Computer Graphics:
Achromatic and Coloured Light

Contents

Today we will start to take a look at various colour models:

- Achromatic or monochrome (r=g=b)
- Chromatic color
  - Additive color
  - Subtractive color
- CIE model (not in syllabus)
- Color gamut
- RGB model
- CMY model
- HSV model
- HLS model

Achromatic or monochrome

- Used as a synonym for “black and white.”
- Different intensities of greys
- Lack hue (pure color), saturation and brightness
- Only measured using the quantity of light (energy in terms of physics)
- All RGB values are equal (r=g=b)
- Different values for these three variables create different intensities of greys

Electromagnetic Spectrum

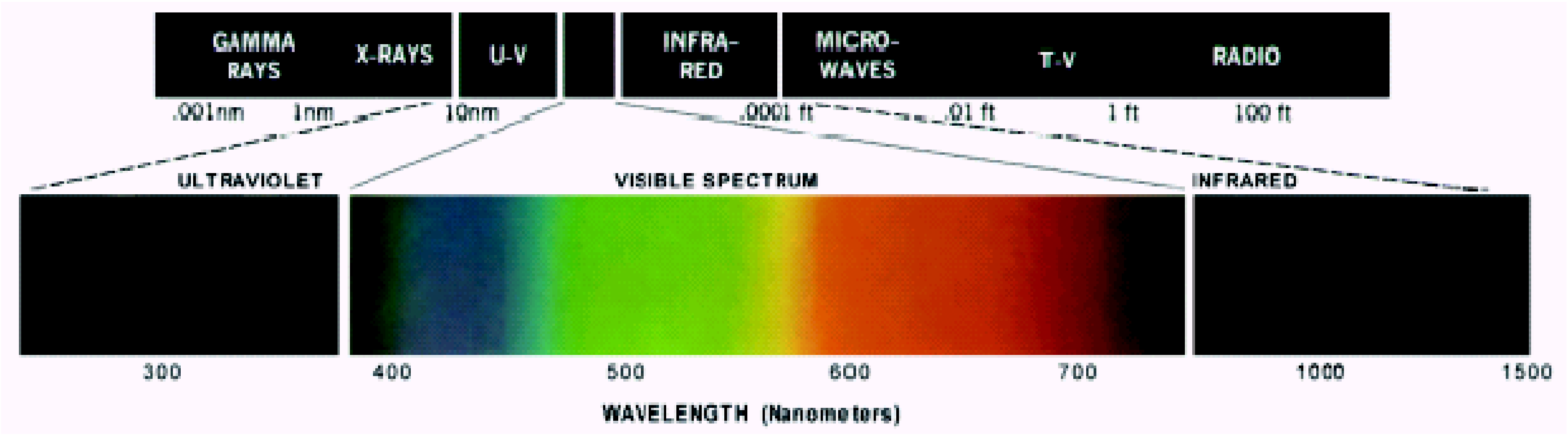


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

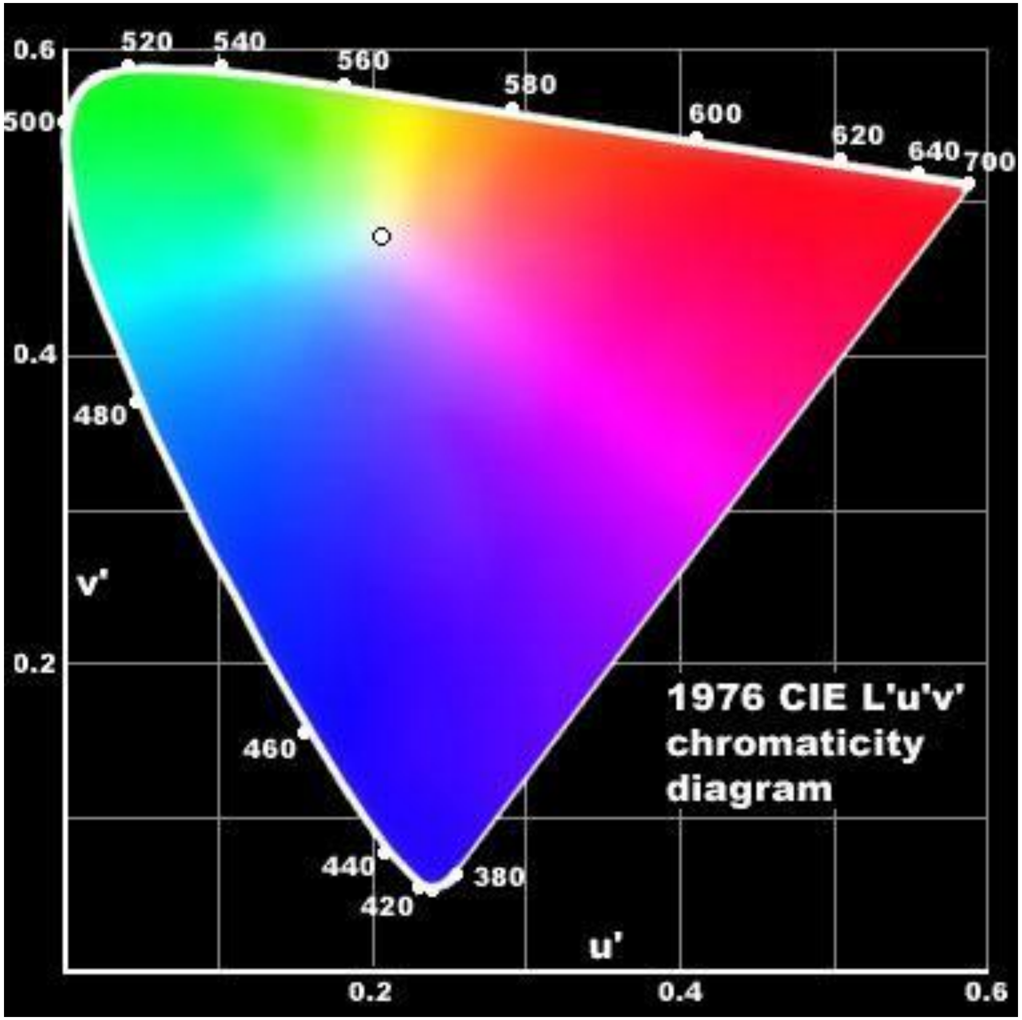
Visible light

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

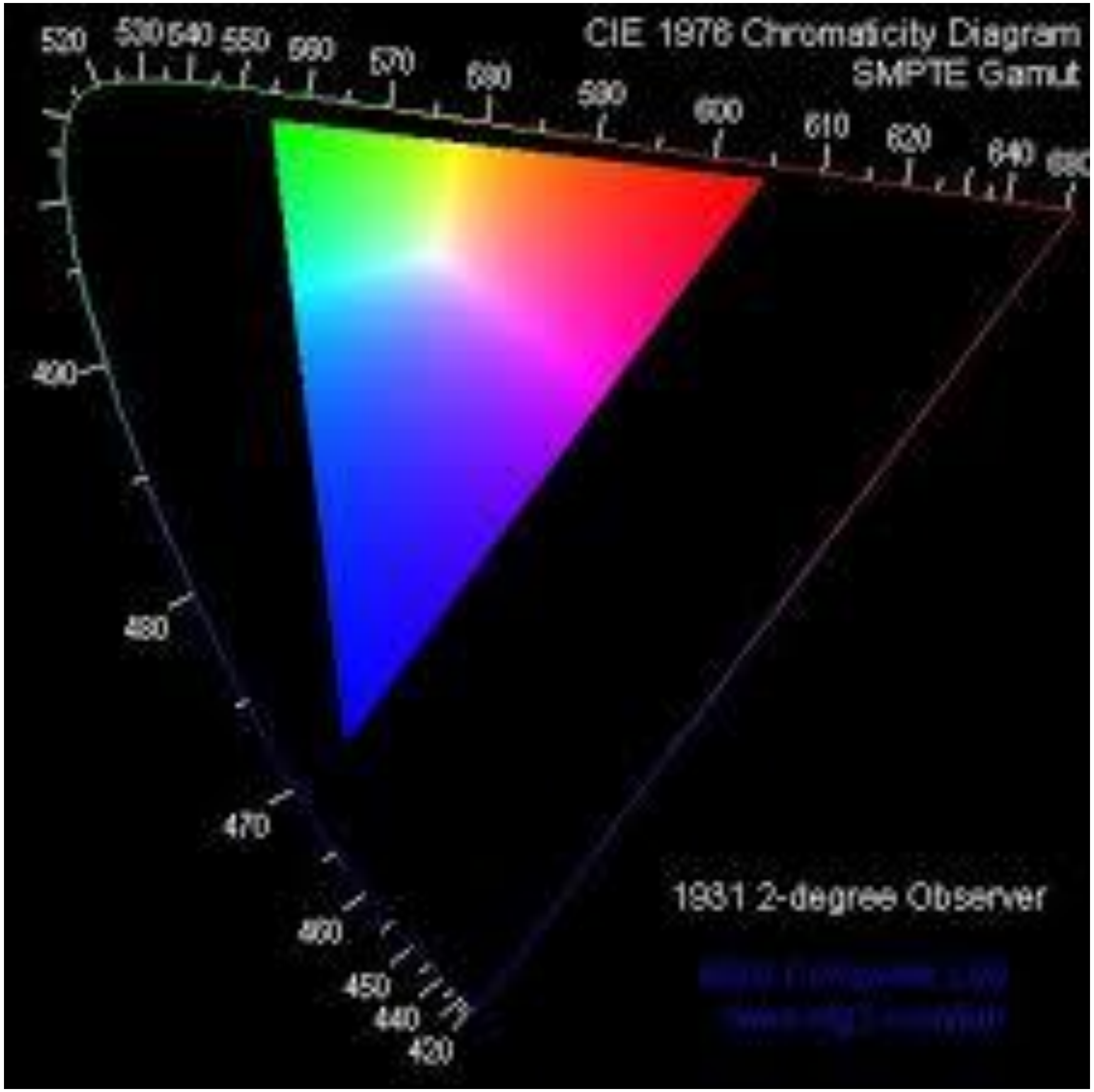
Chromatic Colors

- Visual sensation caused by colors
- spans the electromagnetic spectrum from approximately 400 to 700nm

Chromaticity Diagram



Color Gamut


CIE 1976 Chromaticity Diagram
SMPTE Gamut
520
530
540
550
560
570
580
590
600
610
620
640
490
480
470
460
450
440
420
1931 2-degree Observer

Color Models

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

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)

COLOR SYSTEMS

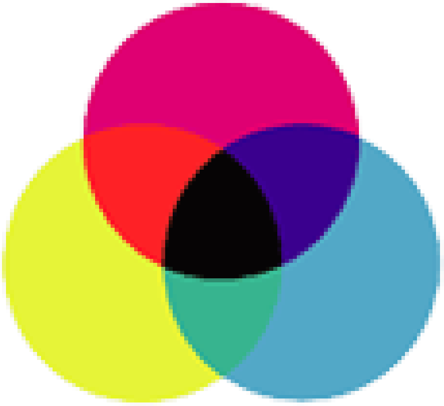
Available color systems are dependent on the medium with which a designer is working. When painting, an artist has a variety of paints to choose from, and mixed colors are achieved through the subtractive color method. When a designer is utilizing the computer to generate digital media, colors are achieved with the additive color method.

Additive Color

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

Subtractive Color

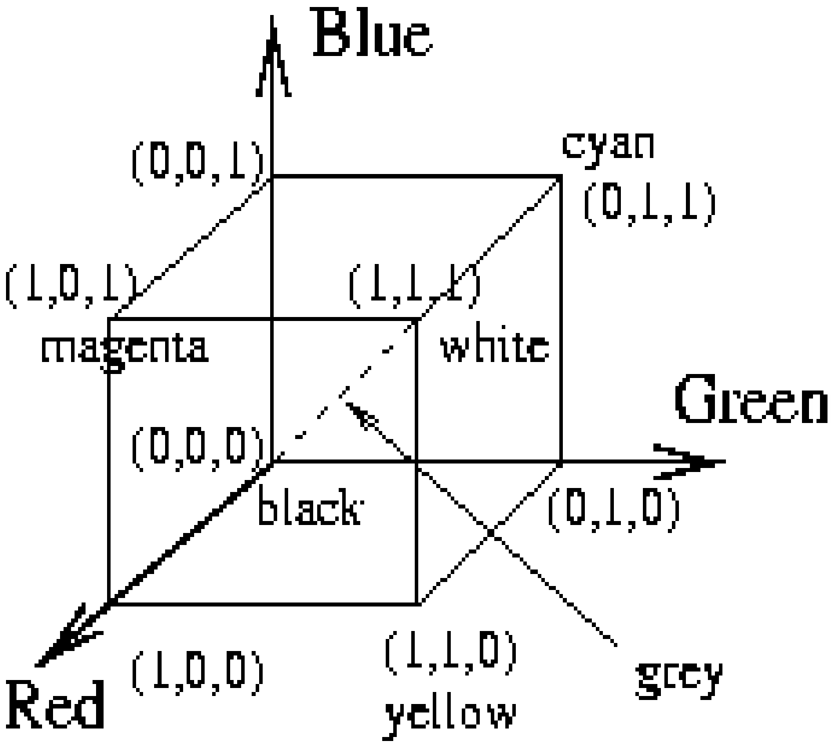
When we mix colors using paint, or through the printing process, we are using the subtractive color method. Subtractive color mixing means that one begins with white and ends with black; as one adds color, the result gets darker and tends to black



RGB Model

- Each color is represented in its primary color components Red, Green and Blue

- This model is based on Cartesian Coordinate System



RGB Model

In this model, the primary colors are red, green, and blue. It is an additive model, in which colors are produced by adding components, with white having all colors present and black being the absence of any color.

This is the model used for active displays such as television and computer screens.

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 equal components of R, G, B.

RGB Color Cube

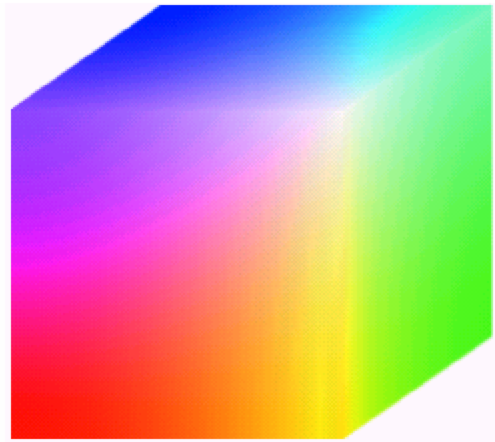


FIGURE 6.8 RGB 24-bit color cube.

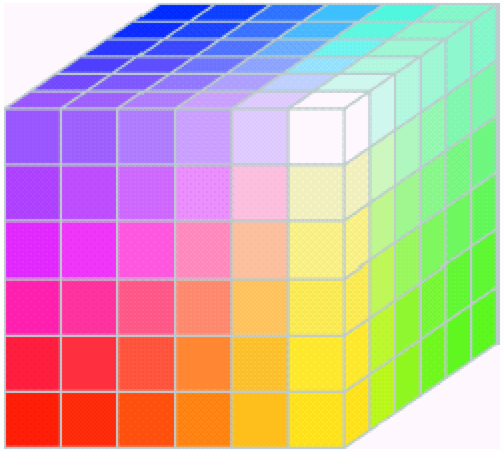


FIGURE 6.11 The RGB safe-color cube.

CMY and CMYK Color 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. This is generally the model used for printing.

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

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

CMY and CMYK Color Model

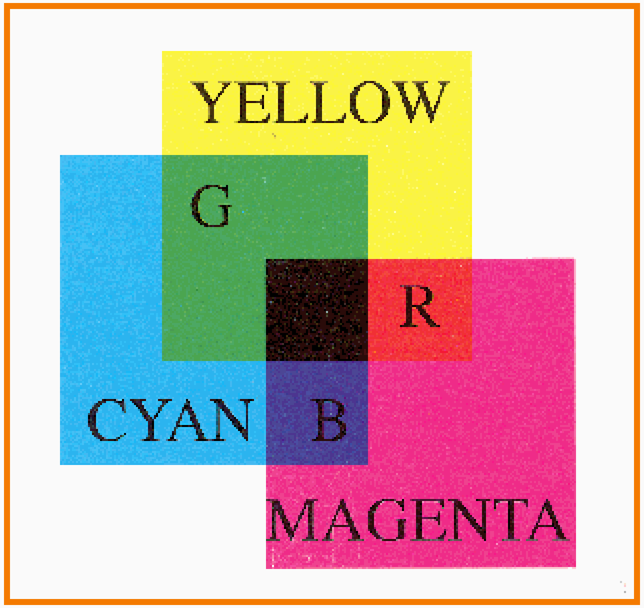
CMY is a Subtractive Color Model

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

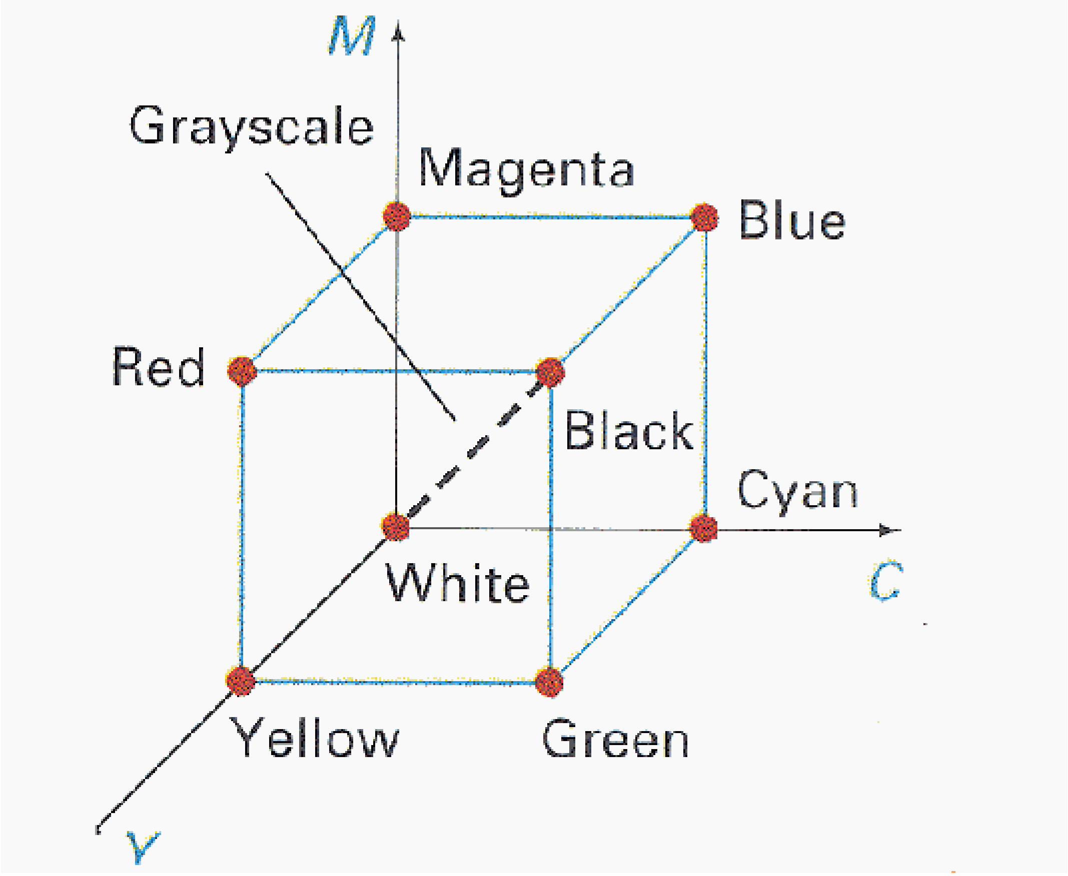
CMY and CMYK Color Model



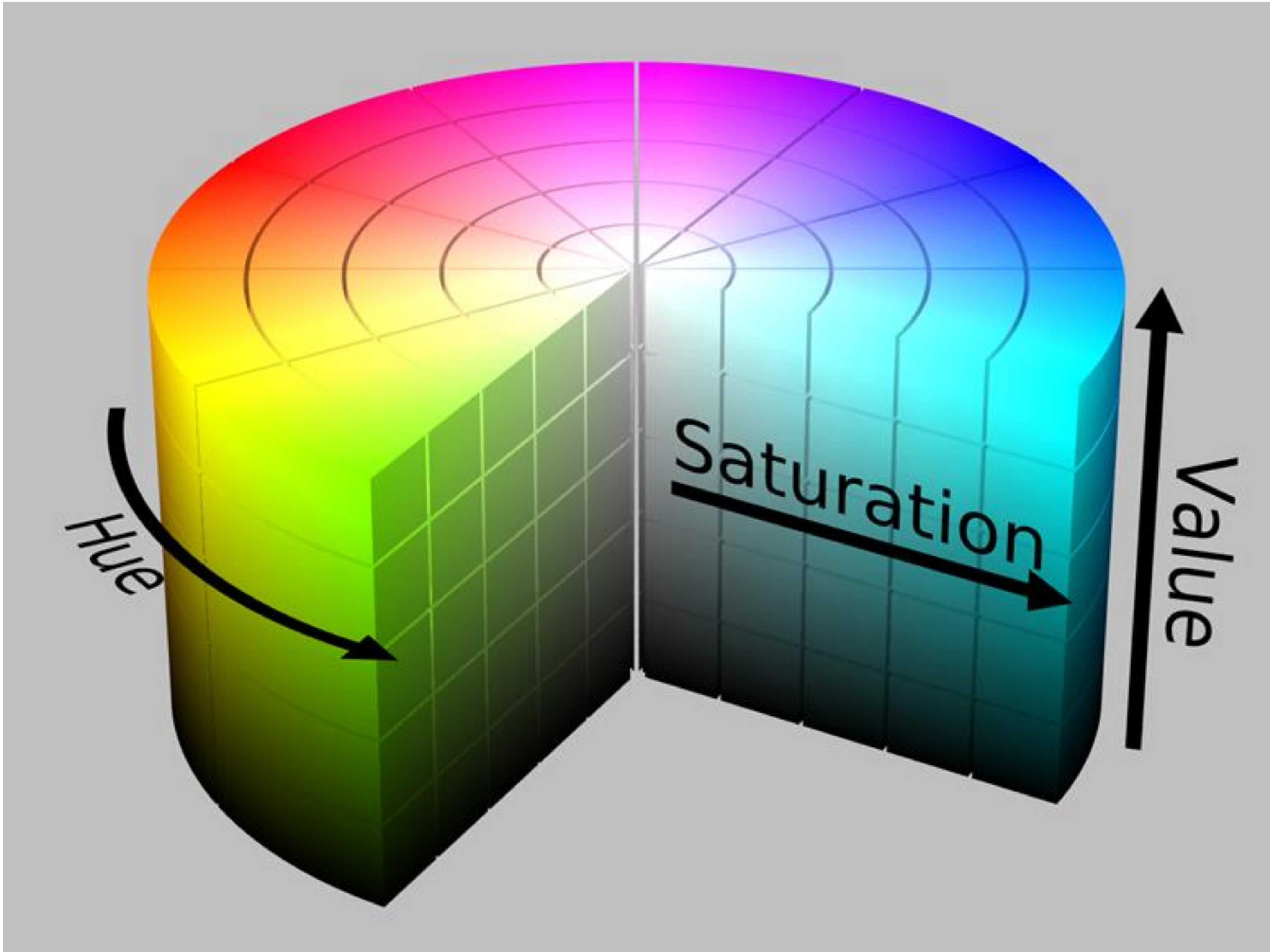
Colors are subtractive

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	

CMY and CMYK Color Model



HSV Color Model Coordinate System



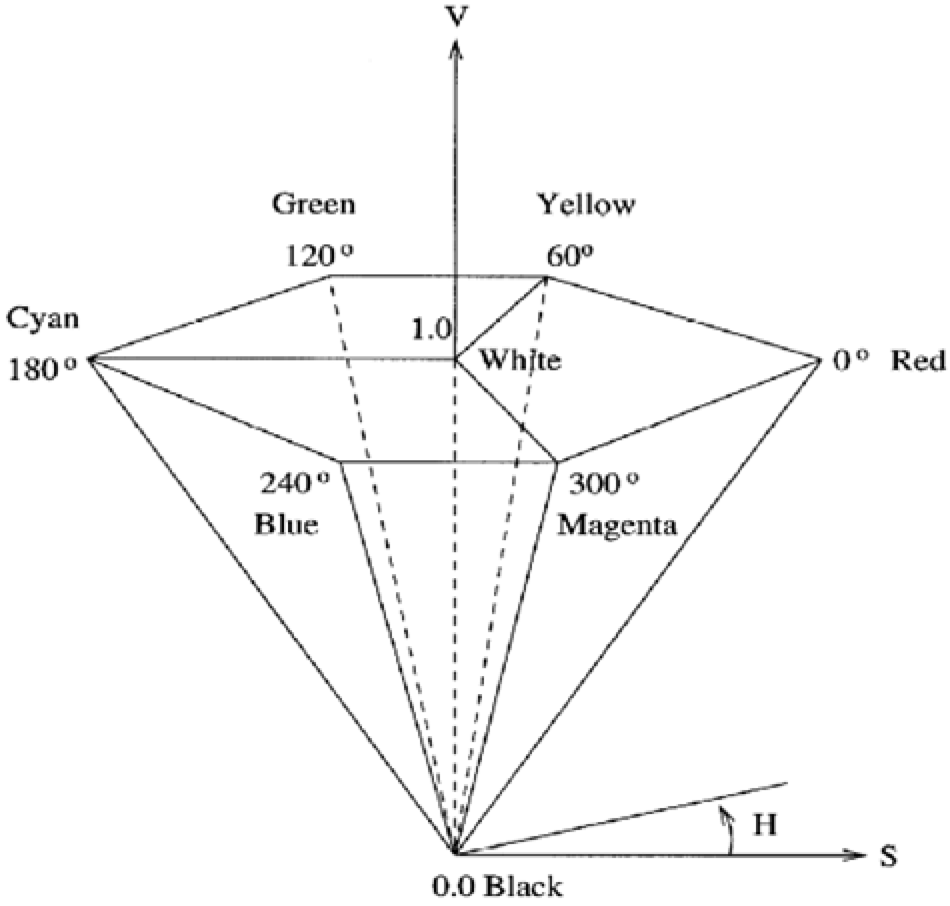
HSV Color Model

- Hue (dominant colour seen)
  - Wavelength of the pure colour observed in the signal.
  - Distinguishes red, yellow, green, etc.
  - More than 400 hues can be seen by the human eye.
  - Since the cone represents the HSV model, the hue represents different colours in different angle ranges.
- Saturation (degree of dilution/percentage 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.
  - How far the color is from equal intensity grey
  - Distinguishes red from pink, marine blue from royal blue, etc.
  - About 20 saturation levels are visible per hue.
  - We use the 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.

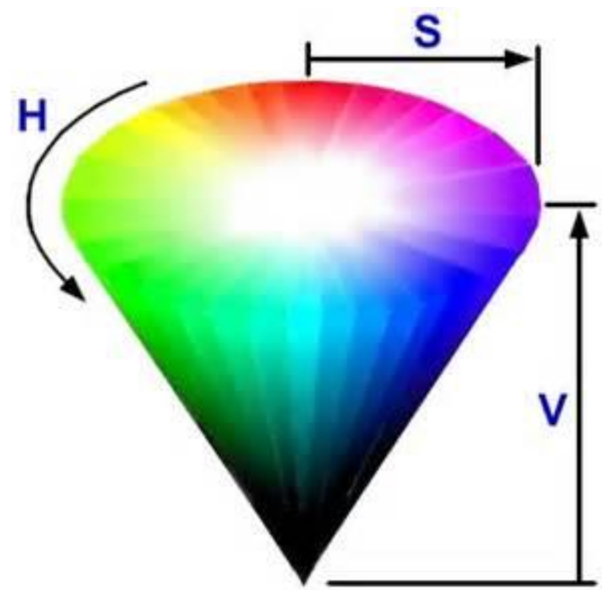
HSV Color Model Application

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.

HSV Color Model



Single hex-cone HSV color Model



RGB to HSV Conversion Approach

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

```
procedure RGB_To_HSV (r, g, b : real;  var h, s, v : real)
{Given: r, g, b, each in [0,1].
 Desired: h in [0,360), s and v in [0, 1] except if s = 0, then h = UNDEFINED, which is some
 constant defined with a value outside the interval [0,360].}
begin
  max := Maximum (r, g, b);
  min := Mimimum (r, g, b);
  v := max                        {This is the value v.}
  {Next calculate saturation, s.}
  if max <> 0 then
    s := (max - min)/max          {s is the saturation.}
  else s := 0                     {Saturation is 0 if red, green and blue are all 0}
  if s = 0 then
    h := UNDEFINED
  else                            {Chromatic case:  Saturation is not 0, so determine hue}
    begin
      delta := max - min
      if r = max then
        h := (g - b)/delta        {Resulting color is between yellow and magenta}
      else if g = max  then
        h := 2 + (b - r)/delta    {Resulting color is between cyan and yellow}
      else if b = max then
        h := 4 + (r - g)/delta;   {Resulting color is between magenta and cyan}
      h := h * 60                 {Convert hue to degrees}
      if h < 0 then
        h := h + 360              {Make sure hue is nonnegative}
    end {Chromatic case}
end {RGB_To_HSV}
```

Fig. 13.33 Algorithm for converting from RGB to HSV color space.

HSV to RGB

1. Compute Chroma (C)

$$C = V \times S$$

- C represents the difference between the maximum and minimum RGB components.

2. Find the Intermediate Value X

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

- X is a secondary value determined by the hue's position within its color segment.

3. Compute the Match Value (m)

$$m = V - C$$

- m shifts all components to fit within the 0–1 range.

4. Determine RGB Components Before Adjustment

The H value determines which RGB components will use C, X, or 0:

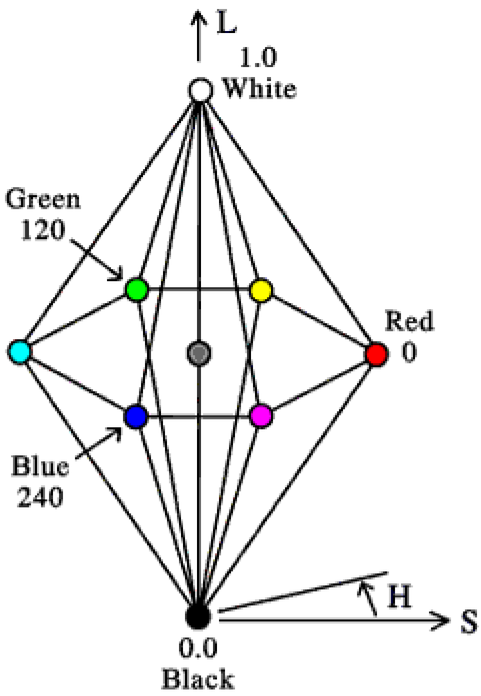
- H is divided into 6 segments (each 60° wide):
  1. $0^\circ \le H < 60^\circ$: $(R', G', B') = (C, X, 0)$
  2. $60^\circ \le H < 120^\circ$: $(R', G', B') = (X, C, 0)$
  3. $120^\circ \le H < 180^\circ$: $(R', G', B') = (0, C, X)$
  4. $180^\circ \le H < 240^\circ$: $(R', G', B') = (0, X, C)$
  5. $240^\circ \le H < 300^\circ$: $(R', G', B') = (X, 0, C)$
  6. $300^\circ \le H < 360^\circ$: $(R', G', B') = (C, 0, X)$

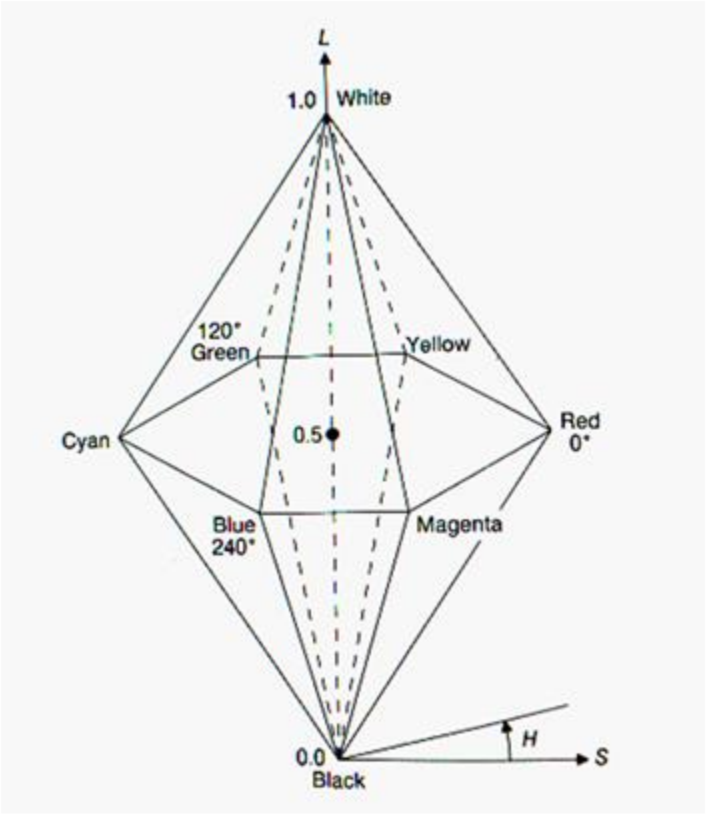
5. Add the Match Value (m) to Each Component

$$R = R' + m, \quad G = G' + m, \quad B = B' + m$$

HLS Color Model

- HLS (Hue, Lightness, Saturation) – A cylindrical color model for intuitive color representation.
- Hue: Angle on the color wheel (e.g., 0° = red, 120° = green, 240° = blue). Lightness: 0=black,1=white,0.5=pure color. Saturation: 0=gray,1=fully vivid color
- Uses: Image editing, color pickers, and design tools. Useful for adjusting brightness without altering color hue.





RGB to HLS

```
procedure RGB_HLS ( r, g, b: real;  var  h, l, s,: real)
begin
   max := Maximum ( r, g, b );
   min := Minimum ( r, g, b );
   l := ( max + min) / 2

   if  max = min  then
      begin
         s := 0;
         h := UNDEFINED
      end
   else
      begin
         if  l <= 0.5  then
            s := ( max - min ) / ( max + min )
         else
            s := ( max - min ) / ( 2 - max - min );

      delta := max - min
      if  r = max  then
         h := ( g - b ) / delta
      else if  g = max  then
            h := 2 + ( b - r ) / delta
      else if  b = max  then
            h := 4 + ( r - g ) / delta;
      h :=  h * 60
      if  h < 0.0  then
            h :=  h + 360
   end
end
```

HLS to RGB

HSL to RGB conversion formula

When $0 \leq H < 360$, $0 \leq S \leq 1$ and $0 \leq L \leq 1$:

$$C = (1 - |2L - 1|) \times S$$

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

$$m = L - C/2$$

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

$$(R,G,B) = ((R'+m)\times 255, (G'+m)\times 255, (B'+m)\times 255)$$

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