Introduction to Robotics
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Lecture 2.3
Industrial Robot- Kinematic Structures

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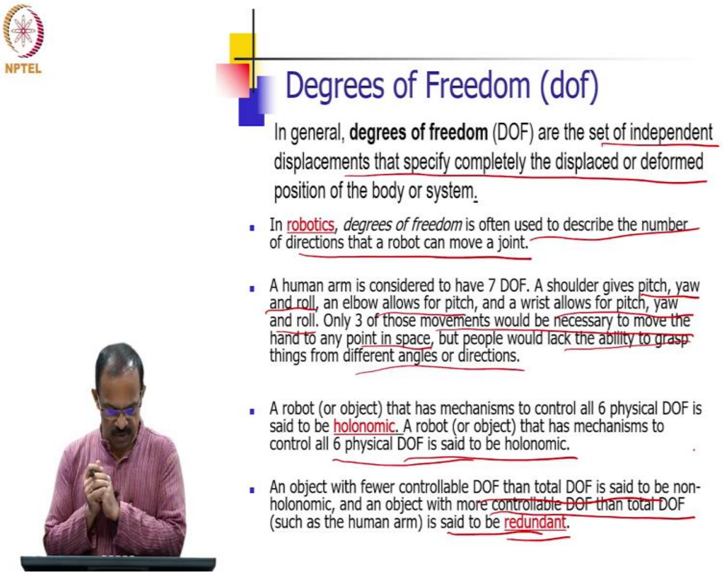

Good morning, welcome back to the discussion on robot kinematics. So in the last class we briefly talked about the degrees of freedom. As I mentioned that in general, the degrees of freedom are the set of independent displacements that specify completely the displaced or deformed position of the body or system.

But in robotics, we define it as the independent, this is the number of directions that a robot can move a joint. So, if our joint can move in 1 direction, we call it as 1 degree of freedom. So if you have four joints and each joint can actually move in 1 direction, then we call this four degrees of freedom robot like that. So that is the way how it is defined in robotics.

Now, as you know, human arm has got seven degrees of freedom, because we have 3 joint motions here at the shoulder and then we have 3 joints motion or 3 independent motion possible at the wrist and we have 1 for the elbow here. So we have like this seven degrees of freedom for our human hands. So we can call this as the pitch, yaw and roll of shoulder. So pitch, yaw, and roll of shoulder and elbow allows for pitch, and the wrist allows for pitch, yaw, and roll. So all of us know that we can actually use these 3 joints to position the wrist at any point.

So we can actually move this here and then in any plane, so we will be able to position the wrist in the space using the first 3 degree of freedom, then the next 3 degrees of freedom can be used for orienting the tool. So I have a tool like this, I can actually use this for orienting it in the space. So the three of these movements would be necessary to move your hand to any point in space. And if you don't have the other things, if you want to have it in different angles then we need to have the orientation that is the way how these 3 plus 3 works for positioning and orientation.

Now, if a robot that has mechanisms to control all six physical degrees of freedom is said to be holonomic that is normally any object in space has got six degrees of freedom. So, if we can actually provide six degrees of freedom for the robot to control all these, then we call it as holonomic 1, so that is the way how it is defined. Now a object with fewer controllable degree of freedom than total degrees of freedom is said to be non holonomic. Suppose your object has got, suppose something has got only four degrees of freedom and if we can control all those four degrees of freedom, then we call it as holonomic.

Suppose the controllable degrees of freedom is less than the number of degrees of freedom, then we call it as non holonomic system. And similarly, if you have more number of degrees of freedom to control, I mean controllable degrees of freedom is more, then we call it as a redundant system.

So, that is how it is defined, if you have more controllable degrees of freedom, then total degree of freedom is said to be redundant. So, we look at the human arm, we have got seven degrees of freedom, but to control this object in space, we need only six degrees of freedom because it has what only six degrees of freedom, but we have seven degrees of freedom to control it.

So, therefore we call it as our human hand as a redundant system. So, that is the way how we define this in robotics. So, we can help holonomic system, non holonomic systems and redundant systems. Let us look at for robotics in the case of robots. So, we know that this positioning is done by the 3 joints at the shoulder and the orientation is done by 3 joints at the wrist.

So, let us see how this is actually happening in the case of an industrial robot. So, we saw that industrial robots are used for positioning and orienting the object and therefore, we need to have the six degrees of freedom in space.

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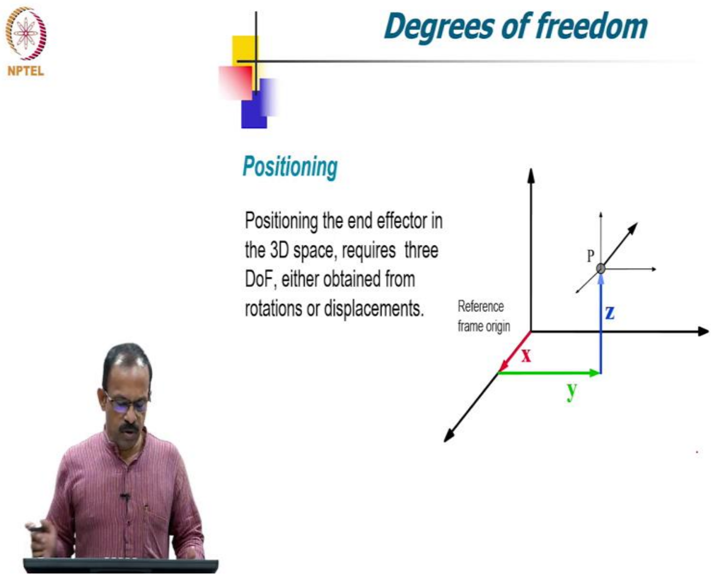

Now, if you look at the positioning of the object using a robot, the positioning of the end effector in the 3D space, because 3 degrees of freedom either obtained from rotation or displacement. So we can actually position this object in space because what we need is positioning in X, Y, and Z. So this can be done by 3 degrees of freedom. So the first 3 degrees of freedom of the robot will be normally used for positioning the object in the space or positioning the wrist of the robot in space. So that is how we get the first 3 degrees of freedom for positioning.

Then, we can get the orientation at the tip so this tool, I mean the wrist, if there is a wrist and then you attach a tool to this, then these 3 orientation that is the roll, pitch and yaw, as I told you with respect to x, y, z axis, so you can actually say this is the pitching motion and this is the yaw motion and this is the roll motion.

So, it is roll, pitch and yaw can be obtained by using another 3 degrees of freedom. So, the 3 degrees of freedom of the robot will be used for positioning or the 3 joints of the robot will be used for positioning and the another 3 joints of the robot will be used for orienting the object or orienting the end effector in the 3 dimensional space. So, positioning and orientation can be obtained by 3 plus 3 degrees of freedom.

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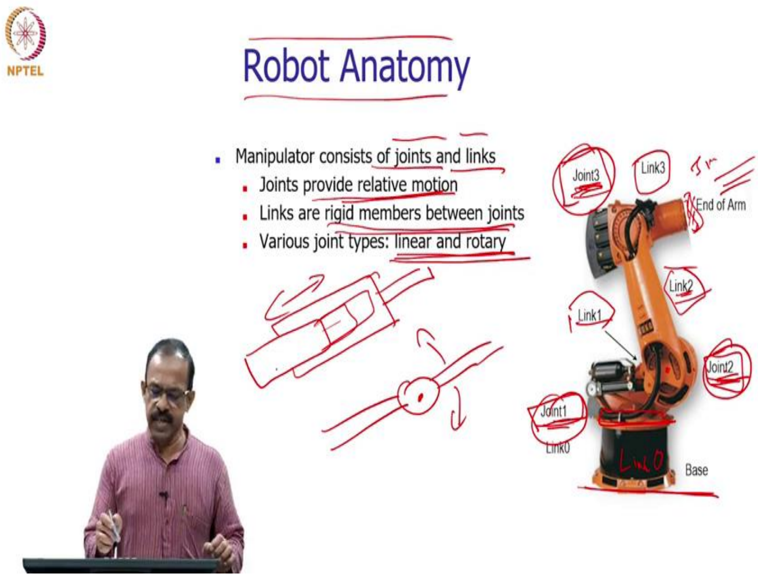

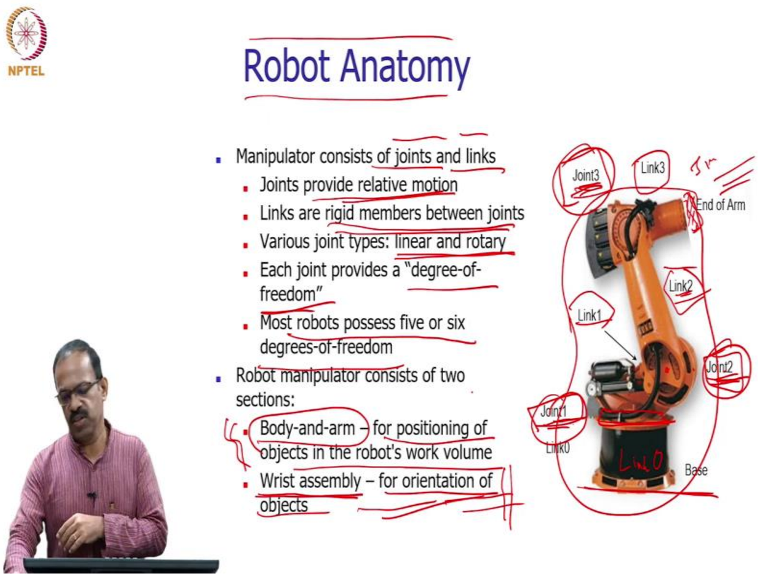

So, now we look at okay how this 3 plus 3 degree is achieved in the robot. So, as you know, the robot will be something like this, you have a base and we call this as the link 0 that the base is considered as a link 0. Then you have a joint attached to this link, I mean this 1 base 1 that is the joint 1 and then you have a link 1 between the link joint 1 and the joint 2, so, this is the joint 2 so you have another joint here. So, this joint 1 and joint 2 connected by a link, then link 2 is connecting joint 2 and joint 3. Similarly, link 3 will be connecting joint 4, etc. so it will be going like this.

Now, if you can see that the joint 3, the three joints joint 1, 2, and 3 will be used to position the wrist of the robot. So, the first 3 joints will be used to position the wrist at one point, and then the wrist will be having 3 degrees of freedom to orienting it. So, these are the first 3 joints; join 1 join 2 and join 3 that can be used for positioning.

So, as I mentioned earlier also there will be joints and links in the robots. And these joints provide that degree of freedom so each joint will be giving one or more degrees of freedom, so normally there will be having only 1 degree of freedom per joint, that is why it says, when you have six degree of freedom, it is known as six joint or six axis robot or six joint robot like that.

So we will be having joints and links and the first 3, joint 1 join 2 and join 3 will be used for positioning the wrist in space. So, the joints are supposed to give the relative motion between the links. So, you can have a joint 1 which provide a relative motion between link 1 and link 0. Similarly, joint 2 provides a relative motion between link 1 and link 2, joints provide the relative motion and links are the rigid members between the joint, so we call this as the links because they are the rigid members. Most of the industrial robots have this rigid links, of course, you can have flexible links also in some special cases. So this is the link which actually connects between the joints and then that is actually a rigid element.

And important point is that these joints can actually be a linear or rotary type. So, you can have a rotary joints, where there will be a relative rotation. So, you can have a rotation with this joint. So, this can actually rotate, this joint can rotate and then this link can actually move so that is the relative rotation, so that is the rotary joint, but we can have a prismatic link also, where one can actually move the other one, this can actually move, the top link can actually move over this one.

So you can actually have a linear motion between the links so you can have either a rotary motion or a linear motion for the joints. Whatever maybe the, weather it is rotary or linear, it will be giving you the relative motion between the links, so the two links will have a relative motion because of that joint.

Most of the robots use rotary joints but there are many robots which actually use linear or known as prismatic joint also. And each joint provides you the degree of freedom, each joint gives a degree of freedom for the robots. And most robots poses five or six degrees of freedom. So as I mentioned, normally we need to have or in general, we need to have six degrees of freedom to manipulate objects in space.

Therefore, most of the robots will be having six degrees of freedom, but does it mean that we need to have always six degrees of freedom, it depends on the applications also, suppose I have an object which is actually moving only in one direction, so I do not need to have all the degrees of freedom.

We look at the requirement of the application accordingly we can say that we can have a number of degrees of freedom, it can be 4, 5, 6 or you can actually have 7 also depending on what actually you want to achieve. So, that is robots have five or six degrees of freedom. And as I mentioned it consists of 2 sections; the first section is for positioning and the second section is for orienting.

So, we call this first section which is for positioning of the objects in the robot's work volume, we call it as the body and arm assembly. So, the first 3 degrees of freedom is used for positioning the wrist or the object in the 3D space so that is known as the body and arm configuration, so that is the body and arm configuration. The first 3 joints and links are known as the body and arm configuration.

The second part is known as the wrist assembly that is for orientation of the objects. So, like in the human arm also. So, we have up to wrist we can say that this is we are using for positioning. So, we want to position the object wherever you want using this and then use the wrist work orienting. So it's the same way, the robot also can be classified or divided into 2 parts, first the body and arm, the second one is the wrist assembly.

So, the first 3 degrees of freedom is provided by body and arm configuration, and the second one is provided by the wrist assembly. So, we have body and arm assembly and wrist assembly so, this basically provides you 3 plus 3. And again, depending on the requirements, not necessarily always it should be 3, positioning will be always 3 because you need to have position in 3 dimensional space, but orientation may not be needed in all the cases. So sometimes it will be less degrees of freedom also. But whatever it is, the positioning part is the body and arm assembly and orienting body is the wrist assembly, that is the way how it is defined.

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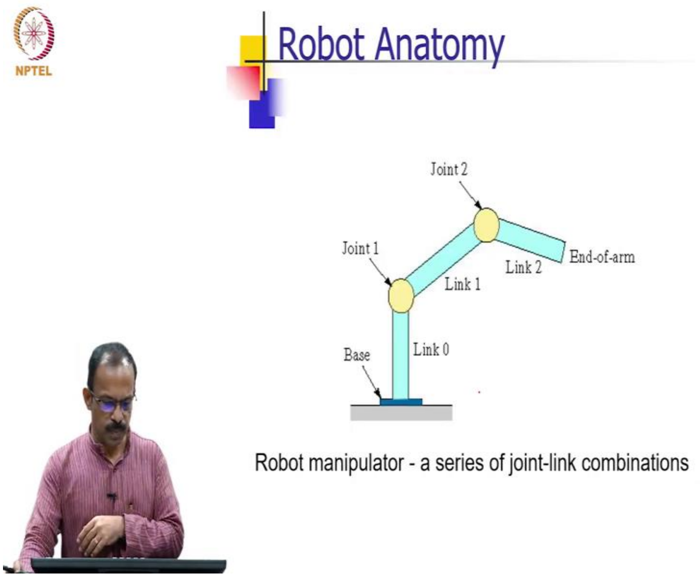

So this actually already explained. So, you have the base, link zero joint 1, joint 2 and link 2, okay. So, that is of course, you will be having joint 3 for the third one. So, the series of joint and link combinations.

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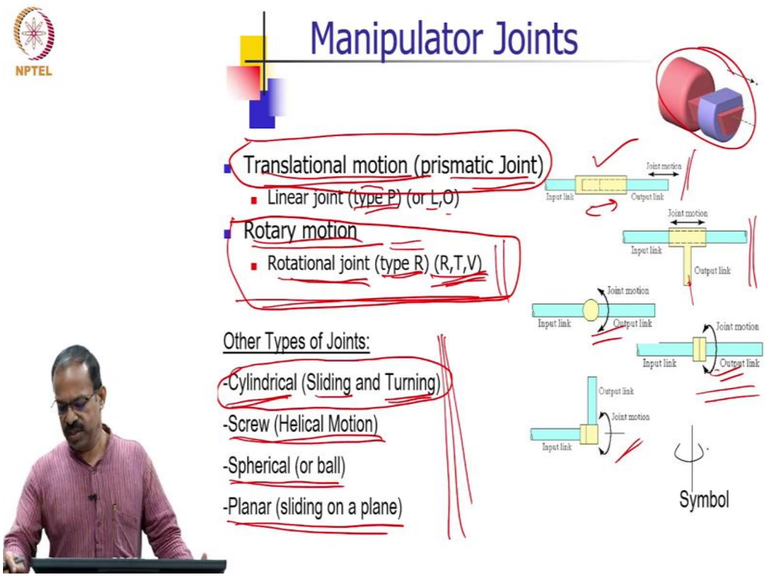

Now, as I mentioned there can be different kinds of joints. So, normally rotary and prismatic are the two types of joints. So, we call this prismatic as the translational motion. So, translational or prismatic joints. So, this is an example for prismatic joints, you would be having a motion, so we can have a relative motion of the link because of the joint.

So, there can be different ways you can actually assemble it, this is the one, this is the other one, okay? So, you can actually have, this is P type joint or prismatic joint. So, it can be L or O, L is the linear one, this is orthogonal one, so orthogonal one is that you are getting output link is actually this one, here the output link is same axis that is why it is different, but otherwise both are giving the prismatic motion, so linear orthogonal type.

And then you have this rotary motion joints. The Rotary is an example for the what i mean this is the CAD model of a prismatic joint. Now, you can have rotary joints normally specified as R type joints. So, prismatic is P and rotary is R, so these are the two major types of joints R and P, rotary and prismatic joints.

And within this rotary we can have variations, so I mean again all provide the relative motion rotary motion between the links, but the way you assemble you can actually get different motions like you can have this one is the normal rotary motion and this is the twist motion and this is known as a revolute motion. So, this basically the way the links are assembled between the at the joints makes the difference and that is why you get this R, T and V joints.

Now, these are all single degrees of freedom. So, you can see that each one provides you 1 degree of freedom, because each one has one relative motion is possible. Here it is rotary twist or revolute joint, you will be getting the same kind of I mean 1 degree of freedom. Now, you can have other types of joints also, that is you can have a cylindrical joint where you can have a sliding and turning. So, that actually gives you 2 degrees of freedom, can actually give one 1 sliding and 1 turning that kind of joins are known as cylindrical joints.

Or you can have a screw motion or a helical motion joint can be there and can have a spherical joint also, a spherical joint actually provides you 3 degrees of freedom because it can actually rotate with respect to all the 3 axis. And you can have a planar one also again, it's a motion in the plane so, you can have 2 degrees of freedom.

So, these are the other possible types of joints, but not really common, not used very much in the industry. But these are all possible, you can actually have joints of this category also. So, important one, the prismatic joint and the rotary joint. So we call this I mean, these are the two major joint types that you can see in the industrial robots. And the representation, so it is basically the rotary joint is represented like this, so this is the way how you represent the rotary joint. This actually shows the axis with respect to which it is rotating.

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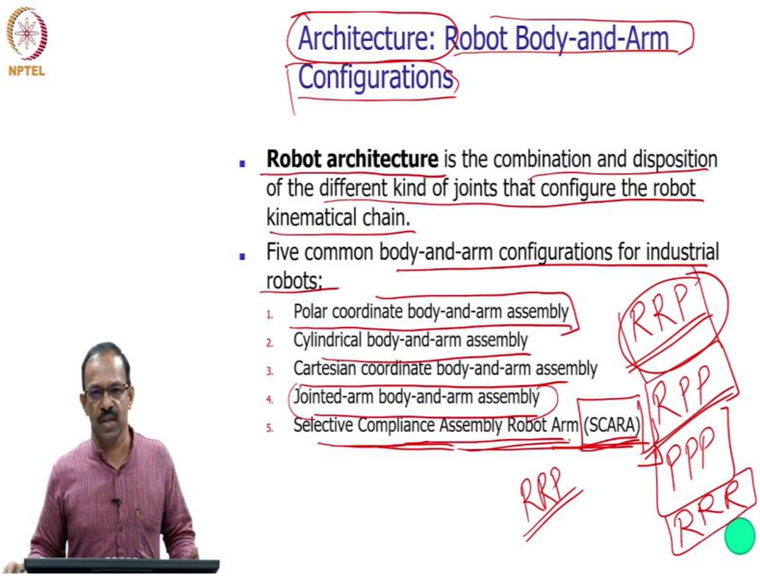

Now, we mentioned about the body and arm architecture. In the body and arm architecture which is used for positioning the wrist, so that is the first 3 degree of freedom which is used for positioning. Now, the robot architecture are classified based on this body and arm architecture, body and arm configuration. By assembling these 3 joint, first 3 joints in different ways or choosing the type of joints in the first 3 joints, you will be able to get different architecture for the robots. So, let us see what are the different architectures possible and how these architectures leads to different types of robots.

So, it is a combination and disposition of different kinds of joints that configure the robot kinematic chain. So the kinematic chain that is the assembly of the joints and links makes the robot configuration and since we have different types of joints, and by arranging these joints in different ways, you will be able to get different configuration for the robot and that is known as the robot architecture.

There are few commonly used architectures. So, we will see what are these architectures in this section and see what kind of workspace it leads to and what are the complications or what are the advantages of using different architectures. Now, we know there are 3 joints. So, the first 3 joints, 3 joints are used for the body and arm configuration. So, that is the one which actually use for positioning.

So, these three joints can be either R or P, it can have either an R architecture or R joint or a P joint. So, you can have an option of having these joints in different combinations. So that is what actually gives you different architectures. So, five common body and arm configuration for industrial robots are there in the market.

There are five ways actually these are arranged and that actually gives you five body arm configuration for robots, and the first one is known as a polar coordinate body and arm assembly that is you can actually represent the position of this by using a polar coordinate and so it actually gives you configuration of RRP, two rotary joints and one prismatic joints gives you a polar coordinate body and fixed arm.

So, this is 1 rotary joint and this is 1 rotary motion, okay, 1 rotation like this, and 1 rotation like this and then a motion, inward or outward motion okay, that is a linear motion. So, these 3 RRP helps the robot to position the tip at any point in 3D space, because you can actually cover this plane and this plane using these two joints and within this plane you can actually move in and out so that you will be able to cover the distance in other plane also. So, this way, you will be able to position the tip using these 3 joints, I mean RRP configuration that is known as the polar coordinate robot and arm assembly.

The second one is, the cylindrical body and arm assembly. So, here you can actually replace one of these R with a P. So, if you do RPP, that is you have a rotary joint like this, which actually cover this plane, and then you can actually move in and out. And then you can go up and down also. So, that actually covers the whole 3 dimensional space can have RPP configuration and that is the cylindrical body and arm assembly. So, you have RRP RPP and then you can have another one Cartesian coordinate body and arm assembly, which is like 3 prismatic joints it can have three prismatic joints.

So, you can go up and down, you can go side to side, and then you can go in and out also. So, of all our prismatic joints, so we can have x direction motion, y direction motion and z direction motion using prismatic joint and that is known as Cartesian coordinate robot, Cartesian coordinate body and arm assembly. And the next one fourth one is the jointed-arm body and arm assembly, which is so, this we have RRP RPP and PPP, so the one is remaining is RRR.

So, RRR is the jointed arm body and arm assembly where this is our rotary joint. So, most of the robots actually fall into this category, and most of the industry robots actually fall into this category because you can have all rotations, you can have one rotation here, one rotation like this, I mean I can move like this and you can have other rotation also.

So you have all the three rotations possible and using these three jointed arm body and arm assembly you will be able to get the positioning in the 3D space. So this is the jointed body and assembly RRR. And the last one is a special category of robot, which we call it as SCARA. So this is known as a SCARA robots, which is basically a selective compliance assembly robot arm.

It is actually an RRP robot, so 2 rotary joints and a prismatic joint. So it is something like polar coordinate, but the only difference is that the joints are assembled in different ways. So the joint axis are arranged in a different way so we get a different configuration. And this configuration allows you to get a compliance in one of the planes. So, one plane you can actually have a large compliance, because all the motors are in a different plane. So it actually allows you to get some compliance, it's known as a select few complaints assembly robot arm SCARA.

So these are the five body and arm architectures possible using this R joint and P joint. So we use the rotary joint or the prismatic joint, and then arrange them in different ways. And we will get five configuration for the robots. So we look into these configurations in detail and try to find out what are the difference between these configurations and how their workspace changes, and how their kinematics get affected because of this configuration. So we will discuss this in the next class. So till then, goodbye. Thank you.