Virtual Reality Engineering
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Lecture- 12
Human Vision (frame rates and displays)

Welcome back. Continuing onward in the previous lecture, we were talking about perception of motion.

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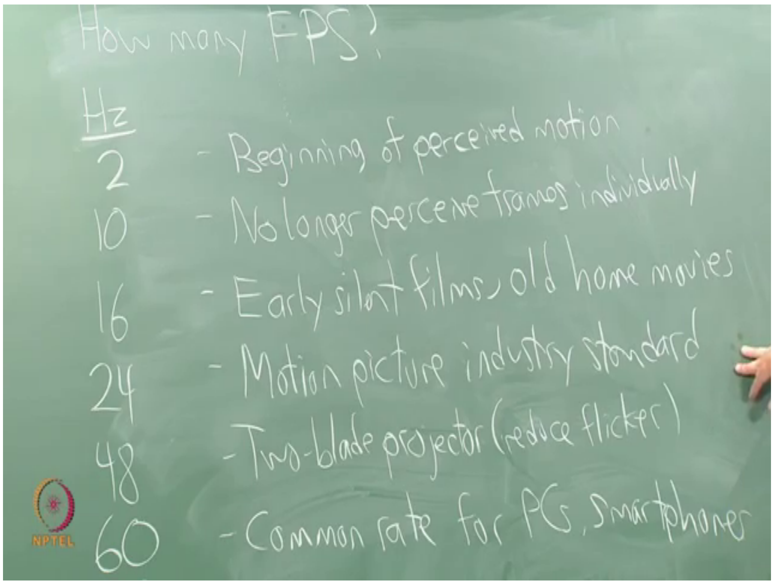

And we looked at a various frame rates, all the way down to as low as 2 hertz where you have the beginning of perceived motion this is stroboscopic apparent motion. We get up to 16, 24 frames per second motion picture industry standard also old CRT based television signals were on 25 or 30 hertz frames per second.

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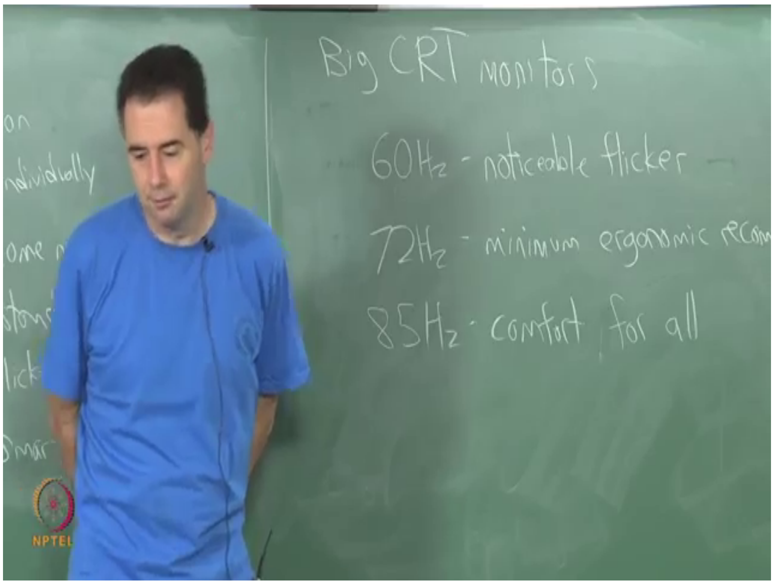

And Eventually I talked about a CRT monitors, and how as monitors got larger there became noticeable flicker as people sit close to them because of the flicker perceived in the peripheral vision. And they became minimum levels beyond which people tend not to directly perceive flicker, but then it may still cause some discomfort headaches and fatigue, until you get up beyond a certain level. So, very often people quote 85 hertz as being sufficient for just about everyone.

So, I want to talk a little bit more about problems with displays, and our perceptions of motion and stationarity, which is the absence of motion. We talked about how the brain perceives motion earlier, before this topic in the last lecture.

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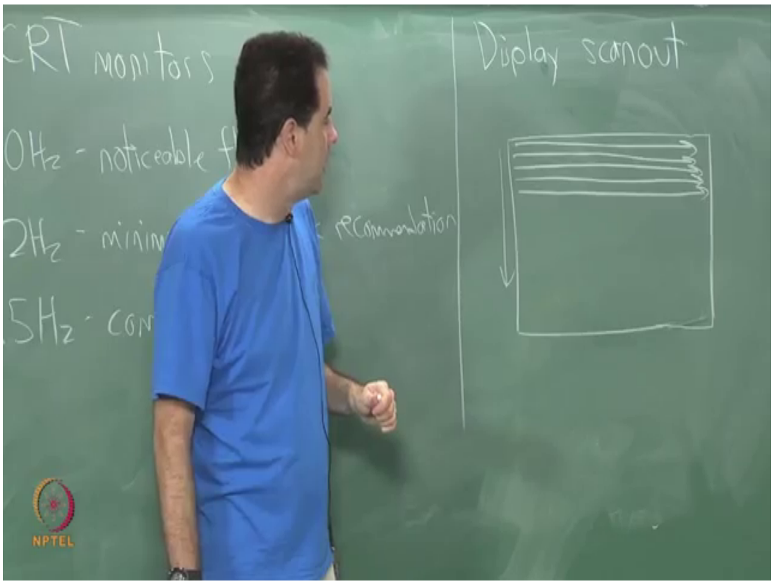

So, one of the problems we have with displays is display scan out, which is that the image that is produced on a monitor this goes all the way back to CRT monitors, but it still happens on most nearly all of the screens that we use, today is that the image is being scanned out in some kind of order line by line, it does not have to be in the same order that it was back in the days when CRT monitors were prevalent. But it is some kind of progression, that goes line by line goes pixel by pixel and then as it is scanning out the pixels start switching.

So, one of the effects of that, is that, if I am looking at some object that is supposed to be stationary in VR, and I turn then because of the time it takes for the scan to go down. So, if you are at 60 hertz for example, then it may take a 15 milliseconds to complete the scan; 16.67 millisecond the time from frame to frame at 60 hertz right. So, it is one divided by 60 um, one second divided by 60. So, there is a blank time as well so, but it is about 15 milliseconds. And so, if you do that and you turn your head back and forth then this causes a waggle effect.

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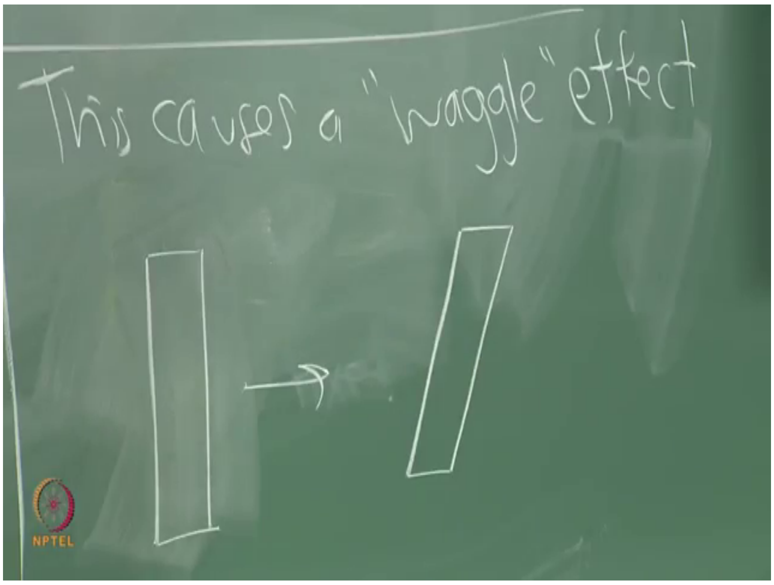

In other words, some object that perhaps it is supposed to look vertical, but when you turn your head back and forth when you have the scan out problem may look like this, alright. So, as you turn your head back and forth, this object may seem to waggle side to side in some way, and undergo some kind of distortion.

So, that is one problem that we face and another problem that we face is even if you were to update all these pixels going in this progressive pattern, the pixels themselves could take up to 20 milliseconds to switch, 20 milliseconds is a long time, right? By that time, you are ready for the next frame. How long does it take to switch? It depends on what particular kind of display you have. If you have an LCD display it could take up to 20 milliseconds if you have an OLED display, it may take only about 80 microseconds, it could be much faster.

So, one of the ways to help alleviate these kinds of problems, is to use old LEDs instead of LCDs because you get faster pixel switching. But that may then lead to another problem, which I will explain in just a bit. The waggle effect has to do it to scan out time, if I have if it takes a long time to update the pixels another thing that will happen is blurring, it will look like this object is smearing in some way because the pixels cannot change faster. So, I am turning my head back and forth, trying to use the vestibular ocular reflex, in addition to the waggle effect there will be a blurring or smearing.

This was very obvious in the oculus rift d k one for example, if any of you had a chance (Refer Time: 05:04) to c d display and you see very obvious blurring. You see other virtual reality headsets with LCD displays; you may notice a kind of blurring like that. So, you can switch to another kind of display to try to overcome the blurring problem.

We still have the display scan out problem. I am sure people in industry are working on this as we speak to try to make complete synchronous scan out and updating of pixels. So, that you get one frame altogether under the assumption that it indeed is necessary. Well, otherwise you have to show that it is not through enough human subject studies.

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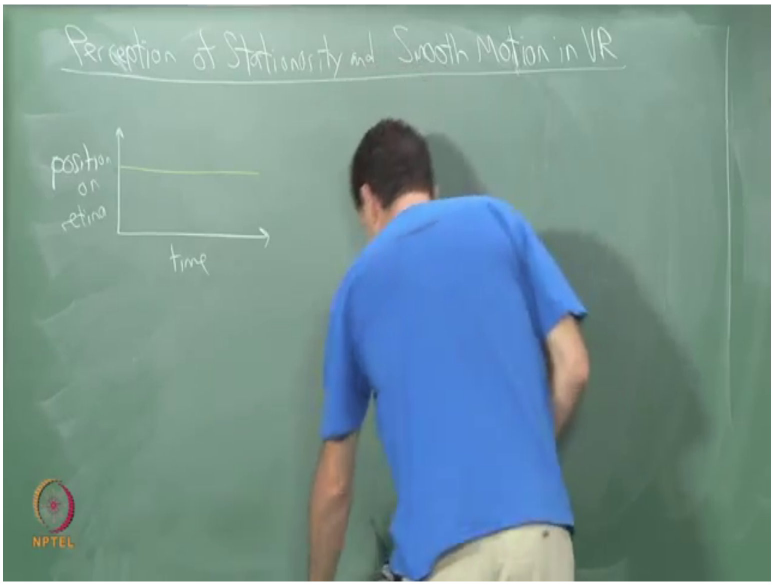

So, perception of stationarity and smooth motion in VR in a VR headset VR a head mounted display in particular I want to talk about. So, if I fixate on a point in the world and that point is not moving, and I turn my head back and forth, and I use my vestibule ocular reflex. That point should be image in the same place on my retina, right. If I just pick one I should be able to the same place on the retina. So, when I do that experiment of let us say I turned my head in one sweep, then the position on retina of that point over time should look constant. That is what should happen in the real world.

So, position on retina some fixed point should look constant. Now, what happens if I have a display in front of my eye, and I do the same thing and I want to have that object that feature appear to be in the same place in the world. Well, I hope that my head tracking is working correctly, and let us assume that that is working perfectly, and let us think about other kinds of problems. If it is not working perfectly, if there is some latency being introduced or some other kinds of errors there is can be additional artefacts on top of what I am telling you today.

So, let us think about what happens when looking at a head mount to display. Before we get to that, in the process of getting to that let me just think about some different cases here. Let us think about displays and I want to look at four different cases, at four different cases here.

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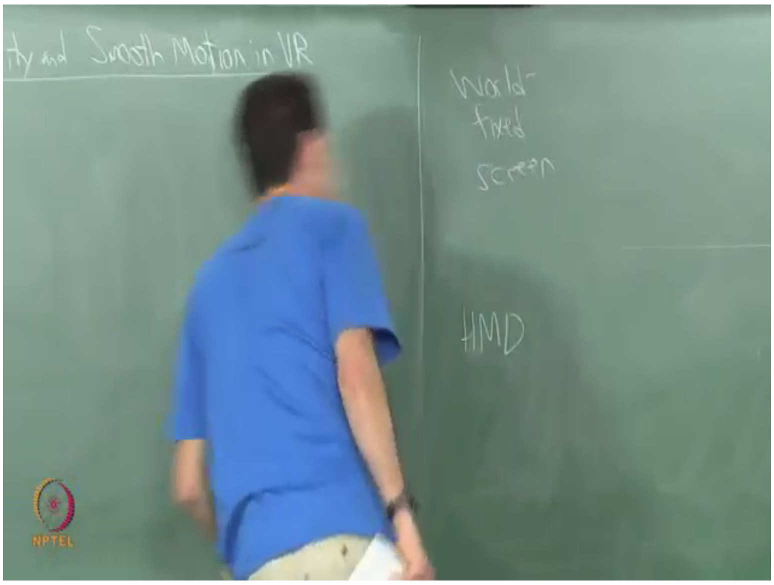

Here I want to have a world fixed screen, in this row, I am going to look at two cases of a world fixed screen and down here I want to have a head mounted display in other words a head fixed screen.

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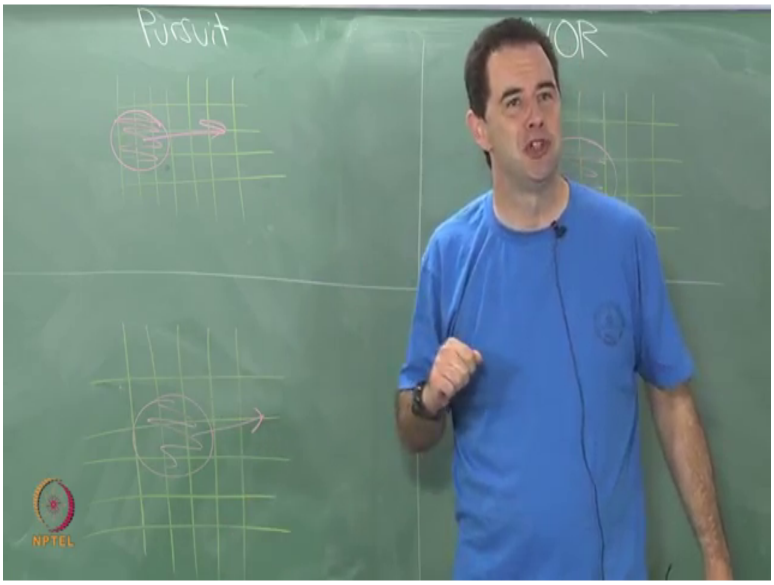

And then on this side, I want to consider the case of pursuit, in other words, that is the kind of eye movement that is going to be happening.

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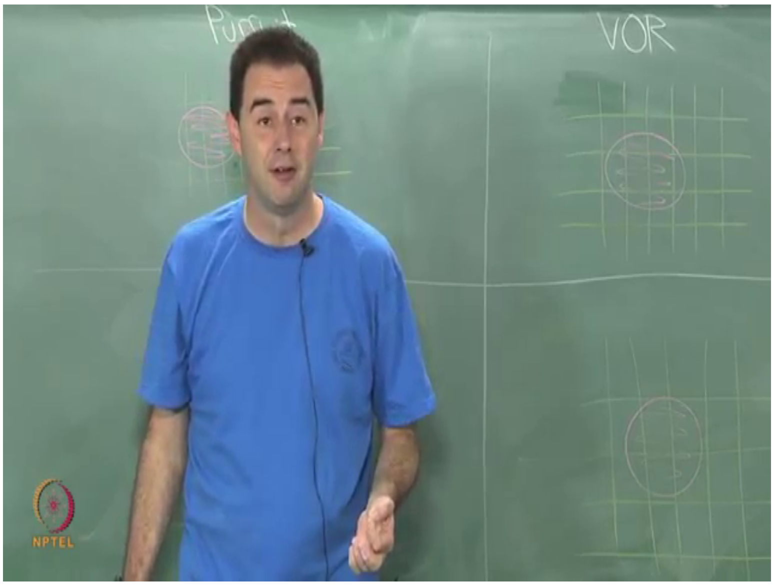

And in this case I want to consider vestibule ocular reflex. So, let us think about pixels on a display. So, I am up here, I am looking at a screen. So, I have some pixels, I have an object that starts moving. Of course, I have not drawn that right, because I should be drawing a blocky version of this, correct? So, I am just trying to illustrate things here. So, I did not draw a blocky version try to make it simple, but it should be blocky and in the case of pursuits. So, suppose I am sitting at the movie theatre, that is a fixed screen and an object starts moving through there, right. So, the pixels will have to be changing, and this is the place where people are arguing that maybe modern movies should be 48 frames a second instead of 24.

So, that these motions become smoother, and more natural like they are in the real world (Refer Time: 09:36) So, we have been accustomed to watching movies at 24 frames a second. So, after some very fast motion that comes across the screen it might not look right. And with cinematographers videographer's people who make produce movies know this, and they be sure they take care to avoid these kinds of artefacts and problems whenever they are constructing movies.

Now, if I am over here, and you are sitting at the movies, and again I guess maybe sitting at the movies is not the right comparison, because in that case I might imagine there is some kind of analogue process going on through the project. And it may you know it is hard to see pixels it depends, I mean, if I project a digital screen, I certainly see pixels on the screen if everything is clearly in focus. But because of the focus part maybe it might look like it does some kind of a conversion to analog if you like so.

So, I can also just say looking at a fixed screen like an LCD monitor like we have in these rooms right. So, if that is the case imagine I am going to have my fixed monitor let us say, suppose the monitor has some object on it. And it stays in one place, I decide to look at the monitor, and I go back and forth looking at the monitor move my head back and forth using my vestibule ocular reflex.

Do the pixels need to change while I am doing that are the pixels are not changing. So, this is very similar to the way a stationary object would appear in the real world, except for the fact that I have quantization due to pixels, but it does not have a problem with re-guard to changes over time.

So, anything has to do with how the pixel gets scanned out how the pixels get scanned out from frame to frame, the frames per second does not seem to matter too much here. So, if I am just sitting looking at a picture on the monitor, I fixate on some feature on the monitor, I move my head back and forth looking at say a particular icon on the desktop it looks stationary in a very natural way. Now, I have a head mounted display, and I hold my head fixed let us say. So, I am holding my head fixed, I am looking through my head mounted display. I see pixels, and the object starts to move, pixels are changing, right?

So, again the same kinds of issues of frames per second are going to matter as they would at the movie theatre. And so, so this is a very similar kind of situation if I decide not to move my head, if I move my head, then I have additional problems of there is going to be even more motion of this object well or less depending on how they combine, but if I am moving my head and the objects moving, they are certainly going to be pixels to change, right? But just the object moving by itself is enough, if my heads moving in addition then it is some kind of combination of those two motions; that are going to cause pixels to be changing as this objects represented.

Now, the 4th case is the most unusual and interesting, and a is very important to pay attention to, which is that we said if we sit and look at a screen, and we are looking at some stationary object it does not matter, how the pixels are switching or the frame rate. But if I want to use my VOR, I have some object that is supposed to be fixed in the real world, sorry, it is supposed to be fixed in the virtual world, right? In the in this world frame, if I turn my head back and forth while wearing a head mount to display, does this object is this is object supposed to stay on the same pixels or not should not right.

So, the image I sort of have or the feeling I have is like this it is almost as if when I put on a head mounted display imagine there were grid lines drawn on it, but it is like a piece of glass, and I see through the glass to the outside world. That is hard you cannot keep them both in focus the grid lines on this piece of glass and the outside world, but suppose you can forget the focus problem.

If I move my head back and forth, then I would see a grid pattern sliding back and forth with respect to all of you right. And so, that is exactly what is going on here, these are the pixels that have to be switching you know as I see you sliding back and forth across my grid or the grid sliding back and forth across you it is it does not matter which way you look at it, this corresponds to the part that has to change.

So, if these pixels are not changing fast enough, then how does that affect my perception of stationarity. So, let us look at a case where we have a very fast switching display I have the same picture.

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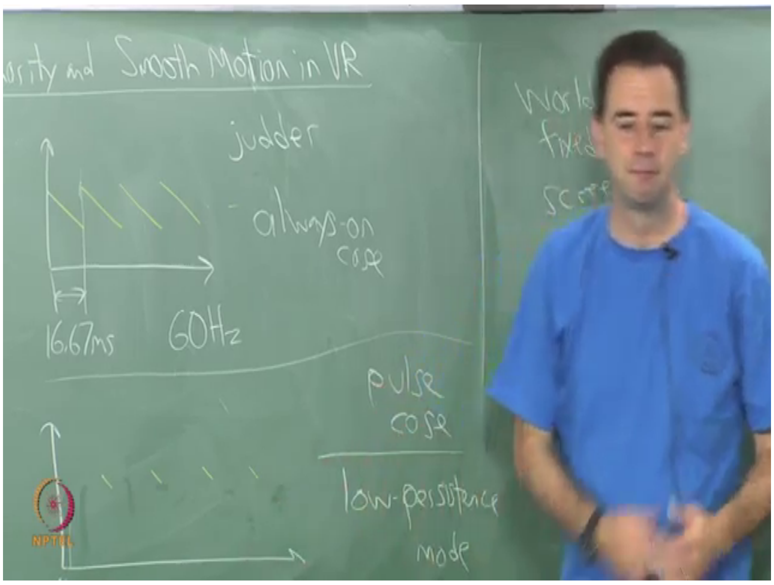

Here I want to look at a particular object just call it a point if you like do not worry about maybe it is so small that it is like one pixel wide. But it can be a few pixels wide we fixate on one particular point and let us suppose that maybe we have a display that updates at 60 hertz. I am going to forget about the waggle problem, let us just suppose you know I update all the pixels at the same time, they switch very, very fast, but they only update it at 60 frames a second right. So, I go back and forth like this, what is going to happen to the image on the retina?

So, what you should instead get is a picture like this. Where if you are at 60 hertz just as an example let us say 60 hertz, then this amount of time here, this would be 16.67 milliseconds, does that make sense why that is happening? Because if the image is frozen in my heads turning it is not supposed to stay the same image for 16.67 milliseconds so, your brain will perceive that object as moving a little bit.

So, that will cause an object that is supposed to be stationary, seem like it is going back and forth like this, it will gradually move across and jump in, and gradually move across, and jump gradually move across, and jump that is what is happening on your retina, when it is supposed to be stationary.

Terrible problem, right? So, one name for this kind of oscillation is judder, judder kind of a fairly generic term used for all sorts of video flaws and things. But this is sometimes considered one example of judder. Now remember I said that you could flash the screen on for as little as one millisecond, and that will be enough to trigger your photoreceptors. So, that is what I could do here, and that should help with this judder problem. So, I could, all right, this is the always on case and this is going to be the other case, which I called what will see what do they call the other case pulse? So, pulse case.

So, in the pulse case it will look something like this. I will get a picture like this, where during all of these intermediate times between these small diagonal line segments, the screen is black let us say completely off. So, I pulse it on for one millisecond. So, this I will (Refer Time: 17:29) make this little thickness here be one millisecond, right? Not rendered too well here, but.

So, it is on for one millisecond, and in the remaining us 15 and something milliseconds the screen is completely off. So, I could do that, and then when I move my head back and forth the amount of judder the amount that this object appears to be sliding is significantly less.

If I try to make it too much less than a millisecond, it might not fire long enough to fire my rota to trigger my photoreceptors. Now I have another problem, if it is off most of the time, and it is just pulsing these bright lights, I see I perceive flicker. So, you have solved one problem, and I have another problem.

So, because of flicker, we have to go back to the same scenario that that we had back with giant CRT monitors in the 1990’s and we have to get the frame rate up higher. Now we could try to use that trick of multi blade projectors, and just show more frames here, but if we do that the objects still not going to be in the right place.

So, you can add more frames, but it will start to look like it is juddering or stuttering you know it is not moving exactly in the correct way, right. The object will not be in the right place at the right time. So, if you increase the frame rate from 60 hertz up to say 90 hertz and you do this single simple pulsing, then you will have solved the flicker problem and this judder problem and the perception of stationarity will be solved.

So, that is the motivation that is why people are pushing for higher frame rates right now in the business of head mounted displays. So, this is sometimes called a low persistence mode because the frame is not persisting.

So, this will be high persistence mode up here on the top, the frame persists the light is on for the entire time in the low persistence mode it is there for just enough time to trigger your photoreceptors and then off of the rest of the time. But the whole frame rate is fast enough so, that not only do you not perceive flicker, but hopefully it is just comfortable in the longer term.

So, there is no subconscious implication as well where you may have fatigue or headaches. So, once you are above 90 hertz it seems to be fine. But just be aware that even 90 hertz is not enough to solve the problem of; if I have an object moving very fast and I am not tracking it will still generate multiple images across your retina, because you cannot track the object and keep it in the same place on your retina anyway, and you will perceive at least a zipper of some kind in that case.

Generally speaking the higher the contrast, the more, you tend to notice these problems as well. That is why in the real world getting a bright led and doing and moving it generating a pulse signal with it with a pulse generator and moving it in the dark is the best way to do the experiment. So, it is a high contrast whether it is the real world or the virtual world well bring out these effects the most.

Questions about that? The LCD case; if you have very slow switching pixels I would just generate a big blur zone here. So, I would not even get sharp images. It is just as I turned my head the object gets blurry, and then gets sharp again. It is probably not going to make anyone sick, but it is it is not very; it is hard to say you have to do the experiments to see, but it is yeah it is just not correct right.

So, instead of having perceive stationary to be right with a very slow switching display like an LCD display the objects become blurry when they are supposed to be stationary. So, they blur the none blur, maybe that is better than judder, but this pulsing method is better than both. If you can support the fast frame rate and reduce flicker. Questions on that? Ok, I am going to switch topics now, significantly and I want to talk about tracking.

So, even in these examples, when I am moving my head back and forth, doing the best using the vestibular ocular reflex in my perception of stationarity, head tracking is coming into this, right? Because you need to figure out which way your head is pointed ideally you would like to know which way your eyes are pointed as well. So, tracking becomes essential to get the viewpoint correct so, that you can draw the images correctly, in the right place, at the right time, and minimize perceptual artefacts and problems.

These are a bunch of perceptual artefacts and problems that are simply due to the displays based on resolution in time and space, but in addition to that we have other problem which is the ability to accurately track over time and space in the physical world. And use that information appropriately to generate the right information or render correctly to the display with as many with as few spatio temporal anomalies as possible, right? Especially the ones that were most critical to our perception, that is how the; that is how it goes.