Cognition and its Computation

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Lecture - 18
Sensory Circuits: Visual - II

Welcome, we have been discussing the Sensory Systems we started our discussion with the Visual System where we talked about the initial stages, where we discussed the circuitry in the retina where light falls onto the photoreceptors which are rods and cones. And they have options that are selective to particular wavelengths of light as you know the RGB red, green and blue approximately in those wavelengths.

And then they project onto bipolar cells and then on to the retinal ganglion cells and those are the ones that project to the central nervous system and the first stage where the retinal ganglion cells make a synapse on to neurons are is in the lateral geniculate nucleus which is the visual region of the thalamus. We have talked about how the receptive fields of the bipolar cells and the retinal ganglion cells are center surround in nature that is the central region is either depolarized and the surrounding region is hyper polarized in case of bipolar cells and similarly, because they do not spike and it is only a depolarization or hyper polarization that we talk about.

And similarly, the retinal ganglion cells they have similar receptive fields with center surround nature with responses in large spikes large number of spikes in the with light in the central region and lack of spikes or inhibition in the surrounding region.

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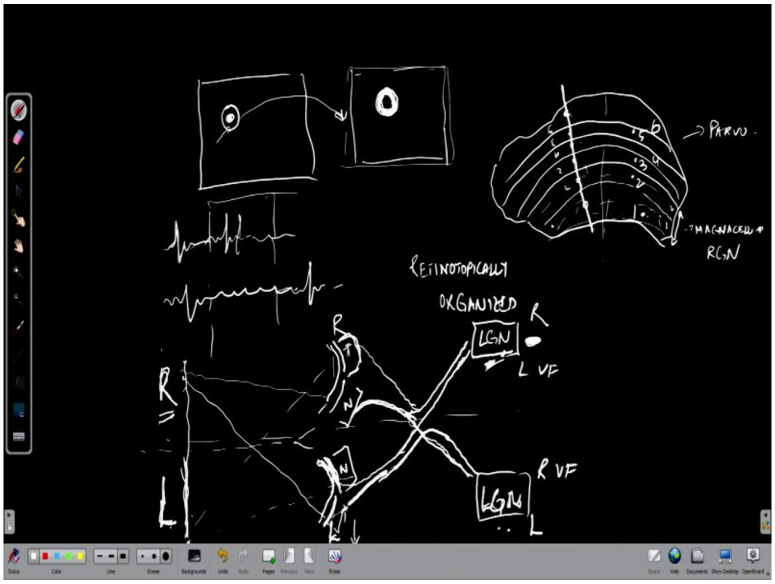

So, just to recollect little bit we have if this is the receptor at the visual field in front of us then a retinal ganglion cell can have a receptive field that is generally circular in nature with when light is falling into the central region then the neuron responds with more number of spikes in the RGN and when there is light in the surrounding region if this is one spike let us say spontaneous activity we see that there is no activity there. And when the stimulus if this is the duration of the stimulus presentation then after the stimulus is gone then there are responses.

So, sort of the best stimulus in that case for the lateral for the retinal ganglion cells is light in the central region and the dark ring around that within the win fulfilling up the receptive field in that manner and that produces the most number of spikes showing that the retinal ganglion cells probably encode that kind of a stimulus.

And in the pathway when the retinal ganglion cells project on to the lateral geniculate nucleus neurons they retain similar properties of receptive fields that is these center surround nature. And, remember, we must also have we must remember that there are again similar neurons that are the opposite in nature that is when there is light in the surrounding region and dark in the center.

So, these are off when the center is lighted and on surround. And these neurons project on to the lateral geniculate nucleus neurons and these also have the similar center surround on center off surround or off center on surround kind of receptive fields the only difference being that the receptive fields get larger in size that is generally if bipolar cells have the smallest kind of receptive fields and gradually by the LGN neurons they are larger in size.

Another aspect of the retinal the of the processing that starts in the retina itself is that produced by the amacrine cells, that we had talked about which are also in the along in the layer with the retinal ganglion cells and they are responsive to movement of a stimulus in their receptive fields. They generally have much larger receptive fields and they are responsive to moving stimulus, moving light in their receptive field.

And this is sort of the start of another pathway and that is differentiated in the LGN itself, that is the lateral geniculate nucleus which is a layered structure and it has six layers sort of shaped in this manner so it has six layers like this. So, 1, 2, 3, 4, 5, 6 and it is again as we had talked about retinotopically organized and so basically if we draw a line along this and if we encounter neurons along this path, the neurons in the LGN structure they are all at the same retinotopic position. That is the receptive fields of the neurons along this axis in the LGN turn out to be from the same region in the field of view.

So, the different areas of the retina are mapped along this axis here and different sections of the LGN represent different again the parts of the retina and in general there are the retinal ganglion cell inputs project on to one of these layers 1, 2, 3, 4, 5, 6. So of this the 1 and 2 layers are the magnocellular layers and 3, 4, 5 and 6 are the parvocellular layers.

So, this is where the movement pathway and the general visual information visual movement pathway and the general visual information pathway becomes segregated. So the processing that starts with the amacrine cells that through the retinal ganglion neurons reach the layer 1 and 2 in the LGN and layer 2, 3, 4, 5 and 6 receives the other information that is not sensitive to movement of light that much.

So, why again two? So we have the retina, there are two eyes and so let us say this is the left retina and this is the right retina and if the nose is in the center then we have two halves of the retina that is the temporal hemi field of the retina that is temporal half of the retina that is towards the ear and the nasal half of the retina, so this is the temporal half and the nasal half, again there is a nasal half here and a temporal half here.

And actually a light if we take the field of view as a plane along this line in front of the eyes, then information from the left side falls left side of the visual field falls on the nasal half of the left retina and temporal half of the right retina. Similarly, the information from the right visual field falls on the nasal half of the right retina and the temporal half of the left retina. So, we have two representations; one in the temporal half and one in the nasal half of the two retina retini of the left side, similarly nasal half and temporal half of the opposite retina of the right side.

So, we in the retinal ganglion cells that are projecting on to the LGN, so if this is the mid line we have two LGNs again, that is on the left side and the right left right side and the left side. And the axons of the retinal ganglion cells that come from the temporal side of the left retina and the nasal side from the left retina, they are going together up to one point. Similarly, here they are going together up to one point and here there is a crossover so that the right LGN gets the information from the left visual field from this left visual field.

So, the right LGN gets information of the left visual field here and this left LGN gets the information from the right visual field here. So, this gets this is the left LGN getting information from the right visual field and so to do that what happens is, so we need the information of the nasal half here which is from the left visual field to crossover on to the other side. So, and this one this from the temporal side of the left retina comes to the left LGN.

Similarly, since the temporal half of the right retina contains information from the left visual field this projects on to the right LGN and the nasal half of the right retina since it contains information from the right visual field it crosses over and goes to the left LGN. So, now, we have information only of the right visual field here and left visual field on the right LGN. And these so the inputs from the two, so basically inputs from both eyes are present in the in each LGN, but information of only one particular visual field is present in each LGN.

So, only the left visual field and here only the right visual field, but inputs to it come from both eyes. However, both the inputs from both eyes are segregated in these layers, for the magnocellular layer the layers 1 and 2, one of them comes the inputs from one onto one layer of neurons comes from one side and the inputs from the other side or other eyes comes other eye comes on to the second layer and similarly, 2, 3 and 5 so 2, 3 and 5 come from one eye and 1 4 and 6 come from the other eye.

So, the inputs from the two eyes are segregated onto the different layers of the LGN and we also have a segregation of the magnocellular or the M pathway that that is the movement pathway and the parvocellular which is more of the visual information pathway. So, these two different sides of different eye inputs the two different eye inputs continue on to the next stage that is in the primary visual cortex.

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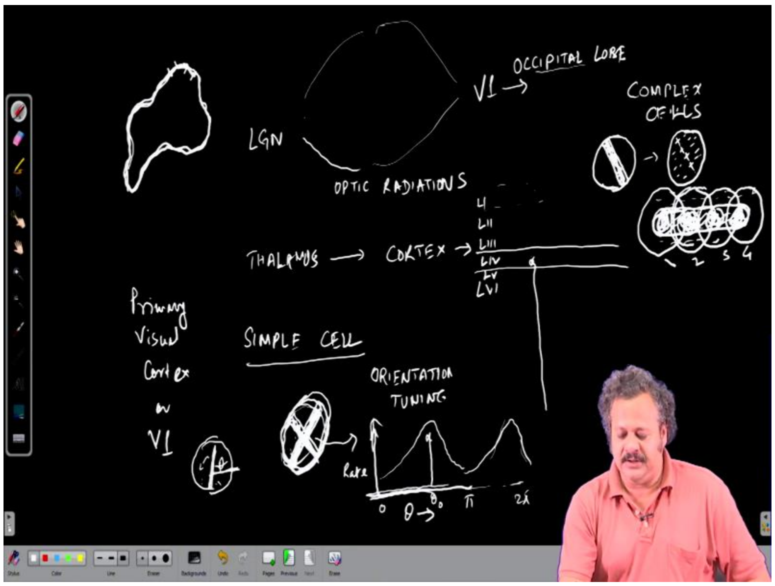

So, if we discuss a little bit more so basically from the LGN, in the anatomical part you will see that the there are optic radiations that carry the input into the visual cortex which is in the occipital lobe. So, there are two paths one is the inferior and one is the superior, I mean one goes on the ventral side and the one goes on the dorsal side, both end up into the primary visual cortex V 1 which is at the back of the head or back of the brain rather and that is in the occipital region.

So, a common theme is that thalamic inputs thalamus is as you have learnt in the anatomical lectures the thalamus is sort of the input path to the cortex or the cerebral cortex. And, the cortex is again a layered structure as you have learnt and that is layer 1 to layer 6, 1 layer 2, layer 3, layer 4, layer 5 and layer 6.

So, how do we identify the layers? They are basically different morphologies of neurons that are present in each layer and functionally also they are different in the sense that, layer 4 is what we know to be the input layer where thalamic inputs come in and project onto neurons you know that is the axons of thalamus neurons or the LGN neurons project on to neurons in layer 4.

Specific regions of layer 4 I mean they can be subdivided further based on morphology and function or where inputs come from, however for our purposes we will think of layer 4 as the input layer which receives the information from the thalamus. And the primary kind of neurons in layer 4 are the simple cells in the visual cortex in the primary visual cortex or V 1.

So, the simple cells the response properties or the receptive fields of simple cells are derived from what we know as the receptive fields of LGN neurons. So, simple cells turn out to be this was discovery of Hubel and Wiesel and further work by them which looked into the columnar organization and form the basis of organization in the cortex.

And they won the Nobel Prize, we know that now very well that simple cells are have a slightly have a circular kind of receptive field that is light in these regions either increase or decrease the responses of neurons and they are best excited by a bar of light and of light and a dark surround. So, obviously the question comes whether the bar is in this way or in this particular way, so it turns out that there is a specific orientation that simple cells like, in the sense that they respond more strongly to a particular orientation of the bar and that is what is known as orientation tuning.

So, once let us if we are able to record from a from a simple cell in the primary visual cortex and we find out its receptive field in the visual field of view in front of the eyes and locate that it that this circular region is where the neuron is responding to. And now if we have a bar of light in there which we rotate gradually in steps and let us say its angle from the horizontal is theta.

And if we take this theta along this axis and the rate response, assuming rate is the code for used by the simple cells, rate of the number of spikes produced or rate of the number of spikes produced by the simple cells as a function of this orientation angle theta, then what we see is sort of a tuned response to a particular orientation theta naught, so this is what is orientation tuning.

And so, this angle will vary from 0 to pi as beyond that the it is going to be repeating the bar is going to be repeating beyond pi to 2 pi. So, if we rotate that we should get simply a repetition of whatever we have seen earlier. So, this nature of orientation tuning is the first stage of feature that is or feature extraction that is seen in the visual pathway in the cortical stage. And what we now understand is why such features thus oriented bars as receptive fields are obtained is essentially to segregate the boundaries of objects.

So, if we have in the field some kind of object that is that has a boundary I mean what we mean is we mean an object only when it has a boundary or we at least can imagine a boundary or we can actually see the boundary, if you look around yourself, you will see that each object is defined by a sort of a limit or boundary of the object or even within that there are objects that will again have boundaries and that is what defines the full object.

And it is with these oriented bars that the boundary of the object can be defined that is a set of simple cells that are responsive to this orientation at this location at this at the visual field or this orientation at in that location of the visual field or this orientation in that location of the receptive field all these together if integrated can represent this object boundary. So, this is sort of what we currently believe as the basis or the mechanism by which objects are represented at the very first stage of the cortex that is through these oriented bars.

So, the next kind of neuron is in this in V 1 that is slightly more complicated than the simple cells are complex cells and these complex cells are essentially made up of inputs from simple cells and they do not have a clear segregation of excitation and inhibition. So, if we take a simple cell receptive field let us say it is circular with the best orientation in this angle so, that means that this is can be represented in this manner that it receives excitation from inputs along this line and inhibition in the surrounding regions.

So, how are these created we said, that it is created from LGN inputs and LGN inputs are center surround kind of receptive field. So, if we have LGN inputs that are like this which have light sensitive in the center and not in the surround and if we have inputs from let us say 4 such LGN neurons we would get simple cell kind of receptive field.

So, retinal ganglion cells that provide input to simple cell whose receptive fields are this 1, 2, 3 and 4 then integrating information from these four a particular simple cell would have oriented bar in this case horizontal as receptive as its excitatory region which is the plus regions of a simple cell and this is the surrounding minus regions.

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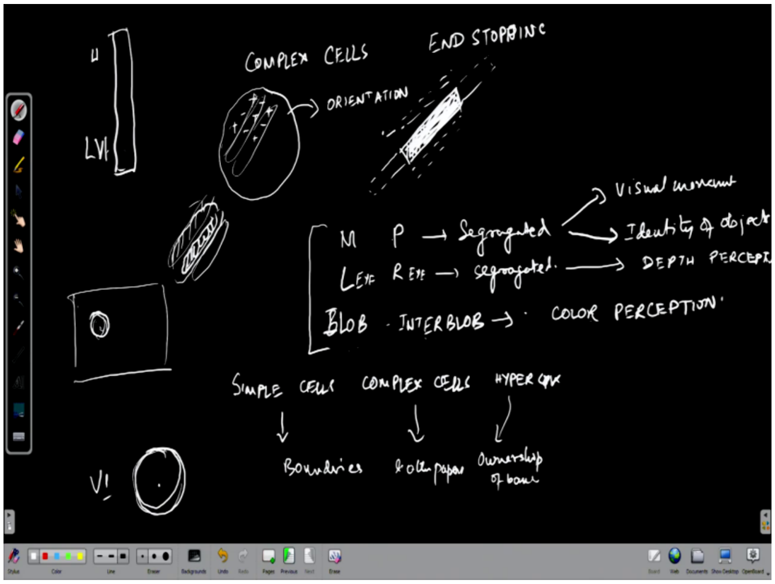

In the similar manner, complex cells come out from inputs from multiple simple cells and they do not have they have overlapping excitation and inhibition in their receptive fields that is so plus minus plus minus plus minus plus minus plus in that manner. And so, if you can think of these being created by multiple simple cells that are oriented in this kind of way in this angle with their center bars like this, but the inhibitory surround of the next simple cells receptive field is going to overlap with it. Then we get this overlapping excitation inhibition kind of receptive field.

They are orientation selective in the sense that they do prefer a single orientation and so they are getting inputs from simple cells of the same orientation selectivity. And but they have their inhibitory and excitatory regions overlapping and that is why we get in complex cells we get responses that are brief when the stimulus comes on and then with the inhibition they are shut off and when the stimulus is turned off again there is a excitation of responses because of release from inhibition.

So, in that sense the complex cells are larger in size also in receptive fields and then we have further have hyper complex cells and or the end stopping cells which you can read in your reading material. They are basically there to explain, they are basically there to provide ownership of boundaries that is they only respond to an oriented bar of light of a specific length.

So, they respond to only a bar of light of a specific lens, so this is end stopping or hyper complex cells and so if the bar increases in length light increases in length they stop responding and so they also have inhibitory surrounding region that is also oriented in a similar manner. And if the bar is extended beyond its beyond its selective region then the neuron stops responding.

This allows for end or boundary to actually identify the different aspects or in the or different two different objects to be segregated based on boundaries. If a bar goes beyond that length then it stops responding showing that it has gone into a different territory sort of. And so these things will come up when we talk about object recognition which is more into perception and these are our building blocks of going into visual perception.

So, what we learned so far is this that the two segregated pathways that is the movement pathway and the simple information pathway the visual information pathway that is the parvocellular and magnocellular regions and what we are talking about here is, mainly the parvocellular regions and so or the parvocellular inputs, the magnocellular inputs are separate at to the stage and in fact form the basis for totally different pathway that originates from the visual cortex and that is and part of the visual motion pathway or the weird pathway which includes the motion pathway motion processing regions.

And the other side is the what pathway which we will talk about more in object recognition. So, the other aspect is that the inputs provided from the two eyes are segregated up to this input layer in the cortex in layer 4. So, we have M and P that is segregated, similarly the left eye and right eye inputs are segregated and we have not talked about color vision really and that has to do with the system called the blob and inter blob system which we will talk more about in color perception. These are also regions in the visual cortex that talk about different regions that are selective to colors and that are not selective to colors.

And these will provide the basis for different things this is for going to provide the basis for visual movement in perception this is go and similarly the identity of objects the two different things. Here this will form the basis when the two eyes are integrated will form the basis of depth perception which we will also be discussed later on and this is going to be the basis for color perception the blob and inter blob system.

And in the P that is in the identity of object we have talked about the simple cells, complex cells and hyper complex cells. And so these are going to be providing the basis for the identity of objects and these are for boundaries encoding of boundaries, these are ownership of boundaries and other features. So, we will talk more during object recognition in more detail about these different types of responses that mediate our final percept of the visual world.

So, the basis of the organization that we have been talking about is retinotopy and on top of that in a particular retinotopic region in V 1 let us say this is the visual field and this particular region in the visual field is represented in a particular region in V 1 and this region has a whole system of blob and inter blob, left eye, right eye dominant inputs, M and P all different kinds of orientation selectivity at that particular location all different kinds of complex cell orientations and hyper complex cell orientations and this whole thing together is going to be called a hyper column and each different featuring that is going to be a column.

In the sense that the different layers if we are talking of the visual cortex region and we are representing this from the top, if we go down in vertically along the cortical layers as we talked about layer 1 through layer 6. This whole region is selective to one particular orientation that is the neurons there are all selective to one particular orientation there is some variability but in general this is one orientation column.

Similarly, this whole hyper column has a whole set of orientation columns that is all the sort of directions that are going to be present in this particular region of the visual field are going to be present within the hyper column, all blobs inter blob systems are going to be in there, whole set of left eye, right eye, input specific regions are also going to be in there and so on. So, this is the basis basic columnar organization that was discovered by Hubel and Wiesel and it forms in the somatosensory system in the auditory system everywhere we will see similar columnar organization to be present.

So, retinotopy and on top of that there is columns and hyper columns in there. So, with this we will end our discussions for the introduction to the visual system and after this we will take this up more as we said in the object recognition in depth perception, color perception lectures more in the cognitive aspects of processing and these will provide us tools to understand the mechanisms behind object perception and so on. So, with this we will stop here and later on we will go into the other systems auditory somatosensory and so on.

Thank you.