Color Models

Unit-1

What is color?

- **Color** is a sensation produced by the human eye and nervous system. It is related to light.

- **Color Gamut**: The range of colors that can be described by combinations of the other colors is called a color gamut.

Color Model

- A color space or color model is a method by which we can specify, create and visualize color.
- A color model or color space is a method for explaining the properties or behavior of color within particular context.
- It is a mathematical way of representing a set of colors.
- A color model is an orderly system for creating a whole range of colors from a small set of primary colors.
- There are several established color models used in computer graphics, **RGB, CMY, CMYK, YIQ** etc. but the most common are the RGB model (Red-Green-Blue) for computer display and the CMYK (Cyan-Magenta-Yellow-Black) for printing.

Electromagnetic Spectrum

- Light or colors form a narrow frequency band within the electromagnetic spectrum.

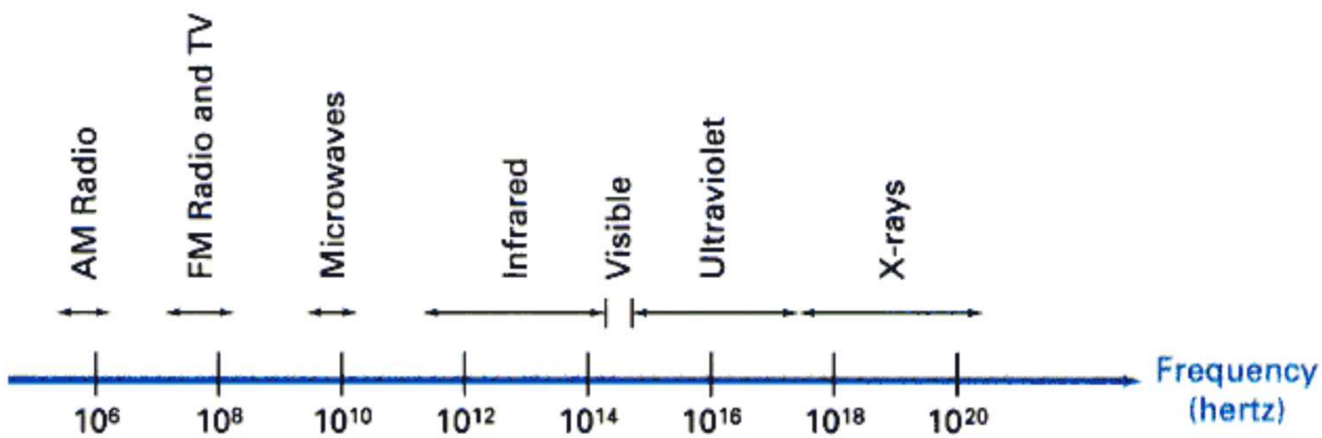


Figure: Electromagnetic Spectrum

Why multiple color models?

- Different color spaces are better for different applications. And one color model cannot explain all aspects of different color. So there is necessity of multiple color models.

Properties of Light:

- ***Hue (color)***: The dominant frequency reflected by the object.
- ***Brightness*** : The perceived intensity of the light. This is related to the luminance of the source.
- ***Purity (Saturation)*** : How pure the color of the light appears.
- ***Chromaticity***: Collectively refer to purity and hue.
- ***Complementary Colors***: e.g.. Red and Cyan, Green and Magenta, Blue and Yellow, which combine and form white light.
- ***Primary Colors***: e.g. R, G, B – starting from these colors, a wide range of other colors can be formed.

Categories of Color Models

Several Color models, but fall into two broad categories:

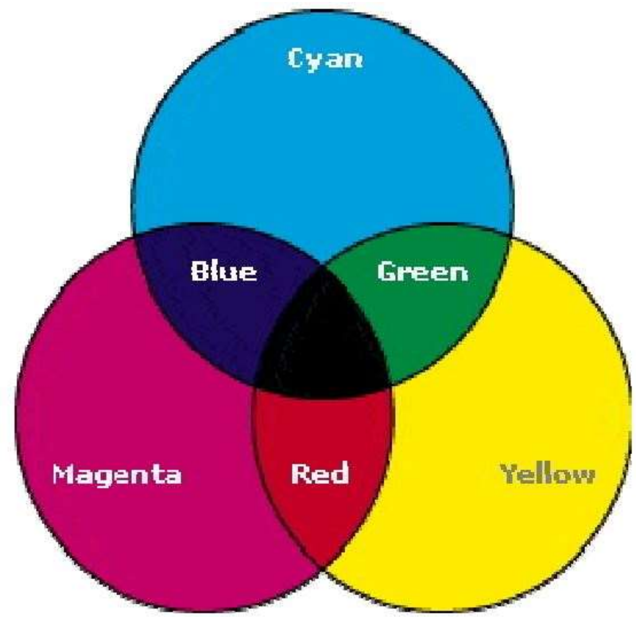
1. Additive Color Model
2. Subtractive Color Model

Additive vs. Subtractive Color Model:

- 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.
- RGB color models is an example of additive color model and CMYK color model is an example of subtractive color model.

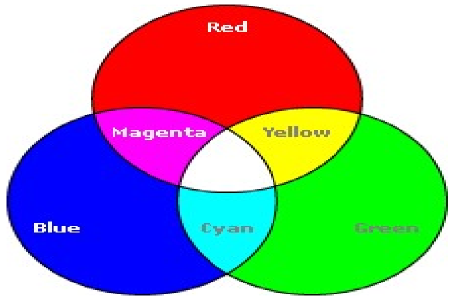
Subtractive Color Model

RGB Combination (R, G, B)	Perceived Color
Red only (255, 0, 0)	Red
Green only (0, 255, 0)	Green
Blue only (0, 0, 255)	Blue
Red and Green (Blue Subtracted) (255, 255, 0)	Yellow
Red and Blue (Green Subtracted) (255, 0, 255)	Magenta
Green and Blue (Red Subtracted) (0, 255, 255)	Cyan
Red, Green, and Blue (255, 255, 255)	White
None (0, 0, 0)	Black



RGB Color Model

- RGB color model is described by three primary colors: Red, Green, Blue. It is a de-facto standard for all other color models.
- Additive color model.
  - Magenta = Red + Blue
  - Cyan = Green + Blue
  - Yellow = Red + Green

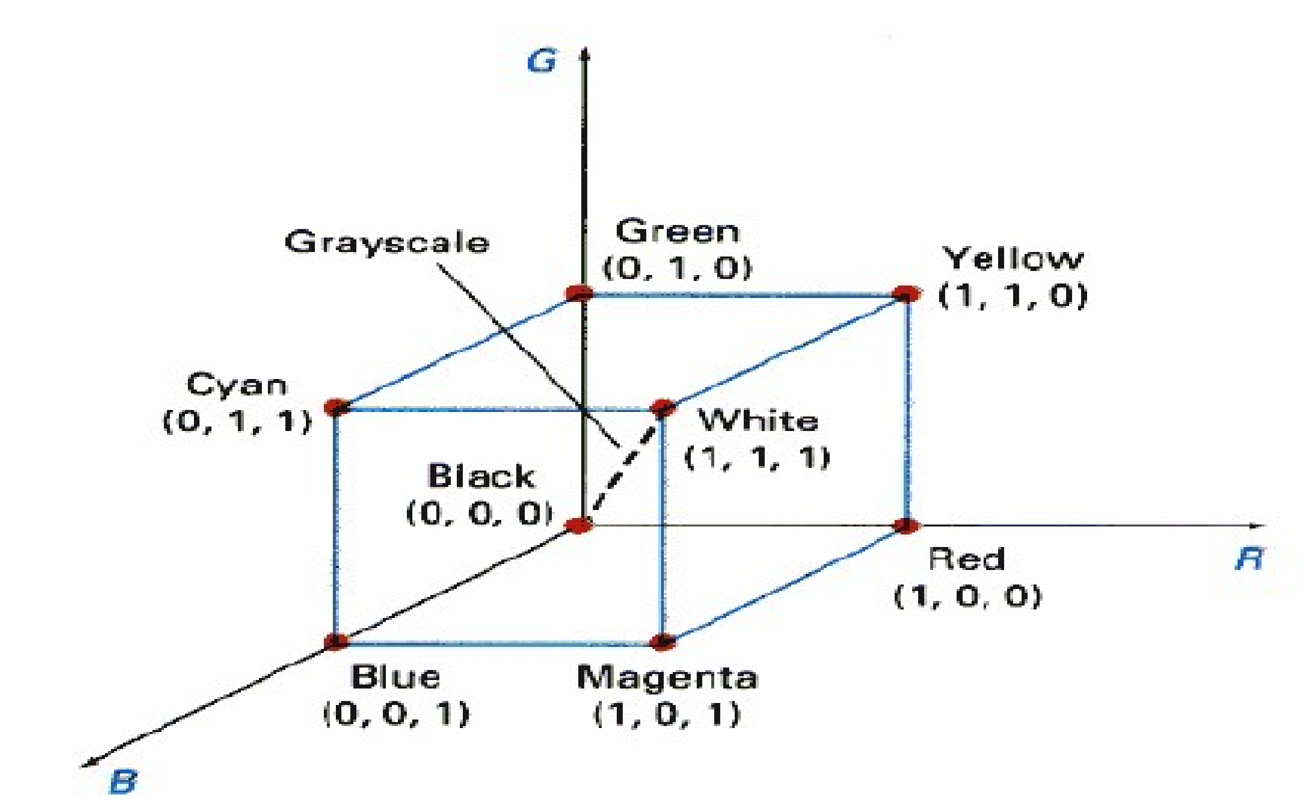


- In the RGB color model, colors are represented by varying intensities of red, green and blue light. The intensity of each of the red, green and blue components is represented on a scale from 0 and 255 (i.e. 24 bit colors, so 8 bits for each component R, G and B) with 0 being the least intensity (no light emitted) to 255 (maximum intensity).
- It is used in hardware application like PC monitors, cameras.

RGB Color Model :Geometrical Structure

- RGB color model geometrically represented an a unit defined on R, G, and B primary axes.
- Each point on this cube represents a color.
- The origin represents black (0, 0, 0) and the vertex with coordinates (1, 1, 1) is white.
- Vertices of the cube on the axes represent primary colors, and remaining vertices represent the complementary color.

RGB Color Model



HSV Color Model

- It is natural way to describe, perceive colors. It is user oriented color model. The HSV color model attempts to characterize colors according to their Hue, Saturation, and Value (brightness).
- **Hue** : The hue of a color identifies what is commonly called "color". For example, all reds have a similar hue value whether they are light, dark, and intense. The hue is determined by the dominant wavelength.
- **Saturation** : The saturation of a color identifies how pure the color is. A fully saturated color is deep and brilliant and as the saturation decrease the color gets paler and more washed out until it eventually fades to neutral.
- **Brightness or Value** : The brightness of a color identifies how light or dark the color is. Any color whose brightness is zero is black, regardless of its hue or saturation.

HSV Color Model: Geometrical Structure

- HSV is derived from the RGB model.
- Polar coordinate representation of RGB color model.
- It has Hex-cone like geometrical structure.
- Hex cone origin (apex) represent black.

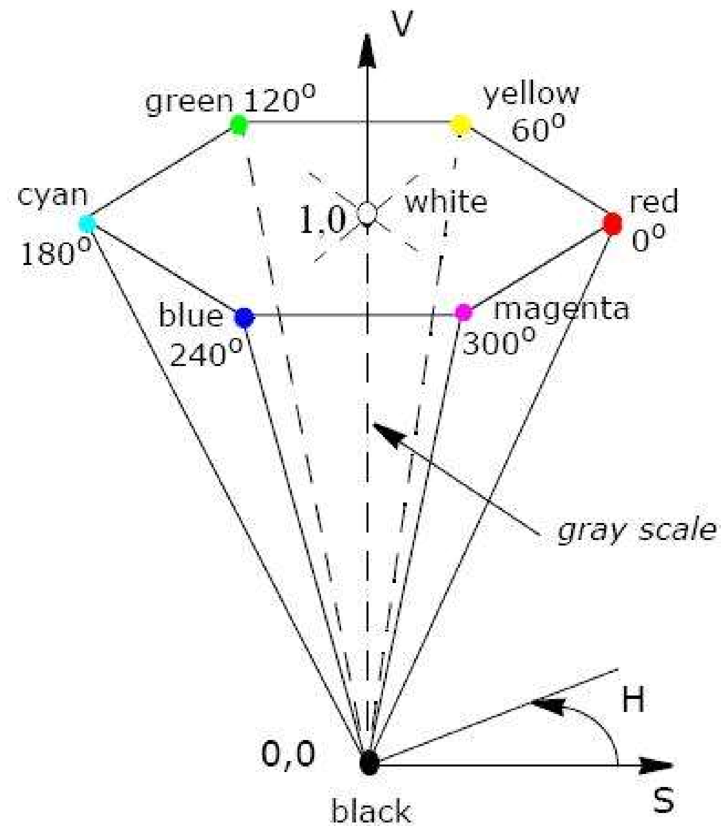


Figure: HSV Hexcone

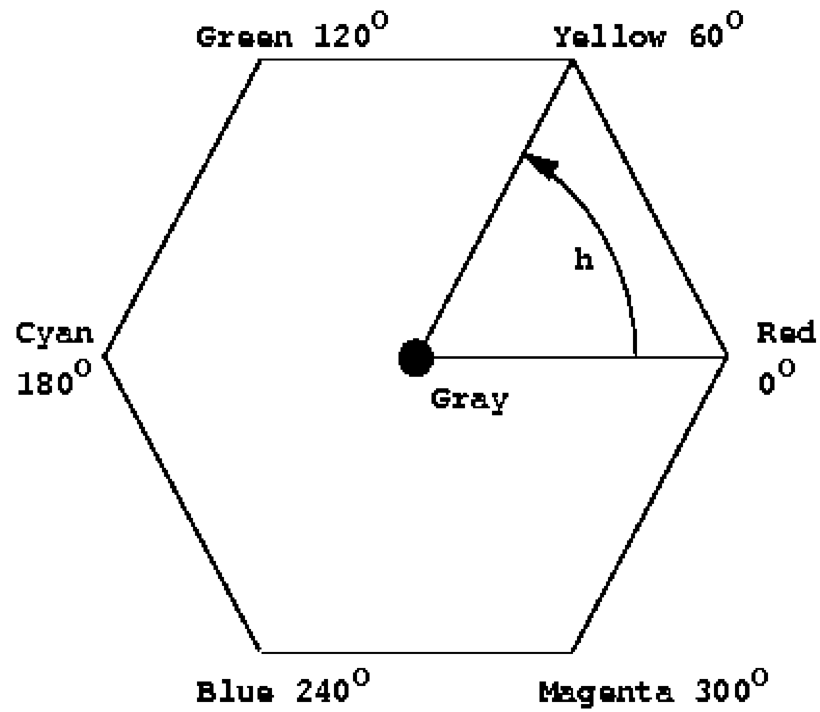
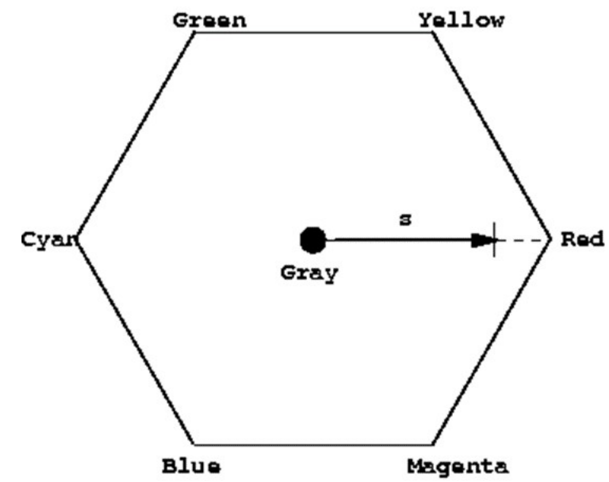


Figure: Various Hues

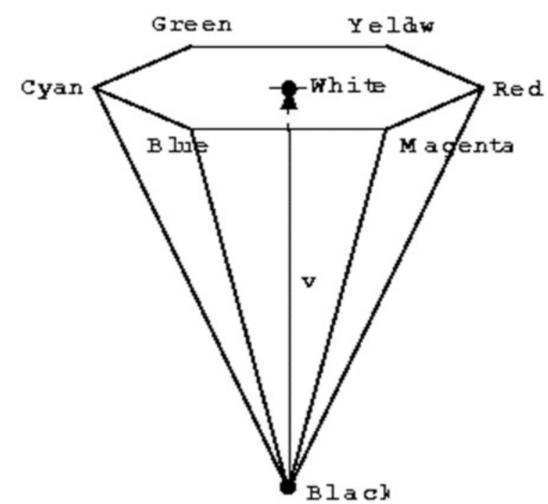
Hue (H)

- It is an angular measure ranges from 0 to 360.
- Hex cone boundary represents various hues.
- Hue is represented as an angle about the vertical axis, ranging from 0 degree at red through 360 degree. Vertices of hex cone are separated by 60 degree.



Saturation (S)

- It is a fractional measure. (0.0, 0.1, …… 1.0)
- It is measured along horizontal axis.
- It varies from 0 to 1.



Value (V)

- It is a fractional measure ranges from 0.0 to 1.0.
- Vertical axis represent Value (V), varies from 0 at the apex (Black) to 1 (White) at the top.

XYZ Color Model

- The 3-D picture is represented in computer graphics by the three vectors X, Y, and Z. The XYZ model represents pictures in additive color space. Any color *Ci* is represented by the equation

$$C_i = aX + bY + cZ$$

  where a, b, c represent the amount of standard primaries required to match C_i.

- For convenience we normalize the amount in the above equation against luminance (a + b + c). Normalized amount are thus given by the following equations:

$$a_n = \frac{a}{a+b+c}, \quad b_n = \frac{b}{a+b+b}, \quad c_n = \frac{c}{a+b+c}$$

such that $a + b + c = 1$.

Conversion : RGB to HSV conversion

Input: RGB

Output: HSV

Step 1: [normalize the RGB values to be in the range [0, 1]]

$r = R/ 255$

$g = G/ 255$

$b = B/ 255$

Step 2: [Find the difference between max and min values]

$M = \max(r, g, b)$,

$m = \min(r, g, b)$.

And, difference $\Delta = M-m$.

Step 3: [Calculate value V]

$V = \max(r, g, b)$

Step 4: [Calculate saturation S]

If $\Delta = 0$, then $S = 0$, otherwise

$S = \Delta / M$

Step 5: [Calculate hue H]

If $M=r$ then $H = 60*((g-b / \Delta) * \bmod 6)$

If $M=g$ then $H = 60*(2 + (b-r)/\Delta)$

If $M=b$ then $H = 60(4 + (r-g)/ \Delta)$

Step 6: [output HSV]

The calculated H, S, and V are the output of the algorithm.

Conversion: HSV to RGB

Input: HSV

Output: RGB

- When $0 \le H < 360$, $0 \le S \le 1$ and $0 \le V \le 1$.

$$C = V \times S$$

$$X = C \times (1 - |(H / 60^\circ) \bmod 2 - 1|)$$

$$m = V - C$$

$$(R', G', B') = \begin{cases} (C, X, 0) & , 0^\circ \le H < 60^\circ \\ (X, C, 0) & , 60^\circ \le H < 120^\circ \\ (0, C, X) & , 120^\circ \le H < 180^\circ \\ (0, X, C) & , 180^\circ \le H < 240^\circ \\ (X, 0, C) & , 240^\circ \le H < 300^\circ \\ (C, 0, X) & , 300^\circ \le H < 360^\circ \end{cases}$$

- $(R, G, B) = (R'+ m, G'+ m, B'+ m)$.

Conversion : RGB to CMY Model

Input: RGB

Output: CMY

Step 1: [normalize the RGB values to be in the range [0, 1]]

$r = R/ 255$

$g = G/ 255$

$b = B/ 255$

Step 2: Calculate

$C = 1- r$

$M = 1 – g$

$Y = 1 - b$

Conversion : CMY to RGB Model

Input: CMY

Output: RGB

Step 1: [normalize the CMY values to be in the range [0, 1]]

$c = C/255$

$m = M/255$

$y = Y/255$

Step 2: Calculate

$R = 1 - c$

$G = 1 - m$

$B = 1 - y$

Applications of Color Models

- RGB model is used in hardware devices such as computer monitors, cameras, and scanners.
- CMYK model is used in hard copy devices such as printer, plotters.
- And HSV color model is used in real life applications to describe perception of viewer.