Computer Graphics
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Lecture # 35
Illumination & Shading (Contd...)

In the last two lectures we have discussed concepts of illumination and shading. First we understood the process of illumination by light sources and understood why it is a very hard problem to solve. Then we of course when through a few concepts based on the ambient illumination model and diffuse deflection model where we simply make certain assumptions to solve or count the hardness of the problem. And we have also seen that the illumination consists of three parts the diffuse, the specular and the ambient term.

Of course we have studied at length the ambient reflection component of the illumination and also the diffuse. And at the end of the last class we just introduced the specular component of reflection which we are going to study in detail in this class today.

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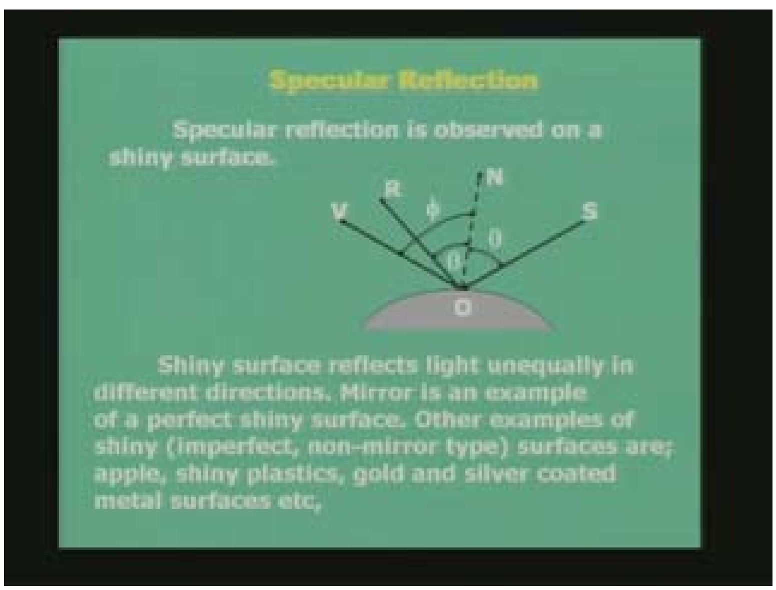

So if you look into the slide now the specular reflection is observed on a shiny surface unlike in the case of ambient or the diffuse term which reflects light equally in all directions ambient component is responsible due to inter-reflected rays many of them which are combined together and fall on a particular surface. And of course we have also seen the effect of distance or atmospheric attenuation specifically in the case of diffuse deflection. And the case of diffuse deflection is the wall, the case of movie screens, projected screens are examples of the diffuse patterns.

Of course dull mat surfaces are also the case. And the case of specular component shiny surfaces mirror of course is a perfect shiny surface and of course there are other non-mirror type specular surfaces and the examples are being an apple surface, shiny plastics, gold and silver coated metal surfaces etc. So what is the equation which governs the specularity? This is one of the model suggested by Phong's. The Phong's illumination model which we considered here is that we have an ambient term here where lambda is the ambient color K is the ambient's reflection coefficient, $O_{dlambda}$ represents the objects diffuse color of course which goes into the ambient term as well.

Then we have seen the f attenuation term based on distance under $I_{plambda}$ is the points light source intensity I_p or $I_{plambda}$ is the points light source intensity. And within that there are two terms K_d O_d cosine of theta which you have seen earlier is the diffuse component of illumination. K_d is the reflection coefficient of the diffuse term, $O_{dlambda}$ is the object diffuse color, cosine of the theta is the angle between the surface normal n and the light source direction vector S. This is the new term which comes here K_s $O_{slambda}$ and cosine to the power m where K_s is the specular reflection coefficient varying from 0 to 1 as like K_a and K_d we also have the specular reflection coefficient of the object surface.

We also have $O_{slambda}$ which represents the objects specular color like we have the object diffuse color here $O_{dlambda}$ we have the object specular color which could be different from object diffuse color. And cosine alpha to the power m this is the important part so this is the exponent alpha we will see is the angle between the vectors R and V.

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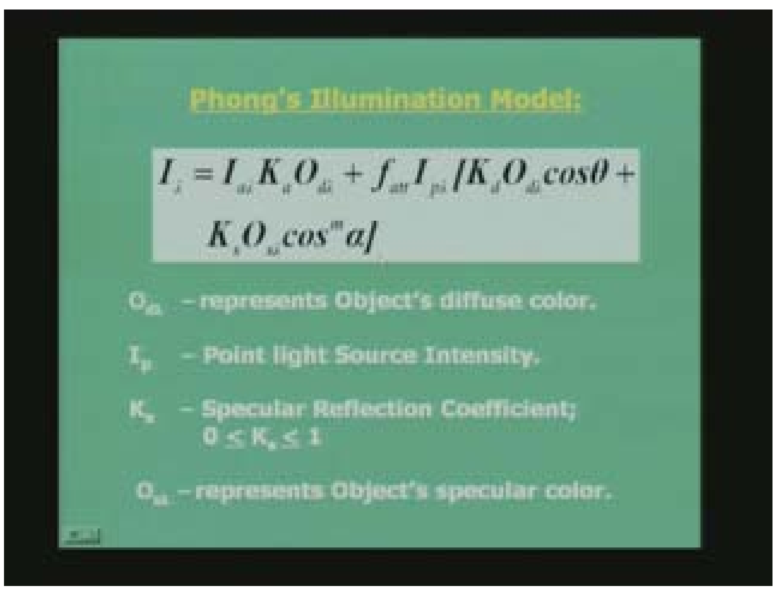

We will come back to that figure once again and see that this is the angle alpha between the vector R. What was that vector R? That was the direction through which the majority of the rays will be reflected the entire intensity almost in the case of mirror of course the entire intensity goes along R the light intensity. But in the case of non-mirror type specular which is shiny but not mirror. Majority of these rays will go along R but a certain section will go along the direction which is close towards the vector R and that will be reflected by the angle alpha. So, if you are close to the R if alpha is equal to 0 the

V and R are exactly same. That is what will happen if alpha is equal to 0 that means you are looking along R. But you could be looking around close to R and that is the angle alpha which will dictate how much of the intensity you are seeing which is not along the reflected direction but close to that. So we look back into the figure and study what is the effect of alpha and then what is the effect of this integer value m on the specularity of the surface.

So if you look into this set of equations and the figure let us understand the figure again object point O, surface normal N, source direction S these are the two vectors the surface normal N vector and the vector pointing to the source direction and angle theta in between them and the vector R pointing to the direction in such a manner that the angle between N and R is also theta. And again I repeat like I mentioned this in the last class that the vectors are N and S all lie in the same plane.

So assume a two dimensional scenario of R, N, S vectors and this is the angle alpha which I am introducing now. This is the angle alpha between the vectors V where V is the viewer direction vector and the angle alpha is the vector between the vectors R and V. Now V could be anywhere in 3D so the angle alpha which is shown may not be in the same plane as R, N and S. So there is no way we can talk about saying that alpha plus theta is your angle phi which you talked about earlier. So you cannot say that right now because this is as I said before R, N and S are lying in a plane but V may not lie in that plane so you have an angle alpha.

That is the significance of the angle alpha which we have seen in the previous slide this is the angle alpha which I have talked about in this case. So that is the specular component this is the specular component we have the specular reflection coefficient here and the specular object specular caller Os lambda and we had introduced what is alpha. We look at m later on cosine of angle alpha where the alpha is given by this particular angle here. How do you compute this cosine of alpha given a vector V N and R S.

The first question comes is how you compute R?
This is given on the top the method of obtaining alpha and I leave it as an exercise the first home exercise in this topic of illumination and shading is two try if vectors N and S are unit vectors of the surface normal and source direction then we should able to obtain that the R plus is the vector sum of R and S can be written as 2_N into dot product N dot S. Remember, this N dot S is a scalar quantity. So it is the 2 multiplied by this scalar quantity N dot S you know it is the cosine of theta because N and S are nothing but your normal unit vectors then this is 2 so this value will become 2. So twice of the normal vector along and twice cosine of theta along the vector n will be the sum of the vectors R plus S.

So I will leave that as an exercise for you to find out that first part if you can derive that then the rest of the part of derivation is going to be very easy where we had seen the sum product of R and S will be twice of that vector N and multiplied by the cosine of theta. So, this is the cosine of theta term here which is N dot S we had seen that earlier and you can derive this equation in this following form where R takes on the right hand side so that is what comes out from here to here and that is what you have as your R and the cosine of alpha is the dot protect we have seen between. We can easily from the figure that cosine of alpha is the dot protect between the vector V and the vector R. So that is given by the cosine of alpha which is dot protect of R dot V. And you substitute the expression from R which you have here on to this so it is V dot product of V with R where R is obtained in the previous expression so substitute it here and that is how you obtain your cosine of alpha.

Cosine of theta you know that it can easily be obtained by dot protect of N dot S which is substituted and so this is the cosine of theta here. And since V, N and S are known to you that, the viewer direction is known, surface normal is known and source direction is known. If these three are known you do not have to worry you can separately calculate R that is inherently present in this expression which I have given in this current slide the last one using V, N and S you can obtain the cosine of alpha term.

So I look back into the figure here cosine of alpha is necessary for you to compute because you will need that in this expression here to compute the overall intensity of the Phong's illumination model. So you calculate cosine of alpha using an expression given here based on V, N and S. So if V, N and S are known you can compute cosine of alpha.
What are V, N and S? You know that viewer direction, surface normal and source direction. If you know that you can use this expression to compute your cosine of alpha term use that cosine of alpha to substitute back in the overall Phong's illumination model it is the sum of all the three components. If you look back the forms elimination model is a sum of the ambient term of course the attenuation factor here. But then you have the diffuse and the specular components. So basically it is the sum of three components specular, diffuse and an ambient term.

Of course the effect of distance does affect the specular and the diffuse term it does not affect the ambient term for that matter and that is what the Phong's illumination model tries to capture. And you know how, you set the ambient term you calculate the diffuse component design of cosine of theta based on the angle between the normal and source direction and then of course you have the specular component contributed to by the cosine of alpha term which is computed by this particular expression as given here.

So this is how the three components of the Phong's illumination model are considered. So I repeat again you have the ambient term, the diffuse term and the specular term. We have studied all the three terms and of course also the attenuation term based on distance.
The only factor which is left to understand in the forms illumination model is cosine alpha to the power m, cosine to the power m.

How does that factor affect this specular component? If you look back into this expression here this is the term which is only unknown otherwise you can set all these terms compute the cosine of theta you know how to compute cosine of alpha now we have seen all these expressions but what is this m doing here and what role does it play here?

Can we put m equal to 1 and what should be this value of m depending upon the specular nature of the object surface.

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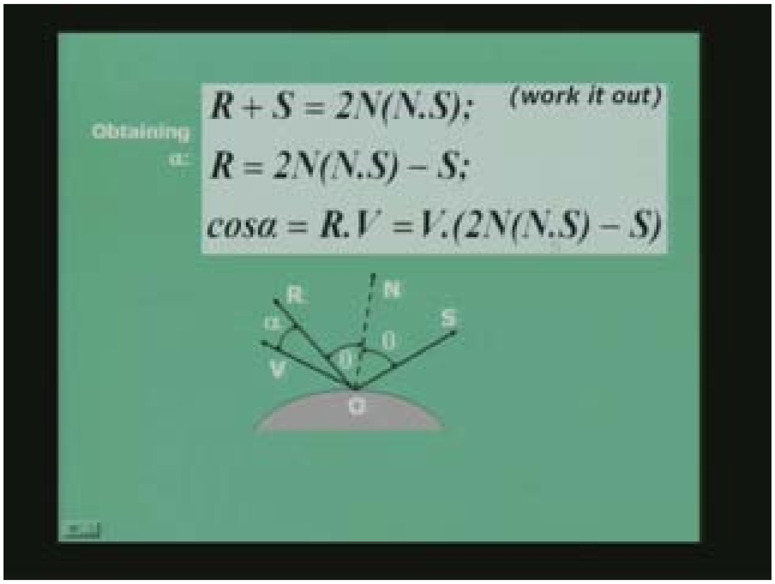

So let us try to understand the effect of m. This is a cosine curve for m is equal to 1 so that is the cosine of alpha. the X axis is alpha and the Y axis is cosine of alpha. You know sine and the cosine curve. this is the cosine curve the X axis is in radians running from minus phi by 2 to about plus phi by 2 that is the range of alpha in radians or the range of theta or you can take in this case alpha running from minus phi by 2 to plus phi by 2 and you know it varies from 0 to 1 and falls back. This is the cosine of alpha for m is equal to 1. You know the cosine of theta function or cosine of x function or cosine of alpha function.

Now if I raise cosine square cosine cube what do you think the function will change. What will the function look like, try to visualize this and try taking a cos x verses x curve from 0 to phi by 2 or even minus phi by 2 to plus phi by 2.

You can try that with sine also. But you take the cosine in the case because that is going to dictate my specular component of the illumination minus phi by 2 to plus phi by 2 each values that is the cosine of X. cos square X cos cube X remember it is a fractional number between 0 to 1 so rational values when you take square it will start going down and so let us look at a value when m is equal to 3. This is how it will look like, square will look in between so if this is cosine of X or cosine of alpha verses alpha this is cosine alpha cube or cosine cube alpha and verses alpha and again ranging from 0 to phi.

If I raise the m further, if I increase the value to a very larger value say m is equal to 11 this is what you have. So as you can see the curve is getting narrower and narrower. Cosine of alpha was a broader curve between minus phi by 2 to plus phi by 2.

Cos cube became narrower cosine of alpha to the power 11 or even higher if you take larger and larger values of m you can super impose these three curves yourself in mind or on the paper and draw it yourself and see that the curve is getting narrower and narrower. Let us repeat this, this is the cosine of the alpha itself when m is equal to 1 m is equal to three cosine cube, this curve will look like this and this is the cosine to the power 11 so as you can see the curve is getting narrower and narrower.

Now cast your mind to what was this alpha? This alpha was the angle between R and V. And viewer saying that majority of these rays which are reflected by a specular object surface travels along the direction of R a small fraction of that gets dissipated around that vector or in 3D. So you can visualize as if you have a cone you visualize a cone in 3D at that vertex of that object O and that access of that cone is along the vector R.

If you go back to this figure and visualize for yourself that you have a cone with the apex or vertex of that cone at object O and the access of that cone is traveling around R and the cone is here somewhere with the access along the direction R and the vertex at O and the V is on the surface of that cone. So you can visualize as if a cone going along R and the angle alpha is the angle of that width or view of that cone subtended at vertex. Angle subjected at the vertex of that cone is the angle alpha.

So if you reduce alpha to almost 0 of course the majority of the rays are going along the direction which is R. As you keep increasing alpha you are talking about larger and larger cone and there are sometimes rays which are not going along or traveling along or reflected along that direction R but also traveling around in that semi infinite volume given by that cone at that subject. And what percentage of rays will be traveling along that R and what are the remaining percentage of that will be spread alone in that cone or conical volume will be dictated by that factor m.

Alpha will dictate the angle between R and V basically that how much is the width of the cone but in that conical volume how much will be reflected along R and the surrounding will be reflected. That m will try to capture the fraction of that light energy or light rays which predominantly go along R and the rest of it the remaining percentage travels along or around the side in that conical semi infinite volume.

I hope I am able to give that figure because if now assumedly start thinking you have seen the nature of that cosine to the power m. Cosine curve, cosine cube and cosine to the power m it is getting narrow and narrow as you can see here this was the cosine curve cosine to the power 3 cosine to the power 11 and assume that the tip of that the cone is this point where the value of alpha is equal to 0 is always is equal to 1.

You know when alpha is equal to 0 the cosine raise to the power any quantity will be always is equal to 1 it is here also 1 and it is also here 1. So that value alpha is equal to 0 so when V and R concept but as you start moving outside how much of percentage will go will depend upon this nature of the value of m in fact you want to dictate. So can you tell me now for a perfect shiny surface which is a perfect specular like a mirror the mirror is a example of a perfect specular the mirror type or mirror surface itself what should be the value of m because all the rays will go only along R nothing will be going outside in that conical volume.

Therefore, for any alpha which is non zero the amount of light which you get is 0 when can you achieve that with this cosine to the power m function whenever when m reaches a very large value as large as you can imagine, infinity virtual. Assume vertically you can visualize the cosine to the power m function when m reaches a very very large value as large as you can imagine infinity in fact that is the case when you reach the mirror. The case of the mirror reflecting all of the light only towards the R direction that is the case when alpha is equal to 0. So when V and R coincide in the case of a mirror you are seeing the all amount of the light.

The movement V comes out of R that means you have a non zero value of alpha if this is the R and the V does not coincide and just coming out of the value R that is the difference between V and R they are not same. Then you have a non zero value of alpha and when cosine is raised to the power of a very large value virtually infinity then for any other non zero value of alpha the value shoots down like an impulse function is what you will where the value is very large or 1 in fact at a value when alpha is equal to 0 for any other non zero value it is 0. So that is the case for a mirror where you model that with the large value of m.

Now what does that mean? That also gives a tool to vary your or tune your m depending upon the type of the specular surface which you have which is of non-mirror type. But specular you tune your value m, you do not have the control of alpha why because alpha is the angle actually present between the V and R you know viewer will be at a certain direction so based on that you will have a vector v and the angle between V and R is your alpha which you know how to compute based on the equation which you have seen. But how will you set the angle alpha? Alpha is what you compute m is what you set based on the objects specular reflection property.

Of course the S term is also there in terms of about how much of light it will reflect. It might observe a few and that will be so. The case is considered to be 1 if all of the light is reflected in case of a mirror. But non-mirror type specular surfaces might observe a few percentage of the light. So the case may fall or drop just below 1 may be a 0.9 0.99 0.9 depending upon whether you are talking of a very shiny surface, apple type, gold or silver coated surface and those values of the case will be close to 1 but less than 1 but more than that since it is non-mirror type. The value of m will not be infinity it will be a finite large value more than 1 of course. So if you set the value at 1, 2, 5, 10, 20 or even 100 will depend upon the surface property because that will dictate how much percentage is going along R and how much you are able to see around that R in a conical semi infinite volume.

So, based on the V assume that V to be moving around that R if it is too for away it is very less the more it gets closer to R that means the value of alpha getting close to 0 when V assume critically [refer slide time 22:26] starts reaching or getting close to the value of R vector V and R getting close together then the alpha gets smaller and smaller when R and V are same alpha is 0 that much you know. But if it is non zero in the case of mirror you do not say anything there is no doubt about it because you just put the value m to be infinity and you can visualize an impulse function and the value of alpha is non zero you do not say anything.

But non-mirror type please understand when you have this non-mirror type specular reflection then you see majority of that when alpha is equal to 0 but when alpha is non zero you also see some percentage. What degree it tapers of how much percentage of the light falls of it, what nature it tapers of will depend on the value of m you select. So more closer to a mirror type a choose a large value of m and more closer to delta dull type if specular reflection is you choose a lower value of m around 1 or 2. This is how you change the value of m and that is how you control the degree of specular reflection not the coefficients specular reflectivity.

So coming back here this is how you compute alpha or the cosine alpha and then based on the closeness of the V to R you control the term here the m will dictate the amount of specularity in terms of the Phong's illumination model and we know how m varies when you vary m what is the degree by which the light rays or the light intensity a viewer is able to see. This is the value of cosine alpha, cosine cube, cosine to the power m 11. So as you go higher and higher this region will start reducing with reducing values of alpha or theta and it will start to taper to 0 much earlier around 0.

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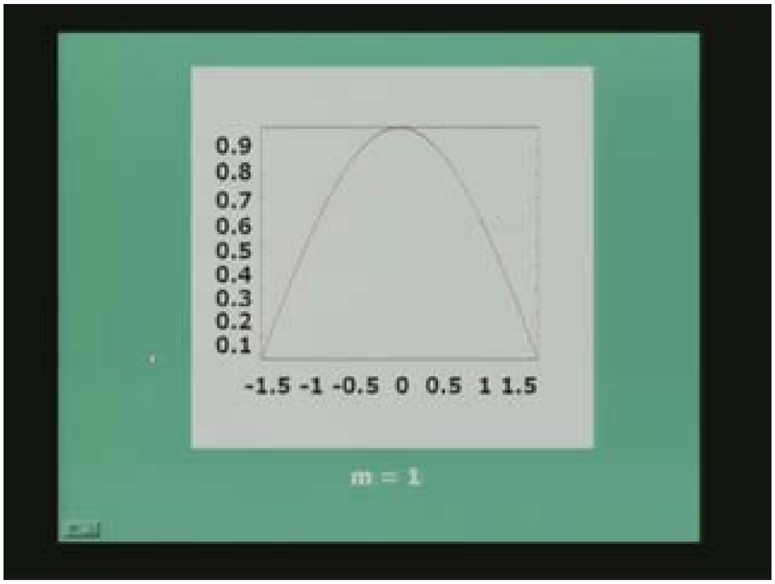

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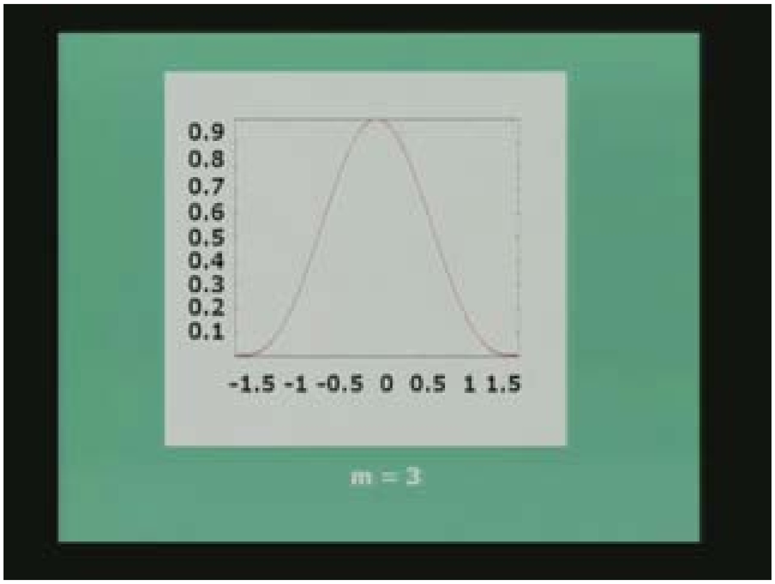

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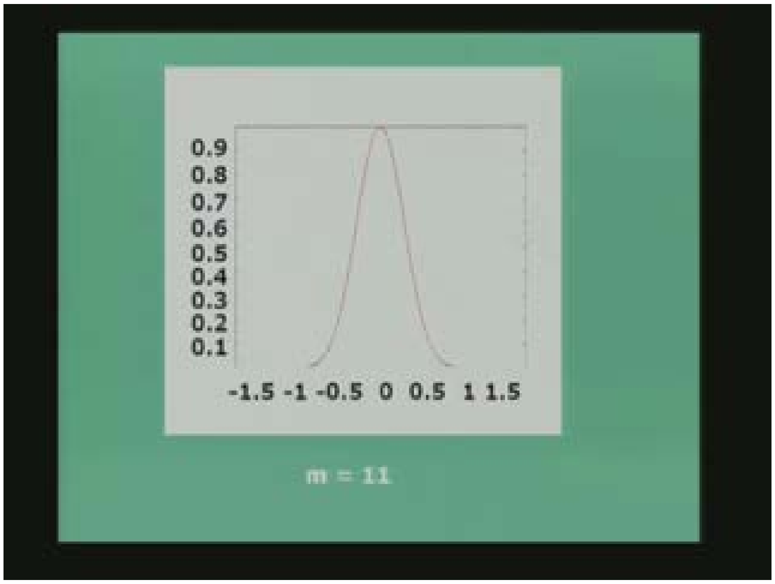

So the last view points regarding the Phong's illumination, if the light source is at infinity the angle between N dot S is a constant whereas R dot V varies across a polygon. So we assume that in Phong's illumination case that if the light source is a special case when the light source is at infinity the angle between N and S is constant. This is the angle theta which we talked about earlier in the case of diffuse deflection this is valid and the same. When S is at infinity, let us take the situation of the sun the source of the light rays from the sun.

If you travel anywhere in the city at any given point of time the light source appears in the same direction.

Of course if you travel across a country from one region to another yes the light source may not appear to be in the same direction. But typically if you move around somewhere close by even around a building in an open space or around a field the light source the sun is virtual at infinity. Of course if you move to nearby cities very nearby just a distance of about few tens of kilometers or up to hundred kilometers or even less than that the light source direction the sun remains the same.

S dot N since N is same for a particular object S is same if the light source is at infinity N dot S the dot protects cosine theta is also a constant if the light source is at infinity. Whereas R dot V varies across a polygon because the viewer direction could change you could look at the polygon from different directions. For curve, surfaces and light source at finite distance both these factors vary across a surface this is very interesting. When we are talking of a curved surface now you cannot assume that although S could be a constant but the N could vary for a curved surface assume a corrugated surface. A sinusoid variation like an asbestos sheet is a very good example. Or any random type of a curved surface it could be a Gaussian, spherical type, conical type, and cylindrical type so those are again circular.

We can take a Gaussian type of a variation or a sinusoidal asbestos sheet at each point to each point the surface normal varies if that varies N dot S will also vary that is the cosine theta term that is number one. Cosine of alpha might also vary because the N. V that phi also changes and hence it will cause that R also to change so the cosine alpha will also vary because that is the angle between V and R.

R will vary because N is varying. So for curved surfaces and light source for a finite distance both these factors theta, phi and alpha all of them will vary causing the Phong's illumination to be computed at each and every point. Whereas for a planar surface light source is at infinity if you compute at one point or close by surface for a planar surface will have the same intensity it will not vary much. Even for a slowly varying curved surface it will almost be the same you can actually use some incremental computation to perform the computation. Whereas for finite distance light source and for curved surfaces you have to compute that for each and every point. So these are the two points which you keep in mind.

I again repeat if the light source is at infinity the angle between N dot S and hence the angle given by N dot S which is the cosine of theta is constant whereas the R dot V which is the cosine of alpha varies across a polygon.

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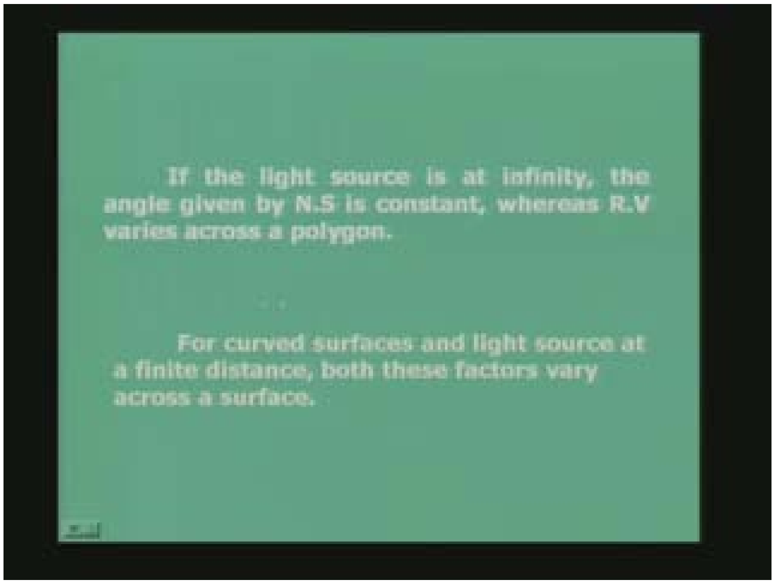

For curved surfaces and light sources at finite distance both these factors vary across a surface. There is a way called a half-way vector H which is used to simplify the computations for the cosine of alpha. If you look at this figure we know what is N. Earlier we know what is S we know what is R also we know to compute this R given N and S. The angle between N and S is cosine of theta is the same angle between the R and N. The angle between V and R is an alpha this is a three dimensional figure R, N and S.

Again I repeat, lies in a plane but this may not be the case between the V and the R we construct in 3D. We introduce a half-way vector H which is the vector between the light source and the viewing vector V. So V, H and S now lies in one plane R, N and S lies in another plane it is very interest for you to visualize. Visualize two planes N given S given V given. Now N, S and V are not lying in a plane but I can construct a vector R given N and S N here S there and R there I can construct this R which lies in the same place as N and V. Now given V and S which lies on may be one plane but not in the same plane as R, N and S I visualize a plane consisting the vectors V and S I construct a half way vector H which lies between V and S as N was lying between R and S. That half-way vector is a bi sector vector between V and S and lies between the plane V and S.

So V, H and S I repeat V, H and S lies one plane R, N and S lies in some other plane and if that is so then we can compute this vector H given this particular equation S and V that is very simple to compute given S and V this is somewhere the vector product on the numerator and Euclidean norm at the denominator S plus V vector. You talk the Euclidean norm just do that to assume that H is also a unit vector but it is the plane between V and S but different from the plane of R, N and S. That is the half-way vector H if the light source and viewer are both at infinity you can compute this H. And the specular term now grades to modified to a simpler form by trying to compute the cosine of beta to per m. So we assume that the beta and alpha are approximately same.

Remember you have to visualize that V H N S are in one plane and R, N and S are in some other plane and whatever is the angle alpha between V and R is the same as the angle beta which is between H and N.

H and N you can of course visualize it is a plane but remember you have to visualize this figure in 3D. I again repeat; R, N and S are one plane and V, H and S is in some other plane and the angle alpha between V and R is the same as the angle beta between N and H. So cosine of beta is nothing but the dot product between N and H. Take the dot product between the vectors N and H that is your cosine of beta raise it to the power m and since N is known H can be simply computed as given in the equation here. You can compute the cosine of alpha as equivalent to cosine of beta and raise it to the power m. This is another method by which you can simplify the computation of your specular term in the form 0 machine model. I repeat; just look at this equation once again, you just replace the all those previous equations by the N dot H and raise it to the power of m.

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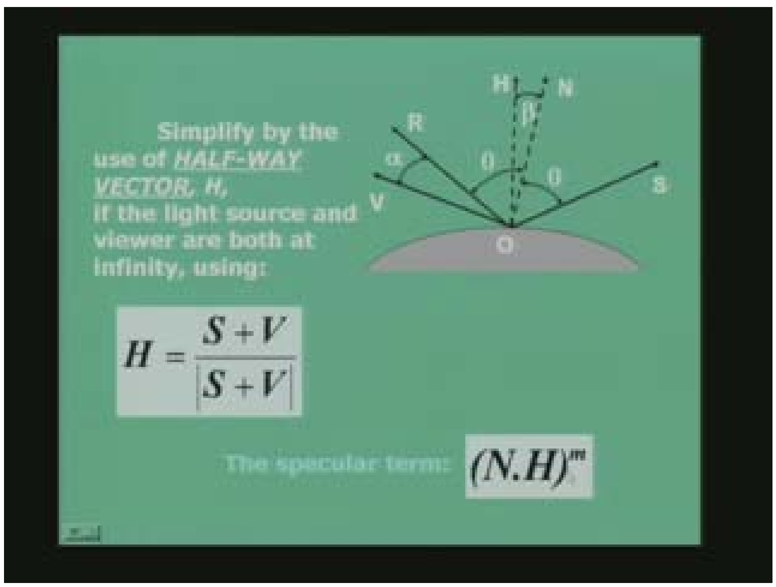

So, that is what you have for your N light sources then the formula is given as this that you have to submit for all the different light sources because $I_{plambda}$ will now vary in fact I will probably vary here. You can visualize this p as equivalent to the index I which varies for the L different light sources because the expression was given earlier without for a single light source.

So, if you have L light sources you have to sum these different terms ambient typically does not change but the diffuse nature of the surface and the specularity terms will change for l different light sources. But there is a danger if you use this equation. You may need to normalize the color intensity value or clamp it or choose coefficients appropriately or display in the log scale to ensure that I lambda term does not cross 1. Typically you always normalize intensity values between 0 and 1 so you must choose these coefficients. What are the coefficients? K_a K_s K_d which also could lie between 0 and 1. Remember, the intensity values also lie between 0 and 1 and the cosine of theta which is the dot product between these two vectors N dot H or N dot S also will lie between 0 and 1 so these are all fractional numbers.

But the sum of all these fractional numbers may actually give you a value which is more than 1 if there are L light sources plus the ambient term. So you should be careful that when you are choosing these terms you always have a resultant light intensity normalized range between 0 to 1 and there many ways to do this. The typical way is if you look back to the steps you actually calculate whatever you get even if it is more than 1 at the end normalize the color intensity value between 0 and 1 or clamp it. Clamp it means if you have a value of I lambda crossing 1 do not consider any values more than 1. If you have 1.5 clamp it to 1, clamping of signals and electronic circuits. So if you have 1 point always clamp it. So just throw out the value which is more than 1 I mean not totally just clamp it at the value 1. Any value which you get the more than 1 clamp it to a value 1.

Or choose the coefficients appropriately that means you have to choose all these $I_{alambda}$ K_a $O_{dlambda}$ $I_{plambda}$ K_d K_s and all these object surface color and reflection coefficient in such a manner that with L light sources L being a number which is more than 1, 2, 3, 4 or 5 as I said before beyond a certain point the light sources may increase of course the brightness will become very bright but will not cause a certain value you have to choose those terms carefully such that even with larger number of light sources the resultant term I lambda term which you get as a resultant sum should not cross lambda so that is one way. So three methods are; normalize the color intensity after addition of all these terms, clamp it that means restrict to the value 1 or choose coefficients appropriately so that you will never have a value close to 1.

But it is difficult to choose coefficients appropriately means you will have to choose the values very less. That is not a very good idea you have to choose it appropriately but as you keep on increasing the value of all there is always a scope mathematically hypothetically or theoretically but the value should sum beyond 1. So in that case you have to normalize it or clamp it. There is another method talked about at the end where you display log scale and when does it happen.

When do you actually display signal in log scale, light intensity also can be visualized as a signal but when do you display in log scale? You display that in log scale when you have a dynamic range of signals or very large grey level values of a pixel because what will happen is most of the values are very bright the surfaces which are only receiving ambient light will have a small value of intensity say 0.1 or even less than that 0.01 0.05 0.02 in that range. And if you have many bright parts of the scene which varies around 0.7 0.8 0.9 and more close to 1 then what will happen is those will become so bright and dominate the scene that the ambient term will not be visible.

So in order to do that what is typically done is you display in log scale because the dynamic range in the log scale will be reduced. That is what we use often for most signal processing amplifies also use the logarithmic scale for displaying the dynamic range of signals at very large you use that in the case of the ambient in the case of displaying illumination effects when the ranges are very large from a very small range from a fractional number of 0.001 say you have values around up to 0.99. When you have values around 0.99 or more values around 0.1 even 0.2 or less will not be visible to the naked eye when you display the monitor scale so display that in log scale. That is also another method by which these dynamic range of pixel values are handled.

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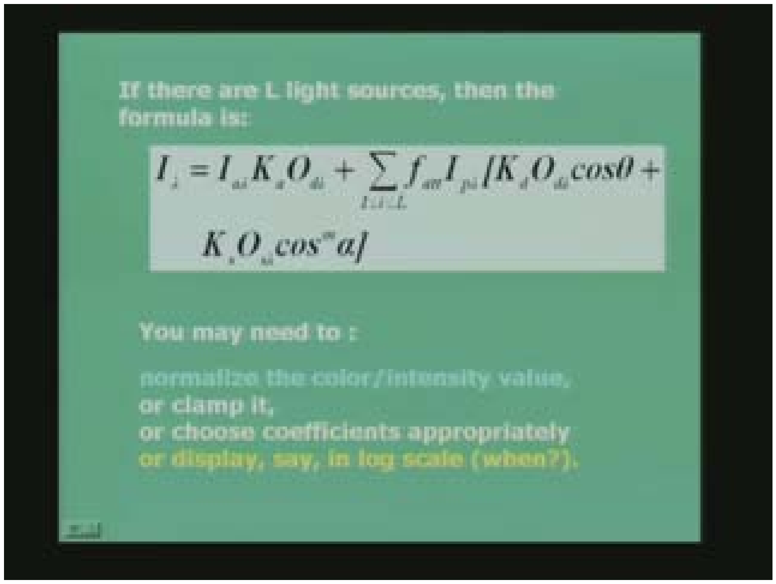

Reflectance properties are a very important one you have the lambertian model which you talked about for the diffuse deflection. This is an example of the lambertian surface. We will go through lots of examples now in the remaining time which we have. This is independent of the viewer as you can see here k_d cos theta theta is the angle between the N and S. Whatever V you put you can change your viewer direction here and keep rotating the object surface you will get the same illumination. This is the example of a lambertian or diffuse surface of the ball with red color.

Let us look at the Phong model which has two terms which has the diffuse deflection and also the specular reflection part here so I will show you two examples and I hope sincerely the picture is very clear. The left hand side picture has a diffuse deflection coefficient of 0.3 and specular component of 0.7 the m is 2 so that means this surface has a large value because remember k_d and k_s are ranging from 0 to 1 and the value m is an integer value typically taken it to be a fractional value also larger value of m larger value of k_s indicates this term is dominating that the specular component is dominating it is a very shiny surface the light surface is reflected here.

The same case is not here there is no sepcularity here, mirror type reflection is not happening in the lambertian diffuse surface but it is happening here where the surface is more shiny here less shiny here because the diffuse components is less that is what you have. Now if change k_d to 0.7 as given in this figure that means increase the diffusion component and reduce the specular component from 0.7 to 0.3. The exponent is also reduced from 2 to 0.5 you see the resultant. That means it has a small effect or insignificant effect of specularity or mirror type more of diffuse. This result is closer to the absolute lambertian surface.

Most of it is lambertian a small amount of specularity exists whereas in this case the lambertian effect is very small or diffuse effect is very small, most predominant effect of mirror type specular reflection is more at the center as I was talking about when alpha is increasing when you are looking to the outside surface like a cone the effect of specularity or the light reflected due to specular reflection will be less as you keep changing the alpha.

So I hope these three figures tell you the difference between pure lambertian surface. Of course pure specular surface is a mirror which I do not have to demonstrate you can see yourself in front of a mirror or put a torch light source and see what happens. But other than that pure diffuse surface more specularity and a combination of specularity and diffuse where we have seen two cases where the specularity dominates in one case and the diffusion dominates the other one.

I ask you to look back into the figure, this is pure diffusion these two figures are a Phong model where the specularity dominates here and the diffuse part dominates so this is the Phong's model and it is a very nice example to show that when you vary the diffuse deflection coefficient and the specular reflection coefficient higher k_s here higher k_d here and the m also you vary what are the different factors here? You can visualize in the lambertian surface that there is no case can be visualize to be equal to 0 and m also can be visualized to be a very small quantity close to 0.

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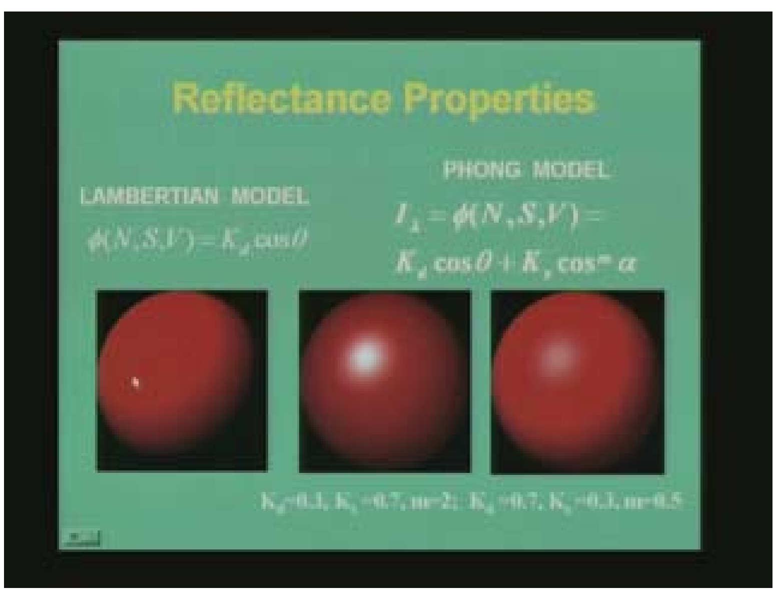

Now let us look us shading models for polygon. Now there are various ways by which shading models are done this is a constant or faceted shading or flat shading as you can see this is a wireframe diagram of a sphere where all internal parts of a polygon in this case quadrilateral or triangle whatever you get has uniform illumination also. As you move from left to right of course there could be variations or bottom to top you assume here that the light source is on the top so the top has more but each particular polygon has a same intensity. So you compute the surface normal and you give the same intensity for the entire polygon a quadrilateral or triangle so that is why it is called constant shading or also called faceted or flat shading.

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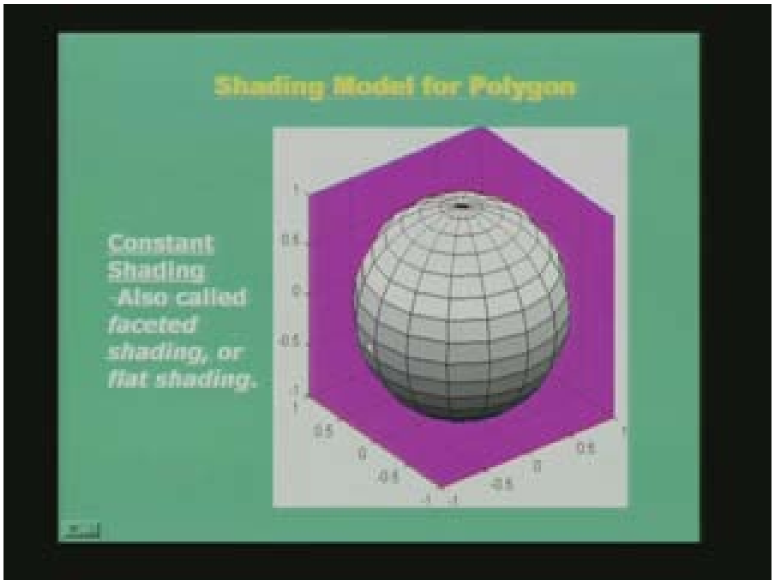

So this is an example of the flat shading. You continue with the flat shading if I remove the wireframe diagram this is the illumination which you get. The illumination surface illuminated from the top so you have absolute white brightness as you keep going down you have um very less illumination because it could be only due to the ambient term at the bottom. You will see more results.

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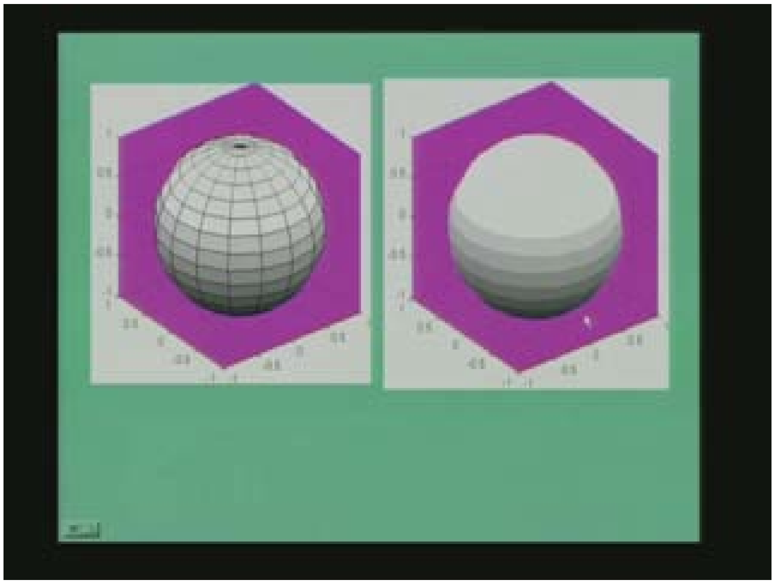

So faceted shading is determined a single intensity value and use it to shade an entire polygon that is what you do for a faceted shading and the approach is valid provided that the light source is at infinity that means the dot product of N dot S which is cosine of theta is constant over the entire face that is what you do for faceted shading. The viewer is also at infinity. So the N dot V is constant over the entire face and it may vary in some cases but typically assume constant and the polygon is not approximating a curved surface.

If it is very curved polygon is a very bad approximation dot So curved surfaces you better used a curved surface representation a polygon null piece-wise approximation is not a good one. And then in that case of course if the entire surface is a planar one like a cubes cubical surface or a large sphere with slowly varying radius of curvature then of course polygon approximation is a good modeling and you can do faceted shading. But if it is a sharp bend polygonal approximation we have seen that in CSD it is not a good approximation so faceted shading is not good.

We have to go to a new model of shading called the Gouraud or smooth interpolated shading. But going to these terms, these points once again we assume that the light source is at infinity, viewer is at infinity and the polygon is not approximating a curved surface.

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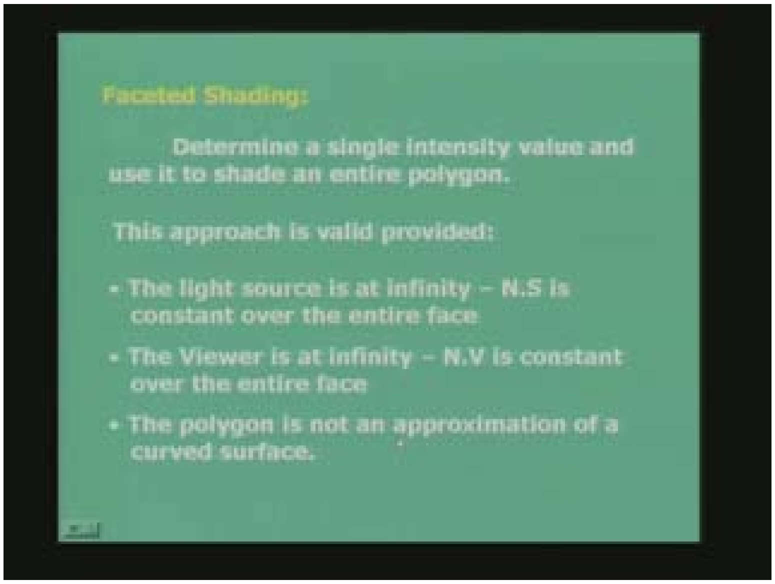

Coming out of faceted shading which is a very coarse approximation we look at Gouraud shading or color intensity, interpolation shading where you suddenly see now the interpolation is very smoothing. It is a very nice visualization of a very smooth surface.

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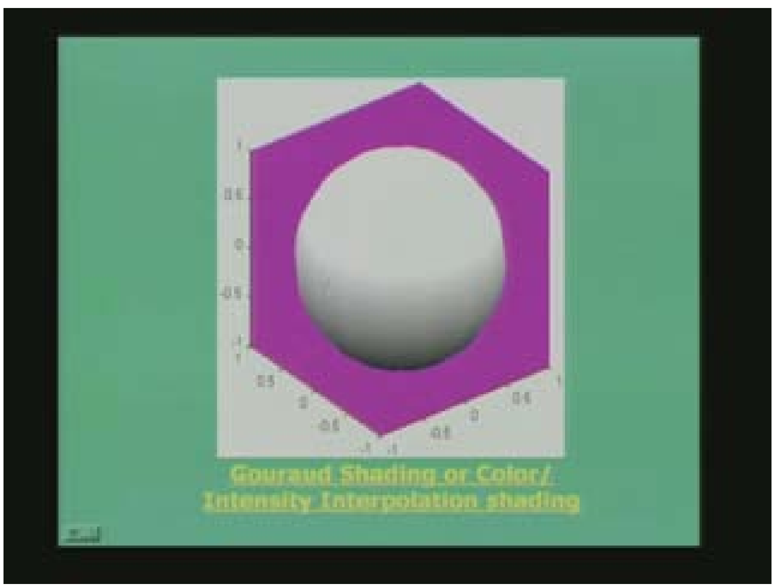

How do you get this? You look at the difference between faceted shading and Gouraud shading for the same. This is what we got earlier by what we call us this wireframe diagram where each polygonal triangle is having the same shade piecewise when you go from one polygon to another move closer towards the light source you have different levels so you have this effect of aliasing in shading. You can talk about discontinuities but it is very smooth. How to interpret this Gouraud or smooth or what is called the interpolated shading?

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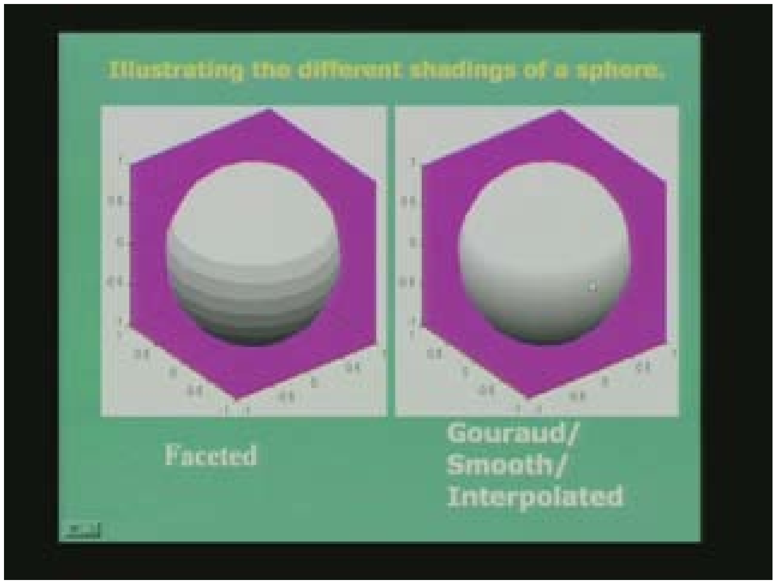

This is another example of the same sphere highly coarse sphere approximation and the light source is coming towards a frontal lighter part as you can see there are some back or hidden faces which does not receive any illumination top surface illuminated less this is having the maximum illumination but it is faceted or flat. This is the case the same coarse wireframe approximation of this sphere taken but when you put the Gouraud or smooth interpolated shading you see the smoothness of the intensity at least.

You can see the coarseness of the representation of the sphere in terms of which structure that is due to the coarse wireframe diagram which has been taken. You can take finite structures or less increments of this sweep representation of a sphere using a circle but when you use that same coarse representation you have the smooth representation of intensity using Gouraud or smooth. And you have to visualize that we have not taken a finer representation of a sweep representation of a sphere and try to shade in facet now that can be done but that is not done here same wire frame representation but Gouraud or smooth interpolated shading gives such a fine picture at least of the smoothing if not for the surface of the intensity variations to implement the Gouraud shading.

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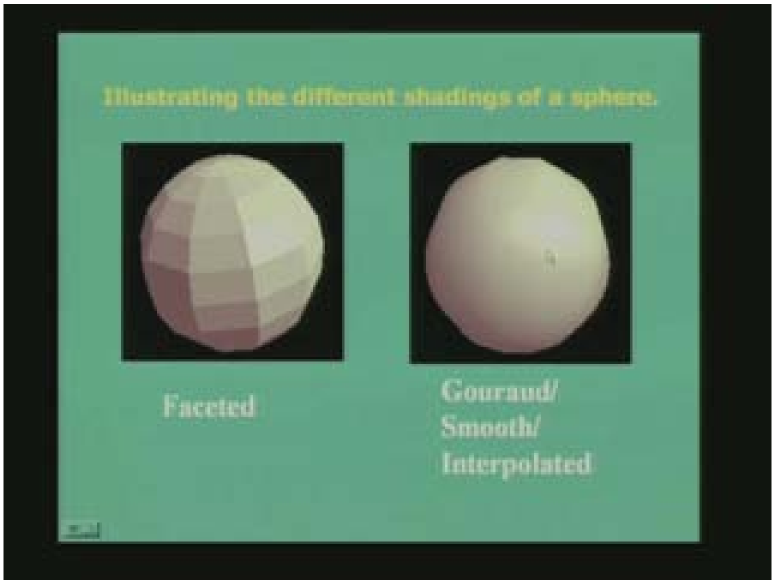

This is the slide which will talk about the principle of Gouraud shading or color intensity interpolation shading. Let us say if you take a triangle, if you take a triangle and you are interested in shading this particular point and we know that this triangle has different intensities at each point.

I will not you facet shading to shade it like the way which is illustrated in the figure constant grey level shading I will not do. So what do I do to obtain what is known to us. We assume that the vertices of the surface at these three the surface normal at these three vertices of the triangle are known. N_1, N_2, N_3 are the surface normals of these three vertices 1, 2 and 3. If that is so then we can use this surface normal and then use the Phong's model to compute the intensities I_1 I_2 and I_3 at these three vertices 1, 2 and 3. We know how to do that because the Phong's model will tell you how the intensity I_1, I_2 or I_3 can be obtained from N_1 N_2 and N_3 provided the viewer direction and source direction is known.

So what is the intensity at this point? What we do is we take a scanline because that is what we use scanline based feeling. So every point will have a scanline from top to bottom or bottom to top. What you do with this scanline? If you go back I compute the intensity at the two intersection points of the scanlines with the edges of the polygon. In this case polygon is a triangle so I compute I_a from I_1 to I_2 by some sort of an averaging or interpolation and I do the same thing for I_v. I use I_2 and I_3 intensities to compute i_b, I will come to those equations now.

How to compute I_a the intersection of this scanline with this left edge and the I_b is the intersection of this point which is intersection of the scanline with the right edge of the polygon. If I_a and I_b can be computed I_a is computed from I_1 and I_2 using interpolation I_b is computed from I_1 and I_3 then the same interpolation along x direction will give you I_p intensity at this point.

What are the equations for this? This is how you compute I_a. I_a is computed from I1 and I_2 based on y variations. What is this y_i? y_i is the y coordinate of 0.01 which has the surface normal N_1 and intensity I_1. You can operate this intensity part in 2D and y_2 is of course the y coordinates of this 0.2, y coordinates of this 0.3 is y_3 and what is y_s this scanline s. The scanline for this point the y coordinates of the scanline is given as this y_{is}. As you can see when y_s is equal to y_1 you will have the intensity I_a is equal to I_1. This is the linear interpolation which you have done earlier, where you have the done this, the linear interpolation? When you talked of atmospheric attenuation you vary the z from zt to z_p in the previous lecture and got scale ranges from s_a to s_b. So you do the same thing here. As you vary y_s from y_1 to y_2 you will get I_a values running from I_1 to I_2.

Let us check this out if y_1 is equal to y_2 if y_1 is equal to y_2 you will have the negative sign here and then I_1 I_1 will cancel out I_a will be is equal to this I_2 term. So this I_a will be vary from I_1 to I_2 linearly using this expression. Similarly, using the second expression I_b will also vary linearly from I_1 to I_3 that is how this value is I. And if I_a and I_b can be calculated once the right hand terms are all known I_1 I_2 I_3 are computed first and y_1 and y_2 and y_s are known then you compute I_a and I_b and how do you compute I_p? That is again a lean x interpolation along the x direction from I_a to I_b.

As you can see here as the x_b is the x coordinate of this point b x_a is the x coordinate of this point a and x_b is the x coordinate of this point p and that it will be intensity of the b. As you can see if you vary x_p to x_a you will get I_a intensity if you put x_p is equal to x_b you should be able to get I_b where I_p is equal to I_b and you will get linear interpolation. So that is what you have the values ranging from I_a to I_b. I will roll this slide once again which will be very interesting for you. So what we are interested into? Given these three triangles as an example of a polygon you interested to get the intensity of this point.

So, the first thing is calculate the surface normal at these three. If these surface normals are same we are talking of a polygon not representing a curved surface in general in that case. Flat shading can be adopted if N_1, N_2, N_3 are all same you will get I_1, I_2, I_3 also as same and then you can uniformly fill the polygon with the same color. But that is not the case in the Gouraud shading, here we have three different surface normals.

We will see when we get the three different surface normals and how to calculate those surface normals because the formula which we know is given three x y z points or n different vertices we know the surface normal of the entire polygon how do you calculate the three different surface normals at three vertices or n different surface normal at n different vertices of the polygon you have to check that out. So we will check that later on but let us assume that with those calculations you can get N_1, N_2, N_3 which gives you I_1, I_2, I_3 so use interpolation along these for these scanline for the left intersection edge calculate I_a by interpolating between I_1 and I_2.

Interpolate between I_1 to I_3 to get I_b intersection at this point and then linear interpolation from I_a to I_b to get the intersection I_p and these are the equations which you have. I hope your copied these equations when I was discussing.

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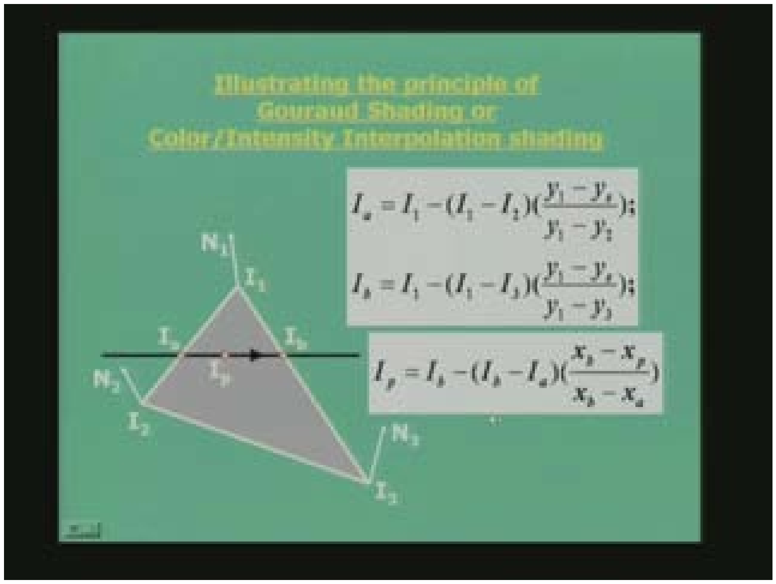

Now, coming back to N_1, N_2, N_3 this is a very interesting principle of how do you compute the surface normal at a vertex. Let us say that this type of adjacent polygon is representing a curved surface, it is on top of a pyramid or something or even pyramid of course could have a planar surface but this is a scenario where you have to visualize that you have a binding representing a planar surface so the vertex is at the top and that the surface is at the bottom.

So what you do is you compute using the previous formula these surface normals N_1, N_2, N_3, N_4, N_5. There are five different surfaces with five different shades I have tried to give five different shades some of them could be same or different but you compute and this we know because given these three vertex coordinates x y z you know to compute the surface normal for each of these. And then take a summation of these vectors and average you get the vector surface normal of this particular vector. So you do this for this point and you keep repeating this for all the other vertices you take the neighboring polygons adjacent polygons which form that vertex and calculate the surface normal for each of those polygons and get N V. You get this N V and for other vertices also do the same and this will result in different normals at different vertices of a polygon which is representing a curved surface because you are doing space wise approximation.

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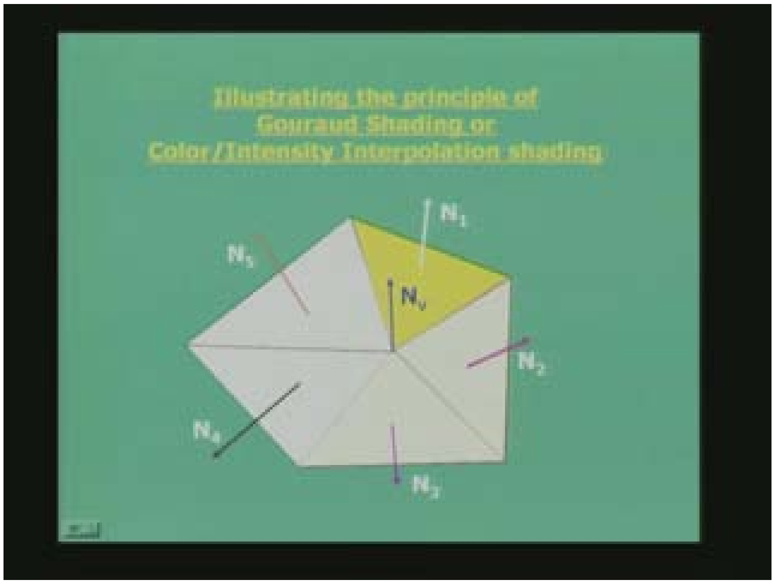

So once you do that what you have is basically N_1 N_2 N_3 for a triangle three different non surface normals and three different intensities as given in the previous interpolated Gouraud shading example and then you start interpolating and calculating the scanline intensities and then do an interpolation along the x axis. If you do that you will have this interesting smooth intensity variation as we have seen for a sphere.

Let us take the example of a tea pot illustrating the difference of shading in case of a tea pot where I have used faceted shading on the left hand side on the top figure and on the right hand side it is Gouraud or interpolated. So you can see that with the same wireframe representation you can see faceted shading for the case of tea pot which gives a very coarse approximation of course forget the aliasing part, this aliasing is a defect which we will discuss later on which is there with even line drawings so it will be there here but if you look at the Gouraud shading it looks like a light smooth metallic finish with a glossy part in the metal.

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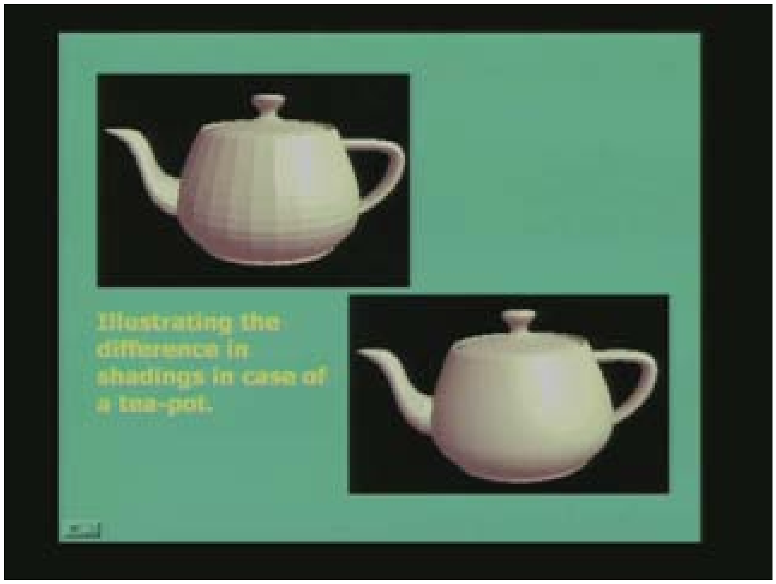

So you have the specularity with the Gaussion part and so now you can see the difference between the tea-pot. of course in the case of a sphere the tea-pot also has a round spherical surface and you can see that the faceted shading will have the flat shading within the quadrilaterals or within the triangles at each part will give this flat sort of shading over the tea-pot and using this smoothness here. In spite of using the same wireframe structure you can see the smoothness of the entire surface not only here but also in the top and the side and the bottom.

This is the nice example for the Gouraud shading. So we have almost come to the end of the discussion of the illumination shading models. Remember we have discussed three different types of shading models ambient, diffuse and specular. We have talked about specularity, atmospheric attenuation, effect of distance, we talked about the reflectance properties, different reflection coefficients, object color, surface color being different, the Phong's model capturing all these terms and then of course towards the end we discussed about Gouraud shading which gives a smoothing effect.

Of course if you take a wireframe structure it represents a solid or curved object the more finely you get it is better but even if you have a coarse representation of a curved object by wireframe Gouraud shading can do a lot of intensity interpolation. That is why it is called as interpolated shading or a smooth shading or a Gouraud shading.

Of course there are effects which use all these and concepts that reduce it to give the realistic effects with the help of shadows to make a realistic sense seen in terms of the virtual reality of visual realism. You need to combine Z buffer and ray tracing of VSD, you need to combine Phong's Gouraud shading, interpolated shading all these terms of effect of ambient, specularity, diffuse, Gouraud shading, effect of shadows, radio city combined together to have sophisticated shading models giving visual realism and simulate virtual reality. That is what you should try to learn for yourself from advanced books and advanced papers and magazines published in good international journals but the basic properties of illumination shading has already been covered right now, thank you very much.