Virtual Reality

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Lecture – 10-2
Human Vision (neuroscience of vision)

Is it good, bad? I do not know, but it is something people have done some research Marty banks at Berkeley for example, has considered making head mounted displays that have multiple depths. There are some lenses for example, that have 2 different indices of refraction based on a current that you apply through it. Based on say putting a electric potential across it. And so, based on that and a series of lenses like that you could get a discrete number. But 3 lenses like that together you could get 8 different focal lengths, and then you could track how the eyes are converging to estimate what depth the eyes are trying to focus on, and then change the focal length of the optical system based on that. And do it all quickly enough to have low latency. So, it is possible, but you know very difficult and probably a long time before we will have engineered solutions that fix this.

So, it is something we have to deal with. So, if you want to put things very, very close up in virtual reality, I would say be careful. Use that sparingly you know, do not make it so that there are things very close up in front of your face. If you put some a sign that someone should read, some kind of menu or something embedded in the world. But I would put it at least a meter or 2 away, right? Does that make sense? All right, questions? I am going to now start to talk about what happens to the information or the signals that are absorbed by the photoreceptors. What happens after the photoreceptors, in order to do that, I am going to show a number of pictures for that.

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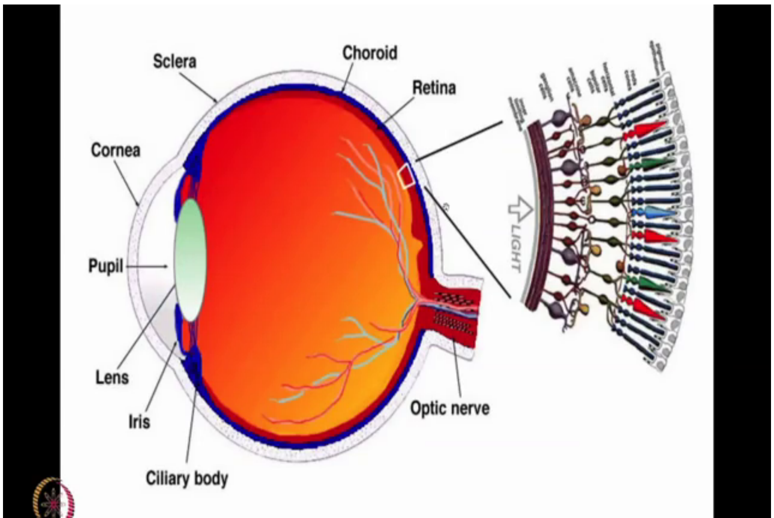

Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

So, let us take a look at the eye again very carefully. So, again it is a standard kind of picture as we seen. And all along the retina, we want to zoom in and get a picture like this. So, let me let me zoom in a little bit more in fact. So, here are the rods in the cones. All the way in the back. Notice that the light is coming in this way. And there are some collections of cells here. So, there are a bunch of neurons that are part of your eye. And they are doing image processing work, if you would like to consider that before it ever gets transmitted back to your visual cortex.

So, there is a lot of work going on before the signals even leave the eye, which I find fascinating. So, some basic kinds of filters let us say are doing their work beforehand.

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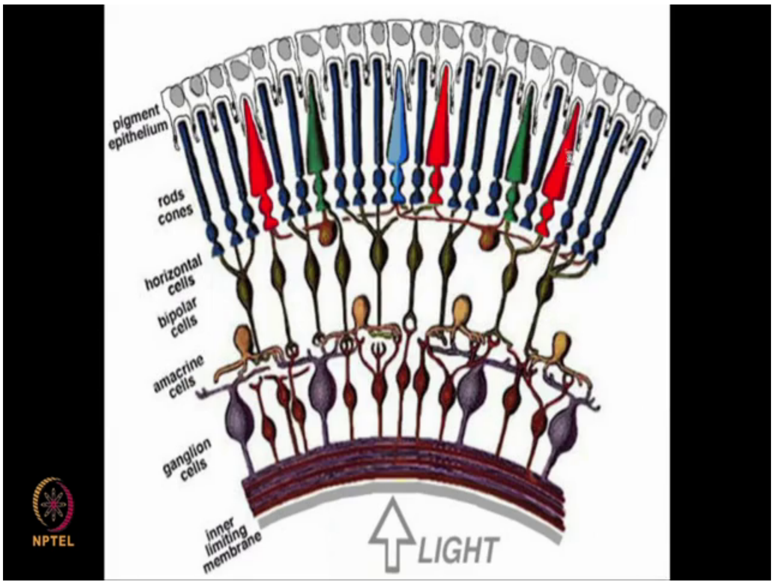

There is also something peculiar let me zoom in just a little bit more. So, you see the same kind of thing, or the light is coming in. The photoreceptors are in the back. And then there are a bunch of neurons in the way here, doing some kind of work, different types of cells. And I will talk a little bit about what these are doing in in just a moment.

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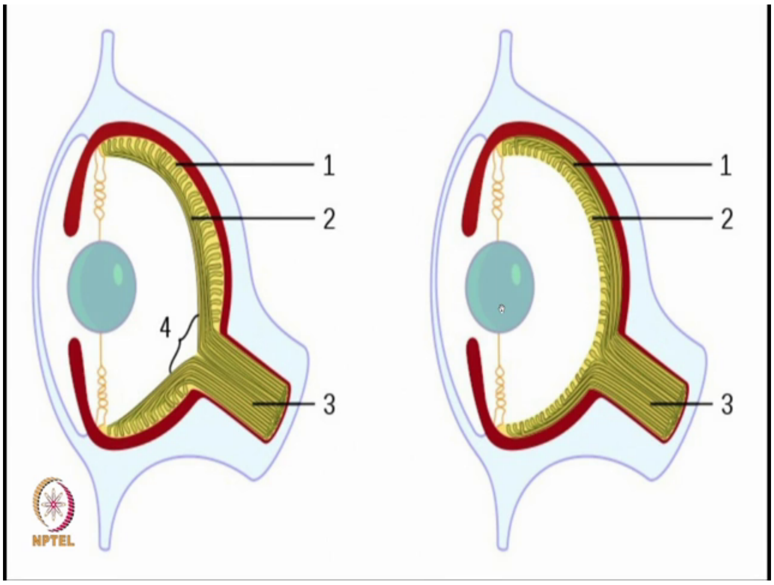

But the interesting thing is that over here on the left, this is roughly how our eyes look. And on the right are how the eyes of cephalopods look, which includes octopus squid cuttlefish. And in in the right case, you see that the photoreceptors are exactly facing the light, and in the human case, although the shape of the eye here is the same as the shape force (Refer Time: 03:29) it is inverted. So, this case is like the way the human eye is and if you decide to do it like that, if the photoreceptors are facing let us say the wrong way, then you have to get all this wiring, it is like a bunch of cables, looks just like electrical engineering and you have to route the wires somewhere.

So, they are all routed across the front, and then there has to be a hole in the field of photoreceptors so that all the cabling can go run back to your visual cortex eventually. And so, because of this. There is a hole in the retina, and this shows up in this picture here; where the optic nerve which sends all the information back to your other parts of the brain needs to occur. So, there is the blind spot, we talked about that in photoreceptor densities, correct? Right, remember there was a blind spot. Very easy experiment to find the blind spot. This is one of these again amazing things that happens with the human brain.

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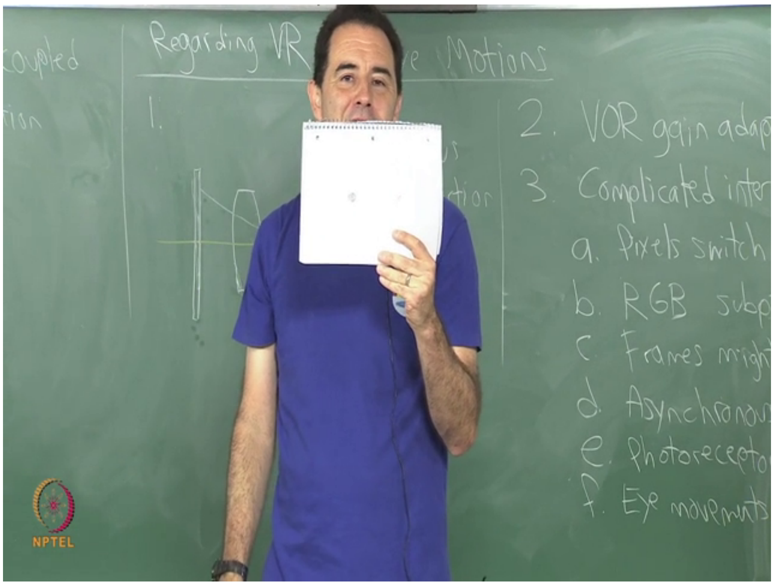

So, if I just put in an x on a piece of paper, and also draw a circular blob about the size of a small coin. I put them about 12 centimeters apart. And then I try this experiment, where I close my, let us see if I do it right, I close my right eye, I use my left eye to stare at the x, and then I change the depth for me, right when I am here, the dot that I have drawn completely disappears, and I perceive blue lines to be covering it.

It’s a very powerful phenomenon. So, it just vanishes. So, I was able to put this dot exactly in the place where the where the optic nerve is, and there is this blind spot in the array of photoreceptors that we have. It is important to focus on the x, because if I rotate the eye to look at this, then it just points the fovea. So, I am not can a let the I cheat like that. You have to look at the x, and you get it just right. Make sure you pick the proper I otherwise you have to do it this way, some (Refer Time: 05:24) because it is over to the side a little bit, right the phobias straight ahead at least.

Um. So, hooray for (Refer Time: 05:31) we have it the wrong way it appears. So, because of that we have a blind spot. But the brain is quick to fix that for us most of the time.

Student: (Refer Time: 05:38).

Yeah.

Student: (Refer Time: 05:39) purpose of having a (Refer Time: 05:41).

I do not know, I have seen a little bits of speculation theory, but I think it is an example of a local optimum. So, in other words evolution got stuck there. Let us say in along some path. So, it does not seem to cause great harm.

Student: (Refer Time: 06:05).

Right, I think having this tiny blind spot, I do not think there is a purpose as far as I know. So, no I would not assume that evolution is going to reach a global optimum every time, I believe that based on the conditions it is going to settle in various local optima, right? And maybe that line will become extinct, when it is eaten by a better design at some point right. So, if you know that is the case, but it seems like having this blind spot was not enough to cause us to get eaten. So, right it would be very difficult for a predator to figure out our blind spot and exploit that I suppose. But I do not know, it is very, very speculative, but there seemed to be no purpose.

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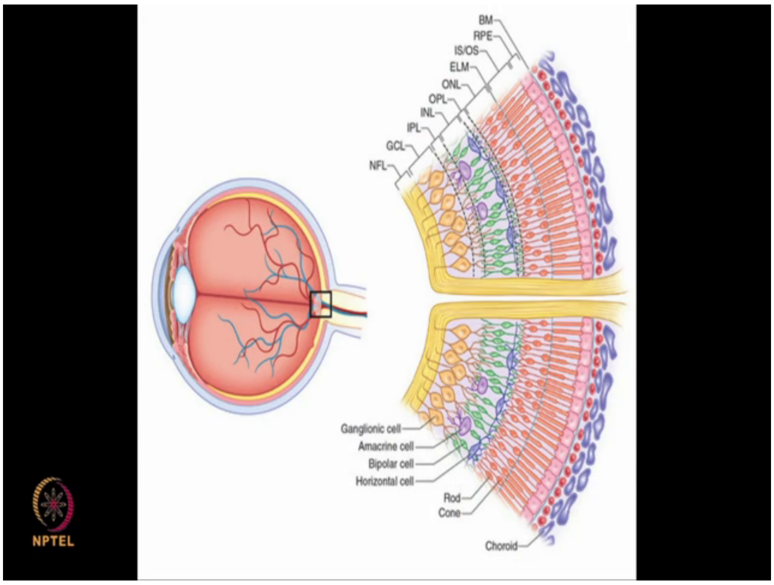

All right, so we have this, and we have all of these structures in between until eventually the light hits the photoreceptors in the back.

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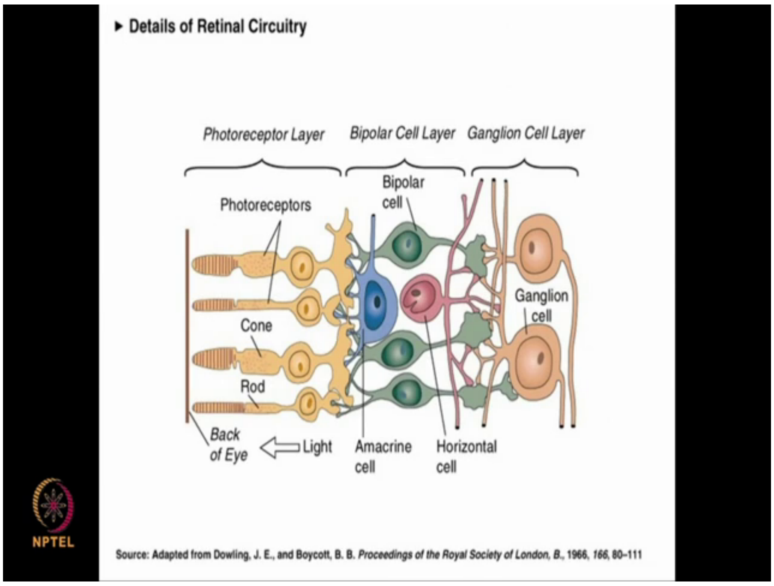

And so, a lot of people study the details of this retinol circuitry, I am not going to drag you through the details of that. But we go from the photoreceptors the rods and the cones, and eventually end up at the ganglion cells; where the axons or the output part of the ganglion cells are connected, they form the optic nerve, and connect to what is called the

LGN in the brain which is kind of a central switching station. Then eventually signals are sent onward to the visual cortex.

And so, I want to talk about a little bit of what is going on inside here, but not drag you through.

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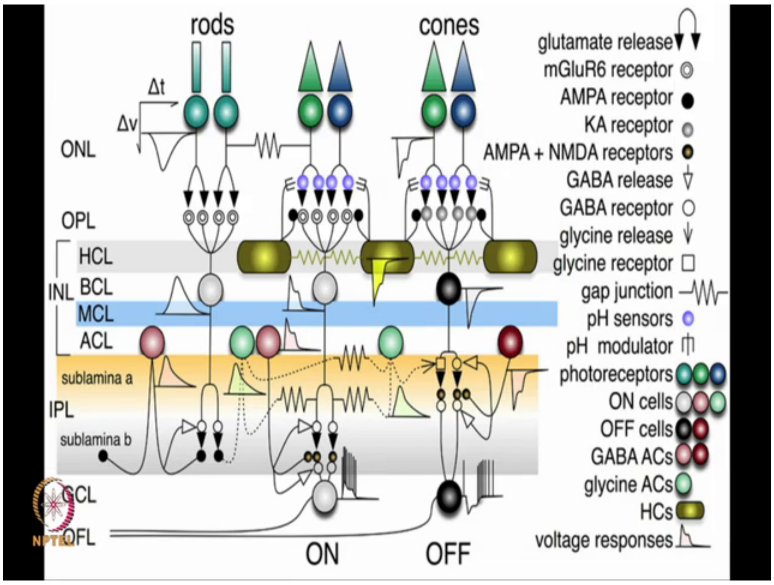

Lots of details. People make very complex electro chemical circuit models of what happens from the rods and cones into these cells, such as if I go back to first step are these bipolar cells, that is one of the main kinds of them. So, what exactly are these doing, and people form very complex circuit models of this; which reminds me of reverse engineering, right as I said. So, imagine if your electrical engineers, you use build circuits, you analyze them, here you are given some kind of circuit that might as well have been designed by aliens. And you have to put sensors in try to figure out what it is doing during it is normal operation. So, you can speculate what these pieces are doing. And there is still a lot that we do not understand. Fact we probably the parts we do not understand are probably greater than the parts that we do understand.

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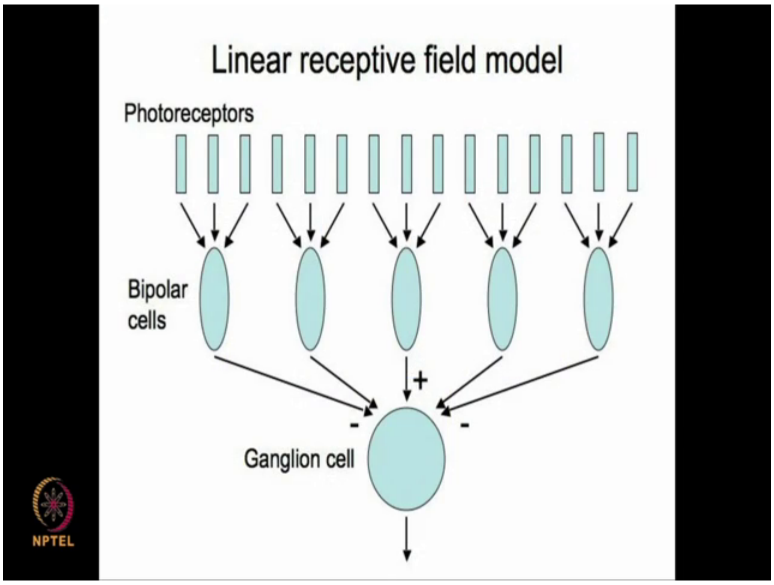

One thing is very clear it seems. There are around 100 million photoreceptors, and there are only around a million ganglion cells.

So, some kind of compression is happening, right. That is one thing is very clear. So, people think that there is some kind of funnelling that is occurring, or some kind of filtering that is occurring. Each one of the intermediate cells has a receptive field. It gets information from multiple photoreceptors in a neighborhood around it. And it could be mixtures of rods and cones, they do some kind of detection let us say, and then they pass that on further. So, that by the time information goes into a ganglion cell through it is dendrites, and the cell just some kind of processing, and then it sends information along the optical nerve, it may be taking into account on average about 100 photoreceptors, right? Or more? Could be quite a bit more, because not necessarily single photoreceptor is not necessarily sending it is outputs in one direction only right.

If I go back to these different types here, there is 3 different kinds of cells any bipolar cell layer. I should just say a little bit about it. So, there are off and on bipolar cells. The role of these is to detect a change in photoreceptor activity. So, the on cell will be fired if the photoreceptor changes from being hardly receiving any photons to suddenly receiving a lot of photons. And then the off bipolar cell detects in the other direction. Like it is turning off right. So, the change is what is being noticed there. There are horizontal cells as you see in the picture here as well. The horizontal cells connect in from a output from multiple bipolar cells together, and they are looking at lateral information, or spatial lateral information; such as there is been a change here, but not here. That would be called a lateral inhibition. There is some kind of place where there is a change in the change across space, right there is change over time, but it does not occur spatially.

So, that is interesting. They are also am amacrine cells, and people are not really sure what those are good for. So, there is still a lot of speculation. So, very difficult to figure out what is going on inside of here.

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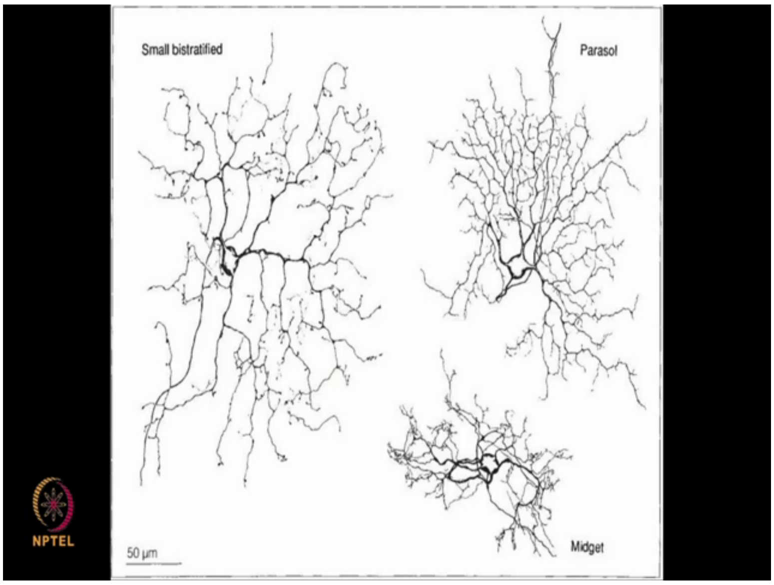

So, when we get to the ganglion cells, there are 3 different kinds called midget parasol and small bison by stratified cells. Or and the midget cells are there is 70 to 80 percent of the ganglion cells are called a midget cells. And these are mainly used for photopic photopic vision. Parasol are used for both photopic and scotopic, and by stratified cells are mainly for photopic as well. And they have different functions. So, the midget cells are also using this opponent see kind of idea which is looking for changes inside of a spatial region.

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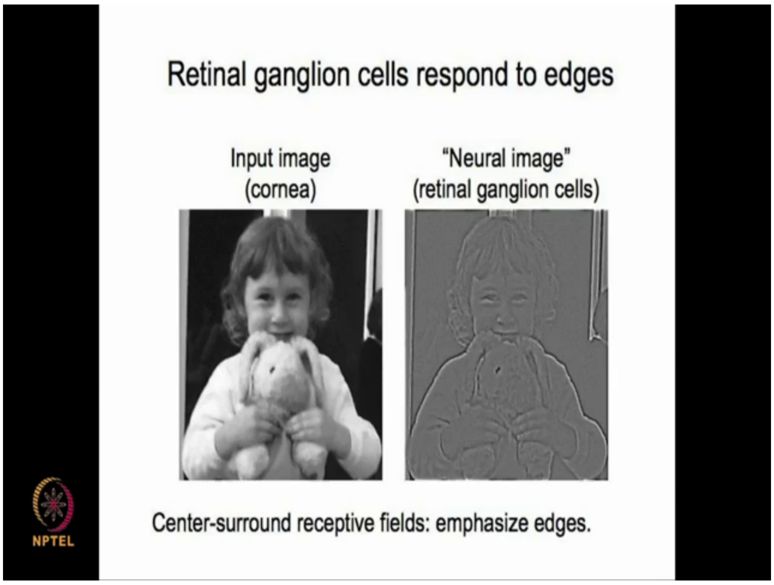

Let me give you some examples of that. So, by the time you get through the ganglion cells, they are mainly generating something that one I call a neural image which is on the right. The original image that we might see which may pass into the cornea, may look like the left by the time it is communicated through the optic nerve, it may only be like something like edge detectors, and things like that right. So, the kind of primitives that you are familiar with in computer vision.

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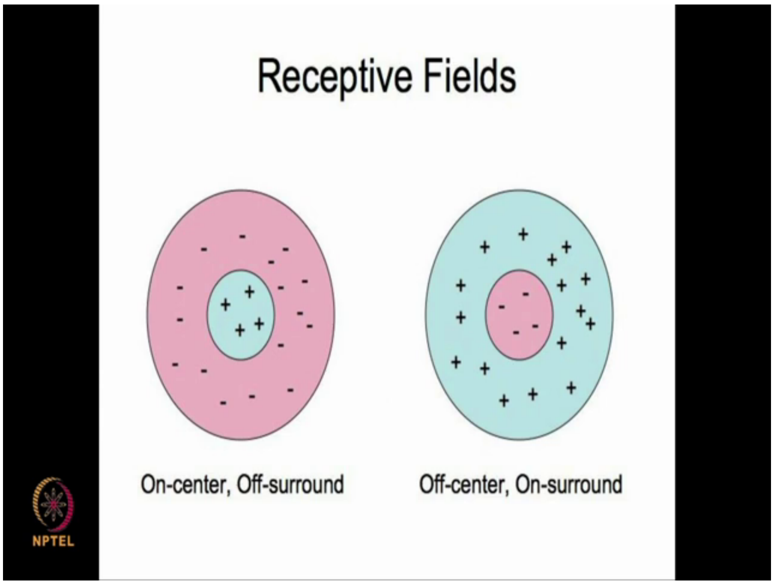

So, for example, is one of the most common types of ganglion cells called on center off surround or off center on surround, where they will look 4 distinct patterns like this.

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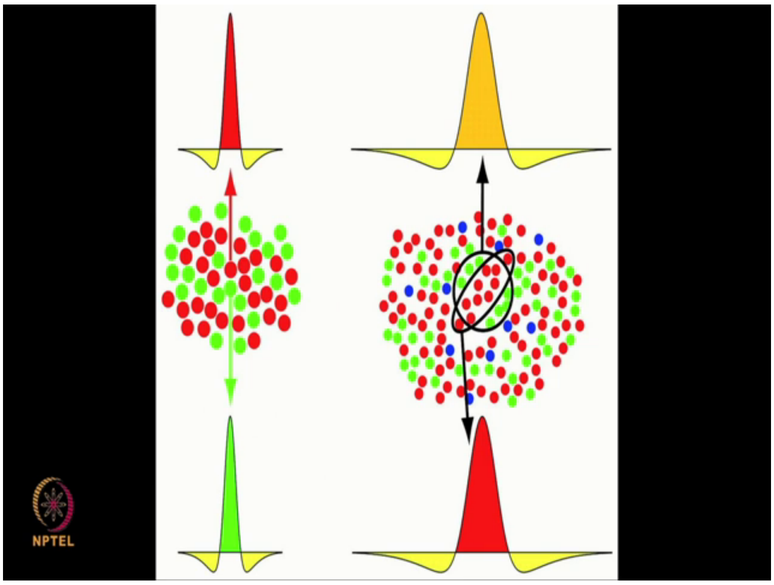

So how this might look in terms of photoreceptor rays there is groups of photoreceptors, and there is a receptive field that will be firing. So, for example, here there may be very simple patterns that correspond to get is a photoreceptor on, red photoreceptor on green, if I have a very complicated pattern together; let us say this look at this disk case. There may be some greens surrounding some reds, and they have the ability to detect changes spatially with regard to those colors.

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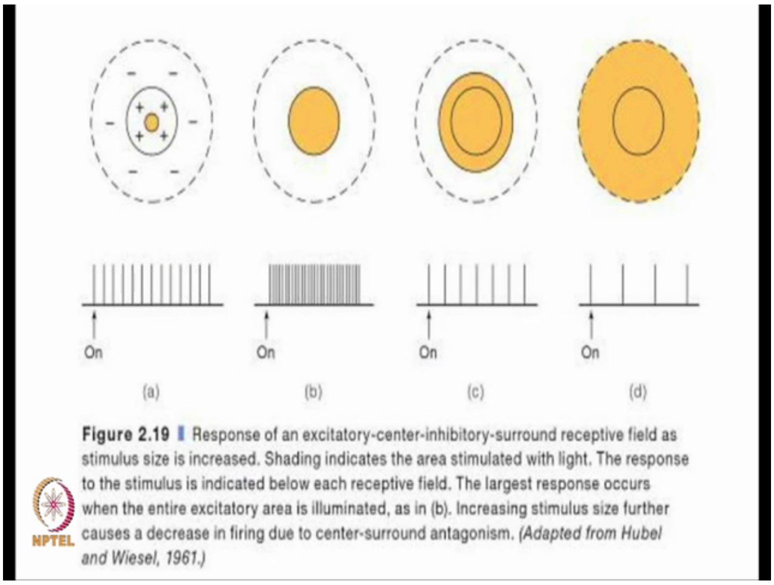

So, here is a very simple example of these on center off center cells. So, it may be the case that, this shows the firing of the output or axon of a neuron. It may be the case that and by the way the firing of them ends up being a pulse train. And the higher the frequency of pulses the more active the neuron seems to be. So, it is it is getting excited let us say, when there is a bunch of blips or pulses. And when there is very few pulses and it is not very excited anymore. So, that is how the signals are communicated. So, this particular type of cell will get most excited let us say in the second case here. So, this is what a ganglion cell is doing believe it is example a midget cell. And it has a very heavy firing occurring here.

Because it is detected activity in some small region, but are not surrounding that there is no activity, right. And this dashed line out here corresponds to it is overall field of view. So, everything inside of this disk, it can detect information with regard to, and there is no stimulus let us say our low stimulus in the low stimulation in the outer part, but high stimulation and interior part. But then as the stimulation region gets larger, it goes back to not firing again. So, it only likes this case where it only gets excited about this case where there is a small region firing, but not too small, because then it goes down again and there is an outer ring, where there is there is there is low simulation.

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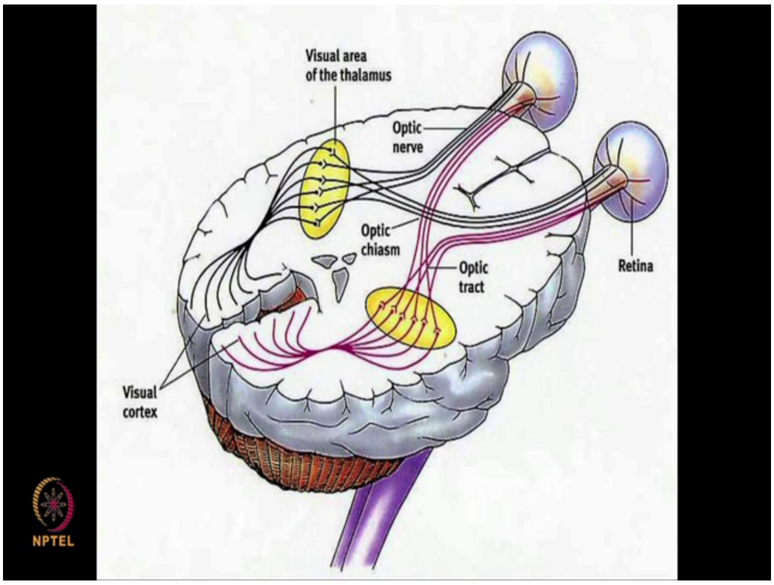

So, that is very interesting. So, it is detecting very specific kinds of patterns. After the information goes through the optic nerve, it goes into this area that is part of the thalamus, which is very, very low level with regard to brain functions. And I should point this out that one thing that is central to these visual pathways is hierarchical processing. Like I will just write that to make sure we get that.

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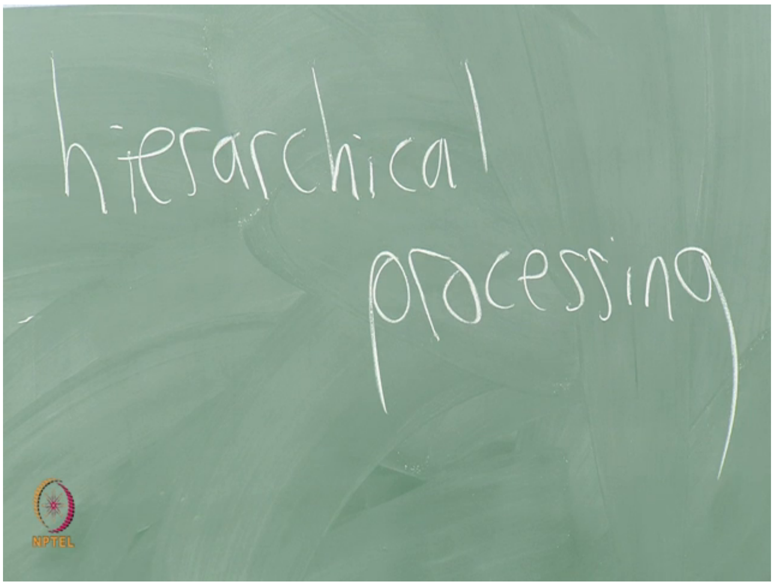

Hierarchical processing, right. The raw data comes into the photoreceptors, it goes through these intermediate cells that we talked about the bipolar cells, the amacrine cells and the horizontal cells, doing low level processing, then it gets up to the ganglion cells that have a larger receptive field for each one of them. And then it goes through the optic nerve, and by the time it gets to the visual cortex, notice there is a crisscrossing performed as well as seen in the picture there. By the time it gets to the visual cortex, then when you think about the number of photoreceptors involved in firing the neurons in the visual cortex, it becomes a very large number. And the overall spatial field ends up being very large. For what is being considered in the visual cortex.

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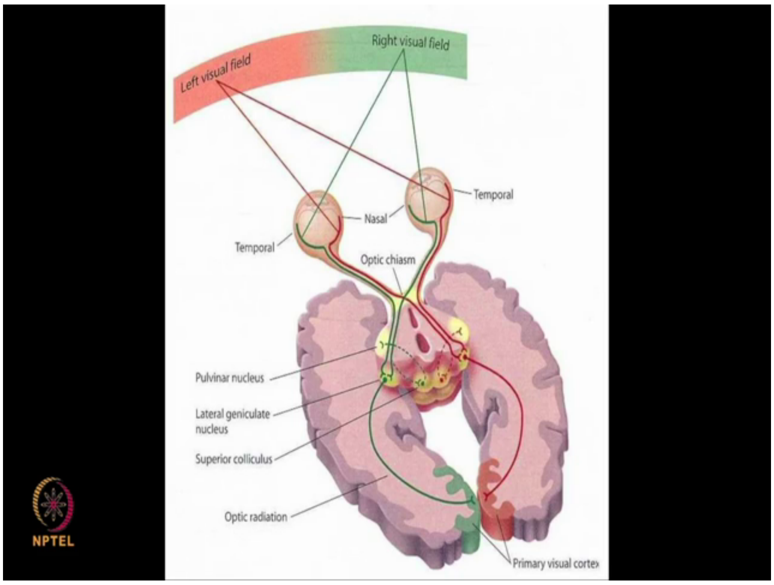

This is another picture of this as well.

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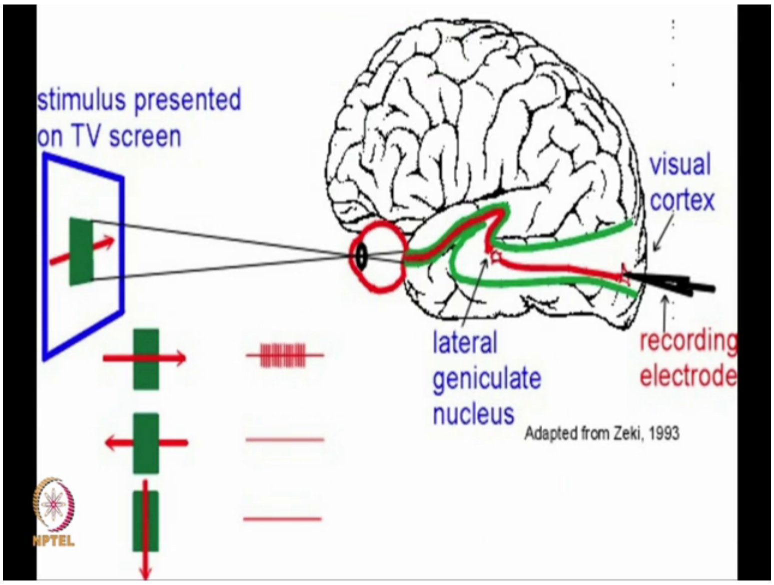

Now, people have done experiments, where you show particular stimulation to the eye, and then you can do what is called a single unit recording, you can measure how neurons are firing based on the visual stimulus. And you can get an idea of how high level the detectors are let us say, the neurons that are doing the detection in the visual cortex.

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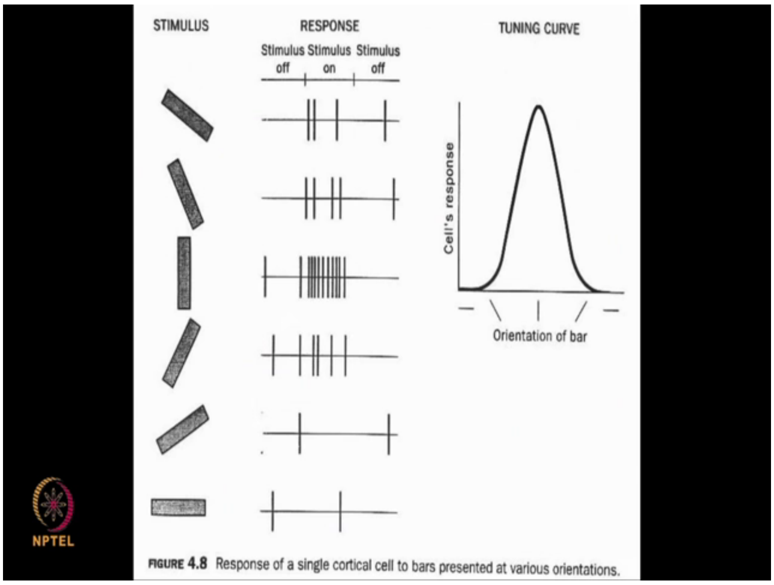

So, for example, you can take a stimulus such as a rectangular bar, and this has been done on primates many animals very large variety of kinds of studies. This is a very simple one, where you just take a bar, and you start rotating it, and you can find a neuron that fires only in a certain direction, right. So, for example, maybe I have my notebook here and I start turning it around, and maybe the neurons will be firing when it is right side up there a one neuron that that likes it when it is right side up and ready for reading, right, or the bottle the same way right.

So, this orientation is quite important. Other orientations make us a little nervous when we know this is water. So, there is reasons for having orientation detectors.

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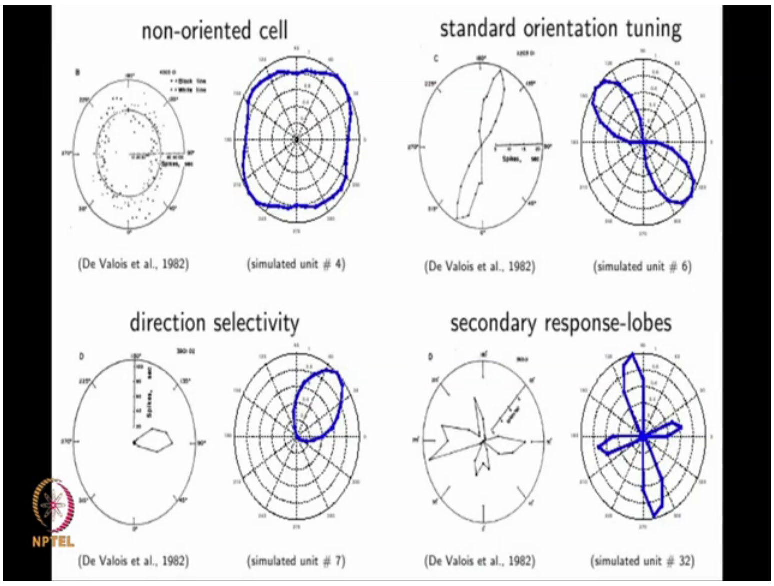

These are some kind of plots where people have done a study for cells that you know some detect orientation some do not. So, for example, this is in polar coordinates this cell, does not seem to respond very much to particular orientations. This one does, but it has a symmetry with regard to upside down and right side up. So, it does not distinguish between those. This one has a particular direction that it prefers, right. So, there are different cells for different kinds of cases in the visual cortex.

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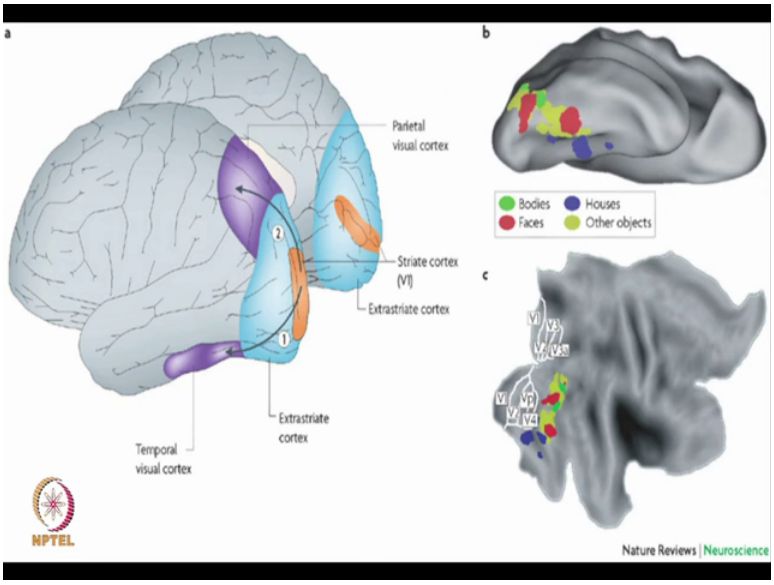

Eventually we could get to higher and higher-level parts of the visual cortex it gets harder and harder to measure these.

But we have regions in our in our visual cortex that correspond to higher and higher-level kinds of concepts. Faces, houses, places, things like that. And one of the big ways to divide up information or processing capabilities inside of the visual cortex is to divide it between where and what right. So, some parts of the visual cortex are doing classification, what am I looking at, and parts are also trying to determine where exactly is that in the scene, right. It may also be then combining with information about your place. I mentioned play cells in the very first lecture.

So, there may be combinations and connections between all of these things that come together to give you a coherent view of the world, all right. Any questions about that; so that is my little bit of neuroscience going through this hierarchical processing. So, I am not giving all the details, but it gives you some kind of view of what is going on.