Chapter 8
Illumination and Shading

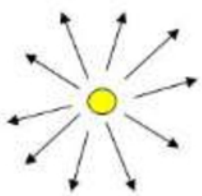
Overview of Illumination and surface Rendering, Shading and Polygon Rendering Model

- To produce a realistic display, we should know which surface of the **object appears brighter or darker and which surfaces appears lighter.**
- Realistic displays of scene are obtained by generating **perspective projections** of object and by applying **natural lighting effect** to **the visible surface.**
- An **illumination model also called as lighting model or shading model** is used to calculate the intensity of light that we should see at a given point on the surface of an object.
- Being more specific, we refer to the model for **calculating light intensity at a single surface point** as an **illumination model** or a lighting model, and we use the term **surface rendering** to mean a procedure for applying a lighting model to obtain pixel intensities **for all the projected surface positions in a scene**.
- A surface-rendering algorithms 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.

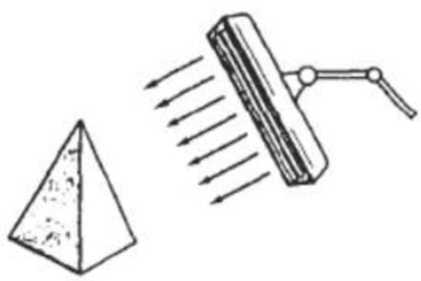
Light Source

- Light source means an object that is emitting radiant energy such as **light bulb or sun.**
- The **intensity of light** seen on each surface of an object depends on **the type of light source in the vicinity** and the **surface characteristics** of the object.
- If all incident light energy is absorbed, the object is invisible. If the incident light energy is reflected, then object is visible.
- Light source that illuminates an objects are of two basic types.

1. Light-emitting source:
   - ➢ Light emitting source like bulb and sun.
   - ➢ The simplest model for light emitter are point source and distributed light source.
   - ➢ In point source, rays from the source follows radially diverging paths (moving along a radius) from the source position as shown below.



   - ➢ Point source model is a reasonable approximation for sources whose dimensions are **small** compared to the size of objects in the scene.
   - ➢ **Sources, such as sun, that are sufficiently far from the scene can be accurately modeled as point source**
   - ➢ A nearby source, such as long fluorescent light as shown in figure below is accurately modeled as **distributed light source.**



   - ➢ In this case, the area of the source is not small compared to the surface in the scene.

2. Light-reflecting source
   - Light reflecting source are like walls of a room.

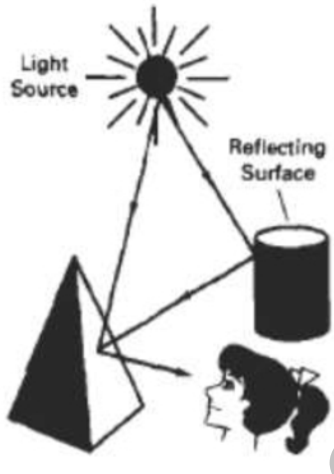


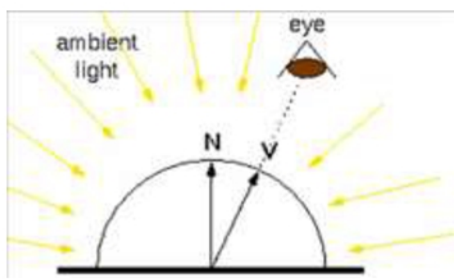
Fig: Light viewed from surface as a combination of light from light emitting source and light reflecting source

Basic Illumination Model

- Illumination models are used to calculate light intensities that we should see at a given point on the surface of an object.
- Here we concentrate on the location and qualities of the light that falls on the objects and the way in which object interact with it.
- 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
  2. Diffuse Reflection
  3. Specular Reflection

Ambient light

- Ambient light means the light that is **already present in a scene**, before any additional lighting is added i.e. light from the environment.
- **A surface that is not exposed directly to light source still will be visible if nearby objects are illuminated.**
- The combination of **light reflections from various surfaces** to produce **a uniform illumination** is called **ambient light or background light.**
- In this model, illumination is usually referring to natural light, either outdoors or coming through windows etc.



- Ambient light has no spatial or directional characteristics and amount on each object is a constant for all surfaces and all directions i.e. Coming uniformly from all directions and then reflected equally to all direction
- If we assume that ambient light impinges equally on all surface from all direction, then

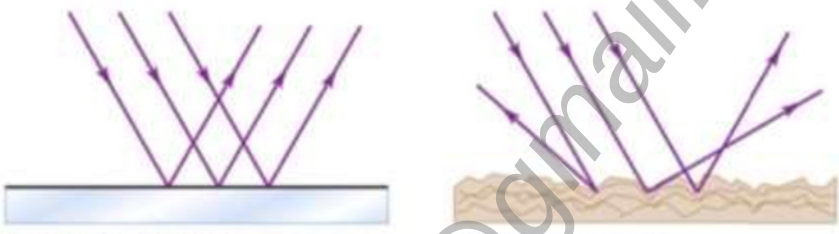
$$I = I_a K_a$$

Where I_a is intensity of ambient light and K_a is the reflectance or ambient reflection coefficient which range from 0 to 1.

- If we want a highly reflective surface, we set the value of k_a near 1. This produces a bright surface with the intensity of the reflected light near that of the incident light.
- If we want a surface that absorbs most of the incident light, we set the reflectivity to a value near 0.
- So, we set the level for the ambient light in a scene with parameter I_a and K_a, and each surface is then illuminated with this constant value.
- The resulting reflected light is a constant for each surface, independent of the viewing direction and the spatial orientation of the surface.
- But the intensity of the reflected light for each surface depends on the **optical properties of the surface**; that is, how much of the incident energy is to be reflected and how much absorbed.

Diffuse Reflection

- Diffuse reflection is the reflection of light from a surface such that an incident ray is reflected at many angles, rather than at just one angle as in the case of specular reflection.



(a) Specular reflection (b) Diffuse reflection

- Surfaces that are rough, or grainy, tend to scatter the reflected light in all directions. This scattered light is called diffuse reflection. A very rough matte surface produces primarily diffuse reflections, so that the surface appears equally bright from all viewing directions
- All materials have diffuse properties, due to the 'roughness' of a surface at the microscopic level.
- Diffuse reflections are constant over each surface in a scene, independent of the viewing direction
- The fractional amount of the incident light that is diffusely reflected can be set for each surface with parameter K_d , the coefficient of diffuse-reflection. Value of K_d is in interval 0 to 1. If surface is highly reflected, K_d is set to near 1. The surface that absorbs almost incident light, K_d is set to nearly 0.
- Diffuse reflection intensity at any point on the surface if exposed only to ambient light is

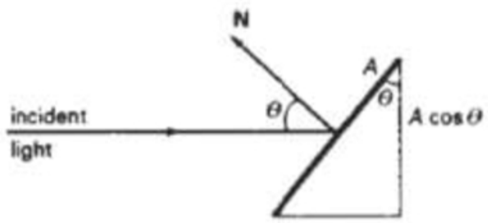
$$I_{ambdiff} = I_a K_d$$

Where I_a is intensity of ambient light and K_d is the reflectance or diffuse reflection coefficient which range from 0 to 1.

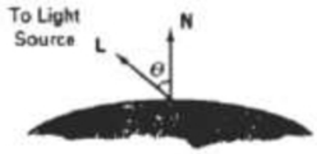
- Since ambient light produces a flat uninteresting shading for each surface, scenes are rarely rendered with ambient light alone. At least one light source is included in a scene, often as a point source at the viewing position.
- If I_i, is the intensity of the point light source and θ is the angle of incidence between the incoming light direction and the surface normal, then the diffuse reflection equation for a point on the surface can be written as

$$I_{idiff} = I_i K_d \cos\theta$$

Where cosθ determines the amount of illumination and θ is in the range o to 90.



- A surface that is oriented perpendicular to the direction of the incident light appears brighter than if the surface were tilted at an oblique angle to the direction of the incoming light.
- If N is **unit vector normal** to the surface and L is unit vector in the direction to the point light source, then



$$I_{l,diff} = K_d I_l (N.L)$$

- We can combine the ambient and point source intensity calculations to obtain an expression for the total diffuse reflection as below

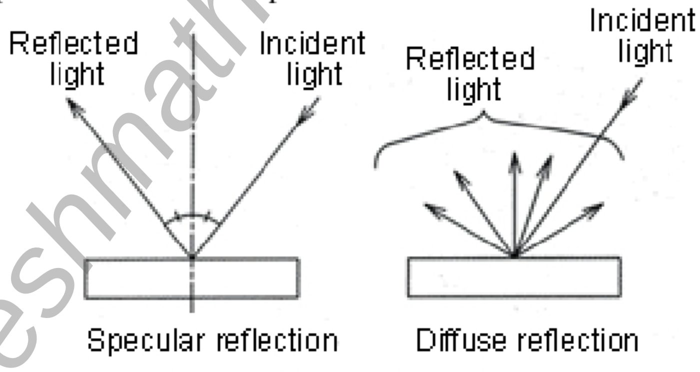
$$I_{diff} = I_a K_a + I_l K_d (N.L)$$

Where K_a is ambient reflection coefficient.

- **Deals with rough surface like paper,cloth.**

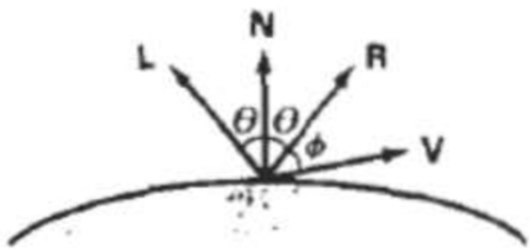
Specular reflection and phong model

- In diffuse reflection, all reflected rays goes in various direction(angle), resulting in distorted image.
- When we look at illuminated shiny such as polished metal mirror, we see a highlight or bright spot at certain viewing directions. This phenomenon is called specular reflection.



(Shiny surface) **(Rough surface)**

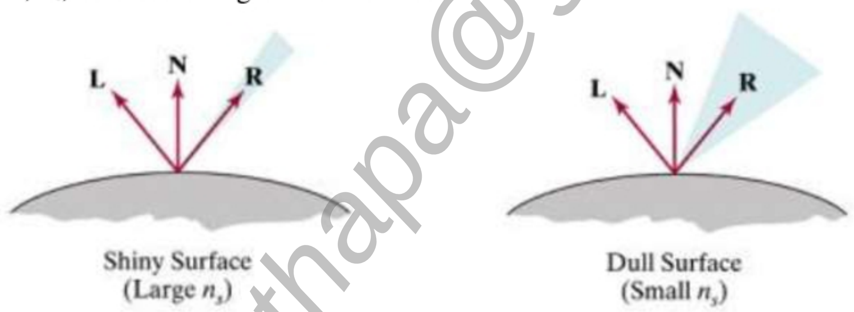
- Specular reflection is due to the total or near total reflection of incident light in a concentrated region around the specular reflection angle.



- Above figure shows the specular reflection direction of a point on the illuminated surface. Here R is the unit vector in the direction of ideal specular reflection, L is the unit vector directed toward the point light source, V is the unit vector pointing to the viewer from the surface position and N is the surface normal vector.
- **The specular reflection angle is equal to the angle of the incident light,** with two angle measured on opposite side of the unit normal vector N,
- The angle ϕ between vector R and V is called viewing angle such that for any ideal specular reflector i.e. perfect mirror ϕ=0(vector V and R coincide).
- An empirical model for calculating the specular-reflection range was developed by Phong Bui Tuong and called the **Phong specular-reflection model, or simply the Phong model**

<u>Phong model</u>

- Objects other than ideal reflectors exhibit specular reflections over a finite range of viewing positions around vector R.
- Shiny surface has a narrow specular reflection range(ϕ) and dull surfaces have a wider reflection range(ϕ).
- **Phong Bui Tuong** developed a popular illumination model for non-perfect reflectors. It assumes that maximum specular reflection occurs when ϕ is zero and falls of sharply as ϕ increases.
- This model sets the intensity of specular reflection proportional to $\cos^{n_s}\phi$.
- Angle ϕ can be assigned values in the range 0^0 to 90^0 so that $\cos\phi$ varies from 0 to 1.
- The value assigned to **specular-reflection parameter n_s**, is determined by the type of surface that we want to display. A very shiny surface is modeled with a large value for n_s, (say, 100 or more), and smaller values (down to 1) are used for duller surfaces. For a perfect reflector, n_s, is infinite. For a rough surface, such as chalk or cinderblock, n_s, would be assigned a value near 1.



- The intensity of specular reflection depends on the material properties of the surface and the angle of incidence and other factors such as the polarization and color of the incident light.
- For monochromatic (single color) specular intensity, variations can be approximated by specular reflection coefficient **w (θ)**

$$I_{spec} = W(\theta)\, I_s \cos^{n_s}\phi$$

Where I_s is the intensity of light source and ϕ is the viewing angle relative to the specular reflection direction R. W(θ) tends to increase as the angle of incidence increases. At $\theta = 90^0$, W(θ) = 1 and all of the incident light is reflected.

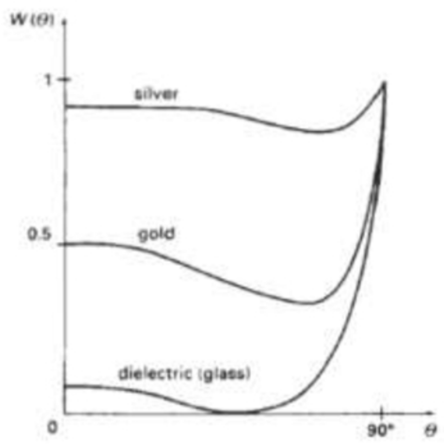


Figure 14-15
Approximate variation of the specular-reflection coefficient as a function of angle of incidence for different materials.

- $W(\theta)$ is typically set to K_s (material specular reflection coefficient) and $\cos\phi$ can be calculated using dot product V.R, the above equation become

$$I_{spec} = K_s I_s (V.R)^{n_s}$$

Where V and R are unit vectors in the viewing and specular-reflection directions.

- Further, a somewhat simplified Phong model is obtained using the halfway vector H between L and V to calculate the range of specular reflections. If we replace V·R in the Phong model with the dot product N·H, this simply replaces the empirical cos φ calculation with the empirical cos α calculation (Figure below). The halfway vector is obtained as

$$\mathbf{H} = \frac{\mathbf{L} + \mathbf{V}}{|\mathbf{L} + \mathbf{V}|}$$

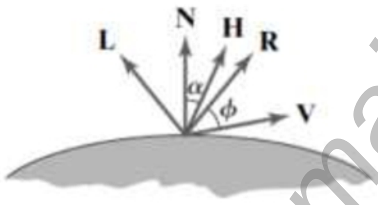


FIGURE 18
Halfway vector **H** along the bisector of the angle between **L** and **V**.

Hence the intensity value is calculated as

$$I_{spec} = K_s I_s (N.H)^{n_s}$$

- N·H requires less computation than V·R because the calculation of R at each surface point involves the variable vector N.

Combined Diffuse and Specular Reflection with multiple light source

- For a single point light source, we can model the combined diffuse and specular reflections from a point on an illuminated surface as

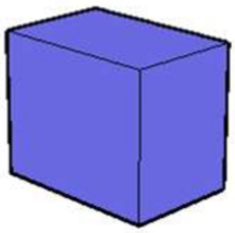
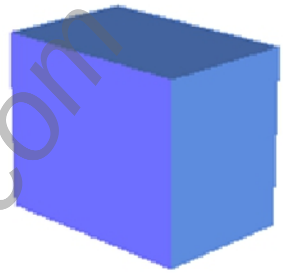
$$\begin{aligned} I &= I_{\text{diff}} + I_{\text{spec}} \\ &= k_a I_a + k_d I_l (\mathbf{N} \cdot \mathbf{L}) + k_s I_l (\mathbf{N} \cdot \mathbf{H})^{n_s} \end{aligned}$$

- If we place more than one-point source in a scene, we obtain the light reflection at any surface point by summing the contributions from the individual sources

$$\begin{aligned} I &= I_{\text{ambdiff}} + \sum_{l=1}^{n} [I_{l,\text{diff}} + I_{l,\text{spec}}] \\ &= k_a I_a + \sum_{l=1}^{n} I_l [k_d (\mathbf{N} \cdot \mathbf{L}) + k_s (\mathbf{N} \cdot \mathbf{H})^{n_s}] \end{aligned}$$

Polygon Rendering Method

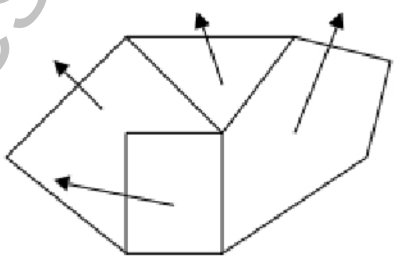
- Surface Rendering is the process of producing realistic images or pictures.
- Realistic displays of a scene are obtained by perspective projection and by applying natural light effects to the visible surfaces.
- An illumination model (lighting model) and sometimes called shading model, is used to calculate the intensity of light that we should see at a given point on the surface of an object.
- A polygon surface rendering algorithm uses the intensity calculations from an illumination model to determine the light intensity.

		
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.

- Some of the polygon rendering method are given below.
  i. Constant intensity shading
  ii. Gouraud shading
  iii. Phong shading
  iv. Fast Phong shading

Constant intensity Shading

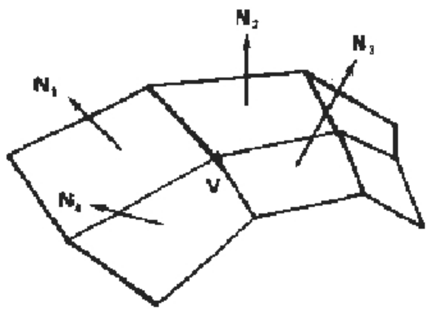
- The fast and simplest method for shading polygon is constant shading. It is also called as Faceted shading of Flat shading.
- Here, illumination model is applied only once for each polygon to determine single intensity value. Then the entire polygon is displayed with the single intensity value.



- Each rendered polygon has a single normal vector so shading for the entire polygon is constant across the surface of the polygon.

Gouraud Shading

- This intensity interpolation scheme is developed by Henri Gouraud and generally referred to as Gouraud shading.
- The polygon surface is displayed by linearly interpolating intensity values across the surface.
- Intensity values for each polygon are matched with the values of adjacent polygons along the common edge. This, eliminates the intensity discontinuity that can occur in flat shading.



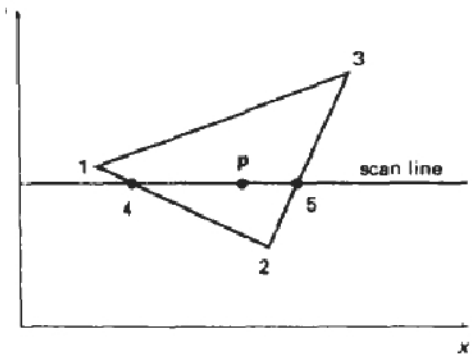
- Each polygon surface is rendered with Gouraud shading by performing following calculations.
    i. Determine the average unit normal vector at each polygon **vertex**.
       For example,
       In the above figure Normal Vector at vertex V is given by $N_v = \dfrac{N1 + N2 + N3 + N4}{|N1+N2+N3+N4|}$

       Where Nv is average unit normal vector at a vertex sharing Four surfaces as in figure.
    ii. Apply an illumination model to each vertex N_v to calculate the vertex intensity
    iii. Linearly interpolate the vertex intensities over the surface of the polygon

For example:

Suppose the I_1, I_2 and I_3 are the intensities obtained by applying illumination model to average unit normal vector N_1, N_2 and N_3, at vertex 1, 2 and 3 respectively.

So interpolating intensities along polygon edge to find intensity at position 4 i.e. I_4 using intensity I_1 and I_2 using **vertical displacement.**



$$I_4 = \frac{y_4 - y_2}{y_1 - y_2} \cdot I_1 + \frac{y_1 - y_4}{y_1 - y_2} \cdot I_2$$

Similar process is repeated for finding I_5 using I_2 and I_3

Interior point p is interpolated from the bounding intensities at point 4 and 5 i.e. I_4 and I_5 using **horizontal displacement**.

$$I_p = \frac{x_5 - x_p}{x_5 - x_4} I_4 + \frac{x_p - x_4}{x5 - x_4} I_5$$

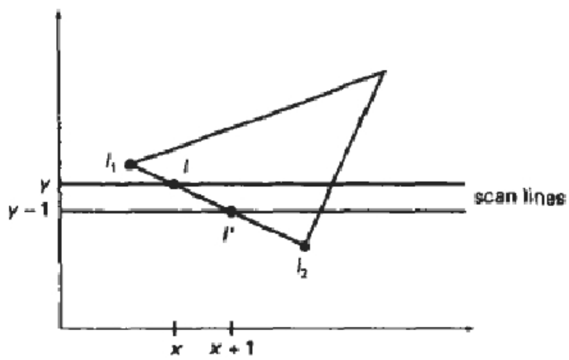
- This can be easily done using incremental calculations for successive edge intensity values

$$I = \frac{y - y_2}{y_1 - y_2} I_1 + \frac{y_1 - y}{y_1 - y_2} I_2$$

For next scan line,

$$I' = I + \frac{I_2 - I_1}{y_1 - y_2}$$

And, similar calculation to obtain intensities at successive horizontal pixel positions along each scan line



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

Disadvantage
- Highlights on the surface are sometimes displayed with anomalous shape and linear intensity interpolation can cause bright or dark intensity streak called Mach-bands at the boundary.

Mach Bands

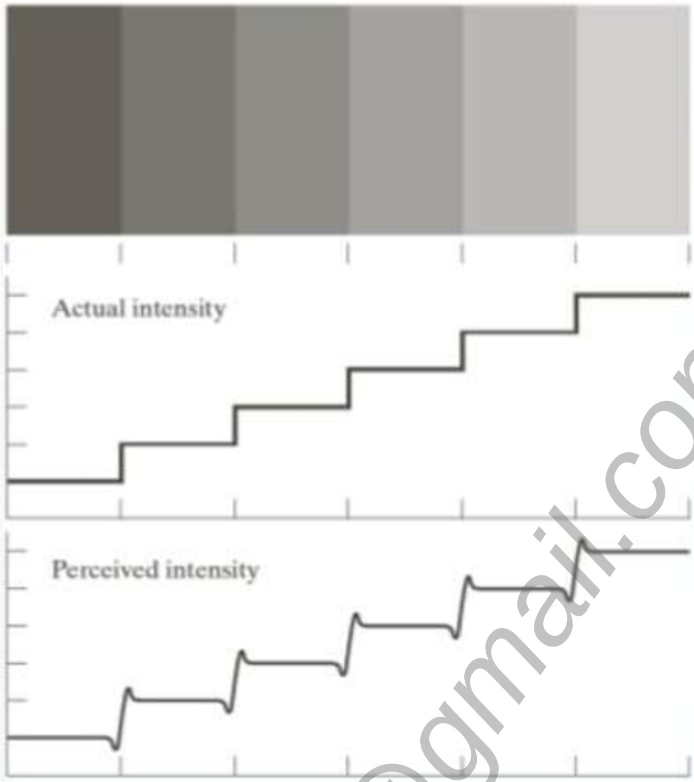


Fig: Match Bands

- 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 can be reduced by dividing the surface into a greater number of polygon faces or Phong shading but requires more calculation.

An example of *simultaneous contrast*

- Note: All the inner square has same intensity but they appear progressively darker as the background become lighter.

Visualization of constant intensity and Gouraud Shading

A B C

A: Polygon mesh approximation of an object

B: Polygon mesh approximation of an object rendered with flat shading

B: Polygon mesh approximation of an object rendered with Gouraud Shading

Phong Shading

- This is more accurate method for rendering a polygon surface which interpolate normal vector and then apply the illumination model to each surface point. **It is also called as "Normal Vector Interpolation Shading".**
- It displays more realistic highlights on a surface and greatly reduces Mach band effect.

Steps

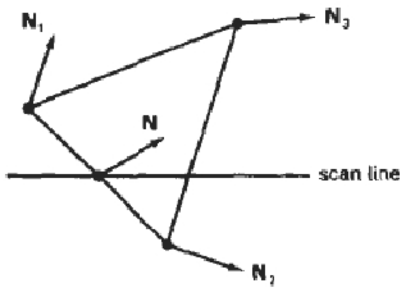
i. Determine the average unit vector normal at each polygon vertex (similar to that of Gouraud Shadding)

ii. Linearly interpolate the vertex normal over polygon surface

iii. Apply an illumination model along each scan line to calculate projected pixel intensities for the surface points

N can be obtained by interpolating between edge and point normals N_1 and N_2

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



Like, Gouraoud shadding, here also we can use an incremental method to evaluate normal between scan lines and along each individual scan line.

Advantage

i. It displays more realistic highlights on a surface.'

ii. It greatly reduces the Mach-Band effect.

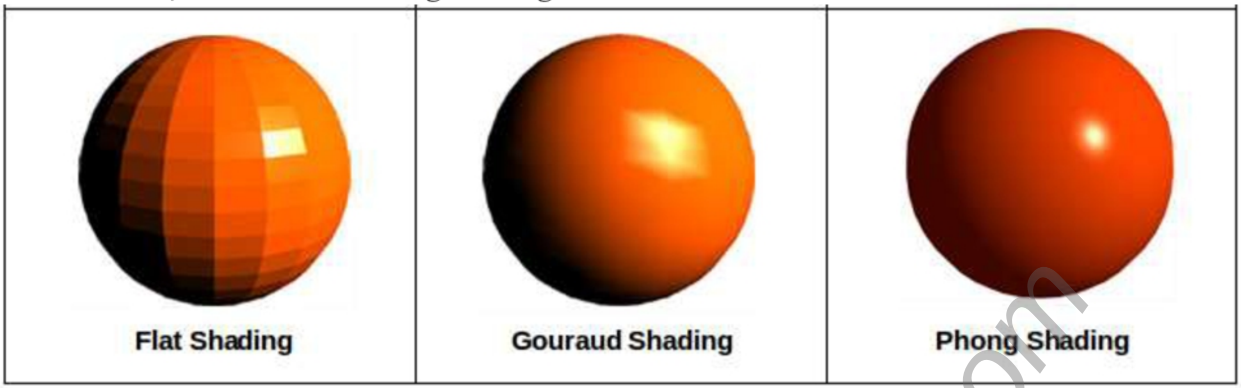
iii. It gives more accurate result.

iv. The most serious problem with Gouraud shading occurs when specular highlights are found in the middle of a large polygon. This problem is addressed by Phong Shading as it can provide specular highlights.

Disadvantage

i. It requires more calculation and greatly increases the cost of shading steeply.

Visualization of flat, Gouraud and Phong Shading



Note:

FPS is two times slower than Gouraud shading, Normal Phong shading is 7 times slower than Gouraud

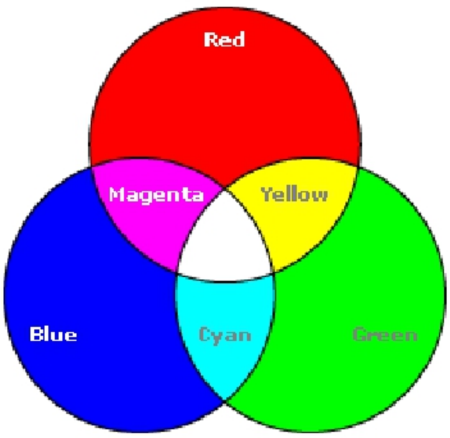
Color Model

- A color model is an abstract mathematical model describing the way colors can be represented as tuples of numbers, typically as three or four values or color components. A color model is simply a way to define color.
- A model describes how color will appear on the computer screen or on paper.
- A color model is an orderly system for creating a whole range of colors from a small set of primary colors.
- Three popular color models are:
    1. Additive Color Model: RGB (Red, Green, Blue)
    2. Subtractive Color Model: CMYK (Cyan, Magenta, Yellow, Black)
- Additive color models use light to display color while subtractive models use printing inks. Colors perceived in additive models are the result of transmitted light. Colors perceived in subtractive models are the result of reflected light.

1. RGB Color Model

- RGB is an additive color model for computer displays uses light to display color, Colors result from transmitted light
- The RGB model is used when working with screen based designs like Monitor.
- A value between 0 and 255 is assigned to each of the light colors, Red, Green and Blue.
- So for example, if we wanted to create a purely blue color, Red would have a value of 0, Green would have a value of 0 and Blue would have a value of 255 (pure blue).
- To create black, Red, Green and Blue would each have a value of 0 and to create white, each would have a value of 255.
- RGB is known as an "additive" model and is the opposite of the subtractive color model.

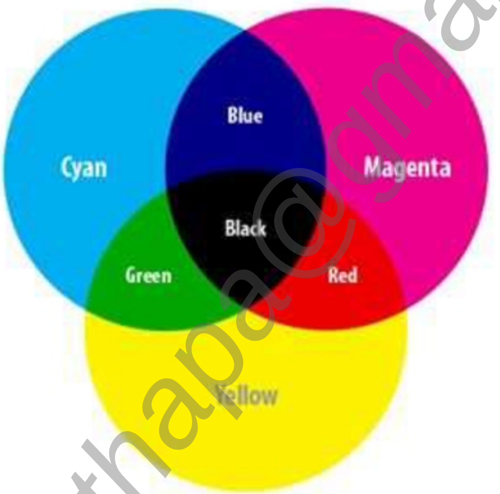
Red + Green + Blue = White



Application

1. Used when project involves digital screens like computers, mobile, TV etc.
2. Used in web and application design.
3. Used in online branding.
4. Used in social media.

2. CMYK (Cyan, Magenta, Yellow, Black)
   - CMYK (subtractive color model) is the standard color model used in offset printing for full-color documents. Because such printing uses inks of these four basic colors, it is often called four-color printing.
   - It describes colors based on their percentage of Cyan, Magenta, Yellow and Black.
   - These four colors are needed to reproduce full color artwork in magazines, books and brochures.
   - By combining Cyan, Magenta, Yellow and Black on paper in varying percentages, the illusion of lots of colors is created. A printing machine creates images by combining these colors with physical ink. when all colors are mixed with 0% degree white color is created, exp CMYK(0%, 0%, 0%, 0%) for white, when all colors are mixed, we get the black color.
   - CMYK is known as a "subtractive" color model. White is the natural color of the paper or other background, while black results from a full combination of colored inks.



   - When two colors of RGB overlaps, we see a new color formed by mixing of the two additive primaries. These new colors are:

Green + Blue= Cyan
Blue+Red= Magenta
Red+Green= Yellow
And Key=Black

   - Writing R, G and B for red, green and blue, C, M and Y for cyan, magenta and yellow, and W for white, and using (+) to mean additive mixing of light, and (–) to mean subtraction of light, we have:

$$C\ (cyan) = G + B = W - R$$
$$M\ (Magenta) = R + B = W - G$$
$$Y\ (Yellow) = R + G = W - B$$

Use

1. Used when project involves physically printed designs etc.
2. Used in physical branding like business cards etc.
3. Used in advertising like posters, billboards, flyers etc.
4. Used in cloth branding like t-shirts etc.

When to use which color scheme?

- If the project involves printing something, such as a business cards, poster, or a newsletter, use CMYK scheme.
- If the project involves something that will only be seen digitally, use RGB Scheme.

Assignment

1. **Differentiate between specular and diffuse reflection.**
2. **Explain Fast Phong Shading.**

Fast Phong Shading

- Surface rendering with Phong shading can be speeded by using approximations in the illumination model calculations of normal vectors.
- Fast Phong shading approximates the intensity calculations using a Taylor Series expansion and Triangular surface patches.
- Since Phong shading interpolates normal vectors, we can express the surface normal N at any point over a triangle as

$$N = Ax+By+C$$

Where vectors A, B and C are determined from the three vertex equation:

$$N_k = Ax_k + By_k + C, \qquad k = 1,2,3$$

with (x_k, y_k) denoting a vertex position.

Discarding the reflectivity and attenuation parameters, the calculations for light source diffuse reflection from a surface point (x,y) as

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

Now, the expression can be rewritten in the form as

$$I_{diff}(x,y) = \frac{ax + by + c}{(dx^2 + exy + fy^2 + gx + hy + i)^{½}}$$

Where the parameter a, b, c and d are used to represents the various dot products. For example,

$$a = \frac{L \;.\; A}{|L|}$$

We can express the denominator as a Taylor series expansion and retain terms up to second degree in x and y

$$I_{diff}(x, y) = T_5x^2 + T_4xy + T_3y^2 + T_2x + T_1y + T_0$$

Where each T_k is a function of parameter a, b, c and so forth.