Color Models

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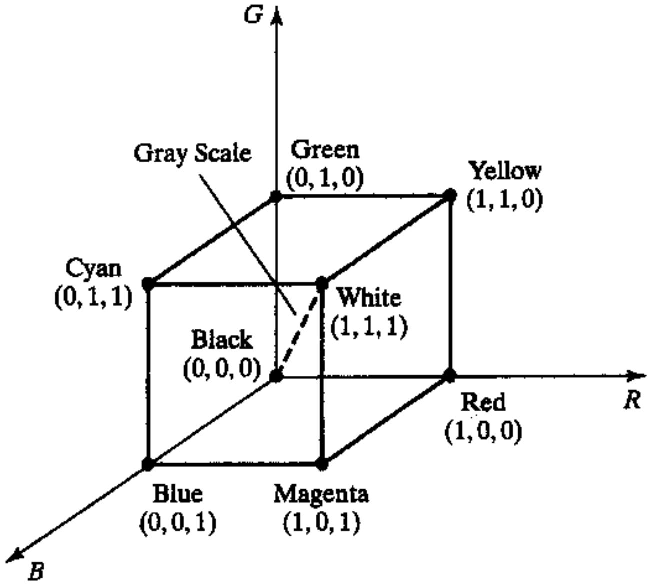
What is Color Models?

- Also known as color spaces or color systems
- To facilitate the specification of colors in some standard way
- Provides a coordinate system and a subspace in it **where each color is represented by a single point**



What is a descriptor in digital image processing?

- In computer vision, image descriptors describe elementary characteristics such as shape, color, texture, or motion, which are visual features of images.

What is Color?

- Color is a powerful descriptor that often simplifies object identification and extraction from a scene (or visual perceptual properties)
- Color is a fundamental attribute of our viewing experience
- Very important in human perception
- Same shapes with different color coding may look different

Cat on a rug?

Tiger in a jungle!

Preview

Preview

Cont.

Light

Light is fundamental for *color vision*

Unless there is a source of light, there is nothing to see!

What do we see?

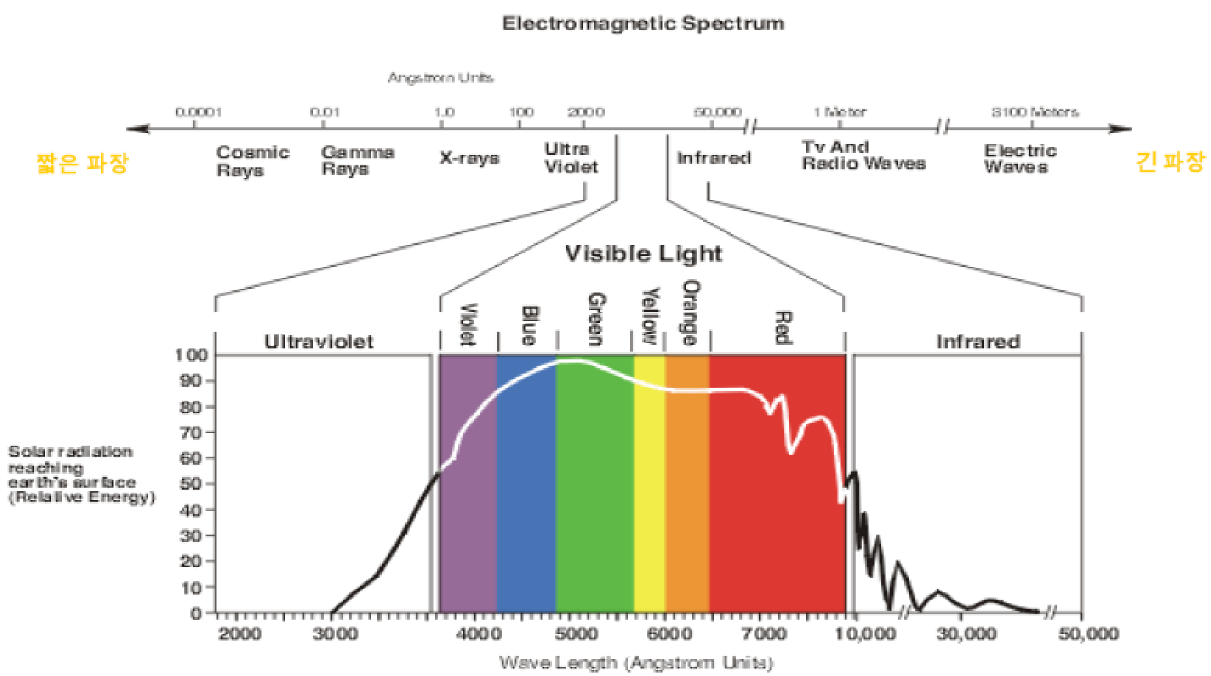
We do not see objects, but the light that has been

reflected by or *transmitted through* the objects

Light and EM waves

Light is an electromagnetic wave

If its wavelength is comprised between 400 and 700 nm (*visible spectrum*), the wave can be detected by the human eye and is called *monochromatic light*



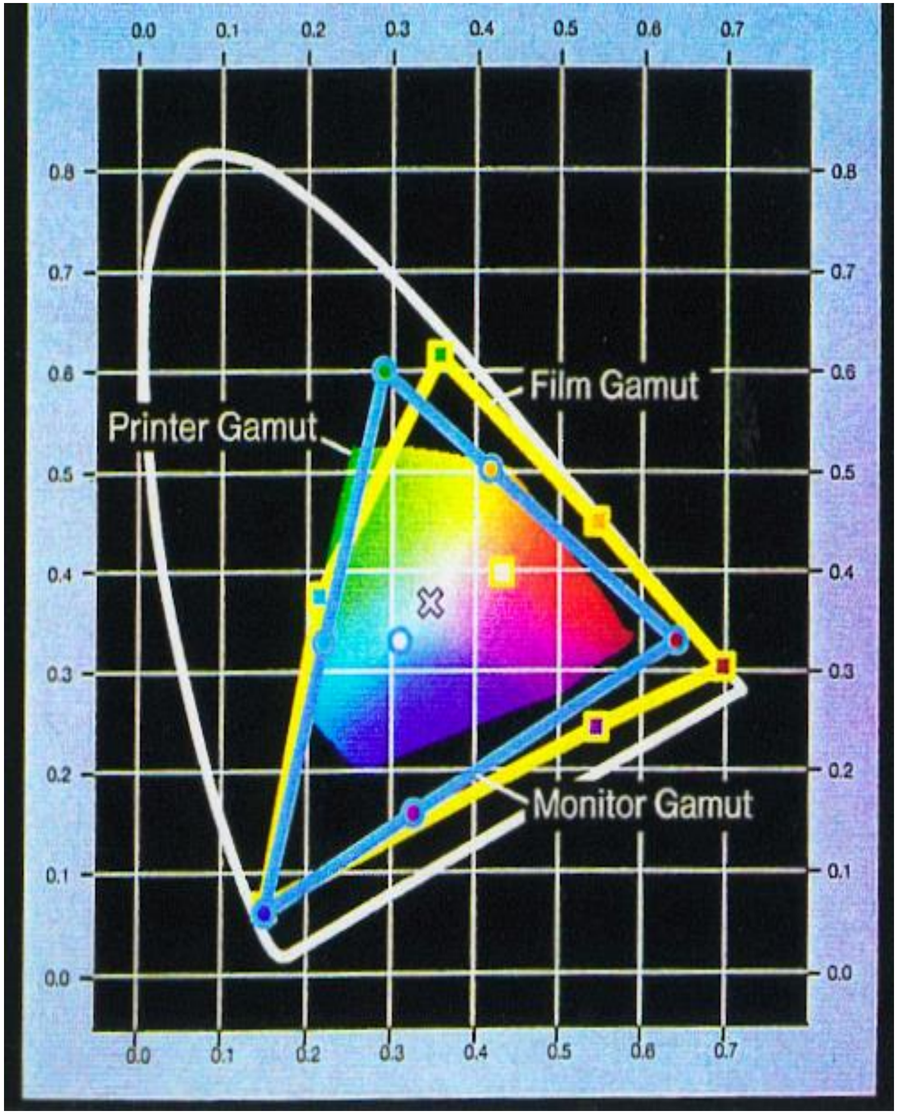
Physical properties of light

This distribution may indicate:

- **Dominant wavelength (or frequency)** represents the color of the light (hue).
- **Brightness (luminance)** indicates the intensity of the light (value).
- **Purity (saturation)** describes the degree of vividness (intensity).

CIE standard

- International Commission on Illumination (1931) is the international authority on light, illumination, color, and color spaces
- not a computer model
- each color = a weighted su m of three imaginary primar y colors



Types of Color Model

- RGB model
  - Color monitor, color video cameras
- CMY model
  - Color printer
- HSI model
  - Color image manipulation
- Grayscale
- XYZ (CIE standard, Y directly measures the luminance)
- YUV (used in PAL color TV)
- YIQ (used in NTSC color TV)
- YCbCr (used in digital color TV standard BT.601)

Cont.

Standard wavelength values for the primary colors

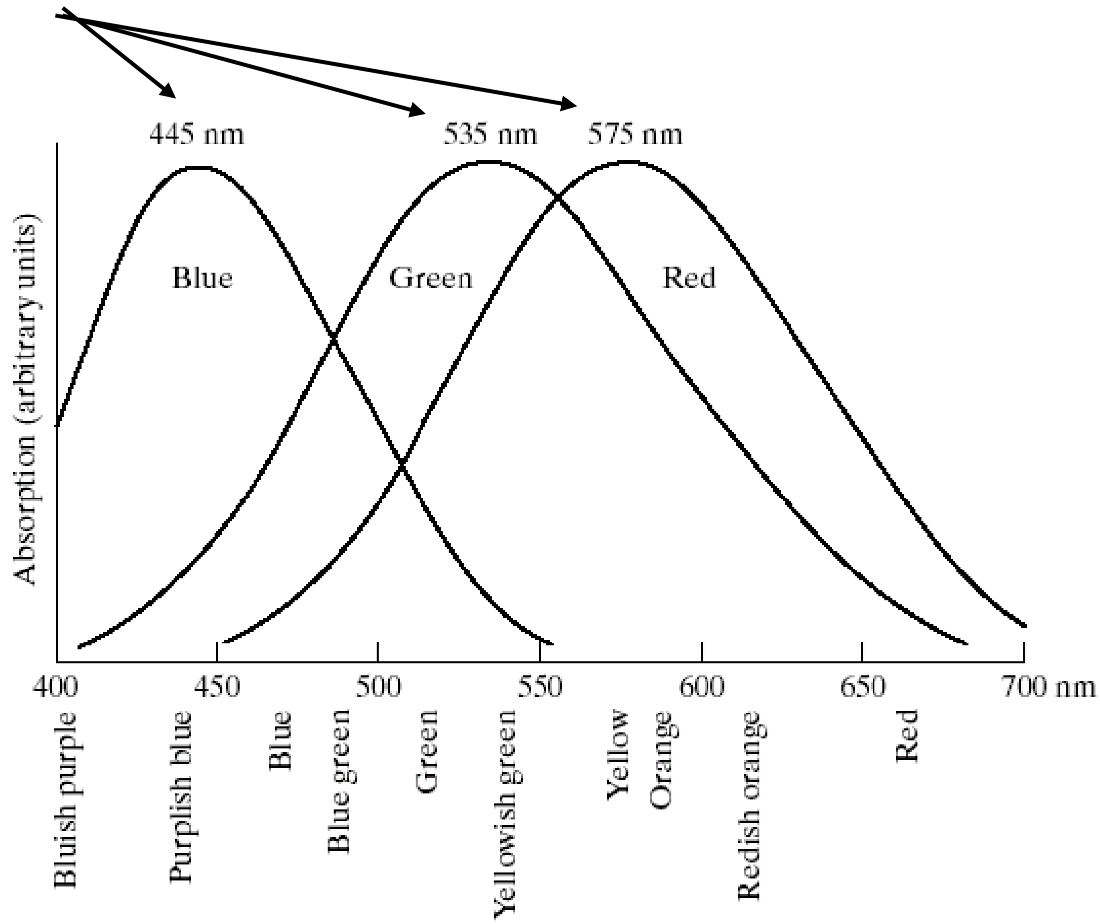


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Cont.

- Tri-stimulus values: The amount of Red, Green and Blue needed to form any particular color

  Denoted by: X, Y and Z

- **Tri-chromatic coefficient:**

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

$$x + y + z = 1$$

Cont.

- The ***purpose*** of a color model (also called color space or color system) is to facilitate the specification of colors in some standard, generally accepted way.
- **RGB** (red, green, blue) : monitor, video camera
- **CMY** (cyan, magenta, yellow), **CMYK** (CMY, black) model for color printing
- **HSI** model, which corresponds closely with the way humans describe and interpret color

RGB (red, green, blue) color model

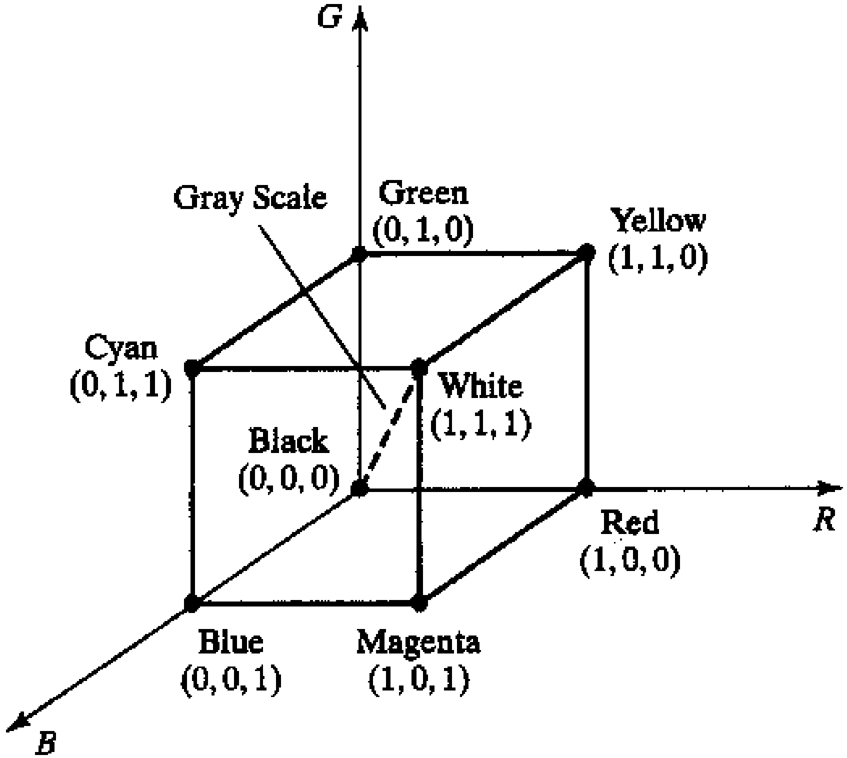
- The RGB color space is related to human vision through the tristim ulus theory of color vision

- The RGB color space or typical color image consists of the **3 additive primaries**: red, green, and blue
  - r gives the intensity of the red component
  - g gives the intensity of the green component
  - b gives the intensity of the blue component

- Spectral components of these colors combine additively to produce a resultant color
- Use 8 bits for each primary color and obtain 16 million colors

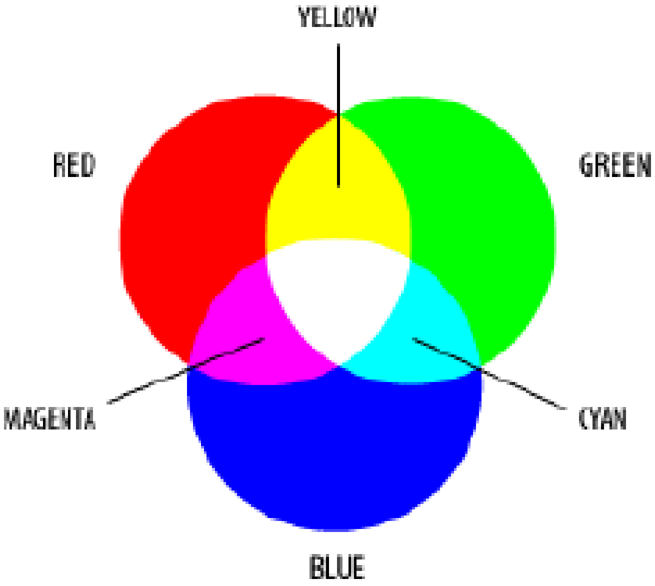
Cont.

- For example, if all three primary colors are 0 percent, the result is black
- If all three primary colors are 100 percent (the maximum value), the result is white.



RGB Color model

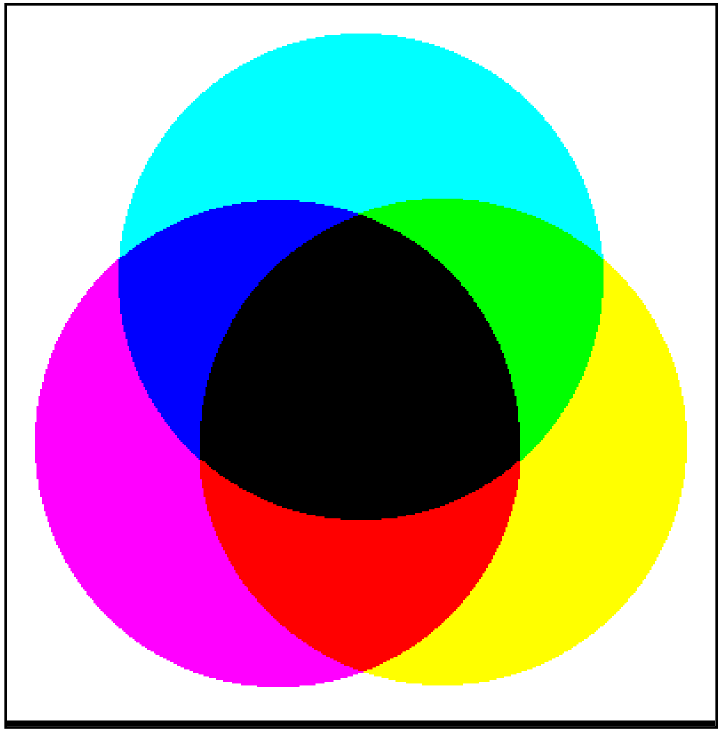
Source: www.mitsubishi.com



Active displays, such as computer monitors and television sets, emit combinations of red, green and blue light. This is an **additive** color model

CMY Color Model

Source: www.hp.com

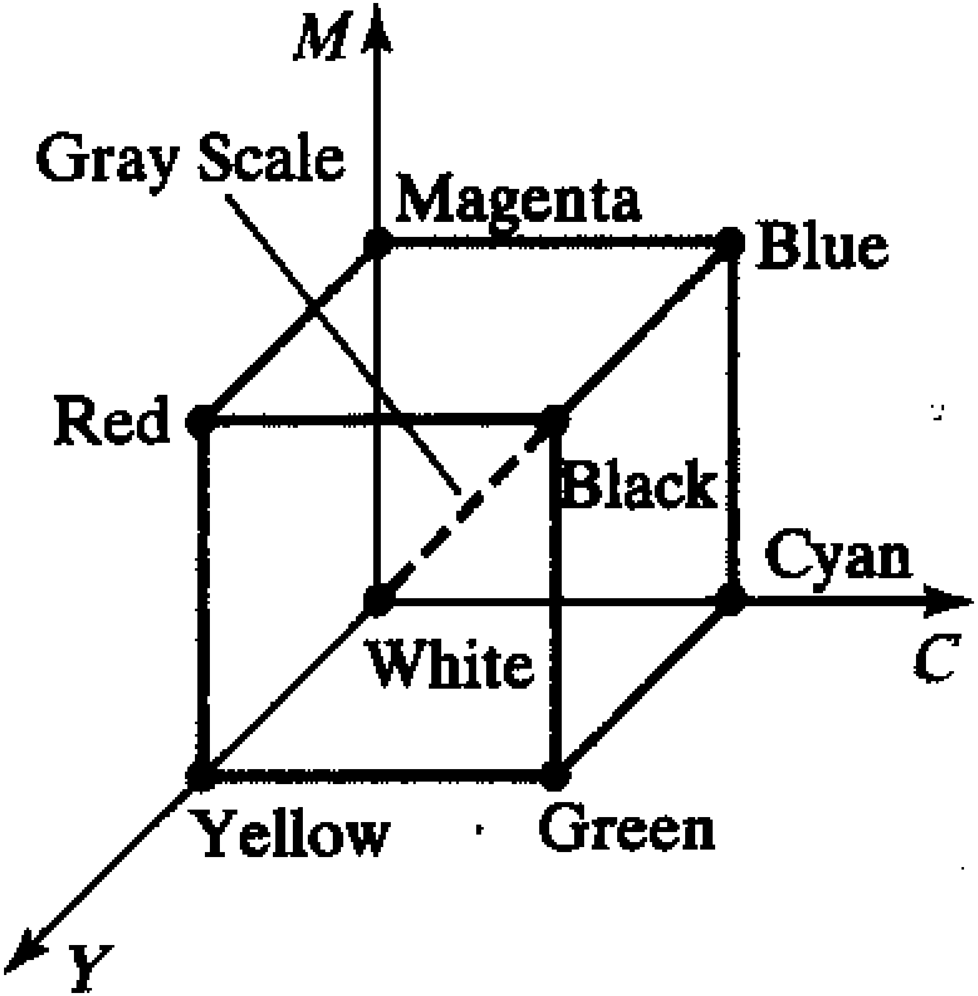


Passive displays, such as color inkjet printers, **absorb** light instead of emitting it. Combinations of **cyan**, **magenta** and **yellow** inks are used. This is a **subtractive** color model.

Cont.

CMY cartridges for color printers.

The CMY and CMYK Color Spaces



Cont.

- Cyan, Magenta, and Yellow are the secondary colors of light

- Most devices that deposit colored pigments on paper, such as color printers and copiers, require CMY data input.

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

Cont.

The conversion from RGB to CMY is given by the formula

$$\begin{bmatrix} c \\ m \\ y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

Example: The red colour is written in RGB as (1,0,0). In CMY it is written as

$$\begin{bmatrix} c \\ m \\ y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix}$$

that is, magenta and yellow.

Cont.

Example: The magenta is written in CMY as (0,1,0). In RGB it is written as

$$\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

giving,

$$\begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}$$

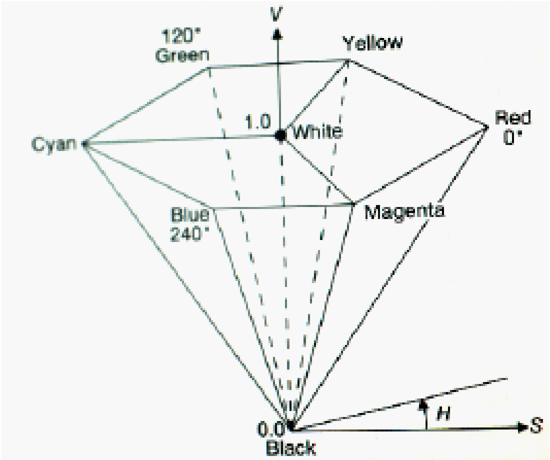
that is, red and blue.

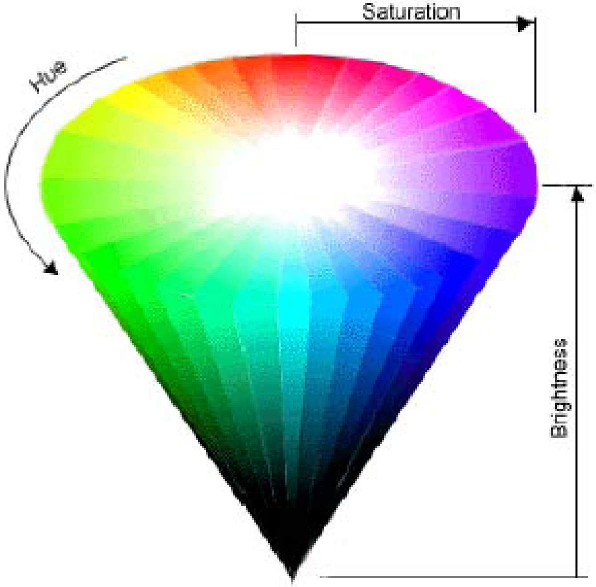
Cont.

- For printing and graphics art industry, CMY is not enough; a fourth primary, K which stands for black, is added
- Conversions between RGB and CMYK are possible, although they require some extra processing

HSI Color Model

- HSI (=HSB)
  - Hue, Saturation, Value (=Brightness)
  - **HUE**: the actual color.
    - measured in angular degrees around the cone
    - Ex) red = 0 or 360 (so yellow = 60, green = 120, etc.).
  - **SATURATION :** the purity of the color
    - measured in percent from the center of the cone (0) to the surface (100).
    - At 0% saturation, hue is meaningless.
  - **BRIGHTNESS/INTENSITY**
    - measured in percent from black (0) to white (100).
    - At 0% brightness, both hue and saturation are meaningless.

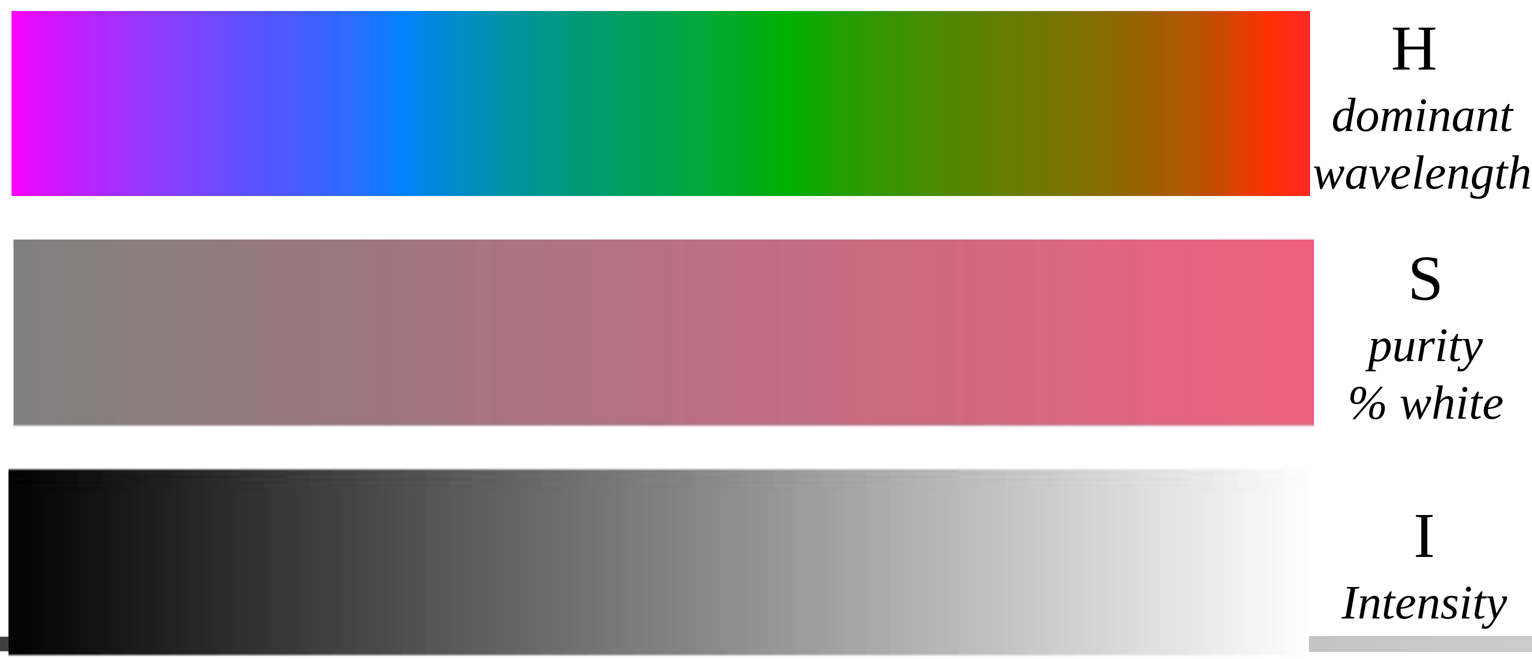




Computer Vision

HSI Color Model

- HSI colors are not described based on percentages of primary colors, but rather by their hue, saturation, and intensity
- Hue and saturation taken together are called *Chromaticity*; therefore, **a color may be characterized** by its Brightness and Chromaticity.



Source: http://www.cs.cornell.edu/courses/cs631/1999sp/

Cont.

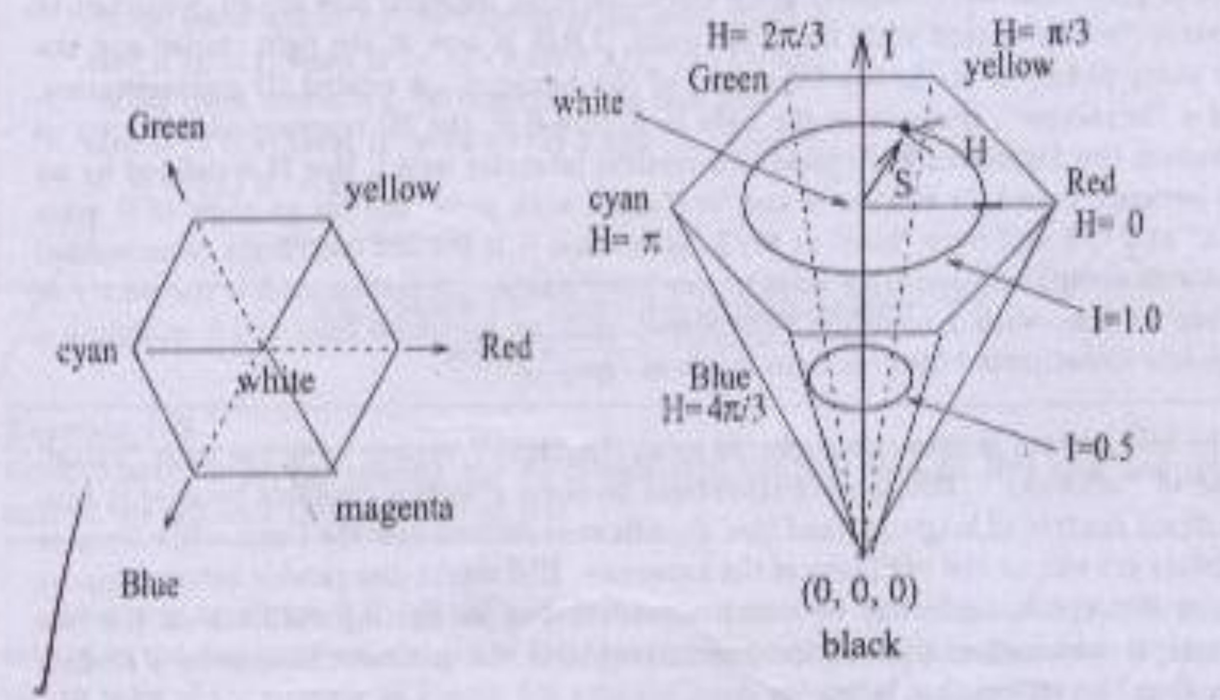


Figure 6.8: Color hexacone for HSI representation. At the left is a projection of the RGB cube perpendicular to the diagonal from (0, 0, 0) to (1, 1, 1): color names now appear at the vertices of a hexagon. At the right is a hexacone representing colors in HSI coordinates: intensity (I) is the vertical axis; hue (H) is an angle from 0 to 2π with *RED* at 0.0; saturation (S) ranges from 0 to 1 according to how pure, or unlike white, the color is with S=0.0 corresponding to the I-axis.

Cont.

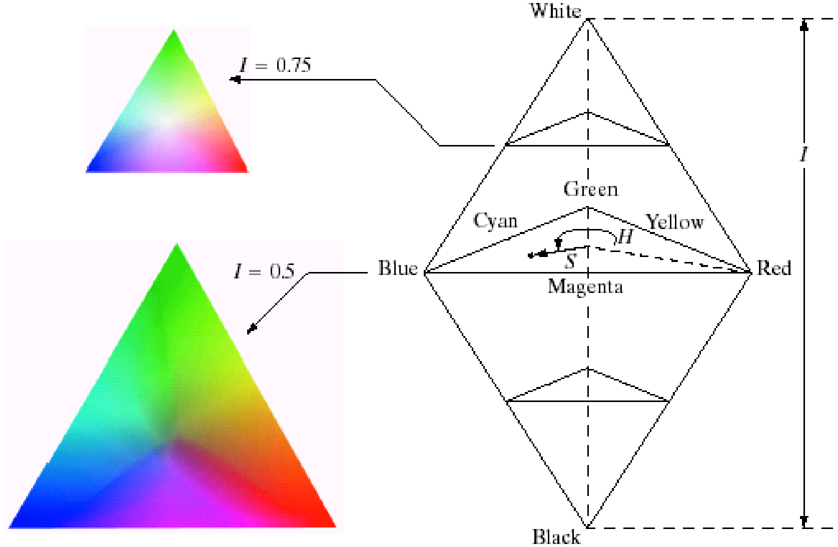
Conversion of RGB encoding to HSI encoding.

R,G,B : input values of RGB all in range [0,1] or [0,255];
I : output value of intensity in same range as input;
S : output value of saturation in range [0,1];
H : output value of hue in range $[0,2\pi)$, -1 if S is 0;
R,G,B,H,S,I are all floating point numbers;

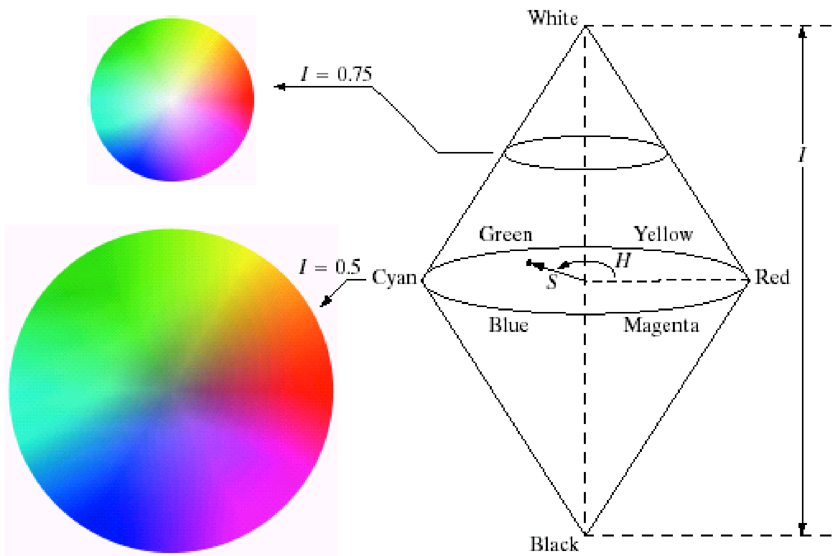
```
procedure RGB_to_HSI( in R,G,B; out H,S,I)
{
I := max ( R, G, B );
min := min ( R, G, B );
if (I ≥ 0.0) then S := (I - min )/I else S := 0.0;
if (S ≤ 0.0) then { H := -1.0; return; }
  "compute the hue based on the relative sizes of the RGB components"
diff := I - min;
"is the point within +/- 60 degrees of the red axis?"
if (r = I) then H := (π/3)*(g - b)/diff;
"is the point within +/- 60 degrees of the green axis?"
else if (g = I) then H := (2 * π/3) + π/3 *(b - r)/diff;
"is the point within +/- 60 degrees of the blue axis?"
else if (b = I) then H := (4 * π/3) + π/3 *(r - g)/diff;
if (H ≤ 0.0) H := H + 2π;
}
```

Algorithm 15: Conversion of RGB to HSI.

Cont.



White
I = 0.75
I
Green
Cyan
Yellow
H
Blue
S
Red
I = 0.5
Magenta
Black



White
I = 0.75
I
Green
Yellow
I = 0.5
Cyan
H
Red
S
Blue
Magenta
Black

Cont.

- **Converting colors from RGB to HSI**

$$H = \begin{cases} \theta & \text{if } \mathrm{B} \le \mathrm{G} \\ 360 - \theta & \text{if } \mathrm{B} > \mathrm{G} \end{cases}$$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}} \right\}$$

$$S = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)]$$

$$I = \frac{1}{3}(R+G+B)$$

Cont.

- **Converting colors from HSI to RGB**
  - **RG sector :**

$$0^\circ \le H < 120^\circ$$

$$R = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

$$G = 3I - (R + B) \qquad B = I(1 - S)$$

Cont.

- **Converting colors from HSI to RGB**
  - **GB sector :**

$$120^\circ \le H < 240^\circ$$

$$H = H - 120^\circ$$

$$R = I(1 - S)$$

$$G = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

$$B = 3I - (R + G)$$

Cont.

- **Converting colors from HSI to RGB**
  - **BR sector :**

$$240^\circ \le H < 360^\circ$$

$$H = H - 240^\circ$$

$$G = I(1 - S)$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

$$R = 3I - (G + B)$$

Cont.

	RGB	CMY	HSI
RED	(255, 0, 0)	(0,255,255)	(0.0 , 1.0, 255)
YELLOW	(255,255, 0)	(0, 0,255)	(1.05, 1.0, 255)
	(100,100, 50)	(155,155,205)	(1.05, 0.5, 100)
GREEN	(0,255, 0)	(255, 0,255)	(2.09, 1.0, 255)
BLUE	(0, 0,255)	(255,255, 0)	(4.19, 1.0, 255)
WHITE	(255,255,255)	(0, 0, 0)	(-1.0, 0.0, 255)
GREY	(192,192,192)	(63, 63, 63)	(-1.0, 0.0, 192)
	(127,127,127)	(128,128,128)	(-1.0, 0.0, 127)
	(63, 63, 63)	(192,192,192)	(-1.0, 0.0, 63)
	...		
BLACK	(0, 0, 0)	(255,255,255)	(-1.0, 0.0, 0)

Gray color model

- Grayscale
  - BLACK = 0% brightness, 100% grey.
  - WHITE = 100% brightness, 0% grey.

YIQ Color Coordinate System

- YIQ is defined by the National Television System Committee (NTSC)
- Y describes the luminance, I and Q describes the chrominance.
- A more compact representation of the color.
- YUV plays similar role in PAL and SECAM.

YUV/ YCbCr Coordinate

- YUV is the color coordinate used in color TV in PAL system, so mewhat different from YIQ.
- YCbCr is the digital equivalent of YUV, used for digital TV, with 8 bit for each component, in range of 0-255

Cont.

YCbCr Color Space is used in MPEG video compression standards

- Y is luminance
- Cb is blue chromaticity
- Cr is red chromaticity

Y = 0.257*R + 0.504*G + 0.098*B + 16

Cr = 0.439*R - 0.368*G - 0.071*B + 128

Cb = - 0.148*R - 0.291*G + 0.439*B + 128

- YIQ color space (Matlab conversion function: rgb2ntsc):

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.528 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Question Please?