Computer Graphics

Chapter 07
Advance Topics

Asst.Prof.Abdulle Hassan

0618370005

cigaleh@simad.edu.so

Outline

- Classification of Visible-Surface Detection Algorithms
- Back-Face Detection
- Depth Buffer Method/ Z Buffer Method
- Light source
- Basic Illumination Models/ Shading Model/ Lighting Model
- Ambient Light
- Diffuse Reflection
- Specular Reflection and the Phong Model
- Properties of Light
- Color Model

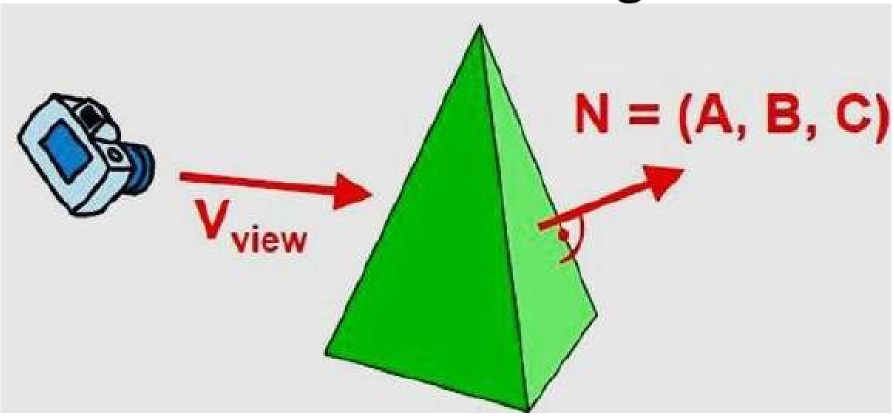
Classification of Visible-Surface Detection Algorithms

- It is broadly divided into two parts,
  1. Object-Space methods (e.g. Back-Face Detection)
  2. Image-Space methods (e.g. Depth Buffer Method)
- Object space method compares objects and parts of objects to each other within the scene definition to determine which surface is visible.
- In image space algorithm visibility is decided point by point at each pixel position on the projection plane.

Back-Face Detection

- Back-Face Detection is simple and fast object space method.
- Identifies back faces of polygon based on the inside-outside tests.
- A point (x, y, z) is inside if $Ax + By + Cz + D < 0$.

  where A, B, C, and D are constants and this equation is nothing but equation of polygon surface.
- We can simplify test by taking normal vector $N = (A, B, C)$ of polygon surface and vector V in viewing direction from eye.

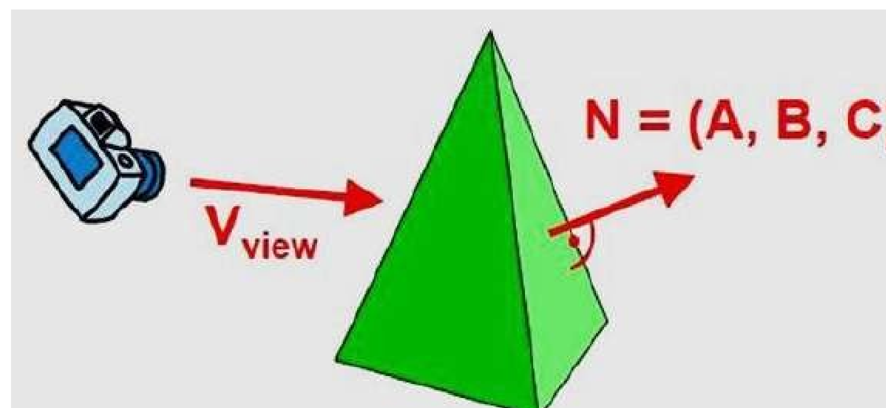


Source: www.tutorialspoint.com

Contd.

- Then we check condition if $V \cdot N > 0$ then polygon is back face.
- If we convert object description in projection coordinates and our viewing direction is parallel to z_v then $\mathrm{V} = (0,0,V_z)$ and,

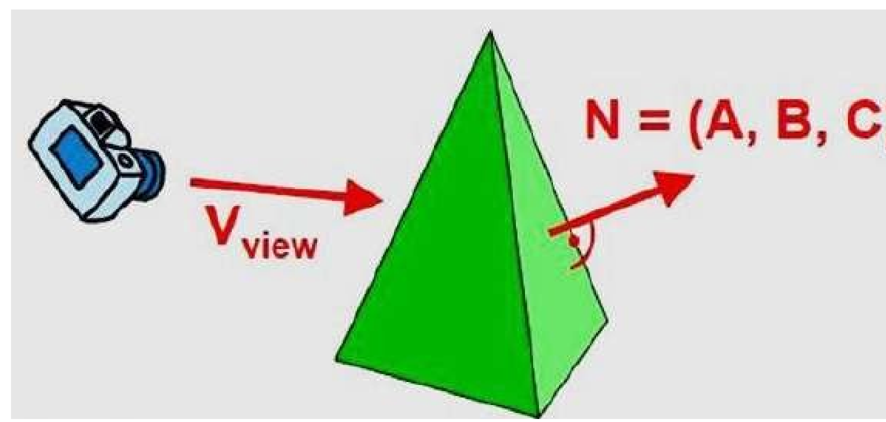
  $V \cdot N = V_z C.$
- So now we only need to check sign of C.
- In right handed viewing system V is along negative z_v axis. And in that case
- If $C < 0$ the polygon is backface.



Source: www.tutorialspoint.com

Contd.

- Also we cannot see any face for which $C = 0$.
- So in general for right handed system
- If $C \leq 0$ polygon is back face.
- Similar method can be used for left handed system.
- In left handed system V is along the positive Z direction and polygon is back face if $C \geq 0$.



Source: www.tutorialspoint.com

Contd.

- For a single convex polyhedron such as the pyramid by examining parameter C for the different plane we identify back faces.
- So far the scene contains only non overlapping convex polyhedral, back face method works properly.
- For other object such as concave polyhedron we need to do more tests for determining back face.

Source: www.pinterest.com

Depth Buffer Method/ Z Buffer Method

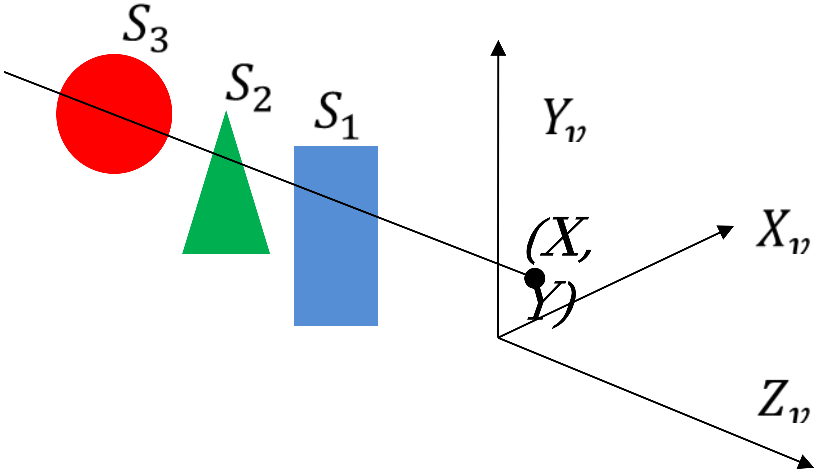
Algorithm

1. Initialize the depth buffer and refresh buffer so that for all buffer positions (x, y),
   - $depth(x, y) = 0, \qquad refresh(x, y) = I_{backgnd}$
2. For each position on each polygon surface, compare depth values to previously stored values in the depth buffer to determine visibility.
   - Calculate the depth z for each (x, y) position on the polygon.
   - If $z > depth(x, y)$, then set,

     $depth(x, y) = z, \qquad refresh(x, y) = I_{surf}(x, y)$

Contd.

- It is image space approach.
- It compares surface depth at each pixel position on the projection plane.
- It is also referred to as z-buffer method since generally depth is measured in z-direction.
- Each surface of the scene is process separately one point at a time across the surface.



Contd.

- We are starting with pixel position of view plane and for particular surface of object.
- If we take orthographic projection of any point (x, y, z) of the surface on the view plane we get two dimension coordinate (x, y) for that point to display.
- Here we are taking (x, y) position on plan and find particular surface is at how much depth.
- We can implement depth buffer algorithm in normalized coordinates so that z values range from 0 at the back clipping plane to z_{max} at the front clipping plane.

Contd.

- Here two buffers are required,
  1. A depth buffer to store depth value of each (x, y) position
  2. A refresh buffer to store corresponding intensity values.
- Initially depth buffer value is 0 and refresh buffer value is intensity of background.
- Each surface of polygon is then process one by one scan line at a time.
- Calculate the z values at each (x, y) pixel position.
- If calculated depth value is greater than the value stored in depth buffer it is replaced with new calculated values and store intensity of that point into refresh buffer at (x, y) position.

Contd.

- Depth values are calculated from plane equation,

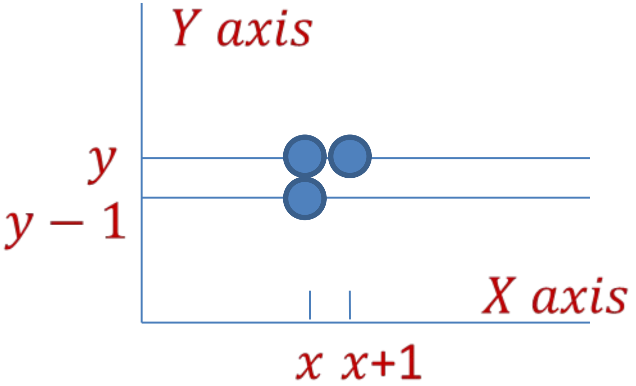
$$Ax + By + Cz + D = 0$$

$$z = \frac{-Ax - By - D}{C}$$

- For horizontal line next pixel's z values can be calculated by putting $x' = x + 1$ in above equation,

$$z' = \frac{-A(x+1) - By - D}{C}$$

$$z' = z - \frac{A}{C}$$

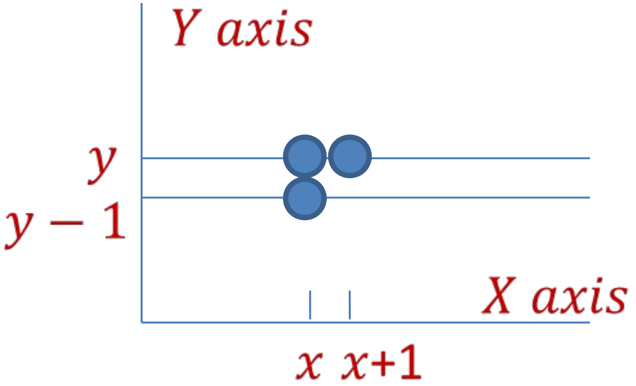


Contd.

- For vertical line pixel below the current pixel has $y' = y - 1$ so it's z values can be calculated as follows,

$$z' = \frac{-Ax - B(y-1) - D}{C}$$

$$z' = z + \frac{B}{C}$$



Contd.

- If we are moving along polygon boundary then it will improve performance by eliminating extra calculation.
- For this if we move top to bottom along polygon boundary we get $x' = x - 1/m$ and $y' = y - 1$, so z value is obtain as follows,

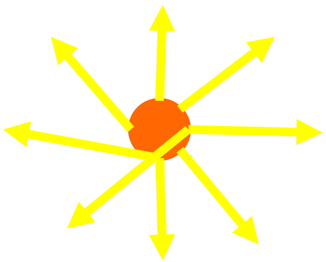
$$z' = \frac{-A(x - 1/m) - B(y - 1) - D}{C}$$

$$z' = z + \frac{A/_m + B}{C}$$

- Alternately we can use midpoint method to find the z values.

Light Source

- When we see any object we see reflected light from that object.
- Total reflected light is the sum of contribution from all sources and reflected light from other object that falls on the object.
- So that the surface which is not directly exposed to light may also visible if nearby object is illuminated.
- The simplest model for light source is **point source.**
- Rays from the source then follows radial diverging paths from the source position.



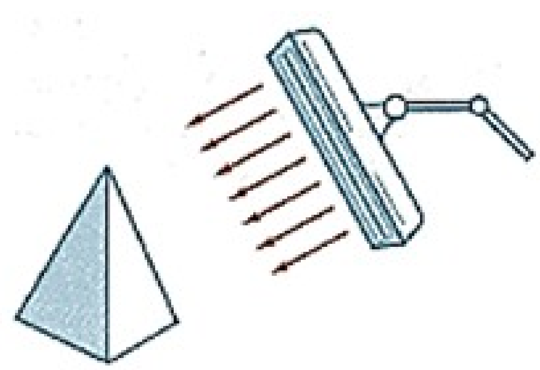
Contd.

- This light source model is reasonable approximation for source,

  - whose size is small compared to the size of object

  - may be at sufficient distance so that we can see it as point source.

- For example sun can be taken as point source on earth.
- A nearby source such as the long fluorescent light is more accurately modelled as a **distributed light source.**
- In this case the illumination effects cannot be approximated with point source because the area of the source is not small compare to the size of object.



Contd.

- When light is falls on the surface the part of the light is reflected and part of the light is absorbed.
- Amount of reflected and absorbed light is depends on the property of the object surface.
- For example shiny surface reflect more light while dull surface reflect less light.

Basic Illumination Models

- It is also known as **Shading Model** or **Lighting Model.**
- These models give simple and fast method for calculating the intensities of light for various reflections.
- Three models we discuss here for light intensity.
  1. Ambient Light
  2. Diffuse Reflection
  3. Specular Reflection

Ambient Light

- This is a simple way to model combination of light reflection from various surfaces to produce a uniform illumination called **ambient light,** or **background light.**
- Ambient light has no directional properties.
- The amount of ambient light incident on all the surfaces and object are constant in all direction.
- If consider that ambient light of intensity I_a and each surface is illuminate with I_a intensity then resulting reflected light is constant for all the surfaces.

Diffuse Reflection

- When some intensity of light is falls on object surface and that surface reflect light in all the direction in equal amount then the resulting reflection is called **diffuse reflection.**
- Ambient light reflection is approximation of global diffuse lighting effects.
- Diffuse reflections are constant over each surface independent of our viewing direction.
- Amount of reflected light is depend on the parameter K_d, the **diffuse reflection coefficient** or **diffuse reflectivity.**
- K_d is assign value in between 0 and 1 depending on reflecting property.

Contd.

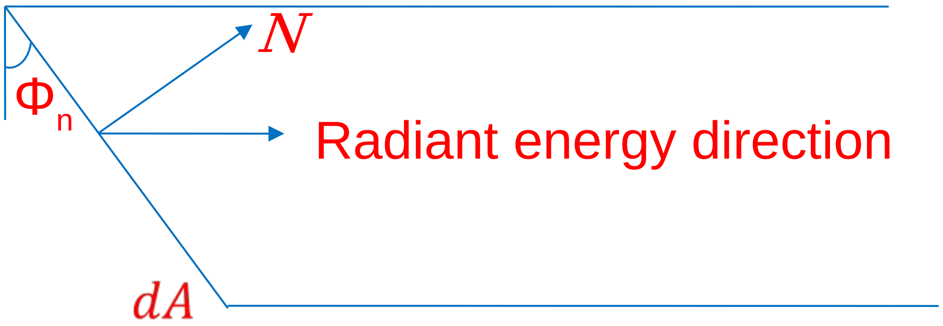
- Shiny surface reflect more light so K_d is assign larger value while dull surface assign small value.
- If surface is exposed to only ambient light we calculate ambient diffuse reflection as,

  $$I_{ambdiff} = K_d I_a$$

  where I_a the ambient light is falls on the surface.
- Practically most of times each object is illuminated by one light source so now we discuss diffuse reflection intensity for point source.

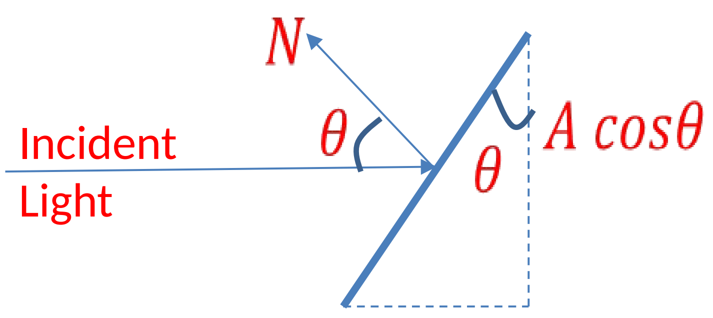
Contd.

- We assume that the diffuse reflection from source are scattered with equal intensity in all directions, independent of the viewing direction.
- Such a surface are sometimes referred as **ideal diffuse reflector** or **lambertian reflector.**
- This is modelled by **lambert's cosine law.**
- Law states that the radiant energy from any small surface area dA in any direction $\emptyset_n$ relative to surface normal is proportional to $cos\emptyset_n$.



Contd.

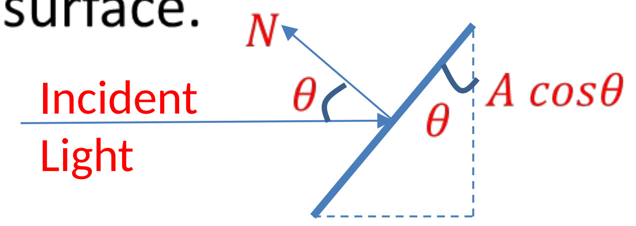
- Reflected light intensity is does not depends on viewing direction.
- For lambertian reflection, the intensity of light is same in all viewing direction.
- Even though light distribution is equal in all direction for perfect reflector the brightness of a surface does depend on the orientation of the surface relative to light source.
- As the angle between surface normal and incidence light direction increases light falls on the surface is decreases



Contd.

- **Angle of incidence** between the incoming light and surface normal is denoted as θ.
- Projected area of a surface patch perpendicular to the light direction is proportional to $cos\theta$.
- If I_l is the intensity of the point light source, then the diffuse reflection equation for a point on the surface can be written as

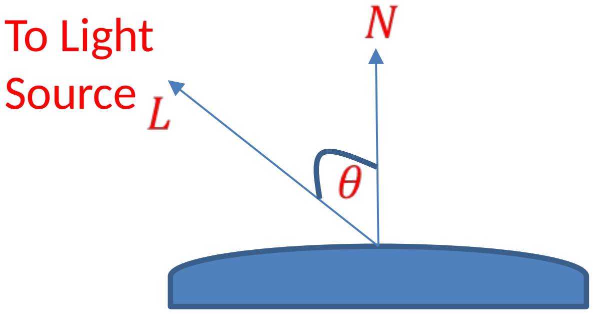
  $I_{l,diff} = K_d I_l cos\theta$
- Surface is illuminated by a point source only if the angle of incidence is in the range 0^0 to 90^0.
- Other value of θ light source is behind the surface.



Contd.

- As shown in figure N is the unit normal vector to surface.
- L is unit vector in direction of light source
- Dot product of this is,

  $N \cdot L = \cos\theta$



- Intensity equation is,

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

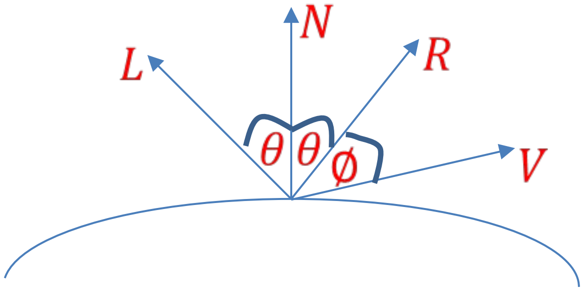
- Now in practical ambient light and light source both are present and so total diffuse reflection is given by,

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

- Here for ambient reflection coefficient K_a is used in many graphics package so here we use K_a instead of K_d.

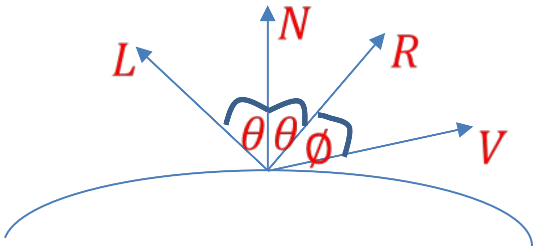
Specular Reflection and the Phong Model

- While looking at an illuminated shiny surface, such as polished metal, we see a highlight, or bright spot, at certain viewing directions.
- This phenomenon is called **specular reflection,** is the result of total, or near total reflection of the incident light in a concentrated region around the **specular reflection angle.**
- The specular reflection angle equals the angle of the incident light.
- R is unit vector in direction of reflection
- L is unit vector point towards light source
- N is unit normal vector
- V is unit vector in viewing direction.



Contd.

- Objects other than ideal reflectors exhibits specular reflection over a finite range of viewing positions around vector R.
- Shiny surface have a narrow specular reflection range and dull surface have wide specular reflection range.
- **Phong model** states that the intensity of specular reflection proportional to $cos^{ns}\emptyset$. Angle Ø varies in between 0^0 to 90^0.
- Values assigned to **specular reflection parameter** $'ns'$ is determined by the type of surface that we want to display.
- A shiny surface assigned $'ns'$ values large nearly 100 and dull surface assigned small nearly 1.



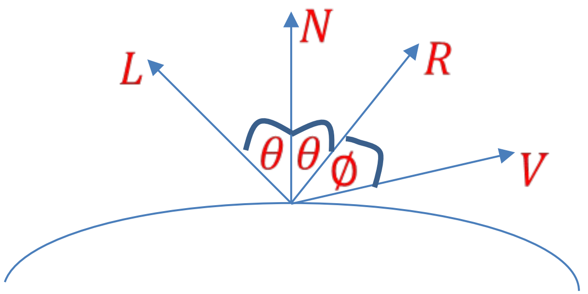
Contd.

- Intensity of specular reflection depends on the,
  - material properties of the surface
  - the angle of incidence
  - **specular reflection coefficient ($\boldsymbol{w(\theta)}$)** for each surfaces**.**
- Specular reflection is given by,

  $I_{spec} = w(\theta) I_l cos^{ns}\emptyset$

  where I_l is the intensity of light source and

  $\emptyset$ is angle between viewing direction V and specular reflection direction R.



- Since $\emptyset$ is angle between two unit vector V and R we can put,

  $cos\emptyset = V \cdot R$

Contd.

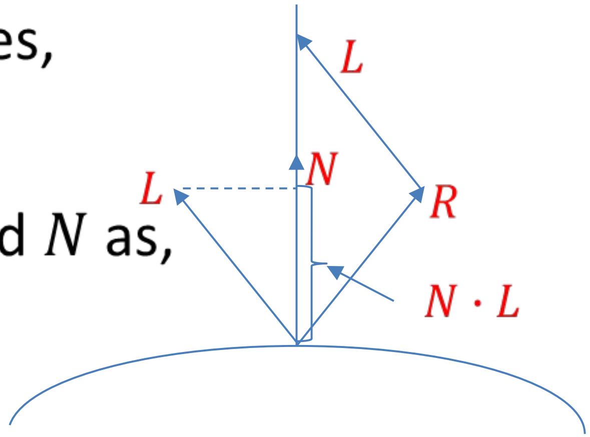
- And also for many surfaces $w(\theta)$ is constant so we take specular reflection constant as K_s so equation becomes,

  $$I_{spec} = K_s I_l (V \cdot R)^{ns}$$

- Vector R is calculated in terms of vector L and N as,

  $$R + L = (2N \cdot L)N$$

  $$R = (2N \cdot L)N - L$$



- Somewhat simplified phong model is to calculate between half way vectors H and use product of H and N instead of V and R.
- Here H is calculated as follow,

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

Combined Diffuse and Specular Reflections with Multiple Light Sources

- For a single point light source we can combined both diffuse and specular reflection by adding intensity due to both reflection as,

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

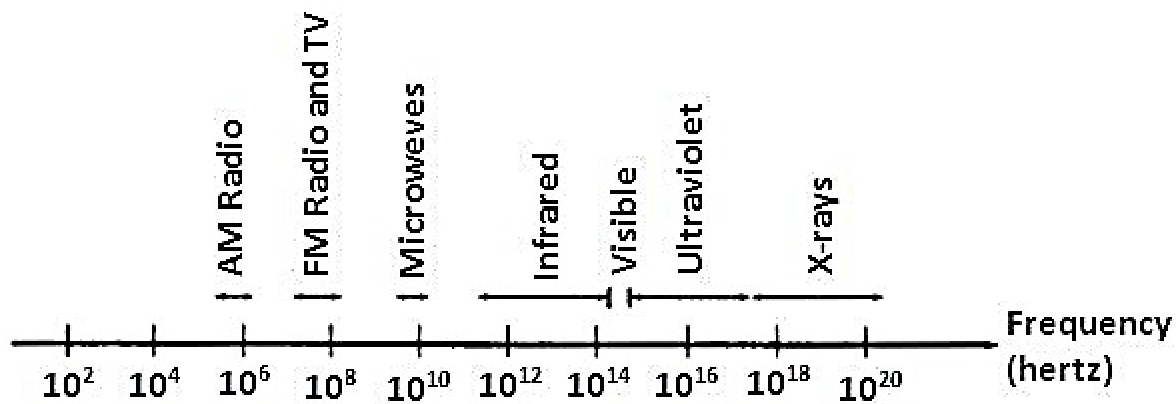
  $I = K_a I_a + K_d I_l (N \cdot L) + K_s I_l (N \cdot H)^{ns}$

- For multiple source we can extend this equation as,

$$I = K_a I_a + \sum_{i=1}^{n} I_l [K_d (N \cdot L) + K_s (N \cdot H)^{ns}]$$

Properties of Light

- Light is an electromagnetic wave.
- Visible light is have narrow band in electromagnetic spectrum only $400nm\ to\ 700nm$ light is visible by human eye.
- Electromagnetic spectrum shown in figure shows other waves are present in spectrum like microwave infrared etc.
- Frequency value from $4.3\ \times\ 10^{14}$ hertz (red) to $7.5 \times\ 10^{14}$ hertz (violet) is visible range.



Contd.

- We can specify different color by frequency f or by wavelength λ of the wave.
- We can find relation between f and λ as follows,
  $c = \lambda\mathrm{f}$
- Frequency is constant for all the material but speed of the light and wavelength are material dependent.
- For white light, source emits light of all visible frequency.
- Reflected light have some frequency and some are absorbed by the surface.

Contd.

- Frequency reflected back is decide the color we see and this frequency is called as **dominant frequency (hue).**
- Corresponding reflected wavelength is called **dominant wavelength.**
- Other property are **brightness** and **purity.**
- Brightness is perceived intensity of light.
- Intensity is the radiant energy emitted per unit time, per unit solid angle and per unit projected area of the source.
- **Purity** or **saturation** of the light describes how washed out or how "pure" the color of the light appears.
- Dominant frequency and purity both collectively refers as **chromaticity.**

Contd.

- If two color source combined to produce white light they are called **complementary color** of each other.
- For example red and cyan are complementary color.
- Typical color models that are uses to describe combination of light in terms of dominant frequency.
- Color models use three colors to obtain reasonable wide range of colors, called the **color gamut** for that model.
- Two or three colors are used to obtain other colors in the range are called **primary colors.**

Color Models

- In practice we use variety of colors.
- For represent color, in display devices, or in hard copy different color models are used.
- Few color models we discuss are,
  - XYZ color model
  - RGB color model
  - YIQ color model
  - CMY color model

XYZ Color Model

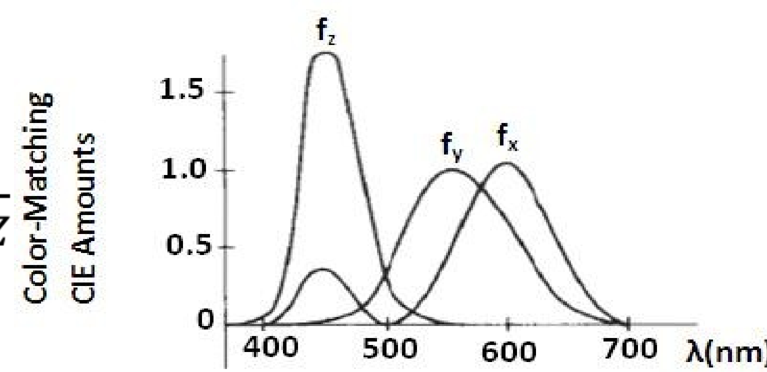
- The set of CIE primaries is generally referred to as XYZ or (X, Y, Z) color model.
- X, Y, Z represents vectors in a three dimensional, additive color space.
- Any color C_λ is a combination of three primary colors as,

  $$C_\lambda = XX + YY + ZZ$$

- Where X, Y, Z is the amount of standard primary need to combine for obtaining color C_λ.
- If we normalize it then,

$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z} \quad z = \frac{Z}{X+Y+Z}$$

- With $x + y + z = 1$.



Contd.

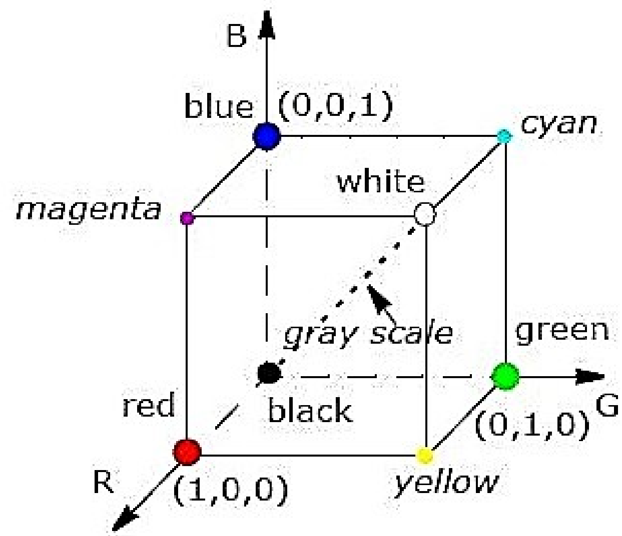
- Now we can represent any color with x, y only as z we can find $z = 1 - x - y$.
- x and y are called chromaticity values because they depends only on hue and purity.
- Now if we specify colors with only x and y values we cannot find amount X, Y and Z.
- So we specify color with x, y and Y and rest CIE amount is calculated as,

$$X = \frac{x}{y}Y \qquad Z = \frac{z}{y}Y$$

where $z = 1 - x - y$

RGB Color Model

- Based on tristimulus theory of vision our eye perceives color through stimulate one of three visual pigments in the cones of the retina.
- These visual pigments have peak sensitivity at red, green and blue color.
- So combining these three colors we can obtain wide range of color this concept is used in RGB color model.
- This model is represented as unit cube.
- Origin represent black color and vertex $(1,1,1)$ is white.

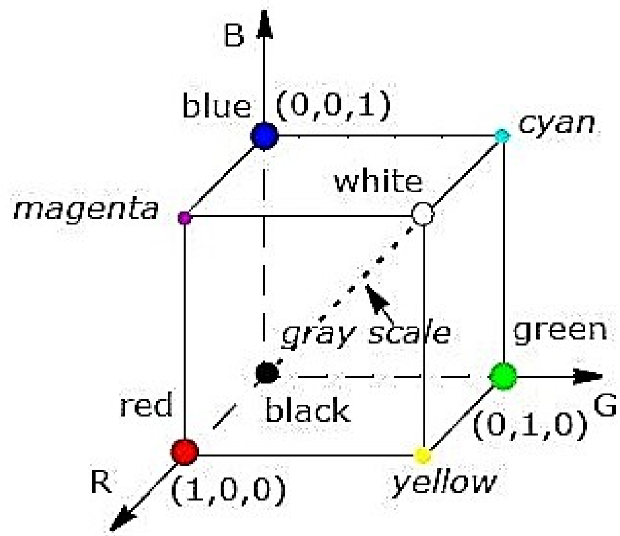


Contd.

- Vertex of the cube on the axis represents primary color R, G, B.
- In RGB color model any color intensity is obtained by addition of primary color,

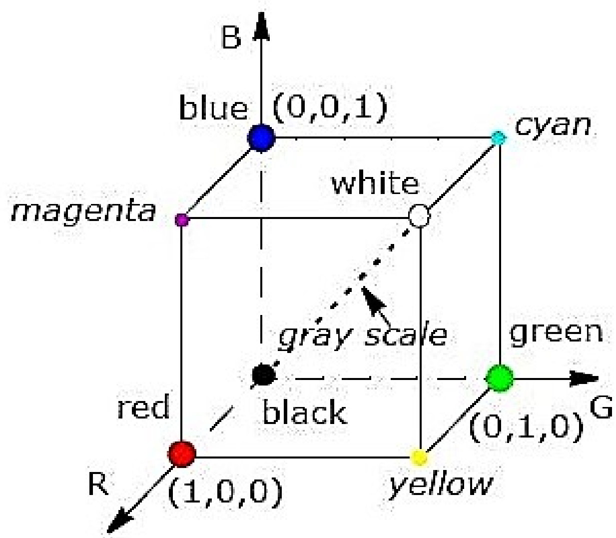
  $C_{\lambda} = RR + GG + BB$

  where R, G, B is amount of corresponding primary color.



Contd.

- Since it is bounded in between unit cube it's values is very in between 0 to 1 and represented as triplets (R, G, B).
- For example magenta color is represented with $(1,0,1)$.
- Shades of gray are represented along the main diagonal of cube from black to white vertex.
- For half way gray scale we use triplets $(0.5,0.5,0.5)$.



YIQ Color Model

- As we know RGB monitors requires separates signals for red, green, and blue component of an image.
- But television monitors uses single composite signals.
- For this composite signal NTSC use YIQ color model.
- Here parameter Y is represented as luminance (brightness).
- Chromaticity information (hue and purity) is specified into I and Q parameter.
- Combination of all red, green, and blue intensities are chosen for Y so black and white television monitors only use signal Y for brightness.
- So largest bandwidth (about $4\ MHz$) is assigned to Y information signal.

Contd.

- Parameter I contain orange-cyan hue information that provides the flash-tone shading, and occupies a bandwidth approximately 1.5 MHz.
- Parameter Q carries green-magenta hue information in a bandwidth of about 0.6 MHz.
- An RGB signal can be converted to a television signal using encoder which converts RGB to YIQ values.
- This conversion by transformation is given by,

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.528 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

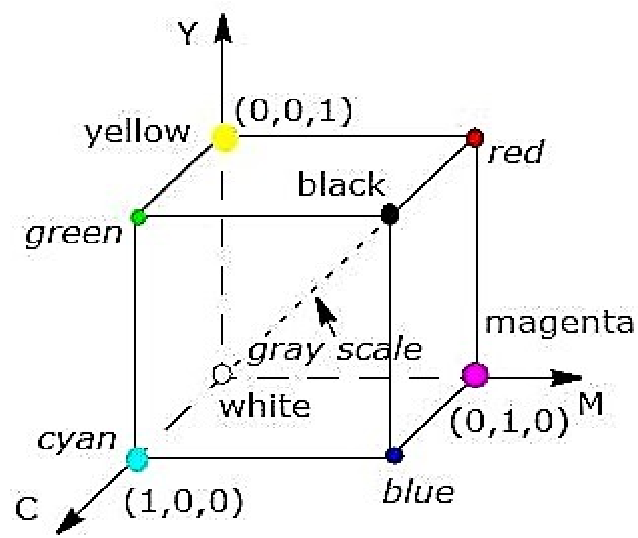
Contd.

- Similarly reverse of this is performed by decoder and by transformation using inverse of above matrix as,

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.000 & 0.956 & 0.620 \\ 1.000 & -0.272 & -0.647 \\ 1.000 & -1.108 & 1.705 \end{bmatrix} \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

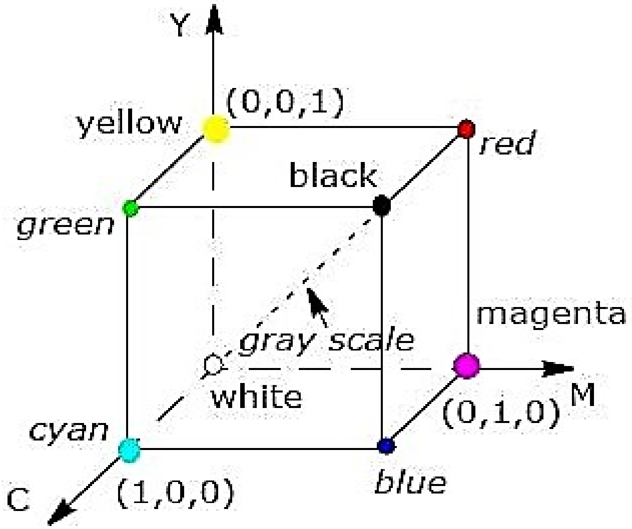
CMY Color Model

- A color model CMY is used for hardcopy devices.
- We produce picture by coating a paper with color pigments, we see the color by reflected light a subtractive process.
- When white light is reflected from cyan colored ink the reflected light must have no red component that is red light is absorbed or subtracted by the ink.
- Similarly magenta is subtracting green component.



Contd.

- Point (1,1,1) represents black because all components are subtracts and origin represents white light.
- Gray can be produce among main diagonal by using all three color in equal amount.
- Printing process often use CMY model generates a color points with a collection of four ink dots, one for each primary color C, M, and Y and one dot is black.



Contd.

- Conversion of RGB to CMY is done by,

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

- And similarly reverse is done by,

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

Thank You