Neural Science for Engineers
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Lecture - 35
Network analysis during visual processing

So, I title this session as Image Processing. We look at how image processing is done within the biological human system and how it would be similar to image processing in engineering. And what are the possible similarities and differences which exist. I will try to make a highlight of it and in fact, once upon a time when the biological part of image processing was taught, you had to accept things at face value.

In fact, you would realize that, but having gone through image processing techniques I understand that in fact you find neural network techniques as an excellent methodology which says that this is the same thing which is going on within the human visual image processing architecture.

So, it is a two-way communication, unfortunately the two way part of it has not happened, most of it is the engineering side taking ideas from human vision and monkey vision and trying to implement and with spectacular results which you are aware.

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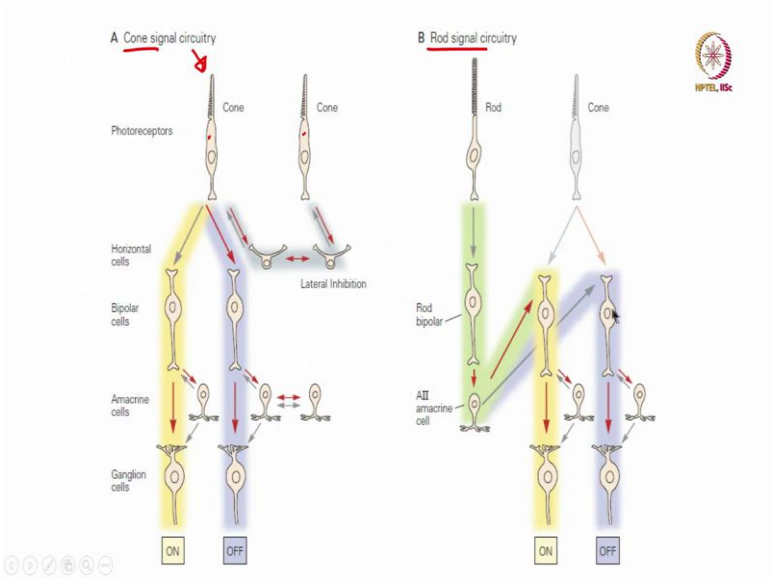

So, I the put it as image processing we start with some basic architecture, you are familiar with these things in the eye retina which has got the circuitry which is which have got multiple cells. The cells are actually in the way of light and the receptors are the depth and the receptors as opposed to conventional neurons are neurons hyper polarize as when the when light in photons impinge on them and that in turn causes reduction in receptor activity.

So, when receptor activity is decreased the output cell which is the Ganglion cell the output activity increases. So, that is how signal is generated in the signal is generated on stimulation with light within the visual pathway. So, with that introduction I think I will start with network analysis.

Network again taken from Kandel, and Schwartz please go through the textbook. I am walking through that because the network is I think they have there is an elegant depiction of the network, and this network is important for subsequent discussion.

So, Cone signal and Rod signal circuitry we will start with the cone data. So, two adjacently adjacent cones there is light only on a what one specific cone over here. What happens with that? Now, things in red indicate that there is negative the other one is positive I think I have only one colour. So, it is red again and it would be confusing, but I think the pointers are very elegantly placed enough to convey the data.

Now, one of the things which I had discussed one key point which needs to be remembered is there is no 1 is to 1 data transmission. So, one cone does not go into one yeah one cone goes to one Ganglion cell in the phobia, but it is not necessarily a feature. So, how the architecture yeah and it is not a linear transmission. So, you have got several cells in between multi synaptic pathway multi synopsis indicating multiple other cells. We now discuss the roles of these cells.

So, a single cone and the single cone, which is over here stimulates a bipolar cell, bipolar because this cell has got one process over here and another process over here this bipolar cell in turn reduces the signal over here and that in turn causes Ganglion cell. Ganglion cell is the output cell of this entire architecture it is an on.

Now, it also implies that this cone sets up another pathway of the adjacent cone in which a bipolar cell is inhibited. This bipolar cell in turn causes negative feedback on Amacrine

cells, it the bipolar cell also inhibits the Ganglion cell, but because the Amacrine cells are also involved there is an off.

So, one photon causes one Ganglion cell to be on and the adjacent Ganglion cell to be off. So, not only that this cone also through these horizontal cells signals these horizontal cells which are involved in subsequent pathway of the adjacent cone negative by which it causes something called lateral inhibition.

So, what happens is you have a central on and then there is a next to adjacent off. If you look at rod signal circuitry it is somewhat similar, there is cone stimulation which in turn causes this bipolar cell to be activated and Ganglion cell activation, but the adjacent Ganglion cell is off. Rod signal bypasses through the rod bipolar amacrine cell and then causes two signals one negative over here and a positive over here positive in the sense of Ganglion cell activation.

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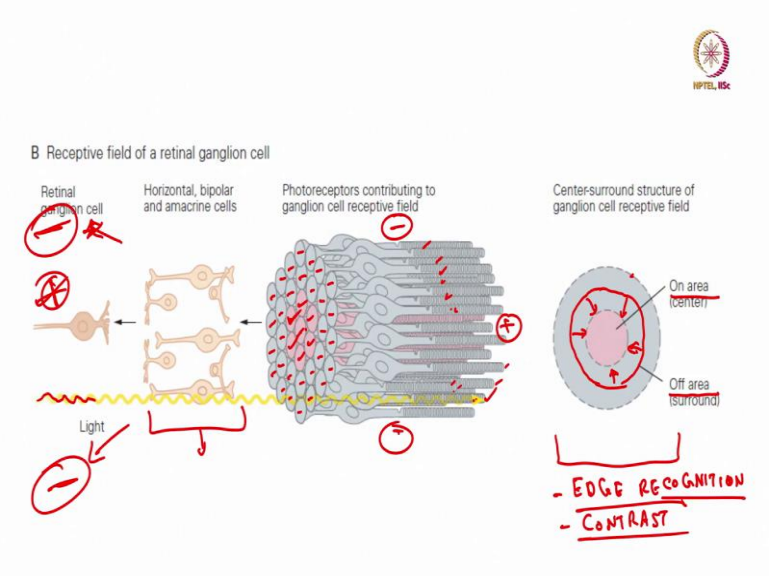

Now, what this means is better explained over here. So, this is the same concept in a different picture, and this is what is I think better represented. So, again if you look the idea that light has to traverse through the entire cell structure is shown over here goes and stimulates a set of you know photon it is not a one photon to one receptor. So, there are many photons which stimulate a set of photo receptors, and all the photo receptors are some of the photo receptors are stimulated meaning it based on intensity of the stimulation.

So, there is a set of cones which are cones or in this case it is rods which are activated, but this implies that because of the secondary circuit over here. So, this secondary circuit ensures that there is one set of Ganglion cells in the centre which is activated because of this.

But it also ensures that all the peripheral; the peripheral in the sense next to this adjacent; adjacent is a better term all the adjacent receptors are inhibited. So, you got a central activation and a peripheral inhibition and remember this is at the level of one single set of one single set of photo receptors, we have how much 6 million or something photo receptors and this is what is the status.

So, if we look at signal generation. So, signal generation would look like this. So, there is an on centre and an off area by which diffuse, say for example the native signal maybe something like this the native signal is something like this. But then it has got focused

into this specific thing it does not activate this entire thing. So, it is this signal is converted into a very specific signal by which you have started the beginning of Edge Recognition and Contrast.

So, these are for sets of receptors please remember. So, the these are 3 dimensional and edge recognition is basically you have formed an edge between light area which is lighted and where whereas an area which is not lighted and that is the principle by which you have the on area in the centre and the off area in the periphery.

So, that processing in turn is mediated multiple through multiple channels, one is of course mediated through the same pathway. But one is the bipolar sorry the Ganglion cells and the next level on the sides are inhibited and the central cells are excited. So, that is the that is the idea and the second the other method is that these cells which in which are in the periphery are inhibited, whereas the centre is stimulated. So, that is a important concept which is there which in which is present within the first level of first level this is retinal signal processing.

So, retinal signal processing is very sophisticated it is it you know the constructs of image processing, such as edge recognition, segmentation multi object segmentation is already started within the retina which is not just a dumb sensor. Sophistication which is far more than any of the devices which I am aware of so this is something.

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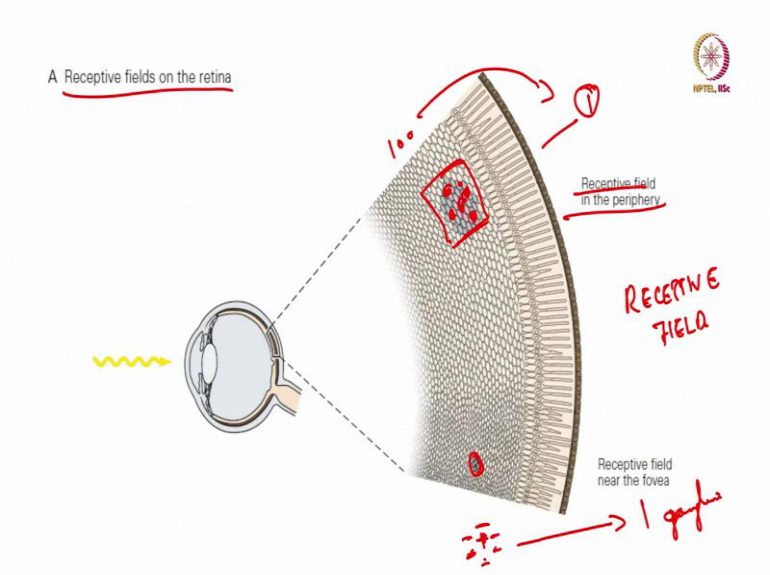

Now, I spoke the idea about spoke about the idea of multiple receptors converging onto a single Ganglion cell. So, the fidelity of transmission obviously depends upon the number of receptors converging into 1 Ganglion cell. So, that is the concept, which is highlighted over here, in the periphery you have very large receptive fields.

So, what that means is that you know anywhere in that area you put in a stimulus you would get 1 Ganglion cell activator it is just a numerical way of putting it. So, you can say that there are about 100 cells over here and that leads to 1 Ganglion cell which is activated.

Whereas, when we look at the phobia you have a very small see here actually it is a hexagon. So, 1 positive which is surrounded by 6 negatives 1 positive 6 negative cell and that goes to 1 Ganglion cell. So, there is a lot of fidelity differences between the peripheral retina and the central retina which is the phobia and that is what is depicted over here.

So now, these the area which is supplied by which is from which data is collected by a single Ganglion cell is the receptive field. Receptive fields of the so receptive field of the Ganglion cell and that is how the architecture is built or rather it is present within the retina.

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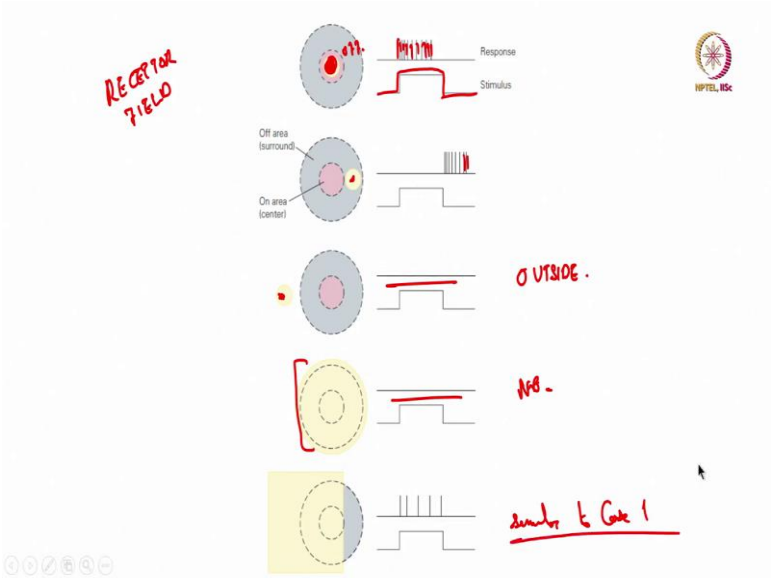

So, now it gives rise to lot of downstream discussion which is which I think I have taken these pictures from various sources commons common media sources. So, this is these are the pictures. So, suppose you have a central area of lighting. So, the stimulus is like this, and you generated you generate responses which are there during the process of lighting, on the off area it is sorry yeah for this is a specific receptor field. So, you shine light in the centre this is the response which you get so light is in the centre and the for a light which is in the centre there is a peripheral off.

Now, if you put light in the peripheral off you have signal which is out of phase when compared to this signal which is outside of the receptive field outside of this receptive field no signal entire area stimulated no signal. So, no signal no signal when signal is either outside of the field or completely this one. If you put part of the field again it would look somewhat like case 1 we skip to the next one so.

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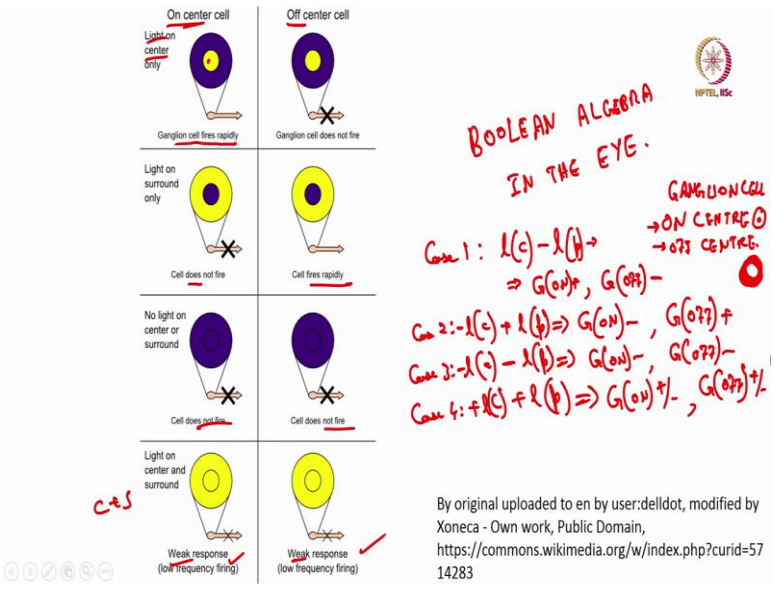

I think the right title for this paper should be Boolean algebra in the eye, I would invite enthusiastic listeners to model this somewhere.

So, let us see what happens with an On center and Off center light on in the center only. So, light is on in the center Ganglion cell fires rapidly, Ganglion cell is the output cell. So, this is On center cell, so there is an Off center cell which fires when the center is off. So, this is On center so center On center cell is it reference to Ganglion cells.

So, Ganglion cell On and On center Off center. So, On center means light is in the center, Off center is light is in the periphery that sort of reflects the idea which is over here. So, we come back to this discussion On center cell light on in the center only Ganglion cell fires rapidly, Off center cell Ganglion cell does not fire because light is only in the center of the receptive field light on surround only. So, the Off center fire cell Off center Ganglion cell fires rapidly this cell does not fire which was On center, no light obviously nothing fires not fire not fire.

Then light on center plus surround center plus surround this is center plus surround is weak response weak response weak response. So, should I attempt center and Off center case 1 as it yeah we need to put something. So, is it a function, it is not a function. So, light center light in the center no light in periphery implies oops On center plus Ganglion cell On center plus Ganglion cell Off center negative.

Case 2 light negative of light in the center, but light in periphery implies Ganglion cell On center is negative and Ganglion cell Off center is positive. Case 3 light in center is not there light in periphery is not there implies I think I should work on the nomenclature bit more negative comma G of negative.

Case 4 plus light in the center and plus light in the periphery implies Ganglion on as plus star comma Ganglion off as plus minus. So, that sort of you know you have actually done the image processing and a lot of gating done with this diagram that is why I thought I should include this.

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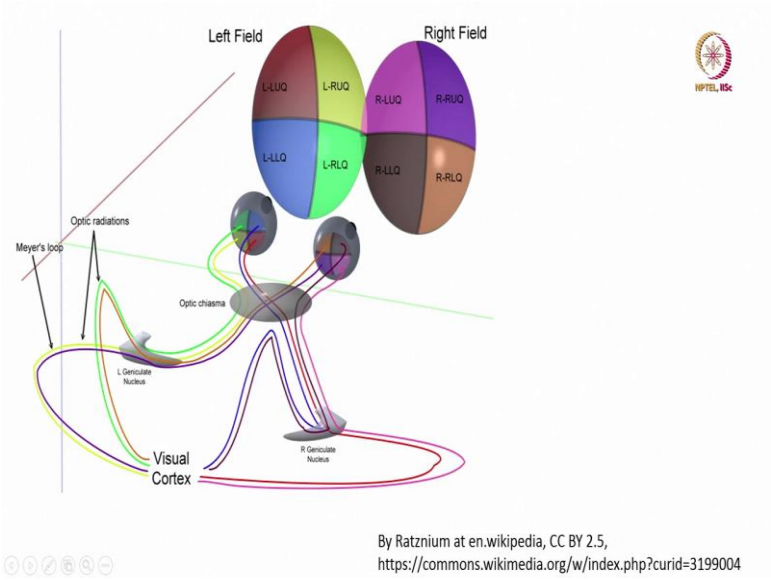

So, what happens is larger context. So, the this is the stuff which is I think it is there in the textbook that is the point. So, there might be many other kinds of processing which I am not which I am not read about and which I am not aware, and I cannot be telling you things which I am not aware of there would be other kinds of processing which are there.

But the highlight of the entire story is that there is a lot of you know the ok I think I should state this an image is actually not formed in the receptor level the receptors just take in data the data is immediately processed. So, there is never an image within the eye you know you at least you know if you look at movies in which you take data from the eye and reconstruct images this is the this is this just goes against biological logic that goes against biological logic.

Biological logic is it is just pure data, the retina takes data and then parse not the retina the receptors take data parses it on to the cells the Ganglion cell which is the first level already gets processed data it is not raw data. It is not just the photon intensity it is not the color channel not just the color channel intensity it is a lot of other it is already changed and that there are different cells which are hard wired for these purposes and combinations and permutations of this.

So, there is already a neural network in the retina. So, as to say and the first level parsing of the image happens over there the image as such is not formed. So, if you cannot say that this is the image in the retina, this is the image in the optic nerve this is the image.

So, there are never has been an image that is a key thing. So, this is something which I think I will skip.

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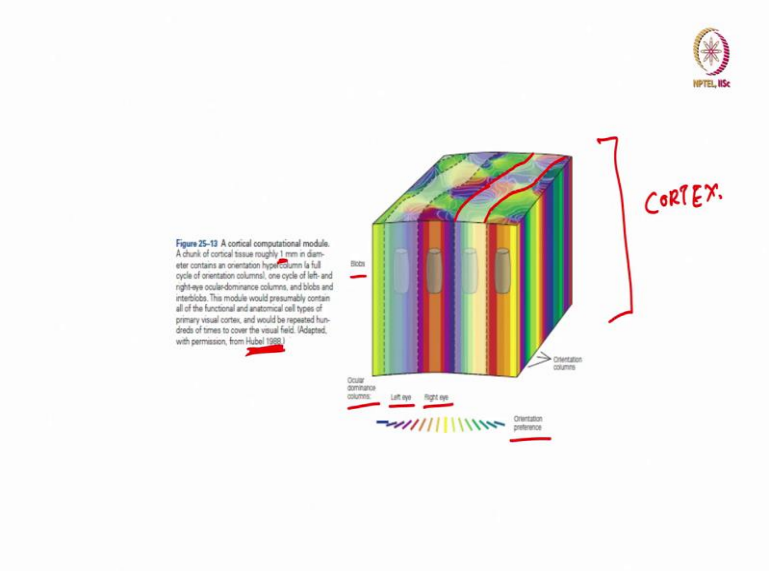

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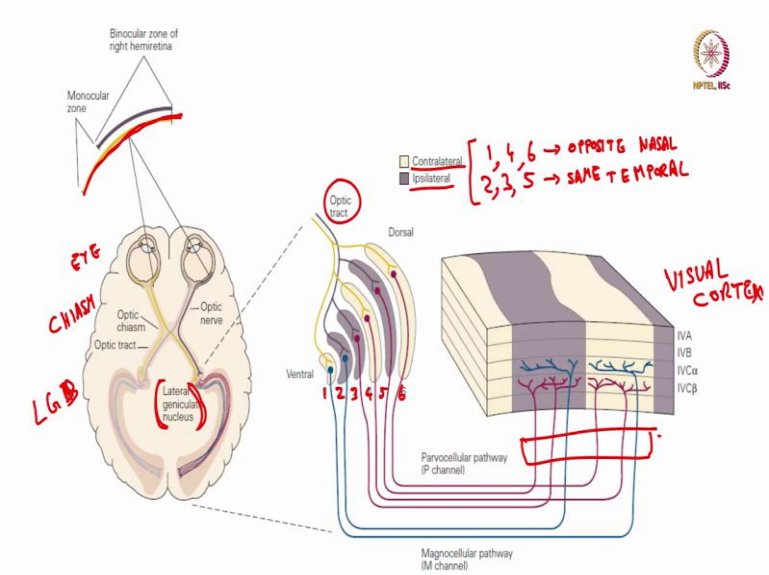

So, yeah so this is the next part of the story which I have to tell. So, what happens so far, I have discussed about what happens within the eye, then I have discussed described stuff which happens in the chiasm. Now, I included this slide in the image processing part of the story for a specific reason. Now the LGB for instance as very funny thing

which I do not know how to interpret this, this is one of the places where I said that Engineering methodology can show or shed light into biological processes.

See so far in the introduction I have told that it is engineering which has been inspired by biology, but there are places where biology may or should be taking in data from the engineering side and workout methodologies by which by using engineering method methods, techniques, algorithms to interpret what is found in biology.

Now, the lateral geniculate nucleus is hired in is designed in layers. So, we have 1 2 3 4 5 and 6, now optic tract is the input and then there is there are there is this there is this layering which is happening. Now, note that you know I have told that half of the data is coming through from the optic tract from the opposite side, half of the data is coming from the same side and what is shown over here in two colours is this contra lateral means opposite, ipsilateral means same side. Now, 1, 4 and 6 layers 1, 4 and 6 take in contra lateral data, 2, 3 and 5 take ipsilateral data.

So, this would mean opposite nasal field same temporal, if we look at it in eye terms you know when I told you about field remember that this is coming from this entire LGB of one side is taking data from this side of the field. So, that is what is drawn over here, so this is the opposite field which is conveyed to this side lateral geniculate nucleus.

Now, this particular funny nomenclature you know 1, 4 and 6 is odd meaning it is definitely numbers are even, but it is odd 2 3 and 2 plus 3 is 5 that is how you remember for writing entrance exams. So, 2 3 [Laughter] and 5 is same side and the importance of this is it is not just a biological meaning curiosity, the same representation carries on all the way up to the cortex.

So, that is the significance. So, this is the visual cortex and this kind of representation you know it is coded ok to put it to explain it in another fashion. Parts of your field are coded all the way from what part of your field is being seen all the way up to the cortex you know that location is mapped and maybe that is a myth you know, and it is with high fidelity that is the point. So, LGB is fairly high up the hierarchy.

So, this data from a particular point in the visual field of a person is taken and there are specific sets of nuclei within the LGB somewhere over here and then it goes all the way to specific layers within the visual cortex. So, there is mapping and to recollect to re jog

some of your thoughts, if you remember the same idea is there in the spinal cord in which you know fibres from the leg which go first into the center of the spinal cord and then the hand fibres go into it and then that gets carried on upwards.

So, this idea of you know locking in spatial data of varying kinds. You know in terms of sense organs it is a data from the foot versus data from the hand which is you know which is anatomically preserved and taken up. In terms of the eye it is data from one field which goes to the opposite side, even within a particular field that is left side field or right side field one of the fields there are areas which go to specific layers of the layers of the LGB and from there go on to the cortex and if you see some of these CNN designs they have been inspired based upon this.

But CNN designs are very straightforward they have very simple notions of this complex architecture and I do not think anybody thought of implementing the 1 4 6 2 3 5 architecture for that. There is a relevance I am not able to find what the relevance is now if we look at you know architecture further on.

So, if you look at visual cortex as such. So, visual cortex as such contain you know the whole thing is a cortical column cortex rather and within the cortex you see these bands over here and I think you should also notice that this is a very old paper 1988 and I used it for that reason. So, the people who are actually you know in the field should look back into these things and you know you would get novel ways of looking at image processing with this thing.

So, I will just read it out a cortical computational module a chunk of cortical tissue 1 mm in diameter contains an orientation hyper column, full cycle of orientation column of orientation column one cycle of left and right ocular dominance columns blobs and inter blobs. This module would presumably contain all of the functional and anatomical cell types of the visual cortex and would be repeated hundreds of times to cover the entire visual field.

So, you know there are cells which are for orientation, then there are cells which are for dominance left eye right eye and then there are these blobs. So, all these various kinds of data I think I have missed something earlier yeah.

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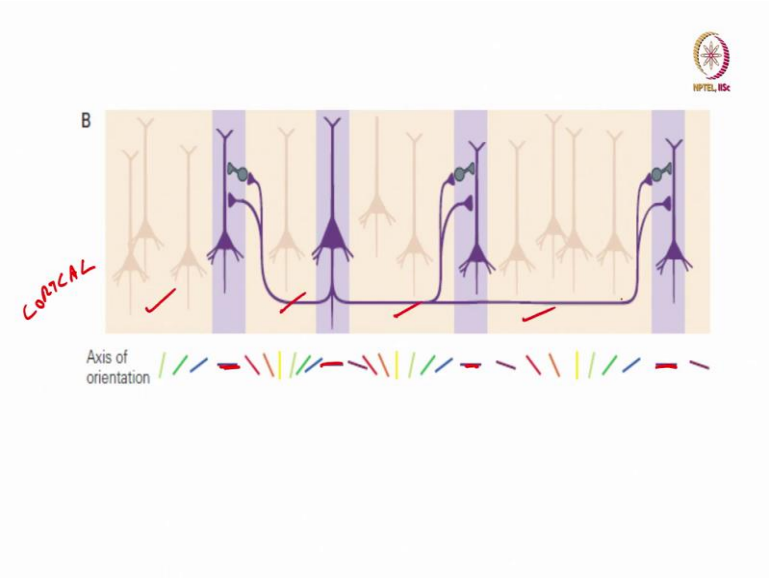

So, this is the slide which I have missed. So, again people who have looked at large what is that deep neural networks with hundreds and hundreds of layers are familiar with this concept meaning they would have read it that somewhere down their anus they start to form neurons which purposedly look at orientations of cells.

Now, that actually came up as I understand neural networks, they that came up as a function of BAP propagation, you know it was not designed to be it was not designed to be implemented like this. When they have done BAP propagation and then take an intermediate layer for analysis, they found out that specific layer's specific neurons artificial, I mean artificial neurons have this property that single neuron would get happy with excited with particular orientation of a line, a curve, a color or something like that that is how CNN is built.

Now, if you look at human cells, they have the similar property. So, this is I think cortical cells and you when there is a particular orientation of cells there is a sorry, when there is a particular orientation there is inhibition and then there is activation in all the other orientation. So, that would set of neurons are there which get higher level, this is not at the retina this is at cortical levels there are sets of cells which get which can be shown to be happy when there are lines of a particular orientation. So, that is one of the things.

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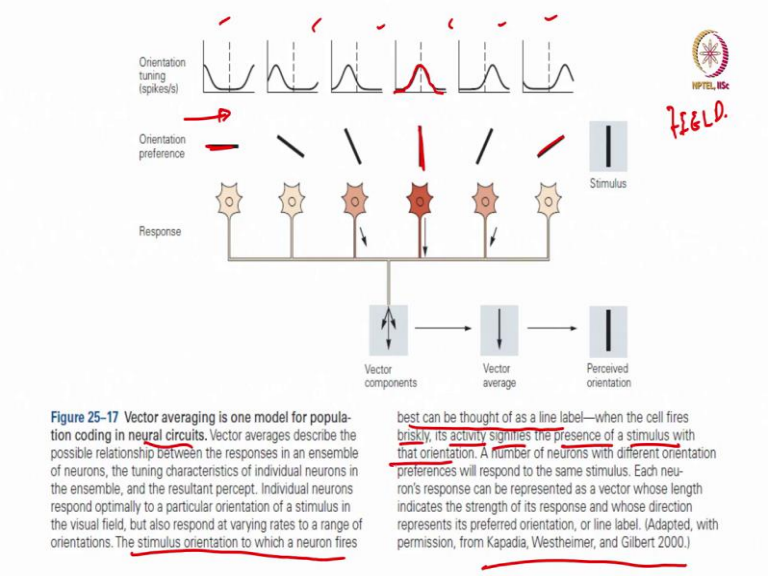

Figure 25–17 Vector averaging is one model for population coding in neural circuits. Vector averages describe the possible relationship between the responses in an ensemble of neurons, the tuning characteristics of individual neurons in the ensemble, and the resultant percept. Individual neurons respond optimally to a particular orientation of a stimulus in the visual field, but also respond at varying rates to a range of orientations. The stimulus orientation to which a neuron fires best can be thought of as a line label—when the cell fires briskly, its activity signifies the presence of a stimulus with that orientation. A number of neurons with different orientation preferences will respond to the same stimulus. Each neuron's response can be represented as a vector whose length indicates the strength of its response and whose direction represents its preferred orientation, or line label. (Adapted, with permission, from Kapadia, Westheimer, and Gilbert 2000.)

So, now we look at different paper this is somebody from 2000 and how you know orientation preference causes change in spikes. So, let us look at data orientation which is like this causes a signal which is happening over here. But, when there is the other kinds of signals you do not have, but what happens is when you have moving cycle of you know movement across the field.

So, you have the neurons perceiving the movement and the direction of the line. So, that is I think I will again read this thing vector averaging is one model of a population coding in neural circuits, vector averages describe possible relationships between blah blah blah and sorry meaning it is the stimulus orientation to which a neuron fires can be thought of as a line label and the cell fires briskly it activates activity signifies the presence of a stimulus with that orientation.

So, orientation can be coded on to individual cell firing and that is something very interesting which is you know there is a 2000 paper way before AlexNet and CNNs. So, way before in 2000 experimental evidence is there that this kind of pattern happens and now, we are seeing that CNNs actually generate neurons with same interest. So, there is some fundamental thing.

So, though BAP propagation does not exist in conventional you know neuronal biology, you know you the neurons do not solve differential equations back and get you weights

and what is that weights and biases adjusted. There are mechanisms maybe that this the network had done its homework a couple of million or billion years back.

But you know they we are seeing the final robust network which is the you know which is the network which is which has been found to be useful. And these networks these biological networks show phenomena which have been demonstrated in CNNs and that I think is a very important reason why I just put the slide I just put the diagrams and I leave it for the audience who are interested to go in greater detail.

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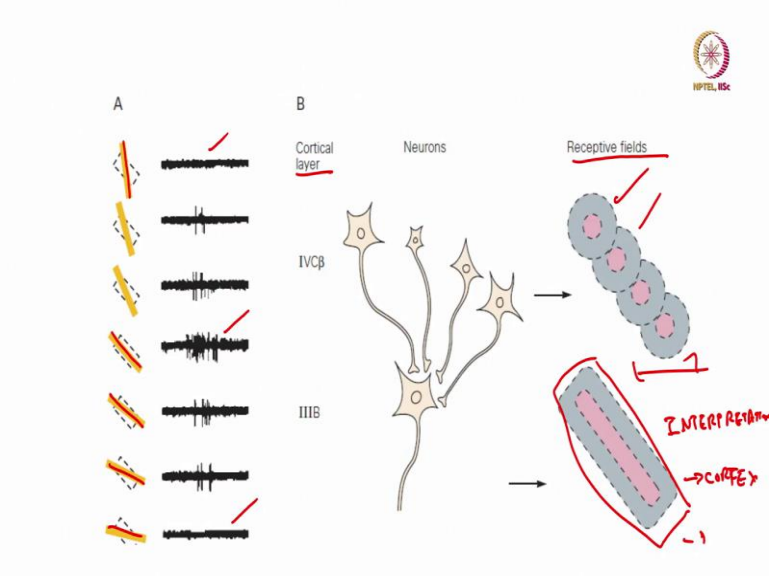

So, another kind of data I think this is again from Kandel. So, free to look up the original paper. So, we are looking at Cortical layer data and what actually happens with these how movement is pursued, I think.

So, you have stimulus which is going from here and then turning signals which have actually which are not there here and which are not there here, but you have got robust signals over here. So, which indicates from the receptive field data that there is a line in the which is the interpretation of a line.

So, receptive field On Off center all that stuff gets, you know it is this is retinal level data. So, retinal level data to higher cortical association and the in between stuff. So, picture which shows all of that data and how you know movement how orientations are perceived by using neural networks and how receptive fields in the retina which are

generated I have been transmitted all the way up to the cortex and the cortex interprets this as a moving line.

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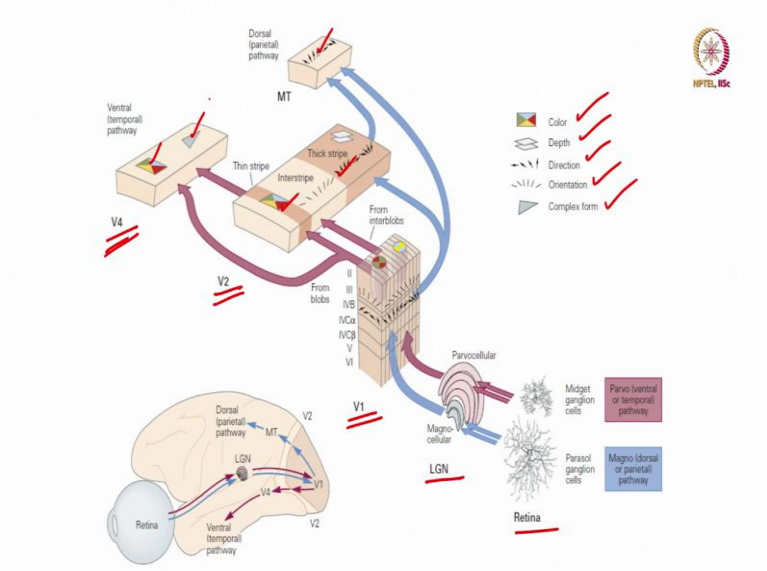

So, this would form I do not know what is next after CNN there is so many of them that I do not recollect the name of hand. But I am pretty sure people who are in the field would recognise something very what you call you know it looks like a CNN architecture. Then what is this; this macaque monkey I do not know some animal model where there is retina, lateral geniculate nucleus, the primary visual cortex and secondary visual cortex and the temporal pathway.

So, different kinds of data color, depth, direction, orientation, complex forms are generated at various levels. And say for example color here then there is direction here goes to a different area for direction mapping, color is process somewhere else and what is these complex forms of process somewhere else.

So, this is how you know the visual system perceives objects, I think I should reiterate here with a greater confidence that images as such are not formed anywhere within the brain. So, it is something else, so you do not take like a camera you do not take a image and store it in the brain it is attributes which are stored. So, these attributes are you know blended with several other kinds of attributes from several other kinds of sensations and mixed up.

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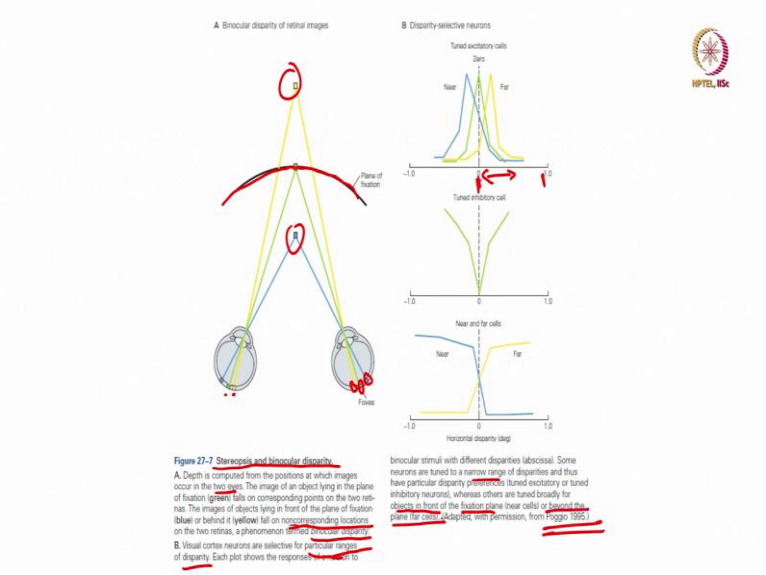

So, that is the other slide in between I think it should because the topic is the same, this is stereopsis and binocular disparity. So, how is depth and you know so many other things sizes depth everything perceived.

So, binocular disparity is the difference which you have because you are viewing from both the eyes and then there is this the difference in focal length which is interpreted. So, how that is interpreted is what is shown 1995.

So, very interesting that many of these things I do not think even now maybe these algorithms have been put into practice in biological sorry in engineering context, not read about anything in the CNN side which is looking at these things. So, depth is computed from the positions in which images occur in two eyes. So, two eyes is the key word here the image of the object lying in the plane.

So, you have a plane which is there which is the focal length for the retina at that given point of time, fixation green falls on the corresponding points of two retinas the images of objects lying in front of the plane of fixation blue or behind it yellow a fall on non-corresponding locations. So, they do not fall on the same area they fall away from the primary phobia which is where the density.

So, that is used to so that causes binocular disparity. So, binocular disparity is between the difference between this and this. Visual neurons are selective for particular ranges of

disparity. So, that is a key term here range of disparity, each plot shows response of a neuron to binocular stimuli based on the deviation from this center. Some neurons are turned towards tuned towards a narrow range of disparities and thus have particular disparity preferences are tuned excitatory or tuned inhibitory neurons. So, the others are tuned broadly for objects in front of the fixation plane or beyond the plane.

So, you have mechanisms by or not they are not mechanisms they are neurons which are happy when there is something in front and there is something behind your field of focus and they are happy about it they are not bothered about whether the object is of interest to the person not of interest to the person they are just excited.

But, when there is something else happen and you know the focus needs to shift from the immediate focus to the next point which is there, this neuron would help you tell help you to tell that the next level of focusing has to be towards you or away from you. Whether the eye moves away to get focused on a distant object or whether eye has to move towards each other to fix on a closer object. So, that is the that is the that is the idea.

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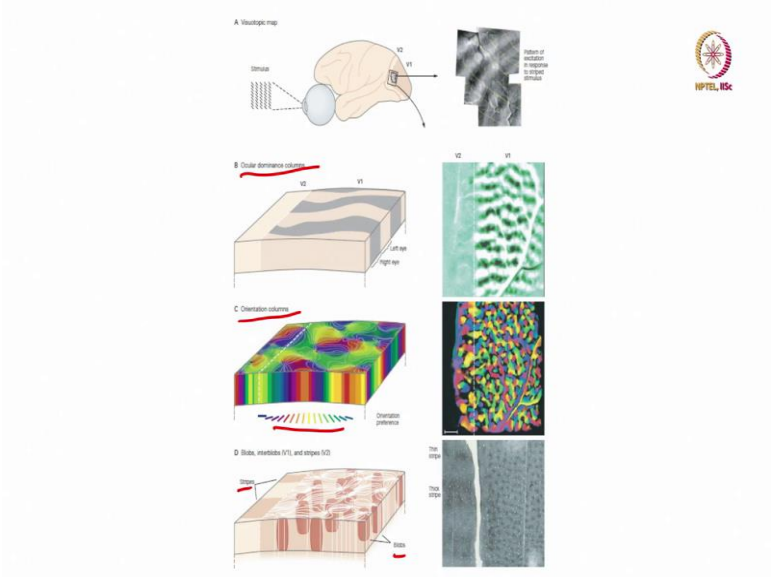

So, the these are maps which are there within the cortex. So, I will just list out. In fact, I myself I have not read this paper. So, I do not think I am an expert on this topic neither am I expected to be expert on this topic. But my idea of conveying it to you is that these

things are there and for people who are interested please do look up read because they are interesting to read if you have the time and necessity of reading it.

So, what is shown here is ocular dominance columns, orientation columns which is all color coded. So, various parts of the cortex are hard wired to different orientations and then there you have these architectures of blobs, stripes, these are higher level computing architectures maybe something like equivalent to server architectures in computation.

So, you have different sets of servers computing different things and they are all wired together. So, something similar to that you have blobs which contains aggregates of neurons doing some specific function. And they do it without you know they are not they do a specific part of the task and that is the similarity within CNN D players.

Where you know specific layers specific neurons within the CNNs take in data for a specific task and then they just pass it on pass it on to the next layer and you get a defined output at the end what you want. But that again remember is BAP propagation and this is not BAP propagation.

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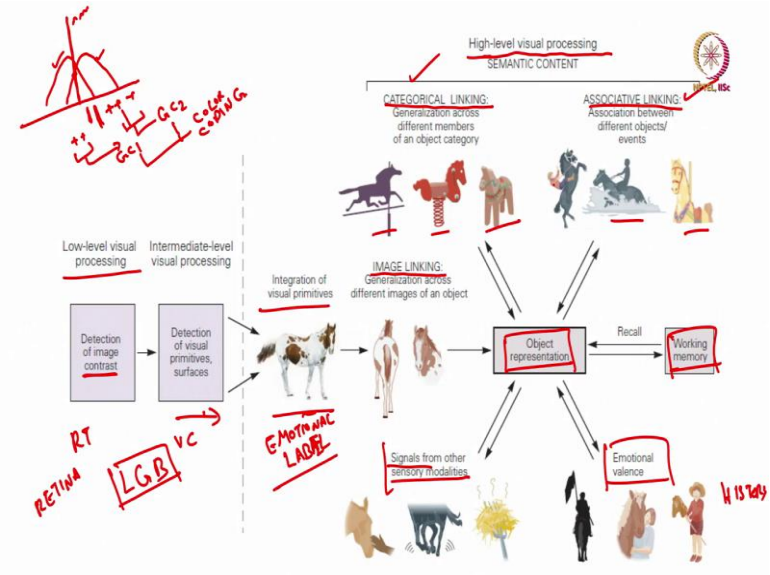

So, this part of the discussion would be incomplete without discussing high level visual processing. So, we have low level visual processing. So, image contrast see On Off Off center, On Off and On center Off center gives you lines boundaries contrast at level of

the retina, you also have data on colour because ranges of receptor function correspond to colour.

So, you have a particular say you have I think I should draw this that is why. So, you have a photon of this intensity you know this intensity on that you have two cones which are side by side and one cone will stimulate at you know plus 3 and then you get plus 2 from the other one and these two go to Ganglion cells 1 and Ganglion cell 2 and then you have a specific colour coding.

So, I had not mentioned this earlier so that is the reason I thought told. So, a photon of this particular nanometre impinges onto the retina. So, that would stimulate one cone which has a spectrum like this and another cone which has a spectrum like this. So, this is just looking at colour it is not looking at spatial orientation which I have discussed so far.

So, colour can be coded like that by differential actuation differential stimulation of two sets of receptors, two colours receptor. So, this is green and red. So, green and red stimulators receptors are stimulator to varying extent for a given single set of photons and that gives a sense of what nanometre of colour has landed on their retina.

So, that is how colour gets coded. So, detection of contrast and images is done lower level that is basically done in the retina, then primitive surfaces go all the way back to visual cortex. So, visual cortex retina then there is a lot of intermediate stuff which is happening at the LGB which is position locking and coding and mixing of data from both the sides of the field.

Then like in image processing so yeah so conventional image processing requires you know pre-processing of data that is the engineering side of the study. So, pre-processing is basically already done you know yeah pre-processing is done in the retina you know contrast enhancement, the color fine tuning, On Off all those are you know pre-processing kind of stuff.

So, pre-processing is done in the retina the image gets on to the LGB where spatial data is integrated, because you know field level data this field this data is mixed specifically reaches specifically the LGB from there it is transferred on to the visual cortex. Visual cortex lines things are drawn and then you have an object recognition which says that

there is a particular object, it can be linked with previous objects say we have a vast storage of these things.

So, maybe various kinds of objects are you know you map it on to your prior here prior history. So, it is an exotic horse it is not exotic horse it is a breed which you recognize breed we do not recognize it is a horse generated by artificial intelligence it is not a artificial intelligence generated horse all that stuff then there may be categorical linking.

So, categorical linking is whether it is a play tool toy different kind of toy then you can have associative linking. So, association of horse with a rider horse on meaning in a game horse as such in a what is that it is a this is a play whatever arcade game. So, you make up associative linking, categorical linking these are higher level stuff. So, starting from image we going we are going into higher level stuff starting from object representation.

So, these representations are saved say partly in working memory then integrated with signals from other modalities say sound of a horse or smell of a toy, you know those things are connected and then there is emotional valence. So, you know you may have an emotional history which you attribute, or you know label this particular you which you can give label sorry my yeah, my so and emotional label also gets attached.

So, the next time or sometime in the future when you are recollecting the horse which you saw now or in this picture, you would also have the emotional baggage which you had labelled along with that object at that point of time.

And that is how you know it is seamless the memories being associated and connected and shown over here are all seamless and that is how vision is processed starting from individual photons, generation of potentials local pre-processing. I think pre-processing is too simple to be told to the activity its contrast enhancement, line recognition, object recognition all that stuff happens over there.

But it is parsed on up you have spatial coding where from the object is obtained and then it goes to the high level cells where motion classification happens, image segmentation happens, multi object classification happens and along with that you add the emotional stuff.

You take in stuff from memory and connect it to it as of a future storage or working memory, you know horse in the present environment is something to be handled hostile not hostile, friendly unfriendly, able to write not able to write all those classifications are made at that point of time. So, that is the idea of this graph. So, I think we can we I close the topic on vision at this place, we will continue with the next class on something else.