**Introduction to Computer Graphics**
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**Lecture - 21**
**Rendering**

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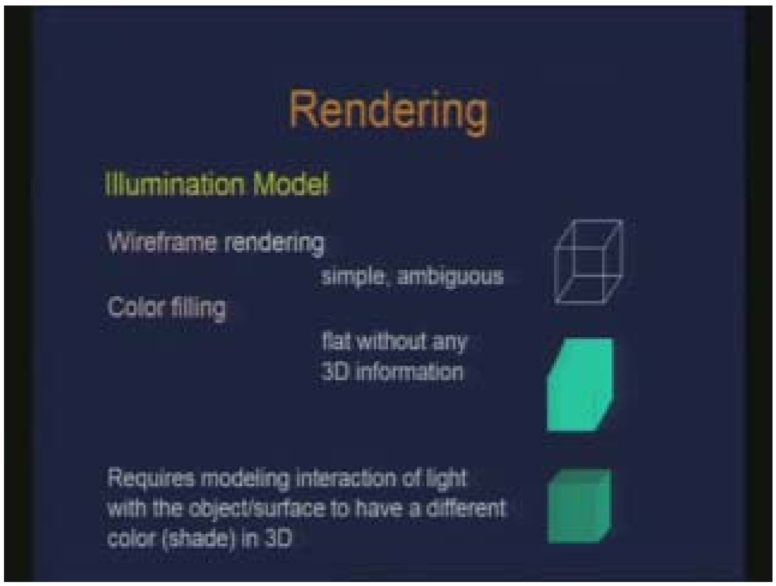


Today we are going to talk about some rendering issues. So far we have looked at the possibility of the rendering objects more like a line drawing or piecewise line drawing. So, in order to be able to have realism in the rendering or the display of the objects of the scene we construct it is important that we try to incorporate the issues which will enhance the realism or the realistic display. So if you look at the kind of possible rendering one may have or what we seen earlier is a sort of a wireframe rendering where we see the display of a cube as a collection of drawing lines.

This is a very simple way of displaying or drawing the objects and we have noticed that it may lead to an ambiguity in understanding what that object is about. If we just try to fill the various primitives or polygons which constitute the object, if you have a cuboid kind of a structure here and if try to just try to fill these polygons are the faces of the cube with just a color so as a consequence I may get just a flat color rendering of the object which does not give me any information about the three dimensionality of the object. But I am not able to appreciate the 3D aspects of the object it is just a blob of color. So in order to enhance that what we need to do is we need to look at the issues which relate to the interaction of the light source.

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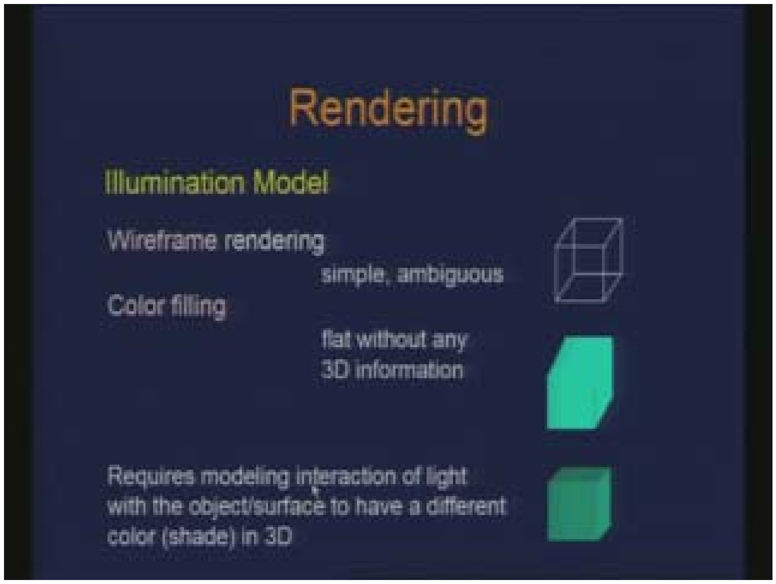


Let us say if I assume some light which is illuminating the object as what happens in reality. So how does an object or the surface which I want to render interacts with that light source or if more than one light source is there then that is what it results into having different shades or color in different point in the object which gives you the 3D notion or the display of the object. So we are going to look at some possible models which are helpful for deciding the illumination of an object. The ideas are borrowed from physics and they are simple so that you can compute them quite fast.

When we are talking about the interaction of the light or light sources with respect to the objects or the scene then from the physics what we have studied we observe that the light when reaches on a surface it gets absorbed, it gets reflected or it may get transmitted. So there are various phenomena but these are the major things which happen to the light.

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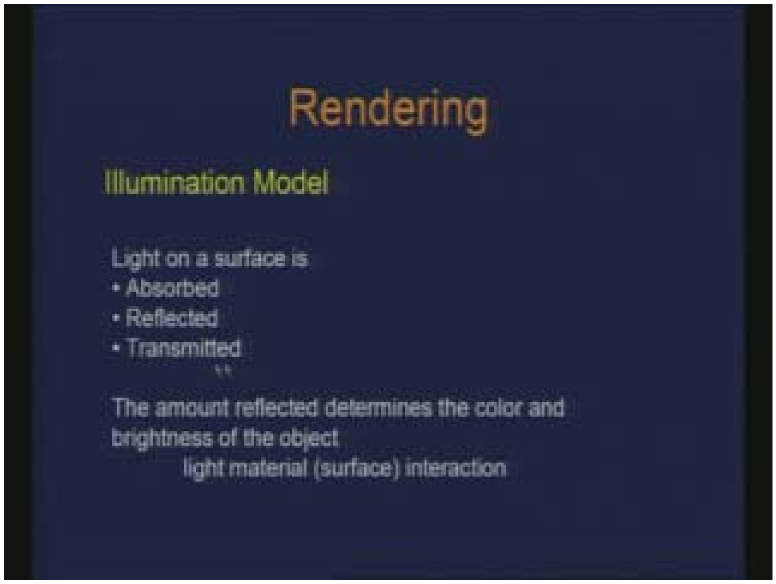


For the time being let us ignore the transmitted part. So what we see is that the amount which is reflected actually determines the color or the brightness of the intensity on the object. So anyway what we are dealing here with is the light material so now there is also a notion of the material properties of the object. So there is geometrical representation of the object and you also need to incorporate some material properties. And the interaction of that we would in turn give you the information about the total amount of reflection on the surface which will give you the color or the intensity you want to determine.

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So while looking at various components for deciding illumination on a point of surface what we observe looking at the reflection of the light on a surface is that there are various components in which we can look at the reflection of light. There is an ambient light which comes from all directions and it is scattered in all directions so there is a sort of a glow in the environment which is basically contributed from various distributed sources of light. Even in the day time you switch of the light or whatever sources of light you have in the room you still have some illumination or glow in the environment. That is what we refer to as the ambient.

There is also a diffused light which comes from one direction and is scattered in all directions. And there is also a specular light which come from one direction and is scattered in some preferred direction. We are going to look at these components and look at the computational aspects of these components and then define an illumination model.

Diffused reflection is something like the light coming from one direction. This l is the light vector, n is the normal vector at a point on the surface and the angle between the light vector and normal vector is theta.

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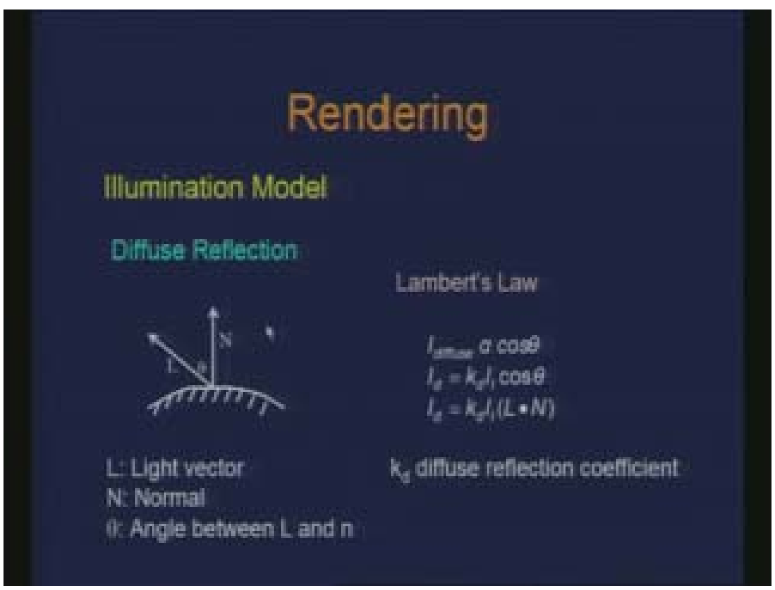


So, observing Lambert’s law which says that the reflected light is proportional to the cosine on the angle between the light vector and normal vector basically means that I can define the diffuse reflection the component given the incident light i l and I define the coefficient called diffuse reflection coefficient which is actually based on the properties of the material of the surface I am going to render. So typically if I am looking at rendering in a single color mode that means in gray levels one in density value then this Kd would vary between 0 and 1. So 0 means very low in intensity so the color of the inherent object is towards black and as I go to 1 then I have the color as more towards white.

Similarly, if I am talking in terms of a color object this could define the color of the object of which I am interested in displaying. So this could have components like rgb. So if I say 1 0 0 that is a vector rgb which would mean that the object which I am interested in is red. So this Kd captures the material property or the color properties of the surface. Now this cos theta is nothing but l dot n. Considering the unit vectors cos theta is just the dot product.

So using Lambert's law I can basically model the diffuse reflection which says that there is a light incident on the surface and there is a uniform sort of a distributed scattering of the light determined by this. Here is an example, these are the light rays I am getting the incident light rays then the outgoing light rays are going to be this blue. They are all uniform at this point. Here we observe that basically the interaction of the light source with the surface or the object gets determined by the angle between the light vector and normal vector. That is the governing parameter which decides everything plus the color properties of the object defined by Kd.

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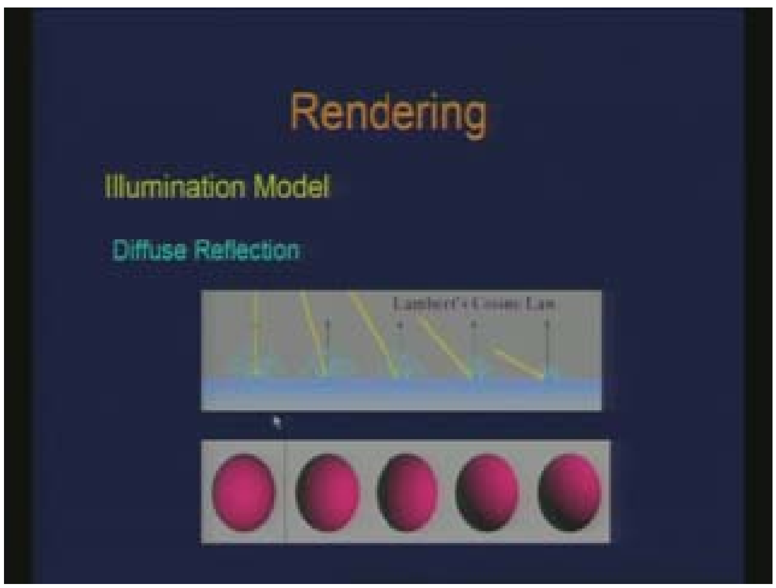


So here is an example. If you have the light incident on the point of a surface coincident with the normal vector then you will have something like this. On a sphere you will observe the distribution of the intensity of the sphere as something like this. So at this point this is uniformly distributed. The moment I change the angle, that is if I make the light vector slightly away from the normal vector it will change the diffuse reflection for the sphere at various points. Here I observe that the total illumination is reduced. So what happens at this point is the total diffuse reflection is reduced which is just a direct function of the angle. And this is what will happen for the points which are towards the boundary or farther from the center of the sphere.

So you will see a variation of a shade on to the sphere. Just by using diffuse reflection you can actually look at the shading of the sphere which already increases the realism of the object. Therefore, this diffused reflection actually only depends on the light vector and is independent of the viewer. It does not matter where the viewer is but all that it is concerned about is the light vector. So it is viewer independent.

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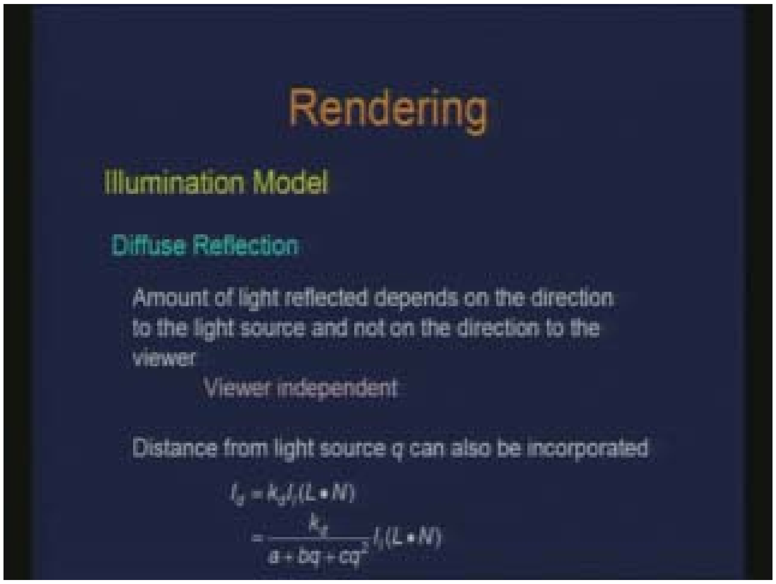


At times what happens is when we are talking about illumination of a point on the surface we observe that the points which are farther from the light source should have less reflection or light glow on to the object.

For example, if there are two spheres one sphere here and another sphere here this sphere which is farther from the light source gets less light incident on it. Therefore the total reflection is reduced. So you may want to incorporate some notion of the proximity of the objects with respect to the light source. This can be done or modeled using an inverse function to the distance. So here if I consider queue to be the distance of the point of the object from the light source then I use this inverse function is a plus bq plus cq power 2 which in some sense attenuates this light intensity as a function of distance. So some people use such a function and some people do not use, it is debatable.

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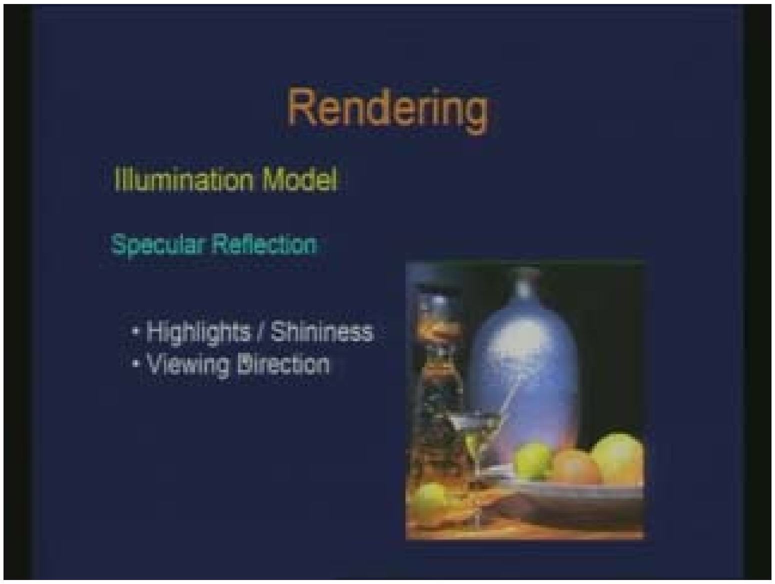


The direction of the light source is already captured through this, the direction of the light source with respect to the normal is not capturing the distance of the light source. In case you are interested incorporating that accept and clearly we observe that there is inverse relationship to the light incident with respect to the distance so we may want to model something like this but many people do not incorporate this preference because there is implicit role of the viewer also which we are discarding.

Now the question is that this diffused reflection does not incorporate many other aspects which we may be still interested in. For instance, often we observe that there are highlights or shininess on an object. Perhaps you may be noticing some glare or shininess on my glasses because of the kind of material they are made of. Here is an example. For instance there is this concentration of light at some points, the portion of the object. This is what is meant by shininess or highlights which are completely ignored by diffuse reflection. And these highlights or shininess in some sense a consequence of incorporation the viewing direction. So whenever you see some shininess as a viewer if you change then you see that the shininess is also changing. Therefore specular reflection which is a sort of information about high lights and shininess considers viewing direction so this something which is viewing dependent. Now the question is how we would like to model this.

There is a phong model which is used for modeling specular reflection. If we consider a light incident of some point here this is the normal vector and this v is the viewing vector that is the reduction of the viewer. So now what happens is that there is a reflection of the light at this point. This R is the nothing but reflected vector. There is also a mirror effect which is what we are trying to capture.

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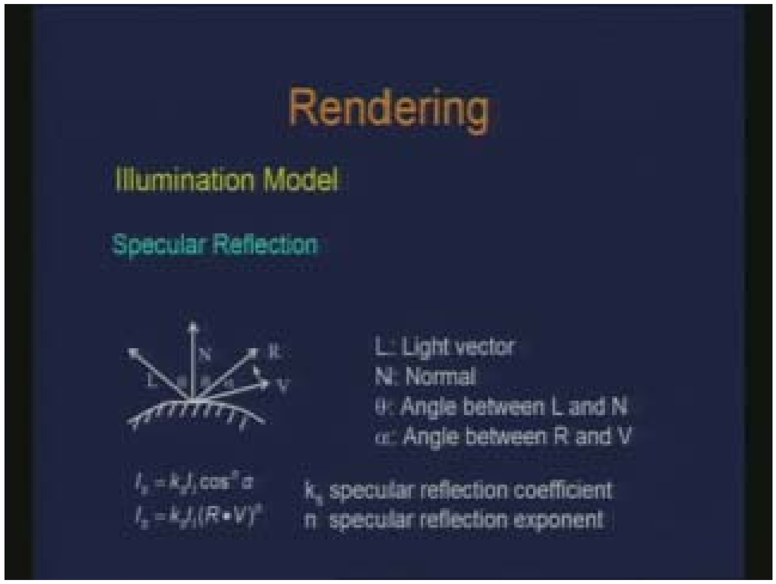


So, if I have the v coincident to R I will observe that the entire light is reflected. So whatever is an image here of the light source I will see that here and that is what is completely reflected. So without worrying about this mirror effect at this point we just want to see that there is a light incident on it which is reflected through the vector R and that is also contributing to the total reflection of the light at this point in addition to the diffuse reflection. And this is actually proportional to the cosine of the angle between the viewing vector and the reflected vector.

An exponent is used here. This cos is the specular reflection or models this specular reflection. In other words what we are saying is that there is this light incident here and there is this reflected vector. What happens is that there is some sort of a distribution of the reflection about this reflected vector which is also determined by the direction of the viewer.

There is some concentration of reflection here but it spreads over and the concentration of that sprit is captured through the exponent which we have used for cos alpha. So, if I use that exponent equals to 1 I have this cos alpha function plotted here and if I use higher exponent 5, 10 or so then the curve changes in this way and I see more of a concentrated intensity at that point hence it basically controls the spread.

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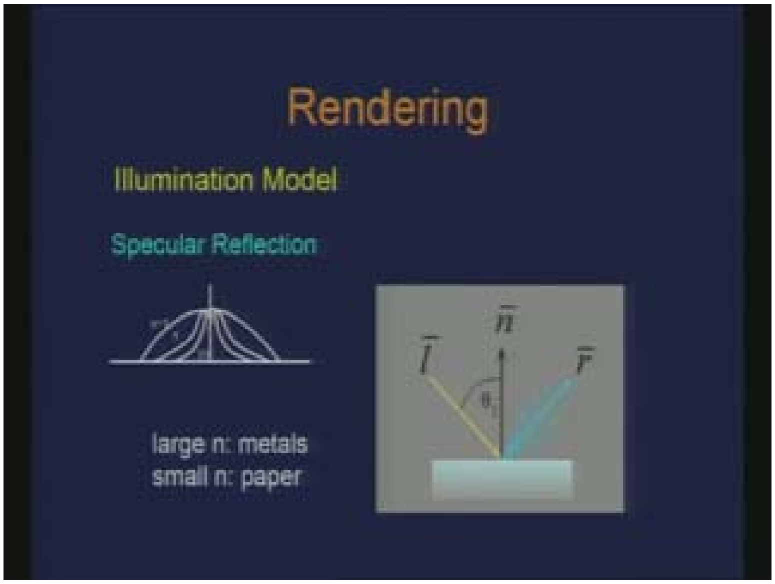


This is actually some sort of a measure of the type of material I am having for the surface. So, if I have large n then these are the more like metallic objects so the shininess is very concentrated. And if the n is small then it is more of a mat like object something like a paper or wood where you do not observe lots of shininess. Actually there are other issues also. When we discuss about ray tracing then we will actually see how we model things like mirror because right now I am looking at the influence of the intensity of the light onto the intensity which I need to render this point. So, if I am just looking at single point reflection then this will be a very large number like infinity, there is no spread basically.

This is sort of a plot of the cos alfa so if I have a cos alfa versus alfa. So how do you plot cos alfa? So this is a cos alfa. Here this is just controlling the spread and is normalized. But what happens to this term here. So how much I get here is altogether a different thing. This is just like, how would this vary with respect to this n in a normalized fashion. Therefore I am just keeping this part here as unity. So when I increase the value of n I see that there is a concentration around this and the spread is reducing.

Here is an example:

Here if I had some other direction I get this shininess and now for these three I have the same direction to show you the variation of the value of n. Therefore here it is parted so it is a high value of n and here you see more spread so it is a lower value of n.

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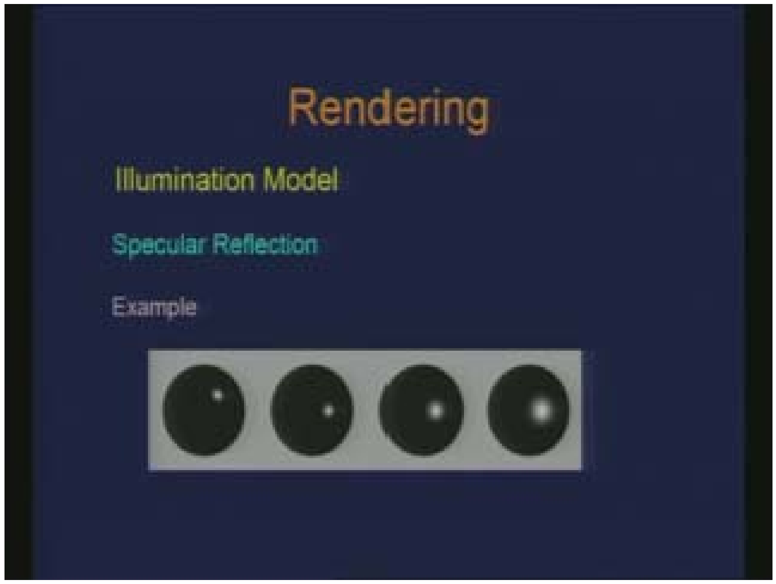


This is the concentration of light which is due to the exponent value. Therefore you have the rest of the diffuse reflection coming, this is an added value to it which gives you concentration of intensity and thereby some shininess or highlight.

Ambient reflection: In fact what happens is that whenever we talk about rendering or display and when we are looking at the light sources which we defined for illuminating the environment in reality there are lot of light sources which may not be explicitly defined as light sources because even objects themselves work as light sources, they have the ability to emit light and so on. Therefore there is a lot of integration of various light sources in the environment which in turn give you some glow of the environment even without having an explicit light source. This is what we try to capture through ambient reflection.

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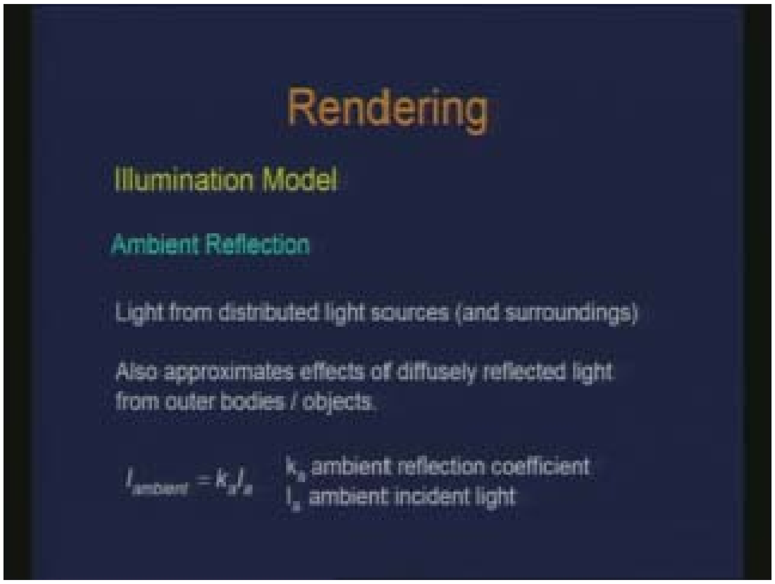


Now clearly if I try to model each object as a potential light source and therefore compute the light distribution for all the other objects it is going to be computationally very interesting. So what we do is we approximate this phenomena, we try to approximate this phenomena just using a simple relation like this where you have an ambient reflection coefficient similar to Kd and Ks and ambient incident light so here we can differentiate from the incident light with respect to a light source.

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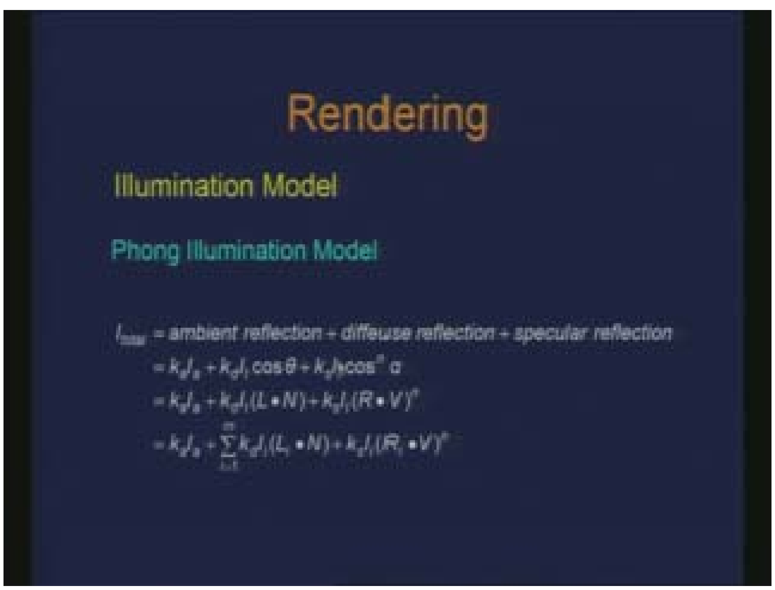


This is the general ambient light which I could define differently from the other incident light. So now we have looked at diffuse reflection, specular reflection and ambient reflection. If I just combine them I get an illumination model which is due to phong illumination model where I get the total intensity just as a summation of ambient reflection, diffuse reflection and specular reflection. So I just substitute the various terms here. Here this Ks is similar to Kd characteristic to the material but most of the time when we look at the shininess they are of the color of the light. So typically when we are talking about white light sources then the shininess we observe is white. Therefore this Ks is generally taken in as white color or just a scalar value unless you are trying to do a color light source which is also possible.

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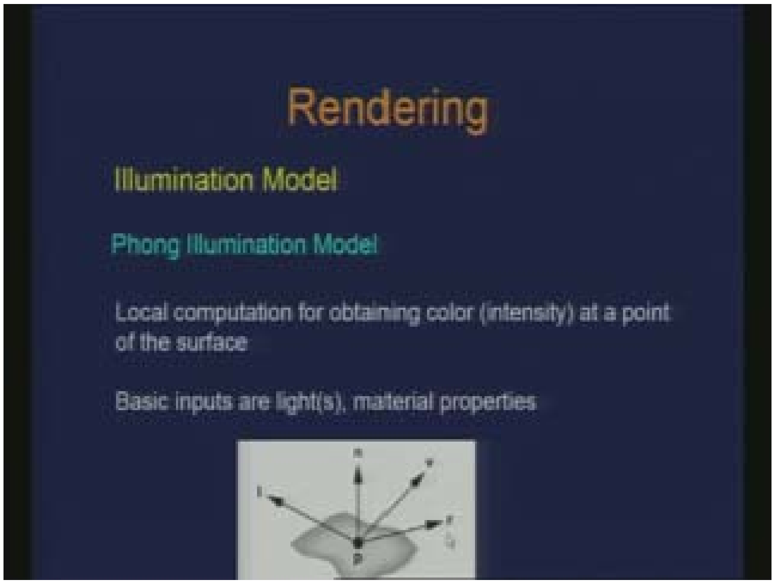


This is what we get if I had only one light source. There is an ambient light coming from the environment and I have one light source from which I get the incident light as IL. Now if I have more than one light sources then what should I do?

All I need to do is just to look at the interaction with all the light sources, compute the respective terms for diffuse reflection and specular reflection with respect to each light source. Taking a sum over the light sources I have like 1 to m I am computing the individual terms for diffuse and specular reflection. Hence I can handle multiple light sources. Ia is generally given to you or you assume that it is given. For example, if you define some IL then what would be the incident light. Similarly, if you assume some ambient light and in fact Ka is also often taken as some toned value of Kd as you do not want to change the color of the object. So now what are the computational issues here?

I need to have this (L dot N) which is easy. I know where the light source is I would define it for the environment of the same, I know the n or I can compute the normal vector and I also require this reflected vector, v is easy to compute the viewer direction is easy to compute I know where the viewer is located then the question comes as how do I compute this R.

Here are some computational aspects. Now just to sum up the phong illumination model it is a local illumination model because the computation which we are doing is local at that point. And if we look at the basic inputs or the number of light sources I have the material property is given through the various reflection coefficients, the viewing vector and the surface. Now the question is I need to compute this r, now how do we get it?

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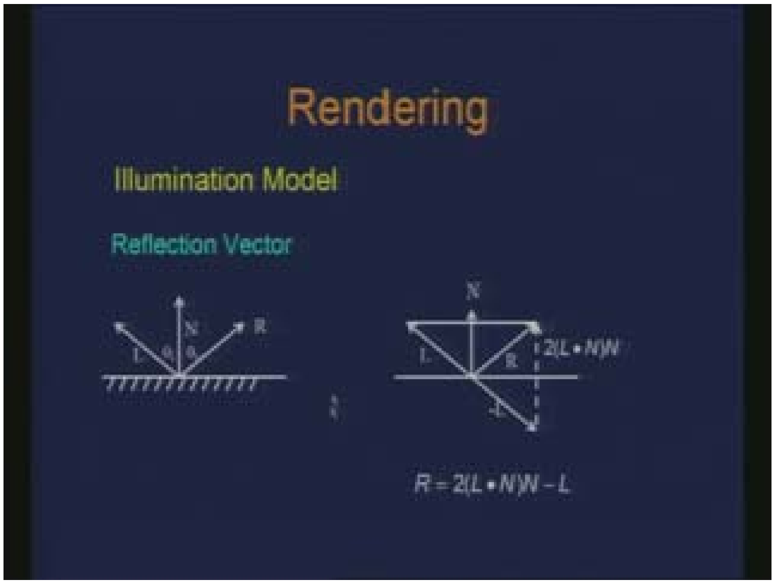


So this is the configuration we are looking at. There is a light vector here, normal vector and this is the reflected vector. So you can also solve it geometrically to find out what R should be in terms of L and N. But geometrically it is straight forward. Geometrically what is happening is, if I consider this where I have this minus l vector and this is nothing but twice of this which is a vector (L dot N)N where L dot N is the amount in the direction of N so it is the projection of this onto this. So this total vector is now 2(L dot N)N. Therefore R is nothing but this 2(L dot N)N minus L dot l so I can compute the reflected vector R in terms of L and N and those are given to me therefore I can compute R dot V. There is an approximation also through what is called as half way vector. So, half way vector is actually a half way vector between V and L.

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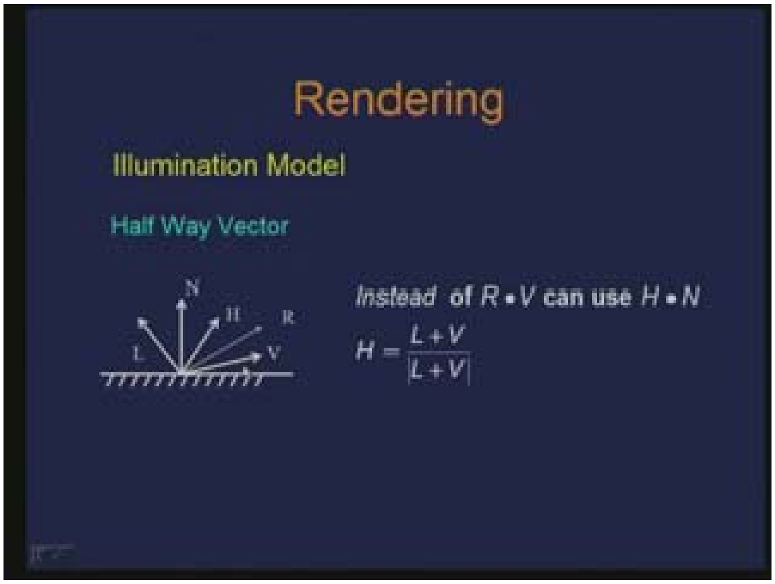


In fact what is told here is that you compute R dot V by computing H dot N. So this angle is somewhat similar to this angle and that is the idea there. So again computing H is easy, you just need to have to V and L, you also know what N is. Therefore you can approximate R dot V using H dot N. Now we also need to have normal vector. During this course we have also looked at the computation of normal vector for various primitives.

Therefore if I have plane given in this form ax plus by plus cz plus d is equal to 0 or I could have a plane defined in terms of the normal vector n dot (p minus p0) is equal to 0 so p is an arbitrary point on the plane, p0 is a known point in the plane so just looking at the solution of this gives me the normal vector as nothing but abc which I can normalize. So I know how to compute the normal vector plane, it is very straight forward. In fact there is an alternate way by taking a cross product. Hence typically you would have the extents given through the vertices of the plane and you can take the cross product of the sides to have the normal vector.

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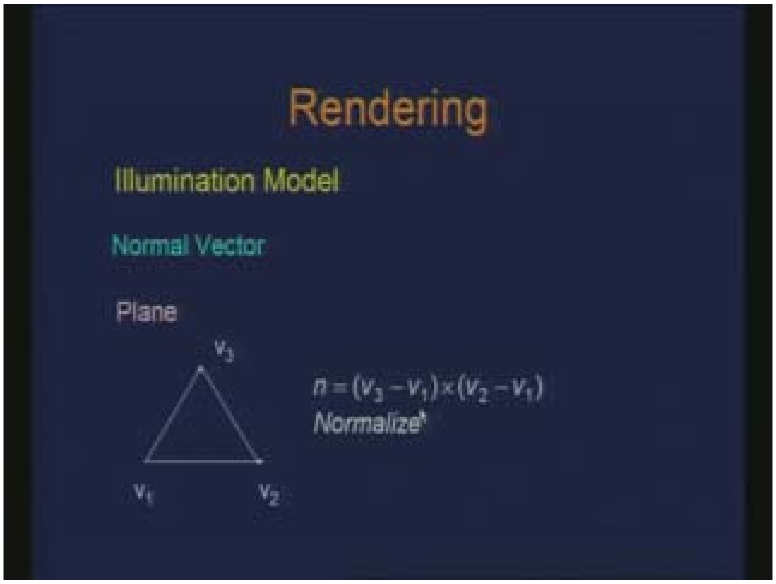


Similarly, if you are interested in getting normal vector for something like a sphere if you use an implicit equation of this kind f(x, y, z) is equal to x power 2 plus y power 2 plus z power 2 minus 1 is equal to 0 then all you need is, take a grade function of f and that defines the normal.

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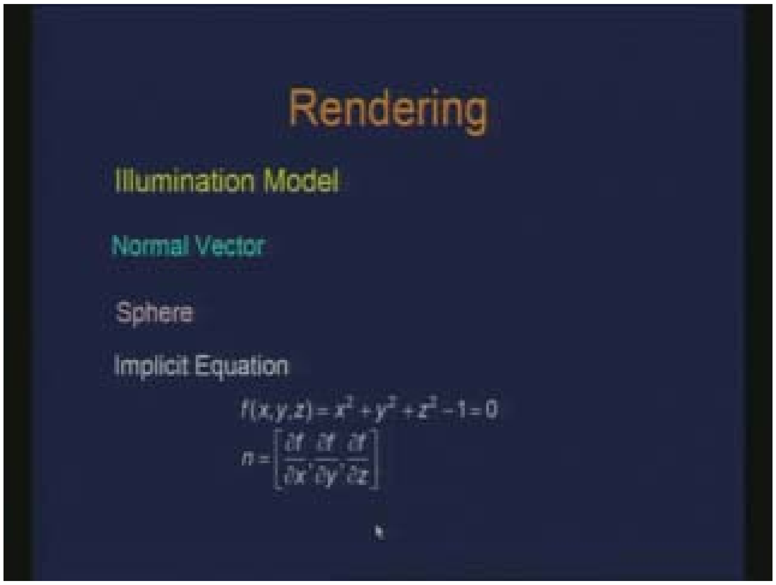


In fact in this case you can also look at the vector form which will be p as a point on the surface of the sphere so p dot p minus 1 is equal to 0 and the solution of that gives me the normal as just p. And we have also seen normal vector for parametric surfaces. There if I take the derivative at a point of the surface and take a cross product of that then I can get the normal of that point. So we have all the necessary information which we require to compute the illumination and the various components of the illumination.

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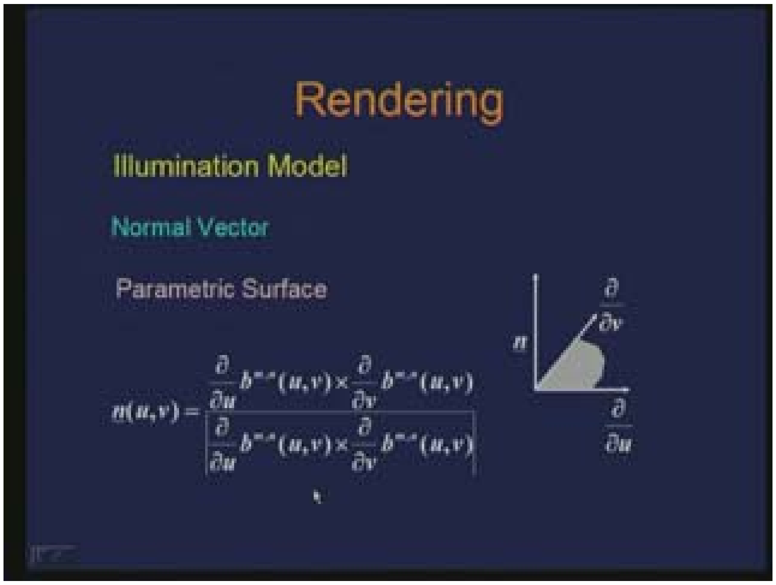


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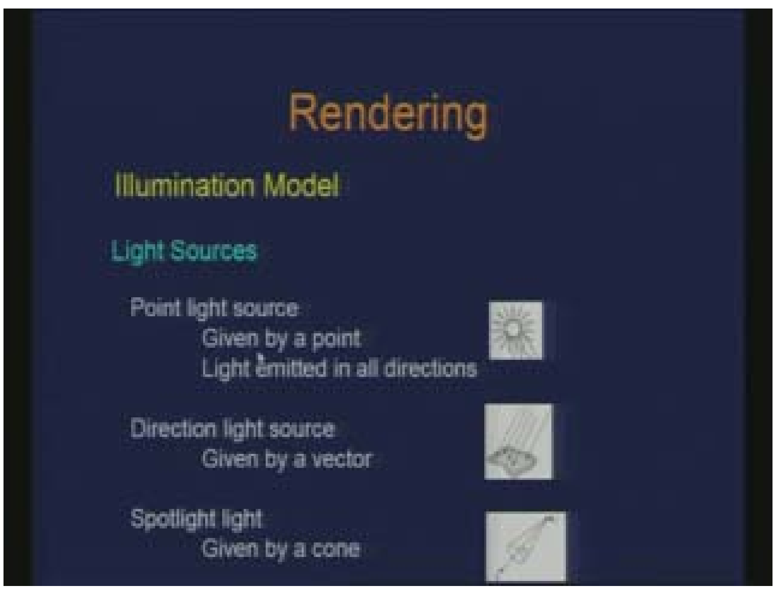


We have looked at light sources but actually you can have various kinds of light sources. You may have a light source defined as a point light source where the light source is given by the position of a point and we consider that the light is emitted in all directions.
Or you may also have a light source which is a directional light source given by a vector so the light is incident along a direction. Therefore, as far as the location of the source is concerned it is said to be at infinity. You can also have spotlight.

Probably you notice that in cinematography or in many other situations or you want to simulate something like in torch so you have a spotlight source also which is given by a cone kind of a structure. All that the cone is saying is that there is some sort of a zone within which you are going to emit the light source from the point. All these light sources are supported on OpenGL. All you have to do is just give the type of the light source you want to use and the rest of it will be done by OpenGL. Here is a small clip:

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This is a short move made by Pixar. Pixar is an animated movie house that has won lots of academic and Oscar awards. This was probably made in 1986. Therefore this basically tells you that just a small feature of lights and shades can do nice things.