Warsaw University of Technology

FACULTY OF
ELECTRONICS AND INFORMATION TECHNOLOGY

ECOGR - Computer Graphics

Polygon rendering methods, Phong illumination equations

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1. Introduction

1.1. What is Computer graphics

Computer graphics is the science and art of communicating visually via a computer's display and its interaction devices. The visual aspect of the communication is usually in the computer-to-human direction, with the human-to-computer direction being mediated by devices like the mouse, keyboard, joystick, game controller, or touch-sensitive overlay. However, even this is beginning to change: Visual data is starting to flow back to the computer, with new interfaces being based on computer vision algorithms applied to video or depth-camera input. Computer graphics is a cross-disciplinary field in which physics, mathematics, human perception, human-computer interaction, engineering, graphic design, and art all play important roles. We use physics to model light and to perform simulations for animation. We use mathematics to describe shape. Human perceptual abilities determine our allocation of resources we don't want to spend time rendering things that will not be noticed. We use engineering in optimizing the allocation of bandwidth, memory, and processor time.

1.2. What we will cover in this essay

Realistic displays of a scene are obtained by generating perspective projections of objects and by applying natural lighting effects to the visible surfaces. An illumination model, also called a lighting model and sometimes referred to as a shading model, is used to calculate the intensity of light that we should see at a given point on the surface of an object. A surface-rendering algorithm uses the intensity calculations from an illumination model to determine the light intensity for all projected pixel positions for the various surfaces in a scene. Surface rendering can be performed by applying the illumination model to every visible surface point, or the rendering can be accomplished by interpolating intensities across the surfaces from a small set of illumination-model calculations.
We will dwell in detail on the topics of polygon rendering, where we will discuss about the different types of rendering such as:

- Constant-Intensity Shading (flat shading);
- Gouraud Shading;
- Phong Shading;

The first two will be discussed quickly and not in great depth, in fact the focus will be on the topic regarding Phong Shading and Phong illumination equation.

2. Polygon rendering methods

2.1. Introduction

In this section, we consider the application of an illumination model to the rendering of standard graphics objects: those formed with polygon surfaces. The objects are usually polygon-mesh approximations of curved-surface objects, but they may also be polyhedra that are not curved-surface approximations.

What does polygon rendering mean? Polygon rendering is a technique where a component produces the smooth gradations in color values that result from parts of a polygon being at different distances from light sources. Basically, it produces polygon surfaces by linearly interpolating intensity values across the surface.

2.2. Constant-Intensity Shading (flat shading)

Flat shading is the fastest and simple method of shading but does not good quality of images. Flat shading requires calculation of intensities for each polygon surfaces. Flat surface rendering or constant shading is the simplest rendering format that involves some basic surface properties such as color distinctions and reflectivity. This method produces a rendering that does not smooth over the faces which make up the surface. The resulting visualization shows an object that appears to have surfaces faceted like a diamond. The disadvantage of flat shading is that it gives low-polygon models a faceted look. Rendering only requires the computation of a color for each visible face. The whole face is filled with this color. This approach is fast and very simple, but it gives quite unrealistic results and non-smooth surfaces. Fig. 2.1 shows an object shaded using flat shading. Fig 2.2 shows an example of a real scene with no surface rendering vs with the flat shading rendering.

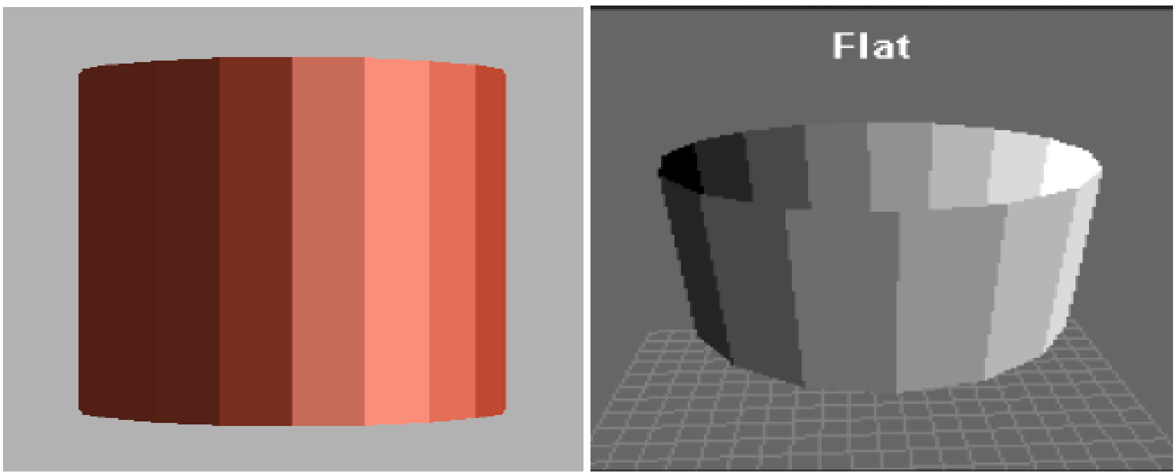

Figure 2.1. Flat shading with colour and no colour

Figure 2.2. No surface rendering vs Flat surface rendering

2.3. Gouraud Shading

Gouraud shading, named after Henri Gouraud, also called as "intensity interpolation shading" is a method of interpolation used for shading surfaces represented by different polygons. Gourard shading explains the concept of interpolation which is applied to individual polygon vertices. The Gouraud shading process requires that the normal be known for each vertex of the polygonal mesh. This algorithm computes the intensities at each vertex of polygonal mesh and then interpolates the intensities across the polygon. The main purpose of Gouraud shading is to eliminate the discontinuities in intensity along polygon edges.
To render a polygon, Gouraud surface rendering proceeds as follows:

1. Determine the average unit normal vector at each vertex of the polygon;
2. Apply an illumination model at each polygon vertex to obtain the light intensity at that position;
3. Linearly interpolate the vertex intensities over the projected area of the polygon.

Even if this shading method is better than the Flat shading as we can see from the Fig. 2.3, it has also some problems for example:

- Gouraud shading tends to miss certain highlighting. In particular Gouraud shading has a problem with specular reflections.
- The linear intensity interpolation can cause bright or dark intensity streaks known as Mach bands.

Figure 2.3. Flat shading vs Gouraud Shading

3. Phong Shading

3.1. How does it work?

A more accurate interpolation based approach for rendering a polygon was developed by Phong Bui Tuong. Basically the Phong surface rendering model (or normal vector interpolation rendering) interpolates normal vectors instead of intensity values. Phong shading is one of the most useful shading algorithms in computer generated images as it provides high degree of practicality. It is slowest but provides best quality of images. It displays more realistic highlights on a surface and greatly reduces the Mach-band effect, that is one of the main problem of the Gouraud Shading.

The first stage in the process is the same as for the Gouraud Shading - for any polygon we evaluate the vertex normals. Phong shading species how to calculate color on every point of surface. But calculating of color at every point may be slow therefore phong shading employs calculating intensities at vertices only and then apply interpolation to calculate in between points.To render a polygon, Phong surface rendering proceeds as follows:

1. Compute a normal N for each vertex of the polygon.
2. From bi-linear interpolation compute a normal, Ni for each pixel.
3. From Ni compute intensity Ii for each pixel of the polygon.
4. Paint pixel to shade corresponding to Ii.

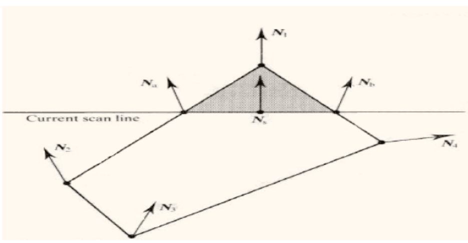

Figure 3.1. Phong shading model

3.2. Phon Illumination Equation

The Phong reflection model (also called Phong illumination) is an empirical model of local illumination. It is based on Phong's informal observation that shiny surfaces have small intense specular highlights, while dull surfaces have large highlights that fall off more gradually. The model also includes an ambient term to account for the small amount of light that is scattered about the entire scene.

For each light source in the scene, components i_s and i_a are defined as the intensities (often as RGB values) of the specular and diffuse components of the light sources, respectively. A single term i_a controls the ambient lighting; it is sometimes computed as a sum of contributions from all light sources.

For each *material* in the scene, the following parameters are defined:

- k_s which is a specular reflection constant, the ratio of reflection of the specular term of incoming light;
- k_d which is a diffuse reflection constant, the ratio of reflection of the diffuse term of incoming light;
- k_a which is an ambient reflection constant, the ratio of reflection of the ambient term present in all points in the scene rendered;
- α which is a shininess constant for this material, which is larger for surfaces that are smoother and more mirror-like. When this constant is large the specular highlight is small.

Furthermore, we have:

- $lights$ which is the set of all light sources;
- $\hat{L}_m$ which is the direction vector from the point on the surface toward each light source;
- $\hat{N}$ which is the normal at this point on the surface,
- $\hat{R}_m$ which is the direction that a perfectly reflected ray of light would take from this point on the surface;
- $\hat{V}$ which is the direction pointing towards the viewer (such as a virtual camera).

Then the Phong reflection model provides an equation for computing the illumination of each surface point I_p:

$$I_{\mathrm{p}} = k_{\mathrm{a}} i_{\mathrm{a}} + \sum_{m \,\in\, \mathrm{lights}} (k_{\mathrm{d}} (\hat{L}_m \cdot \hat{N}) i_{m,\mathrm{d}} + k_{\mathrm{s}} (\hat{R}_m \cdot \hat{V})^{\alpha} i_{m,\mathrm{s}}).$$

where the direction vector $\hat{R}_m$ is calculated as the reflection of $\hat{L}_m$ on the surface characterized by the surface normal $\hat{N}$ using:

$$\hat{R}_m = 2(\hat{L}_m \cdot \hat{N})\hat{N} - \hat{L}_m$$

and the hats indicate that the vectors are normalized. The diffuse term is not affected by the viewer direction $(\hat{V})$. The specular term is large only when the viewer direction $(\hat{V})$ is aligned with the reflection direction $\hat{R}_m$. Their alignment is measured by the α power of the cosine of the angle between them. The cosine of the angle between the normalized vectors $\hat{R}_m$ and $\hat{V}$ is equal to their dot product. When α is large, in the case of a nearly mirror-like reflection, the specular highlight will be small, because any viewpoint not aligned with the reflection will have a cosine less than one which rapidly approaches zero when raised to a high power.

Although the above formulation is the common way of presenting the Phong reflection model, each term should only be included if the term's dot product is positive. (Additionally, the specular term should only be included if the dot product of the diffuse term is positive.)

When the color is represented as RGB values, as often is the case in computer graphics, this equation is typically modeled separately for R, G and B intensities, allowing different reflections constants k_a, k_d and k_s for the different color channels.

4. Final comparison between rendering methods

In conclusion bellow a table with all the main information about these rendering methods and in Fig. 4.1 a graphical comparison of the same object, but rendered with these rendering methods.

Flat shading	Gouraud shading	Phong shading
Also called constant shading. Computes illumination once per polygon and apply it to whole polygon	Computes illumination at border(vertices) and interpolates.	Also called accurate shading. Applies illumination at every point of polygon surface.
Creates discontinuities in color.	Interpolates colors along edges and scanline.	Interpolates normals instead of colors.
Problem of machbands .	Handles machbands problem found in flat shading.	Removes machbands completely
Low cost.	Not so Expensive.	More Expensive than gouraud shading.
Requires very less processing and is fast in time.	Requires moderate processing and time.	Requires complex processing and is slower but is more efficient as compared to other shading methods.
Lighting equation used once for polygon.	Lighting equation used at each vertex.	Lighting equation used at each pixel.

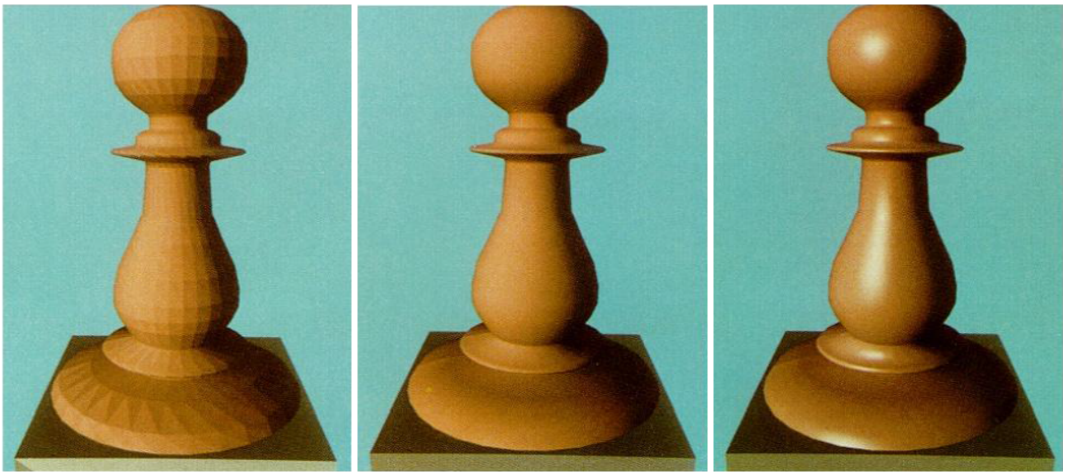

Figure 4.1. Flat shading vs Gouraud Shading vs Phong Shading

5. References

1. *Illumination Models and Surface-Rendering Methods , "Computer Graphics C Version" second edition Donald Hearn, M. Pauline Baker*
2. *International Journal of Advanced Research in Computer Science and Software Engineering Volume 4, Issue 5, May 2014*
3. `https://en.wikipedia.org/wiki/Phong_reflection_model`