Computer Graphics
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Lecture #34
Illumination & Shading (Contd...)

So we continue the discussion on concepts of illumination and shading in the course on computer graphics. In the last lecture we introduced the concept of illumination and shading from the point of view of the last stage of a 3D graphics pipeline where we have a set of polygons and from the set of polygons we have removed some of those faces using back face culling and we have found out the visible surfaces or parts of some visible surfaces using any suitable VSD algorithm.

You can visualize either ray tracing or Z buffer algorithm. And we spent a lot of time discussing why the process of illumination and shading of a polygon or any point of a polygon or a point (X, Y) on the image plane or a pixel is a hard problem. So we will start from there where we assume that lot of compromises and simplifications are considered in order to solve the complex problem of illumination and shading which is a big burden or the bottle neck in terms of trying to create pictures which are appearing as real as possible because we are trying to create virtual reality and virtual realism to create realistic effects in scenes and illumination and shading either an important property of that.

So the complexity of the process of illumination and shading comes from the fact that you have one or more light sources and several sets of polygons in a complex scenario. I talked about million but in certain cases in very greater applications you may have several orders of tens or hundreds of millions of polygons for that matter in a very complex scene. So you can visualize how complex the scenario can become not in computational complexity in terms of generating the scene, illuminating the scene but also in trying to find out the exact illumination which could be proper.

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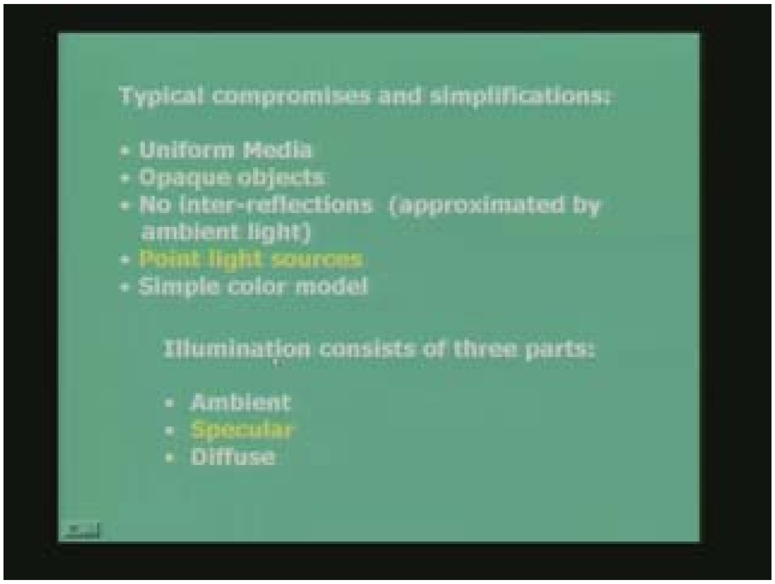

So regarding the typical compromises and simplifications which are done in the slide we discussed in the last class that we assume a uniform media, we assume opaque objects, we assume no inter-reflections or even if it is there it is approximated by what we call as ambient light, point light sources is what we assume and a very simple color model.

Out of these simplifications which we consider the two most important facts are the no-reflections or the inter-reflections part where we assume that there is an ambient light present in an environment it could be an outdoor scenario or indoor environment, could be a class room and the typical example of the walls and the ceiling and certain parts of the floor receive ambient illumination which are due to a combined or integrated or a summing effect of all different inter-reflected rays reflected by different objects from one to another and so on and they dissipate in the open space. Those parts which are only receiving ambient light may not receive the light rays from the source directly.

If the rays fall directly from the source on to the object and get reflected to the sensor or the projection plane or view plane then of course the ambient term could be neglected but however in certain cases of background objects or background scenes it is possible that you do not have the sources of light hitting on to certain objects directly and it is the ambient light which only falls on the object. And if you paint those objects which are receiving ambient light by a completely dark pixel assuming it to be 0 the scene becomes very unrealistic. In fact in a dark room or a darkish room you can almost visualize that you will able to see objects although there is no direct light source. So ambient light plays a very important role and you have to provide this ambient term in the illumination component of the model which we are assuming.

The second part one of the other important part is the opacity of the objects. Opaque objects make it much simplifier because the objects are not opaque they are transparent like a glass or translucent type of objects structures. If you have the material property such that it allows some part of the light to pass through the object and some part gets reflected so if you have to model that property of how much fraction of the light gets traversed through it gets reflected from the surface and then more than that you do find out what are the light rays which are passing through the object and coming out of the surface.

So there are three factors which increase the computational complexity and the complexity of the modeling also when we do not assume opaque objects. But typically most objects which we see except glass are opaque objects in an environment. But of course there are some objects which are transparent or semi transparent or translucent for that matter. And if you need to model them you have to have sophisticated mechanism by which you can handle these scenarios.

Therefore, coming back to the slide, here if you look the illumination consists of three parts we talked about this in the last class where we talked of an ambient term, a specular term and a diffuse term. These are the three components of the illumination effect and we have just introduced the ambient term at the end of the last class.

We will talk about that in details now today where the ambient light is considered in the case of a diffuse non-directional source of light. It is a case of a diffuse that means equally in all direction that is the meaning of this term. We will talk about the diffuse reflection also and diffuse light sources later on. But the ambient light is considered to be a case of diffuse non-directional source of light and these results from the effect of multiple reflections of light from many surfaces present in the environment and that is the key.

So all these multiple reflections or inter-reflections from one object which we talked about in the last class from the light source the rays directly falling on the object get reflected in one direction hits another object that gets reflected in some other direction hits the third object and so on this can go on in an environment. And if you have a set of large number of polygons not even ten or hundred, I am always asking you to visualize millions of polygons so you can visualize how many such rays which exists from direct sources, direct rays from the source itself and indirectly reflected from several objects and of course as they traverse their intensity keeps on reducing.

We will see a function model of that also but we know the hardness of the problem here. The hardness of the problem is simplified to almost a very large extent. In fact the main hardness of the problem is due to the inter-reflections of the object which result in ambient illumination. And this component has to be modeled in a very simplistic manner such that the complexity of the illumination process is not very very large and definitely not hard that which cannot be solved.

It cannot be solved so we do not try to solve that problem we assume that there is ambient illumination present in an environment and that is what we move on and it results from the effect of multiple reflections of light from many surfaces present in the environment.

So, if you look back this is what I said just now that this case of ambient light is a case of diffuse non-directional source of light and it results from the effect of multiple reflections of light from many surfaces present in the environment. Ambient light is assumed to impinge equally on all surfaces from all directions. This may not be also actually true in a realistic scenario. There could be variations you may not be very large. that means one part say the background wall or the ceiling of your room may receive a larger fraction of larger percentage of this inter-reflected rays causing larger what you call as ambient illumination or larger ambience in terms of illumination and shading in this context.

It is possible that some part of the ceiling or even the walls if you look around in a particular room in a class room or in a room where there are no light sources pointing towards these background objects like the ceiling, walls or even floor but of course floors most part of it receive direct sources of the light. So I will not take the example of the floor. But if you take the background wall or the ceiling of a room and you will find that you have ambient illumination which varies from one point to another. But typically the variation is not that large to be considered in the computational stage. So we assume it by an average ambient illumination. That is one sort of approximation which we do for ambient light.

So it is assumed to impinge equally on all surfaces from all directions. And the illumination equation is simplified with the product of two terms; the ambient light component is a multiplication of two of these components I_a into K_a where I_a is the intensity of the ambient light and is assumed to be constant for all objects, so that is what is assumed. So throughout the environment or the room you have this I_a which is the constant. Of course again I say it is almost close to reality but if you have some idea about which part of the scene may have larger ambience or a larger ambient illumination compared to the other parts you can actually vary these I_a component from one point to another in the scene if you are able to model it using a simple linear or a nonlinear function for that matter.

So if it is possible you can go ahead if you think that you could measure ambient illumination by some device say typically it could be a light measuring device in 3D scenario and you want to import it into your graphical package just to make the scene realistic as to what you saw may be in a real environment then you can measure ambient illumination also if possible using sensors and then fit it using a nonlinear and linear function and then say I_a is a function of the X Y Z if it is possible.

And of course X Y Z and V of course if that is so but it is typically assumed to be invariant to the viewer or light source direction but it could a function of X Y and Z. That is what we need to find out otherwise typically I_a is assumed to be constant that is the intensity of the ambient light which is assumed to be constant for all objects and then of course you have the ambient reflection coefficient K_a.

This is equivalent to the reflectivity term row which we used in the last class. The row will have different components depending upon the illumination components being talked about. Either we talked of an ambient illumination or specular and diffuse which will be coming up in this class after sometime and we will see that the row is considered to be different for different types of lights and it could be of course different for different surfaces there is no doubt about it.

That means a particular surface may reflect more of ambient light and less amount of other types of illumination direct sources or diffuse or specular type which we will see later on because we talked of these three components but we are discussing ambient light. So K_a is the ambient component of the reflection coefficient which is also termed here as ambient reflection coefficient K_a which varies in the normalized range 0 to 1. And of course it is the property of the material. That is I_a into K_a which is giving you the ambient light term in the illumination equation.

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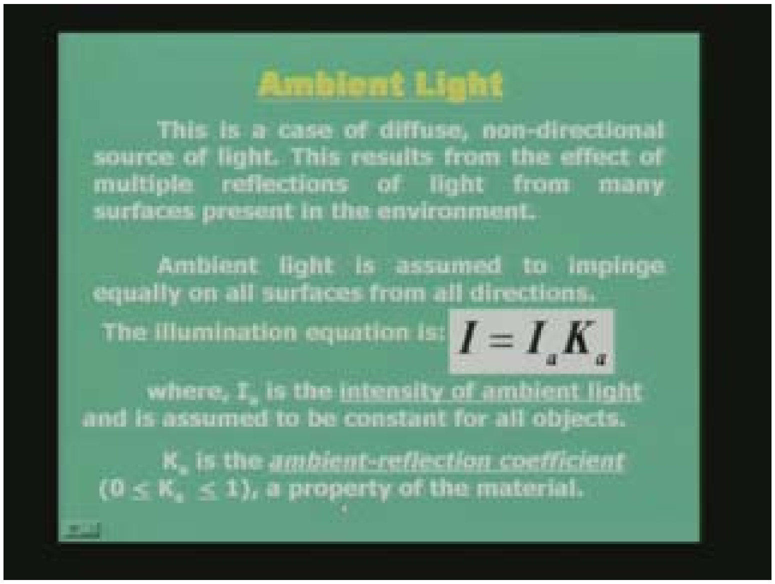

This is a picture which talks about the different effects of ambient light on a typical surface. We assume that it is sphere with a red color and of course it is a glossy or a shiny part which is reflecting this one light source on the top left which is illuminating all these spherical or wall type of a structure.

And courtesy this image has been obtained and you can find it very easily in the demonstration of Matlab graphics toolboxes and it is a very nice demonstration here where you will find that there are about different walls with different types of spheres or ambient illumination. The largest being on the top right and the lowest being the left column. The left column typically has the less amount of ambient illumination. Still you will see some variations as you keep going from top to down and left to right.

As you go from left to right the ambient illumination term and each of these rows is increasing as you also go from top to down you will also find that the ambient strength of the reflectivity of the surface and the light both are actually varied from one point to another. So ambient strength is increasing from left to right and ambient component of the light is increasing from top to bottom.

I repeat again; as you go here the ambient strength is increasing from left to right as you can see here that the more amount of ambient illumination is present towards the right than on towards the left and if you go from bottom to top the ambient light itself is actually increasing. So it is a combination of two factors anything like you are playing around with these two terms I_a and K_a. I_a being the component of the ambient strength of light and Ka is the ambient reflection coefficient or the ambient component or part of the reflection coefficient which is the property of itself. So both are varied here and of course I have not leveled these figures but again you can visualize as I keep repeating from left to right you have the ambient strength increasing and ambient reflection coefficient increasing and from bottom to top you have the ambient strength of the light increasing.

These are the examples by which the ambient strength of the light and the reflection coefficient could vary the way a surface could look like. You can have different color combinations also.

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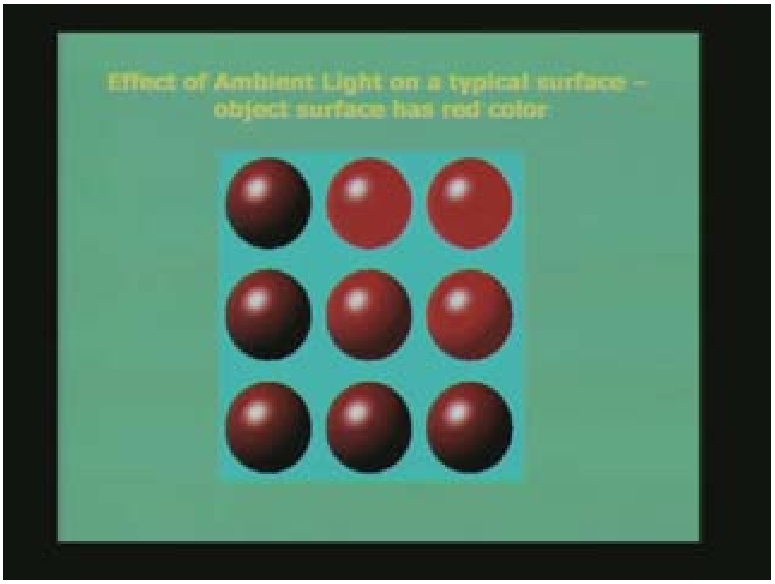

So that was an illustration of the ambient reflection component of the light source. And we talked about in the beginning of the slide today that there are three components of the light source; one is the ambient and second one is diffuse and third one is this specular. So we will move on to the second component assume that the ambient term has solved a lot of problem in terms of the hardness of illumination and shading. It is a simple term which has approximated those infinite set of rays floating around in all directions, impinging on the surface, getting reflected, inter-reflected back again and so on and so forth and it is assumed to be a simple constant term. That is what has simplified our problem to a great extent.

Let us look in to the second component which is called the diffuse reflection. So here we assume that we have a point light source whose rays illuminate uniformly in all directions from a single point. So assume here now for the first time we are talking about light sources and rays coming out of the light source and directly hitting an object.
So we are talking about light rays coming out of a light source.

We assume a point light source you can visualize a sun in the universe as a point light source because that is illuminating light in all directions and that incandescent lamp also is a very crude approximation of a point light source not typically but never a torch or a tube light is definitely not a very good example of a point light source.
Some sections of tube light is but not on the hole.

Assume a point light source and the basic assumption for a point light source is that rays emanate uniformly in all directions from a single point. The object's brightness varies from one place to another depending on the direction of the light source and also distance to some extent so it is very important.

If you remember a diagram which will come again now, we talked of a point on the surface of an object linear or nonlinear a surface does not matter and we have a light source direction so the light sources are coming from that direction source. We have a surface normal, we have an incident angle theta and a sort of the viewer direction V the angle between the V and N is phi, we will come back to that figure once again.

But what I meant was you have to visualize that figure in 3D and we assume that wherever you are viewing this object you see the same illumination in case of diffused surface which has the property of diffuse reflection.

A diffuse surface has a property of a diffuse reflection, it has another term called the lambertian surface also we will see. Then what does the illumination depend on in the case of diffuse surface? It depends on the angle between the N and S vector. That means the relative positions of the surface normal and the source direction, the angle between them actually dictates what is going to be the illumination in this case. That is what is talked about here which says that the objects brightness varies from one place to another depending on the direction of the light source and also we will model the distance factor to some extent later on.

I talked about this term that the diffuse surface is also called the lambertian surface which exhibits diffuse deflection and typical examples of lambertian surface which has or exhibits diffuse deflection are dull mat surfaces, snow, chalk projection and movie screens, uniformly painted walls etc.

If you go to a theater to watch a movie and you can watch the movie from any position or any point on the theater hall and you will be able to almost see the similar brightness. Of course there is an effect that the different rows are illuminated more than the rows behind that is an effect of the distance but that is not due to the effect of specularity or the property of lambertian surface which we are talking.

If you take constant area distance and move anywhere in the theater hall or the movie hall and you are watching the movie points on the surface of that movie screen will appear the same. It is typically same for projections screen also which are used to project presentations. So that also is supposed to illuminate or dissipate light equally in all directions. Thus, whatever light falls on a point there is a little bit of granularity of that lambertian surface such that it dissipates light equally in all directions. That is the key that is dissipates light equally in all directions and other examples are chalk, snow, dull mat surfaces. Any mat surface, table tops typically unless it is textured.

Forget the texture part of it do not worry about that for the time being. If you have a flat surface may be the background walls as you can see. If you observe this background walls from any direction in your class room walls painted with certain diffused color whatever could be the color white, blue or whatever it is but if it is painted with a color which has the diffuse deflection property you should able to see the same illumination from a direction because the illumination component only depends between the angle between the surface normal and the light source direction N and S that is the key. So that is what we saw for diffuse deflection for a lambertian surface. A surface which exhibits diffuse deflection so we will keep interchanging these words lambertian, diffuse and interchangeably. So when we talk of the lambertian surface we will understand henceforth that it exhibits diffuse deflection and we talk of a diffuse surface or diffuse deflection we are talking of a lambertian surface that is what we will use interchangeable. These laws are come from concepts of optics of basic physics.

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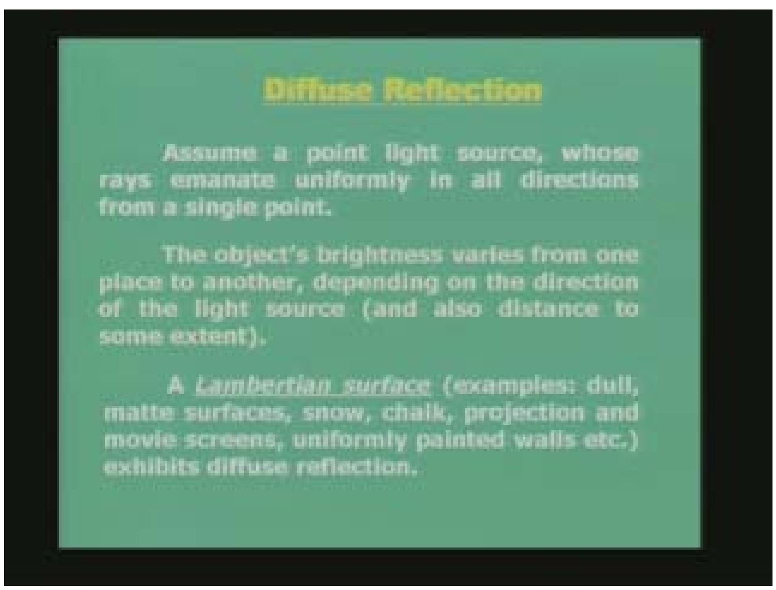

These surfaces as I was talking appear equally bright from all viewing angles because they reflect light with equal intensity in all directions. This is what we just said now we talked about this that they reflect light with equal intensity on all directions. So independent of the viewer direction you will have the same illumination. That means whatever be the viewer direction you will have the same illumination of object points which are of lambertian or diffuse properties and they appear equally bright from all viewing angles.

For a lambertian surface the amount of light seen by the viewer is independent of the viewers direction as follows. Let us look at this figure which we bring back. As I was promising sometime back that we bring back this figure where if you remember that we are interested to calculate the diffuse intensity at an object point O and the source at a direction S viewer at a direction V and N is the surface normal. Remember, this is again a three dimensional figure V N and S may not lie on a plane in general. And the angle between the vectors N and S, I again repeat N is the surface normal source is the viewer direction this arrow shows the direction of the light source not the direction of the source vector from with respect to the object point O, N and V vectors shows the direction of the surface normal and the viewer direction respectively.

To know the vector S which points the resource direction you must reverse this arrow but in this case arrow just pointing to the light rays coming out of the source S an impinging on the object O and the angle between the N and S which is also called the incident angle I have put the level theta.

I have purposely omitted this angle which was given as phi in the previous class the angle between V and N because it is immaterial; the diffuse component of illumination is invariant with respect to the viewer direction and this angle. So the illumination component which you get is going to be independent of the angle between V and N. That is why the term is eliminated from that figure, it will be only dependent on theta by this following relation.

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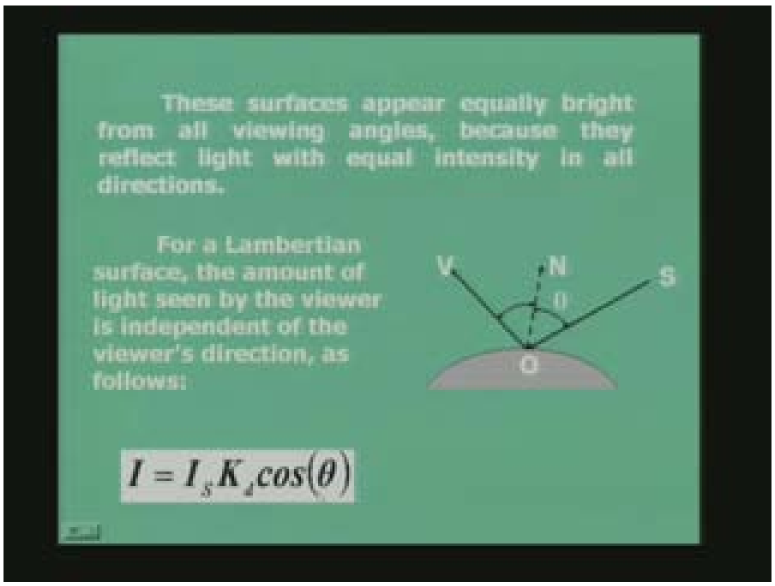

Is K_d cosine of theta where this is the diffuse illumination equation I was talking about shown in the previous slide where I_s is the point light source intensity K_d which varies again from 0 to 1 is the material's diffuse deflection coefficients and of course theta values between 0 to 90 it is a cosine of the theta so you can almost visualize that when theta is equal to 0 that means N and S coincide you will have the maximum diffuse deflection or diffuse intensity whereas when theta is close to 90 degree you will have a very less amount of illumination due to diffuse properties of the surface or diffuse deflection.

And again the K_d term if you look back it is same as the Ka term. In the ambient illumination term we introduced the ambient deflection coefficient Ka in the earlier slide, in the current slide K_d is talked about the materials diffuse the letter D stands for the term diffuse so the diffuse deflection coefficient is K_d, I_s is the point's light source intensity which is a very important factor.

Earlier in the ambient illumination we talked about an I_a term which was due to the result of various light sources light rays getting into reflected about the various objects and resulting in ambient illumination. So it could be a combination of various rays which creates ambience and various light sources also. But here at an object point getting illuminated by one light source, you may have many we will come to that but one light source will illuminate one point on the object and that particular intensity of that light source is going to dictate the intensity in terms of the diffuse deflection or diffuse deflection component of that illumination. So I_s is the point light source intensity and K_d the diffuse deflection coefficient and a theta term.

So the other triangle phi is irrelevant so you can put V anywhere as you had seen in the previous light here and V could be anywhere in 3D diagram here, it could be along N, it could be along S, it could be anywhere else the diffuse deflection component i here in this equation does not change, it is invariant to this angle so I have not label this angle as to where. This is the diffuse illumination equation which we have I_s K_d cosine of theta and the above equation can be rewritten as the following manner. This is what is usually followed I_s K_d and a dot product of N and V vectors cosine of theta can be visualized as assuming N and V to be normal unit vectors. If they are not in unit vectors we better normalize them and what is the formula for the dot product of two vectors? We had seen this many times you use in his back face culling as well. It is the product of the amplitude of the two vectors which is a scalar quantity. Dot product is a projection of one vector onto the other one.

A. B, project A to B or B to A whatever the case may be and the direction does not matter, the order does not matter in the terms of dot product and the formula is the product of the two amplitudes of the vectors N and V and cosine of theta. Since I mentioned just now that you better take unit vector, normalize the vector N and V so the amplitude should be 1. So N. V in this case will be cosine of theta because the amplitudes of both N and V are unity or 1.

So that is what we are able to replace the cosine of theta term by these out product of N dot V assuming this to be the normalized unit vectors along the surface normal and source direction.

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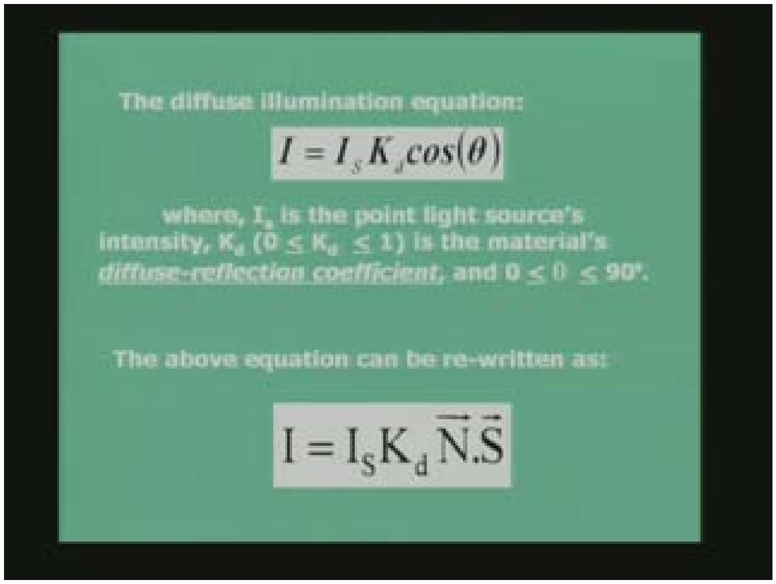

Unless you are in a perfect dark room which is typically used for developing films, a more realistic illumination equation using the concepts or knowledge which we have studied so far is the total intensity i which is the sum of two different components the ambient component here given by I_a into K_a and the diffuse component of the illumination consisting of the Is K_d N dot product with S where I_s is the intensity of the source, K_d is the diffuse deflection coefficient and N the surface normal vector and the S is the source direction and I_a K_a are also similarly the ambient illumination and the ambient reflection coefficient. So these are two terms which can now be combined to make this scene look realistic.

In the case of surfaces having diffuse deflection properties and also ambient illumination due to inter-reflected rays by other objects so we combine these two illumination equations and see the effect. Now, of course there is another, the effect of distance which I was talking about which talks of the effect of distance or attenuation is possible that although when you watch a movie in a hall or a theatre you can sit anywhere in the gallery and watch the movie and see the same illumination and have the same effect as part as the visibility is concerned and the illumination on the screen is same from or independent or invariant with respect to your position in the gallery.

Although this is true but I also mentioned and you must have realized that when you are sitting on the frontal few rows front few rows you definitely see a larger illumination than the people at the back or at the middle definitely at the back of the theater towards the back.

So although seen from the frontal few rows in a movie may not be very pleasurable to the eye because of the very large illumination where the light rays will be glaringly impinging on to your eyes could cause a very harder or burning effect after sometime. It is not advisable to show in general because of that particular reason for the health of your eye. But the illumination is very large and so it is perfect that have your seat in the middle or towards back of the theater. But what basically means in terms of illumination and shading as per as computer graphics is concerned that the reason effect of distance which causes attenuation of the light sources intensity.

Hence, when you have the light source very close to an object you will typically have a larger amount of illumination. If you take it away the illumination starts glaring so you come forward the illumination will be brighter if you take it away the illumination may go down. So there is an effect of distance which reduces the light sources intensity as it traverses.

I was talking about this when you talked about inter-reflections of ambient illumination where the lights get inter-reflected between various parts of that object and they have to travel. So, as they keep traveling and getting inter-reflected their intensity also starts falling down in some sort of an exponential manner. Therefore, after some point of course you do not have to worry about although there are infinite rays but beyond a certain point in those lights the strength intensity of those rays will be falling down anyway so you do not have to worry about that. The ambient term will be very large because the ambient lights which fall on a surface would have been reflected by several hundreds or more objects, they might have traveled a lot of distance before actually coming and hitting on that surface which is exhibiting ambient illumination.

Number one; from the point of ambient illumination also it has approximated by I_a K_a term. You do not worry about the effect of distance there. But it has a role to play which is approximated there. In the case of diffuse deflection where the light sources directly come from light rays come directly from the source and impinge on the surface without passing through or getting reflected by some other object. So it is directly coming from the source and impinging on the object if you take the object away from the light source the effect will be such that the illumination will start falling on. It is typically a case that when we move closer to the sun, in terms of if you are able to move from one planet to another from earth you go closer to the next planet or move away to a farther planet say Jupiter certain or even farther away you will see the intensity of that light source of the sun is also glaringly low. It also happens typically when the moon rotates around the sun depending upon its distance you will see a brighter moon or a very dull moon. So there is an effect of distance of course in the case of the atmosphere there are atmospheric effects which often causes effect of dullness.

Of course if there is a cloud cover you may not be able to see the sun or the moon but the atmospheric effects in terms of the troposphere and the pollution in the air may cause the brightness to also vary. But since we assume smooth medium we assume that light travels in a vacuum without any interceptions and when you are closer to the source you have a brighter effect of illumination as you kept dragging away as you kept pulling out or moving away from the source the illumination will start falling down. So let us try to model this effect of distance or attenuation with an equation where we change the previous equation of illumination model using an intensity I the same ambient term there is an f attenuation function which is put here before this term, we are trying to put that term on the diffuse deflection component.

The diffuse illumination part here remains unaltered and we just add a multiplicative term f attenuation which is the function of distance and the two typical distance measures which are used often are these two 1 by dl square l being the distance of the light source and the object is written as dl and you can take 1 by dl square. So 1 by dl square 1 by x square function you know typically it will have an exponential fall and at dl very far off the assign particularly go down to 0. This is the case which will happen of course if you are moving away from the light source in an artificial environment like the incandescent lamp or tube light.

Although you may able to see the light from a very good distance but the effect of illumination of that light source on the object can be considered almost to be negligible if the object is sufficiently far off. So 1 by dl square when dl is very far off it is not a problem and when dl is equal to 1 the functional value will go to the maximum, dl could be less than 1 and there is a problem with dl as it is very small as in critically approaching 0 the f attenuation term may actually shoot up to a very large value. So this value of 1 by dl square the functional form has to be used with lot of care, precautions in the sense that what you visualize that dl is a positive number usually typically more than 1 that is what you assume.

If you are certain that the value of the dl which you are using in this f attenuation term given as 1 by dl square if you are using this functional form and you guarantee or some how ensure in a programming environment and you are sure in the scene which you are modeling that the value of dl will be 1 or more than 1 then you can safely use this otherwise it is not.

But in a programming environment it is difficult to guarantee such things unless precaution is taken so a very safe functional form is given the next one which is given in this form. It is more realistic a nonlinear term the denominator but this term takes care of the fact that this can handle even the case when the dl equal to 0. What will happen when dl is 0? Well it will be the minimum of this function that is 1 by c_1 and 1. So you have to constant term where c_1 and c_2. You set those terms depending upon the way you want. This attenuation term which is a function of a distance or it is trying to capture this effect of attenuation based on the distance between the light source and the object surface you have the effect of attenuations. So we are trying to capture that effect by this functional form by minimum of that is what you are taking.

That means if the value of 1 by c_1 and the denominator term shoots more than 1 you choose 1. If the value is less than 1 you choose that particular term so that is the minimum of these two values. So, if the frontal term with the help of these constants c_1, c_2 and c_3 there are three constants here and there is a dl which is the distance of the light source and the surface of the object which is under consideration so this term is less than 1. We consider that otherwise if this term shoots over 1 we take the value of f attenuation to be 1.

When f attenuation is equal to 1 there is no effect of distance in that case because it is equivalent to considering that previous equation which we talked about. So this is the original equation which we started with and in that case it can be considered that this equation is a special case when the f attenuation term here is equal to 1. Otherwise it will be typically considered to be less than 1. That is how the effect of this distance is visualized.

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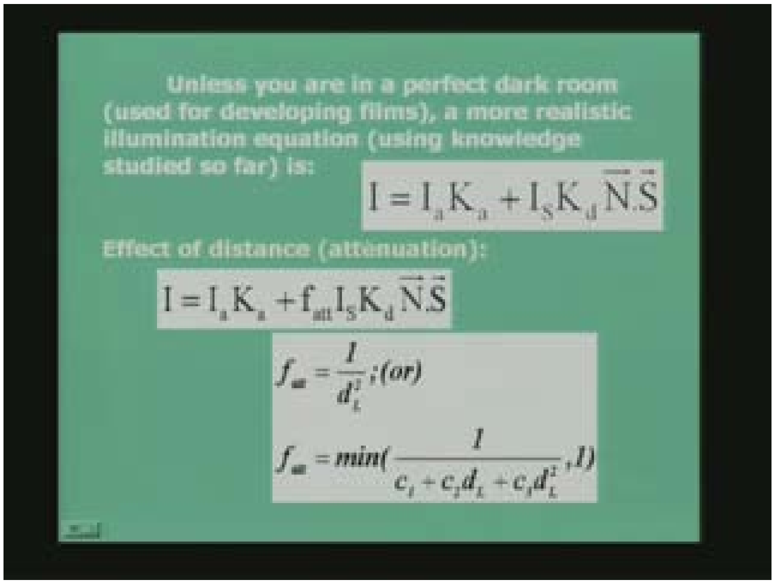

There is another concept of atmospheric attenuation which is considered. It is similar to the effect of distance which is considered and it is a process of simulation of the effect of depth cueing. It is the process of simulation of the effect of depth cueing where distant objects are rendered with lower intensity than the closer ones. That is the term which is also used to model the same. And using normalized projection coordinates if you remember the 3D graphics pipeline we used to predefine these parameters called as, let us go through these parameters which are used to model this atmospheric attenuation.

The first of them is the scale factor two of them which are used which are again varying between the range 0 to 1 normalized scale factor range. We have the range of depths now Z_t and Z_b something like a background depth and a foreground you can say Z_f and Z_b. So we assume that there is a range of depth we also did this in the case of a canonical view volume when we were truncating or scaling down the entire three dimensional rectangular parallelepiped, finite view volume for orthographic parallelepiped or a pyramidal structure. In the case of perspective projection we also had a foreground and a background plane if you remember when we were discussing 3D graphics viewing pipeline much earlier. So we have a range of depths as well. So that is what is considered here Z_t and Z_b could be the range of depths which will dictate my scale factor S_t and S_b respectively. That also should always be in the range 0 to 1 and we have a depth cue color $I_{dclambda}$. Depth cue color which is the color based on depth original intensity of the source I_{lambda} and based on these values we have to compute the depth cued value of intensity I_{lambda} prime. So we have to compute this Ilambda prime based on the other factors like range of scales, range of depths and the intensity depth cue color also which is given by $I_{dclambda}$ and the original light intensity. So let us see what is the functional form which relates this I_{lambda} prime with the other parameters here to get our atmospheric attenuation function.

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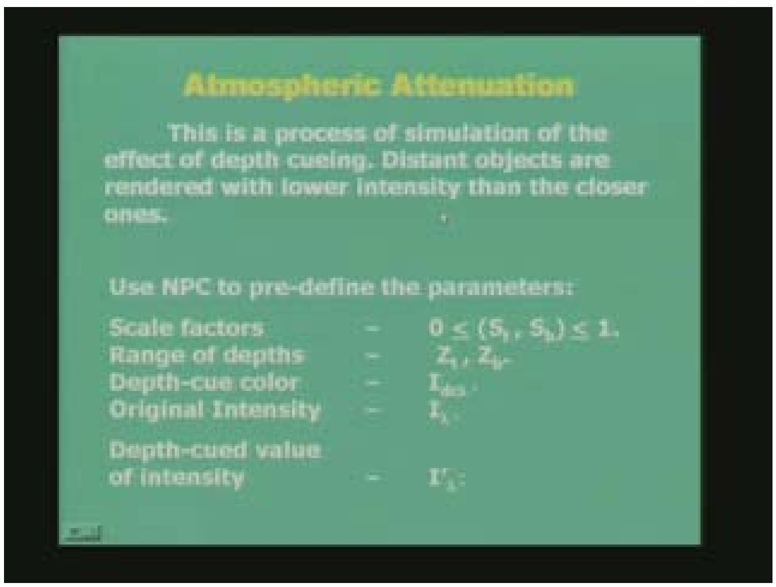

This is the function which we have to consider which is considered as an Ilambda prime is defined as S_0 into Ilambda and this particular term. You can see that when S_0 is calculated based on depth and scale. So this is all known to us that means the range of that Z_t and Z_b are known you set your S_t S_b term you know what is the original intensity of the light source you know the I depth color which is calculated here the depth cue color $I_{dclambda}$ is also calculated here in fact it is a constant term which is set and put here S_0 is the term which is calculated from the lower expression based on the values of the range of depths and the range of scale values which you are considering. Again range of scale values will be always between 0 and 1. So that is what you compute and let us see how this functional form looks like. If you look at this particular plot this is what we used to compute the S_0 values scale factor. We need to compute this S_0 here in this expression and substitute here on the top and calculate the computed intensity Ilambda prime.

So you set here Ilambda and $I_{dclambda}$ which are known, original intensity of the light source and depth cued intensity which could be different from the original intensity and then based on your depth values on the depth which you are interested in of the object surface point Z_0 is the depth of the object point for which you are calculating the intensity

Z_b Z_t S_t S_b are all set and the same.
So you set your S_t and S_b range of scale values which could be between 0 and 1.

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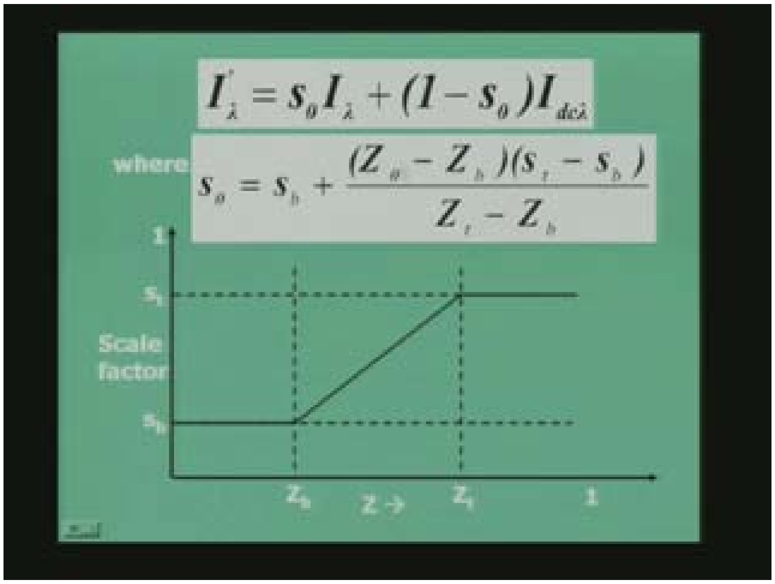

The minimum value of S_b is 0 maximum value of S_b is 1. Similarly Z_t and Z_b also will have a minimum and maximum range. You can again visualize a normalized range from 0 to 1 since you are considering canonical view volume it goes from minus 1 to plus 1 or 0 to 1 whatever be the normalized range and that is what you send. So Z_0 will be of some value between Z_b and Z_t as given here. This value of Z_0 will be somewhere within this range. And if you see if Z_0 is equal to Z_b which is this point here or even anything less than that we assume that S_0 equal to S_b that is what we typically assume that Z_0 equal to Z_b you know this term will be equal to 0 so S_0 equal to S_b. If Z_0 is of course less than that then it will still remain in S_b. But if you are ensuring that the value of the Z_0 always lies between Z_b and Z_t. I repeat Z_0 which is the depth of the object point lies between the values Z_b and Z_t that is the minimum value Z_0 is Z_b and minimum value of Z_0 is Z_t here then it is a linear functional form that means the Z_0 is equal to Z_b you have the value of scale as S_b when Z_0 equal to Z_t you are reaching this point Z_0 equal to Z_t these two terms cancel out and you have the value of S_0 equal to this particular term. So you can easily calculate that this is a linear function and as you vary Z0 from Z_b to Z_t this value of scale runs linearly it goes up from S_b to S_t.

Of course you can have a nonlinear function of this variation if you want to know you can have a gradual exponential rise and a exponential tapering at the end typically like a sigmoid function in mathematics as it is called about. Please read about that and see that you can fit a sigmoid function between for this value which will result in a range of scale values for a certain range of Z_0 between Z_b and Z_t.

So that is what you use here since we are assuming that Z_0 value will be lying between Z_b and Z_t. You will get so far a certain value of Z_0 here you use this equation and get the value of scale S_0 substitute that in the front equation and since Ilambda and $I_{dclambda}$ is known you will get the value of I_{lambda} prime. And minimum value of S_0 could be 0 if that is so what typically happens is this value of I_{lambda} in fact when S_0 equal to 0 we will have the I_{lambda} prime as your $I_{dclambda}$ and whereas when you have S_0 equal to 1 which is the maximum value of S_t is set to 1 and then S_0 also becomes 1 when Z_0 equal to Z_t you will have the effect of that I_{lambda} prime or equal to I_{lambda} because this term will be equal to 0. So what you are saying is, as range varies from Z_b to Z_t you are actually changing your illumination term based on the atmospheric attenuation or depth values or depth ranges from a minimum value of $I_{dclambda}$ to an I_{lambda} which is the source's original intensity.

That means when you are getting nearer to the object you are almost getting your original intensity as you keep drawing out the Il_{ambda} term effects starts reducing an $I_{dclambda}$ trust term starts increasing more and more. So this is the range and again we are only taking simple linear variation from a very low value to a high value Z_b to Z_t. You can have a linear variation as shown in this case but you can also have a nonlinear variation but it should be smooth it should not be a jerky or an abrupt variation you can have a small sigmoid function making in this variation of S versus Z vary in sort of a smooth manner like an S type of sigmoid function as I talked about is what you can use and that is how the scale will vary with respect to depth and in turn that will also make the intensity vary in a similar manner. So those were the two terms which you have seen earlier the effect of diffuse term and the ambient illumination and the part which is left is the specular reflection. And we have seen these two terms in fact we have talked about it earlier there are three components of the illumination, the ambient term, the diffuse term, and the specular reflection.

We have discussed at length about ambient term we have discussed in length about the lambertian or diffuse deflection caused by the lambertian surface and you are left with the specular reflection. With the time available to us we will introduce this specular reflection and discussing in detail in the next class and in the time available to us we will introduce the specular reflection component. As you can see here it is an interesting phenomena of specular reflection observed on a shiny surface. And we now introduce this angle theta which is phi between the vectors V and N we have the angle phi we have the angle theta between N and S and we have introduced a vector R which is an angle theta between the vectors N and S.

So which is the same figure with one more vector R introduced which is bearing the same angle theta between N and S and is the same angle theta is between R and N and this R is called the reflection vector and the angle between V and N is the angle of phi. Now this term which comes here as you can see that earlier we had the vector N then we had the vector S and we had a angle theta between N and S we also had the viewer direction vector V and we had the angle phi between the viewer direction and surface normal N.

We introduced a vector R which is with the same angle theta, the angle between vector R and N is given by the angle theta which is the same angle between the N and S as we look back into the figure once again and I must tell you here that the vectors R, N and S are on the same plane. Now the vectors R, N and S are in the same plane whereas the view vector V can lie anywhere in 3D. This angle phi could be anywhere in 3D. You can visualize this figure again in 3D where R, N and S are on this plane which you are seeing and view vector V can be anywhere else in 3D. So the plane which constitutes the R, N and S may not have the vector V and V could be somewhere else in this 3D.

What is the significance of this R vector R which is introduced? This is called the reflection vector because for a specular or a shiny surface that is the vector which shows the direction about which the major or almost in some cases all of the light is reflected. The tree of a surface of the specular reflection tries to model shiny surfaces.

What are the examples of shiny surfaces which are different from ambient and totally different from diffuse? The most simple and the common example given is a case of a mirror. In the case of a mirror all of the light which falls on a mirror surface gets reflected along one particular direction given by this vector R. And in the case of a mirror whatever light falls on the object surface will also get reflected along a particular direction that is given by the vector R.

If you assume a small tiny mirror surface patch and it is illuminated by a ray of pencil it is illuminated by a pencil beam that is the single ray of light falling on that then if the viewer direction is aligned with that vector R then only we able to see the light reflected by the particular point. You can try this experiment using a small patch which is a mirror type and allow the light ray to fall on that you will not be able to see the reflected light from any arbitrary direction.

In fact an all direction except one particular direction you will not be able to see the light reflected ray. And that particular direction is given by this vector R in the figure. If you see here which is the vector R if the viewer direction coincides with the R or if you position yourself along the reflected direction R the vector direction R you will be able to see the light source single light ray which falls from the S and gets reflected by this one.

So we will stop with these words where we talked about shiny surface which reflects light unequally in different directions and mirror is an example of the perfect shiny surface.

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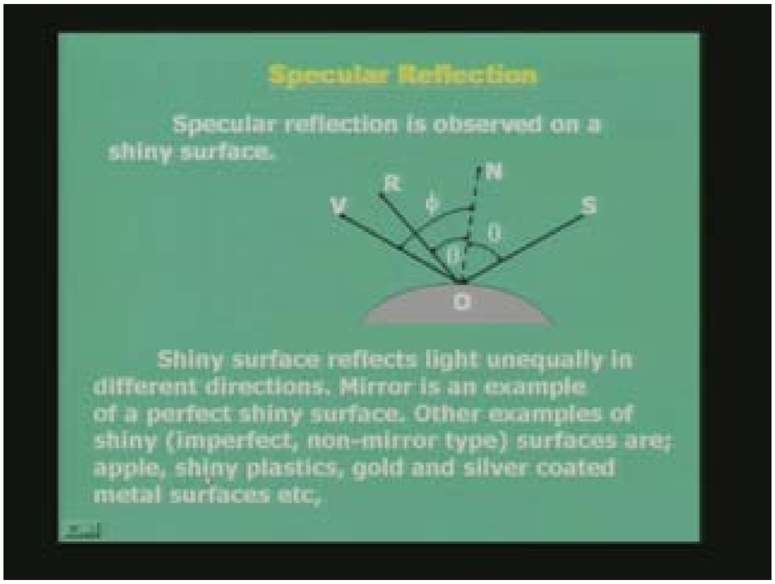

Other examples of shiny surfaces are which are imperfect or non-mirror types are apple surface, shiny plastics, gold and silver coated metal surfaces etc.

I repeat again, this paragraph which says that the shiny surface reflects light unequally in different directions. Mirror is an example of a perfect shiny surface. Other examples of shiny surfaces are imperfect non-mirror types which are surfaces of apple, shiny plastics, gold and silver coated metal surfaces etc.

Now, comparisons of specularity with diffuse. If you see the diffuse surface or the ambient surface was reflecting light equally in all directions. When I use the word in an opposite way that the specular surface will reflect light unequally in different directions, it may not actually reflect light in certain directions itself. Take the case of a mirror which is a perfect specular surface example. It in fact reflects light only in one particular direction and does not reflect light in all the other directions which is given by that vector R. So, along the R it reflects all of that light which it receives and you know how to compute that. Given N and S and the angle theta you will able to compute R.

We will see those expressions may be in the next class. But what we see here is that the mirror reflects all of the light in a certain direction which is given by this R. But there are other non-mirror type specular surfaces which are imperfect mirror types like the surfaces of gold and silver coated metal, shiny plastics, apple surfaces cleaned apple surfaces the surfaces should be absolutely clean and neat and undisturbed or perturbed those are cases where the major part of the light is reflected along R that reflected direction. But some part is also reflected along other directions around that vector R. So that is what we have to model. We will start from here in the next class where we see how to model a mirror and other surfaces which are non-mirror but specular type is what you have to model.

And again I repeat, the mirror is a perfect specular reflection case other non-mirror type specular reflections is what you have usually in practice available in front of us and we have to model all of these. So there is where we stop and we start in the next lecture when we start from here onwards to discuss trying to model the last component of the illumination which is the specular reflection, thank you very much.