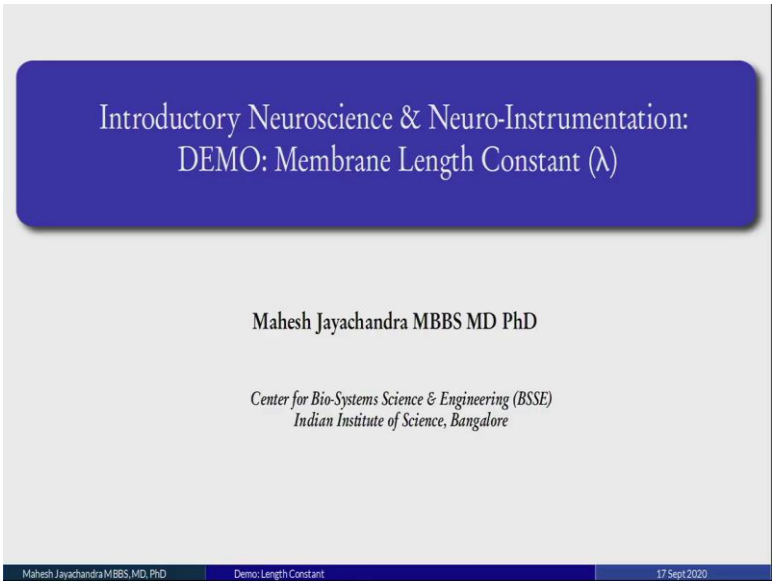
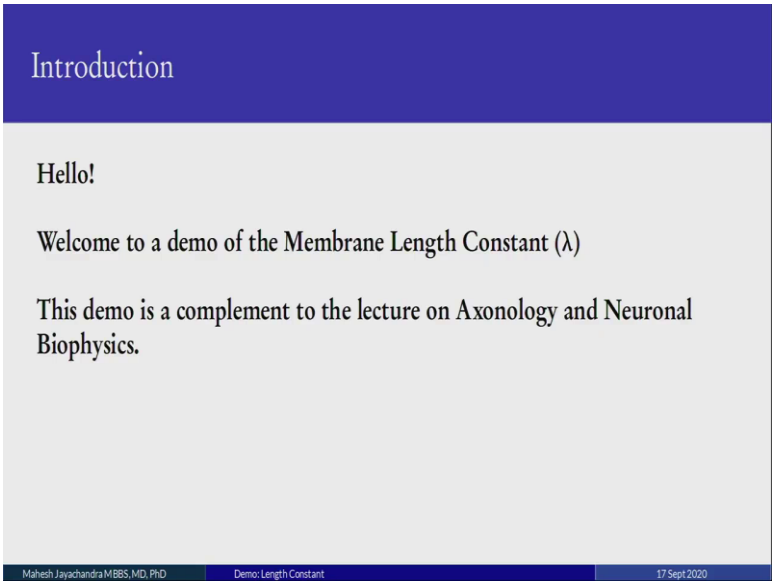
Introductory Neuroscience & Neuro-Instrumentation
Professor. Mahesh Jayachandra MBBS MD PhD
Center for Bio-Systems Science and Engineering
Indian Institute of Science, Bangalore
Lecture No. 54
Demonstration: Membrane Length Constant (λ)

(Refer Slide Time: 0:24)



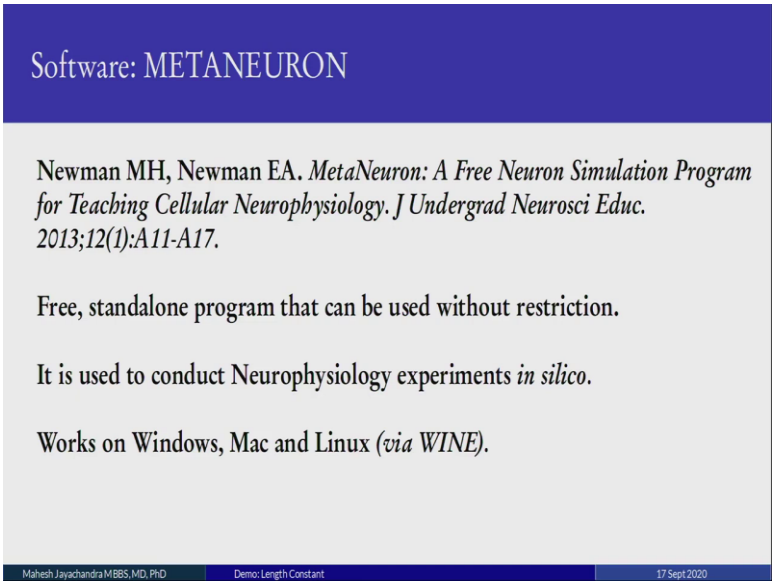
Introductory Neuroscience and Neuro-Instrumentation demo. This is a demo on the membrane length constant denoted as lambda.

(Refer Slide Time: 0:28)



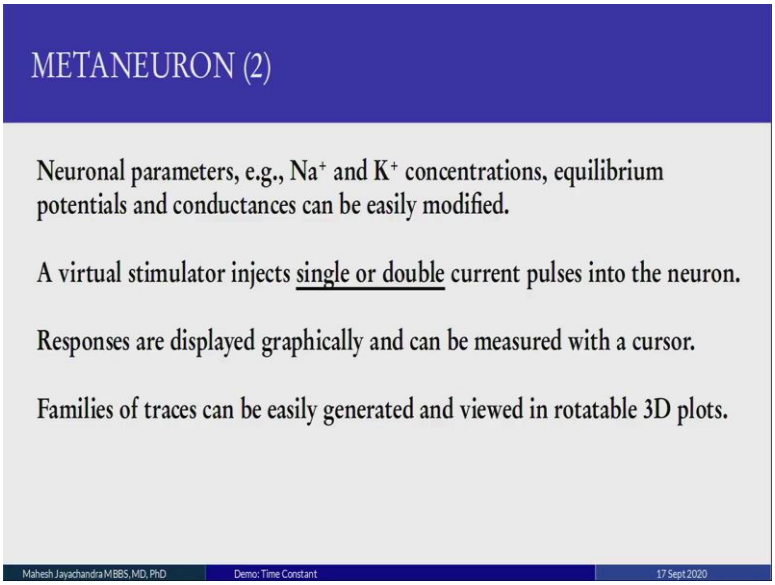
So, welcome to a demo of the membrane length constant lambda. This demo is a complement to the lecture on Axonology and Neuronal Biophysics.

(Refer Slide Time: 0:38)



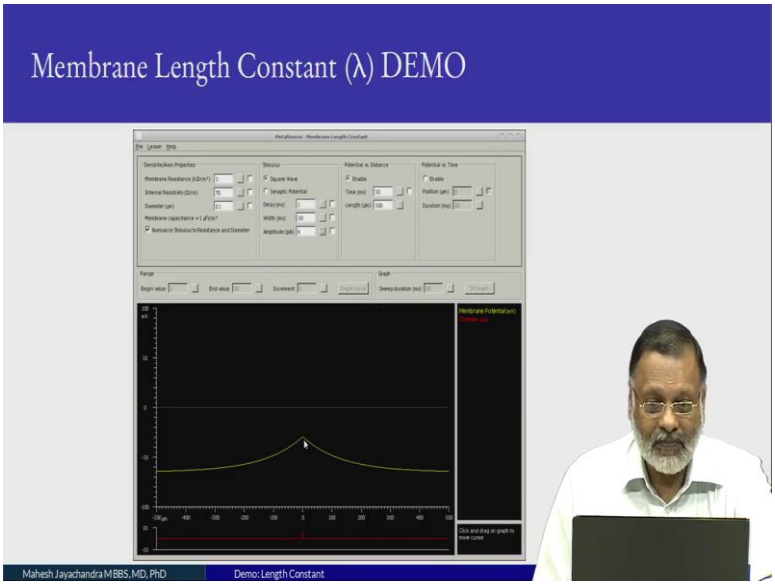
So again, we are using MetaNeuron made by professors Newman and Newman in the University of Minnesota. It is a free standalone program that can be used without restriction and it works on Windows, Mac and Linux, if you are using Linux, you have to use WINE to get it going. And it is used to conduct neurophysiology experiments in silico.

(Refer Slide Time: 1:02)



So, as mentioned earlier, neuronal parameters, sodium, potassium concentrations, equilibrium potentials and conductances can be easily modified. A virtual stimulator injects single or double current pulses into the neuron and responses are displayed graphically and can be measured with a cursor. And families of traces can be generated and viewed in rotatable 3D plots.

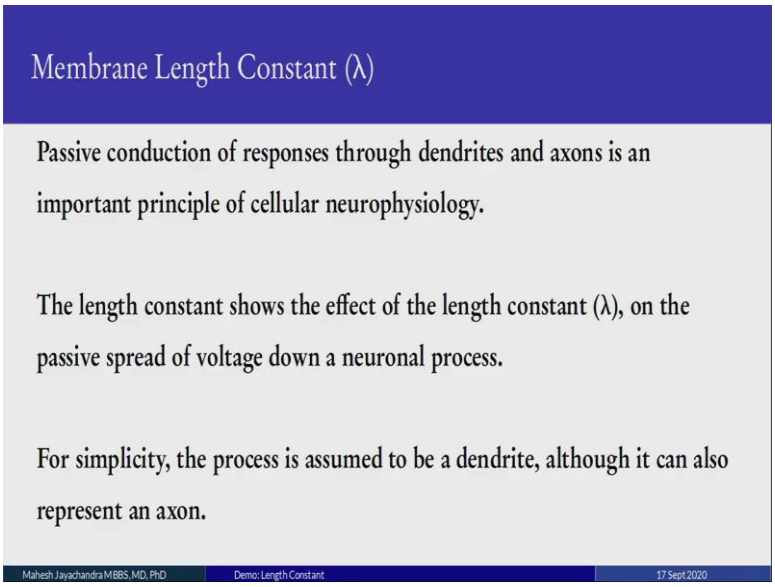
(Refer Slide Time: 1:26)



So, this is similar conceptually to tau. But here we are looking at distance rather than time. So, consider this image. This is a part of the demo. You inject the red trace indicates stimulus, you inject stimulus in the central of the dendrite or the axon, it does not matter and then you see how it decays. Again, it is an exponential decay on both sides of the injected stimulus.

And we can change different parameters and get an idea of how lambda is dependent on these parameters like properties of the dendrite and axon, the stimulus intensity and then you can look at potential versus time.

(Refer Slide Time: 2:17)



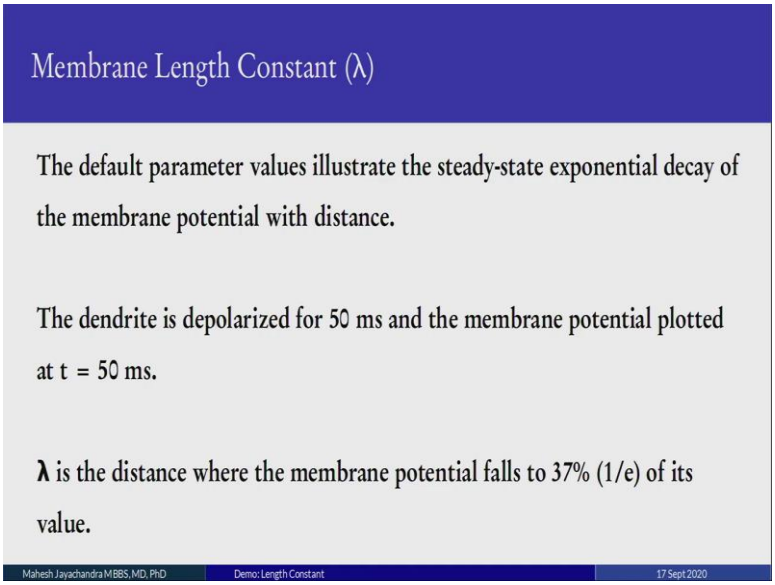
So, just to remind you the membrane length constant lambda, so passive conductance of responses through dendrites and axons is an important principle of cellular neurophysiology. So, these principles were first formally enunciated by a researcher such as Wolfed Roll and if you want to model a neuron realistically, when I say realistically, I mean put in exactly all the physics of the dendrites, the denditictory, the axon, the cell body, etcetera. Then you need these concepts of the length constant lambda as well as tau.

Many people do not bother and they just use, and this is an older way of doing it where you consider a neuron, a single unit and it is called a spike and integrate. Integrate and spike, so you have many different impulses coming through the neuron, it integrates everything in a very very primitive fashion and it generates spikes.

But when you use lambda and tau, you can get a realistic idea of how the neuron actually works and this obviously is computationally much more intense and needs a lot of power compared to just the simple integrate and spike units. But this is realistic.

So, coming back from the integration, the length constant lambda, it show shows the effect of the spread of voltage down a neuron process and again we are looking at the distance, not time, time is for tau. So, for simplicity this process is assumed to be a dendrite, but it can also represent an axon.

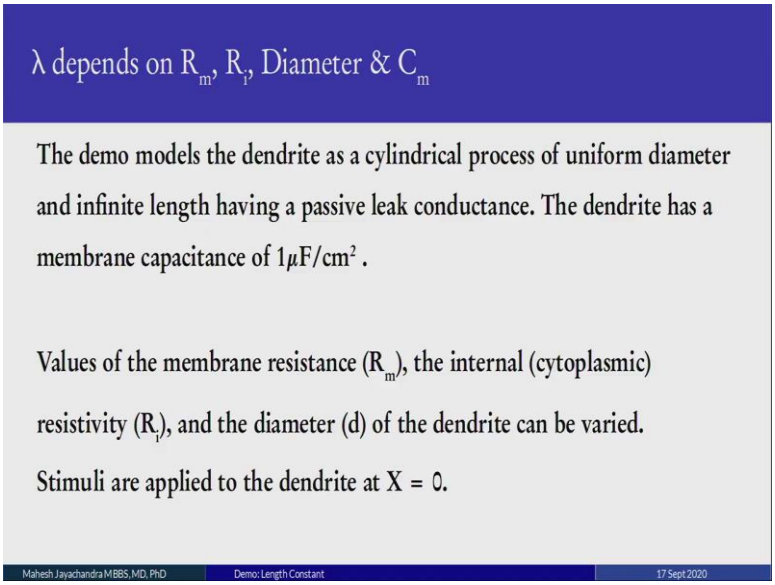
(Refer Slide Time: 4:06)



So, the default parameters illustrate the steady state exponential decay of the membrane potential with distance what you saw earlier. So, you see the, you see a stimulus being put in here and then the decay over a distance. And here, the dendrite is depolarised for 50

milliseconds and the membrane potential plotted at t equal 50 milliseconds. Lambda or the length constant is the distance where the membrane potential falls to 37 percent, 1 by e^{th} of its value.

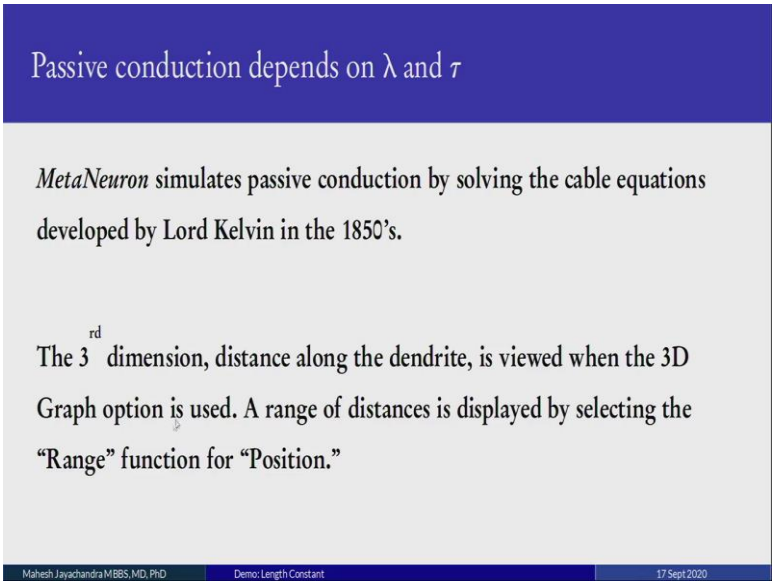
(Refer Slide Time: 4:42)



And this demo models the dendrite as a cylindrical process of uniform diameter and infinite length having a passive leak conductance. Membrane capacitance is kept at one microfarad per centimetre square. So, lambda depends on the membrane resistance. It also depends on the internal, that is the cytoplasmic resistivity. So, you have the axon, the membrane and you have the impulse going in here.

The membrane resistance is the resistance of the membrane. The internal resistance is the resistance along the dendrites longitudinal axis or the axon's longitudinal axis. And it also of course, depends on the diameter, diameter has an effect on lambda which we will see shortly and the stimulus is applied to the dendrite at X equals 0. Again this is distance.

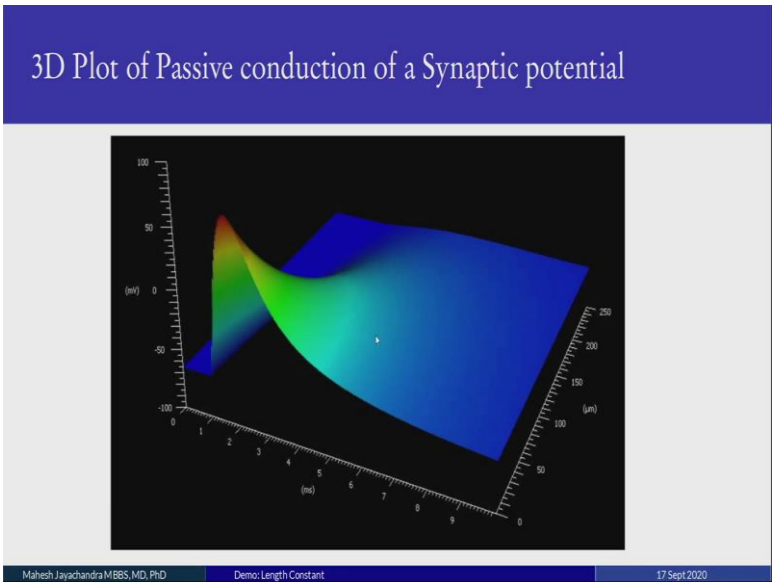
(Refer Slide Time: 5:35)



So, a MetaNeuron simulates passive conduction by solving the cable equations. This was developed by Lord Kelvin in the 1850's because they were laying the cable between Europe-England and the United States and that is very similar to an axon. You have a cable, the cable has an outer conductor, it has insulation and then you have a central conductor which is pretty much how the axon also functions.

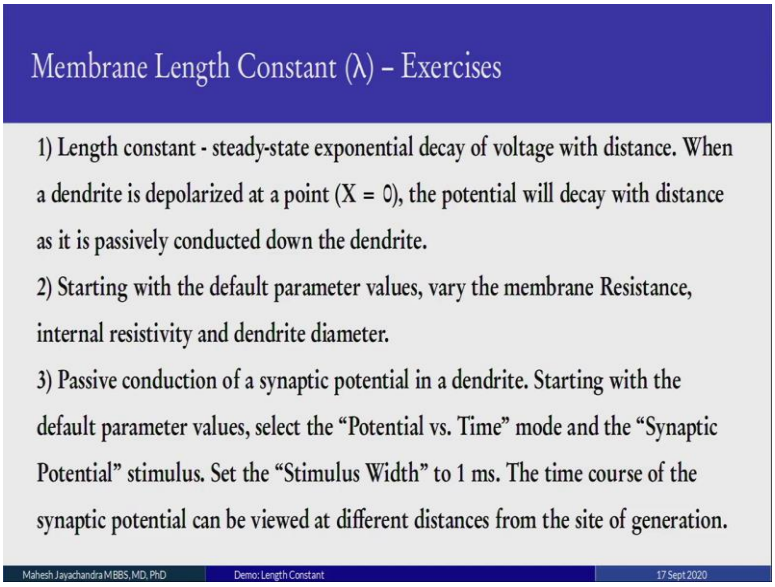
So, those equations were very useful and to model the cable properties of an axon or a dendrite. The third dimension, distance along the dendrite can be viewed using the 3D graph option and a range of distances is displayed by selecting the "Range" function for "Position".

(Refer Slide Time: 6:27)



So, this is how it looks. Here you have the time, here you have the millivolts on the y axis and here you have the distance, how it decays and this is a surface contour plot.

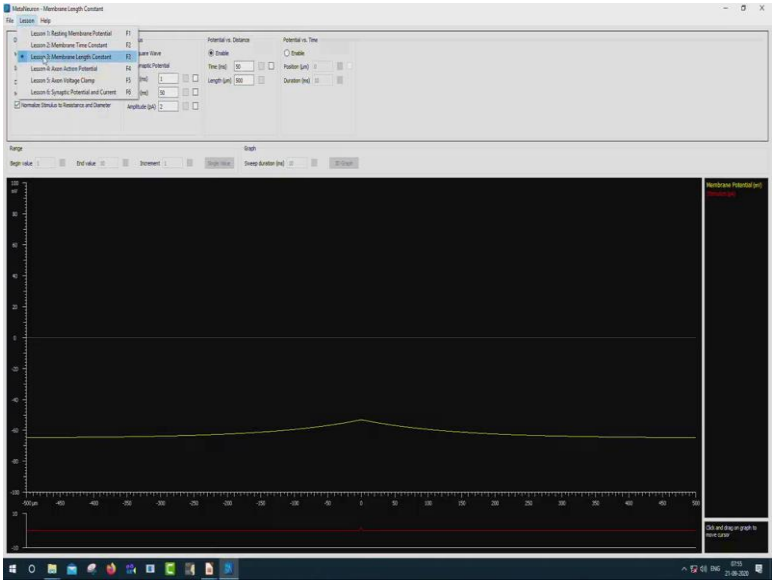
(Refer Slide Time: 6:45)



So, some of the exercises you can do is you can look at the steady-state exponential decay of voltage with distance. So, when it is depolarized, the axon on the dendrite at a particular point where X equals 0, this will decay with distance as it is passively conducted down the dendrite. So, the other exercise to do is to vary the membrane resistance, then the internal resistivity and the dendritic diameter.

Then another exercise you can do is the passive conduction of a synaptic potential in dendrite. So, we select the potential versus time and the synaptic potential stimulus rather than electric stimulus and you set the "Stimulus Width" to 1 milliseconds. When you select a synaptic potential is a realistic scenario because a square wave is not realistic, a synaptic potential is realistic. So, then the time course of the synaptic potential can be viewed at different distances from the site of generation.

(Refer Slide Time: 7:44)



So, this is the MetaNeuron program and here I have a checked the membrane length constant demo and just to briefly take you through the different boxes etcetera, on the top left you have the dendrite or axon properties. So, here you have the membrane resistance, kilo ohm centimetre square. You have the internal resistivity which is ohm centimetre. And you have the diameter, here it is 0.1 and membrane (capa), this is in microns. And membrane capacitance is at 1 microfarad per centimetre square. And here we have normalised the stimulus to the resistance in the diameter, otherwise you will get graph which would go out of the visual area.

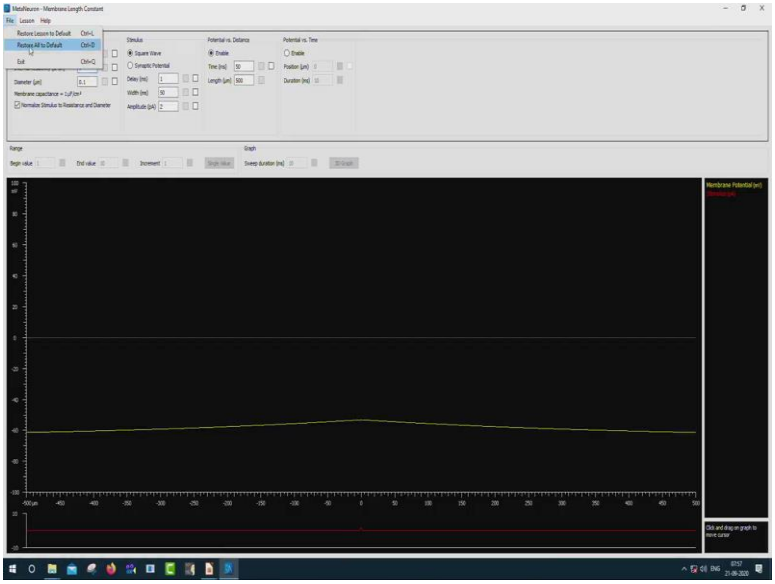
And the stimulus here is a square wave which you see over here. This is little thing in the red trace and the membrane potential is maximum where it is the stimulus is given and then

decays exponentially on either side on the stimulus. And here we are looking at potential versus distance. And the time over here is 15 milliseconds and the length is 500 microns which is half a millimetre.

(Refer Slide Time: 9:05)

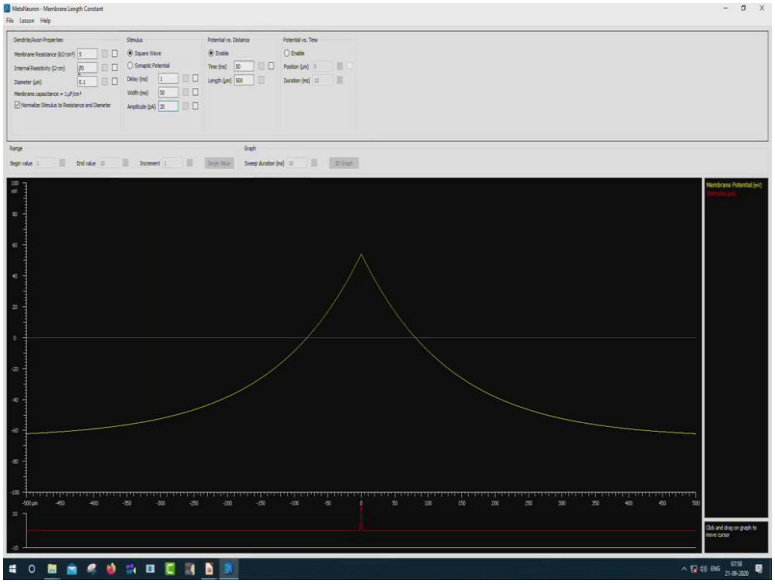
So, let us see, let us start changing things. So, the membrane resistance, so gain the axon and the resistance, membrane resistance which is the resistance of the membrane. So, it is a trans so giving the stimulus here is a traverse leak outside and above and below the axon. And if you change the membrane resistance from 5 to 10, it becomes less and if you change it to 100, becomes even less. Let us go back to default.

(Refer Slide Time: 9:36)



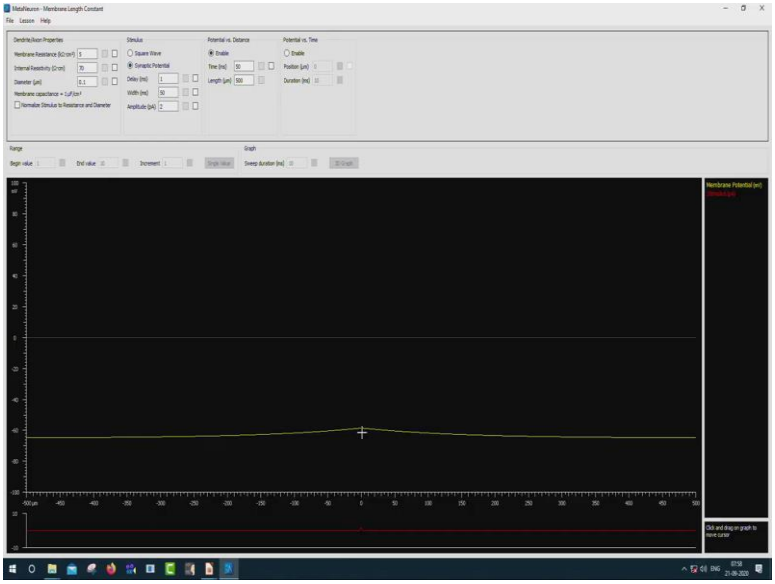
So, let us change the internal resistance. So, let us change the internal, let us make it 1 tenth, so from 70 let us make it 7, again it goes for a longer period and how do you make that out well? You can change the sweep duration over here but before we do that let us just go to the diameter tool. So, restoring back to, everything back to normal. Let us go to the diameter. So, here it is 0.1 micron, let us make it 1. So, again. So, it (beca) so you see, changing these parameters makes the potential last for a much longer time

(Refer Slide Time: 10:16)



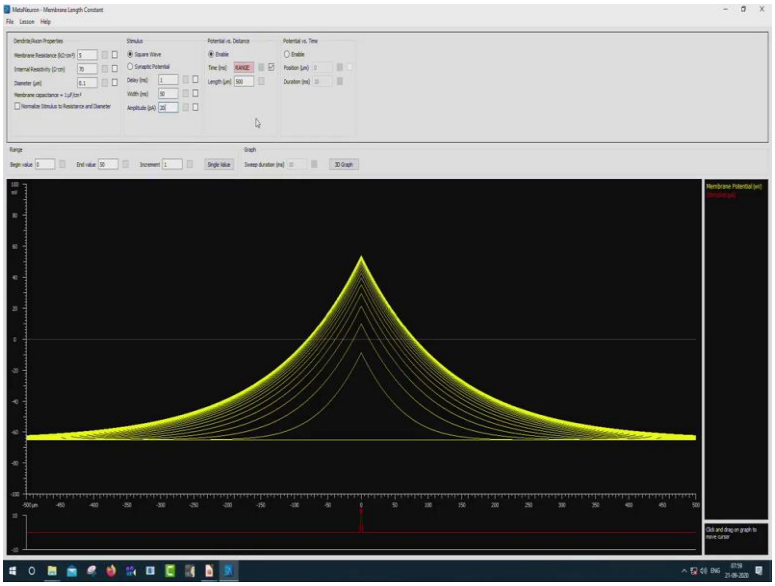
Going back to default. So, we can instead of a square wave, actually let us do the square wave. Let us increase the amplitude, so we increase the amplitude to from 2 to 10 times, 20. There you go, so again it is huge now, but you have an exponential decay on either side of the point of application of stimulus which is 0 and this is the stimulus. And we can make it back to normal.

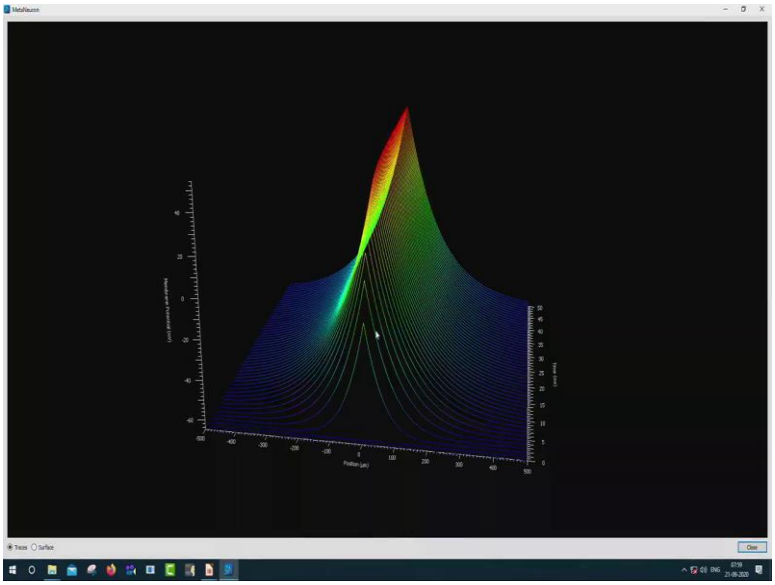
(Refer Slide Time: 10:59)

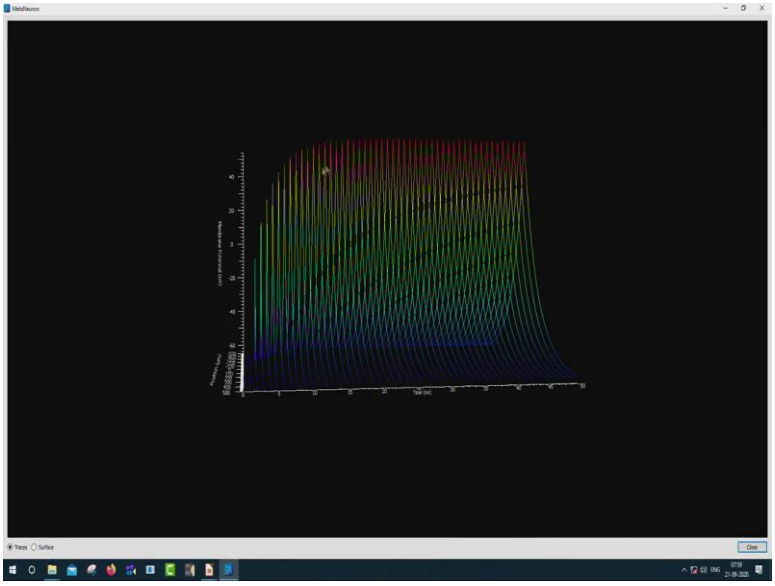


So, we go to the synaptic potential which is not a square wave but which is more of what we get in we encounter in the real state. So, this is what it looks like, not that much different.

(Refer Slide Time: 11:14)



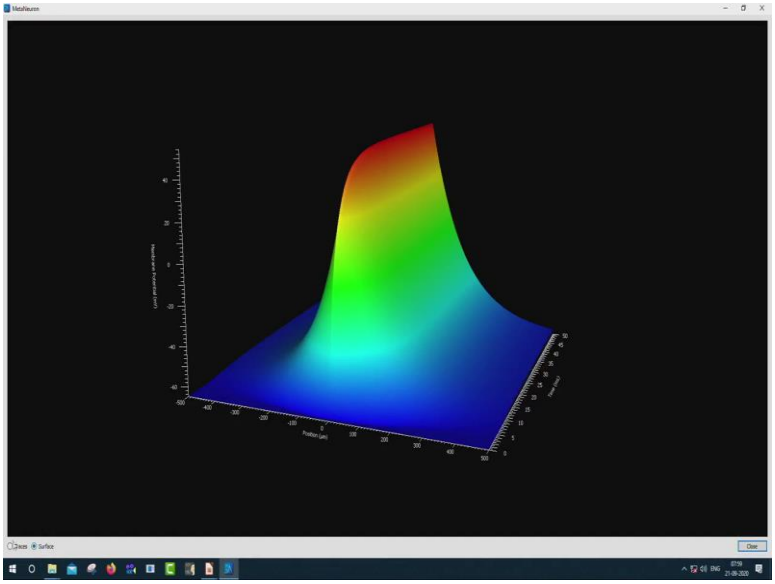




So, now we go back to square wave. So, let us look at what are happens when we value, change the distance and we look at a range, individual things are little difficult, so look at a range. So, there you have a range of different stimuli and you can see how it decays. Let us increase it a little more because I can barely see it. So, I will make it 20. So, it looks very nice in symmetrical, does not it?

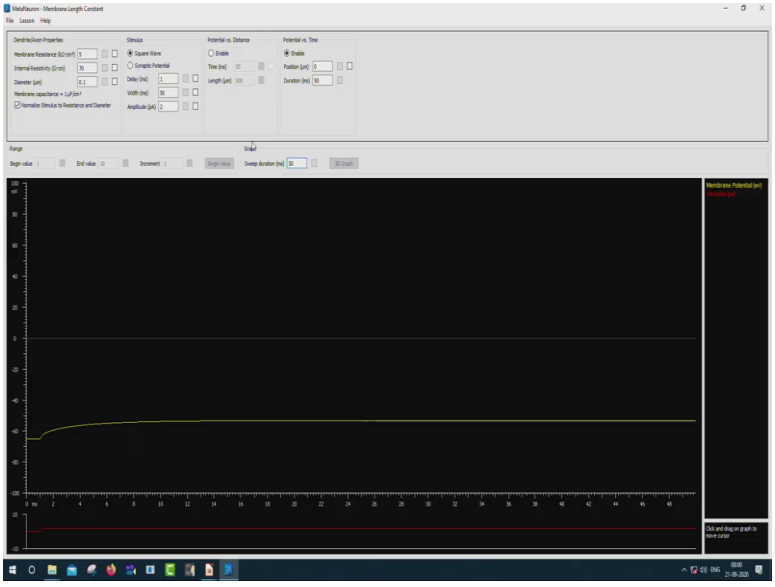
So, what we do is we can do a 3D graph and you can actually rotate it and get a sense. Here, it is so much and then you keep increasing it, you can see it being increased over there and then it plateaus. It plateaus after certain point, after that it does not go above.

(Refer Slide Time: 12:08)



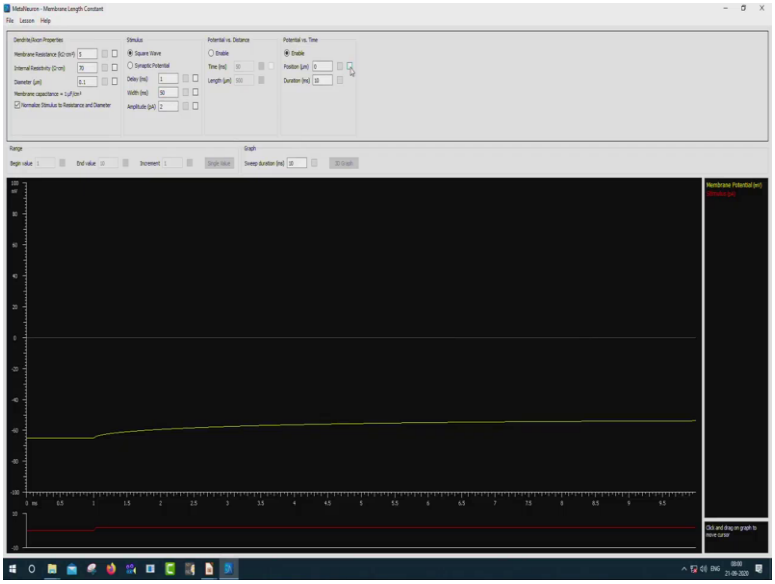
An another way to look at would be to look at a surface plot. Much prettier. But actually I cannot see much on this, I prefer traces. So, let us stop that. Let us go back to defaults and now let us look at potential versus time.

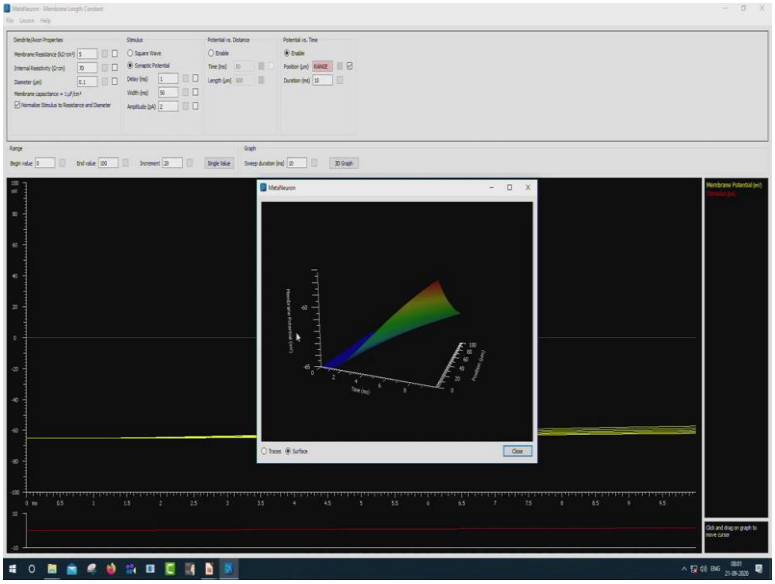
(Refer Slide Time: 12:32)



And so let me change the sweep duration because I cannot see what is happening. So, let us change it to 50, so this you see the impulse which is stimulating current over here and you see the change in the membrane potential.

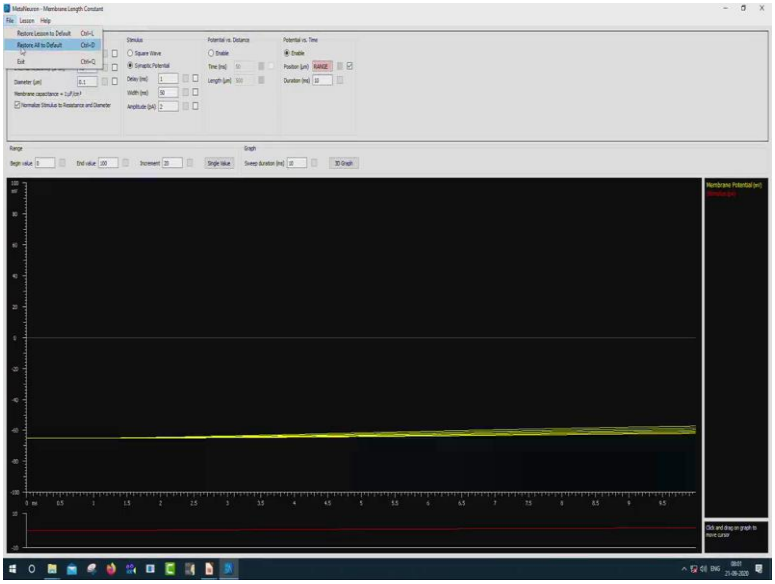
(Refer Slide Time: 12:56)

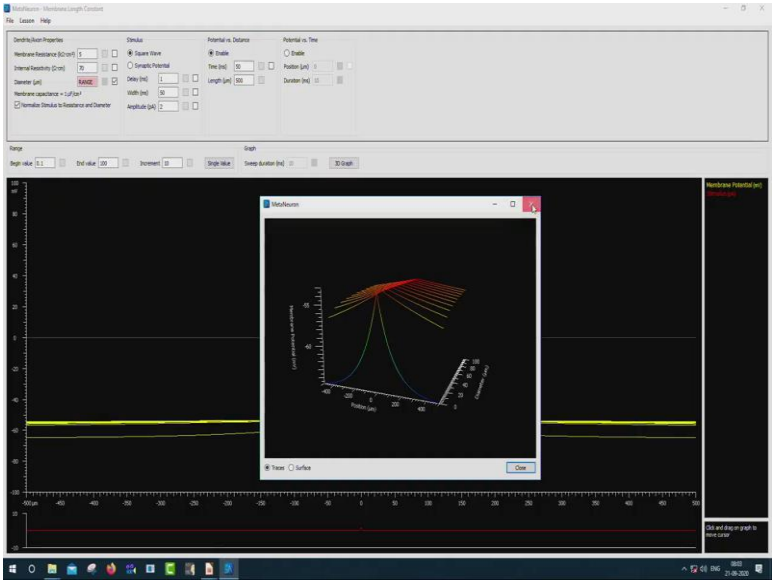




Now, let us change it to a synaptic potential. A synaptic potential is much more gradual and let us look at a range. Again synaptic potential, let us look at a range and sweep duration, we will look at a 3D graph. You can see how, so you can see the position where you are looking at the potential, and looking at the time and then you see the change in the membrane potential.

(Refer Slide Time: 13:41)



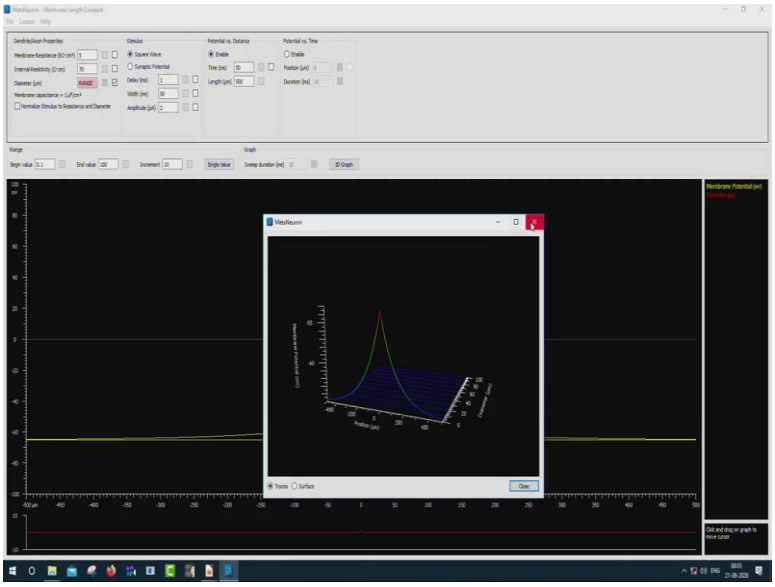


So, I would like to show one more thing. We will restore everything back and let us look at what happens when you change the diameter because this is important because axons, dendrites they all range so you can have dendrites as a squid, axon is the 1 millimetre and it is 1000 microns and you can have dendrites which was 0.1 microns. So, it is different how it behaves, how the current decays along the length of a dendrite, on an axon each of these instances.

So, here we are changing the diameter and we have a range begin value, diameter of 0.1 mu and ends at 100, sorry at 10. I would like to make it a 100 and make this 1. Or in fact, make this 10. So, you have a 3D graph. It is better to have traces. So, the first one behaves normally and then after that it overloads it. So, these are not realistic, though it gives you a sense of

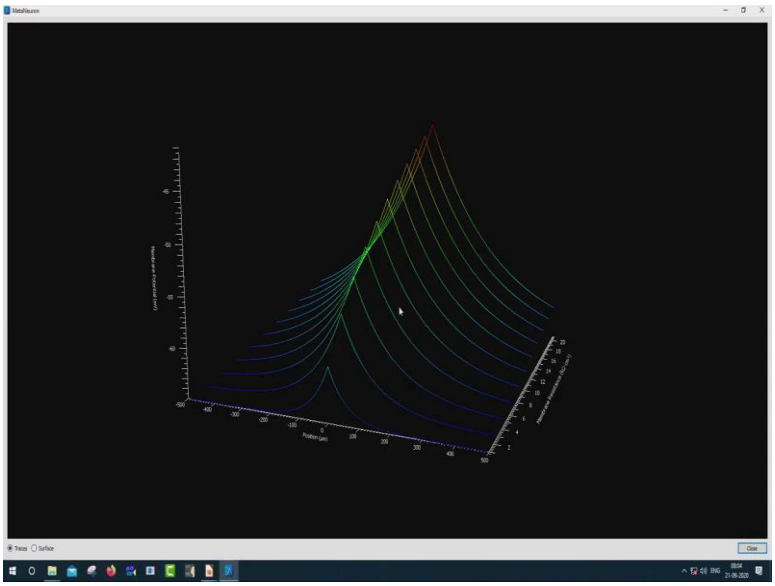
what is happening, you do not have such things happening. It is just to give you an idea of how the program works.

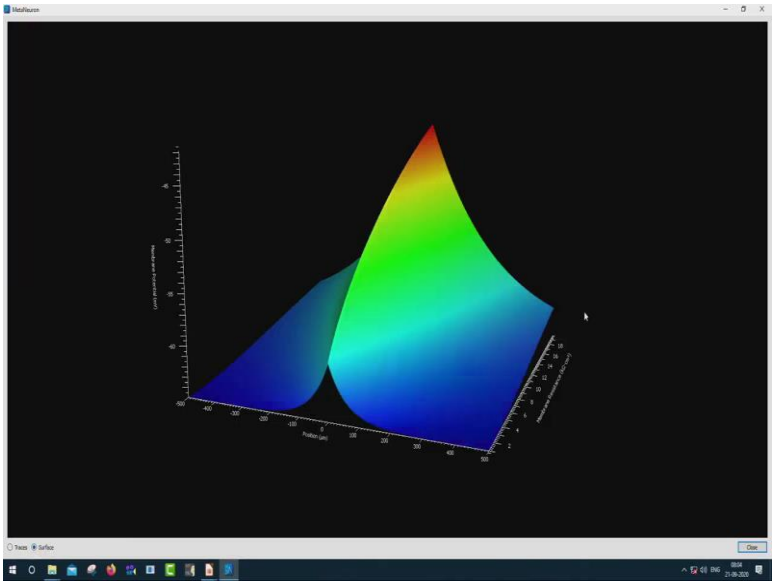
(Refer Slide Time: 15:21)

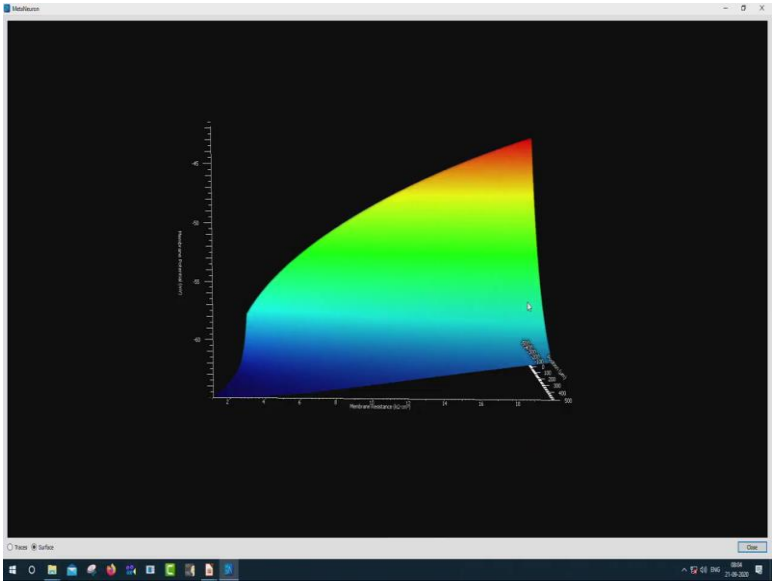


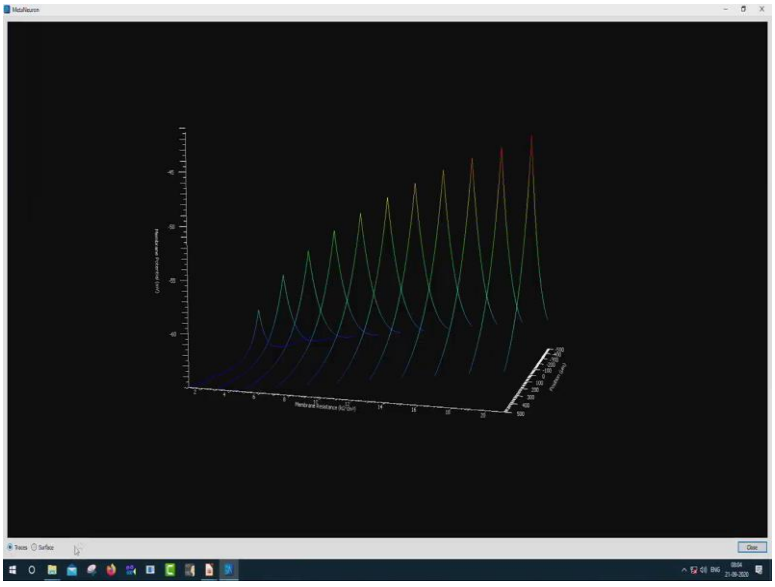
And in fact, so as you are saying, here I have remove the normalising part so, only the first stimuluses works and all the others are beyond the physiological limits of this program. So, I come back to all to default and then we can do the same thing for membrane resistance.

(Refer Slide Time: 15:42)



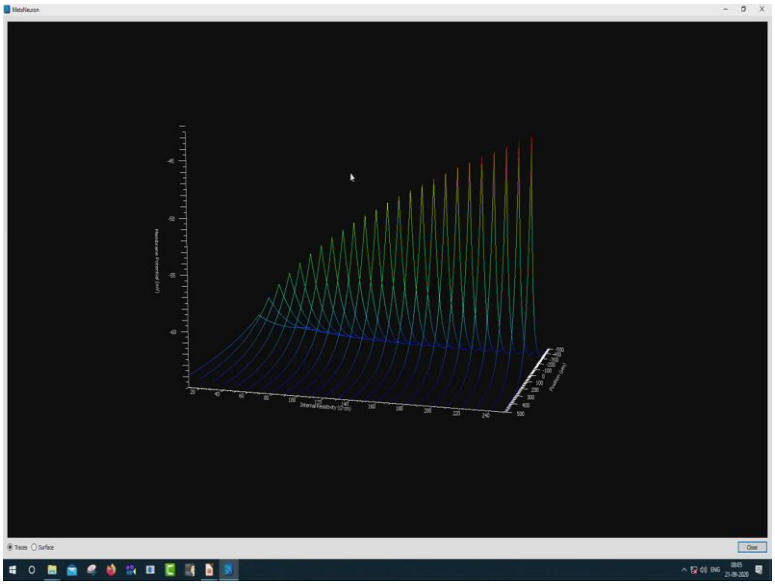






So, use a range and see, and now we are changing the membrane resistance. We have a begin value of 1 kilo ohm centimetre square, end value of 20 and we increment it by 2 and we can see how it decays. We can do a 3D graph and so this is the lowest and then it keeps rising and then the decay is you can see the effect of the exponential decay, how it, the lambda changes and again we can use a surface plot if you like and turn it around, look around. So, here you see, over here you see the membrane potential. Here you see the membrane resistance as it changes. And this is the position and this is the decay.

(Refer Slide Time: 16:42)



So, similarly we can look at the internal resistivity. So, one minute. So, our beginning value is 70, so we can have a range and we have a range of 10 to 250 and we incremented by 10 and we can plot a 3D graph and see the effect of diameter. Now, again as I said suggested

that it will be good if you keep this program running while you are going through the axonology and axono, neuronal biophysics lecture to get an idea of both the theory and the practical way of changing lambda and how it works. And we already went through diameter.

So, this is and also once you change these you can also look at potential versus time and see how the change in membrane resistance, internal resistance and diameter affects the potential in time. So, that is basically it and please like play with this, play with all the different parameters and if you have any questions, do not hesitate to contact us. Thank you very much.