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CHAPTER -7

Illumination and Shading

7.1 Illumination Theory or Illumination Model

- Realistic displays of a scene are obtained by generating perspective projections of objects and by applying natural lighting effects to the visible surfaces.
- Illumination model also known as shading model or lightning model is used to calculate the intensity of light that is reflected at a given point on surface.
- A surface rendering algorithm uses the intensity calculations from an illumination model to determine the light intensity for all projected pixels positions for the various surfaces in a scene.
- Surface rendering can be performed by applying the illumination model to every visible surface point.

There are three factors on which lighting effect depends on:

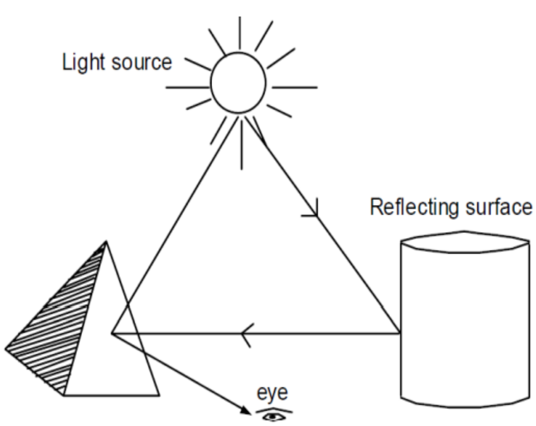
a. **Light Source:**
   - Light source is the light emitting source. When we view an opaque non-luminous object, we see reflected light from the surfaces of the object.
   - The total reflected light is the sum of the contributions from a single light source or illuminated nearby objects.

   There are three types of light sources:

   i. **Point Sources:** The source that emit rays in all directions (A bulb in a room)

   ii. **Parallel Sources:** Can be considered as a point source which is far from the surface (The Sun).

   iii. **Distributed Surfaces:** Rays originate from a finite area (A tube light). The area of the source is not small as compared to the surfaces in the scene like fluorescent light.



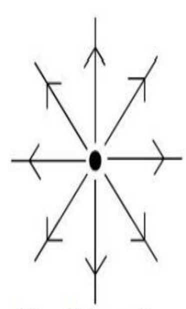


Fig. Diverging ray paths From a point light Source.

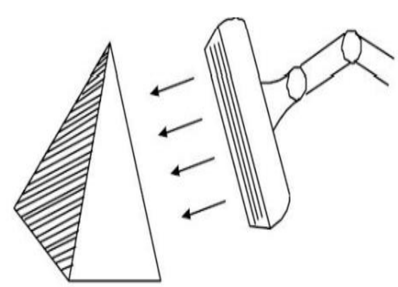


Fig. An object illuminated with a distributed light source.

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7.2 Ambient Light

- In case of ambient light, or background light, the surface of interest is not exposed directly to a light source but reflections from various surfaces to produce a uniform illumination or visibility due to illuminated nearby objects.
- Ambient light has no spatial or directional characteristics and amount on each object is a constant for all surfaces and all directions.
- The reflected intensity *I* due to ambient light of any point on the surface is:

$$I = I_a.K_a$$

Where I_a = Intensity of ambient light

K_a = ambient reflection coefficient/Reflectivity $0 \le Ka \le 1$.

7.3 Reflections of Light

- When light strikes a surface, some of it will be reflected. Exactly how it reflects depends in a complicated way on the nature of the surface called the material properties of the surface.
- Reflections are of mainly two types in 3D graphics.
  - **i. Diffuse Reflection**
  - **ii. Specular Reflection**

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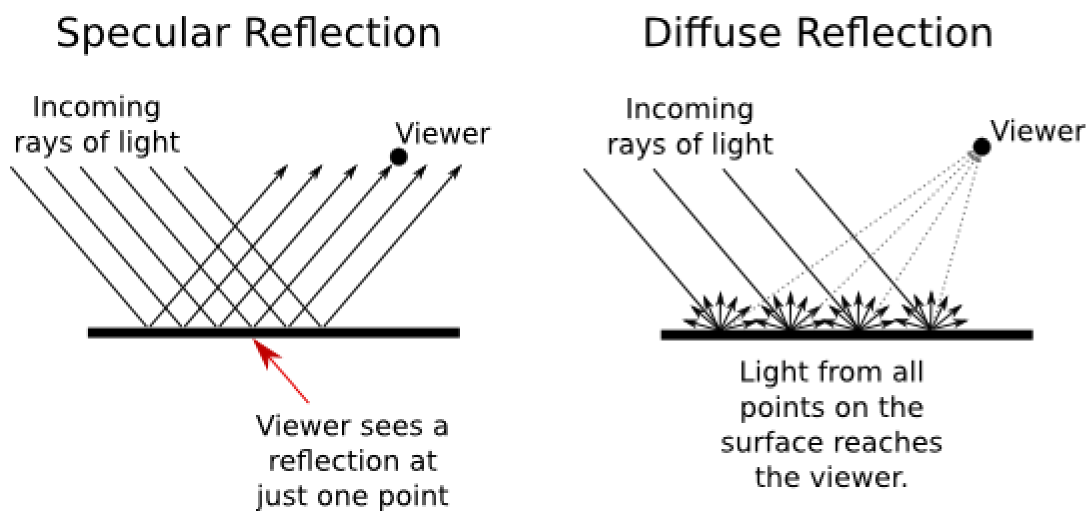

i. Diffuse Reflection

- Surfaces appear equally bright from all viewing angles since they reflect light with equal intensity in all directions.
- In this reflection the brightness of a point depends upon the angle made by the light source and the surface.
- The reflected intensity I_{diff} of a point on the surface is:

The reflected intensity I of any point on surface is

$$I = I_l K_d \vec{N} . \vec{L} = I_l K_d cos\theta$$

-

$$I_{diff} = K_d \, I_p \cos(\theta) = K_d \, I_p (N \cdot L)$$

Where, I_p : the point light intensity
K_d : the surface diffuse reflectivity, value of K_d varies from 0 to 1
N : the surface normal
L : the light direction

- Net diffuse reflection = Diffuse reflection due to ambient light + Diffuse reflection due to light source

$$I_{Netdiff} = I_{amb,diff} + I_{light,diff} = I_a.K_a + K_d I_p(N.L)$$

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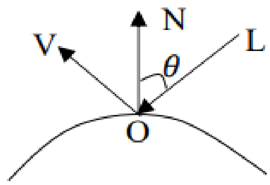


L=light source

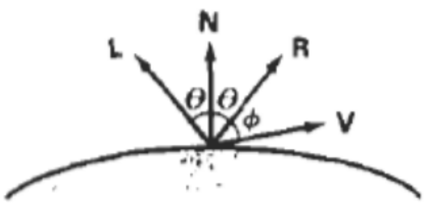
N=normal to surface

V=viewer direction

θ=angle bet^n S & N

ii. Specular Reflection

- In shiny surface we see highlight or bright spot from certain viewing directions called specular reflection.
- Light reflected with unequal intensity.



L=incident light

N=normal to surface

R=direction of ideal specular reflection

V=viewer

ϕ=angle bet^n R & V

$$I_{l,spec} = K_s I_l(\vec{V}.\vec{R})^{n_s}$$

Where, K_s= specular reflection coefficient
n_s= specular reflection parameter

Phong model:

$$\boxed{I_{l,spec} = K_s I_l cos^{n_s}\phi}$$

<u>Combined diffuse and specular reflection</u>

$$I = I_{diff} + I_{spec}$$

$$I = I_a K_a + I_l K_d(\vec{N}.\vec{L}) + K_s I_l(\vec{V}.\vec{R})^{n_s}$$

7.4 Surface Shading Methods

- In computer graphics, shading refers to the process of altering the color of an object or surface or 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 to create a photorealistic effect.

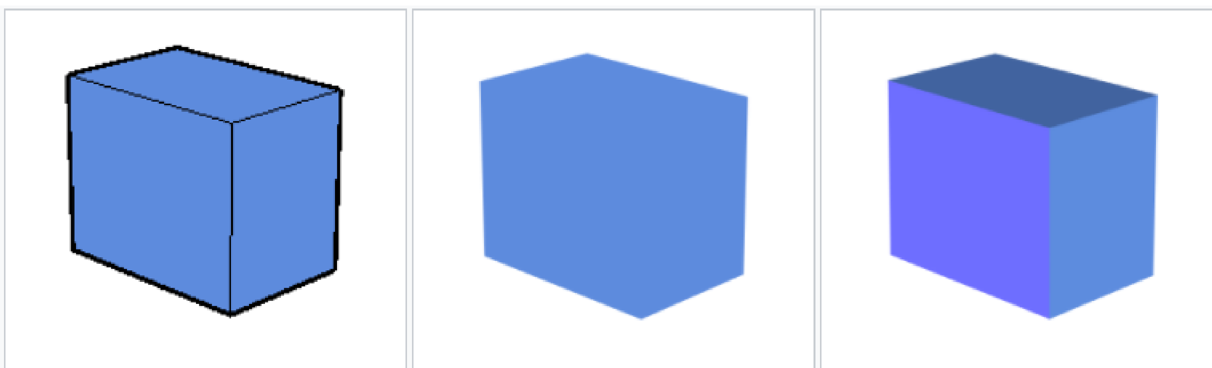
- Shading is referred to as the implementation of the illumination model at the pixel points or polygon surfaces of the graphics objects.
- Shading model is used to compute the intensities and colors to display the surface.
- The shading model has two primary ingredients: properties of the surface and properties of the illumination falling on it.

Shading alters the colors of faces in a 3D model based on the angle of the surface to a light source or light sources.

The first image below has the faces of the box rendered, but all in the same color. Edge lines have been rendered here as well which makes the image easier to see.

The second image is the same model rendered without edge lines. It is difficult to tell where one face of the box ends and the next begins.

The third image has shading enabled, which makes the image more realistic and makes it easier to see which face is which.



Four types of surface shading methods:

1. Constant Intensity Shading (Flat Shading) Method

- It is a fast and simple method for rendering an object with constant intensity shading with polygon surfaces.
- In this method, a single intensity is calculated for each polygon.
- All the points over the surface of the polygon are then displayed with same intensity value.
- Constant shading can be useful for quickly displaying the general appearance of a curved surface.

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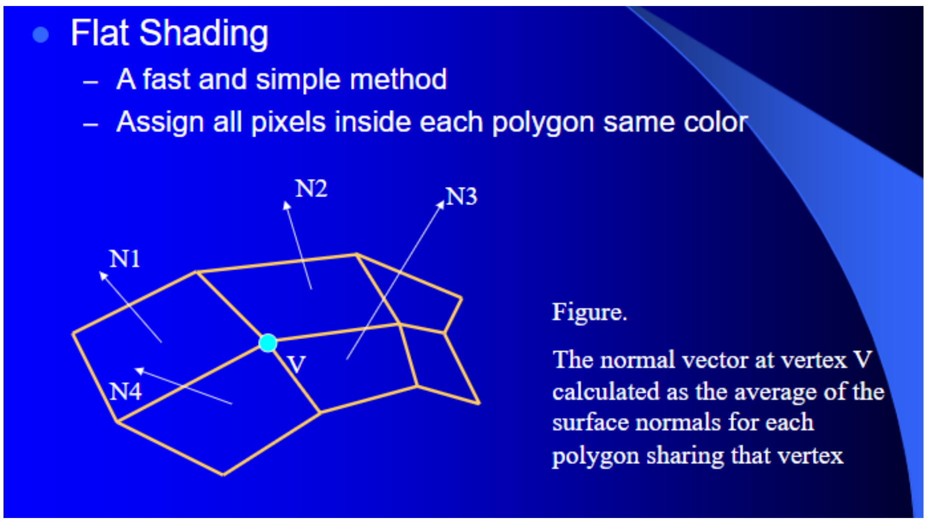
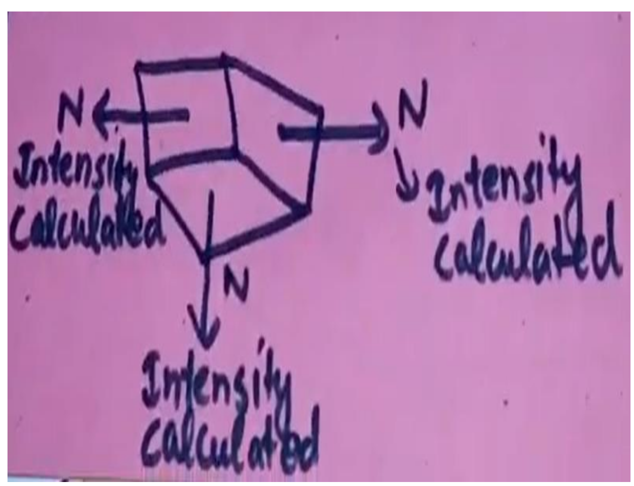
- In general, flat shading of polygon facets provides an accurate rendering for an object if all of the following assumptions are valid:-
- The object is a polyhedron and is not an approximation of an object with a curved surface.
- All light sources illuminating the objects are sufficiently far from the surface so that N. L and the attenuation function are constant over the surface (where N is the unit normal to a surface and L is the unit direction vector to the point light source from a position on the surface).
- The viewing position is sufficiently far from the surface so that V. R is constant over the surface (where V is the unit vector pointer to the viewer from the surface position and R represent a unit vector in the direction of ideal specular reflection).





Disadvantages: Discontinuity

2. Gouraud Shading Method

- This method overcomes the disadvantages of constant intensity method or flat shading i.e. discontinuity.
- This method uses the Intensity Interpolation method.
- Intensity interpolation is a mathematical method which will find the intensity values between any points if intensity of two points are given.
- This method shades a polygon by linearly interpolating intensity values across the surface.
- Intensity values for each polygon are matched with the values of adjacent polygons along the common edges, thus eliminating the intensity discontinuities that can occur in flat shading.
- Gouraud Shading steps:
  - Determine the average unit normal vector at each polygon vertex.

$$\vec{N}_{avg} = \frac{\sum_{i=1}^{n} \vec{N}_i}{|\sum_{i=1}^{n} \vec{N}_i|}$$

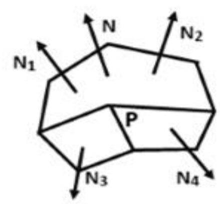
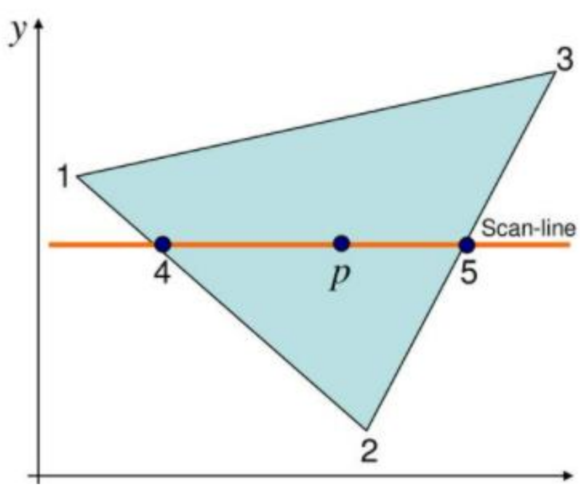


Fig: The normal vertex at vertex V is calculated as the average of surface normal for each polygon sharing the vertex.

  - Apply illumination model at each vertex to calculate vertex intensity.
  - Linearly interpolate the vertex intensities over the projected are of the polygon along edges and along scan lines.



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

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

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

Advantages:

- It removes the intensity discontinuity which exists in constant shading model.

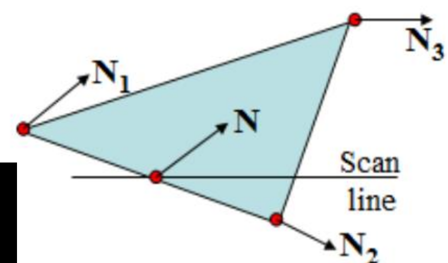
Disadvantages:

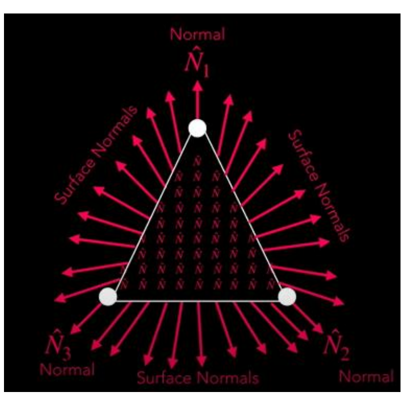
- Highlights on the surface are sometimes displayed with anomalous shapes and linear intensity interpolation can cause bright or dark intensity streaks, called Mach Bands to appear on the surfaces.
- Mach bands can be reduced by dividing the surface into a greater number of polygon faces or Phong Shading (requires more calculation).

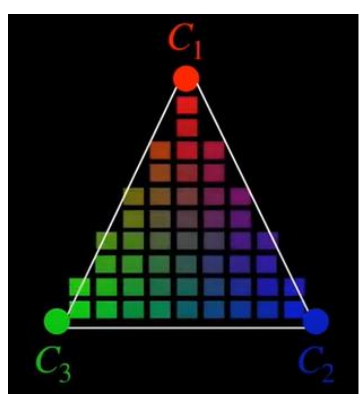
3. Phong Shading

- A more accurate method for rendering a polygon surface is Phong Shading, or normal vector interpolation shading which first interpolate normal vectors, and then apply the illumination models to each surface point.
- Unlike Gouroud shading it interpolates normal vectors instead of intensity values.
- It displays more realistic highlights on a surface and greatly reduces the Mach-band effect. A polygon surface is rendered using Phong shading by carrying out the following steps:
    - Determine the average unit normal vector at each polygon vertex.
    - Linearly interpolate the vertex normal over the surface of the polygon.
    - Apply an illumination model along each scan line to calculate projected pixel intensities for the surface points.
- The normal vector N for the scan-line intersection point along the edge between vertices 1 and 2 can be obtained by vertically interpolating between edge end point normal:

$$\mathbf{N} = \frac{y - y_2}{y_1 - y_2}\mathbf{N}_1 + \frac{y_1 - y}{y_1 - y_2}\mathbf{N}_2$$







- Incremental methods are used to evaluate normal between scan lines and along each individual scan line (as in Gouraud).

- At each pixel position along a scan line the illumination model is applied to determine the surface intensity at that point.
- Intensity calculations using as approximated normal vector at each point along the scan line produce more accurate results than the direct interpolation of intensities, as in Gouraud shading but it requires considerable more calculations.

4. Fast Phong Shading (FPS)

- Surface rendering with Phong Shading can be speed up by using approximations in the illumination model calculations of normal vectors.
- Fast Phong Shading approximates the intensity calculations using a Tylor 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

$$\mathbf{N = Ax+By+C}$$

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

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

With (x_k,y_k) denoting a vector position.

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

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

We can write this,

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

Where, a, b, c, d are used to represent the various dot product. For e.g.

$$a = \frac{L\cdot A}{|L|}$$

Finally, denominator in eq. (i) can be expressed as a Taylor-series expansion and retain terms up to second degree in x & y. This yields

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

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

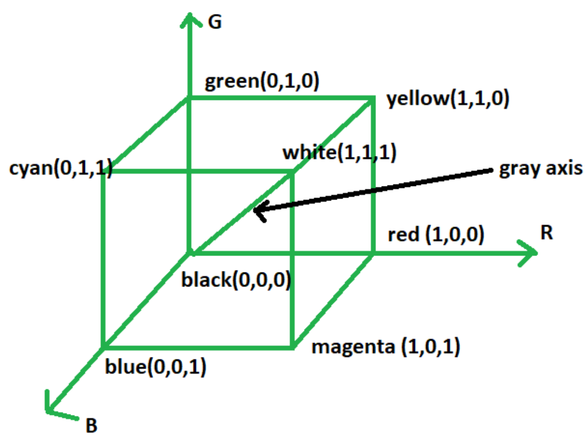
- Finally, the denominator in equation (i) can be expressed as a Taylor-series expansion and retain terms up to second degree in x & y.

7.5 Computer Color Models

Models or methodologies used to specify colors in computer terms are RGB, HSB, HSL, CMYK, CIE others. The main purpose of these color models is for the sensing, representation, and display of images in electronic systems, such as televisions and computers. Although the eye perceives colors based upon red, green, and blue, there are actually two basic methods of making color in computer system: additive and subtractive.

RGB Color Model: Additive

- The RGB color model is an additive color modes in which Red, Green and Blue light are added together in various ways to reproduce a broad away of colors.
- The name of the model comes from the initials of the three additive primary colors: Red, Green and Blue.
- We can represent this model with the unit cube defined on R, G and B axes like shown below:



- The origin point (0,0,0) represent black and the coordinate point (1,1,1) represent white.
- Since RGB is an additive model, each color point within the bounds of the cube can be represented as the triple (R,G,B) where values of R, G and B are assigned from 0 to 1.
- The Magenta vertx (1,0,1) is obtained by adding Red and Blue to produce the triple (1,0,1)
- White is produced when all three Red, Green and Blue have value 1 i.e. (1,1,1).
- The main purpose of the RGB color model is for the sensing, representation and display of images in electronic systems, such as televisions and computers.
- One common application of the RGB color model is the display of color on a Cathode Ray Tube (CRT), liquid crystal display (LCD), plasma display or organic light emitting diode (OLED) display such as a television , a computer's monitor etc.

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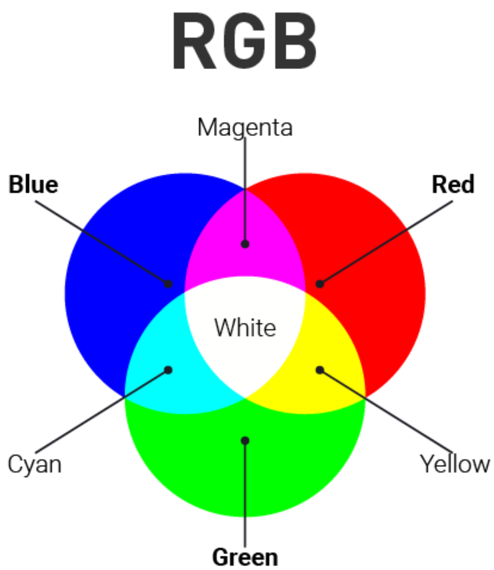
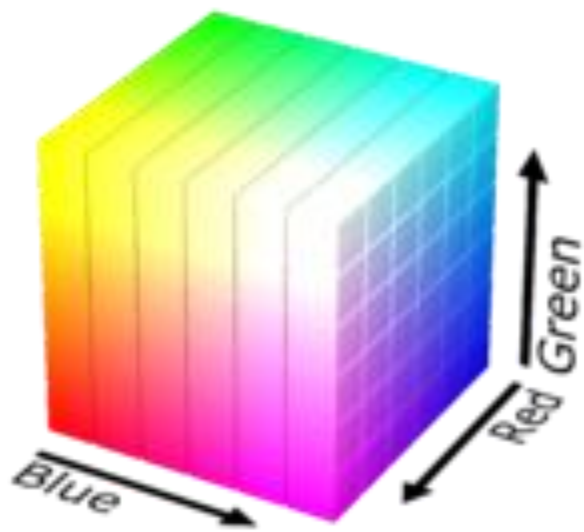
- Each pixel on the screen is built by driving three small and very close but still separated RGB light sources.
- At common viewing distance, the separate sources are indistinguishable which tricks the eye to see a given solid color.





CMYK Color Model: Subtractive

- The CMYK color model is a subtractive color model used in color printing and is also used in describing the printing process itself.
- The CMYK refers to the four inks used in some color printing Cyan, Magenta, Yellow and Key (Black).
- The CMYK model works by partially or entirely masking colors on a lighter usually while background.
- The ink reduces the light that would otherwise be reflected. Such model is called subtractive because inks “subtract” brightness from white.
- In additive color models such as RGB white is the “additive” combination of all primary colored lights, white, black is the absence of light.
- But in CYMK model, it is the opposite: White is the natural color of the paper of other background, while black results from a full combination of colored inks.
- To save cost on ink, and to produce deeper black tones, unsaturated and dark colors are produced by using black ink instead of combination of cyan, magenta and yellow.

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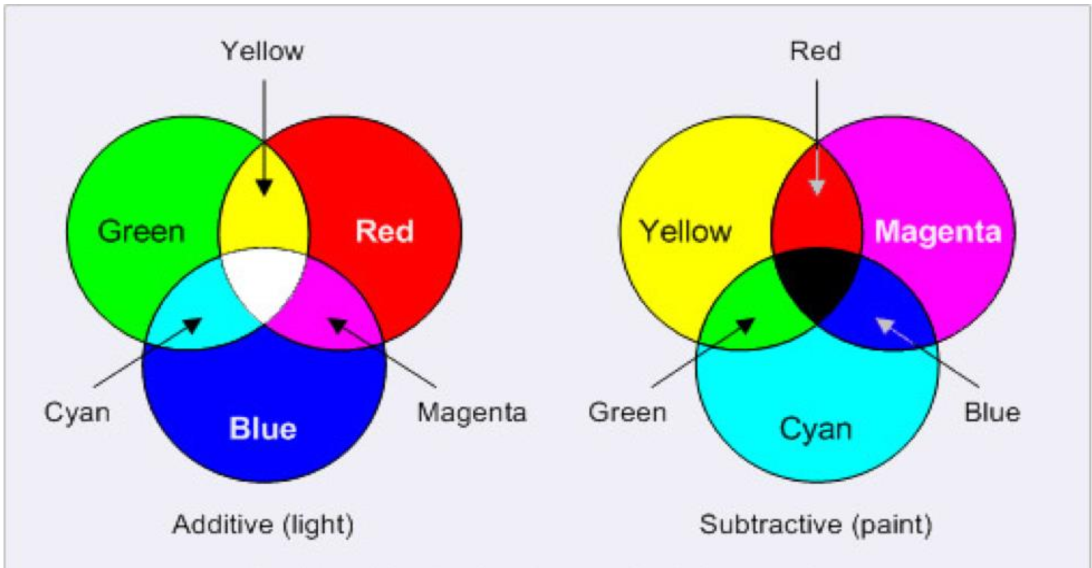
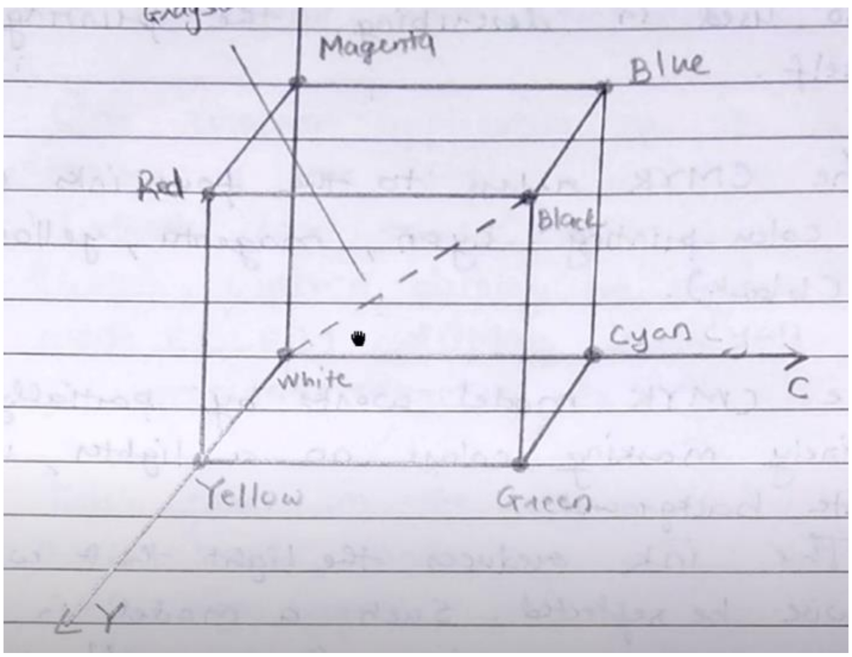


Additive and subtractive color combinations



- The Cyan is produced by adding Blue and Green Colors. It shouldn't have Red component i.e. Red is subtracted from Cyan completely.
- Similarly, in Magenta, Red and Blue are added but green component is subtracted. Also in yellow, blue is subtracted.
- To convert RGB representation to CMY representation with the matrix transformation with this formula

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- To convert CMY representation to RGB representation with the matrix transformation with this formula

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$