Virtual Reality
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Lecture - 19
Interfaces (locomotion)

Hello, welcome back. In the last lecture we finished with the audio component of virtual reality, and then I gave a little bit of an overview about interfaces for VR and so, I gave you 5 categories which I will go into detail on in this lecture and the next one.

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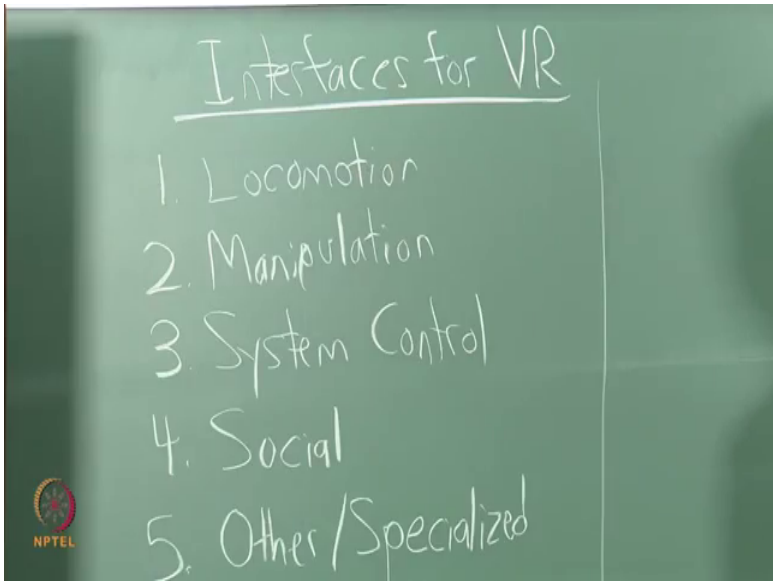

First one was locomotion, second one is manipulation, third one is system control, fourth one is social or social interaction and I made a fifth category which I called other, which correspond to specialized kinds of interfaces and methods for one particular kind of application whereas, the first four categories correspond to fundamentals, these may show up in category 5 as you develop particular systems, but you may also find very unique issues.

For example in category 5 maybe you want to develop software or write a textbook, maybe you want to play some kind of a hand to hand combat game with your friends, with some kind of actual interaction at a physical level. So, different interfaces would arise; obviously, for problems such as that, they are very specialized and yet some of the general principles may still apply.

So, let us go into locomotion.

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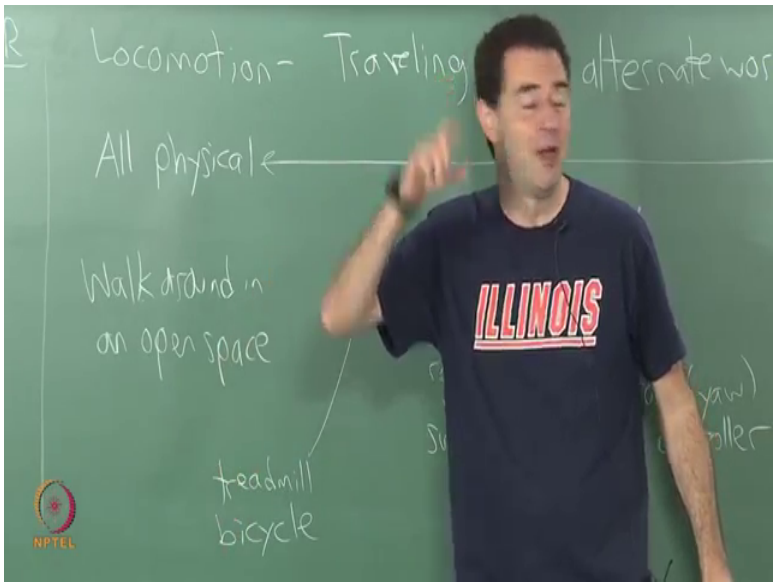

So, locomotion which I will call traveling in this alternate, world that we are making could be virtual could be some kind of capture of the real world. And in order to understand locomotion, I think we should make two different extremes and reason about them. So, one of them I will call all physical and the other extreme I will call all virtual and then we will have this kind of spectrum between them and let us go to the all physical case first.

So, in the all physical case, suppose we are in a cave like environment and we can walk around and there is no other way to induce a motion beyond the actual physical walking that you are doing, and the moving of your head to change the viewpoint and that is all or if you put on a head mounted display. Suppose you are in an entire and an entire cleared room in the physical world, and you can walk around, you can look at things, you can get down on the floor and lie down and look up to anything you want. All of the physical motions are being captured and the viewpoint that you observe everything from is being tracked and transformed into the alternate world so, that is there is no mismatch of any kind right.

So, that is a very nice extreme that is the most comfortable case assuming there is no latencies or other kinds of tracking artifacts and display artifacts and this is the most comfortable case. So, let us say walk around in an open space. If you had like to walk

around in an enormous open space, then you will need a lot of physical space for this. So, it is not always very practical.

Let us go over to the other extreme and look at the all virtual travelling.

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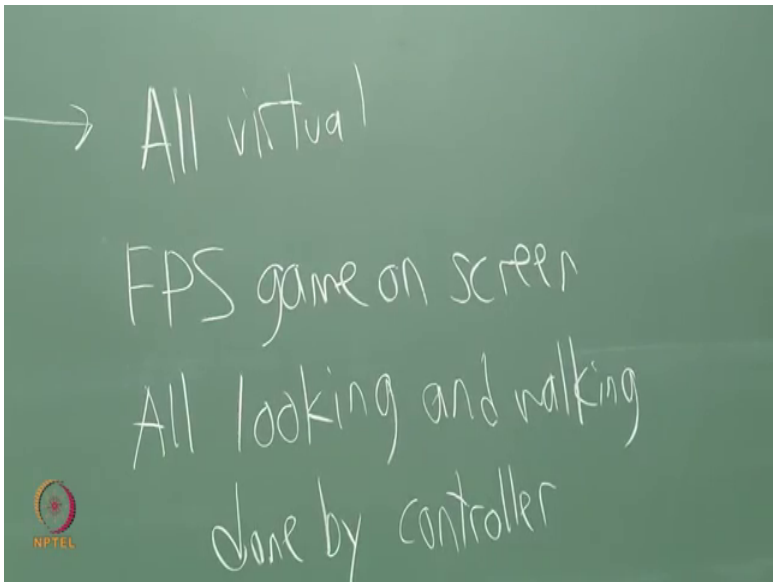

So, if you are playing for example: A first person shooter game or some other kind of game, that is first person perspective on a screen, then all of the motions you see our virtual right. You grab onto your controller and you move your character around through some kind of virtual world, but there is no tracking of your actual motion of your head all right. So, the entire thing is virtual.

So, all looking I mean in a sense that when you change your look at, you have to use a controller for that too right, you grab onto a controller and you make control looking up or down or left and right using the controller. So, all looking or generation of look ats and walking is done by the controller.

So, it does not correspond to tracking; maybe these two extremes make sense. So, this one generally is the most comfortable in virtual reality, the all virtual case may be comfortable on a small screen and if you sit in front of a large screen, some people do complain of discomfort in first person shooter game sitting in front of a very large screen very close to it and through adaptation people tend to overcome that large majority of people.

However, if you put on a virtual reality headset and you feel completely immersed and all of the motions are done by controller so, that you are not even having head tracking, this would be the most uncomfortable case.

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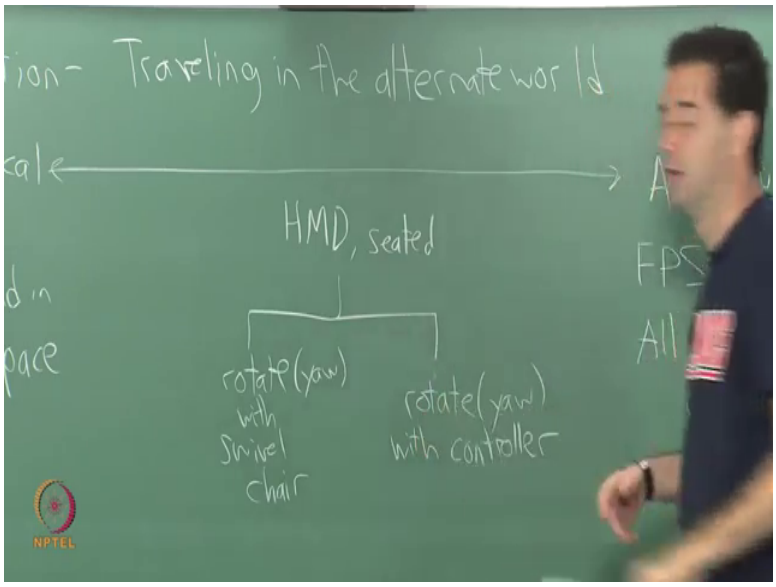

So, what most people are doing if you want to visit a very large world in the alternate world right, a very large alternate world when you are in the middle here somewhere, where you have on a head mounted display and you are seated in the physical world right.

Let me let me grab a chair just to illustrate a bit. So, if I am in the seated case right I may grab onto a controller, but as I move my head around and imagine I am wearing a head mounted display, I look around and all of the motions that have to do with the look at based on my human body have been matched using a tracker right.

Now, if the tracker does orientation only, then it can only handle above this much looking around and then, I need to have position tracking as well so that I can do motions like this. But notice that I am seated in a chair and so, what happens in virtual reality. Well first of all one issue is that are you seated in a chair in virtual reality or are you standing in virtual reality, even that mismatch of height causes some confusion and discomfort for people.

The next question is, if I want to move myself around in virtual reality, well I could go forwards and backwards let us say so, I grab onto a controller and I move forwards and backwards, and so, I see the motion of that. There is an interesting question about what happens when I am turning. So, I could grab on to a controller and press some buttons and then in the virtual world my head turns right. Now, we have talked about vestibular mismatch in comparison to vision and I will remind you of that a little more later.

But one easier alternative is if I am in a rotating chair, I could actually just rotate my body like this and then push forward, and then I can rotate back some other direction and then push forward right. If I did that then I am using one more degree of freedom from the physical world, I am actually doing the all correctly, but the mismatch then corresponds only to the additional components the pitch in the role and of course, the translation or positional changes. So, this by rotating in the chair it is more comfortable for the for the user, because it involves less of this rotational vection may eliminate the rotational vection altogether if the tracking and everything else works correctly.

So, that is interesting; however, not everyone going to be sitting in a rotating chair and if you rotate too much, if you have a cable system then you become tangled up in the cables. So, these are the interesting kinds of tradeoffs that we have when thinking about locomotion. So, over here closer to all physical is you could rotate with a swivel chair or office chair and over here you rotate this is just the yaw component. So, I should put this yaw with controller or buttons on the keyboard or the keyboard is not at all ideal.

So, rotating the swivel chair that is closer to all physical therefore, I claim that it is more comfortable. However, as I said it is more complicated to implement in the physical world. Somewhere over here for walking around, you might want to make a treadmill, perhaps it is a one dimensional treadmill, perhaps it is some kind of omni-directional treadmill, you could make a very expensive and complicated mechanism for walking in any direction horizontally, you could be walking inside of a giant spherical ball and feel very much like a hamster right.

So, lots of things that could be done here perhaps you have a bicycle. So, you can feel like you are riding around in a virtual city. So, these are not too bad, there is some motion going on that corresponds to what you would be doing in the real world if you were in fact, moving, but your head is still staying roughly in the same place. But it is

causing I would say a lot of vestibular signals to be generated and a lot of physical body motions that are familiar in the real world. So, I would suspect that it becomes more comfortable because of that.

But you know this is also more expensive of a setup more difficult to get working and so, um. So, it is a bit more of a challenge, but it is further down to this side of all physical which is generally more comfortable, when implemented correctly. There is one beautiful trick which it which you can do if you have a large enough physical space to walk around in and assuming we do not have cables that limit us. So, you could be using a purely mobile headset, and it is called redirected walking.

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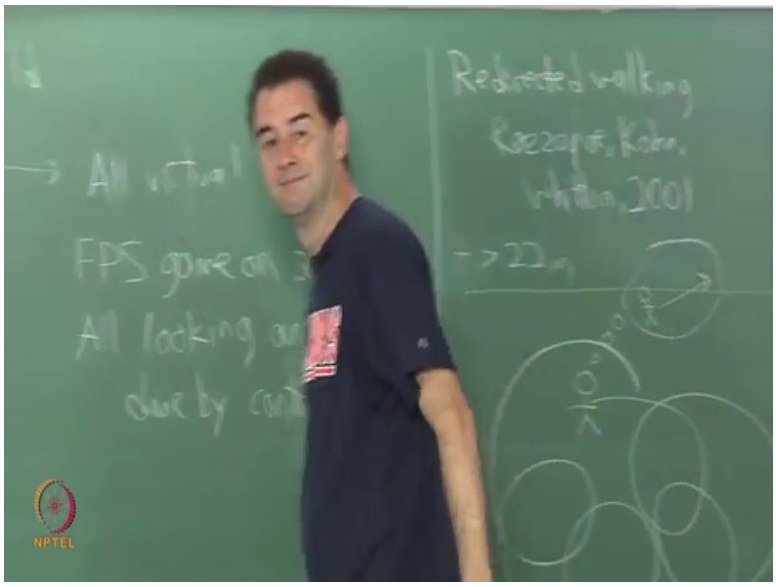

This is due to Razzaque Kohn and Whitton from University of North Carolina 2001. The idea is that you provide visual stimuli to trick the user into walking in circles even though they think they are walking straight. So, it turns out that as we integrate our own internal gyro, which is the vestibular organize we integrate the data from that it is possible to fool your brain. So, that is you think you are going straight over a long distance, but you are actually curving.

Now, if you make the curvature amount to much so, that in VR, it looks like I am walking straight and maybe I am walking in only a 3 meter radius you will figure that out it turns out. So, there is an interesting question of what is the minimum radius. So, just to

keep this clear in the real world the character, may be tricked into walking in circles, all the while they are trapped inside a way inside of a large box.

So, you may have a bounded space here, we always have a bounded space in the real physical world. So, they are trapped inside of here, but as far as their thinking goes, they are if they imagine themselves they think they are just walking perfectly straight the whole time that seemed all right. So, you just keep introducing artificial your rotations to guide them.

And there are interesting challenges as far as you know you cannot ensure that they will not hit the boundary right, they may reject the visual stimuli and keep trying to fight against it maybe they are just bad luck and the man appearing the boundary anyway and you will still have to do something.

But generally speaking it is possible to guide people into circles like this over long periods of time and experiments have been done showing that, and if you want to make an enormous space for this, but make it let us say as small as you can get away with and still have this effect work reliably, researchers have said that the radius should be greater than about 22 meters

So, if you have a large space. So, if you were to walk around outside say in an enormous a cricket field all right; when you would have enough space and then you could walk around in an entire virtual city right. So, you can walk around and explore an entire virtual Chennai let us say until you are just you collapse with exhaustion, and you will be can maybe convinced in your brain that you have been walking all over the place and exploring and you can have a map with you, and it can show you where you are going and you do all of this in a very comfortable way, while in fact, you are just walking around in some physical space and you have everything tract.

Of course, you need to have your tracking system extended to the entire space right to make this work. If you are outdoors you may be able to get some positional tracking information from GPS, we will not be very accurate you will have to figure out what to do about that.

Questions about this?. So, I want to talk a little bit about what this means in terms of the transformations that we apply, because we have gone through the chain of transformations before and so, we have to add a locomotion component to that.

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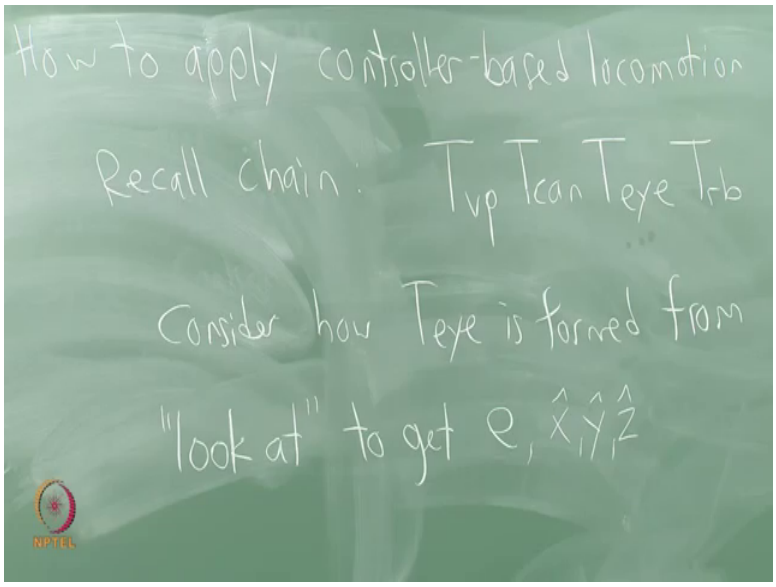

How to apply controller based locomotion, when you may recall the chain of transformations T viewport, T canonical view, T eye which we broke into two components for left and right eyes in the stereo case, but I am not going to worry about that today and T rigid body right. So, these are the transforms that we did before worrying about rendering just trying to make the geometric models end up in the right place. So, they end up being in the right place on the screen corresponding to the viewpoint of the eye.

So, if we have locomotion we are going to be artificially changing the look at of the eye. So, recall consider recall how T eye is formed, from the look at which I covered a few lectures ago, where we had these various directions vectors eventually we had a position which I called a the eye location and we had some coordinate system, I believe I labeled as X hat, Y hat, and Z hat. So, we have these components that correspond into which direction you are looking which way is up and the location of the eye.

So, in the case of all physical when we are at that extreme, then T eye is generated entirely from tracking right.

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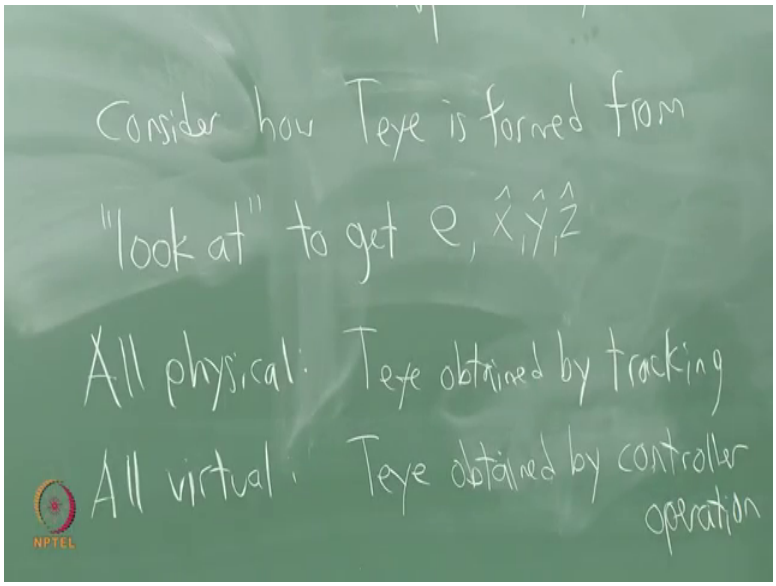

So, the all physical case T eye obtained by tracking in the all virtual case right I mean the virtual being just a locomotion part. So, if the locomotion part is entirely virtual, then T eye is entirely determined, by the controller operation and so, you may be press buttons move knobs on the controller.

However, whatever kind of controller you might have you do some kind of interaction with it and then from that T eye is transformed.

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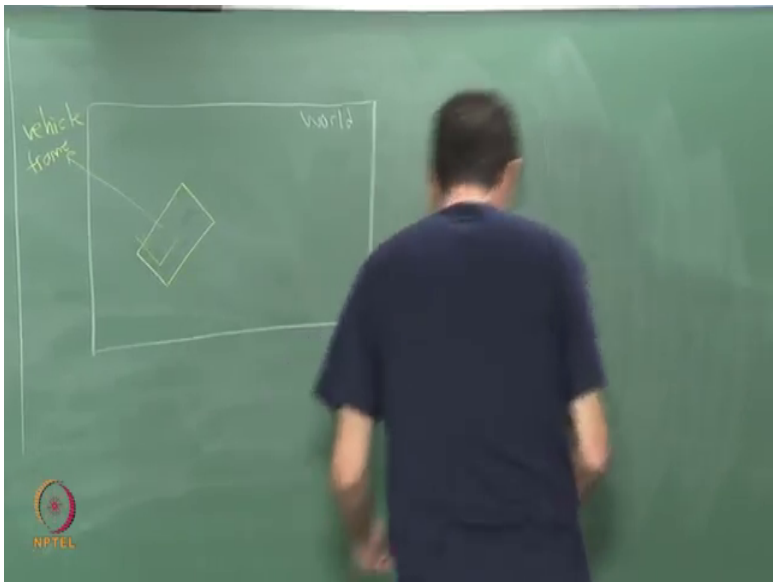

Let me give you a simple example that would be common for a head mounted display, imagine this is a top down view of the world and, since the alternate world that we are generating. So, this is the world frame feel like showing how things look in the world frame.

And then inside of here I like to imagine that we are riding on a kind of virtual cart right a virtual platform and, this platform is being transformed from the physical world while I am sitting in my chair into the virtual world and, then when I get to use the controller to move I am just controlling this platform that is how I like to imagine it.

So, here is a platform it is like a robot or a cart and so, this one will have it is own body frame all right. So, imagine this is a vehicle frame, just an example of the body frame will call this kind of virtual cart a vehicle. And then somewhere with respect to this vehicles frame, I have my eye location and direction of looking.

So, I want to have everything referenced with respect to this vehicle frame in terms of where my eye position orientation is rather than with respect to the world and, then I will also consider how to place the vehicle into the world and, I have these two transformations now that come together to replace what was once just T eye.

So, I would do it like this I will say I have I have two transformations.

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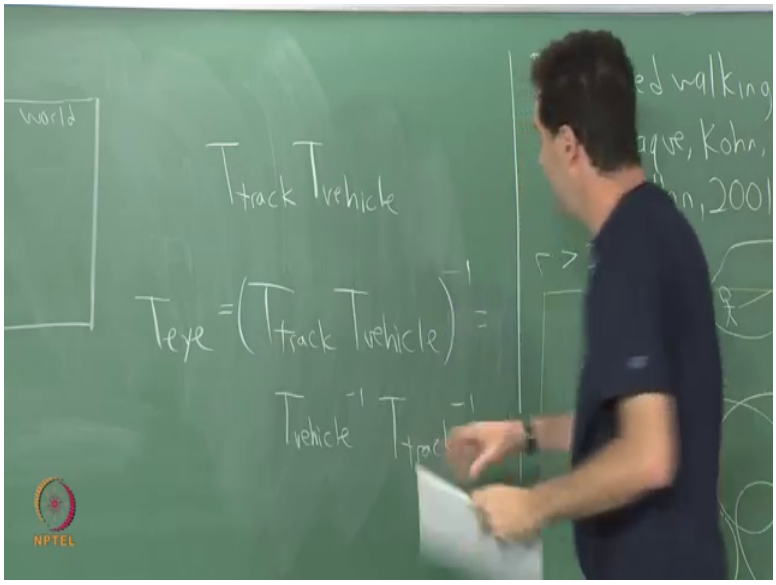

Now, I have T vehicle which places the vehicle in the desired position and orientation, you only need those components just your rotation and X Z right, it is the horizontal plane X Z coordinates for placing the vehicle into the world assuming that the vehicle is driving on level ground. If it is driving on a terrain, then you still only need two coordinates, if it is flying through space I do not feel some kind of virtual space ship, then you need more degrees of freedom for that, but nevertheless the math at this level looks the same.

So, we have this we have T vehicle that we apply. So, we can apply this directly after the rigid body transform. So, we put that here and then we have the transformation that corresponds to the tracking part; So, which part is being tracked that transformation would be applied next to place the virtual eye in the appropriate location with respect to the vehicle.

And now you might remember that we formed T eye by taking the inverse of the rigid body transform that places the eye right remember that, we had we had to do the inverse because it corresponds to how the world looks with respect to the eye rather than how it would be in the world, if we were to look at the eye and c worth placed all right; So, exactly from the perspective of the eye.

So, it is inverted so T eye is actually equal to the inverse of this and you might remember that when we do the inverse, once I will just take the inverse here you might remember that when we take the inverse, then we swap the order. So, T so we just get these two transforms. Now, that are replacing T eye questions about that.

Now, there are some interesting issues that come into play here, one of them I will show I will illustrate again with this chair that is good to have a prop all right. So, if I initialize my system and I grab onto the controller and then I decide to rotate. So, I decide to rotate my cart right, or vehicle. The question is what should the center of rotation be for that? that is a very efficient questions I might not even be aware that I am on some kind of virtual vehicle, what should the center of rotation be.

So, one possibility is to make the center of rotation be wherever your cyclopean eyes. So, that when you grab on to the controller and you do a rotate you rotate about, the point between your pupils um.

Now, what if I am leaning like this all of a sudden would it make more sense to rotate about the center of the chair. So, that I feel like I am going like this when I grab onto the controller, or would it still makes sense to rotate about this point what would be more comfortable, or should I just continue to rotate about whatever point I was rotating about with respect to the world whenever I started the system, right in the physical world should I just keep rotating about that point.

So, there are several choices for the center of rotation and, while it is a great source of debate, I think I found that various people will have varying opinions about what is the best and most comfortable way. So, I am trying to think, I think I think I think my favorite was having it be the center of the chair. So, when you are leaning it feels like you are rotating like this, but I cannot even recall any more so and so, which one was my favorite.

And remember if you have a vehicle moving in the plane, you get X Z and yaw coordinates, if you have a vehicle that you perceive to be flying through space, then this T vehicle transformation may include a full 6 degrees of freedom right, it can have the entire yaw pitch roll which you may want to represent as a quaternion I would recommend that and, then the X Y and Z translational or, positional components would be there as well, I want to remind you of the vestibular mismatch problem we have already talked about it.

Let me just be brief here, it is becomes very important in the case of locomotion in fact, locomotion is the primary reason, I think why people are getting some simulator sickness in virtual reality, this is the primary motivation people want to loco mote move around explore larger worlds than the 1 that they are sitting in and, even if the headsets are functioning perfectly this vestibular conflict that you get is what is causing the trouble right.

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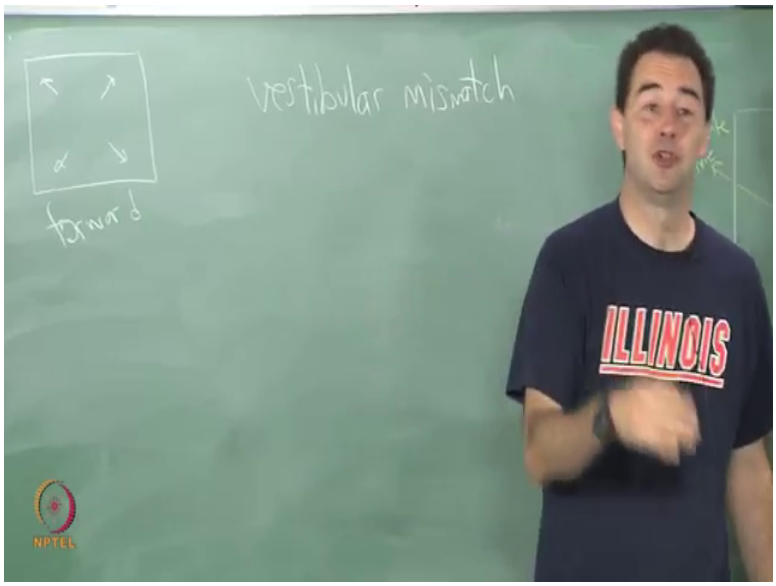

So, remember as you as you go forward, you get optical flow present it to your eyes that goes outward, when you go backwards it goes inward and we talked about the other cases when you are rotating or moving sideways. So, problem is the vestibular mismatch, or conflict and, you may recall that I mentioned the case where, if you instantaneously start moving that is actually more comfortable right.

If you instantaneously go from being stopped to being at a full normal walking speed, that is actually more comfortable than gradually ramping up because, when you gradually ramp up you may have for example, 2 or 3 seconds of vestibular mismatch because, your eyes are perceiving an acceleration, but your vestibular organs that you do not have that right, then we said that just doing a quick impulse is better is more comfortable, you can do the same thing for orientation.

So, you could you can make it. So, that every time you tap a button on the controller for example, you may rotate by 5 or 10 degrees rather than doing a gradual circular motion. And this also seems to help with this vestibular mismatch.

Now, if every time you tap the controller you rotate 90 degrees, you may have a lot of confusion about which way you are facing, you get a kind of disorientation from that if you every time you tap the controller you only move 2 degrees, then you end up having to contact a controller many times really fast. In which case you will experience vection again, you will have the rotational vection.

So, there is a kind of balance you have to strike between having them be very small motions and being very large motions, they each have an unfortunate side effect and whether, or not some number in between ends up working really well for everyone, I think it remains to be seen.

So, in the 10 degree range 10 to 15 degrees perhaps that is a good number to try and every time you hit the button you rotate 10 degrees or. So, and that is still not going to be as comfortable as sitting in the chair and, rotating your body in the physical world if you have a rotating chair and, do not get tangled up in the cables right.

And you understand that in the case of circular motion even at a constant angular velocity, there is vestibular conflict right that makes sense right you may remember, that let me just write it quickly.

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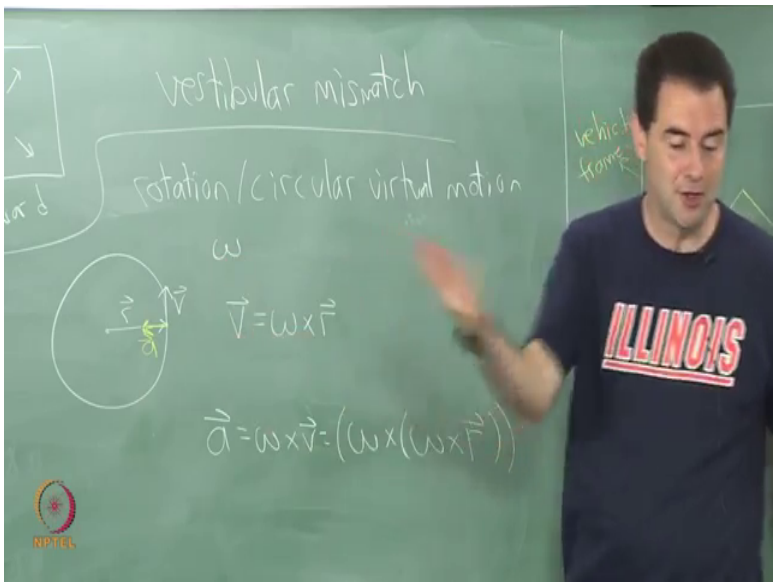

So, rotation or circular virtual motion; So, suppose this is the radius vector, in the virtual world or alternate world I am moving along in a circle, at constant angular velocity omega and from basic physics the linear velocity is equal to omega cross r, the omega component is along the Z axis, if you write it as a three dimensional vector has 1, outward component right maybe it is not the Z axis here maybe the Y axis.

So, because of the axis that we have chosen to use, I am in physics and most of engineering out would be the Z axis. So, it is the outward axis to keep (Refer Time:

08:02) confusion. So, this would give you a linear velocity vector V that seems appropriate because, as this if you are on maybe go around staying around, this is the instantaneous direction you are moving you are about to be hurled in that direction ok. Except for on the forces of that are due to accelerations which an acceleration is using basic formulas from physics is omega cross V, which is then equal to omega cross omega cross r, which gives you a component like this of acceleration right so, inward.

So, there is an acceleration component and, if you present visual stimulation that convinces your brain that you are in fact, rotating in a circular arc like this at constant angular velocity, then you are perceiving and acceleration again with your eyes non 0 and your vestibular organ knows that you are not rotating in this way and not does not perceive this acceleration. So, you have a mismatch.

So, in the straight walking case, if you are walking in constant velocity there is no mismatch right, there are no accelerations going on, but in the case of turning just be very careful this is a very uncomfortable case and, I think it ends up being one ends up being effectively the worst case these kind of rotations. So, we need to do something better to handle this difficulty.

And I will say one final thing even, if you are moving along a constant velocity, I still do not think it is completely comfortable. So, you start looking around in different directions you see optical flow the system may be working perfectly, or nearly perfectly I still sometimes experience discomfort and, I am not completely sure why, I think it is left for researchers to figure that out perhaps you will figure out why that is happening.

I do not think there is any case in the real world, where we are moving along truly at constant velocity with no additional forces right, even if you are on a train, or in a car wherever you might be doing I am coasting on along on a bicycle, there are always more vibrations more motions going on more stimulation to the vestibular oregano along different directions and to have perfectly smooth straight motions with no other stimulation going on is I think odd, it is a bit unusual and I find that uncomfortable in virtual reality myself is.

So, even at constant speed; So, just something to pay attention to; however, we know that when there is a mismatch, it leads to discomfort for large fraction of people, if there is no

mismatch may still cause some discomfort for some people and we are trying to figure out why all right.

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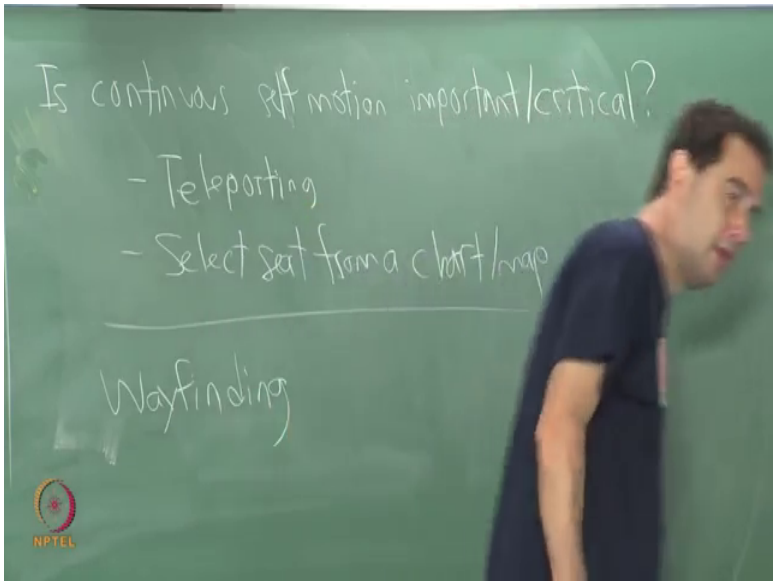

So, in response to this what you should be thinking about, in the design of a virtual reality system is the following. So, it is continuous self motion important or critical all right.

So, for the application that you are building the experience that you are making is it important that you drag your virtual self, through all the gradual motions that we would be doing in the real world right, what if I can just point somewhere where I had like to go perhaps on some kind of map that pops up right, where even if I am in a big room I can just point and click and say I want to be there.

Now, and then all of a sudden we are teleported, there if you could do that in the real world, you might choose that as an option right you become lazy very quickly of course, but it is nothing wrong with giving people superhuman powers, in a in a virtual reality or alternate world experience, there are interesting questions about how real does it feel when you are able to do that, my guess is that with a very little effort you will be training your body to convince yourself that you have these superhuman powers like being able to teleport to another location easily.

So, that when you come back to the real world, you will feel sad and frustrated that you do not have those powers anymore; So, that is what I think will happen, but which ones of these abilities become very natural and, which ones will just stay unnatural is very hard to say very hard to speculate about that.

So, just something to pay attention to you can do, when I called teleporting just point and click where you had like to go, if you have a virtual concert you had a virtual you had a sporting event maybe you are in a virtual movie theater could be watching a live sporting event perhaps and, there may be cameras located at different places inside of an actual stadium, do you want to try to do all of the intermediate motions, or would you rather just have a seating chart pop up and, then you just click where you want to sit very often when you buy tickets for a concert you have a seating chart anyway. So, you might as well just have it set as soon as you click and buy the ticket you just appear there and you are in there place.

So, you may decide select a seat from a chart, or map right perhaps, you want to navigate in a city and you have panoramas that have been captured like, in the case of Google street view you may have a bunch of panoramas of a city, you do not even have intermediate video that will transition you from place to place people may eventually make all these things and connect everything together. But while you do not have intermediate video, why not just pop up a little map and you can see where the different places are you can stand and, you just click where you want to go makes sense.

So, even if you do not have the data you may you may you may guide you towards a more comfortable experience because, standing and looking at a panorama is very comfortable because, it does not have this kind of vestibular mismatch. There is one interesting general topic called way finding and, this goes back to what I mentioned in the very first lecture, when we as humans or other organisms explore physical spaces, we end up developing play cells in our brains part of the neural structure, we start allocating neurons towards particular places and they fire the neurons fire, whenever we arrive back in those places again.

So, there is an interesting question of if you start doing these kinds of tricks of teleporting maybe using a map to get around can you still do way finding a few, if you were to explore a virtual city suppose we picked Washington DC and you want to go

exploring that maybe you have never been there before and you start looking at panoramas you have some kind of map and you start moving around, then I take you to the real Washington DC, will you know where you are going will you have learned that or, will it be a completely different experience and it does not really match.

So, that is something I wonder right is how far can you go and generally, if you are going to explore a large space like a very large building, or big city in virtual reality after doing some of these kinds of tricks to reduce simulator sickness can you find your way easily or do you tend to get lost right.

Now, some people tend to get lost in the real world very easily right, and in the virtual world maybe they are less likely to get lost maybe they are more likely to get lost at least, it is interesting to ask the question of under what conditions is the performance comparable between the real world and this kind of virtual world of exploration using some specialized techniques like teleporting using maps and such right.

So, our abilities to use a map to navigate in a real city vary from person to person right questions about this.