Unit 8: <u>Illumination and Surface Rendering</u>

- Realistic displays of a scene are obtained by perspective projections and applying natural lighting effects to the visible surfaces of object.
- An illumination model is also called lighting model and sometimes called as a shading model which 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.

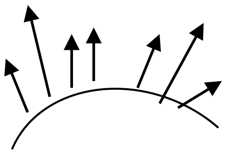
<u>Light Sources</u>:

- Sometimes light sources are referred as light emitting object and light reflectors. Generally light source is used to mean an object that is emitting radiant energy e.g. Sun.

<u>Point Source</u>: Point source is the simplest light emitter e.g. light bulb.

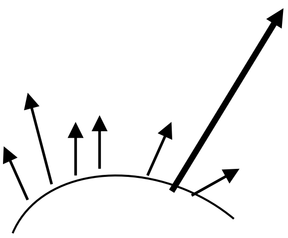
<u>Distributed light source</u>: Fluorescent light

- When light is incident on an opaque surface part of it is reflected and part of it is absorbed.
- Surface that are rough or grainy, tend to scatter the reflected light in all direction which is called diffuse reflection.



Diffuse reflection

- When light sources create highlights, or bright spots, called specular reflection



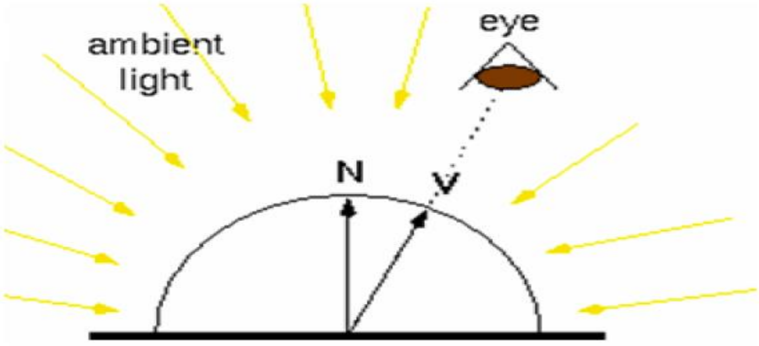
Specular reflection

<u>Illumination models</u>:

Illumination models are used to calculate light intensities that we should see at a given point on the surface of an object. Lighting calculations are based on the optical properties of surfaces, the background lighting conditions and the light source specifications. All light sources are considered to be point sources, specified with a co-ordinate position and an intensity value (color). Some illumination models are:

1. **Ambient light:**

- *Ambient light* means the light that is already present in a scene, before any additional lighting is added. It usually refers to natural light, either outdoors or coming through windows etc.
- This is a simplest illumination model. We can think of this model, which has no external light source-self-luminous objects. A surface that is not exposed directly to light source still will be visible if nearby objects are illuminated.



- The combination of light reflections form various surfaces to produce a uniform illumination is called ambient light or background light.
- Ambient light has no spatial or directional characteristics and amount on each object is a constant for all surfaces and all directions.

  The equation expressing this simple model is

$$I = K_a$$

Where I is the resulting intensity and K_a is the object's intrinsic intensity.

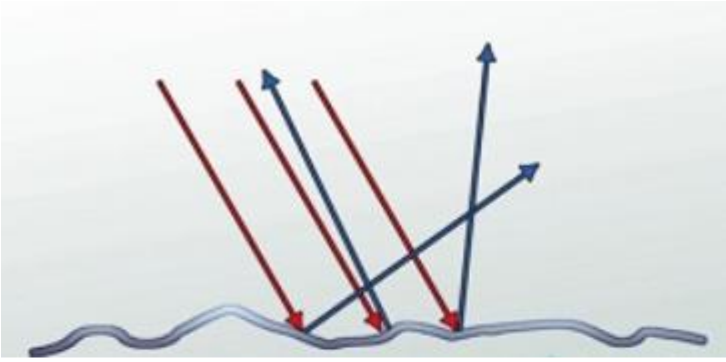
If we assume that ambient light impinges equally on all surface from all direction, then

$$I = I_a K_a$$

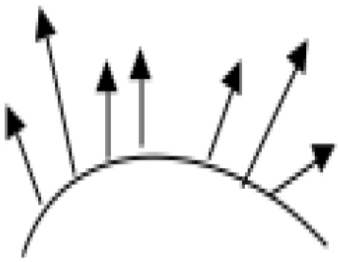
Where I_a is intensity of ambient light. The amount of light reflected from an object's surface is determined by K_a, the ambient-reflection coefficient K_a ranges from 0 to 1.

2. Diffuse reflection

In diffuse reflection, each individual ray strikes a part of the surface that is oriented in a different direction. The law of reflection still applies, but the normal is different for each ray. So, the reflected rays end up going in all directions. As you can see below, one incident ray reflects over in one direction, another incident ray reflects elsewhere, and another one reflects somewhere else. The effect of all these rays going everywhere is that all of the waves are spread out. Diffuse reflection occurs when a rough surface causes reflected rays to travel in different directions.



Diffuse lighting of an object approximates how photons will bounce off of the object's surface in many different directions. Assuming diffuse reflections from the surface are scattered with equal intensity in all directions, independent of the viewing direction (surface called. "Ideal diffuse reflectors") also called Lambertian reflectors and governed by Lambert's cosine law.



$$I_{diff} = K_d I_l \cos\Theta$$

Where I_l is the intensity of the point light source.

If N is unit vector normal to the surface & L is unit vector in the direction to the point slight source then

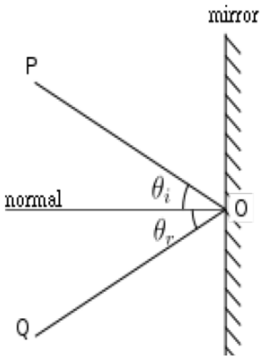
$$I_l, diff = K_d I_l (N.L)$$

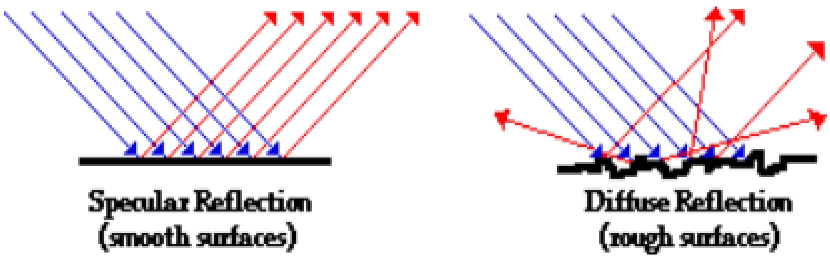
In addition, many graphics packages introduce an ambient reflection coefficient K_a to modify the ambient-light intensity I_a

$$Idiff = K_a I_a + K_d I_l (N.L)$$

3. Specular reflection

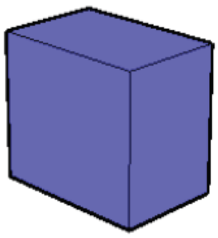
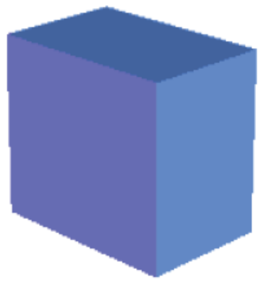
Specular reflection, also known as regular reflection, is the mirror-like reflection of waves, such as light, from a surface. In this process, each incident ray is reflected at the same angle to the surface normal as the incident ray, but on the opposing side of the surface normal in the plane formed by incident and reflected rays. The result is that an image reflected by the surface is reproduced in mirror-like (*specular*) fashion





Surface Shading Method

In computer graphics, shading refers to the process of altering the color of an object/surface/polygon in the 3D scene, based on things like (but not limited to) the surface's angle to lights, its distance from lights, its angle to the camera and material properties (e.g. bidirectional reflectance distribution function) to create a photo realistic effect. Shading is performed during the rendering process by a program called a shader.

		
Rendered image of a box. This image has no shading on its faces, but uses edge lines to separate the faces.	This is the same image with the edge lines removed.	This is the same image rendered with shading of the faces to alter the colors of the 3 faces based on their angle to the light sources.

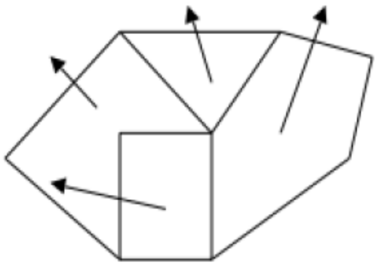
A shading model is used in computer graphics to simulate the effects of light shining on a surface. The intensity that we see on a surface is dependent upon

- The type of light sources.

- The surface characteristics (eg. Shining, matte, dull, and opaque or transparent).

Types of Shading

1. Constant Intensity Shading (Flat Shading)



- The intensity value for the whole polygon is calculated once and the whole polygon will be shaded with the same intensity value.
- Each rendered polygon has a single normal vector; shading for the entire polygon is constant across the surface of the polygon.
- Fast and simple but can not model specular reflection.

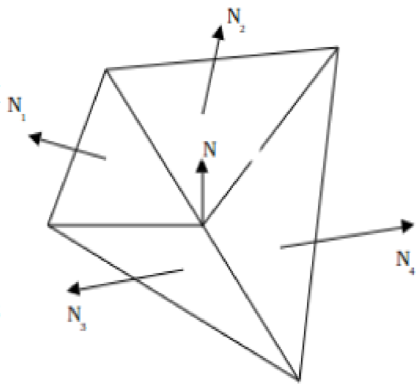
2. Gouraud Shading

- The intensity value is calculated once for each vertex of a polygon.
- Each polygon has one normal vector per vertex, the color of each vertex is computed and then interpolated across the surface of the polygon.
- The interpolation of color values can cause bright or dark intensity streaks, called the Mach-bands, to appear on the surface
- Calculation for each polygon surfaces

  - Determine the average unit normal vector at each vertex. At each polygon vertex, we obtain a normal vertex by averaging the surface normals of all polygons sharing the vertex as:

$$N_v = \frac{N_1 + N_2 + N_3 + N_4}{|N_1 + N_2 + N_3 + N_4|}$$

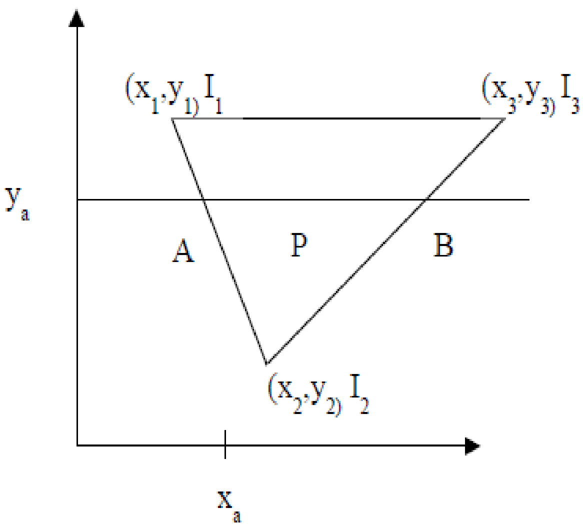
Where N_v is normal vector at a vertex sharing Four surfaces as in figure.



- Apply illumination model to calculate each vertex intensity.
- Linearly interpolate the vertex intensity over the surface of the polygon.

Once N_v is known, intensity at the vertices can obtain from lighting model.

- Here in figure, the intensity of vertices I_1 , I_2, I_3 are obtained by averaging normals of each surface sharing the vertices and applying a illumination model.
- For each scan line , intensity at intersection of line with Polygon edge are linearly interpolated from the intensities at the edge end point.



So Intensity at intersection point A, I_a is obtained by linearly interpolating intensities of I_1 and I_2 as`

$$I_a = \frac{y_a - y_2}{y_1 - y_2} I_1 + \frac{y_1 - y_a}{y_1 - y_2} I_2$$

Similarly, the intensity at point B is obtained by linearly interpolating intensities at I_2 and I_3 as

$$I_b = \frac{y_a - y_2}{y_3 - y_2} I_3 + \frac{y_3 - y_a}{y_3 - y_2} I_2$$

The intensity of a point P in the polygon surface along scan-line is obtained by linearly interpolating intensities at I_a and I_b as,

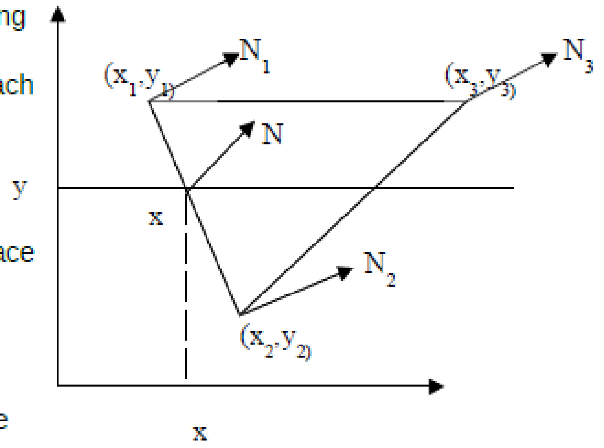
$$I_p = \frac{x_p - x_a}{x_b - x_a} I_b + \frac{x_b - x_p}{x_b - x_a} I_a$$

Advantages: Removes intensity discontinuities at the edge as compared to constant shading.

Disadvantages: Highlights on the surface are sometimes displayed with anomalous shape and linear intensity interpolation can cause bright or dark intensity streak called mach-bands.

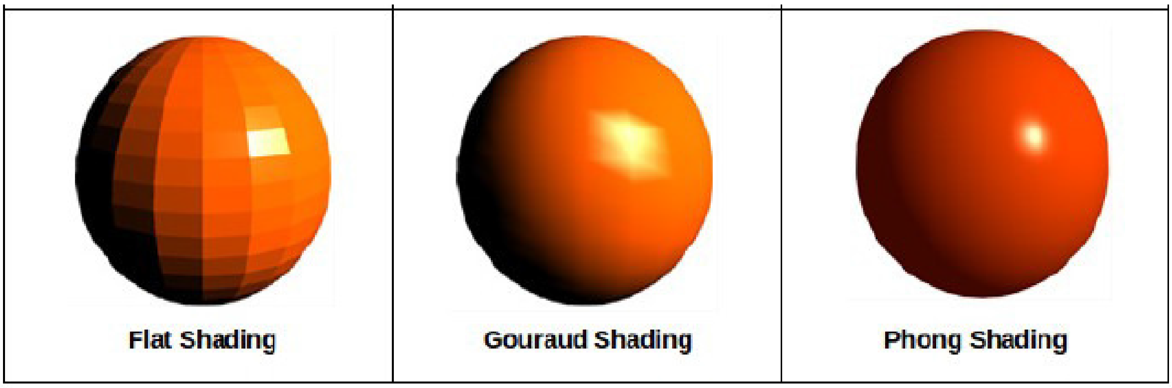
3. Phong Shading

- Each rendered polygon has one normal vector per vertex; shading is performed by interpolating the vectors across the surface and computing the color for each point of interest.
- Interpolating the normal vectors gives a reasonable approximation to a smoothly-curved surface while using a limited number of polygons
- This method greatly reduces the Mach-band problem but it requires more computational time
- A polygon surface is rendered with Phong shading by carrying out following calculations.
  - Determine the average normal unit vectors at each polygon vertex.
  - Linearly interpolate vertex normals over the surface of polygon.
  -Apply illumination model along each scan line to calculate the pixel intensities for the surface point.



In figure, N_1, N_2, N_3 are the normal unit vectors at each vertex of polygon surface. For scan-line that intersect an edge, the normal vector N can be obtained by vertically interpolating normal vectors of the vertex on that edge as.

$$N = \frac{y - y_2}{y_1 - y_2} N_1 + \frac{y_1 - y}{y_1 - y_2} N_2$$



4. Fast Phong Shading:

Fast Phong shading approximates the intensity calculations using a Taylor series expansion and Triangular surface patches. Since Phong shading interpolates normal vectors from vertex normals , we can express the surface normal N at any point (x,y) over a triangle as

$$N = Ax + By + C$$

Where A,B,C are determined from the three vertex equations.

$N_k = Ax_k + By_k + C$, $k = 1,2,3$ for (x_k, y_k) vertex.

Omitting the reflectivity and attenuation parameters

$$I_{diff}(x,y) = \frac{L.N}{|L|.|N|} = \frac{L.(Ax+By+C)}{|L|.|Ax+By+C|} = \frac{(L.A)x+(L.B)y+(L.C)}{|L|.|Ax+By+C|}$$

Mach bands

Mach bands are an optical illusion where a band of gradients will appear in places to be lighter or darker than they actually are.

When looking at Mach bands, one sees a central band of a light to dark gradient surrounded on one side by the lightest color and on the opposite side by the darkest color.

Mach bands, as well as numerous other visual and perceptual illusions, help scientists study the way the eye and brain process visual information.