Virtual Reality
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Lecture - 09
Human Vision (photoreceptors)

Hey, hello welcome back. Let us continue onward. In the last lectures we covered light some of the basic physical properties of propagation of light, and then got into optical systems. I explain various kinds of lenses, and what happens to objects at various distances explained real images, and virtual images.

And then we explain the eyes ability to form images on the retina, using it is lens to change the diopter of the eye. And so, I gave you several cases of that. And I want to now explain what it looks like when in a head mounted display you have a screen placed in front of the eye, with a convex lens in between. So, this is a very common situation and this is what you have in the lab.

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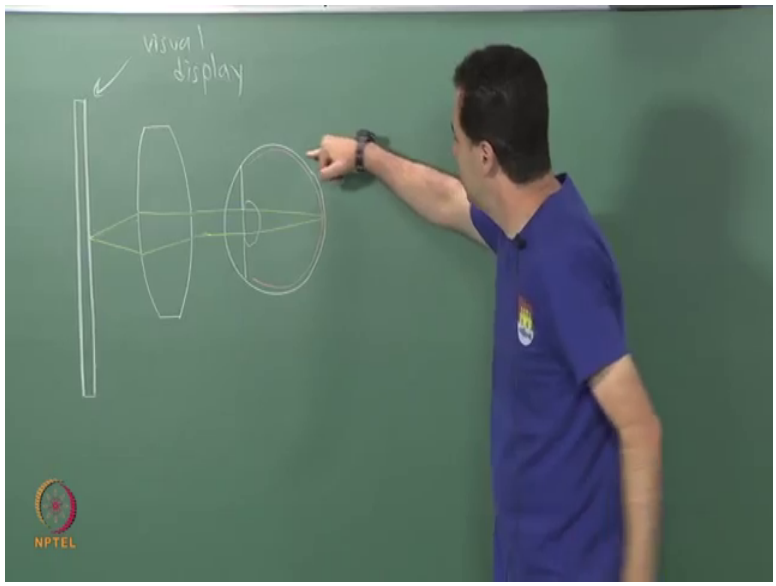

So, if we take the eye again I am drawing the same kind of pictures like I did last time. So, the retina is in the back here. I have the lens of the eye here. Suppose we have light coming in through parallel rays, and then it focuses on the on the retina in this particular example at the place called the fovea which is the place of highest visual acuity which is something that will cover today. As we go along today I will be explaining human vision,

the biology of it some of the neuroscience some of the particular components that we have trying to get you to understand how visual perception happens in our brains. So, I want you to get an understanding of that because that is a critical part of engineering of V R systems overall, alright.

So, we have this and then I have a display, let us say here. So, this is a visual display if you put a display. Very close to your eyes, can you focus on it, right. So, if it is very, very close you will not be able to focus, because if you remember from last time, if you consider each one of these pixels as a point source of light the rays are going to be very much diverged right.

So, and remember the diopter will tell you if you have parallel rays, how far it will take before they converge back from the parallel case. If they are diverged, it will take a very, very powerful lens to do that the lens in your eye can compensate for some of that, but not all of it. So, if I take a very weak lens; so I just brought a week convex lens with me today, and if I want to go up and try to focus on some particular part on the board, I have to stop the lens about I put it you know very close to my eye and see how close I can get I have to stop about right here.

Um I tried with some students in the class a little bit before the class started and they could get it up quite a bit closer, because they are using this lens to further converge the rays are using their eye muscles to further converge I have lost about 30 percent of my ability to do that. So, I have to hold it back maybe in a year till have to hold it even further back. So what is going to work for me on more powerful lens right; so, it is going to do all of the work that this lens, used to do when I was younger and more so that it will work for everyone.

At least everyone who is able to focus on light coming in at a in parallel rays, and focus it onto the retina . You could adjust some lens that you put in between back and forth to cover different cases of nearsightedness and farsightedness. But what you cannot easily compensate for is a stigmatism, which is one of the lens aberrations that we talked about last time and the human eye is subject to astigmatism the eye becomes ellipsoidal in shape in some way and then the focusing becomes a symmetric.

So, if you remember, there is a horizontal focal plane and a vertical focal plane, for example, and they are not the same when there is an astigmatism. But you can at least by

adjusting the lens location have some range of dioptres which makes it comparable for a very large range of people. So, I put a lens in the middle here. And I did not bring up powerful enough lens to really illustrate being able to go very close. You need a powerful if you to go out and buy a very powerful magnifying lens. little bit should be exactly right for this and you can do the experiment yourself.

So, this comes out of the lens, but the point I may be looking at here the pixel, that I may be looking at has very divergent raised if I draw this right here maybe a very divergent raise, but then they bend. Through, the lens and come out a parallel not quite drawing that, right, to put them the lens should be taking these divergent rays. And making them come out parallel. If they come out converging then you have a problem, right, they may come out converging and then no matter what you do with your lens you will you will see blur because they are converging short of the retina. So, you got to be careful with that if you go the other way if they are still diverging a little bit maybe your eye can compensate.

And so, that is that is how depending on your ability to change your lens, all right. questions about that. So, the retina is this part all around back here. I am going to go into the details of the retina, and the neurons that are very close to it. And then I will eventually cover the visual pathways that we as the signals go all the way back into the visual cortex which is back here under your skull alright. So, placed along the retina are what are called photoreceptors.

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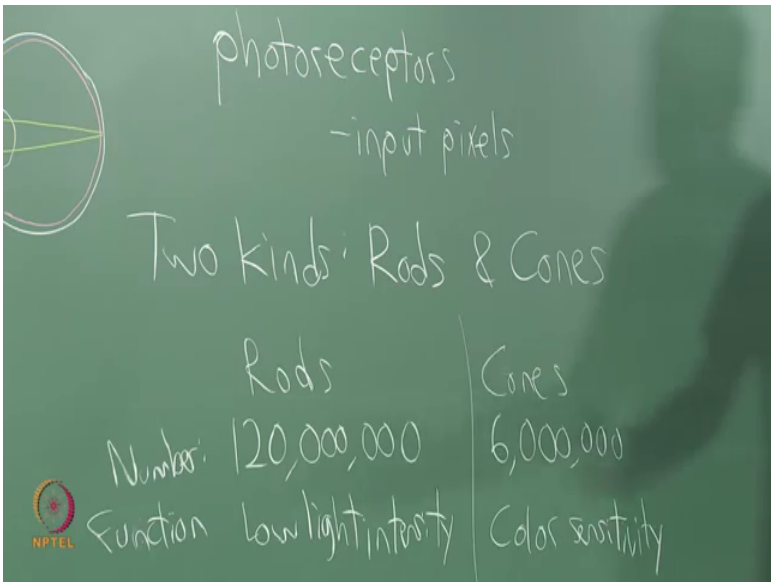

The photoreceptors, let me write it out photoreceptors, I like to think of these as the input pixels and if we think of engineering terminology.

So, the display has it is pixels on it right RGB pixels there are essentially input pixels on the retina whereas, the display is producing the output pixels. And there is some kind of interface going on here that involves a significant amount of optics, right? The eyes lens the cornea remember is doing the most amount of light bending and the engineered lens as well. So, all of this comes together.

There are a 2 kinds of photoreceptors. You may have seen this before rods, and cones. I am regarding rods, we have about 120 million pry. So, and for cones we have far fewer only about 6 million. And the function of these different types considerably different rods are for low light, low light intensity, and the cones are for colour sensitivity. This separation of different types of photoreceptors has a profound impact on the way that we perceive brightness levels, colour, all sorts of things as we process visual information, and we get to the perception of vision. This fundamental separation; so, you may have noticed that if you are outside at night you are getting you are in a low light setting you cannot distinguish colours very well right.

So, it is one of the fundamental outcomes of this. Let me show you a picture of how these rods and cones are distributed around the retina, right. And notice that you know when the light comes in from say the bottom here, it hits this part of the retina right up at

the top. When the light comes in from the top it hits the bottom part of the retina. So, in some sense the image is upside down, right? Why do not I look upside down to you right now? At the image on your retina is upside down yeah.

So, I mean you been your brain has learned to accept that, right? During your entire lifetime; so, it is considered normal there is no such transformation that has to be applied to it there is not like a some neurons that go and flip the image, do not think so. It is just what you have learned you may have heard of experiments where people put on prism glasses, that invert the images and then after some number of days or weeks they do not see the inversion anymore, everything looks fine again.

So, your brain can learn the orientation as being correct and it does not matter this is upside down the right side up is now I have a special piece of hardware you have this devoted to inverting it and correcting it, because it in some sense seats, it is consistent with what you have had your entire life, alright. Let us see, let me show the picture that is always know you.

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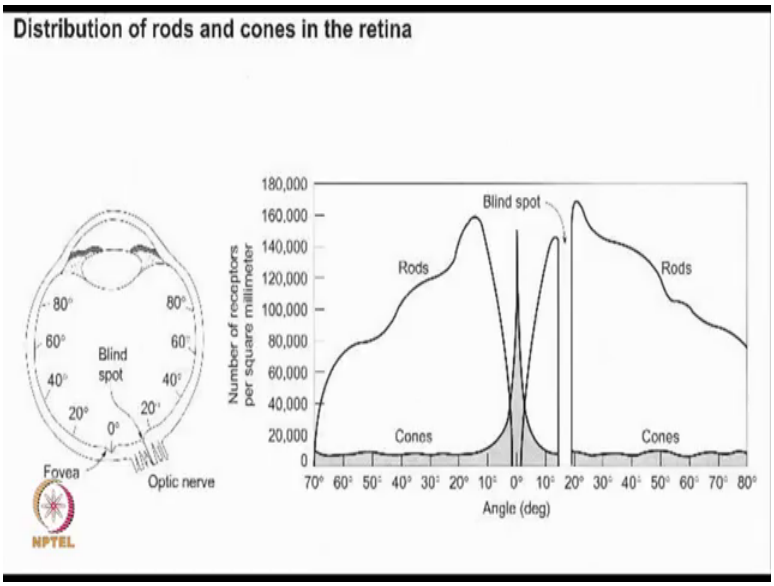

So, this shows the number of receptors per square millimetre. And 0 is right at the fovea, and that is the place where you have the greatest concentration of cones, and then as you get a degree or 2 off from that the cones start to get replaced by rods, and then the rod density increases and until you get about 15 degrees away or so to either side except for this strange anomaly, over here between 10 and 20 degrees which is the blind spot on the

retina. And the reason why the blind spot is there is because of the connection to the optic nerve; which I will show the geometry of in just a little bit.

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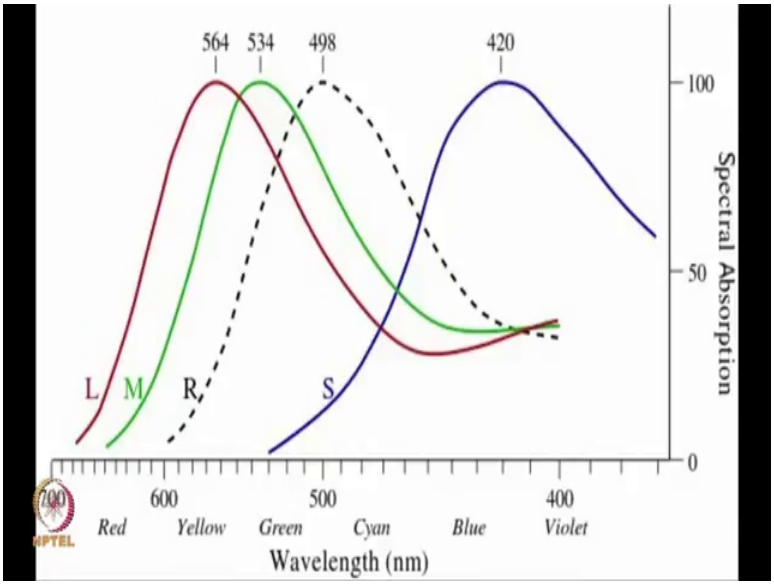

So, for these different types of photoreceptors that we have, the rods are responsive to light across these wavelengths shown in the dashed line here. So, centered at let us say 498 and of course, they will respond to an area around that, but with let us say lower and lower probability for an equivalent intensity of stimulus. And then there are for the cones 3 different kinds, this amazes me it is it is a RGB just like the way we design our monitors. So, in this place; so, we have a we have red cones,, green cones, and blue cones distributed around in some kind of your regular way along the retina.

So, let me just draw a little bit here of a picture as well. So, in the in the fovea at 0 degrees it is all cones, and they are very densely packed.

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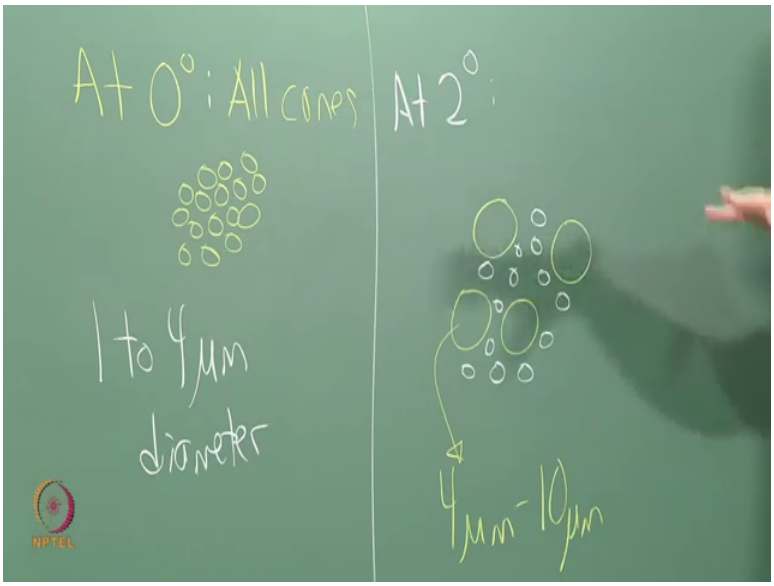

I am not drawing them as different colours, but there is also some kind of irregular arrangement of colours. So, these are quite small there the diameter is between 1 to 4 micrometers in diameter. What I think is interesting about that, is that if we think about wavelengths of visible light. So, let me put that squeeze that up here, wavelengths of visible light.

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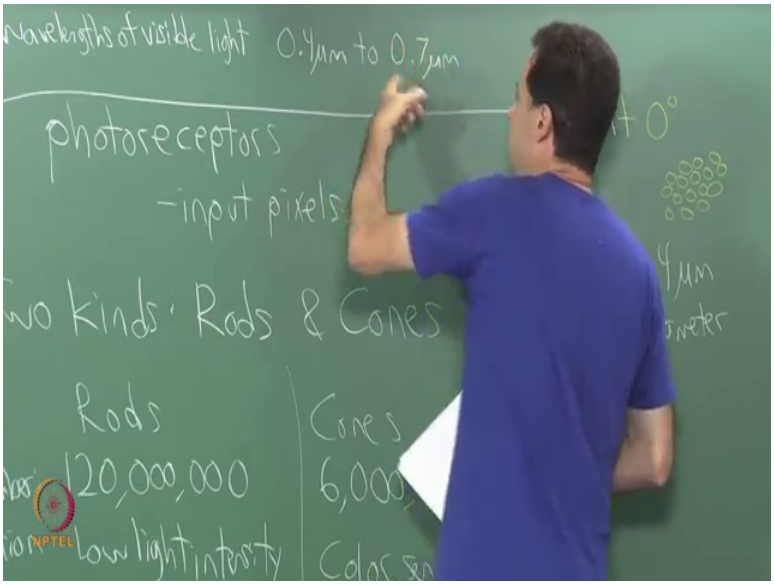

What did I say? It is between a 400 and 700 nanometers last time, but let us convert it to micrometers. So, it is 0.4 micrometers to 0.7 micrometers. So, using 10 to the minus 60

units instead of 10 to the minus ninth units and if we do that, then we see that at the very center of the fovea these things these cones pack in to the size of one micrometer; which is not very much larger than the wavelength of visible light which I find really incredible.

So, if you tried to make these any smaller, you would start to get very difficult kinds of interferences, right. Because with the waves I mean they would be much smaller than the actual wavelengths, and would not operate so well. So, so this seems to be about as small as you can make this and still have it function well, which I think is quite amazing that you know, the density of these again are down to roughly the size of the wavelengths of visible light.

So, quite small; so, these are as I said it is 0, it is all cones. Already when you get over 2 degrees off, then you are leaving the fovea. What happens there, is the cones already are getting bigger and rods start appearing among them. So, the cones are in the 4 micro meter to 10 micrometer range whereas the rods are down to 1 micrometer. So, they are small like the cones were and the cones are now getting larger and loosely interspersed with a lot of tightly packed rods and then by the time we get all the way over to 50 degrees.

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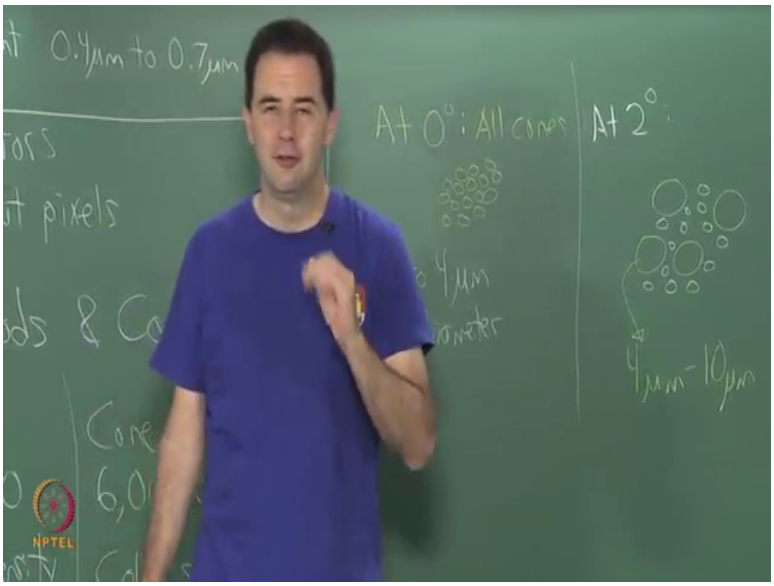

It is almost entirely rods a few strong couple of cones in there. So, that suggests that when we are looking we look forward, when the fovea is fixated, we have a very high visual acuity in colour. And then as we look off to the side without rotating the eye

rightful you look off to the side. So, that the image is over to the side of the retina towards the top or bottom from my horizontal pictures I look to the side right. So, if we if we are looking over to the side without rotating the eyes over here, then we start losing spatial resolution in terms of colour eventually the whole thing tapers off, as I showed in this picture, here eventually when we get 60 or 70 degrees away.

You can see that the density is going down significantly. So, you end up losing eventually everything right, but certainly your ability to distinguish colours out here, it is very weak if you believe you can see colours there it is because your brain is filling in information, that is not there right, and trying to speculate let us say. Any questions about this?