And finally, the axons aimed at certain interesting points which are called synaptic terminals. And there can be many synaptic terminals as we have seen in earlier that in different you know number of neurons can have ten times thousand times million times you know connections in terms of the synaptic you know synapses of the neurons.

Now, basically in this whole system the center of attraction will become the axon because it can convey electric signals over distances ranging from 0.1 mm to 2 meter. These signals which are also known as action potentials are initiated at a specialized trigger region near the origin around these point these signals are triggered.

So, this is what of course, this is the configuration of a typical neuronal system. Now, there are actually many differences between different neuronal systems. There are some of the other points also which we will later on talk about as you can see that if this the blue regions there these are giving you actually the myelin covers.

And between these covers you have the node of ranvier and you can see the myelin sheath in the blue regions ok. So, between that you can see the nodes of ranvier, they actually together form a very important part in terms of the mechanism by which the action potentials actually travel ok.

So, the signals are gathered from different you know dendrites essentially. And they are integrated in the soma once they cross a particular value then only the triggering occurs and the signal starts to travel and then the signal reaches to each one of these synapses.

Again these synapses beyond a certain region they actually carry the signal to the next neuron and that is how this whole thing; and this next neuron these are the this is the presynaptic neuron the top part and the next parts after the synapse is the postsynaptic part. So, this is the typical neuronal system from one neuron to the other neuron.

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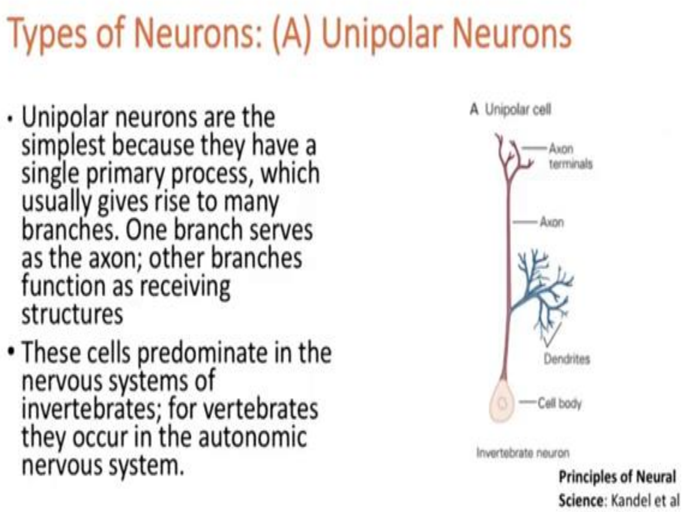

Now, if you look at the types of neurons; you will see that the common description that I have so far told you there are certain finer variations of it. For example, the first variation is in terms of the unipolar neurons. Now, unipolar means that it is having only one process in it; that means, only one connections from the cell body and part of it is related to axon and the other part is related to the dendrites. So, that is what is the unipolar neuronal cells.

Now this is one of the simplest cells and this is something that you will usually see in the invertebrates. For vertebrate's unipolar systems you will see mostly in the autonomic nervous system. If you remember that I have talked about sympathetic and parasympathetic nerves. And there are these sympathetic nerves which directly controls the breathing the heart rates etcetera. So, this is where the autonomic nervous system where you will this is one of the primitive part of the human body where you will see the unipolar neurons that are present in the system.

Sometimes you will see that not like you know from a single soma you are having only one process that is coming out in terms of excellent dendrons, but there are more than one processes that are coming out. So, if there are two of them that comes out then it will become bipolar system and if there are many then it will become multi polar system. Let us look into these different types of systems as well.

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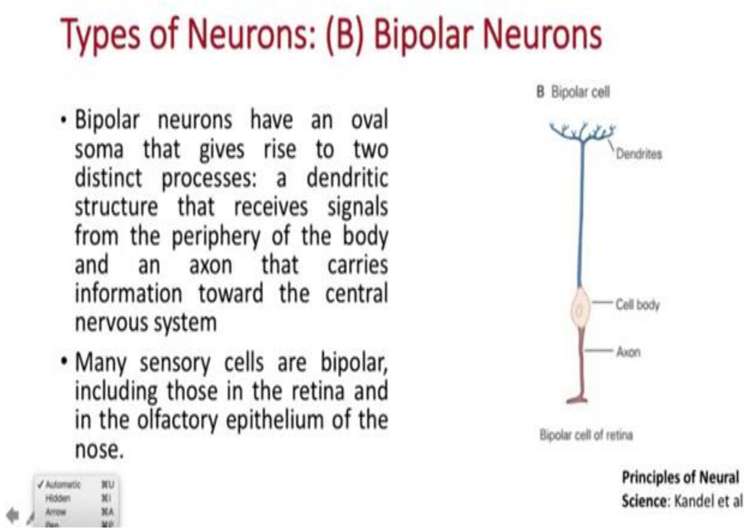

Now, we will look into what we call the bipolar neurons so these are the bipolar neurons. For the bipolar neurons it has an oval soma and as you can see that there are two different parts two different processes. So, the dendrites coming and in one part their joining in the cell body.

And the other part is from where the axon is triggering and taking the signal out. So, because of these two polar part this is the bipolar configuration many sensory cells are actually bipolar. For example, sensory cells from retina, from olfactory epithelium of the nose they are actually bipolar in nature.

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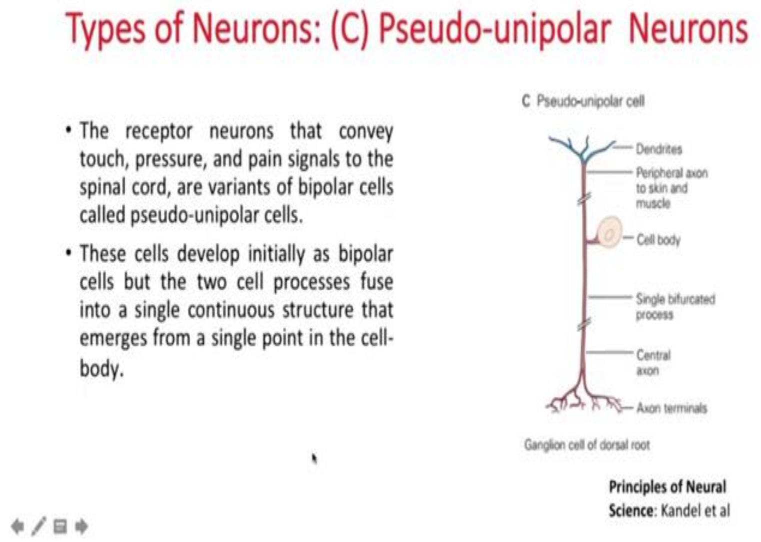

Now, if you look into more complicated neurons then; you would see that there are some neurons which are not exactly bipolar they initially start with a bipolar configuration, but this is what we call them to be pseudo unipolar system. So, for pseudo unipolar system there is these dendrites, there is this peripheral axon to you know and then the signal is coming here.

But instead of having a different pathway you can see that this is where is these outer axon central axons going to the axon terminals. And both of them are joined to the cell body through a single process that is why it is called a pseudo unipolar. That is other than these they are actually of two types.

Now, these cells develop initially as bipolar cells, but the two cell process actually fuse into a single continuous structure; that emerges from a single point in the cell body.

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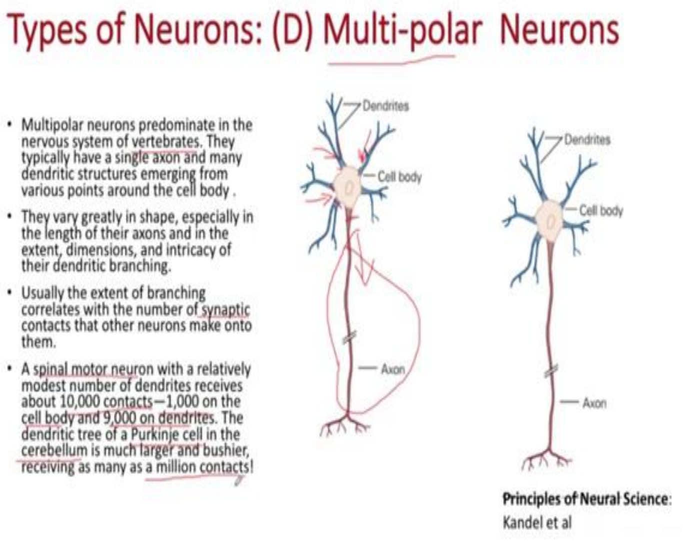

We also have systems like multipolar neurons. So, as the name suggests that it will be having many different processes you can see that here, here particularly you know whenever you will be having basal dendrites you will see many of such things so here as well as here. And this is where is the axon part and there are many inputs that are coming in to it so these are actually multipolar many inputs taken by it.

Now, this is a very common type of a neuron in the case of vertebrates. And they vary greatly in shape especially the length of the axon part that actually greatly varies depending on the size of the living beings etcetera and also in terms of the extent dimensions, intricacy of the dendritic branching. Usually the extent of branching correlates with the number of synaptic contacts that they will be having.

For example, if we are talking about a spinal motor neuron; then there is a relatively lower number of dendrites. Like something like 10,000 contacts and out of which about 1000 could be on the cell body and 9000 could be with the dendrites. But if you look at the dendritic tree of a Purkinje cell then which is in the cerebellum part then it is much larger and bushier and it can receive as many as million contacts.

So, depending on which region of the brain there you will see the number of synopsis for a multipolar neuron will actually change.

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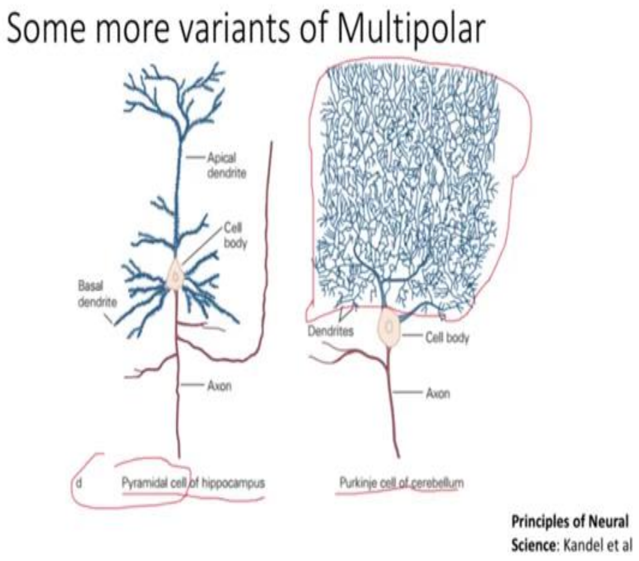

These are some of the variation so for example; this is for the hippocampus we have earlier talked about hippocampus. The neurons in the hippocampus are something like these pyramidal cells and you can see that they are having so many basal dendrites directly from the soma itself also they have a few apical dendrites and then it has the axon.

And this in fact, phenomenally increases even more for the Purkinje cell of cerebellum. As you can see that there is a huge number of synapses, you have to keep in your mind that cerebellum is something which is used for many kinds of learning, you know procedural memory related to it the motions, movements related to that you know something that we for example, learn in terms of particular behavior motion or any dynamic behavior.

So, you can easily imagine that how many neuron connections are required for such a system. Now this is what is that is the Purkinje cell of a typical cerebellum system. So, these are the variants of multipolar systems

It is very interesting to note that it is not just the neurons that actually develop a nervous system like the brain and other central nervous systems etcetera. There will be neurons which will be accompanied with something which is you know it is very extensively abundant in the system. When we talk about the brain system for example, it will be about 80 percent of it will be this type of cells and these are called glial cells. The role of these glial cells is that they actually complement and they try to supplement the neurons in terms of supplying.

Say for example, nutrition’s to the neurons, in terms of absorbing the additional potassium and also sometimes the neurotransmitters excess neurotransmitters. So, they ah they try to actually keep the neurons in a healthy level immune it from the diseases and also help them in terms of you know facilitate them in terms of the neural transmission.

So, that we will look into this has a very important role in terms of developing the neural network. So, we will look into the glial cells now.

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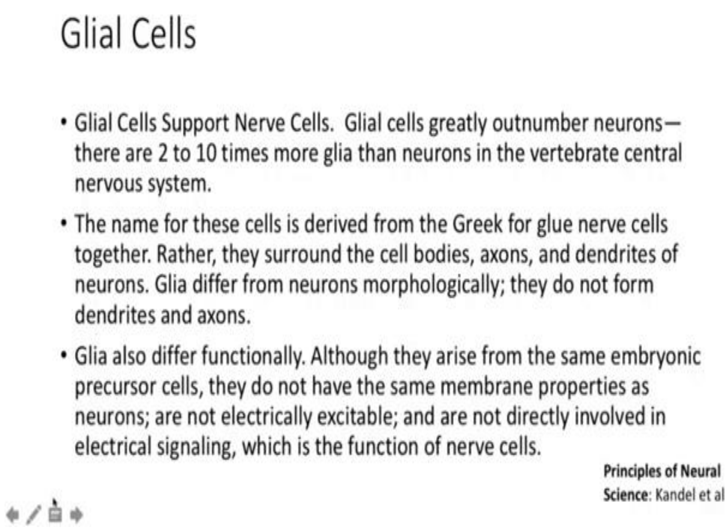

To look into the glial cells as I told you that their basic role is actually to support the nerve cells and they greatly outnumber the neurons. They are 2 to 10 times more glia than neurons in the vertebrate central nervous system. And this name glia actually in Greek it means glue they do not glue as such, but they actually glue themselves with each one of the individual nerve cell. And they surround the cell body the axon sometimes the dendrites and they also greatly differ from the neurons morphologically because they do not have things like dendrites or axons.

Now, glia also differs functionally because even though they arise from the same embryonic precursor cells they do not have the same membrane properties like neurons.

For example, they are not electrically excitable and they are not directly involved in electrical signaling, they are indirectly involved and there are many interesting variations of that axons that we will see.

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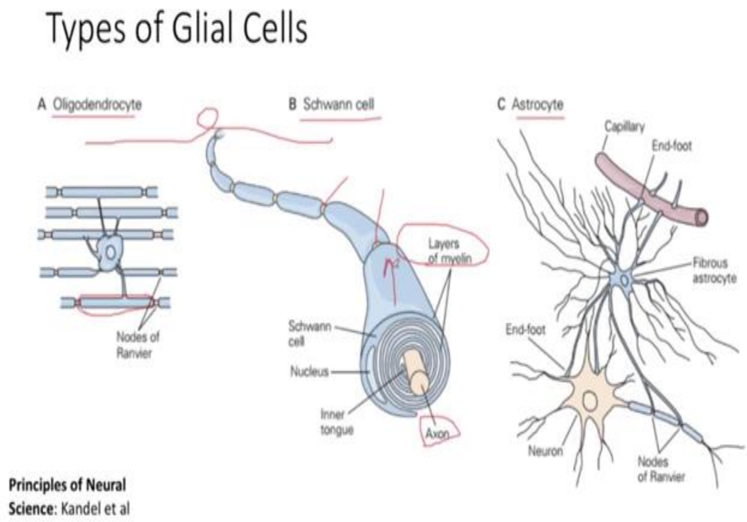

There are different variations of glial cells of course, for example, you have oligodendrocytes; that is one type. We have oligodendrocytes and then Schwann cell and then the astrocytes. Now, both oligo dendrites and the Schwann cell their role is in terms of actually giving these myelin covers. And they are something you know which are part of the micro glials.

In fact, there are some macro glials macro glials these are part of the macro glials all three of them. Where there are some micro glials also I have not shown them here they actually help the neural network system in terms of immunities etcetera.

Now, as you can see that the main role of both of these two types of macro glials is to give this layer of myelin cover. So, you can see that they actually cover the axon. So, that is very important because wherever the cover is not there you will have the nodes of ranvier.

Now, this cover actually is you know it helps in terms of the action potential the traveling of the action potential in terms of the speed it actually increases the speed you know ah. Because it actually gives a coverage insulating cover of the axon layer so it actually helps in terms of the action potential we will discuss about it in the mechanism part. So, it helps the traveling speed in terms of increasing the traveling speed of the action potential.

Now, there are also another group of glial cells called astrocytes they both actually keep these things with the capillaries and as well as with the nodes of ranviers as you can see from a typical neuron you know they keep contacts of both of them. And because they have this star shapes that is why they have these astrocytes that is the name of this. So, they also work in terms of giving supplying nutrition and also absorbing some of the things from the neuron itself.

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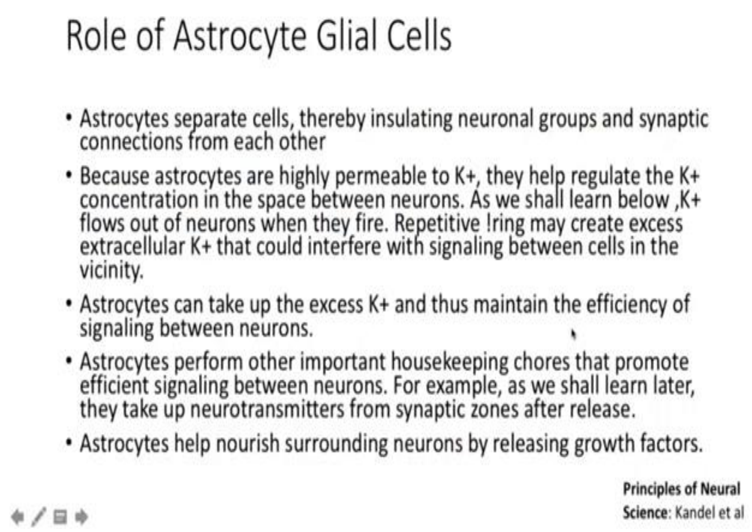

So, in terms of the role of this astrocytes glial cells, they of course, they help in terms of separating the neural cells that is one. And thereby they can insulate the neuronal groups and the synaptic connections, but also astrocytes are highly permeable to potassium ions.

So, they help to regulate the potassium concentration in the space between the neurons. As you know that during the action potential travel potassium flow is controlled very heavy, the potassium goes out of the axon, and astrocytes basically reserve this potassium flow and then supply the potassium.

So, repetitive firing of these firing of this system they actually may create excess extracellular potassium you know firing of the axons. And that is something which could otherwise interfere with the signaling between cells and that is where the glial cells come in terms of a rescuer because it absorbs this additional excess potassium that is one important role.

They also help in important housekeeping chores that promote efficient signaling between neurons. For example, they take up the neurotransmitters also from the synaptic zones after release and sometimes they also release the growth factors. So, thus glial cells they actually, they have a very much complementary role in terms of the neural transmission.

We have seen the basic morphology of a neuron. Now we will try to understand that how this neuron works in a complete system. Let us say the easiest of it is in terms of a reflex system. So, we will try to see that how in a reflex system the afferent neurons. Let us say you know there are pressure receptors in our hand so if I press it the afferent neurons are going to actually take the signals towards the motor.

And in some cases you are going to see that there is a reflex action that is happening to the system. So, we will try to explain the neural circuit in terms of what happens during the reflex action. Let us look into that.

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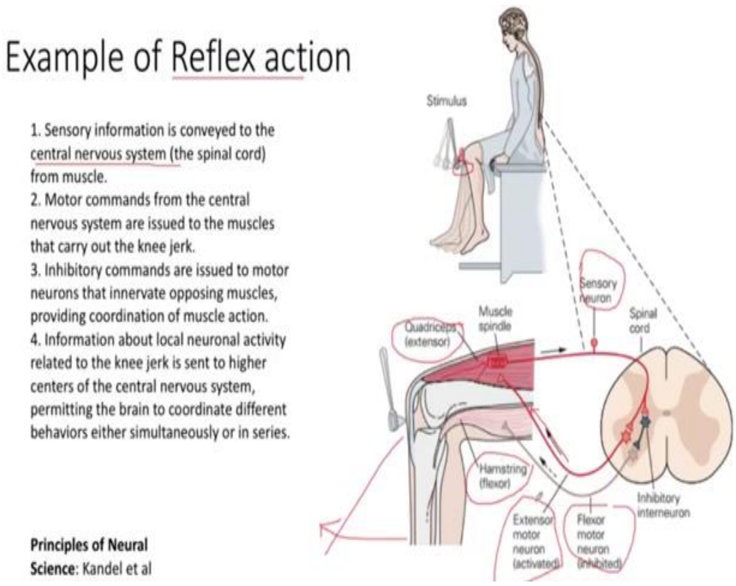

Let us take an example of a reflex cell. So, the sensory information you know if you just let us say if you take this region just below that knee if you heat it if you give a stimulus the sensory information is conveyed to the central nervous system ok.

So, that is something that will happen from the muscle spindle there is this muscle spindle. And there is this particular muscle which is these quadriceps or the extensor muscle that is the top part the extensor muscle. So, from here the signal will travel and it will come to the spinal cord.

Now, once the signal is coming to the spinal cord there are two things that are going to happen. One is that because of the reflex action there will be another, neural you know, neuron which will actually it is the motor neuron so this is the flexor motor neuron.

So, as the sensory neurons are actually bringing the signal the flexor motor neuron will actually, sorry, in this case the extensor motor neuron the flexor motor will come at just a little later stage. The extensor motor neuron will take this signal back to the muscle spindle so that it will be able to pull the system. I told you that it actually pulls and as the pulls the leg goes outward so the leg moves outward.

Now, as this is happening then you have to also make sure that the hamstring is ready about it otherwise the hamstring itself may actually oppose the motion then it would not. So, as you are pulling the hamstring has to be kept ready that it should not you know respond to that. So, that is where the you know the extensor motor they would actually once they get this sensory neuron signal they would actually come into action. And the flexor motors the flexor motors will actually keep this part reduced in order to assist this motion.

So, once again we have to keep in mind that first of all the heating will generate signals in the muscle spindle which will be captured by the sensory neuron and that signal will come to the spinal cord. Once the signal comes to the spinal cord then two things will happen one is that the signal will travel through motor neurons in this case the extensor motor neuron back here which will actually pull this system. So, that pulling is going to occur here as I have shown you earlier that it will be pulling.

And simultaneously a part of this sensing is going to a interneuron this is the inhibitory interneuron. And this inhibitory interneuron is going to alert the flexor motor neuron system which is which in turn will be working on the flexor itself to keep it ready in order not to oppose this motion. So, this is the example of the reflex action that happens in the knee and that is what we call a knee jerk reaction in a system.

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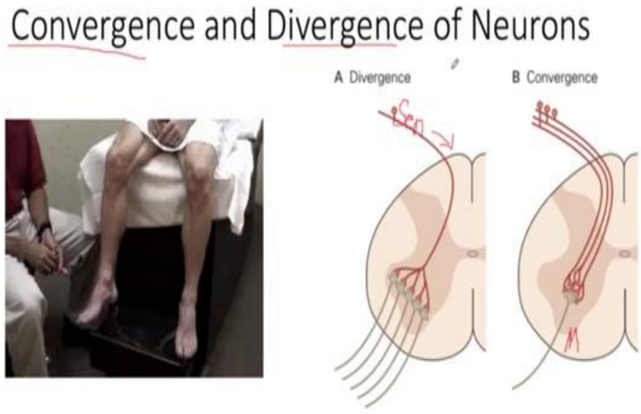

Now, let us look into a small video in which you would be able to see that how this knee jerking actually takes place.

Hyperreflexia can be demonstrated in the patellar reflex in this case the patient is suffering a stroke affecting the left side of the brain ah. The patellar tendon extends from below the patella which is right here it is a broad banded tissue it is easily palpable. If you are not sure where it is having the patient extend their leg which will cause the tendon to shorten and you can strike directly on the tendon.

And that is reflexes are very brisk I mean fact there are few extra beats of movement which referred to as clonus, again classic for an upper motor neuron syndrome. In cases like this reflux can be elicited by simply tapping on the tendon often. We see the same reflex requires very little stimulus.

Here again with the normal side patellar tendon again extending from below the patella strike on the tendon. So, that would be a normal reflex and certainly diminished prepared with the certain hyperreflexia.

Now, in this entire you know reflex system we have seen also two interesting thing. One is called a convergence and another is called a divergence of neurons. When the sensor sensory neurons are actually, so the sensory neurons so when they are actually bringing the signal. So, let us just you know call just denote them as sensory neurons.

When they are bringing the signals they actually put it into many neurons so this is actually diverging. On the other hand, when the signal is after divergence when it is coming through the motor neuron so; at that time there is a convergence of the signal that is happening. So, this is the motor neuronal system. So, you will see that in any reflex action there is both convergence and divergence of neurons that is taking place.

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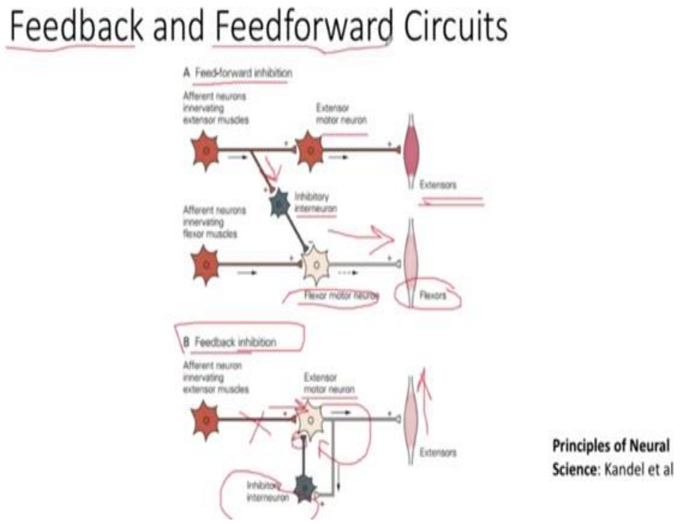

Now, if you look at it to even more in a minutely you will see that there are two different types of circuits that are present here feedback and a feed forward circuit. Now, what is the role of the feedback circuit? Well let us say for example, I told you that the extensor muscles the afferent neurons are actually bringing the signal to the soma of the extensor motor neuron that now you have to pull this extension muscle.

Now, what if it continuously starts to pull that it may actually harm itself. So, as it is pulling the feedback is going and there is an inhibitory neuron which actually nullifies it beyond a certain level it says enough this is to be crossed. So, this is what is the feedback inhibition part which; actually judges up to what extent the excitation will be tolerated.

On the other hand, there are quite a few feed forward inhibitions also. For example, you consider the same afferent neuron which is actually innervating the extensor muscles the signal is coming. I told you that one part of the signal goes to the extensor motor neuron the other part goes to the inhibitory interneuron. So, this is where it is going and this actually gives an inhibitory signal. And that inhibitory signal now works on the flexor motor.

So, the flexor motor this negative sign actually goes and it actually informs the flexor that you have your role is secondary you have to help the extensor in terms of the reflex action. So, this is a feed forward that is directly going to the system. Whereas, this is the loop so this is a feedback system. So, you will see both this type of feedback and feed forward circuits that are present in a simple neuronal circuit like reflex itself.

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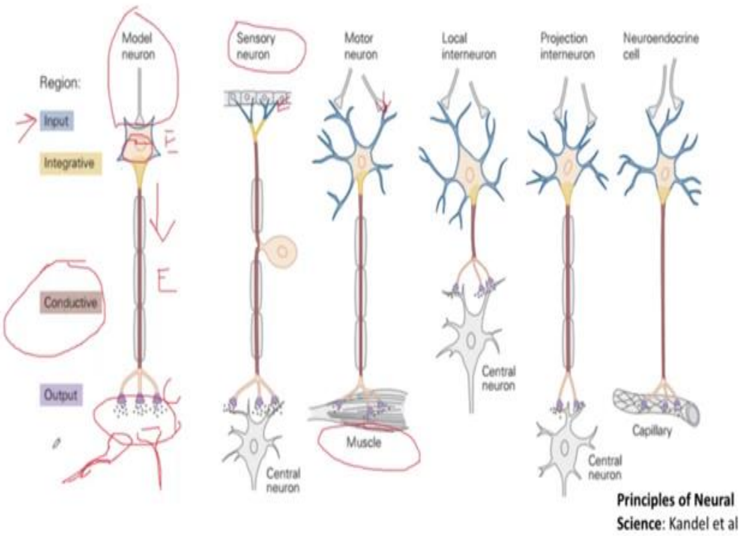

Now, there are actually many different types of neuronal systems. As you can see that you have these model neurons that we have worked on, but there are the sensory neurons which essentially have this it is like the bipolar neurons I talked about.

Then the motor neurons are there which directly works on the muscles. And then there are interneuron which works between the neurons and then there are other types of projection type of interneurons local interneurons. And also there are some neuroendocrine cells also which actually works between the capillaries and the next level of neurons.

So, for all of them one basic problem that you can simulate through this model neuron is that; every one of them will be having some input, that input is coming like say some sensory input it can come like that or it can come from the synaptic joint like that. So, that is the input part then there is a integrative action that is happening inside the soma. And then based on that there is a trigger and there is a conductive part that is what that conduction is taking part in this axonal part.

And then finally there is an output, that output is in terms of certain chemicals that will be transmitted and the new receptor is going to take it. So, a new receptor is going to take this signal ok. So, there are there can be many such receptors there.

So, you can see that the signal is essentially electrical here, the signal is electrical in this region also, but whenever it is coming here then it becomes actually a chemical signal. And that is are these are the four the stages in which it happens; input, integration, conduction and output.

Well, in this lecture I have given you an exposure to a neuron and how a neuron behaves. Now, we will go much deeper in the next lecture in terms of how the neuron transmits the signal. That is what we will be covering in the next lecture.

Thank you.