

COMPUTER GRAPHICS

Disclaimer

This document is part of teaching materials for COMPUTER GRAPHICS under the Tribhuvan University syllabus for Bachelors of Science in Computer Science and Information Technology (BSc. CSIT). This document does not cover all aspect of learning COMPUTER GRAPHICS, nor are these be taken as primary source of information. As the core textbooks and reference books for learning the subject has already been specified and provided to the students, students are encouraged to learn from the original sources because this document cannot be used as a substitute for prescribed textbooks..

Various text books as well as freely available material from internet were consulted for preparing this document. Contents in This document are copyrighted to the instructor and authors of original texts where applicable.

©2021, MUKUNDA PAUDEL

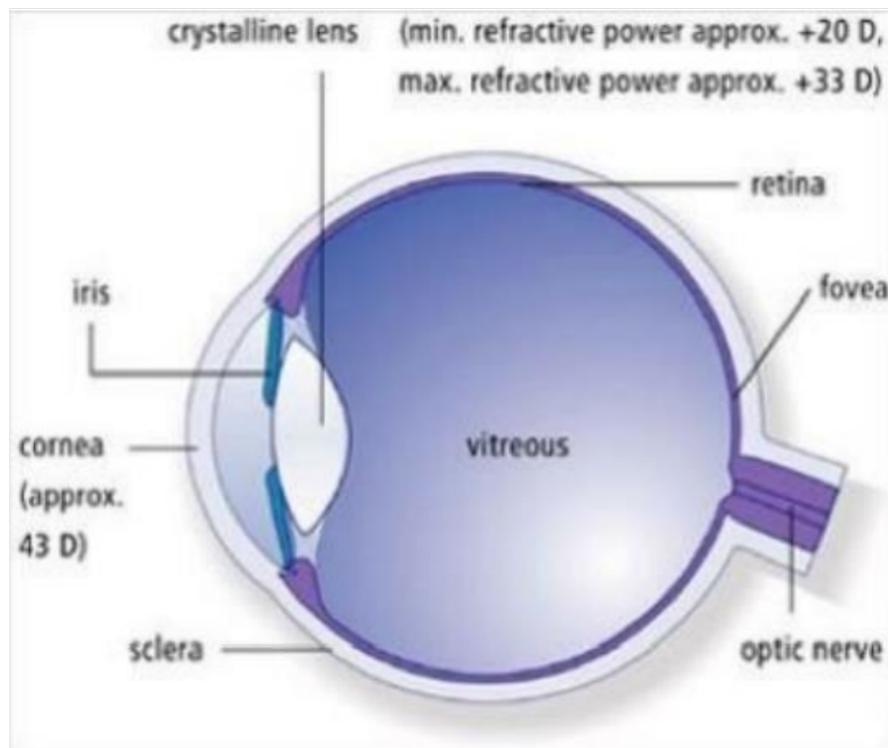
Chapter – 7 Illumination and shading

Before we start,

1. What the human eye (or virtual camera) sees is a result of light coming off of an object or other light source and striking receptors in the eye. In order to understand and model this process, it is necessary to understand different light sources and the ways that different materials reflect those light sources.
2. Trying to recreate reality is difficult.
3. Lighting calculations can take a VERY long time.
4. The techniques described here are heuristics which produce appropriate results, but they do not work in the same way reality works - because that would take too long to compute, at least for interactive graphics.
5. Instead of just specifying a single color for a polygon we will instead specify the properties of the material that the polygon is supposed to be made out of, (i.e. how the material responds to different kinds of light), and the properties of the light or lights shining onto that material.

Let's Create Background of content...

Human Eye...



- ✓ The eye works like a camera
- ✓ Sensors at the back of eye
- ✓ Sense the amount of light coming from different directions
- ✓ Similar to CMOS and CCDs

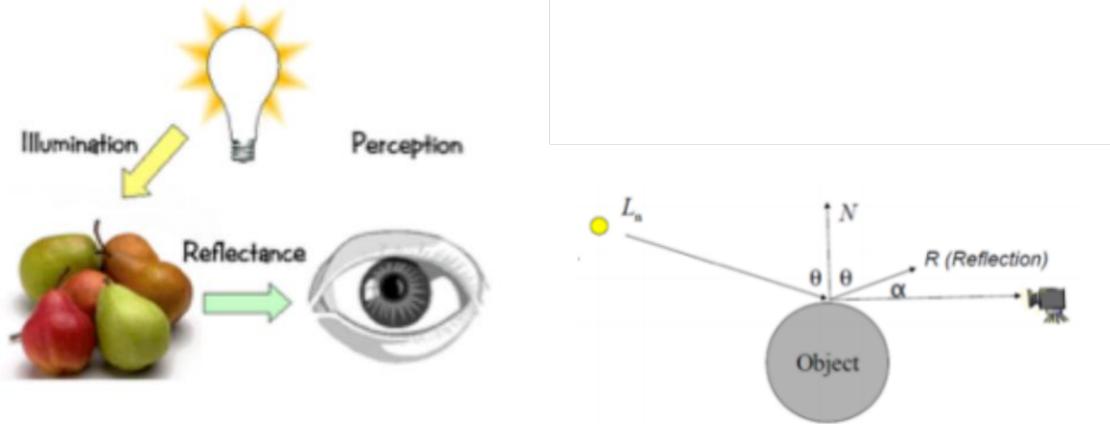
Bonus Knowledge...

CCD (charge coupled device) and CMOS (complementary metal oxide semiconductor) image sensors are two different technologies for capturing images digitally. Each has unique strengths and weaknesses giving advantages in different applications.

Both types of imagers convert light into electric charge and process it into electronic signals.

*Or, they have to **convert light into electrons**.*

Light coming into the eye...



- ✓ Position of the point the eye is looking at
- ✓ Position of the light source
- ✓ Color and intensity of light
- ✓ Vector from eye to point
- ✓ Normal vector of surface at point
- ✓ Physical properties of the object

Let's start the syllabus....

Illumination

- ✓ Act of illuminating , or suppling with light
- ✓ The state of being illuminated
- ✓ **CHAMAK (चमक)**

An observable property and effect of light is **Illumination**. The illumination of the subject of a drawing or painting is a key element in creating an artistic piece, and the interplay of light and shadow is a valuable method.

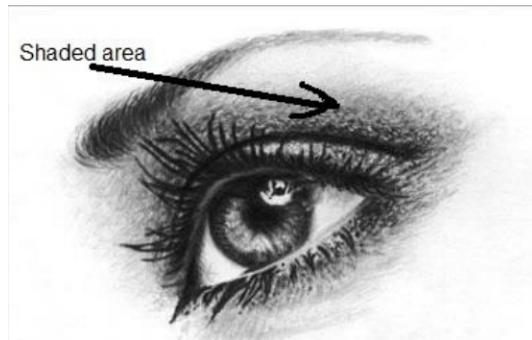
The placement of the light sources can make a considerable difference in the type of message that is being presented.

For Example

Multiple light sources can wash out any wrinkles in a person's face, for instance, and give a more youthful appearance. In contrast, a single light source, such as harsh daylight, can serve to highlight any texture or interesting features.

Shading

- ✓ **Darkness where light, particularly sunlight, is blocked**
- ✓ A variety of color, in particular one, obtained by adding black.
- ✓ Shading is the implementation of the illumination model at the pixel points or polygon surfaces of the graphics objects.
- ✓ Shading model is used to compute the intensities and colors to display the surface.



Note: Figure of eye just indicates the random picture obtained by adding black. Picture may not have perfect meaning in this topic but it may help to get concept of shading.

Intensity

- ✓ Degree of strength
- ✓ Quantity of illumination

Illumination model

- ❖ Also called a lighting model / shading model
- ❖ It is used to calculate the intensity of light that we should see at a given point on the surface of an object.

Surface rendering

- ❖ It is a procedure for applying a lighting model to obtain pixel intensities for all the projected surface positions in a scene.
- ❖ 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.

Light Source

- ❖ When we view an opaque non-luminous object, we see reflected light from the surfaces of the object. The total reflected light is the sum of the contributions from a single light source or illuminated nearby objects.
- ❖ When light is incident on an opaque surface part of it is reflected and part of it is absorbed.
- ❖ 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.

1. Point source:

- ❖ Point source is the simplest light emitter e.g. light bulb
- ❖ All light rays originate at a point and radially diverge

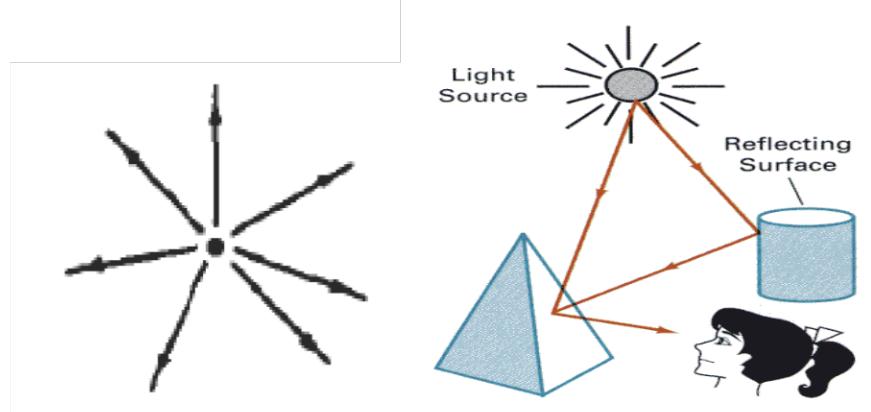


Figure: diverging ray path from the point light source

2. Parallel source

- ❖ Light rays are all parallel. May be modeled as a point source at infinite distance (the sun)

3. Distributed source

- ❖ All light rays originate at a finite area in space.
- ❖ It models a nearby source, such as a fluorescent light.

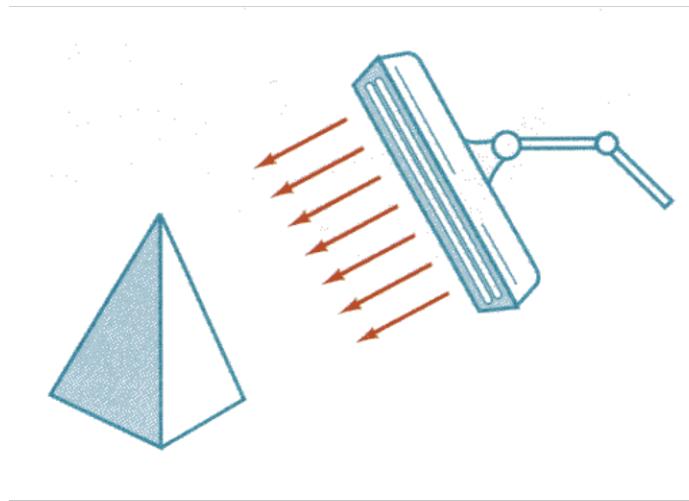


Figure: An object illuminated with a distributed light source

Illumination models:

- ❖ 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 coordinate position and an intensity value (color).

Different illumination models are:

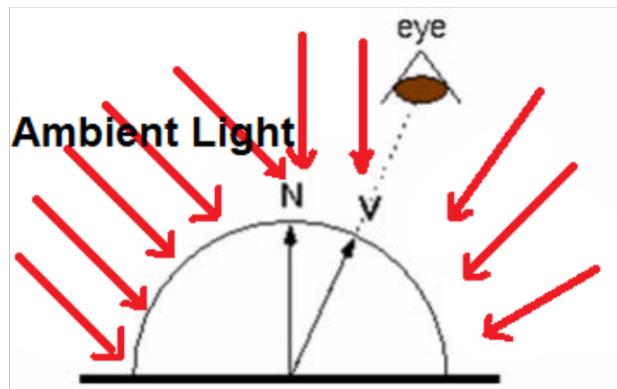
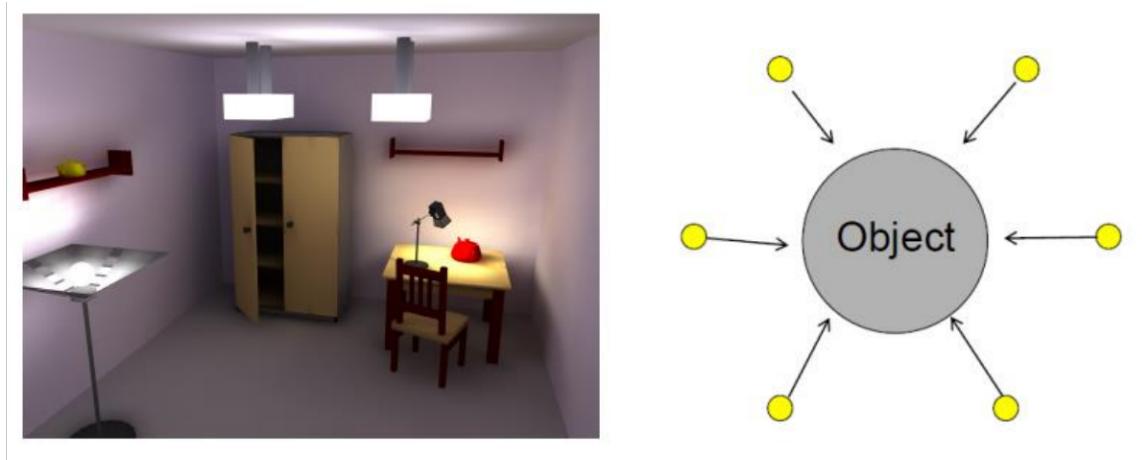
7.2 Ambient Light / Background light

- ❖ 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 combinations of light reflections form various surfaces to produce a uniform illumination called ambient light or background light.

OR

Light that is already present in a scene, before any additional lighting is added is called Ambient light.

- ❖ It usually refers to natural light, either outdoors or coming through windows etc.
- ❖ It can also mean artificial lights such as normal room lights.
- ❖ Ambient light has no spatial or directional characteristics and amount on each object is a constant for all surfaces and all directions.
- ❖ Ambient light has a uniform intensity in all directions. It causes a surface to be uniformly illuminated at any viewing position.



- ❖ In this model, illumination can be expressed by an illumination equation in variables associated with the point on the object being shaded

The equation expressing Ambient Light model is given by

$$I = K_a$$

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

And, $K_a \rightarrow$ is the ambient-reflection coefficient which determines the amount of light reflected from an object's surface. Value of K_a ranges from 0 to 1

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

$$I = I_a K_a$$

Where, $I_a \rightarrow$ is the intensity of ambient light.

7.3 Reflection: Diffuse and specular

When light is reflected (or refracted) from a surface, it does not reflect all light that enters the surface. Part of the energy will be absorbed by the surface. The reflection coefficient represents the amount of light reflected from an object's surface.

Diffuse Reflection:

- ❖ Lambertian Reflection
- ❖ When light hits an object with a rough surface, it is reflected in all directions and Objects illuminated by ambient light are uniformly illuminated across their surfaces even though light are more or less bright in direct proportion of ambient intensity.
- ❖ Amount of light hitting the surface depends on the angle between the normal vector and the incident vector of the incoming light.

OR

The object's brightness varies from one part to another, depending on the direction of and distance to the light source.

- ❖ The larger the angle (up to 90 degrees), the larger the area the incident light is spread over.
- ❖ **Diffuse reflections** are constant over each surface in a scene, independent of the viewing direction

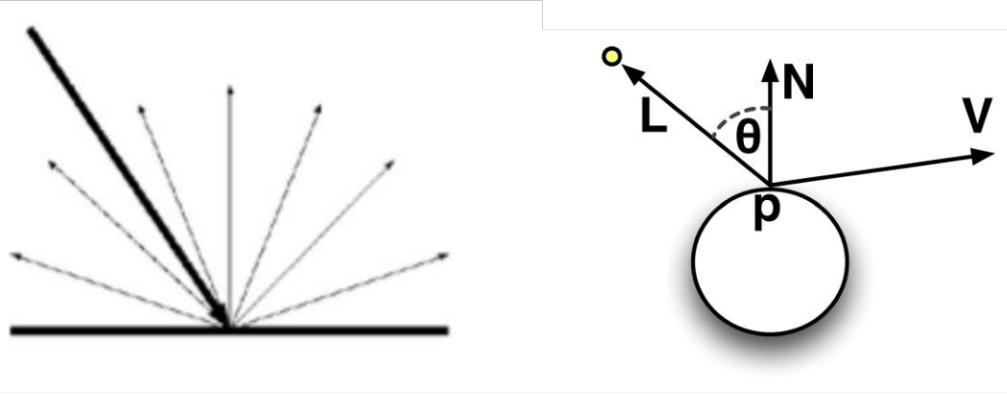


Figure: diffuse Reflection

- ❖ Diffuse lighting of an object approximates how photons will bounce off of the object's surface in many different directions.

- ❖ In diffuse reflection, we consider the surfaces (surface called. "Ideal diffuse reflectors / Lambertian reflectors), which reflect light with equal intensity in all directions (i.e. independent of the viewing direction). The amount of light energy that falls on a given area and hence the intensity of the reflection is proportional to the **cosine** of the angle of incident (i.e. $\cos \theta$). This kind of surfaces are normally dull or matt. **This mechanism is governed by Lambert's cosine law**

$$I_{\text{diff}} = K_d I_l \cos \theta$$

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 light source then

$$I_{l,\text{diff}} = K_d I_l (N \cdot L)$$

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

$$I_{\text{diff}} = K_a I_a + K_d I_l (N \cdot L) \text{ is Required Expression.}$$

OR

Above derivation can be done in this way too...

$$I = I_p k_d \cos \theta$$

Where, I_p Light intensity

θ Angle between normal vector and direction to light source

k_d is Diffuse reflectivity

Note: there is no dependence on the angle between the direction to the camera and the surface normal.

Specular Reflection

- ❖ Also called regular reflection.
- ❖ 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.
- ❖ Result of this reflection is that an image reflected by the surface is reproduced in mirror-like (*specular*) fashion
- ❖ When we look at an illuminated shiny surface, such as polished metal, a person's forehead, we see a highlight or bright spot, at certain viewing direction. Such phenomenon is called specular reflection.
- ❖ It is the result of total or near total reflection of the incident light in a concentrated region around the specular reflection angle.

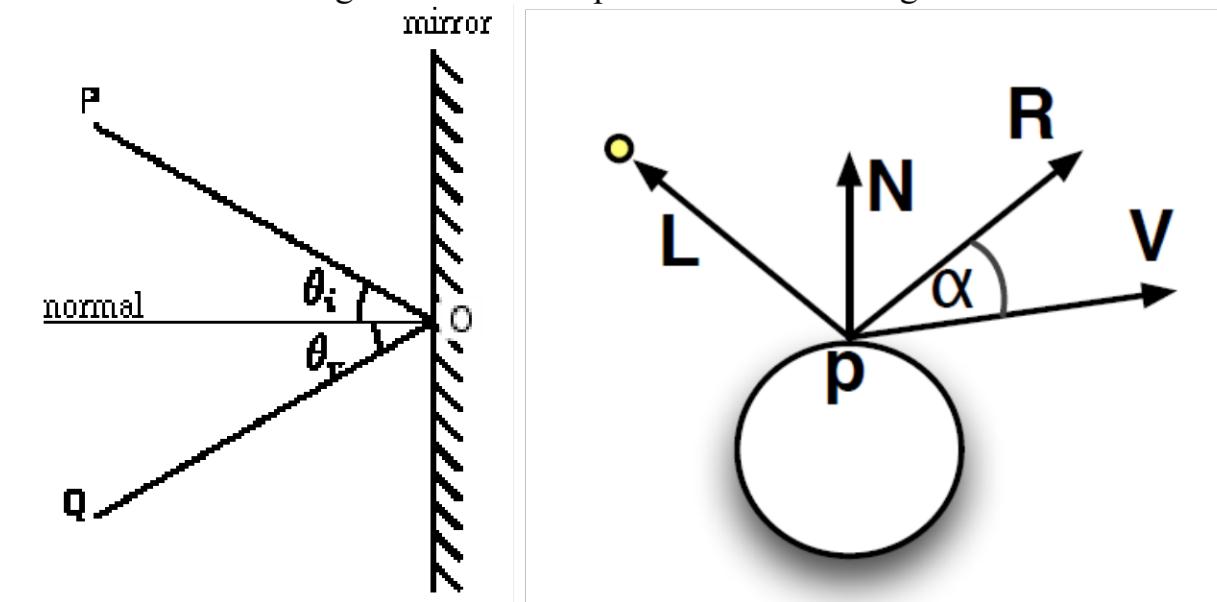


Figure: Specular-reflection equals the angle of incidence θ

Where, N - Unit vector normal to surface at incidence point

R - Unit vector in the direction of ideal specular reflection.

L - Unit vector directed to words point light source.

V - Unit vector pointing to the viewer from surface.

α - Viewing angle relative to the specular reflection direction.

Intensity Calculation

$$I = I_p k_s \cos^n \alpha$$

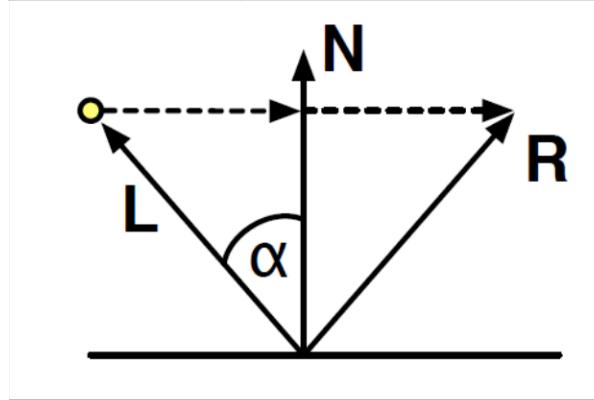
Where,

I_p → Light intensity

α → Angle between reflection vector and direction to camera

k_s → Specular reflectivity and

n → Specular intensity



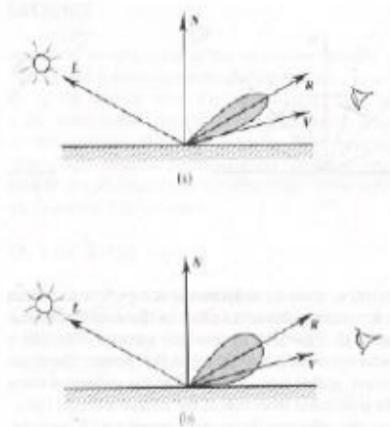
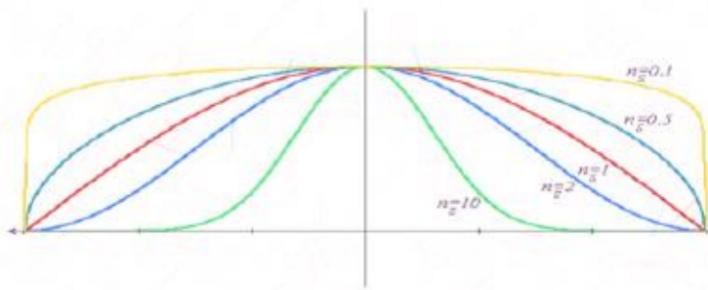
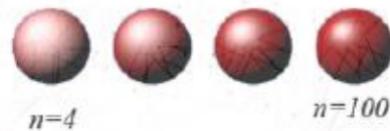
$$\text{Specular Reflection } R = 2N(N \cdot L) - L$$

Note: how this reflection (R) is obtained will described in phong modle below. No need to describe in specular diffusion.

- ❖ For ideal reflector (perfect mirror), incident light is reflected only in the specular reflection direction i.e. V and R coincides ($\alpha = 0$).

- ❖ Shiny surfaces have a narrow specular-reflection range (narrow α), and dull surfaces have a wider reflection (wider α).

- Specular light with different n values



Intensity Attenuation

- ❖ Attenuation is the loss of intensity over distance.
- ❖ The farther the distance, the more the light energy spreads out over space and less arrives per unit area at the surface.
- ❖ Point lights and spotlights look much better if attenuation is considered.
- ❖ The attenuation factor is based on the distance between the light source and the surface.
- ❖ Physically, the intensity falls off according to the inverse square law.
- ❖ In the physical world the attenuation is proportional to $1/d^2$, where d is the distance between the light source and a surface.
- ❖ Using the function $1/d^2$ causes light to decrease very rapidly and so it is common for CGI applications to make attenuation be proportional to $1/d$.
- ❖ Notice that if d is greater than 1, both equations calculate a fraction between 0.0 and 1.0. Attenuation simply calculates a percentage of the original light that is used to color a pixel.

In computer graphics, attenuation is reduction or loss of intensity of any kind of flux through a medium. For instance, sunlight is attenuated by dark glasses, x- rays are attenuated by lead, and light and sound are attenuated by water.

Attenuation is the gradual decrease in energy as the X- radiation passes through absorbing material.

Intensity = power per unit cross sectional area

$$I = P / A$$

SI unit of intensity is Wm^{-2} .

For a light at position p_1 with intensity I_p and a surface point p_0 , the arriving intensity I is:

$$I = \frac{1}{(p_1 - p_0)^2} I_0$$

Physically based attenuation often appears too strong in virtual environments. For distance d , a flexible attenuation equation is often used:

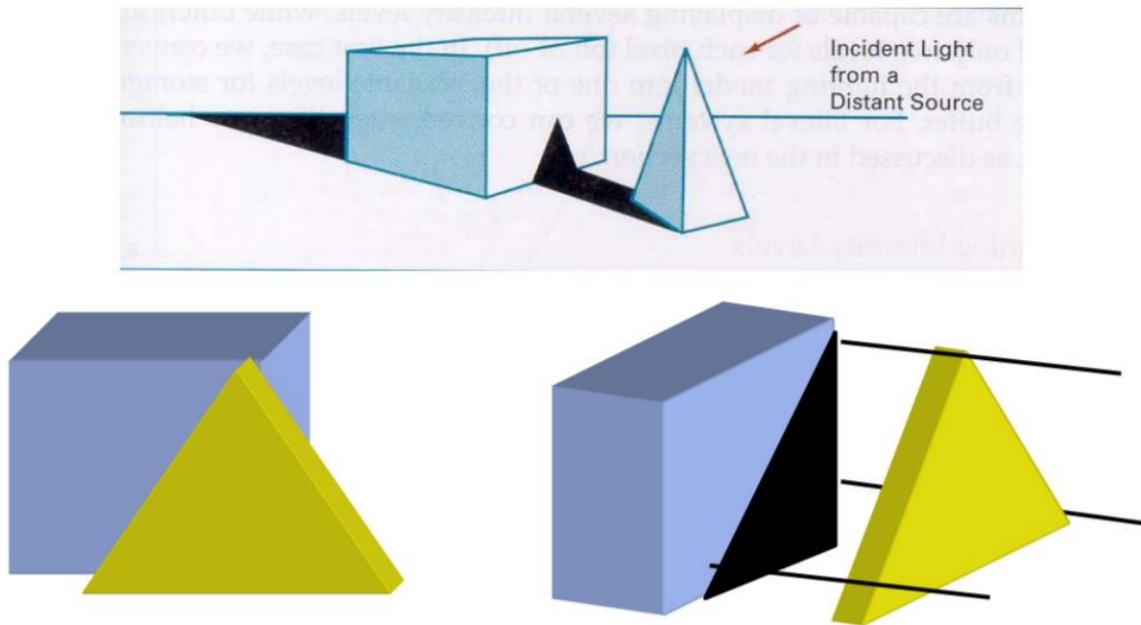
$$(a + bd + cd^2)^{-1}$$

The coefficients allow easy scaling of the constant, linear, and quadratic falloff terms. The attenuation factor can then be applied to the intensity:

$$I = a I_p$$

Shadows and Transparency

A shadow covers surfaces that are not “visible” by the light source while being visible by the viewer



- Intuition: hidden surface detection and shadow generation are in practice the same problem
- Illumination equation for m sources, and including attenuation and shadows:

$$I = I_a K_a + \sum_{1 \leq i \leq m} S_i f_{att_i} I_p \left(K_d (\bar{N} \cdot \bar{L}) + K_s (\bar{R} \cdot \bar{V})^n \right)$$

where

$$S_i = \begin{cases} 0, & \text{if light } i \text{ is blocked at this point;} \\ 1, & \text{otherwise} \end{cases}$$

Observation: ambient light is not affected by shadows and attenuation

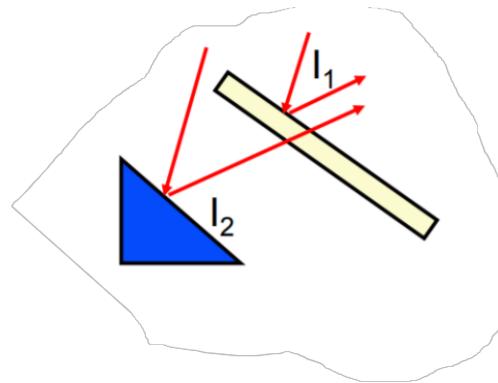
Transparency

- ❖ A transparent surface produces both, reflected and transmitted light
- ❖ The relative contribution of transmitted light depends on the degree of transparency of the surface

$$I = (1-K_1) I_1 + K_1 I_2$$

K_1 is the transmission coefficient

- $K_1 = 0$ for an opaque surface
- $K_1 = 1$ if the surface is completely transparent.



Nonrefractive Transparency

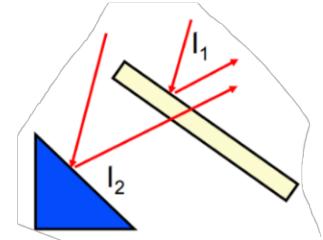
$$I = (1-K_1) I_1 + K_1 I_2$$

Interpolated transparency K_1 is the transmission coefficient of surface 1

Filtered transparency

$$I = I_1 + K_{1\lambda} I_2$$

$K_{1\lambda}$ is the transparency color of surface 1. Depends on wavelength λ



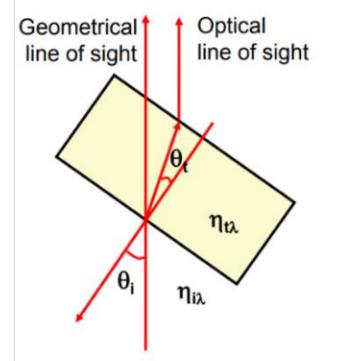
Refractive Transparency

Geometrical and optical lines of sight are different
Harder to model than non refractive transparency

Refraction angle depends on both material and wavelength

Snell's Law:

$$\frac{\sin \theta_i}{\sin \theta_t} = \frac{\eta_{t\lambda}}{\eta_{i\lambda}}$$



Where, $\eta_{i\lambda}$ and $\eta_{t\lambda}$ are the refraction indices of the materials for the wavelength λ



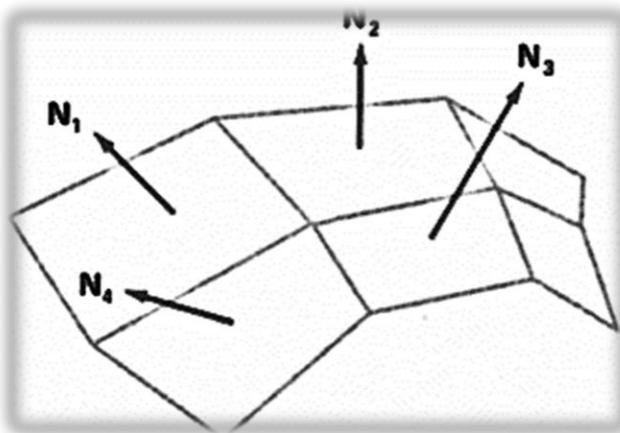
7.4 Surface Shading Method:

- ❖ **Shading model** is used to compute the intensities and colors to display the surface.
- ❖ **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
 - Properties of the surface (i.e. The surface characteristics e.g. Shining, matte, dull, and opaque or transparent)
 - The type of light sources (i.e. Properties of the illumination falling on it)
- ❖ Shading refers to the process of altering the color of an object / surface / polygon in the 3D scene, based on following facts (may more facts) to create a photo realistic effect.
 - the surface's angle to lights, its distance from lights
 - Its angle to the camera and material properties (e.g. bidirectional reflectance distribution function).

- ❖ The principal surface property is its reflectance, which determines how much of the incident light is reflected.
- ❖ If a surface has different reflectance for the light of different wavelengths, it will appear to be colored.
- ❖ Shading models determine the shade of a point on the surface of an object in terms of a number of attributes.
- ❖ Shading is performed during the rendering process by a program called a shader.

In order to produce a realistic image with various kinds of reflection, there are 3 common shading methods which are mainly applied to polygons:

7.4.1. Constant Shading:



- ❖ Also called **Flat shading / Faceted Shading**
- ❖ This approach implies an illumination model once to determine a single intensity value that is then used to render an entire polygon. Constant shading is useful for quickly displaying the general appearance of a curved surface. (**i.e. one lighting calculation per polygon**)
- ❖ Fast and simple but cannot model specular reflection.

- ❖ Problem of intensity discontinuity between polygons (The light intensity is computed based on the normal of each polygon surface. Since different polygons have different normal, the light intensity computed may be quite different).
- ❖ This approach is valid if several assumptions are true:
 1. The light source is sufficiently far so that $\mathbf{N} \cdot \mathbf{L}$ is constant across the polygon face.
 2. The viewing position is sufficiently far from the surface so that $\mathbf{V} \cdot \mathbf{R}$ is constant over the surface
 3. The object is a polyhedron and is not an approximation of an object with a curved surface.

Remarks: Even if all of these conditions are not true, we can still reasonably approximate surface-lighting effects using small polygon facets with flat shading and calculate the intensity for each facet, say, at the center of the polygon.

Interpolated Shading:

Remarks: This is not in syllabus of PU but we have to know for the understanding of Gouraud and phong shading)

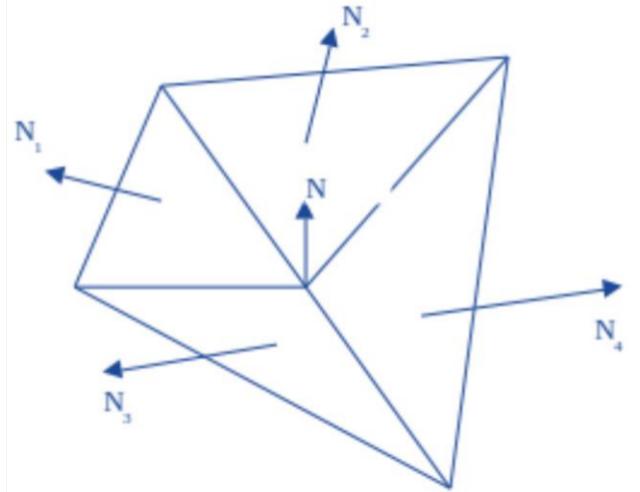
- ❖ An alternative to evaluating the illumination equation at each point on the polygon, we can use the interpolated shading, in which shading information is linearly interpolated across a triangle from the values determined for its vertices. Gouraud generalized this technique for arbitrary polygons.
- ❖ This is particularly easy for a scan line algorithm that already interpolates the z-value across a span from interpolated z-values computed for the span's endpoints.

7.4.2 Gouraud Shading

- ❖ Henri Gouraud, French computer scientist
- ❖ Also called intensity interpolating shading or color interpolating shading eliminates intensity discontinuities that occur in flat shading

- ❖ Method of simulating the effects of light and color across the surface of an object, based on estimates of the surface normal of each vertex in a polygonal 3D model.
- ❖ **one lighting calculation per vertex** (i.e. 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** (*An optical illusion, discovered by Ernst Mach*), to appear on the surface
- ❖ This method eliminates the intensity discontinuity problem, But Still not model the specular reflection correctly
- ❖ Each polygon surface is rendered with Gouraud shading by performing following calculations.
 1. Determine the average unit normal vector at each polygon vertex.
 2. Apply an illumination model to each vertex to calculate the vertex intensity.
 3. Linearly interpolate the vertex intensities over the surface of the polygon

Consider a polygon as shown in figure below,

**Process:**

Step 1: At each polygon vertex, we obtain a normal vertex by averaging the surface normal of all polygons sharing the vertex as:

$$N_v = \frac{\sum_{k=1}^n N_k}{\left| \sum_{k=1}^n N_k \right|}$$

From the above polygon,

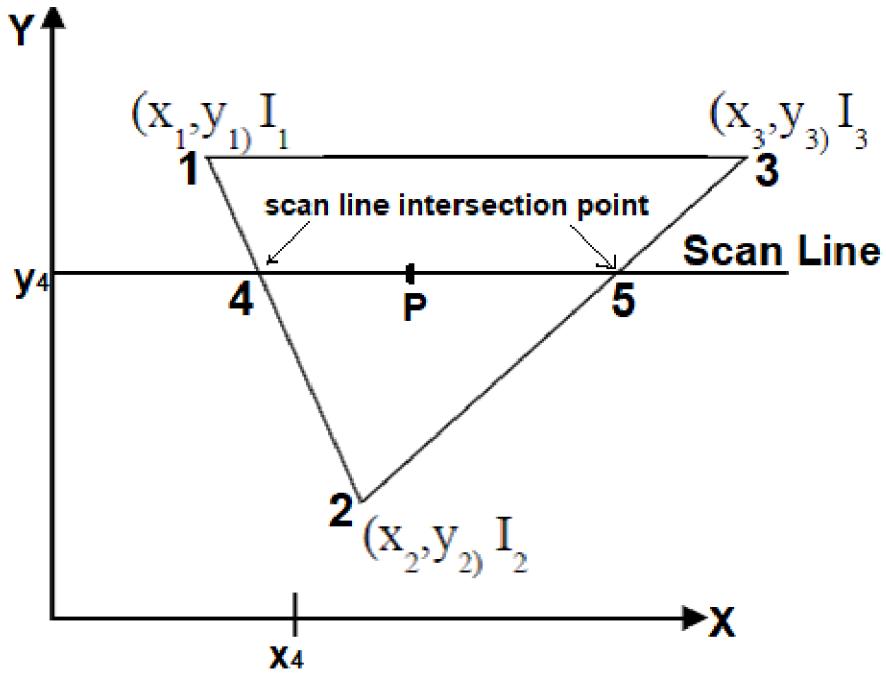
$$N_v = \frac{N_1 + N_2 + N_3 + N_4}{\left| N_1 + N_2 + N_3 + N_4 \right|}$$

Where,

N_v is normal vector at a vertex sharing four surfaces as in above figure.

Step 2: Gouraud model is one lightening calculation per vertex therefore, **Once** we have the vertex normal (N_v), we can determine the intensity at the vertices from a lighting model.

Step-3: Now to interpolate intensities along the polygon edges consider following figure.



In This figure, the intensity of vertices 1, 2, 3 are I_1 , I_2 , I_3 respectively, are obtained by averaging normal of each surface sharing the vertices and applying an illumination model.

For each scan line, intensity at intersection of line with Polygon edge is linearly interpolated from the intensities at the edge end point.

So intensity **at point 4** is to interpolate between intensities I_1 and I_2 using only the vertical displacement of the scan line:

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

Similarly, the intensity **at point 5** is obtained by linearly interpolating intensities at I_2 and I_3 as

$$I_5 = \frac{y_5 - y_2}{y_3 - y_2} I_3 + \frac{y_3 - y_5}{y_3 - y_2} I_2$$

The intensity of **a point P** in the polygon surface along scan-line is obtained by linearly interpolating intensities at I_4 and I_5 as,

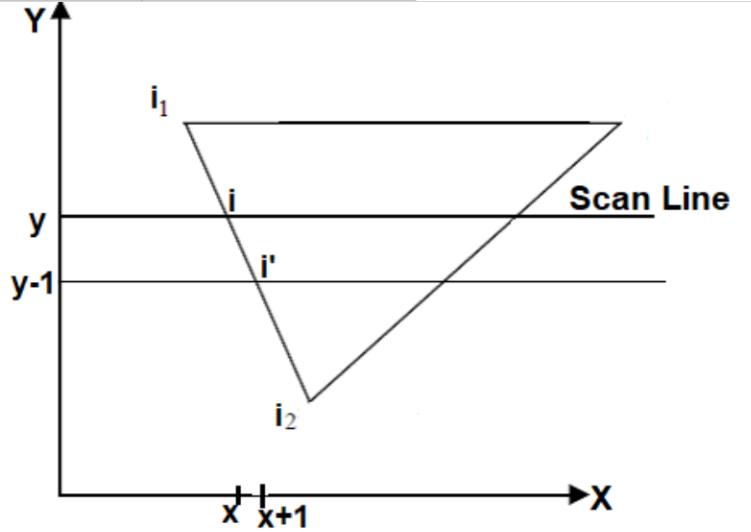
$$I_p = \frac{x_5 - x_p}{x_5 - x_4} I_4 + \frac{x_p - x_4}{x_5 - x_4} I_5$$

Then incremental calculations are used to obtain Successive edge intensity values between scan-lines as and to obtain successive intensities along a scan line. As shown in Fig. below, if the intensity at edge position (x, y) is interpolated as:

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

Which is required Expression

Furthermore, for next scan line



Then, we can obtain the intensity along this edge for next scan line at y-1 position as

$$I' = \frac{y-1 - y_2}{y_1 - y_2} I_1 + \frac{y_1 - (y-1)}{y_1 - y_2} I_2 = I + \frac{I_2 - I_1}{y_1 - y_2}$$

Similar calculations are made to obtain intensity successive horizontal pixel.

Problems with Gouraud shading

In specular reflection the highlight can be sharp, depending on the shape of $\cos^n \alpha$

- ❖ Gouraud shading interpolates linearly and so can make the highlight much bigger
- ❖ Gouraud shading can miss highlights that occur in the middle of a polygon
- ❖ Highlights on the surface are sometimes displayed with anomalous shape and linear intensity interpolation can cause bright or dark intensity streak called mach-bands.

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

7.4.3 Phong Shading

- ❖ **Also called normal vector interpolation shading**
- ❖ Lighting computation is performed at each pixel
- ❖ More accurate method for rendering a polygon surface is to interpolate normal vector and then apply illumination model to each surface point.
- ❖ It displays more realistic highlights and greatly reduces the mach-band effect
- ❖ 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

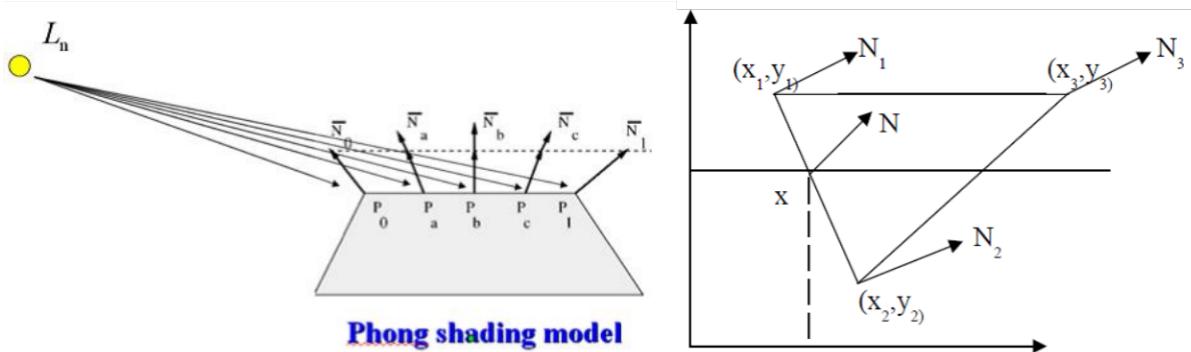


Figure: a) Phong Shading Model **b)** Polygon surface having normal vector on Every vertex

- ❖ 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 normal over the surface of polygon.
 - Apply illumination model along each scan line to calculate the pixel intensities for the surface point.

In figure b), 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.

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

7.4.4 Fast Phong Method

- ❖ Surface rendering with Phong shading can be speeded up 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 from vertex normal, 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.

$$N_k = Ax_k + By_k + C, \quad k = 1, 2, 3 \text{ for } (x_k, y_k) \text{ vertex.}$$

Omitting the reflectivity and attenuation parameters, we can write the calculation for light-source diffuse reflection from a surface point (x, y) as

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

Re writing this expression in generic form,

$$I_{diff}(x, y) = \frac{ax + by + c}{(dx^2 + exy + fy^2 + gx + hy + i)^{\frac{1}{2}}} \quad (\textbf{i})$$

Where, Parameters a, b, c, d... are used to represent the various dot products as $a = \frac{L.N}{|L|}$ and so on

Finally, denominator of equation (i) can be expressed as Taylor series expansions and retains terms up to second degree in x and y. This yields

$$I_{diff}(x, y) = T_5 x^2 + T_4xy + T_3y^2 + T_2x + T_1y + T_0$$

Where each T_k is a function of parameters a, b, c, d, and so on.

- ❖ This method still takes twice as long as in Gouraud shading.
- ❖ Normal Phong shading takes six to seven times that of Gouraud shading.

Mach Bands:

- ❖ Physicist Ernst Mach (1838–1916).
- ❖ Mach noticed that when two bars, one dark and one bright, are next to each other, you see little bands of extra dark at the edge of the dark band and extra light at the edge of the light bar.
- ❖ Mach bands is often based on the concept of lateral inhibition. Lateral inhibition is a process by which the collection of light by retinal cells in the eye is affected by the light collection of neighboring cells. In nature, this helps boost the perception of object edges, making it easier to see the edge of an object that might otherwise not be noticed.

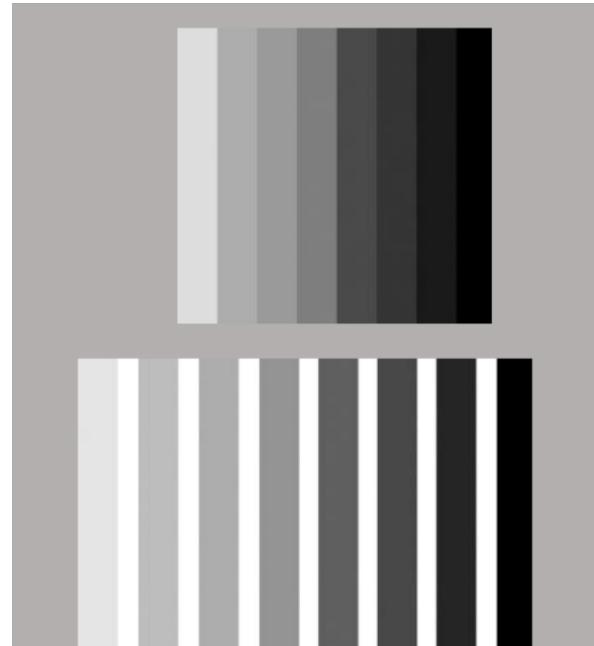
- ❖ Mach Bands are an optical illusion that leads us to perceive densities that do not exist in reality.
- ❖ **Mach bands** are an optical illusion consisting of an image of two wide bands, one light and one dark, separated by a narrow strip with a light-to-dark gradient. The human eye perceives two narrow bands of different *brightnesses* either side of the gradient that are not present in the original image. (see below image)



Figure: Mach Bands Effect

If you look closely at this grey scale it appears that each band of grey is not a consistent density. The left side of each band appears slightly darker than the right. This is another example of the Mach band optical illusion. →

These are the same grey blocks separated by a white strip. They now appear as solid shades of grey. →



Depth Cueing:

- ❖ Depth cueing aims to improve the 3D effect by displaying objects at the front more brightly than those at the back. The extent to which this improves 3D perception varies according to what is on display and it may not always be effective.
- ❖ Depth cueing is implemented by having objects blend into the background color with increasing distance from the viewer.
- ❖ It is the process of rendering distant objects at a lower intensity than near ones, hence giving them the appearance of depth.
- ❖ Depth cuing indicates the process in which the lines closest to the viewing position are displayed with the highest intensities, and lines farther away are displayed with decreasing intensities.
- ❖ Depth cueing is applied by choosing maximum and minimum intensity (or color) values and a range of distances over which the intensities are to vary.

7.5 Color Models: RGB, CMYK

- ❖ A color model is an abstract numerical system for describing color, using three or four main numbers to represent primary colors.
- ❖ A color model is an orderly system for creating a whole range of colors from a small set of primary colors.
- ❖ There are two types of color models, those that are subtractive and those that are additive.
- ❖ 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.
- ❖ There are several established color models used in computer graphics, but the two most common are

- 1. RGB model (Red-Green-Blue)** for computer display and
- 2. CMYK model (Cyan-Magenta-Yellow- Key / black)** for printing

RGB model (Red-Green-Blue)

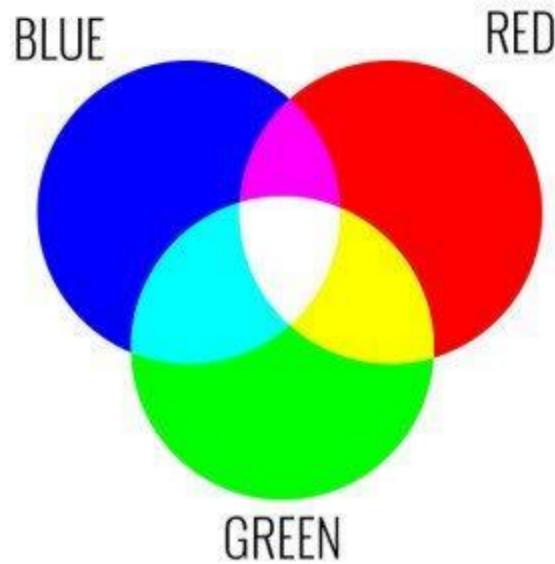


Figure: RGB color model

- ❖ RGB stands for Red, Green, Blue
- ❖ RGB is primarily used for designing elements that will be displayed on a television set, a computer monitor, a mobile phone, or any other kind of light source.
- ❖ RGB (Red, Green and Blue) is the color space for digital images. Use the RGB color mode if your design is supposed to be displayed on any kind of screen.
- ❖ It is a device dependent color mode.
- ❖ A light source within a device creates any color you need by mixing red, green and blue and varying their intensity. This is known as additive mixing or additive color model, means all colors begin as black darkness and then red, green and blue light is *added* on top of each other to brighten it and create the perfect pigment. When red, green and blue light is mixed together at equal intensity, they create pure white.
- ❖ Designers can control aspects like saturation, vibrancy and shading by modifying any of the three source colors. Because it's done digitally, the designer manipulates how the light on the screen manifests to create the color they want.
- ❖ If the end destination of your design project is a digital screen, use the RGB color mode. This would go for anything that involves computers, smartphones, tablets, TVs, cameras, etc.

❖ Following design project involves RGB pattern:

- **web & app design**

- icons
- buttons
- graphics

- **Branding**

- online logos
- online ads

- **Social media**

- images for posts
- profile pictures
- profile backgrounds

- **Visual content**

- video
- digital graphics
- infographics
- photographs for website, social media, or apps

Summary:

- ✓ Additive color model
- ✓ For computer displays
- ✓ Uses light to display color
- ✓ Colors result from transmitted light
- ✓ Red + Green + Blue = White

CMYK model (Cyan-Magenta-Yellow-black)

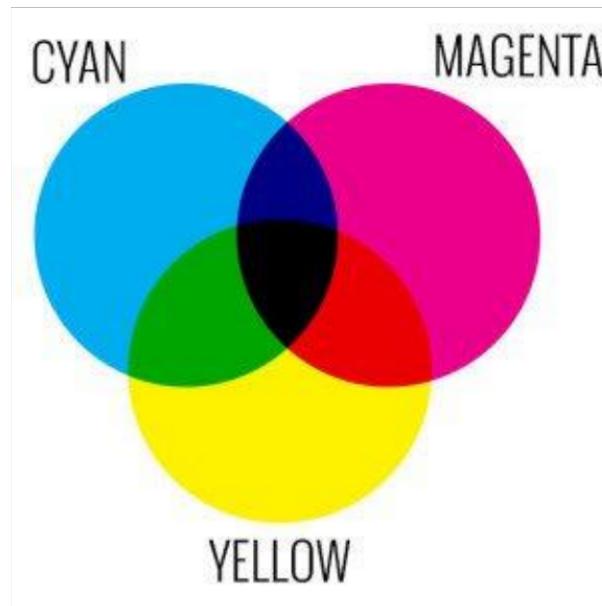


Figure: CMYK color Model

- ❖ CMYK (Cyan, Magenta, Yellow, Key / Black) is the color space for printed materials.
- ❖ CMYK is also a device dependent color mode
- ❖ It is most frequently used to this day as the main color mode used in printing, whether it's posters, brochures, business cards, books, or magazines.
- ❖ A printing machine creates images by combining CMYK colors to varying degrees with physical ink. This is known as subtractive mixing. All colors start as blank white, and each layer of ink *reduces* the initial brightness to create the preferred color. When all colors are mixed together, they create pure black.
- ❖ Use CMYK for any project design that will be physically printed, not viewed on a screen. If you need to recreate your design with ink or paint, the CMYK color mode will give you more accurate results.
- ❖ Following project involves CMYK pattern:

- **Branding**

- business cards
- stationary
- stickers

- signs & storefronts

- **Advertising**

- Billboards
- Posters
- Flyers
- vehicle wraps
- brochures

- **Merchandise**

- T-shirts, hats and other branded clothing
- Promotional swag (pens, mugs, etc.)

- **Essential materials**

- product packaging
- restaurant menus

Summary:

- ✓ Subtractive color model
- ✓ For printed material
- ✓ Uses ink to display color
- ✓ Colors result from reflected light
- ✓ Cyan + Magenta + Yellow = Black

***** End of Chapter *****