Cognition and its Computation
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Lecture - 17
Sensory Circuits: Visual - I

Welcome. So, we were discussing our neuronal coding in terms of how information is encoded in the neurons by means of spike rate and spike timing. And, these will be referred to all the time in terms of when we discuss the sensory systems or sensory circuits. And it will be used in terms of understanding what aspects of stimuli are being encoded by neurons in the different levels in the hierarchy of the different sensory circuits.

And, so to begin our discussions on sensory circuits, we will introduce another new term and that is what is called the Receptive field or Receptive field of a neuron.

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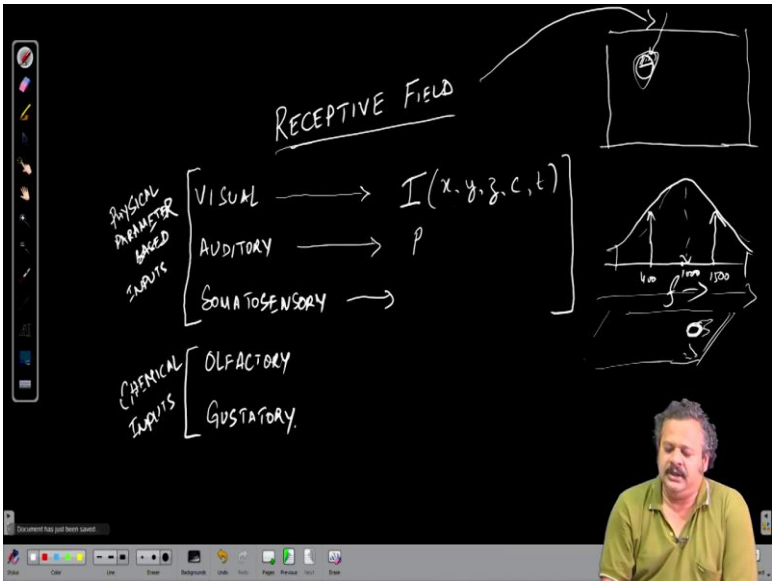

So, as we said that we will talk about the five senses like the visual system, the auditory system, the somatosensory system, the olfactory system and the gustatory system. So, as you will quickly realize that these three are different from these other two where these

are based on chemical or molecule based inputs. And, these are more physical parameter based inputs, not more they are physical parameter based inputs.

So, the discussions of the receptive field also will change based on which of these two groups of systems that we are talking about. For example, the visual system we are talking about the light coming into the retina or coming on to the retina through our eyes from the external world. And these this can be parameterized the input stimulus can be parameterized based on the location of the source of the light or where it is being reflected from, the object that we are seeing, the color, the intensity and the change over time.

So, it is basically the based on some measurable parameters and like an image based on x, y, z some color and some time. And I mean this is the intensity at this particular point of these particular variables. And, so, the way these three physical parameter based inputs work is that we can actually put the stimulus parameters on to a space on to an ordered space.

And so they can be parametrizable and easily mathematically treatable. And, on the other hand the olfactory and gustatory systems they being chemical input based the space is not parameterizable at least the so far we do not know of a way to parameterize the olfactory or gustatory input space. People have tried many ways of looking at the size and structure and shape and the number of carbons, if it is some aliphatic hydrocarbon or something like that.

But still there is no clear idea about how these can be mapped on to a particular space based on which we can treat the response of neurons as a function from this kind of an input space. So, on the other hand here in the visual system and auditory system auditory system basically it is a sound pressure waveform. And, it is essentially it is again the as a function of location x, y, z and intensity that the pressure is changing over time intensity and time.

So, again we can actually form a function as to find out what from the input space is being transformed into the spiking activity of a neuron. Similarly, in the somatosensory system we will talk about pressure vibration and so on which are all which all can be put into a physical parameter space. And we can try to model the output of neurons based on

like function transforming from the input parameter space to the space of spiking responses of neurons.

So, the notion of receptive field is basically I mean it is it can be called a receptive field at many levels I mean the representation of a neurons receptive field can be in many different levels. It could mean simply the range of the receptor space. So, when we say receptor space we mean the input space where the original sensors are there for the visual or the auditory or the somatosensory pathway and the x, y, z region or the color that is present that together the whole range of it is the receptive field.

We can also talk of an explicit function from this input space to the rate responses or spike train spiking responses spike time based responses as the receptive field. So, we will see that if a neuron in the visual system let us say this particular rectangle that I am drawing, let us say it is representing the visual space in front of me. And, we will see that a neuron in the visual pathway may respond to light stimulus in a particular round region only in that visual field.

And so we may say that this region is the receptive field of the neuron, but it is it may be qualified further in the sense that within that receptive field are there features to which the neuron is sensitive to. For example, we could say that it is sensitive to let us say light on one side and dark on the side may be the neuron responds much more strongly to this kind of stimulus feature.

It may be that it responds more strongly to some other kind of feature within that receptive field. So, we can basically keep on making this complex further complex features being present in the receptive field to define the receptive field. Similarly, in the auditory system like we discussed earlier we saw that a neuron is responding to different frequencies with different firing rate and we said that the neuron is tuned to a particular frequency or 1000 hertz in that case.

And we said it is selective to frequency and this curve this shape could be defined as the receptive field of the neuron, but remember it does not mean that the neuron would we know based on this receptive field that what would the response be when there is a tone at this particular frequency. Let us say 1500 hertz or and also a tone at let us say 400 hertz those being presented together how the neuron would respond.

We do not know that based on this receptive field. So, further qualified further qualified model or transformation from this frequency axis to the to the response rate domain can be called the receptive field. So, we can basically say that we can get further and further complicated representations of receptive fields, but at the simplest level what we mean by the receptive field is this circular region or this range of frequencies with one particular frequency being most important.

Similarly, in the somatosensory system also we can have if we stretch out the skin and represent it on a 2D location 2D space where fingers are in one region and then the feet are in another region and so on. And, let us say we are talking about only pressure sensors then the receptive field could mean the palm of the hand of the receptive field of a neuron could be the palm of the hand or something like that, that is this the neuron is sensitive or responsive to stimuli being presented within this particular region.

So, that is the idea of receptive field. We talk about receptive fields primarily in this sense for the physical parameter based inputs. We call the we do not really call the sensitivity of neurons to different olfactants or gustatory systems neurons responses to different gustatory inputs or particular gustatory inputs as receptive field, but I mean there it is going to be a set of input set of olfactants that serve as a way to stimulate the neuron.

That is the neuron is sensitive in its response to these set of inputs which is discrete space so far as we understand which has which can have all these molecules in there. So, with this idea of receptive field we will delve into the discussions on the visual system.

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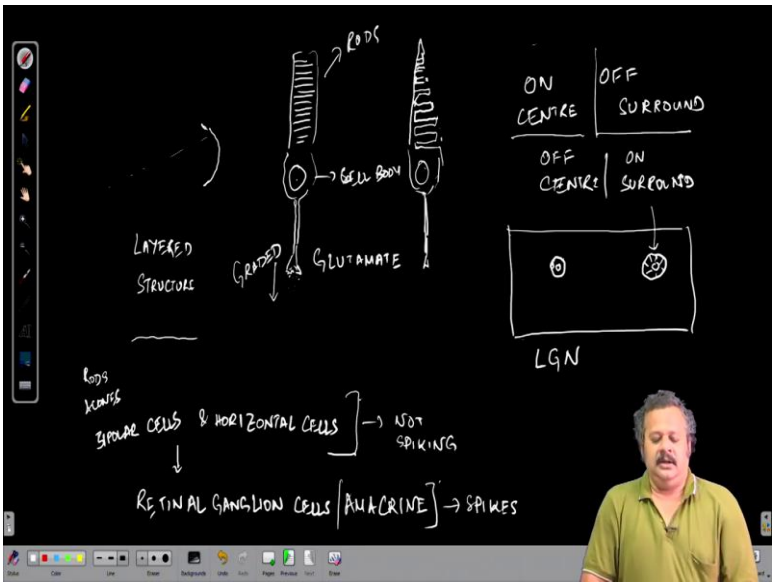

So, in the visual system the as we all know the visual system starts from the retina in our eyes. And so light impinges on to the retina, the retina is a layered structure. So, and in these there are multiple types of neurons and it is kind of arranged in an opposite way in the sense that at the back of the retina are the cells which are responsible for the sensing of light; and those are the rods and cones. So, the rods and cones the name comes from their structure.

Because of the outer segment of these neurons being of these types of cells being of the shape of rods or cones. And, that is basically like this and then there is the cell body and then there is an axon that projects out making a synapse onto the next stage neuron. So, this is the soma region or the cell main cell body and the nucleus is present here. And, the upper region is striated with disc like structure increasing the surface area of these receptors and cones.

So, these are rods because of the shape and cones have a conical shape again there are disc like gaps in these particular cells. And, so this is how it may look like and then again there is the main cell body with the nucleus. And then again an axon making synapse onto the next stage neuron within the next within the retina and these are the next stage are bipolar cells.

And horizontal cells and these neurons then project onto the third layer which is the retinal ganglion cells which are the main output neurons from the retina.

So, light or photons rather are absorbed here through particular molecules that have certain selectivity of the OPSIN that is present there the certain selectivity or of wavelength of light for the OPSIN that is present there which absorbs a photon and ultimately through a number of steps at a very fast time scale and then at very slow time scales finally, modulates or closes ion channels that stop release of glutamate from these axon terminals.

So, glutamate is the neurotransmitter in these neurons or in these receptor neurons and they project onto the bipolar cells. And, interestingly the photoreceptors that are rods and cones they through the decrease in neurotransmitter release convey information to the bipolar cells or the horizontal cells. And that is because in the dark in the dark they are these neurons are actually releasing neurotransmitter.

They are actually depolarized at about minus 40 millivolts and are continuously releasing neurotransmitter with the fall of photons or absorption of photons on to the receptors. Finally, there is decrease in the membrane potential which stops the release of glutamate. So, basically the postsynaptic neuron now is not getting any more of the neurotransmitters.

And, it is the bipolar cells which has the glutamate receptors they cannot they do not get any more further current the current is being reduced and the transmission here is actually graded and not through action potentials. So, they are graded in the sense that the potential is getting transferred and not an action potential based neurotransmitter release.

So, in that sense it is very different from what we have been discussing so far. Similarly, the bipolar cells and the horizontal cells that project to the retinal ganglion cells, and another type or amacrine cells. They actually again transmit through graded potentials and these synapses that are present form from bipolar cells on to the other types of neurons can be sign preserving or sign reversing in the sense that the receptors of glutamate in this case for bipolar cells and horizontal cells.

They can increase the potential in the retinal ganglion cells or reduce the potential in the retinal ganglion cells. Similarly in the rods and cones also, it the receptor of glutamate the particular receptors that are present in those synapses can be sign preserving or sign reversing. And, what this provides is a way to over a way to produce some very

important properties of receptive fields of the bipolar cells and retinal ganglion cells and beyond in the visual pathway which has to do with on center and off surround on center off surround.

So, these neurons here did are not spiking. The retinal ganglion cells and amacrine cells produce spikes in response to inputs from bipolar cells and horizontal cells. So, in this in this case we have the on center off surround or off center on surround kind of responses. We will describe that in a little bit.

In the bipolar cells we it is similar on center of surround, but here we say on depolarized of hyper or center depolarized and surround hyper polarized or center hyper polarized surround depolarized on positive center positive of surround negative because they do not spike. So, what we essentially mean is if we look at the receptive field that is in the field of view of the eye.

Let us say at a particular position light coming from this particular region is able to change the release of glutamate on this photoreceptor and hence the depolarization or the membrane potential of the bipolar cell and. So, this region is the receptive field of the bipolar cell what is seen is that these receptive fields have a central region light in that region can cause increase or depolarization of the bipolar cells.

And if I and the surrounding region if there is light it is actually hyper polarized. And the opposite is off the on surround and off center that is or rather hyper polarized center and depolarized surround where light in the outside region actually increases the membrane potential of the bipolar cell and light in the center region actually hyperpolarizes the bipolar cell.

And these features are achieved through the sign preserving and sign reversing synapses and the circuitry within the retina. And these then project onto the retinal ganglion cells. And so the retinal ganglion cells which are spiking they respond with increased spikes in the center and with reduction in spikes in the surround that is they get inhibited with respect with light in the surrounding region of the receptive field.

Just like it is depolarized or hyper polarized in the center and the surround the retinal ganglion cells are actually spiking more in the center for the on center and actually reduce their spiking in the surround for the on center off surround and the opposite in the

case of off center on surround. So, the retinal ganglion cells are the first spiking neurons; actually amacrine cells which we have not talked about are the first spiking neurons in the retina.

And retinal ganglion cells are the main input to the central nervous system. And so from the retina the retinal ganglion cells with receptive fields like what we have described project onto the lateral geniculate nucleus which is the thalamic region of the visual pathway. So, you have learnt about the thalamus in the introductory lectures of brain structure.

And part of it is the lateral geniculate nucleus which is where the projections from the retinal ganglion cells reach on to neurons there and the LGN is also a layered structure. So, the very basic organization of these from the retina to the LGN to beyond in the central nervous system is that the there is a retinotopic or visuotopic arrangement of the neural real estate in the lateral geniculate nucleus and beyond in the cortex of the visual system. So, what we mean by retinotopic or visuotopic is that regions in the structures.

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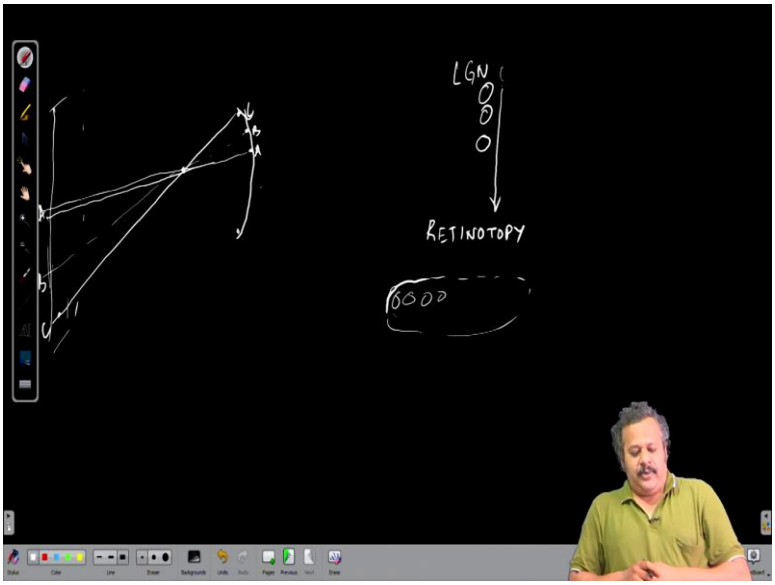

Let us say in the retina. So, the photoreceptors here in these regions and this region let us say region A region B region C. I should for a particular reason I should let us say discuss three points A, B and C. And, let us say they are mapped for from the visual field from this particular region this is where the light enters. B is here, C is here. So, the optics of this is such that the points along this line let us say or maybe if we consider a

plain points around this region are arranged here in such a way that nearby points in the visual space is mapped on to nearby points in the retina.

And that mapping goes on be reflected in the thalamus in the lateral geniculate nucleus where the A, B, Cs will be similarly present in the sense that neurons with receptive fields in the regions A or in the region B or in the region C are actually mapped on to similarly spaced locations in the LGN, that neurons in the LGN are also arranged such that one particular region of the visual field is in one particular region of the LGN.

What I mean by that is neurons responding to light in one particular region of the visual field are together the nearby region are together in the nearby region are together in the LGN and so on. So, if we record from the neural real estates in the visual pathway up along beyond the LGN and so on. What we will see as a basic feature of organization is retinotopy that is the neurons are arranged in a way such that they reflect the external space.

So, this kind of arrangement of visual space is also present or rather this total organizational what should I say property of some topy that is this arrangement is present in all the three physical parameter based sensory systems. That is in the auditory system where we have tonotopy which is selectivity to nearby frequencies of sounds.

Neurons with similar selectivity to sounds are present nearby each other. And as we go from one side physical side of a auditory structure in the hierarchy to another side there is a change gradual change in selectivity of frequency in general of the neurons that we will encounter. Similarly, there is a clear map in the somatosensory system also along the pathway where different spots on the skin are mapped on to similarly spaced or rather in an arranged manner in the somatosensory pathway as well in structures in the somatosensory pathway.

So, these this kind of arrangement is there and have been the basis for understanding many kinds of phenomena in terms of developmental plasticity and so on. And this is a very basic feature that has been observed in humans to many many different species in all the three cases. And so we have beyond the thalamus we have the primary visual cortex which goes into the cortical regions from the thalamus.

And so this retina to LGN is through the optic nerve. And then from LGN to the visual cortex the inputs are through the optic radiations. And the primary visual cortex the visual the first region where the inputs come in from the LGN that region is also retinotopically organized and has a columnar representation that we will start with in the next lecture.

Thank you.