Virtual Reality
Prof. Steve Lavalle
Department of Multidisciplinary
Indian Institute of Technology, Madras

Lecture – 9-1
Human Vision (sufficient resolution for VR)

So, this is a very interesting question that arises and this is fundamental to design of virtual reality headsets. If I put a display in front of the eye like this how much resolution is enough right, how much resolution should this display be given that I know the photoreceptor density in from this plot and from these pictures I have made. We should be able to do some simple calculations and just try to estimate.

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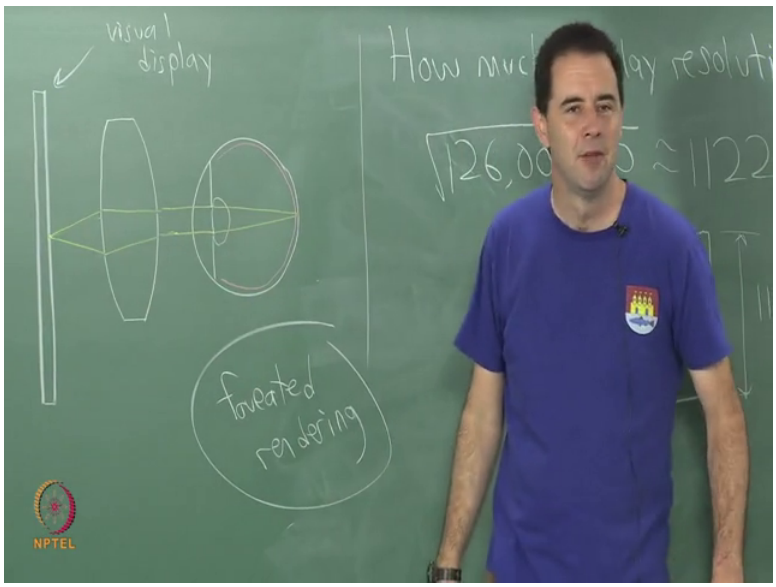

So, when I do that just to give an idea you see this around people in industry are talking about how much is enough I think it is quite difficult to say without doing the experiments. So, somebody has to manufacture high resolution displays higher than 1080p, I mean something like 2k by 2k per eye and then it may be 4k by 4k per eye and maybe 16k by 16k per eye and so forth and see where the limits are right. That is the kind of things that should be done.

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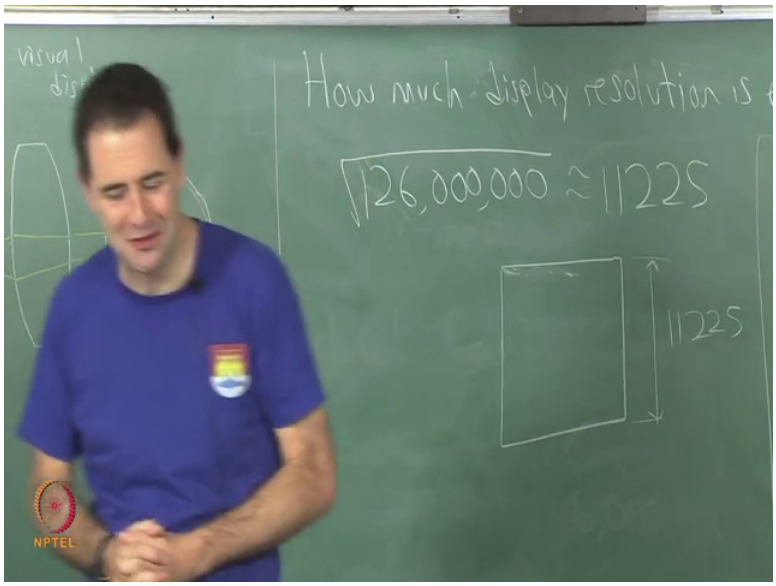

So, how much resolution let us say I display is enough for VR?

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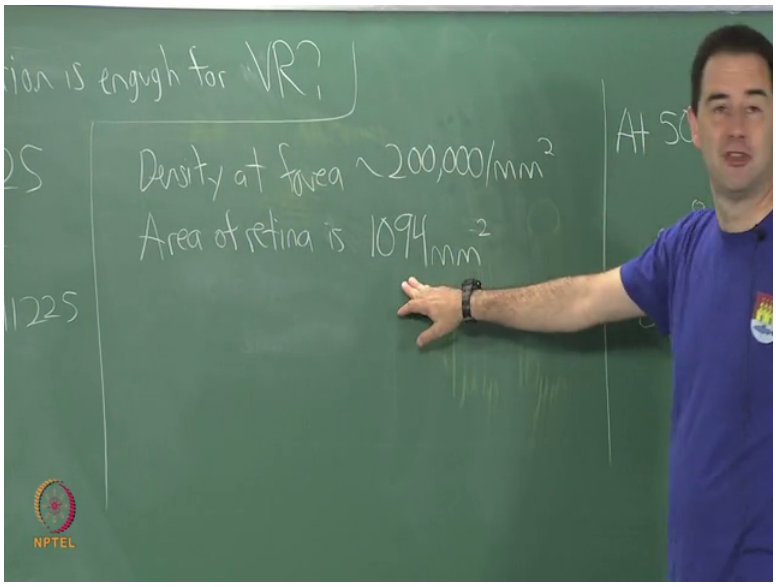

Like I will leave my picture right here that I made.

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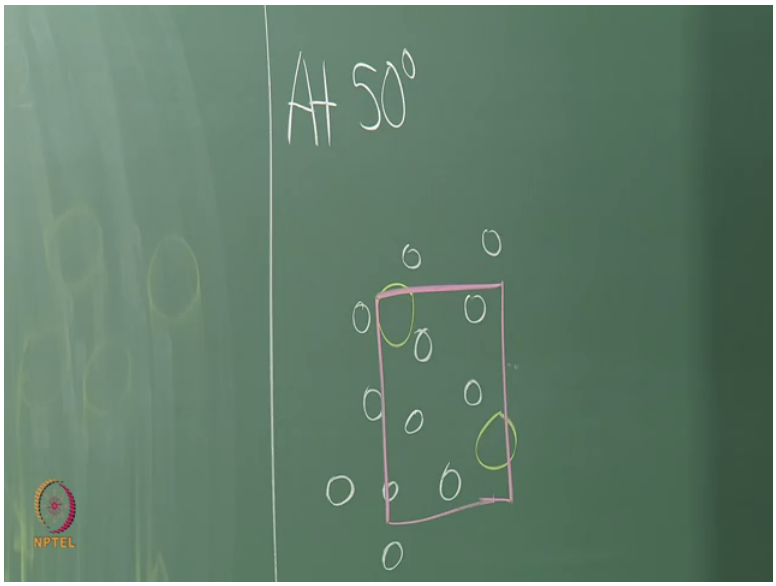

Let us suppose I guess I am all the way off at 50 degrees from the picture I have remaining, but even if this were at the fovea let us say and we will return to the other picture. When if I had very low resolution in this optical system here, when the pixels think about one individual pixel there like a kind of square let us say, they do not really look like that, but let us suppose they are perfect squares and they get imaged on the retina somewhere.

So, if that is the case, if the resolution is low there will be this pixel that gets projected onto the retina and then there are a lot of photoreceptors to detect it right and as we increase the density of the photoreceptors here for close to the if were at the fovea let us say we may have a lot of photoreceptor. So, you perceive there is a square there right you seeing what is called the pixel structure. Now, it is not exactly a square because and you can do this after class if you like you can use the same magnifying lens, walk up to this screen over here and take a look at the sub pixels if you have never done that before the r g and b components are interlaced in some kind of way. So, they do not make; it is not exactly one r g b rectangle print. So, you have to go in and look at the even lower or even higher resolution which is even smaller contributing components to the images that we see.

Well, here is one thing I could do, I could I could make a rough estimate and say we have 126 million photoreceptors all right total because I said we had a what did I say a 100

million, no 120 million which one cones or rods, 120 million cones and about 6 million rods where as the other way around. 120 million rods and about 6 million cones because the cones are all concentrated as you can see from the other picture the cones are all concentrated around the fovea, but then rods is quite a lot of them and distribute over a much larger area. So, it makes sense that they are significantly rods.

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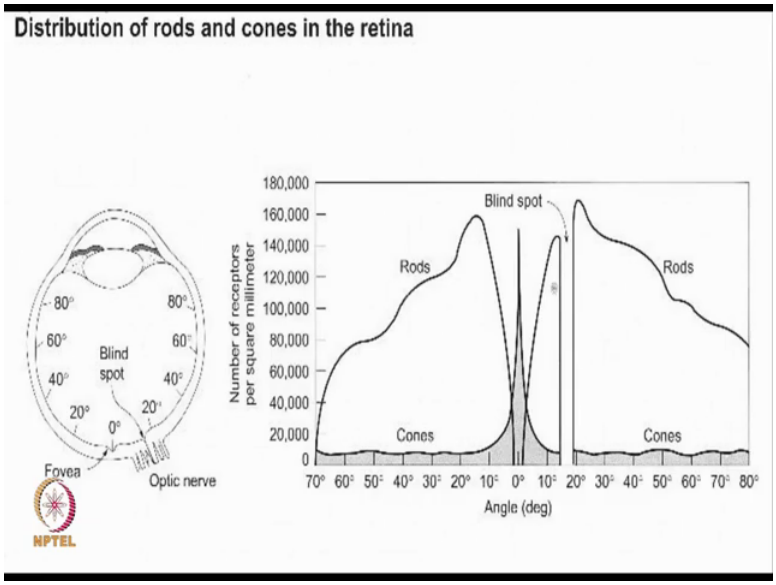

Well, I could just take the square root of this and that is roughly equal to 11225 and if I imagine now why did I take the square root well let us just imagine that the retina if I were to unwrap it, it is really a spherical cap I am just imagining fun rolling it and flattening it out. So, if I were to do that it does not have a square shape, but I am just trying to make a very rough estimate here.

So, if I were to do that try and imagine what a rectangular screen should look like then perhaps it should be 11000 by 11000 roughly. If I wanted to have the total number of pixels that I present to an eye match the total number of photoreceptors, is that even a good idea I am not sure all right. So, we could adjust further and say well why do not I just take the area of highest visual acuity which is around here and I am because I am going to have the fovea let us say aimed at the place where I am looking most of the time. So, why do not I say that is going to be the place where I am going to be looking for pixels; so maybe I should use that right.

So, I could make a more careful calculation I could say the density at the fovea and I will even round up a bit I will say it is about 200,000 per millimetre squared. So, if I look at it that way turns out that the area of the retina is I looked this up before class this is 1094 millimetres squared of course, there must be some variations among humans, but 1000, roughly 1000 square millimetres. So, if I imagine that the retina had maximum density in all places well that is kind of a strange assumption why would I do that I will say why in a minute.

But if you imagine that this is the limiting case then if I take the square root of the 200,000 million that I get because if I had maximum density and I had it spread across let us say roughly a 1000 square millimetre, square millimetres, then this would be about 200 million photoreceptors.

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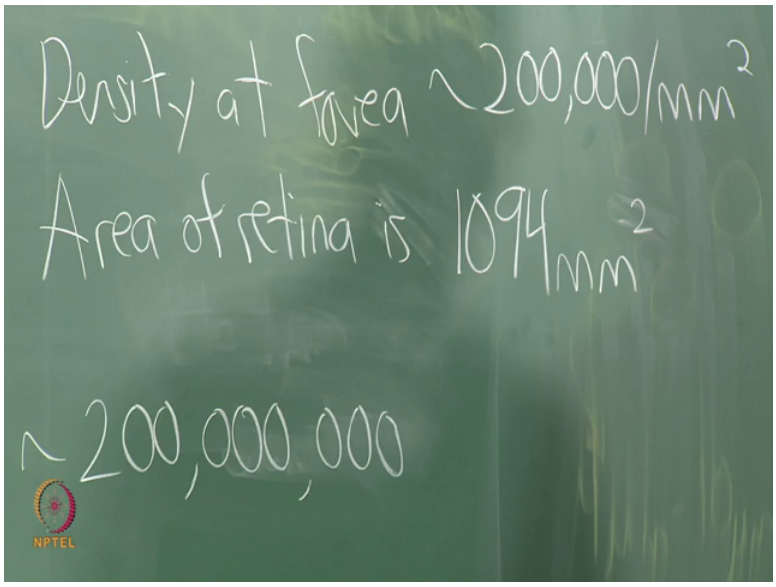

And if I take the square root of that, this is about 14000. So, a little bit bigger.

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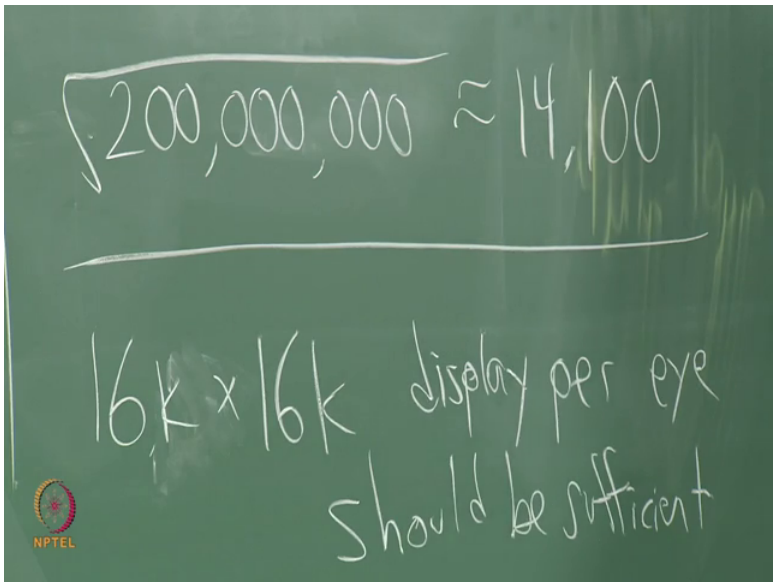

And what is interesting about that the reason why I tried to look at the case of imagining as if the fovea were propagated across the entire retina. In other words imagining at the fovea were so large it has that top density the highest density of photoreceptors everywhere is because this I can rotate right. So, you can rotate the eye and look at the top and bottom of the screen as you rotate. So, it effectively becomes like that right. If you trying to ask how high the resolution of the screen should be, so this is reasonable. So, maybe a reasonable upper bound may be a 16 let us say 16k by 16k display per eye should be sufficient, should be sufficient for not proceeding pixels.

Now, at this point you might ask why do not I just track which way the eye is looking, and then only present that in highly dense information exactly in the right place where it needs to be and do not worry about the rest of the image right. And that would save a lot of effort in computer graphics a lot of effort in trying to put out so many pixels across this entire display all these pixels have been will be rendered here on the off chance that your eye is looking at them, but it does not know where your eyes looking. So, it just has to render all of them. So, a great idea it is called foveated rendering, foveated rendering is to track the eye and then only draw high resolution images in the place where we know that the eye is looking where the fovea can perceive these areas of greatest concentration right. So, and that is all fine it is more expensive to do the eye tracking and it introduces latency into the pipeline.

So, there is tracking latency and then you have to do customized rendering for that. Maybe a few years down the road that will be feasible in the consumer space a consumer space of products and things, but for right now it is not effective enough at low cost and may not even be effective enough that at a very high cost, but its right on the kind of thresholds let us say.

Questions about this, now sometimes I look at this and I feel motivated to go even higher and say well maybe it should be 32k by 32k because I looked at the number of photoreceptors, but I did not take into account the fact that there is r g and b photoreceptors right. So, maybe I should imagine well I need to have enough to wait which way should I go in that case. Let us see I have, I do not have this density of r g and b photoreceptors, I actually have a lower if I just pick one of them of just red's I have a lower density of them right. And also when I look at my display it has some kind of pattern of r g and b components as well. So, I have not taken into account the patterns of r g and b here and the patterns of r g and b here right along the retina. So, I have not even taken that into account. If I take that into account with this estimate increase or decrease.

Student: Decrease.

Perhaps it would decrease yeah, it may decrease this may be sufficient let us say overkill and an interesting question is if I were to make a 4k by 4k display would that be enough would you ever be able to perceive anything, would there be any need right would you ever see pixels at 4k by 4k. And the honest answer right now is I do not know I have never experienced it before and I cannot say I feel fairly certain that at 16k by 16k per eye I would not perceive pixels but.

But you know the brain and the human vision system is often full of surprises. So, who knows, but it seems that this should be sufficient. Questions about that.

Student: Sir.

Yes.

Student: (Refer Time: 10:55).

Yes, there is some asymmetry I believe it corresponds to which I this is and I am afraid to be quoted on this, but I believe you have you go further in this direction which I would

guess for evolutionary reasons is that something may be coming from this side to eat you and it is better to see as far as possible whereas, your nose tends to block the side anyway and then its asymmetric you know it is the mirror image for the other eye. So, that is why that is why I believe it is asymmetric like that. Anyone else. To be I wanted it myself a few months ago and I looked it up I believe that is that is the answer there could be wrong, all right.

Let me say a little bit more about photoreceptors and then I want to start to get into the visual pathways let us say that lead from photoreceptors up to your visual cortex. I want to say a little bit more about photoreceptors as we go along here.