# Computer Graphics

## Color Models

# Achromatic or Monochrome

- Used as a synonym for ‘black and white’
- All RGB values are equal ( r=g=b)
- Different intensities of grey
- Lack of hue (pure color), saturation (intensity of a color) and brightness
- Only measured using the quantity of light

# Electromagnetic Spectrum

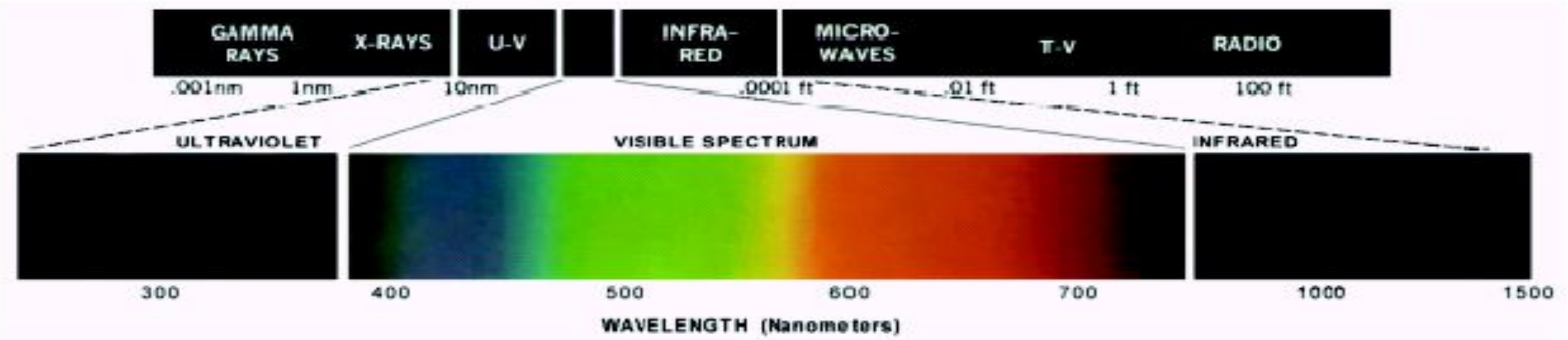
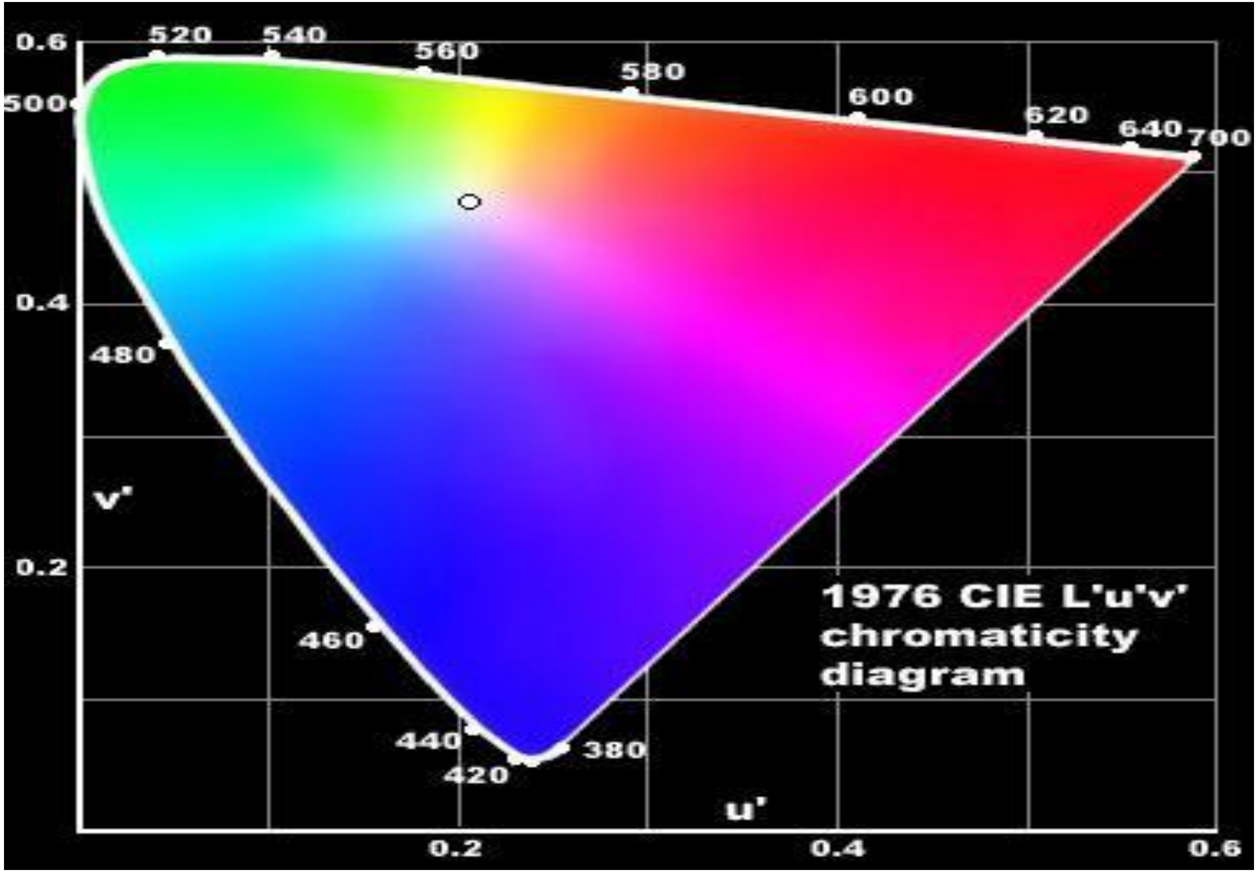


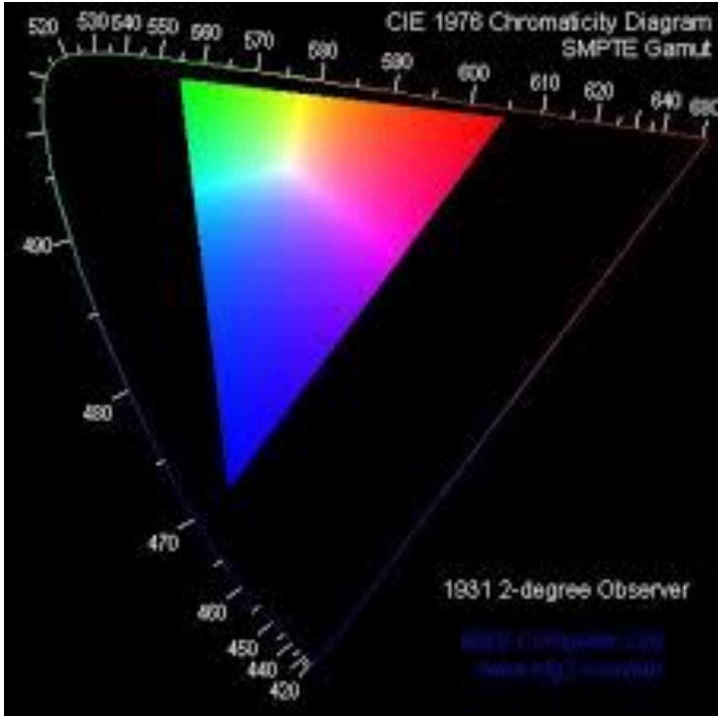

**FIGURE 6.2** Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

- Visible light: a narrow band of electromagnetic radiation →
  **380nm (blue) - 780nm (red)**

# Chromaticity Diagram



# Color Gamut




The color gamut describes a range of colors within the spectrum of colors, or a color space, that can be reproduced on an output device. Depending on how wide the gamut is, every screen will display different quantities of color.

# Color Systems

- The purpose of a color model (also called Color Space or Color System) is to facilitate the specification of colors in some standard way.

- A color model is a specification of a coordinate system and a subspace within that system where each color is represented by a single point.

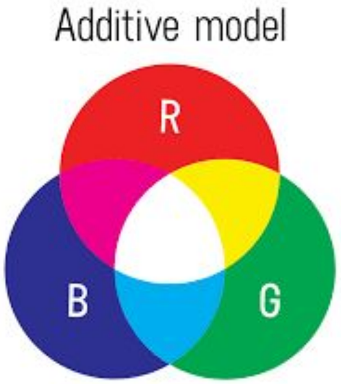
- Available color systems are dependent on the medium on which one is working.

# Different Color Models

- RGB (Red, Green, Blue)
- CMY (Cyan, Magenta, Yellow)
- HSV (Hue, Saturation, Value)
- HLS (Hue, Lightness, Saturation)
- YIQ (Luminance,In phase, Quadrature)
- YUV (Y' stands for the lumaY' stands for the luma component (the brightness) and U and V are the chrominance (color) components )

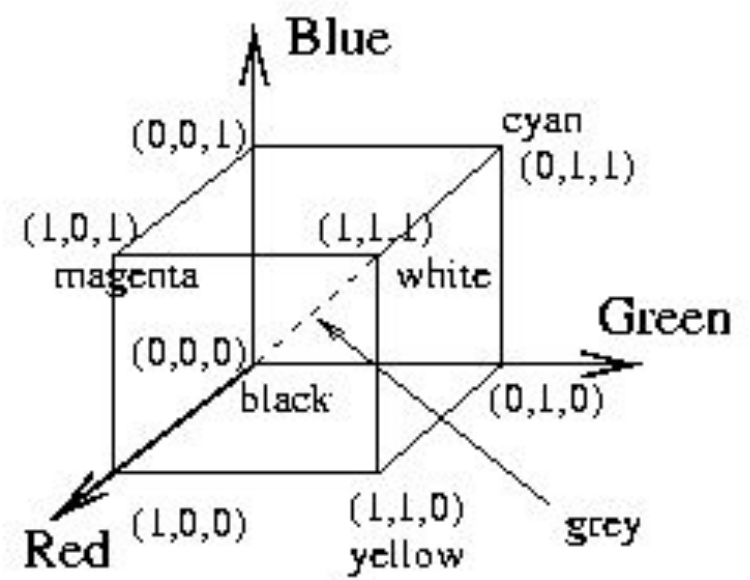
# Additive Color

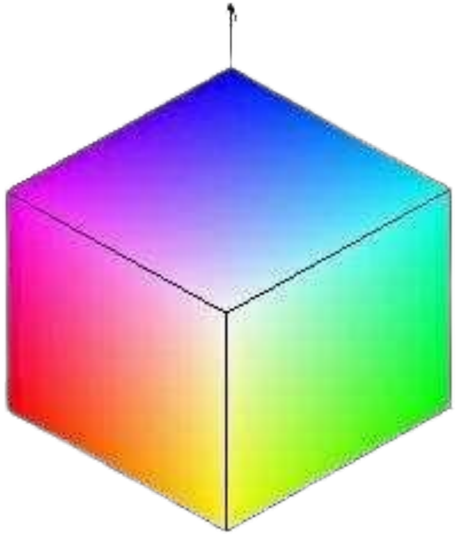
Additive color mixing begwe are working on a computer, the colors we see on the screen are created with light using the additive color method. ins with black and ends with white; as more color is added, the result is lighter and tends to white. If




**RGB** color model applies
**Additive** model

# RGB Model



Model based on Cartesian Coordinate System

RGB 24 bit color cube

# RGB Model

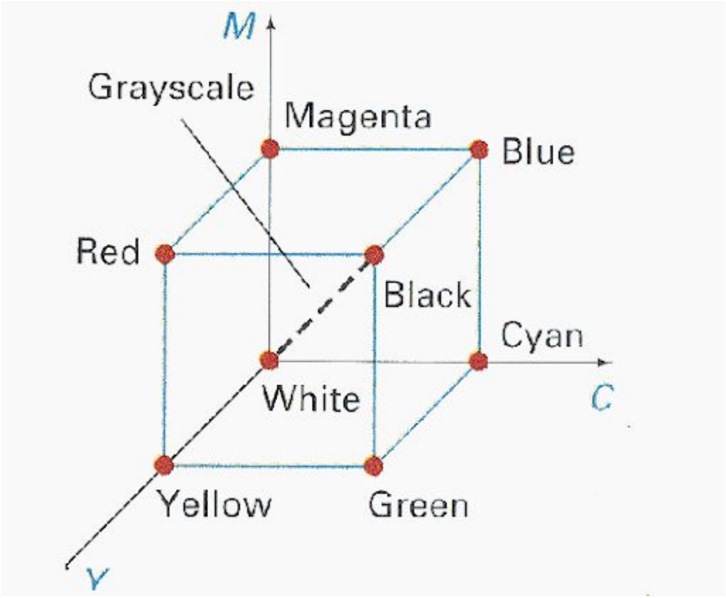
- Primary colors are **red**, **green**, and **blue**.
- The RGB model is usually represented by a unit cube with one corner located at the origin of a three-dimensional color coordinate system, the axes being labeled R, G, B, and having a range of values [0, 1].
- The origin (0, 0, 0) is considered **black** and the diagonally opposite corner (1, 1, 1) is called **white**. The line joining black to white represents a gray scale and has R=G=B.
- This is the model used for active displays such as television and computer screens.

# Subtractive Color

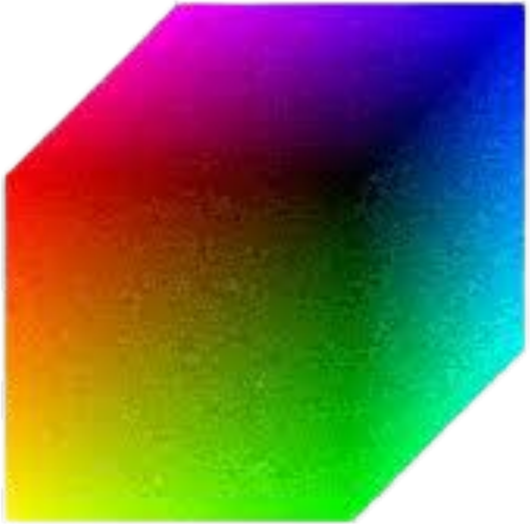
Subtractive color mixing means that one begins with white and ends with black; as one adds color, the result gets darker and tends to be black. When we mix colors using paint, or through the printing process, we are using the subtractive color method.

**CMY** color model applies **Subtractive** model

# CMY Model




Model based on Cartesian Coordinate System



CMY color cube

# CMY Model

- Cyan, magenta, and yellow are the secondary colors with respect to the primary colors of red, green, and blue. However, in this subtractive model, they are the primary colors and red, green, and blue, are the secondaries.
- In this model, colors are formed by subtraction, where adding different pigments causes various colors not to be reflected and thus not to be seen. Here, white is the absence of colors, and black is the sum of all of them.
- Most devices that deposit color pigments on paper **(such as Color Printers and Copiers)** requires CMY data input or perform RGB to CMY conversion internally.

$$\begin{pmatrix} C \\ M \\ Y \end{pmatrix} = \begin{pmatrix} 1.00 \\ 1.00 \\ 1.00 \end{pmatrix} - \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

# RGB - CMY Conversion

Q. Convert RGB value of (64, 128, 192) to CMY

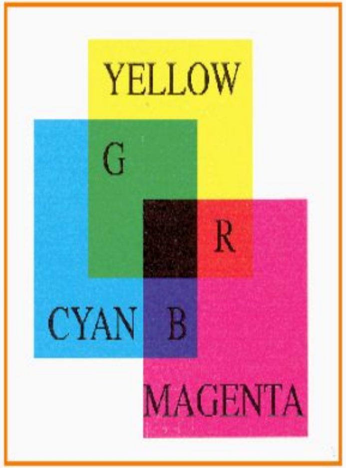
(Normalise) $R' = \frac{64}{255} = 0.251, \quad G' = \frac{128}{255} = 0.502, \quad B' = \frac{192}{255} = 0.753$

$$
\begin{aligned}
C &= 1 - R' \\
&= 1 - 0.251 \\
&= \underline{0.749}
\end{aligned}
\qquad
\begin{aligned}
M &= 1 - G' \\
&= 1 - 0.502 \\
&= \underline{0.498}
\end{aligned}
\qquad
\begin{aligned}
Y &= 1 - B' \\
&= 1 - 0.753 \\
&= \underline{0.247}
\end{aligned}
$$

# CMYK Model



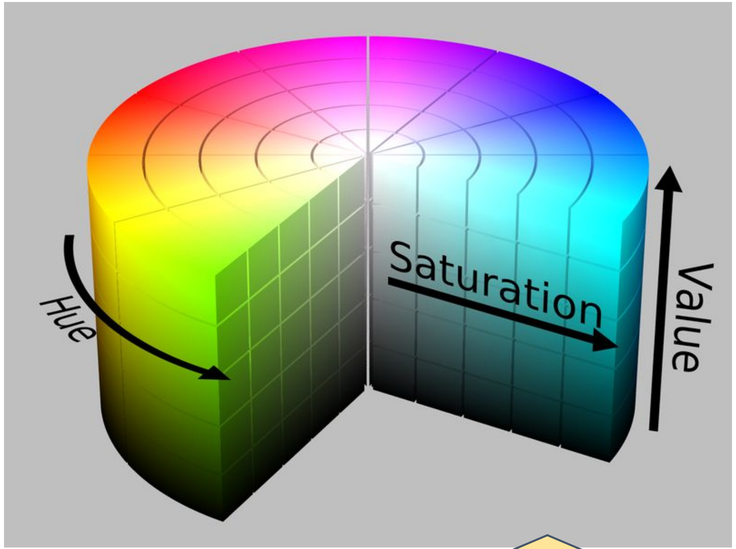
Equal amounts of pigment primaries (**Cyan**, **Magenta** and **Yellow**) should produce Black. In practice combining these colors for printing produces a "Muddy-Black" color. So in order to produce "**True-Black**" a fourth color "Black" is added giving rise to CMYK model.

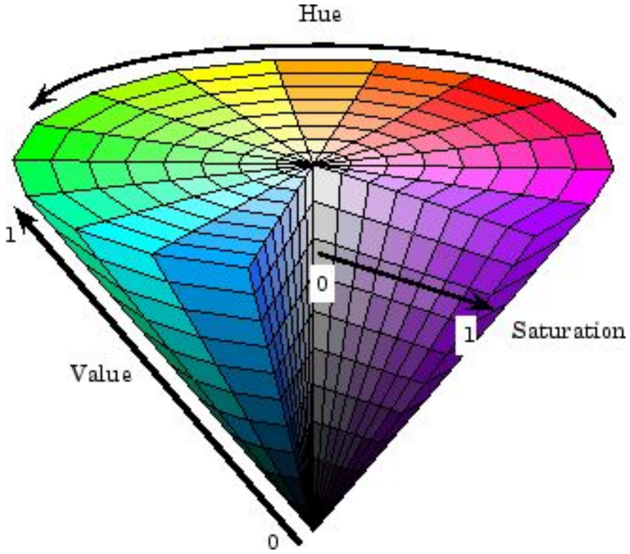



Colors are subtractive

| C | M | Y | Color |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | White |
| 1.0 | 0.0 | 0.0 | Cyan |
| 0.0 | 1.0 | 0.0 | Magenta |
| 0.0 | 0.0 | 1.0 | Yellow |
| 1.0 | 1.0 | 0.0 | Blue |
| 1.0 | 0.0 | 1.0 | Green |
| 0.0 | 1.0 | 1.0 | Red |
| 1.0 | 1.0 | 1.0 | Black |
| 0.5 | 0.0 | 0.0 | |
| 1.0 | 0.5 | 0.5 | |
| 1.0 | 0.5 | 0.0 | |

# HSV/HSB Color Model




Check this link

# HSV Color Model

### Hue (color wheel/dominant color)

- Wavelength of the pure colour observed in the signal.
- The cone represents the HSV model, the hue represents different colours in different angle ranges.
- More than **400 hues** can be seen by the human eye.

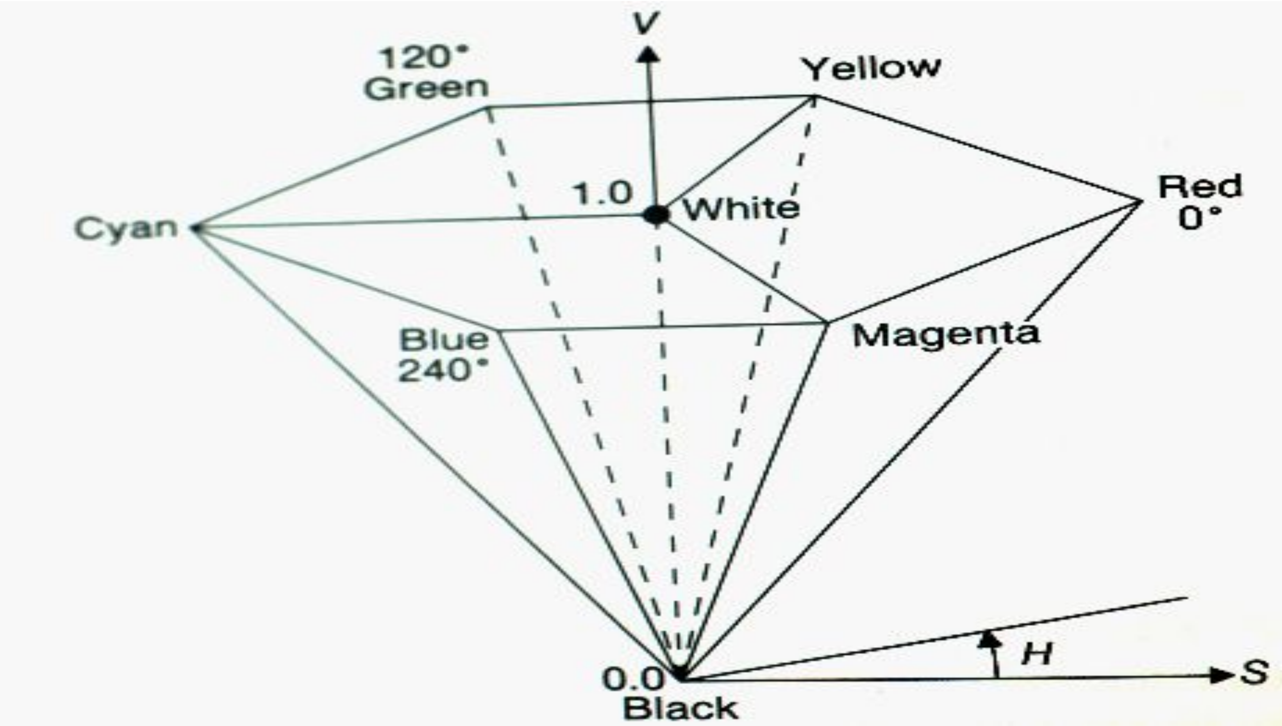
### Saturation (percentage/purity of the color)

- Inverse of the quantity of “white” present in the signal. A pure colour has 100% saturation, the white and grey have 0% saturation.
- About **20 saturation levels** are visible per hue.
- How far the color is from equal intensity grey
- Range **[0,1]**

### Value (brightness or intensity of a color)

- Distinguishes the grey levels. Its value lies in percentages **from 0 to 100**. 0 is black and 1 is the brightest and reveals the colour.
- Value describes how light or dark a color appears. Eg. A bright yellow has a high value. A dark brown or deep blue has a low value.
- Helps in generating shading or lighting effects in graphics.

# HSV Color Model



# RGB to HSV Conversion

1. Divide r, g, b by 255 (if the scale is 0-255, otherwise skip)

2. Compute cmax, cmin, difference
3. Hue calculation :
   - ❑ if cmax equal 0, then h = 0
   - ❑ if cmax equal r then compute h = **(g – b) / diff**
   - ❑ if cmax equal g then compute h = **2 + ((b – r) / diff)**
   - ❑ if cmax equal b then compute h = **4 + ((r – g) / diff)**

   **h = h * 60**

   **if h<0 → h = h + 360**

4. Saturation computation :
   - ○ if cmax = 0, then s = 0
   - ○ if cmax does not equal 0 then compute s = **(diff/cmax)*100**

5. Value Computation: **v = cmax*100**

# RGB to HSV Conversion Example

Q. RGB value of (200, 100, 50) to HSV

$$R' = \frac{200}{255} = 0.784, \quad G' = \frac{100}{255} = 0.392, \quad B' = \frac{50}{255} = 0.196$$

$$c_{max} = 0.784 \ (R)$$

$$c_{min} = 0.196 \ (B)$$

$$\text{difference} = 0.784 - 0.196 = 0.588$$

Calculate H:

$$c_{max} = R.$$

$$\therefore H = \left(\frac{G-B}{diff}\right) \times 60 = \frac{0.392 - 0.196}{0.588} \times 60 = \underline{20^\circ}$$

Calculate S:

$$S = \frac{diff}{c_{max}} = \frac{0.588}{0.784} = \underline{0.75}$$

Calculate V:

$$V = c_{max} = \underline{0.784}$$

# HSV to RGB Conversion

### 1. Calculate Chromatic Component ($C$)

The chroma C, represents the difference between the maximum and minimum RGB components:

$$C = V \times S$$

### 2. Find the Intermediate Value (X)

The value X is a scaled component based on the current segment of the hue:

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

### 3. Calculate the Adjustment (m)

The adjustment m, shifts the RGB values to match the value V (the maximum component):

$$m = V - C$$

### 4. Assign RGB Values Based on Hue Segment

The hue ($H$) determines the sequence of R,G,B. Divide $H$ into 6 segments (0º-360º):

| | |
|---|---|
| $0 \leq H < 60$ | $R = C, G = X, B = 0$ |
| $60 \leq H < 120$ | $R = X, G = C, B = 0$ |
| $120 \leq H < 180$ | $R = 0, G = C, B = X$ |
| $180 \leq H < 240$ | $R = 0, G = X, B = C$ |
| $240 \leq H < 300$ | $R = X, G = 0, B = C$ |
| $300 \leq H < 360$ | $R = C, G = 0, B = X$ |

### 5. Adjustment

Adjust the RGB values to match the original value (V):

$$R' = (R+m),\ G' = (G+m),\ B' = (B+m)$$

# HSV to RGB Conversion Example

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Q. HSV $(30°, 0.8, 0.9)$ to RGB

$$H = 30°, \quad S = 0.8, \quad V = 0.9$$

$$C = V \times S = 0.9 \times 0.8 = 0.72$$

Calculate $X$:

$$X = C \times (1 - |H/60 \bmod 2 - 1|)$$
$$= 0.72 \times (1 - |\tfrac{30}{60} \bmod 2 - 1|)$$
$$= 0.72 \times (1 - |0.5 \bmod 2 - 1|)$$
$$= 0.72 \times (1 - |0.5 - 1|)$$
$$= 0.72 \times (1 - 0.5)$$
$$= 0.72 \times 0.5 = 0.36$$

Calculate $m$:

$$m = V - C = 0.9 - 0.72 = 0.18$$

$0 \leq H < 60$ : $(R, G, B) = (C, X, 0)$

$$(R, G, B) = (0.72, 0.36, 0)$$

$$(R+m, G+m, B+m) = (0.9, 0.54, 0.18)$$

Scale: $(R * 255, G * 255, B * 255) = (230, \underline{138, 46})$

# HSV Color Model Application

1. The HSV model is widely used in computer graphics for intuitive **color selection** in tools like color pickers and gradient design.
2. It aids in **image processing** tasks such as color-based filtering, segmentation, and thresholding.
3. In **shading, lighting, and special effects**, HSV simplifies dynamic adjustments and smooth color transitions.
4. It's critical for **color grading** in video editing and **data visualization**, mapping values to colors effectively.
5. Additionally, HSV is essential in **gaming, AR/VR, and AI applications**, where it supports object highlighting, procedural content generation, and feature extraction.

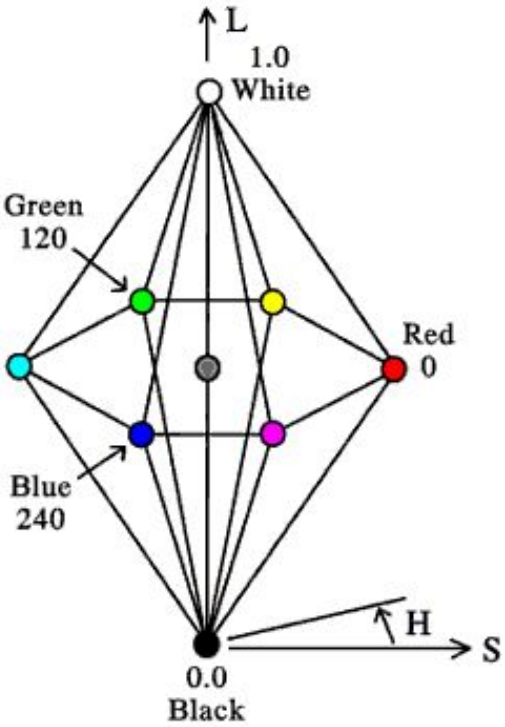
# HLS Color Model

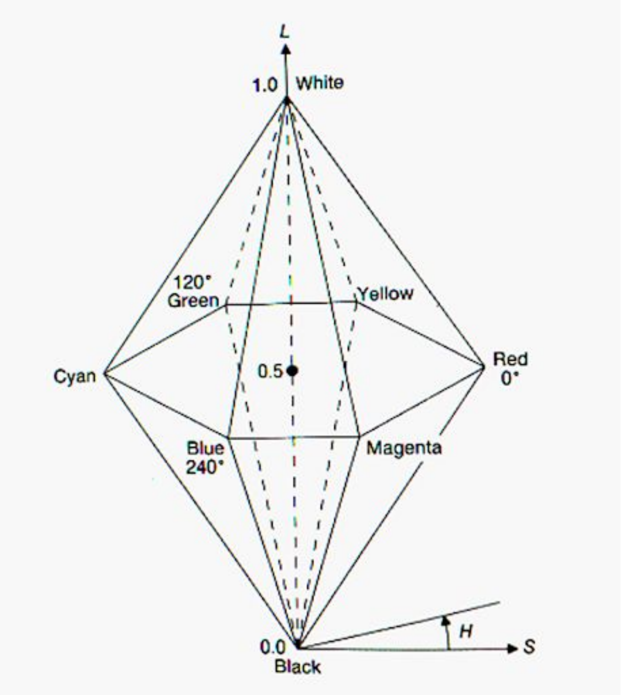
1. HLS (Hue, Lightness, Saturation) – A cylindrical color model.

2. a. Hue: Angle on the color wheel (e.g., 0° = red, 120° = green, 240° = blue).
   b. Lightness: 0=black,1=white,0.5=pure color.
   c. Saturation: 0=gray,1=fully vivid color

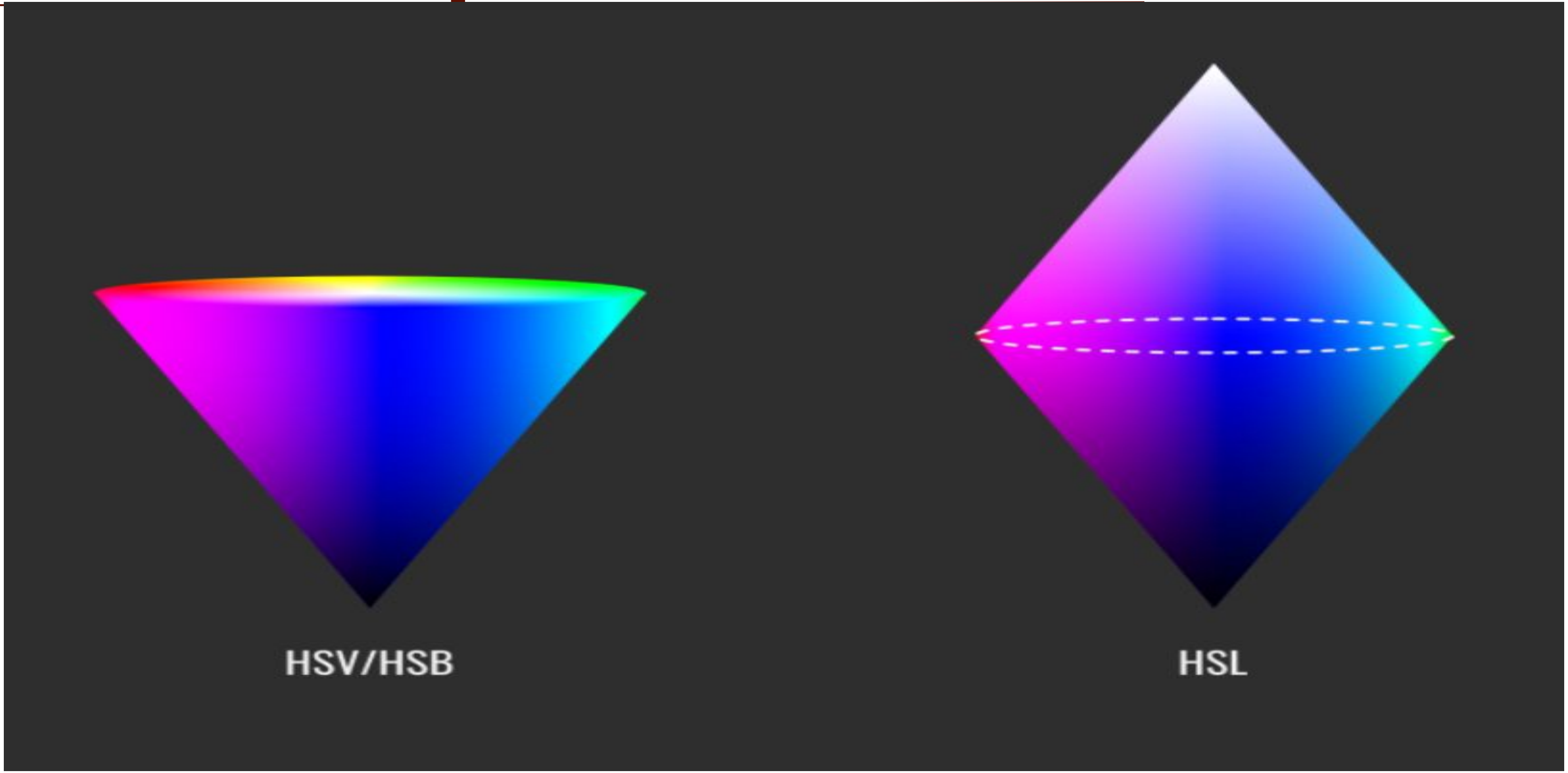
3. **Application: Image editing, color pickers, and design tools. Useful for adjusting brightness without altering color hue.**

# HLS Color Model



# HSV - HLS Comparison



# RGB to HLS Conversion

1. Normalise
2. Compute cmax, cmin, difference
3. L = (cmax + cmin) / 2
4. Hue calculation :
    - if diff = 0, then h = 0
    - if cmax equal r then compute H = **(g – b) / diff**
    - if cmax equal g then compute H = **2 + (b – r) / diff**
    - if cmax equal b then compute H = **4 + (r – g) / diff**
    1. **H = H * 60**
    2. **if H < 0 → H = H + 360**
5. Saturation computation :
    - if diff = 0, then S = 0
    - S = diff/(cmax + cmin)  if L <= 0.5
    - S = diff/[2- (cmax + cmin)] if L > 0.5

# RGB to HLS Conversion Example

Q. RGB (255, 165, 0) to HLS

(Normalise) $R' = \frac{255}{255} = 1$, $G' = \frac{165}{255} = 0.647$, $B' = \frac{0}{255} = 0$

$c_{max} = 1 \ (R)$

$c_{min} = 0 \ (B)$

$\text{difference} = 1 - 0 = 1$

Calculate L:

$$L = \frac{c_{max} + c_{min}}{2} = \frac{1+0}{2} = 0.5$$

Calculate S:

Since $L = 0.5$, $S = \frac{\text{diff}}{c_{max} + c_{min}} = \frac{1}{1+0} = 1$

Calculate H:

$c_{max} = R$, $H = 60 \times \left( \frac{G - B}{\text{diff}} \right)$

$$= 60 \times \left( \frac{0.647 - 0}{1} \right) = 38.82^\circ$$

# Exercise

Convert the following colors:

| | R | G | B | Hue | Sat. | Brightness/ Value | C | M | Y |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 0.25 | 0.30 | 1.0 | 236° | 75% | 100% | 0.75 | 0.7 | 0.0 |
| **2** | 0.01 | 1.00 | 0.99 | ? | ? | ? | ? | ? | ? |
| **3** | 1.0 | 0.11 | 0.01 | ? | ? | ? | ? | ? | ? |
| **4** | 0.8 | 0.8 | 0.3 | 60° | 62.5% | 80% | 0.2 | 0.2 | 0.7 |
| **5** | ? | ? | ? | ? | ? | ? | 0.1 | 0.3 | 0.1 |

# Reference


1. Computer Graphics: Principles and Practice: John F. Hughes, James D. Foley, Andries van Dam, Steven K. Feiner (2nd Edition)

   **Chapter: 13.1(before 13.1.1), 13.3.1, 13.3.2, 13.3.4, 13.3.5**

2. Website Links:
   - Link 1
   - Link 2
   - Link 3