Advanced Graphics – Physically Based Rendering

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ABSTRACT

A video game without lighting is never going to look pretty and will rather look uninteresting. Real world lighting calculation are complex and expensive for video games to handle. Many modern video games make use of a lighting calculation technique called Physically Based Rendering (PBR) which mimics the real-world lighting in a digital world and makes it look realistic. PBR works on microfacet surface model, energy conversations and Bidirectional Reflective Distribution Function (BRDF) to make it happen.

This report explains the process to achieve the approximation of realistic views using PBR and future for the project in context of video game graphics.

**KEYWORDS**

PBR; BRDF; Lighting; Lights; Irradiance; Billboards; HDR; Tone Mapping; Shading

**INTRODUCTION**

In computer graphics, lighting plays a vital role of making the player/viewer believe the realism of the digital worlds. In old arcade style games like Pac-Man, Wolfenstein 3D, lighting was non-existent, and player can see the whole level or map even at huge distance (E.g., A corridor in Wolfenstein 3D). Even if expensive lighting algorithms existed, the CPUs of that era were not powerful enough to handle those lighting calculations in real time.

Later, as CPUs and GPUs become more powerful; “close-to” realistic lighting also became possible.

**RELATED WORK**

1. *Lighting in old video games*

One of the greatest games of all time – Doom and others like Heretic, Hexen did show some sort of dynamic lighting although not realistic which is called Sector-based lighting. In Doom game, the world is divided into sectors which are made by connecting line segments to form a polygon. Every sector had different properties like floor, ceiling, texture and most importantly the light levels. Every sector had a light level ranging from 0-255 with 0 being dark and 255 being very bright.

Lighting attenuation computations were done such that the light travel from one sector to its adjacent sectors and based on the distance of how much it traveled, the light level of current sector will be slowly attenuated. It did support additional light sources like lamp for doing light computation for that sector and its adjacent ones.

* 1. *Light Diminishing*

Another fine addition to lighting Doom introduced in “Light Diminishing”. Where the brightness of the area from the player’s point of view slowly decreases as the distance from the player increases. This did not create any realism as well, but it did create impressive scary atmosphere for the game. This same mechanism was also used to simulate fogs. [1]

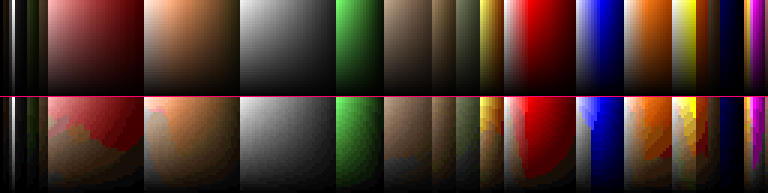
* 1. *Colormap implementation*

Before explaining Colormap, I need to first explain what color quantization is.

* + 1. *Color quantization*

Quantization in general is an image compression technique which is used to narrow down certain range of values to a single value. This also helps in reducing the file size. Moreover, color quantization works by reducing colors of the image such that the compressed is visually like its original.

In the PC port of original doom engine, it made use a Colormap which is a color quantized gradient texture which starts from a different color starting at top and slowly fades to black color as moving down. It is a precomputed lookup table which was used to fit in the game’s 256-color palette. The first 32 levels in the colormap were purely dedicated for implementing lighting. See Figure 1 for example.



**Figure 1: Top – Pure gradient. Bottom – Doom’s quantized colormap light levels**

Overall, the lighting calculations in Doom was simple and not realistic, but it did bring immersive gameplay which made the maps look and feel believable.

1. *Lighting in mid video games*

Games from Doom 3, Unreal Tournament onwards started introducing dynamic lighting and shadow casting. Different light sources were introduced like Point Light, Directional Light and Spotlight.

To quickly summarize these different light sources:

* 1. *Point Light:*

This type of light source emits lights in all directions. In technical details it contains the position in 3D world, color, intensity value and range.

* 1. *Directional Light:*

This light emits light in the single direction, and it has no attenuation and light travel infinitely in the game world. Just like a sun, however the sun in real life is one big point light in the solar system.

* 1. *Spotlight:*

This type of light emits light just like directional light, and it falls in a certain radius. Surfaces outside the radius are not lit at all. A good example of spotlight is flashlight which are common to use in horror games.

In real life, when a light falls onto an object, some of it get bounced or reflected and some get absorbed by the surface. The light which gets reflected leaves a white shining effect depending on the object’s shininess. This shining effect is called Specular highlights.

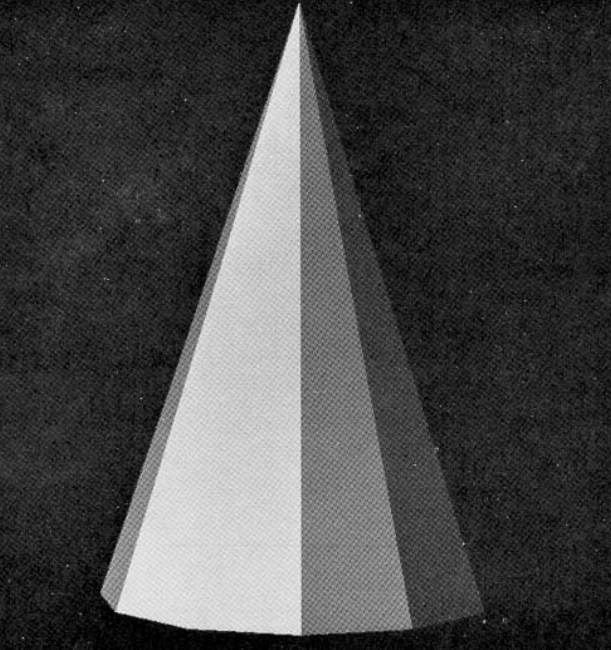
In computer graphics, the most popular shading model for specular highlights in the Phong shading model which he has explained in detail [2]. His work is influenced from previous shading model such that of Warnock’s [3] and Newell, Newell, Sancha’s shading model [4] and Gouraud shading model which needs to be explained first.

* 1. *Warnock’s Shading:*

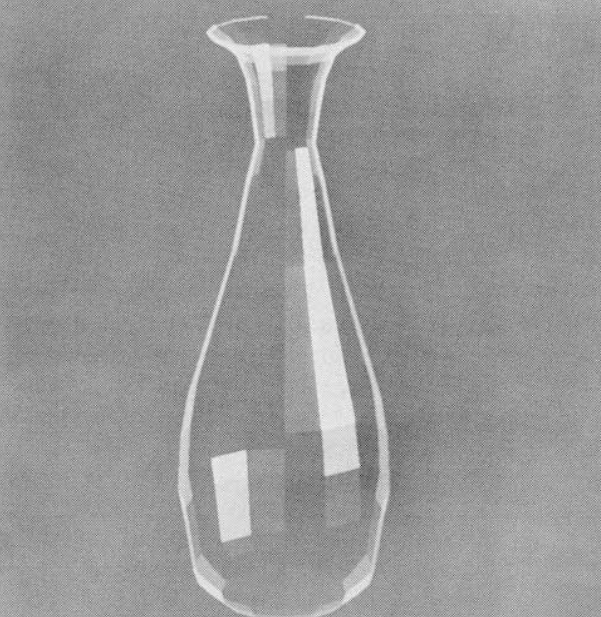
Light source and camera position are placed at the same position and function returns the sum of two terms: Normal and Specular reflection. Surfaces facing towards the light source are always bright compared to its adjacent which were shaded with different light intensities. Also, discontinuity can be easily seen on curved surfaces as seen in Figure 2.

* 1. *Newell, Newell, Sancha’s Shading:*

These people showcased an idea for creating specular highlights on transparent object. From experiments in real world, they found out that specular highlights are not created from a light source, but also from other objects as well which is highly depends on if the object has high reflective surfaces or transparent like glass. The application of this type of shading unfortunately is highly limited to transparent object and the specular highlights created on glass is like Warnock’s shading as it can be seen in Figure 3.



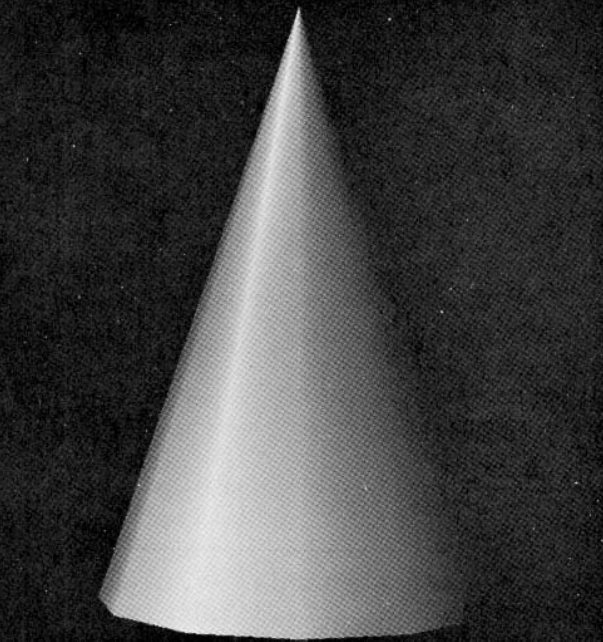
**Figure 2: Warnock’s Shading destroys smoothness on curved surfaces**



**Figure 3: Newell, Newell, Sancha’s Shading showing highlights on transparent object**

* 1. *Gouraud Shading:*

Gouraud [5] developed an algorithm which computes the specular highlights on curved surfaces of each vertex of the triangle. From the surface’s curvature, reflection intensity is calculated and is linearly interpolated towards zero between its edges connecting the neighbour surfaces. This generated visually appealing shading effect and retained the smoothness of curved surfaces as it can be seen in Figure 4.



**Figure 4: Gouraud Shading effect on low-polygon cone**

Unfortunately, the algorithm was still not perfect, and it still created same discontinuity issue if the object has low polygons. If the surface of the object contains high amount of specular reflection, then the highlights are often irregularly shaped because it depends on the shape of the polygons approximate curved surface and not the curved surface of object. In computer generated films, the frame-by-frame discontinuities can be seen even more when the object is in motion, in one frame the faces which are orthogonal to direction of light ray takes a uniform shade and in the next frame, those same faces are in different orientation towards the light source. This same effect happens, when the object’s orientation is changed.

This problem can be solved if the number of polygons is increased, but this is not an efficient solution, because of high memory amount required. Here’s where enters the Phong shading model.

* 1. *Phong Shading:*

Bui Tuong Phong [6] introduced new shading model based on the Gouraud shading. It consists of three components viz. Ambient, Diffuse and Specular.

Ambient lighting is where Object is never dark, there is still some amount light in the world. It is a simple constant value that is added to object’s surface color. In simple term, Ambient light is omni-present even when there is not a single light source.

Diffuse lighting is an important which directly simulates the light ray on the object’s surface. Surfaces that face the light source are brighter than the ones that are not facing.



**Figure 5: Diffuse Light Ray and surface normal N used to calculate the cosine angle**

It is calculated by taking an incident ray or light ray direction vector, the normal vector which perpendicular to the object’s surface and thereby calculating the dot product or the cosine angle of these two vectors. If the angle is greater than zero means the surface of object is facing the light source and vice versa. That is why it is best to check if dot product is always greater than zero beforehand.

To calculate light ray direction is simple by subtracting the light’s position and surface position and normalizing it.

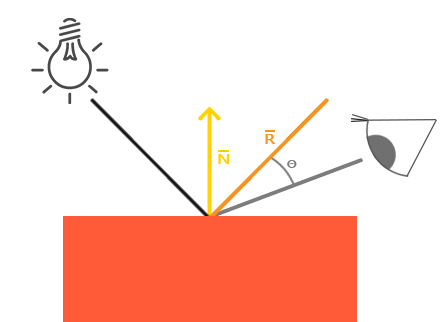
The normal vector is calculated from a triangle of a mesh. It is stored with the mesh data file as it is not required to calculate it every frame. To calculate the normal vector, we first take a difference vector from the two vertices to the one vertex and normalizing it and taking the cross product of those difference vectors gives the normal vector.

Once the angle is retrieved, it is simply multiplied with the light color and lastly added with the ambient component to create a believable image. This can be seen in Figure 6 with ambient lighting.



**Figure 6: Diffuse + Ambient Lighting on the mesh**

Specular lighting computes the bright spot on the surface of the object depending on the shininess of the surface.



**Figure 7: Specular lighting introduces View direction vector**

It takes same input from diffuse i.e. the light direction which is a normalized difference vector of light position and surface position in world space and surface normal. Additionally it takes the third input which is a direction vector which is obtained by normalized difference of camera/eye position and surface position again in world space. Then the reflection vector is calculated from the light ray direction and surface normal.

Lastly the dot product is done from the view direction and reflection vector and is again made sure that its value is positive. This dot product is then raised by the shininess value constant. A high shininess value tightens the bright spot. See figure 8.



**Figure 8: Specular effect with shininess of 128**

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