Computer Graphics
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Lecture # 33
Illumination & Shading

Today we will start to discuss the concepts of illumination and shading in computer graphics. This is one of the most important stages in computer graphics which can be visualized as almost the last most important and vital stage in a 3D graphics pipeline. Of course you may have a two dimensional transformation and then a viewport on the screen. If you remember the stages of the graphics viewing pipeline which we discussed earlier, of course, very lately we have seen different methods of Visible Surface Detection which is followed by illumination and shading.

In fact, if you remember most of the algorithms, or in fact all of the algorithms on VSD or Visual Surface Detection talks about a pixel or a polygon being rendered. And when we were discussing that fact we did mention that later on we will discuss the algorithms and methodologies and concepts of illumination and shading of a polygon or a point. So this is the time we need to discuss about illumination and shading. That is the key idea of the lecture today and in the following couple of lectures. And you remember this diagram, you definitely remember this diagram which was used for two different VSD algorithms; one was used for ray tracing or even the Z buffer were a particular pixel (x, y) is rendered based on the intensity obtained of the polygon which is in front.

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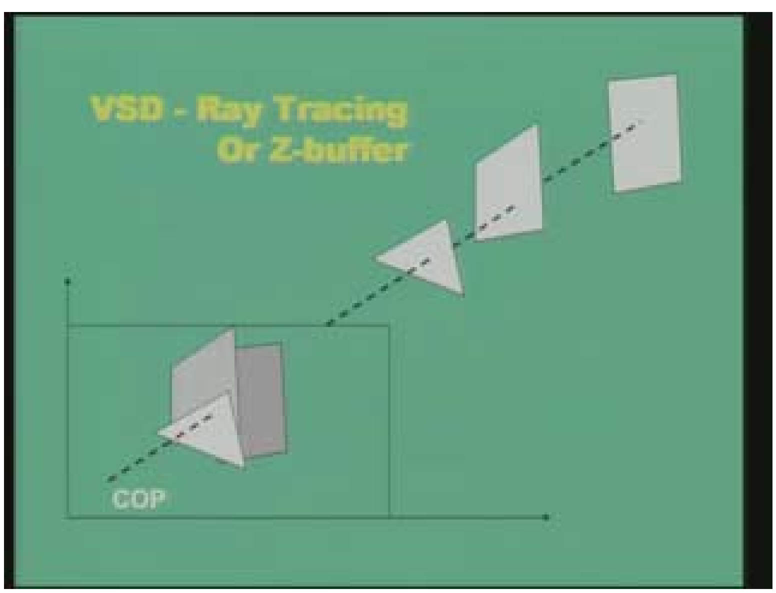

So if you are talking of shading a polygon it can be visualized as a 2D polygon filled algorithm with the intensity obtained from a 3D data and prior to that of course we have the Z buffer or a method based on ray tracing where of course we take a pixel out from a point (X, Y) on the image plane or we can process polygon wise or object wise where we process one polygon with the other and do the Z ordering or depth ordering to find out which is the nearest polygon in part or in whole at a certain point or a certain pixel (x, y).

Once that is done with the help of ray tracing or Z buffer as you can see this ray can be visualized either as a ray traced backward to the direction of the light source or also could be visualized as at light rays coming out from the 3D screen and impinging on the projection plane. Well, if you are interested on a particular point (X, Y) on the screen this point will be illuminated due to the shading effect of the nearest polygon at that point which is this one let us say. That is what you have to see. And if you remember, we discussed about ray casting in the last lecture. That is easy to visualize with respect to this diagram. The intensity or that particular point (X, Y) on the image plane can be visualized as the intensity obtained due to that point on the polygon in 3D.

Now when you retrace the path of the light ray back and strike the polygon you have to basically illuminate that pixel based on the intensity reflected by the polygon at that particular point. And the question comes is how much of a light ray will be reflected by a polygon or a point on the polygon or on an object, that is the key and we have to model that process and find out how much amount of light is reflected from an object point towards the viewer or the projection plane. Well, it depends on various factors, just to name a few factors it depends on the light source, it could depend on the number of light sources.

If you have more than one light source so there could be various types of light sources and at various positions in the screen which are radiating light. Of course typically if you say that you are visualizing an outdoor scene then of course you have only one light source which is the sun. But typically if you take a class room or an indoor environment you may have multiple light sources radiating light equally may be and unequally may be in different directions. That is the first thing which you have to model.

The second thing is you must find out how much fraction of the light source emitted by the light source or the light sources one or two light sources may be there in the scene and a very small percentage of that light falls on a particular object on that too in a small planar patch represented by a polygon and that too one particular pixel. So, a particular pixel will also receive some amount of light. And depending upon the surface properties, the most important surface property being the surface reflectance property dictates how much amount of light will be reflected from that surface which will actually determine the amount of light which will be reflected away from the surface.

That means there is some amount of light which is falling on a surface and something is reflected back. Something could be absorbed, something could be reflected back along a particular channel like a single ray or it could be diverse and equally dissipated in all directions. Several things may happen depending upon the surface property. That is what is going to happen and that is what we have to model. But there are other problems which will come in.

Number one is we have to model, we have already seen that we have to model a light source or multiple light sources, number one. We have to model different parts of the object which may have different colors and difference reflectance properties.

We discussed about reflectance properties just now and we will see mathematical equations which are used to model such a reflectance properties. Now it could be possible that the light could be of a particular color and the surface object itself could be some other color. Let us say we are working in a white or yellow light environment and we are viewing an object which could be radar or bluing color. So, depending upon the surface color and the surface reflectance properties and depending upon the illumination color or the intensity you may visualize different types of shades of colors and intensities of a particular sheet. These are the various facts. First of all we have to model and what are you trying to do? When you are trying to create a scene either is a question of virtual reality environment or to give virtual realism which we discussed about in ray tracing or VSD algorithms.

If you look at reality for that matter in a class room type of a scenario or an indoor environment you may have one or multiple light sources. It is quite difficult for you to visualize based on what viewing angle and what direction and what point, how much amount of the light you are seeing, why? It is because a scene may have various objects. Each of these objects will have different types of parts, different colors, different reflectance properties and there could be multiple light sources. There could be a scenario where the amount of light source impinging on an object, some part of that light ray suppose the light source is here and some amount of light falls here on the object, some section of that will reflect along that certain direction. You have another object at that point which will again reflect the light and so on. So there could be multiple reflections which are possible.

I am not saying multiple reflections in the case where you have only multiple mirrors. The object themselves produce inter reflections. It is possible that a light ray may fall on object number one, go to object number two, go to object number three and come back to object number one, this is reality. In fact, truly speaking, in reality there are uncountable number of rays, infinite amount of rays which are traveling around in the universe and also in space and also in the classroom even with a single light source. And what happens is, then of course you should ask a question when you are viewing it with your own eye, how can you view it.

Yes you can when you also use a digital camera you view, but what do you view? At a particular given point of time or when you are looking along a particular direction with your eye which is the natural sensor or the digital camera which is an artificial sensor among all the different rays virtually you can imagine almost infinite number or infinite amount of rays. Infinite rays are reflected in all directions with different lighting and propositions and different intensities. You can visualize that using a digital camera in a small region. In a small aperture you are capturing only a small section of those light rays but that is what you have to model as well. With our eye also you can rotate and see in a classroom right now and what you will be seeing is you are orienting an aperture through which if the light rays are falling on your retina or the human eye. So, among all the different rays which are traveling in front of you, you are only seeing a section of those rays which are passing through your eye lens through the aperture and falling on the retina which is sensitive to certain light intensities.

Similarly, in a digital camcorder or a digital camera for that matter you have the sensitive charge coupled devices which will transform the light to electrical energy. But at any given point of time you cannot capture all the rays for a particular snapshot or a screen but you are only capturing a smaller section of the those rays. What are those rays constituting of? Some of those rays could be even such that could be directly coming from the source one or two more. But your viewing object most of them are getting reflected by the object and coming towards you that too from different objects of course at any particular given pixel point of pixel (x, y) you will of course be seeing only one particular point of an object that is true. And of course the amount of the light which is again reflected depends upon the surface reflectance properties a perfect log object will have 0 reflectance.

Then you can have something like a snow or a silver which will reflect almost all of the light which is it proceeds. So there are various degrees of reflectivity of surfaces which you have starting from absolute dark absolute bright and grey colors and definite shades and intensities and colors in between. Those are the different rays which first of all could be directly reflected on to the projection plane or view plane in this case for computer graphics. It could be the case that these objects which you are viewing in addition to direct rays of the sun or the light source which it is receiving, it also receives inter reflected light rays from the object transmitted to this. That is what you see here that this particular light ray which is reflected from this object point of the polygon to the projection plane could be resulting due to rays of light which could fall directly from this source to the projection plane at this point or rays indirectly coming from or reflected from different objects one or two more objects and then falling all of that again on this point and then reflected back. This concept happens at each particular pixel on the projection plane as well as on each object point which is reflecting the ray.

So you have all source of rays coming from all different directions impinging on the object or object points and the object points also radiate or reflect back these light rays may be in all directions may be towards a particular direction depending upon various properties of the surface on the object which are termed as reflectance properties or color of the surface.

Well, you see if you want to model this entire thing in a typical scenario in a classroom if you see and I did say sometime back uncountable number of rays, infinite rays exist in a 3D space even in and around the environment and there is no way you can model this accurately enough to give the impression that it is a true picture. But still the computer scientist and other engineers working in the field of visual realism, virtual reality, computer graphics cannot stop, we have to create pictures for various applications which we have seen from the beginning of the scenes.

So we will make certain assumptions and see how to model this process of illumination and shading because so far I have tried to give an idea about how difficult this problem is or in computer science terms what is called as the shading is a very hard problem. That is the point which we start now that the process of illumination and shading is a hard problem and I hope in the last two minutes I have tried to give you an illustration or describe why shading is a very hard problem. So we need to create a virtual reality, say a classroom as I was talking about sometime back of a real scene which involves, there are various methods by which the shading and illumination is done for complex 3D scenes.

We need to model and position several complex objects in that 3D scene. That we have seen in the first stage of the 3D graphics pipeline. But once that is done you determine using the Visual Surface Detection algorithms, find the visible surface at any particular point, you can use Z buffer, the Z buffer algorithm or ray tracing.

I think we will stick to mainly these two algorithms because they are very common, popular and they are more sophisticated ones which are used among those suggested in the classic literature of the books which you have been following. Those are the two which are most commonly used and I am not saying they are always implemented but they are quite algorithmic and one of them, the ray tracing in fact simulates the real world which is the essence of virtual reality. So, using VSD algorithms determine this visible surface and project the view with respect to the viewer.

Project the view as you are seeing it and obtain the shading using surface normals, surface properties and light sources that is what you do next. This is the main essence of our talk today. This is the most important part where we talk about shading using surface normals, surface properties and light sources then obtain shadows from occlusion. This is an important part which we discussed at the end of the discussion on ray tracing.

Ray tracing is called the most efficient method by which we can implement shadows because shadows gives you, we had seen in lot of illustrations at the beginning of the lectures in introduction when I gave lots of examples that shadows really give.

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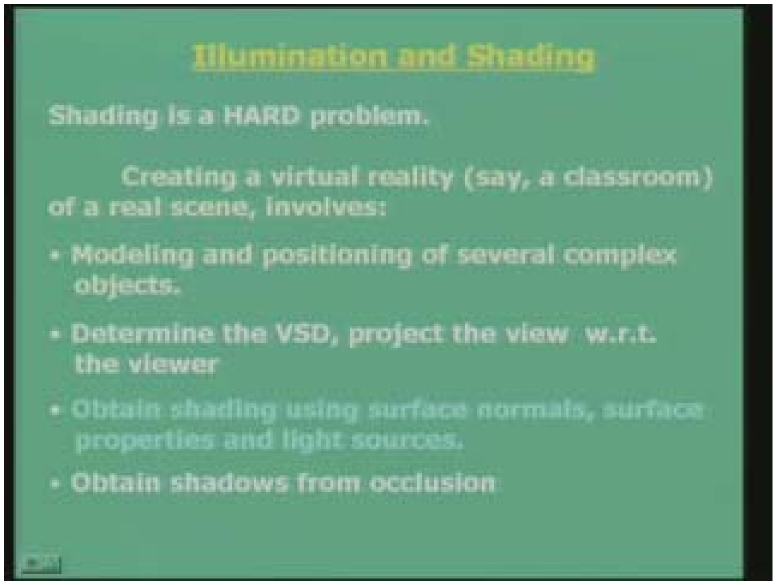

We probably do not see shadows you can almost immediately guess this is a very core approximation or a very approximated scene which is denied because typically except planets, asteroids and satellites in space nothing hangs in space. So we have object sitting on a surface you are sitting in a chair now my hand rests on a table on so on. So, if you have one or multiple sources you are bound to have shadows on the platform in which the objects are resting. We will see examples of that later on but you have already seen examples of it. So you have to implement shadows so that is another key part and ray tracing could help in this particular case. So, in real world environment the light rays flow in almost infinite directions. I talked about this sometime back and the some of these light sources are directly from this source and some are reflected from shiny surfaces of the object.

Of course the surface reflectance properties have a very important role to play here. If you have an almost perfect dark or a black object it will not reflect any light of course even if it reflects a small amount that can be considered negligible. Of course when we talk of shiny surfaces like aluminum foil or silver or it can be gold that reflects almost the entire part of the light which is a special case of that also is a mirror surface. But there are lots of other shiny surfaces. You can produce a shiny surface using a glossy paint so some parts of the surface may reflect more and some reflect less, it all depends upon the surface reflectance properties as to what extent it will reflect and of course in what direction.

I discussed about the real world environment, there are virtually rays going in almost infinite directions and we have to capture only a small subset of that. And that is impossible to model so we will see what the simplistic assumptions are to generate a scene which appears as close as possible to real world. That is the essence and that is the motivation behind which the computer scientist and computer graphics engineers had been working to try to come up with sophisticated algorithms may be a little bit complicated not too complex if possible to generate realistic scenes in virtual reality which may appear as close as possible to reality.

It may not appear absolutely real, true because almost everybody given two photographs however realistically one generates by graphic scene and a photograph taken from a digital camera of even a lay man could distinguish between the two but our objective here is not to make scenes which appear too virtual.

Let us say I am talking of cartoon pictures or even some videogames the old traditional ones. Some of the videogames have lot of effects of 3D shadows and good amount of animation and all that but I am talking of reality in terms of education, training, scientific and engineering studies where you need to provide realistic scene whatever you are modeling and give it to visualization such that it appears almost natural and real as possible.

Again I use the word almost and near because I say that we cannot model infinite rays and a fraction of an infinite rays passing through a smaller aperture. You can visualize that is also infinite in some sense so that also cannot be modeled. So what we model is a set of finite amount of rays coming out may be from the source some of them reflected by object inter reflected by other object that is the most difficult problem to simulate or model inter-reflections which causes a particular type of illumination which we will see later on.

But right now we will see that we will consider certain simplistic model and try to create scenes which is almost as real as possible and that is what we are studying computer graphics for. So, coming back to this problem which says why it is a hard problem the problem of illumination and shading as to why it is hard because in a real world environment light rays flow in almost infinite directions some direct from the source and some reflected from shiny surfaces of objects.

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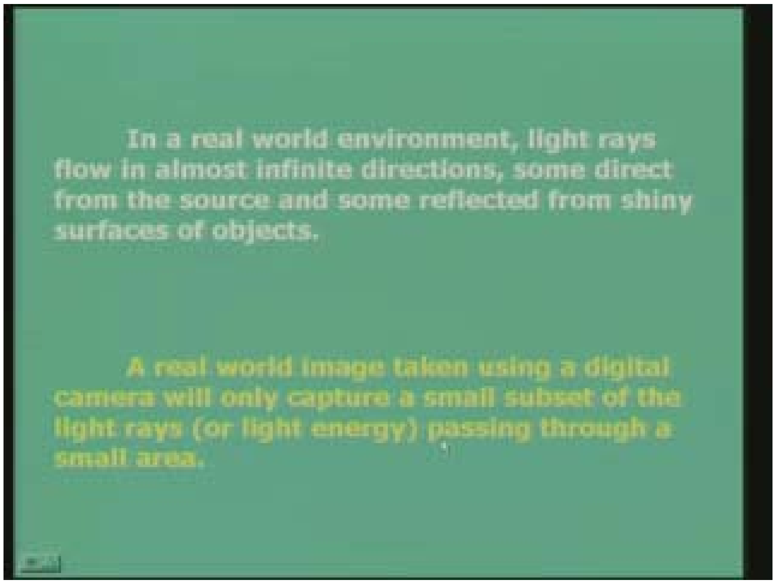

A real world image taken using a digital camera will only capture a small subset of these light rays or light energy passing through the small area. So I repeat again, a real world image that is not what you are simulating using computer graphics but the image captured on a snapshot taken using a digital camera will only capture a small subset of these light energy which is again infinite in terms of the number of rays passing through the small area and so we have to make a crude approximation of that area that approximation will be quite close to reality it will not be far away. We have to ensure how close we can go to reality to ensure that scenes look as real as possible.

Hence, to accurately construct a picture of this room say the room in which you are sitting or studying at the room in which this current computer graphics lecture is being recorded and use that to model and reconstruct the picture of this room via computer graphics we have to simulate this illumination process and be able to calculate the shading at each point of each surface in our scene, so you see the difficulty now.

If you look at this room in which are sitting or this room where I am currently delivering this lecture, well there are lots of light sources here which are illuminating light in all direction of course most of them coming towards the object and when we talk of objects here the tables and chairs in which we are sitting here or of the objects of the computer system which you are working or the body parts, the cloths fabrics which were varying each will of them will be receiving light in virtually infinite directions. They will be reflecting light also in different directions. The inter-reflection rays will also come. They will also be reflected back and so on and that is where you have to model this as accurately as possible.

How is it possible to model infinite amount of rays? You know that there is no way a value which is infinity or a database cannot hold infinite amount of records. We cannot do that, we cannot store infinite amount of rays, but the information about that in a system we can store as much as possible. We will try to see whether that is the ray by which illumination is modeled or some other approximations are considered and then combine with the VSD algorithms to create virtual reality, visual realism in virtual reality. That means you should able to view reality through computer graphics that is the case. And then we often have an approximated view or often an approximated view is generated using many complex formulations and algorithms. Therefore, we will see how this complex environment is modeled using some complex formulation. So you may not have time to go through all the sources of complex formulation but at least we will discuss algorithms based on some of the basic concepts of illumination and shading and will see how different concepts are combined together to provide real pictures.

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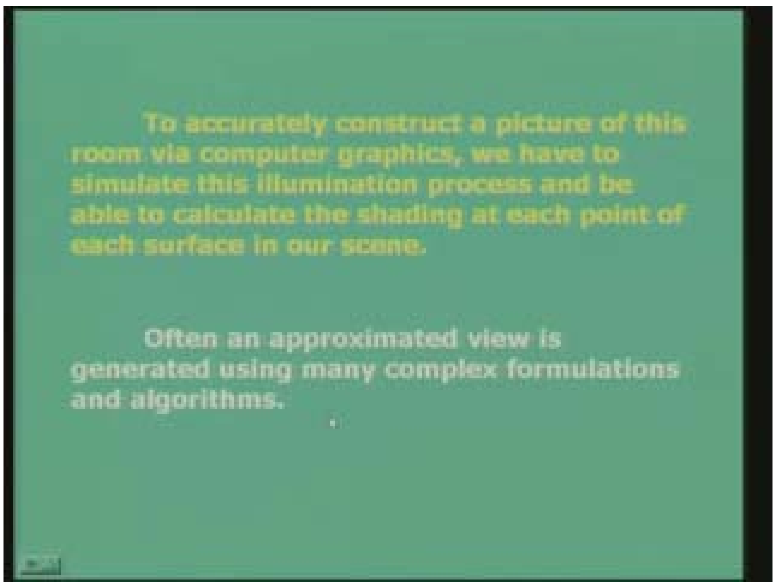

Of course there has been lot of developments on this illumination and shading. I talked of this term called radio city which we discussed at the end of ray tracing. That is probably one of the best methods so far advances based on those to create visual realism of pictures in virtual reality or computer graphics. Now let us try to understand the process of illumination which involves the surface normal source and viewer directions. And we will also see why these three vectors are the most important key parameters in trying to obtain the illumination of a particular surface.

In this case what I have taken is the upper part of a spherical surface it could be also be a cone, it does not matter and I am interested to find out the illumination at this point O, you can consider it to be a small planar patch or a single pixel. Let us say you have sort a ray from a certain pixel (x, y) from the projection plane towards this object and that pixel ray has struck the curved surface or solid object whatever the case may be at that point (X, Y, Z) which is labeled as O in this figure. We will go back to this figure so there is a small planar patch a polygon there we can assume a small polygon or a single point and that point will have a surface normal n. We can actually compute a surface normal n for any curved surface at any point (X, Y, Z) or even if you are approximately using a planar patch.

As you know how to do that using, we have seen about wireframe diagrams, sweep representations how to approximate curved surfaces with the help of small polygonal triangular or a quadrilateral planar patches. That is what it is. We are talking about this point O, a small area around this and we want to illuminate that area and calculate the intensity of that point when viewed from a certain direction. So n is the surface normal of that, S is the light source so the light rays are coming from S towards the object O and V represents the viewer directions, V represents the view direction. All these are with respect to the point O which is on the surface, it is a curved surface.

Now what are these two angles? These are very important. I have marked two angles pie and theta. Theta can be visualized as an angle between N and S vectors. I repeat; what is N? N is the surface normal which is retained here, S is the source direction of course the direction of the arrow could be reversed to a point towards the vector pointing towards the resource direction. Although this arrow marks the direction of the light source which are falling on the object surface from S, but you can reverse the arrow direction and say that this is my S direction from O towards S so that this was direction and V of course is pointing towards the viewer direction. So theta is the angle between the surface normal N and the source direction S.

I repeat again, the surface normal and source and theta is the angle between N and S. What is pie? It is the angle between the surface normal N and viewer direction V is the viewer direction. You can have that viewer direction to be arbitrary, source also could be arbitrary, N of course depends upon the properties of the surface objects structure. Now, you must visualize this figure in 3D. This is a very careful observation although it is not mentioned in this slide that is figure is in 3D. What it basically means is S, N and V may not lie on a plane, this is a very interest fact.

Remember, if you take any two vectors you can form a plane consisting of those two vectors, there is absolutely no problem. Any two vectors in 3D space you can actually find out the plane on which these two vectors are aligned. That is absolutely not a problem. Now what about a third vector? It may or may not lie in a plane. In fact you should now visualize that this V does not lie in the plane in general.

Of course it could be a special case when all of these V, N and S there were three vectors look back into the screen N, S and V three vectors could lie on the surface on a plane which is this screen. If you assume this screen which you are viewing on the plane in 3D surface then all of these could be lying on a plane so that is a special case. But what you should visualize is if you have S if you have N the V may not lye in the same plane of N and S it could be anywhere. If you have N here the S there and the V like this, the V could be anywhere in the screen. That means you want to view that object surface or that object point from any direction it should be able to calculate the intensity because when you keep changing V not only in that plane of N and S but anywhere in 3D.

Actually V could align itself with N, V could align with S or it could be anywhere between N and S or anywhere, only the restrictions are there, those angles pie and theta should be less than in absolute terms pie by 2 or 90 degree.

If you take a look at that, that is the only restriction the angle in fact theta sometimes called the angle of incidents because this is the incident ray coming from S and with respect to the N. We have an angle of incident I but I used the value theta here, you can have the viewing angle pie. So theta and pie are the angles used here but this figure is in 3D we could be anywhere.

Of course N and S could be anywhere N of course um anywhere means it is dictated by the object point and that particular point S of course depending upon the light source and V could be any viewer point. That means you should be able to view this object from any point in the 3D scene. Of course with restriction again I repeat that phi and theta phi should be less than 90 degree plus or minus that is number one and theta also should be less otherwise there will not be any light source falling on the object point to illuminate. So these are the two important facts of V, N and S. V could be anywhere. This should be visualized as a figure in 3D.

Although the figure shows, I wish it is a two dimensional figure but I keep repeating this, this is not. The only restriction is this will come in the calculation when we talk of equations and models we will see that these angles phi and theta in absolute terms should be less than pie by 2 radiance or 90 degree. Now, coming back to this figure, this is the scenario where you are talking of just one light source coming from S hitting this object point at the point O and this light ray could be going in any direction.

But you are observing it from, the viewer or the projection plane is located in such a direction that it is pointed to by this vector. Now, what are the different scenarios which can happen in terms of light rays coming and light getting reflected? Let us see one of the scenario here. This is the scenario where the viewer direction could be anywhere. I was talking about this sometime back but these are the three other possible viewer directions. And again you should visualize this picture in 3D.

V is a three dimensional figure as is N and S. V may not lie in the plane constituted by these two vectors N and S. N and S two vectors form a plane you can find out the equation of the plane, you have done that exercise already in 3D structure, 3D solid modeling and VSD Visible Surface Detection algorithms. But the V when it lies on the place of N and S it is a special case only.

It can lie anywhere in 3D and the phi will be just the angle between N and V in 3D. Remember, if this is N this is your V you can position it anywhere and the angle is the angle phi which you are talking about. So there could be different values of phi I leave it as an exercise for you to take each of these directions as your view direction and draw the angle phi, so the viewer direction could be anywhere, number one.

Number two, an important fact is that the light source may not only come from one direction but it may come from many directions. What do you mean by light source coming from different directions?
We discussed about this. This was the key factor which let us to understand that the illumination and shading is a hard problem. If you see that picture again carefully the main vector S which is shown in the reverse direction shows the light ray coming from a light source S but there are other dashed arrows which also show that the light rays could come from all other directions. Those light rays could be due to various reasons.

First reason, there could be more than one light source S, it could be S_1, S_2 and S_3 and so on. Of course if there are too many light sources there will be too much of illumination and all that. One of those may not have a significant role to play because there are other ends light sources.

But when you talk of one light source and the second and the third, yes there is a difference in illumination as you are viewing a particular object that is always true. That is very significant information because when you switch off a light source and switch on one then the amount of light which falls on an object and gets reflected will definitely. You can do that experiment right now if I request one of you to come and switch off one of the light sources.

Can you switch off one of the light sources? As you can see now one part of my face is dark and one part of my face is bright. I would request that the light is switched on. You can see that you have uniform illumination because there are two light sources basically illuminating my face, skipping this on and this can be switched off as you can see. Now this is a fantastic effect. As you can see only my right side which is to your left is my portion of the face which is getting illuminated and that is because one light source is on. And this is a back face with respect to the light source. So this has to be switched on for this part to be illuminated.

Can you switch this on? Now, there are two light sources. Now, of course you can have effect of more than two or three such light sources illuminating an environment. But of course it does not matter much if you have more than quite a few. So but one to two to three light sources yes, there is a variation. So those arrow directions could be indicating the directions of the light sources or the direction of the light rays coming out from the light sources and impinging on the object.

I hope this was a very nice light demonstration which you had recorded, which you had just seen now in terms of the light sources effecting the illumination of parts of objects in a three dimensional scene.

Number one is the light sources, number two is the fact which is also true is those directions which you saw in addition to the main light source S could be inter reflections. That means there could be many other objects present in 3D scene and most of them assume to be non dull or non dark objects because if most of them are dark they will not reflect light. So there should be shiny or shiny type of object surfaces which should reflect light and those reflected lights of the other objects may not actually reach the viewer they could get reflected from some other direction towards me or towards the object which you are viewing and then get reflected back to your projection plane or the camera which is recording the scene. And more the number of objects you have the 3D scene more amount of inter reflections. In fact you can visualize just two objects in a 3D scene in a class room which is surrounded by the floor sealing and the walls will have lot of scope of inter reflections because there could be a principle light source falling on object one getting reflected to object two going to a ceiling on a wall and then coming back.

In fact I cannot show a further situation; right now you can as students look up into the ceiling or look down on the floor. You can see that most parts of those objects may not have the illumination directly obtained from the light rays coming from the source directly. I repeat, parts of the ceiling, floor and wall may not have light rays coming from the source directly but still they are illuminated may be that the illumination strength or level is small when compared to the illumination of other objects which receive the light rays directly. But where do those light rays come from, from those other objects which are not receiving light rays directly.

Let us take a very simple example, even if you are working, if you are walking in the evening in a full moon lit night what will happen is there is no sun and the light rays which you are seeing in an environment however small the illumination may be or due to the light rays of the moon.

Now moon does not generate light rays like the sun. Where does it get? Moon’s surface receives, the surface of the moon receives light rays directly from the sun reflects it back to the hard surface in some proportion.

A small percentage reaches the earth, other fraction goes elsewhere as well and some of those light rays which fall on the earth’s surface when you are viewing those object surfaces it could be any three dimensional scene outdoor in the evening in dark is not fully dark you can see some objects in a full moon day because those light rays however small the intensity may be illuminates those objects, those are indirect rays reflected from the moon surface to other surface and then going to your eye.

If you use a camera the similar thing may happen that you have indirect light rays inter reflected from various objects finally hitting the floor sealing or the walls of a room and then getting into your eye or getting into the projection plane of the viewing system or the camera which is capturing those light rays.

So now you can visualize the hardness of the problem in terms of trying to model so many scenarios in terms of light sources, surface reflectance properties of objects and more than that the hardness comes from these inter reflection. It is impossible to model that. You can make a large super computer run from wide days or months or years together to model that object and still you may not get the actual reality.

You will of course get close to visual realism. In terms of visual realism you will get very close to reality but it will never be real because I think a very simple statement if I make the computer cannot hold the value infinity or in a database in a computer I cannot store infinite values or records. This is a sufficient clue you tell you why I cannot model infinite rays which are moving in this universe, space or even in this class room right now. So two, three light sources and some approximations based on the fraction of the light which is reflected directly from the object source towards the viewer or projection plane can be substantially modeled with great degree of accuracy. The most difficult part is the inter reflection. So if you look back, as I was talking we left this diagram long back. These light rays may be other light sources due to other light sources but most of these are the result of inter reflections or indirect rays reflected by other objects in 3D scene in the environment and impinging on the surface.

Now, where do this other objects which are reflecting light get the light sources? Yes they are getting the light source or the light rays on the same source which we are also getting but the main objective is receiving light. One or two light sources may exist and they are illuminating the whole three dimensional senses. All objects at least the frontal faces with respect to the light source are receiving light.

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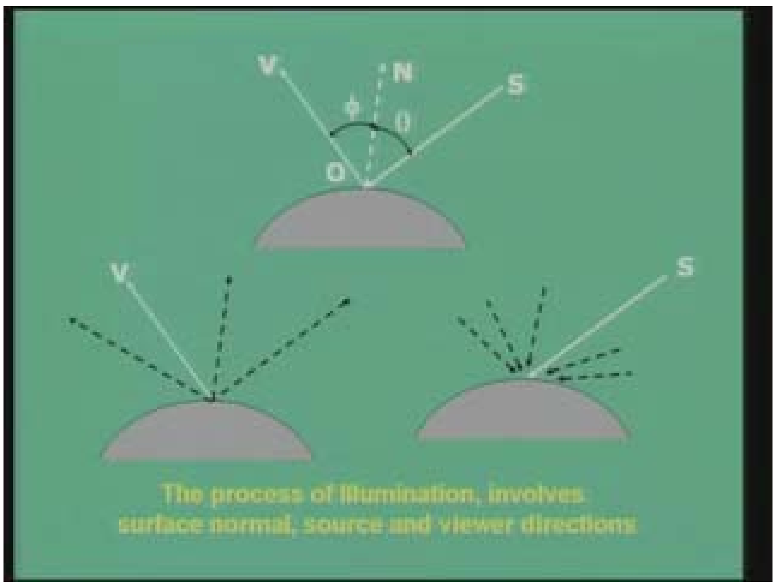

But when inter reflections happen there are indirect rays which are reflected, direct source falls on the object and get reflected out. Now some of these if you do not reach the camera or the projection plane or the human eye will reach some other object and then get reflected again and so on and so forth. So it keeps going on as it keeps traveling the light source intensity reduces, we will see that sort of the model which is also used in general and then what happens, this inter-reflected rays create a scenario, I will use a simple term right now and come back to the term later on called ambience or ambient illumination just to talk about and this is what is used to model the most hardest part of the problem.

It is just almost single, one or two terms are used, one or two variables are used to model the complex part and that is the coarsest part of the simplification. That is responsible for generating the coarseness of the picture and that is what a does not give the picture making it as real as possible to a real picture.

These are the inter-reflected rays reflected directly from other objects, those objects could be receiving the rays from the source directly and getting reflected here. So you have to model the figure here in terms of the number of light rays, ambient illumination is also in use and then these objects you do not know how much of this light will reflect towards the viewer, how much fractions will reflect in other directions. That depends on this light intensity, the light color, the surface reflectance properties and the surface color.

There are three or four facts which are responsible for that illumination of that particular point. And of course your viewer direction that is the angle phi between V and N will also be one of the responsible factors. You will see that the other angle incident angle which you discussed about between the surface normal N and S is actually the main key factor which is responsible for the illumination. If you look at this equation which can be considered as the basic equation of the illumination model which we have been talking so far takes into account two different conditions.

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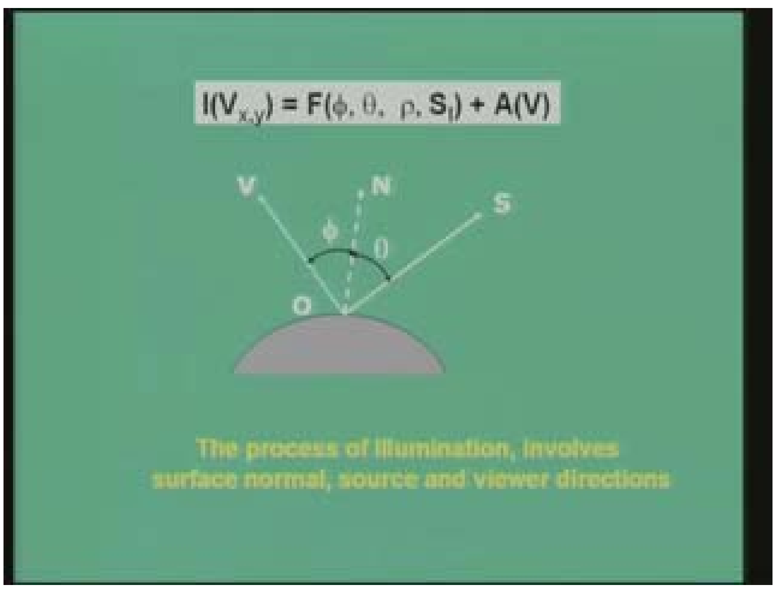

It says I of $V_{x\ y}$, now that must be understood but before that we will say that the intensity at a certain point (X, Y) on the image plane is a function of all the two angles phi and theta which we have described earlier.

Row is the reflection coefficient, we will also come across this term later on, reflection coefficient at that point O on the object surface and Sl is the intensity of the light source plus of course this term which is very important and interesting which I just said now that it is the ambient illumination as a function of V which takes care of all these inter reflected rays and ambient terms. So the intensity at a point (X, Y) is a function of one of the light sources.

If there is only one of course if there are two light sources we will see later on that there could be two such functional forms F1 plus F2 with similar A V R, two angles phi and theta reflection coefficient row, light source intensity Sl and ambient term. So you can see there that now we are talking of two components of the illumination model or two components which results in the illumination at a particular point (X, Y).

One is the ambient term which very much simplifies the entire hardness of the problem which we have been talking about. It is difficult to set that term, we will not discuss methods by which this term is difficult but you can vary it in the low range somewhere that A as a function of V. Now that could be assumed to be a constant.

We will see generally that A is assumed to be a constant in variant to B it does not depend on B but it may. If have a surface in which the ambient illumination appears different from different directions then it becomes a function of V or the angle phi whatever way we look at it. But that is the component which simplifies the inter reflections. The main component of illumination comes from the source, direct rays obtained from the source which hit. So phi, theta, row and the light source intensity and colors. Those are the main factors which are responsible inter related of course in some sense.

We will see in some cases the phi may be important the theta may not be important or vice versa and we will see or these two put together as we go and look back into the equation again when you are studying the process of illumination which involves surface normal source and view directions this gives the right hand side summation of the two terms gives the intensity at a viewer direction for a particular value of x, y.

Now what is this x y related to 3D?
We assume here, imagine ray tracing, a particular point (X, Y) on the image plane, particular point or pixel (x, y) on the image plane shoot a ray out, that ray will go and strike a particular object which is in the front at a certain point (X, Y, Z). So we say that the intensity in the viewer direction x, y based on the direction which the light rays are shot back will depend on the object point O which this ray has gone and struck back. This viewer direction V shown in the figure is the inverse direction of the light ray which is traced back or cast back from the image plane towards the object.

We are assuming here that a ray cast out from (X, Y) is traveling in the reverse direction of V and goes and hits the object O first. There could be other objects. Of course if you hit the other object that is the point which we are seeing at a particular point for a particular pixel x, y. But if that is the object we are considering that is the one which you are interested in so that is why that i as a function of $V_{x,y}$ basically means that I have the image plane in a viewer direction V and there are parallel rays which are coming out each point (X, Y) in the image plane. All of these are parallel rays coming out in the reverse direction with respect to the viewer direction. I am talking about the viewer direction

with respect to the object point O. So whatever V I am pointing to the light rays are cast in the opposite direction because actually the light rays would have gone and hit the eye or the sensor at that particular point if you put your eye or digital camera. But in terms of computer graphics or virtual reality we are casting rays from back from all points xi yi.
So take one of those rays cast back in the direction opposite to that comes and hits the object surface O. That is why $V_{x,y}$ depends on this (X, Y, Z) point O is reflectance properties is normal and theta and phi angles plus the ambient term is all at least these could be modeled plus a few more. This is just the starting point of the illumination model which we are recommending light.

Now we will see a lot of formulations and on top of these in terms of ambient terms and when does it depend on theta, when does depend on phi, when does it depend on both, to what degree more does it depend on theta, more does it depend on phi that means the angle between the V and N and S.

We will see that later on and how much does it depend, it does depend on row the reflectance properties which could be very dark 0 I repeat row could be varying from normalized value 0 to 1, 0 for a perfect dark object black body, it does not radiate any light to a very almost shiny surface like a snow, silver, aluminum foil which I was talking about where row is 0.99 or close to 1. That is what we are talking about. These are the parameters which affect the illumination at a particular point (X, Y) in the corresponding viewing direction.

So I repeat again, that is the explanation of this $V_{x,y}$ which we are talking about that in the viewer direction we have the projection plane and at certain point (X, Y) this view will go and struck the image plane at a certain point (X, Y) or from the point (X, Y) you cast the ray reverse direction to be and let it struck the object point or object surface at point. I hope the explanation of the terms and parameters of this equation are clear by now as we start analyzing in detail each term one after another. Before we do that we talk of typical compromises and simplifications which are used to model realistic scenes.

The first of the assumption is the uniform media. Well, when you are seeing me and I am looking at you there is probably only hearing in between. From the earth surface only look towards, listen most of the space is a vacuum. We are probably looking into a summing pool which is very crystal clear the media is water. We assume that the media is not turbulent even if air is turbulent it does not matter much. of course but there could be mediums like glass, water through which rays could also flow, non opaque objects, translucent objects as part of the rays flow.

We assume whatever be the medium pure, clean, glass, water, air, vacuum it is uniform that means the rays do not get disturbed. The concept of ray casting is where light rays travel along a linear path in one particular direction without deviation. Of course if it goes from one media to another it may be deviated. We know those concepts from basic laws of physics but we assume that just one single uniform media between the object and the projection plane that is all. There could be many objects in the 3D scene, some of them could be objects, some of them could be transparent, some of them could transcend that is all right. But with respect to the objects in a 3D scene and the projection plane which is viewing a set of objects here you assume that the media is uniform and the light rays coming out finally from an object surface will go undeviated in a linear path and hit the projection plane at a particular point x, y and that is the first assumption.

Next one is the opaque objects. Typically that simplifies the scenarios still further, why? Well if you have opaque objects you no need to worry about rays which are observed by the object transmitter through in between like a glass or a translucent object like a plastic let us say with which you can partly see, a transparent rubber and the objects reflected back and you will reach the other. The ambient terms become more and more invalid if non opaque objects exist in the scene. The complexity is little bit different because now if you ray cast you not only have to visualize rays which are received directly along with ambient and reflected back on to the sensor or the projection plane.

I use this term interchangeably a sensor in a real world and a projection plane in computer graphics, you should try to put these two together and see the difference. So I am putting that scenario in front of you but in terms of non opaque objects when the object surface is non opaque there could be light rays passing through the object coming out and then also moving towards the projection plane. And where are those rays coming from passing through the object? There are the other rays reflected from other non opaque or opaque objects for that matter. They all are combined together, pass through the object, come out of the surface. We have not seen but the picture does that. That can make it very complicated.

Opaque objects we do not have to visualize rays, we do not have to model rays which are coming out from within the object. All rays which are received by the surface will be reflected back. There is no ray which is generated from within the object by another light source inside that is of course very funny environment more than that when you talk of non objects, translucent structures then rays from other objects inter reflected or from other sources will pass through that object and come out of that surface. You have to visualize that the previous figure which I have shown in the slide where the S comes from the light source gets reflected towards V.

Now you have another light source coming from the bottom of the object surface and also going to towards V. I repeat again, not only S from S direct light sources are reflected towards V but object rays from within the non opaque objects coming out and then also get transmitted or cast towards the viewer direction. So opaque objects is a simplification which is easier to handle and no inter reflections approximated by ambient light we discussed about this. That we use a constant term of course that term could be dependent on view to make it realistic if necessary of course you do not have to do it always.

You must know the surface you are modeling whether it has the property such that you are looking into ambient illumination on that surface of that object and does that ambient illumination vary with the direction of the viewer. That means if you are viewing from this direction or from the other direction does that illumination term vary.

That is what you have do model. It is very difficult so ambient light we discussed about this hardness, removed in one shot in the problem where inter reflections are approximated by ambient light and then we talked about point light sources which illuminate light equal in all directions, sun incandescent lamps may not be large tube lights. But since that could be difficult model but point light sources is a very good approximation.

In most scenarios point light sources are considered or even disc light sources and of course a very simplified color model. Illumination with all these compromises and significance to handle and modulate will consists of three parts. One is the ambient term, another is a specular term, another is a diffuse term.

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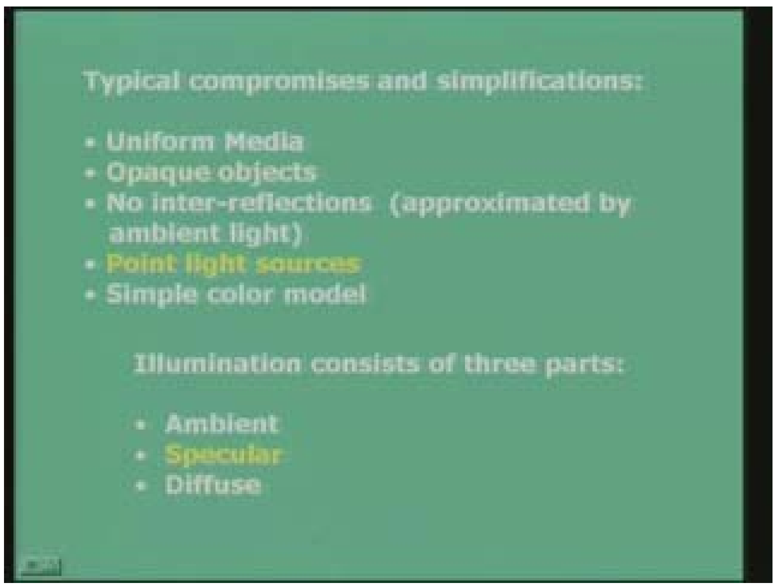

The ambient light is a case of a diffuse non directional source of light which results from the effect the multiple reflections of light from many surfaces present in the environment. Ambient light is assumed to impinge equally on all surfaces from all directions this also we know. And the illumination is considered to be an equation like this where we have I_a as the intensity of ambient light and is assumed to be constant for all objects and K_a is the ambient reflection coefficient varying from 0 to 1 which is the property of the material. This is the ka related to this row which talked about, the surface reflectivity and we have a constant for the object surface in terms of ambient illumination.

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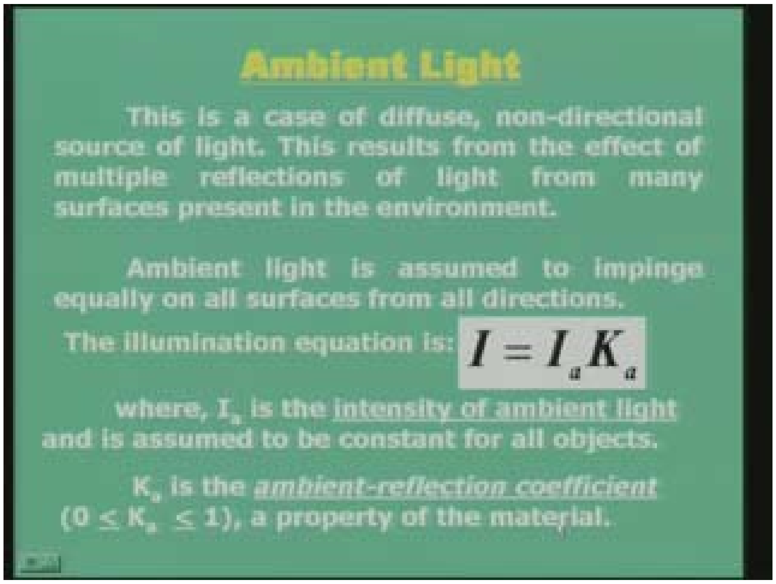

So we have seen in the first equation the general model ambient term plus direct sources F and we have also seen an expression which can handle I_a multiplied by K_a which takes care of the ambient illumination and which simplifies the hardness of the inter reflection patterns.

We will talk about the other two types of illumination models mainly the specular and the diffused part in the next class.

We will start from here in the next class where we will introduce the ambient light term once again, look into the equation and moving to other two types of illumination models of diffuse and specular and continue that in the next class, thank you very much for today.