Neural Science for Engineers
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Module - 02
Lecture - 07
Threshold and Action Potential Propogation

Hi. So, in our previous discussions we had understood something about what is meant by a propagated action potential. I also dwell something on EPSPs and IPSPs. And the general idea, which I wanted to convey is how ionic currents produce changes within excitable cells, which are neurons, muscles, etcetera. And these ionic changes get propagated from one place to another and that is the core idea of information transmission across.

Some of the important things, which I had highlighted earlier was the importance of the constant amplitude of the action potential, the limitations for a frequency generated by a single neuron, which is fixed and can be changed in some context. So, that was the basis and also conveyed about how IPSPs and EPSPs are useful in computation because of ionic current gradients which extend across different membrane pathways.

Now, it is natural that one would think that why are there two systems of discussion, that is you have something happening on the action potential side and something happening on the EPSP, IPSP side. Now, I have so far not dealt with anything about the structural part of the story. So, far we have been looking at the dynamics, we have been looking at the chemistry, we have been looking at the way things happen. But we have not discussed about where these things happen.

So, I will continue with the prior discussion because some more important concepts are there. As I had suggested in my intro, I was saying that there is an idea to connect between existing fields. Say for example, when you look at a ANNs and CNNs and things like that, how comparable are these two things? You always have a disclaimer in your first class of ANNs that, ANNs though are modelled on neurons are not like neuron. So, what is the not neuron part of the story is what is being told.

So, I will start again with an important concept.

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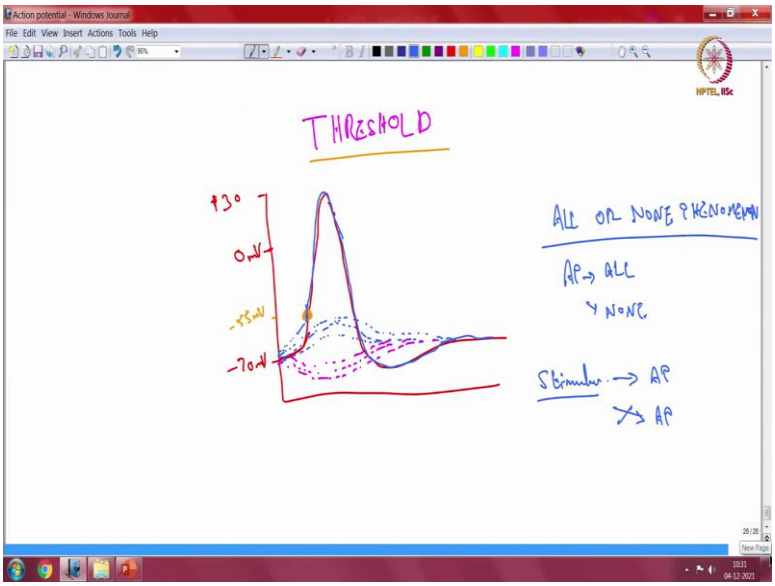

So, that is called threshold, for all those people in the AI space and ML space understand this concept. And we will try to see how it is implemented in the biological systems. So, again we go back to the graphs, because now we are familiar with the graphs, and we can start. So, it starts at -70 millivolts, I had in my previous only shown my 0 and the +30 ok.

So, we know that you know there is a negative, when there is a voltage which is applied and you would have something called an action potential and that is how it looks like. I also said that you can have EPSPs, so EPSPs are this one. So, you can have EPSPs, which you know they change the membrane potential and then they are graded you know. So, graded in the sense that corresponding to the amount of stimulus, you have voltages which change.

So, small stimulus causes a small change in voltage and a larger stimulus causes a larger change in voltage. IPSPs on the other hand are easier to understand because they just change the membrane potential to the negative. They are also again graded because the mechanisms are pretty different.

So, a key issue which has to be dealt with here is the concept of threshold, which I have already told. So, somewhere at around -55 millivolts is the something called as the threshold. So, when the EPSP reaches -55 millivolts the path taken by the action potential is the regular action potential. So, if in case it reaches up to that, then you trigger the action potential.

So, 55 is sort of a cut off and that is the time when the actual cascade happens within the sodium channels on the surface of the membrane. So, below 55 millivolts these sodium channels operate in a fairly linear fashion and after 55 you know all the channels in the surrounding are open. And then that results in the cascading effect resulting in the action potential.

So, why it happens in some places we will learn a little more about it when we discuss the structure of the neuron and the functions of different parts of the neuron. So, a neuron is not unlike ANN neuron it is not just about weight and passage to the next neuron. So, there are several parts of the neuron, which do a lot of computation and there is a rich biological framework for its rules and regulations. Why these rules and regulations exist? I do not think anybody is even commented upon it, but these rules exist.

And since we are looking at millions of billions of years of evolution, they might have had some relevance in some point in the past and I think this should be a very efficient model for that particular reason. There are very interesting concepts in this, which I will highlight in subsequent classes. So, the concept of threshold now is there. So, when we speak about it in biological terms, we call it as the all or none phenomenon.

So, if you give a search for this you would find as an action potential its all or it is none. So, either stimulus can either generate an action potential if it is of a particular intensity or no action potential if it is below this one. So, that is the idea of titling the discussion as threshold. Now, I would like to draw a graph for that purpose.

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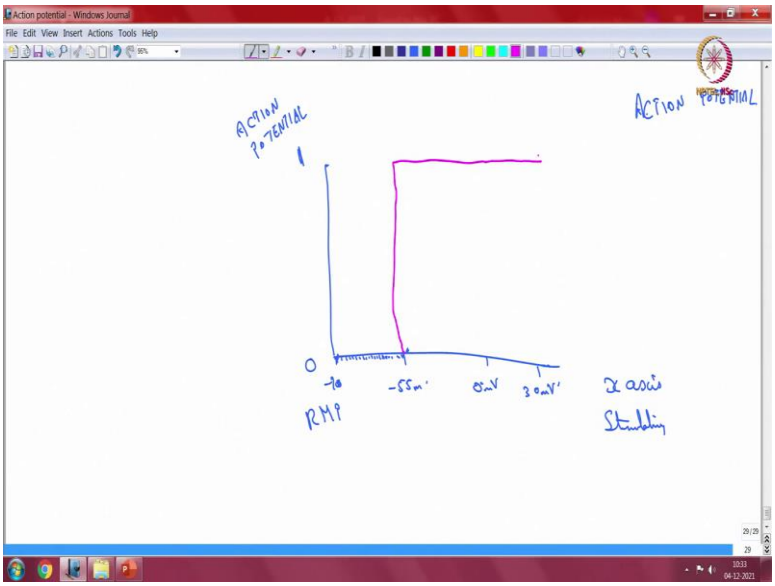

Now, we have come to the conclusion that action potential is an all or none. So, we either have an action potential or we do not have an action potential. Now, if we look at the part of the neuron, which generates an action potential, remember we are just discussing action potential. I am not discussing the EPSPs and IPSPs here because the computation logic there and the structure everything is different.

So, if we plot voltage on the x axis, so you start with -70 which is the 0, then you have -55 over here, you have 0 millivolts and 30 millivolts. So, remember that this graph does not actually show the time scale. So, I am just comparing action potential to generation of the action potential to various stimulating voltages.

So, from anyway between -70 which is the resting membrane potential you apply any amount of stimulus there is no action potential which is generated. So, basically it is a 0, now 0 this is in the part of the neuron which is generating action potentials. We are not looking at EPSPs or IPSPs as of now. So, when you have -55 you have a action potential.

So, you have an action potential and that is a single action potential. So, at any stimulating voltage, which is greater than minus, greater than this which is able to generate the membrane potential across greater than -55 from -70 to -55, you would get a single thing.

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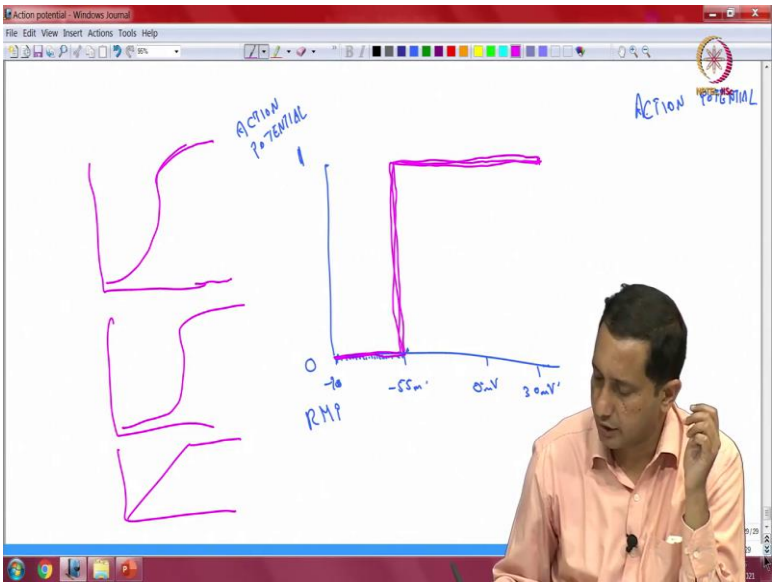

So, we are looking at this kind of a rectangular graph saw-tooth graph which is the actual activation function of an axon of a neuron and what is considered to be an output function of the neuron. Now, generally you have AI this one as Sigmoid, Tan and ReLU, I think ReLU is something like this.

So, in comparison to various activation functions which I used in ML this is the activation function of a neuron. Remember this is in the part of the neuron which is producing the action potential. So, this is just not the only computation. So, neurons are just happy with the, I think the closest function which approximates is the Tan function. So, I think computationally they have started with sigmoid.

So, sigmoid and then they start, went up to Tan and I understand that the most popular one right now is the ReLU activation function. Neuron suggests they are happy over a couple of million years with the saw tooth function, and they been doing really well with that enough to generate the other curves.

So, this is something which I think many people in the ML side would find it interesting that this is how the action potential thresholding function is implemented within the biological neuron.

So, we have defined thresholding, we have defined how ionic currents differ. Now, I think this is time enough to summarize a bit or to jock through the stuff, which we have

gone through so far. So, I have because I think I am switching gears, so summarize in order.

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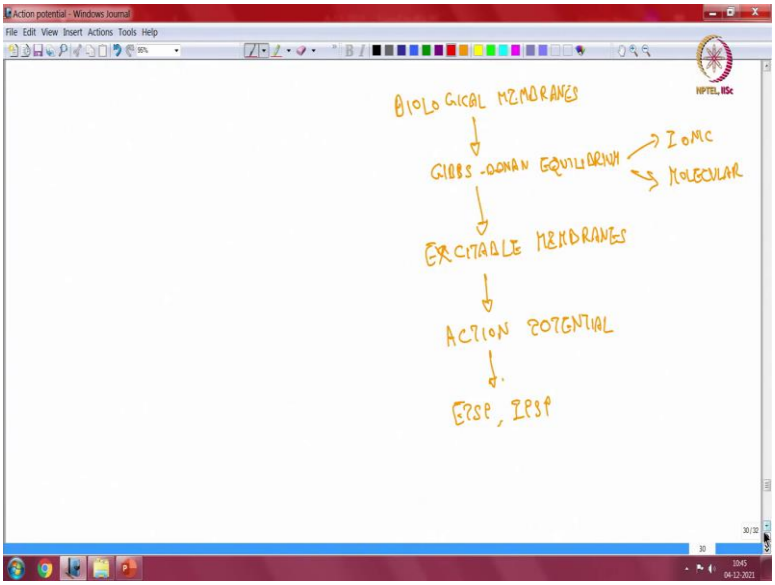

So, we first started with biological membranes. So, biological membranes and then we switched on to the Gibbs Donan equilibrium. So, this is the ionic and molecular equilibrium which is across the cell. Then we went to the idea of excitable cells, excitable membranes and then we went into the action potential.

So, how excitable membranes can generate the action potential? We also looked at other concepts of EPSP and IPSP with of course, some basic understanding of how they are present within the neuron, different part of the neuron. So, this is where we stand.

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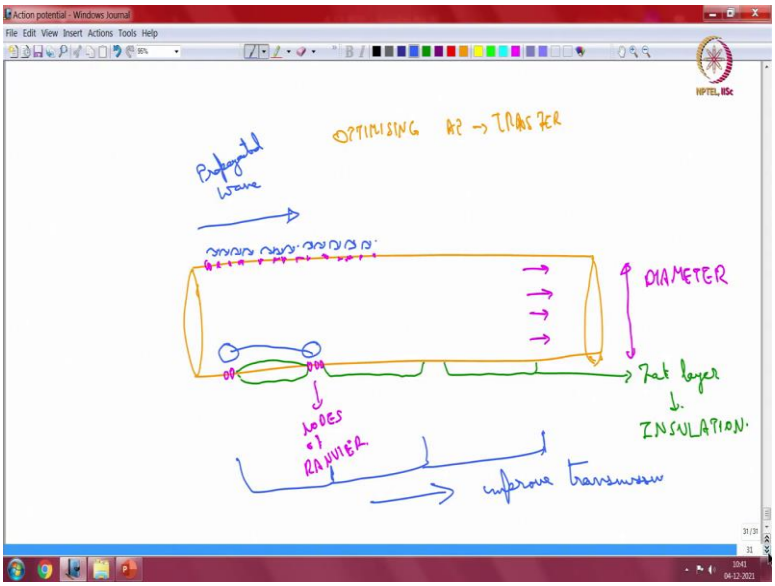

Now, another thing before I close down this discussion is the discussion of optimizing what you call action potential transfer. So, when we thought about membrane, which is cylindrical membrane and then we decided that there are small sodium channels, which are over there and there and there.

So, the idea of propagation is that each sodium channel produces a local change in current. So, the local change in current produces changes in the subsequent sodium channels. So, this is the method by which the action potential actually becomes a propagated wave, electronic propagated wave, ionic propagated wave to be very clear. So, there is an interesting mechanism by which nature takes care or optimizes the transfer.

So, one method is by increasing the diameter. So, the amount of ions passing through define surface of the membrane tube increases. And thereby you can actually increase the speed of transfer of the membrane potential. A more interesting concept and which is very prevalent in all advanced systems is the idea of insulating. So, what actually happens is the membrane actually is covered on the surface by something called as myelin.

So, myelin is again another fat layer which basically means that it is insulation and the channels which are distributed uniformly across the surface are just distributed in these nodes of Ranvier. So, these are called nodes of Ranvier. So, what actually happens is the

small changes which are happening, and which causes the action potential to move from point to point in the membrane, they sort of jump.

So, there is a local change over here and then the local change causes local change over here. So, literally the action potential jumps from one node of Ranvier to another node of Ranvier. And that is interesting way by which you improve transmission across the membrane. So, I think I should draw an electrical circuit here. So, how do you draw the electrical circuit?

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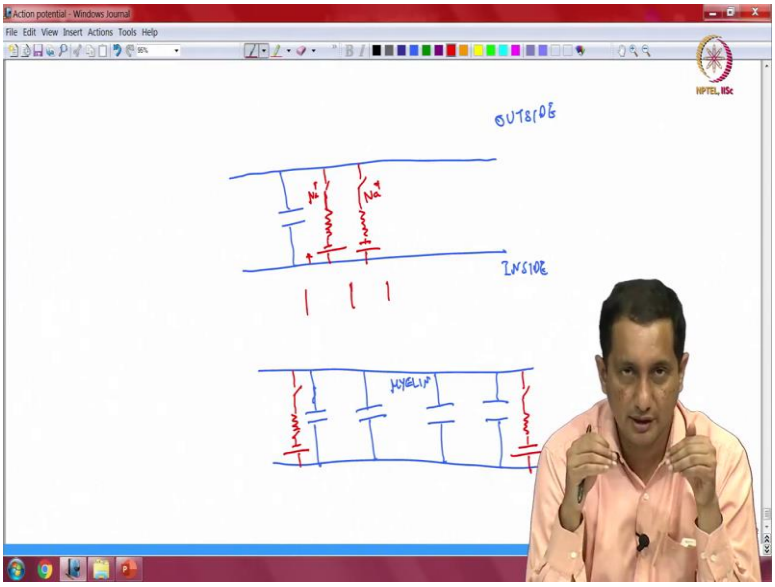

So, generally you would have the outside of the cell and the inside of the cell. And you have the cell membrane, which is basically the capacitance over here. And each of these channels the general idea which is described in text book is it is just a resistance with a battery.

But I think a more appropriate idea would be to put it in terms of a switch. Because there is a, there is a particular voltage which acts the switch and that is responsible for the transmission of the current. For the sodium channel I will put it like this because it generates positive current towards the inside of the cell.

So, if we look at the conventional membrane idea how propagation happens is there is this line of sodium channels, each of these circuits represent a sodium channel. And that is responsible for local changes in current which happen within these segments.

Now, if you look at myelinated fibres, we are looking at a similar picture, but with a twist, you have not only membrane capacitance to get rid of, but you also have this myelin, which improves the capacitance of the system. And so, this forms myelin, and the sodium channels are dispersed much in between.

So, this would form, so I think this is a more accurate description for people who are electronically minded, and it sort of represents the phenomenon which happens within this one. So, there is an exponential leap in the rate of transmission. So, velocity of propagation of these fibres in the myelinate fibres vis a vis no non myelinate fibres and that is a method by optimization of inclined transmission across large organisms.

So, to give you an idea why this is important say for example, when you are walking you know your feet are on the ground and then you see what is ahead. Now, both of them are acquired at different temporal rates. So, we need to integrate both to ensure that there is a smooth walk, which means basically the walk is the motor part of the storage, where the actual muscles are acting.

But the sensation of the ground and the signal from the eye both of which are located at different distances from the brain. So, they need to be synchronized. So, you need fast transmission to ensure that this synchronization happens and most of the important messages in the body are conveyed to myelinated fibres. Of course, pain is something which is very important, but it is through non myelinated fibre.

Anyway, so the secret of why say the logical question would arise that if you have something which is optimised why do you need non optimized systems within the biological system? I think that is something which people can research and find out. So, that is some add on which I had to convey about optimization within the nervous system for propagation of action potentials.

There is nothing like back propagation in the nervous system. So, the nervous system uses different philosophies, for that I think we will come to that in the next a couple of classes. So, we have so far, I think I discussed about all of these the issues, so biological membranes, the equilibrium, the excitable membranes, the action potential, EPSPs and IPSPs.

So, with this understanding about how membrane dynamics are responsible for transmit generation and transmission of electrical stimulus, we will go on to the next part of the story.