Digital Image Processing
Chapter 6:
Color Image Processing

Spectrum of White Light

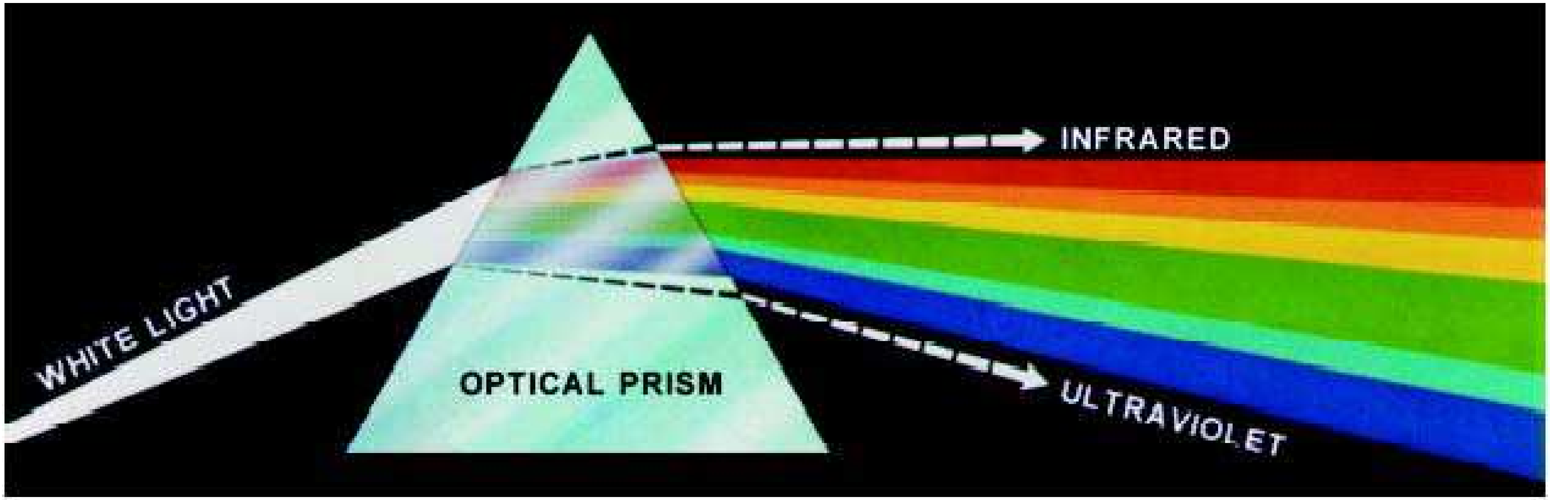
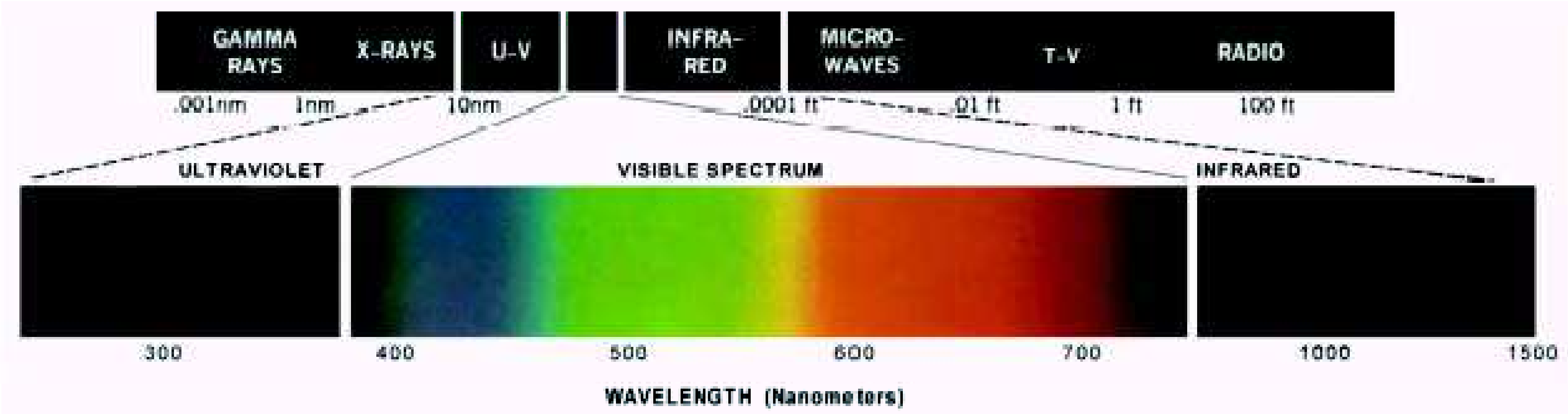


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

1666 Sir Isaac Newton, 24 year old, discovered white light spectrum.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Electromagnetic Spectrum



Visible light wavelength: from around 400 to 700 nm

1. For an achromatic (monochrome) light source, there is only 1 attribute to describe the quality: intensity

2. For a chromatic light source, there are 3 attributes to describe the quality:

Radiance = total amount of energy flow from a light source (Watts)
Luminance = amount of energy received by an observer (lumens)
Brightness = intensity

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Cross section illustration

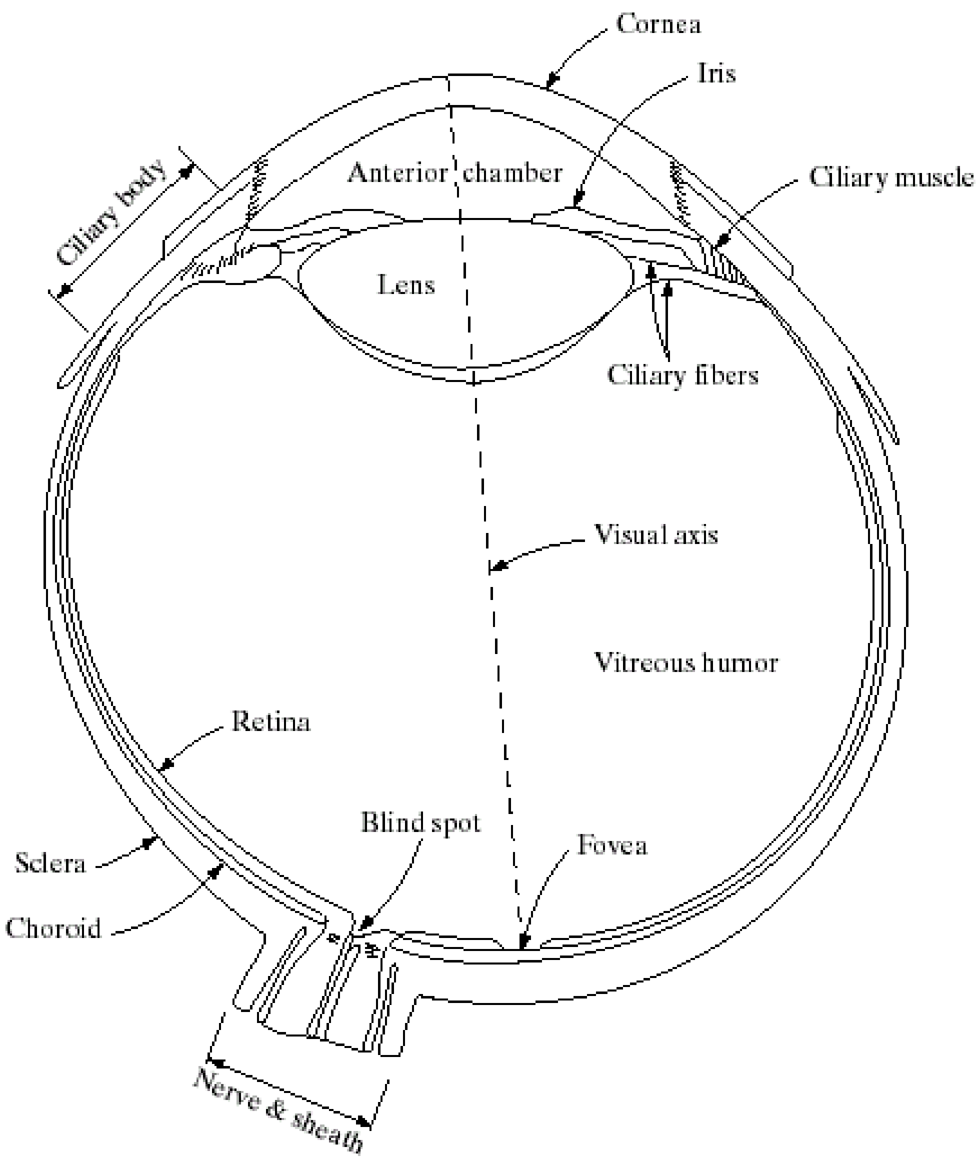


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

Figure is from slides at Gonzalez/ Woods DIP book website (Chapter 2)

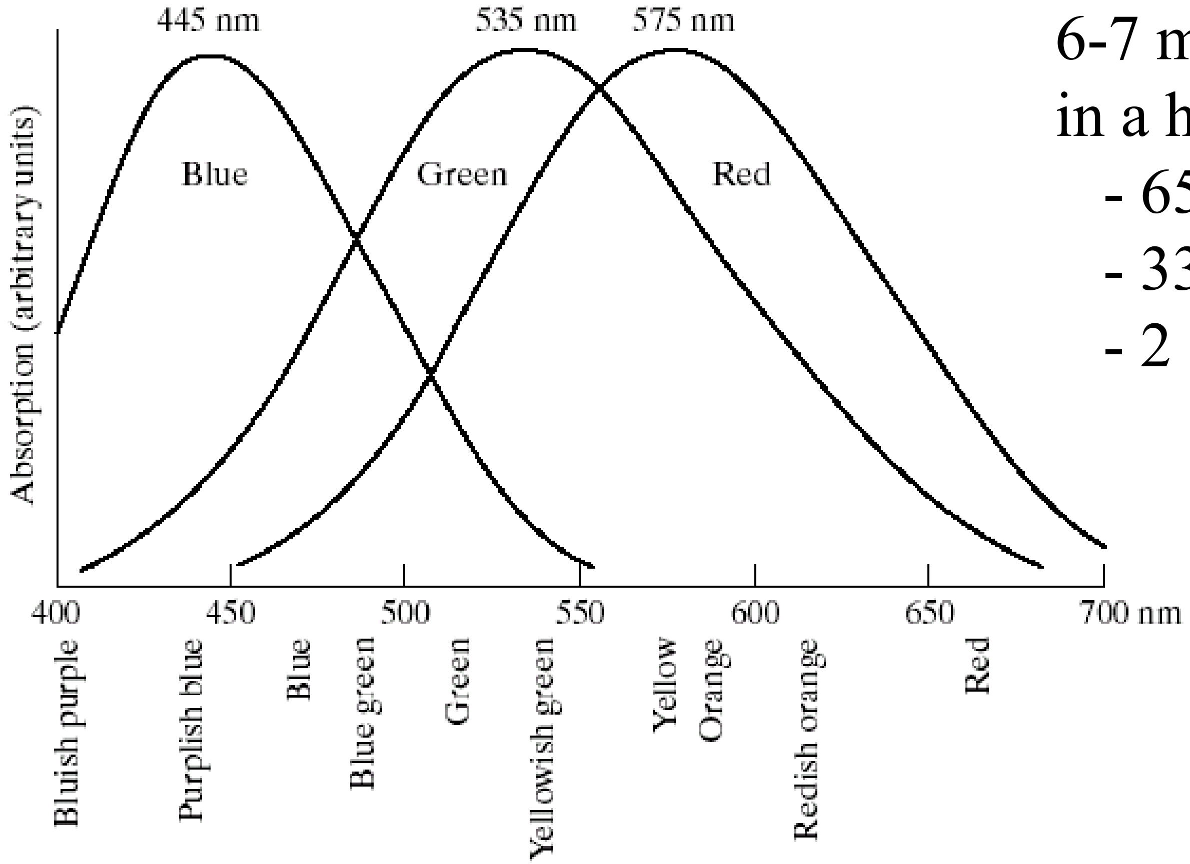
Two Types of Photoreceptors at Retina

- Rods
  - Long and thin
  - Large quantity (~ 100 million)
  - Provide *scotopic* vision (i.e., dim light vision or at low illumination)
  - Only extract luminance information and provide a general overall picture
- Cones
  - Short and thick, densely packed in fovea (center of retina)
  - Much fewer (~ 6.5 million) and less sensitive to light than rods
  - Provide *photopic* vision (i.e., bright light vision or at high illumination)
  - Help resolve fine details as each cone is connected to its own nerve end
  - Responsible for color vision

    our interest
    (well-lighted display)

  - Mesopic vision
    - provided at intermediate illumination by both rod and cones

Sensitivity of Cones in the Human Eye



6-7 millions cones in a human eye
- 65% sensitive to Red light
- 33% sensitive to Green light
- 2 % sensitive to Blue light

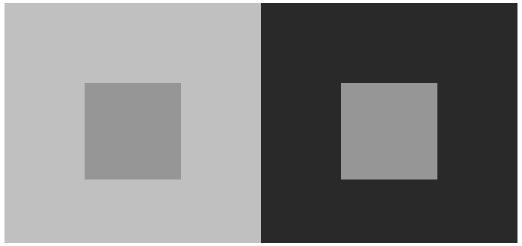
Primary colors:
Defined CIE in 1931
Red = 700 nm
Green = 546.1nm
Blue = 435.8 nm

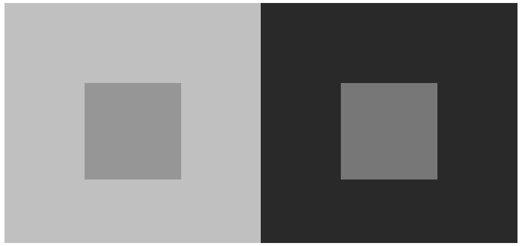
CIE = Commission Internationale de l'Eclairage
(The International Commission on Illumination)

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Luminance vs. Brightness

Same lum.
Different
brightness





Different lum.
Similar
brightness

- Luminance (or intensity)
  - Independent of the luminance of surroundings

$$L(x,y) = \int_0^{inf} I(x,y,\lambda) V(\lambda) d\lambda$$

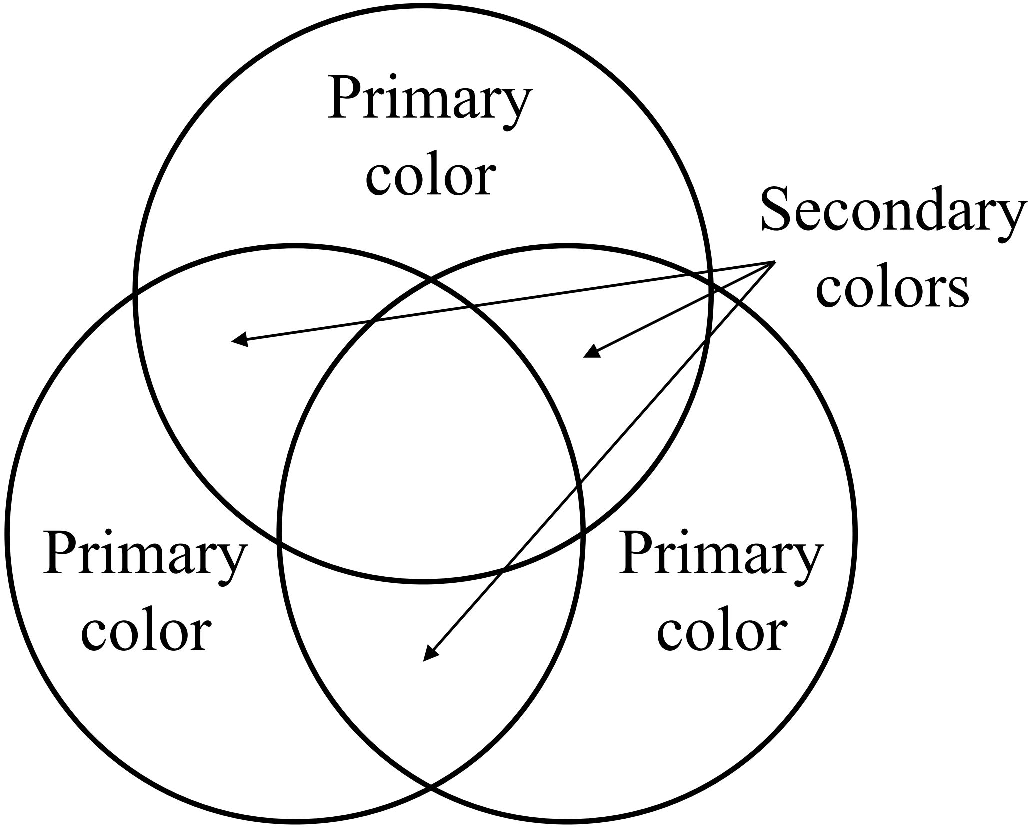
$I(x,y,\lambda)$ -- spatial light distribution

$V(\lambda)$ -- relative luminous efficiency func. of visual system ~ bell shape

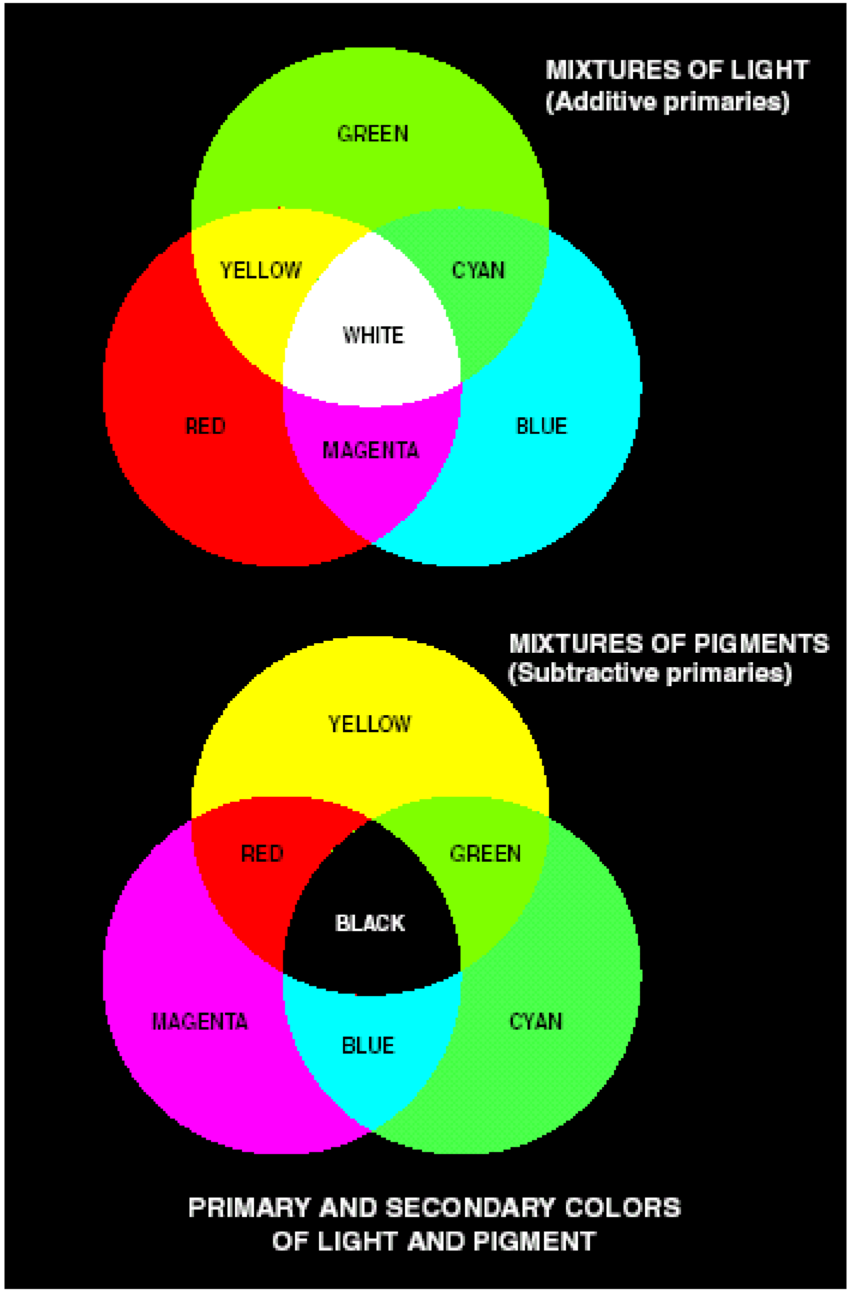
(different for scotopic vs. photopic vision;
highest for green wavelength, second for red, and least for blue)

- Brightness
  - Perceived luminance
  - Depends on surrounding luminance

Primary and Secondary Colors



Primary and Secondary Colors (cont.)



Additive primary colors: RGB use in the case of light sources such as color monitors

RGB add together to get white

Subtractive primary colors: CMY use in the case of pigments in printing devices

White subtracted by CMY to get Black

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Characterization

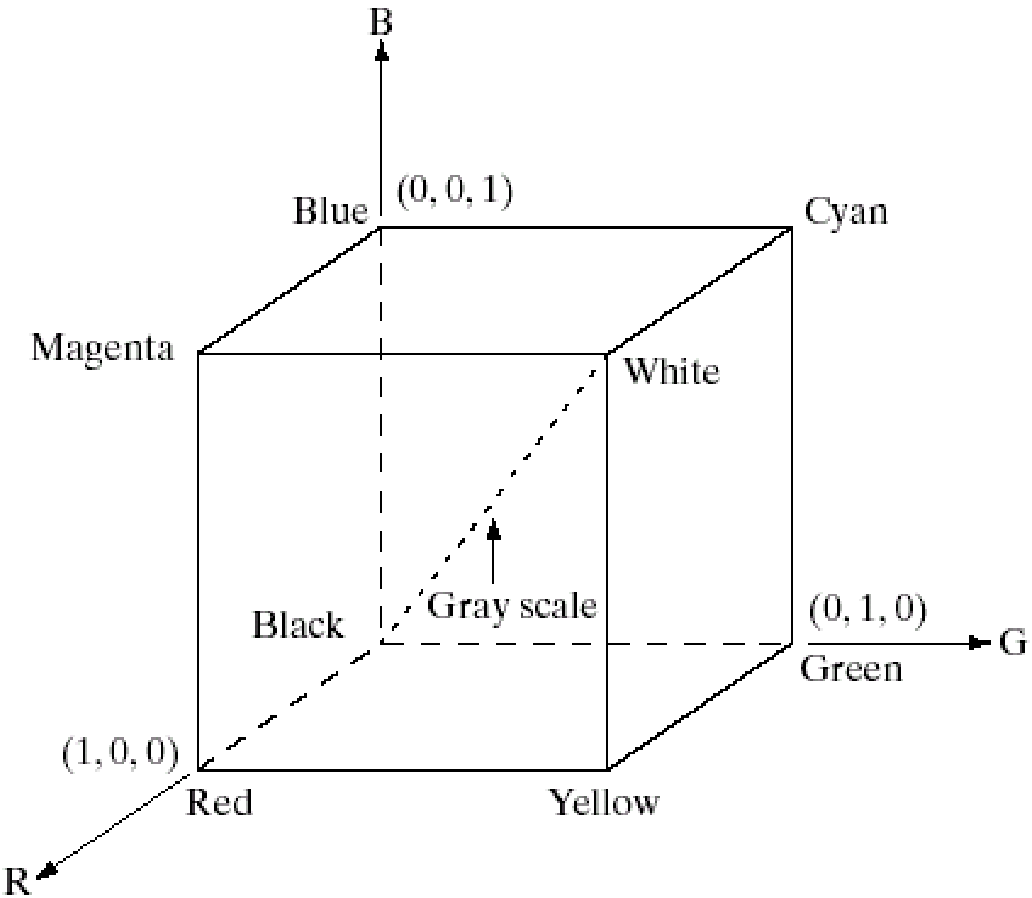
Hue:	dominant color corresponding to a dominant wavelength of mixture light wave
Saturation:	Relative purity or amount of white light mixed with a hue (inversely proportional to amount of white light added)
Brightness:	Intensity

$$\left.\begin{array}{l}\text{Hue}\\ \text{Saturation}\end{array}\right\}\ \text{Chromaticity}$$

amount of red (X), green (Y) and blue (Z) to form any particular color is called *tristimulus.*

RGB Color Model

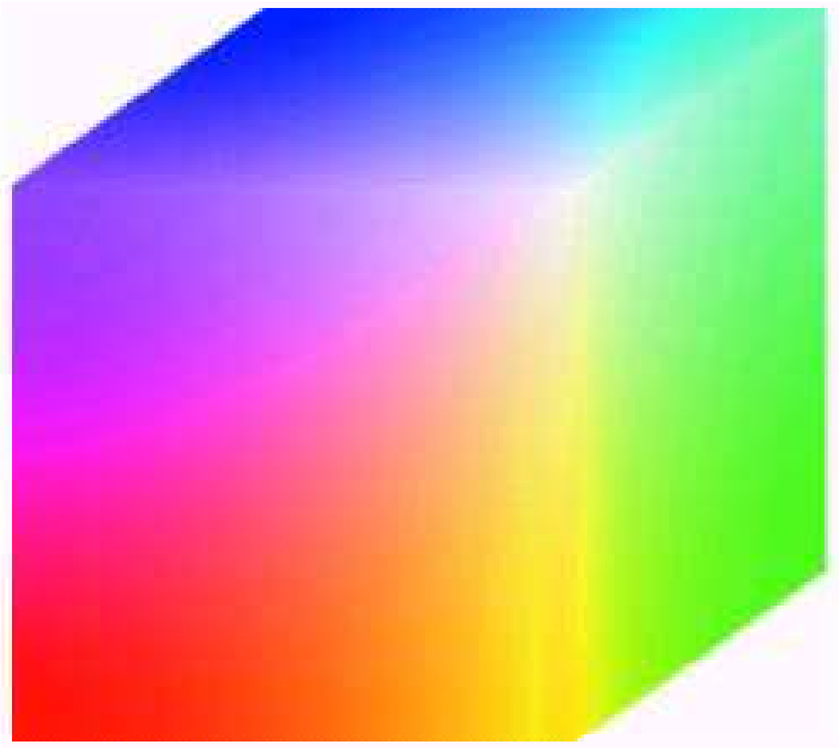
Purpose of color models: to facilitate the specification of colors in some standard



RGB color models:
- based on cartesian coordinate system

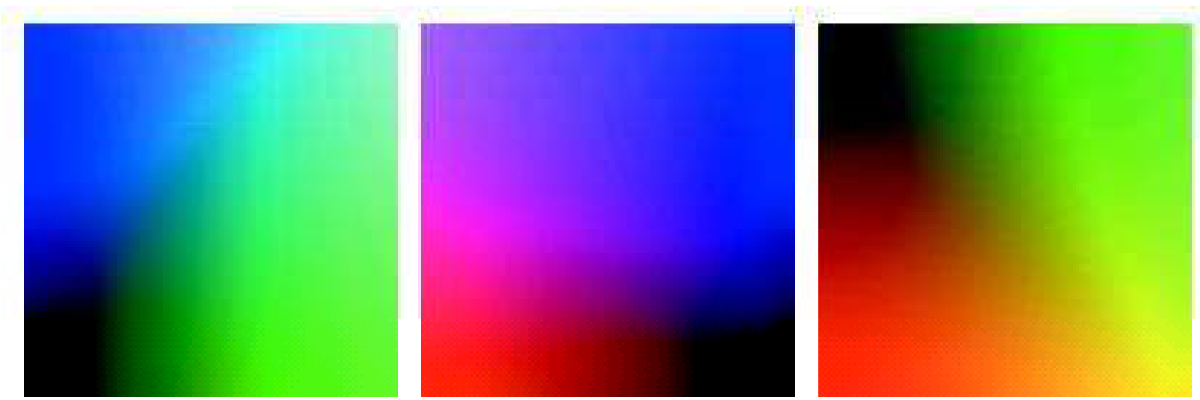
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Color Cube



R = 8 bits
G = 8 bits
B = 8 bits

Color depth 24 bits
= 16777216 colors

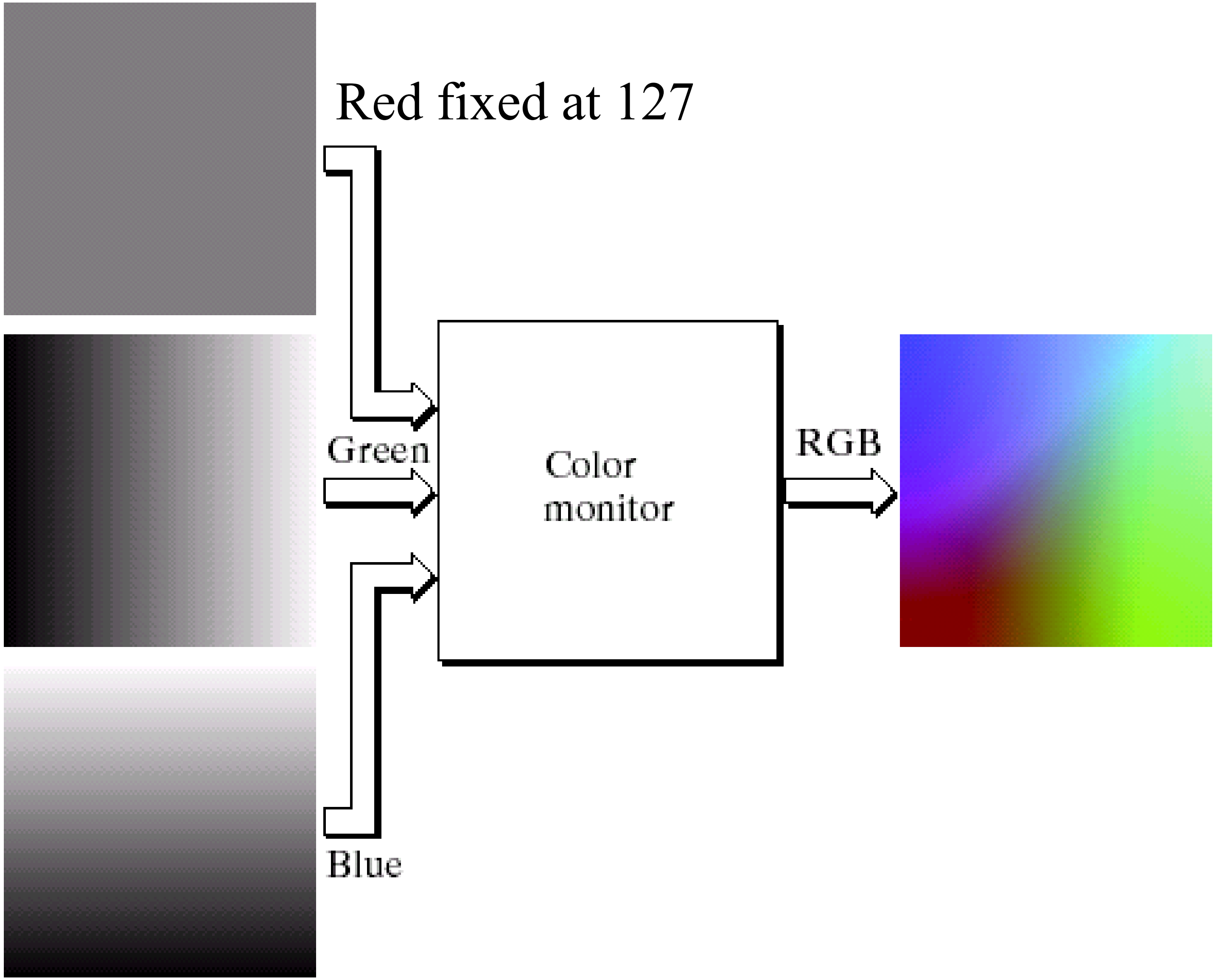


$(R = 0)$ $(G = 0)$ $(B = 0)$

Hidden faces
of the cube

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Color Model (cont.)

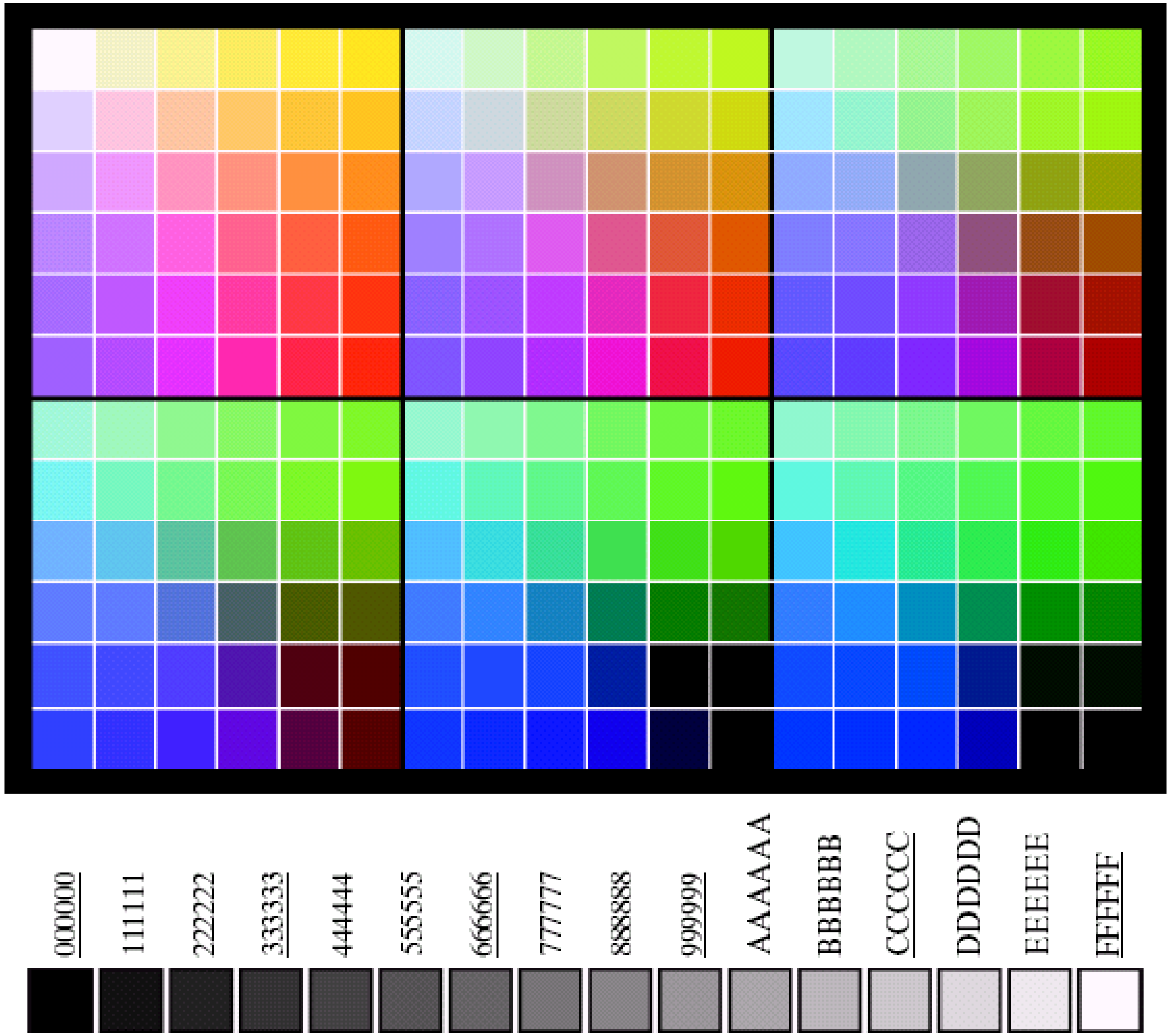


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Safe RGB Colors

Safe RGB colors: a subset of RGB colors.

There are 216 colors common in most operating systems.



a
b

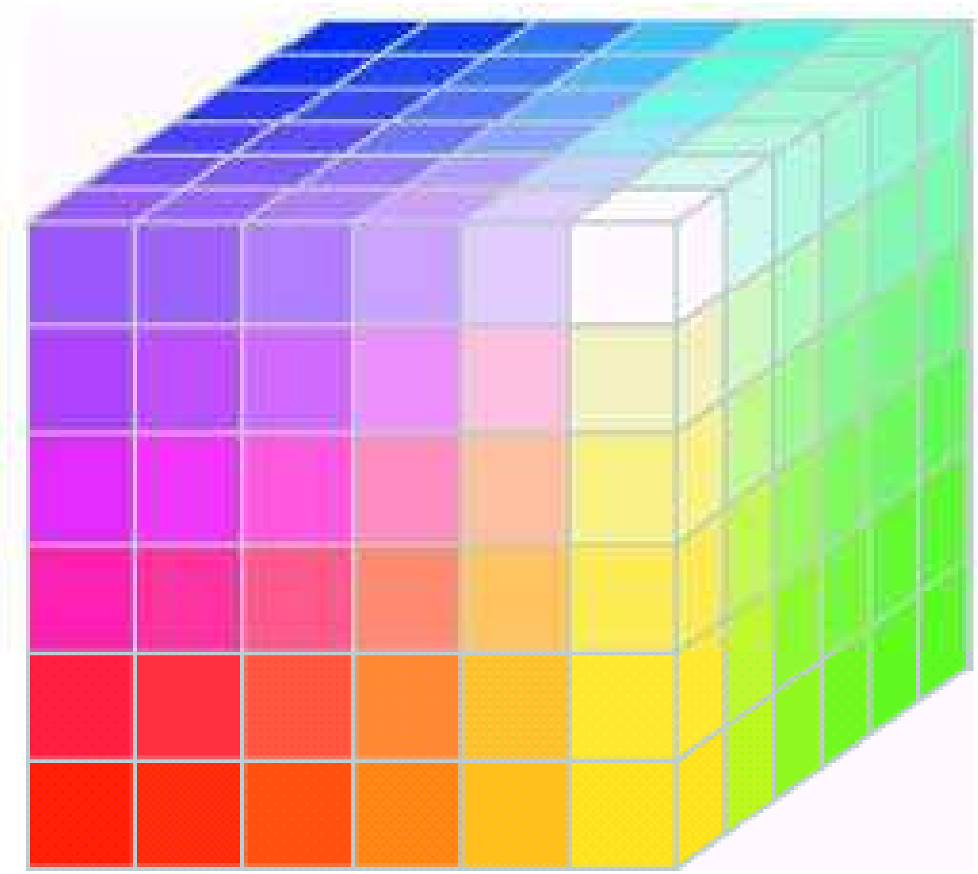
FIGURE 6.10 (a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Safe-color Cube

Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

TABLE 6.1
Valid values of each RGB component in a safe color.



The RGB Cube is divided into 6 intervals on each axis to achieve the total $6^3 = 216$ common colors.

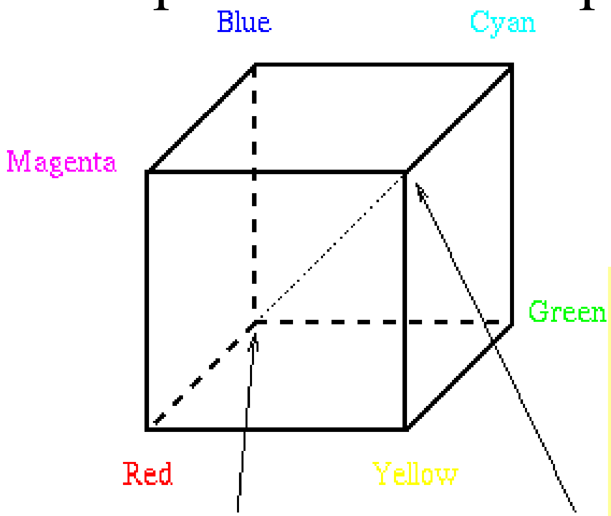
However, for 8 bit color representation, there are the total 256 colors. Therefore, the remaining 40 colors are left to OS.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

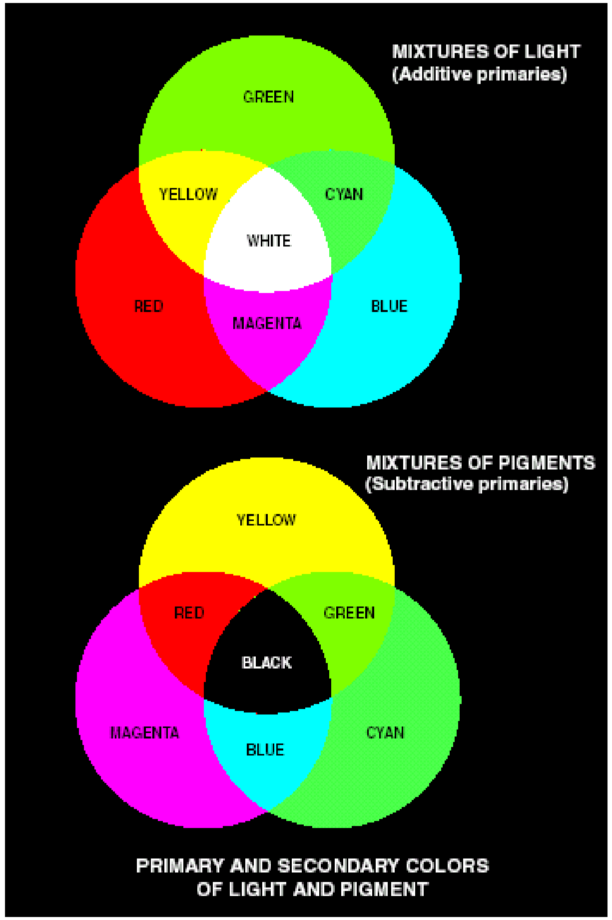
CMY and CMYK Color Models

C = Cyan
M = Magenta
Y = Yellow
K = Black

- Primary colors for pigment
  - Defined as one that subtracts/absorbs a primary color of light & reflects the other two
- CMY – Cyan, Magenta, Yellow
  - Complementary to RGB
  - Proper mix of them produces black



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



HSI Color Model

RGB, CMY models are not good for human interpreting

HSI Color model:

Hue: Dominant color

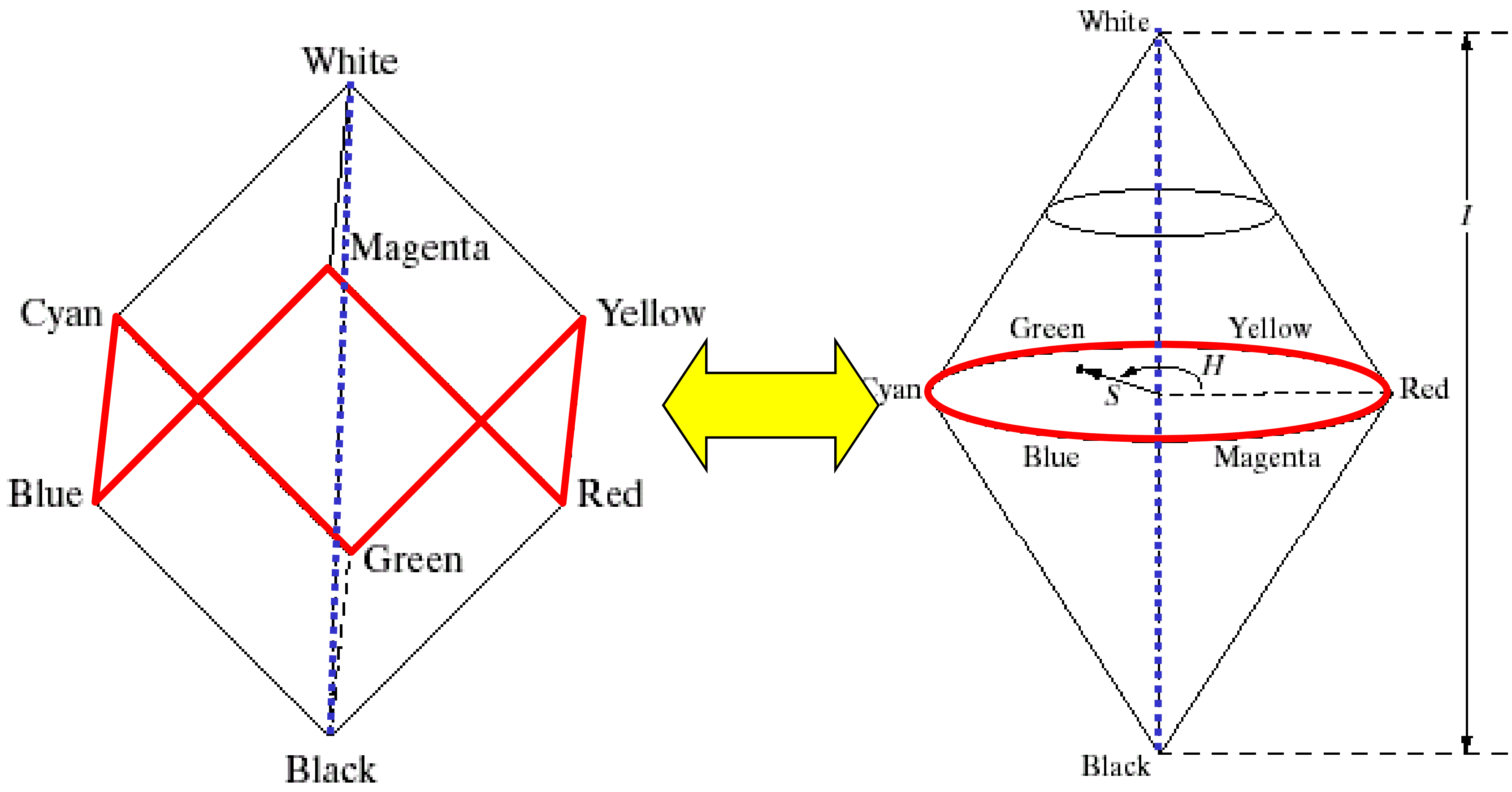
Saturation: Relative purity (inversely proportional to amount of white light added)

Color carrying information

Intensity: Brightness

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Relationship Between RGB and HSI Color Models

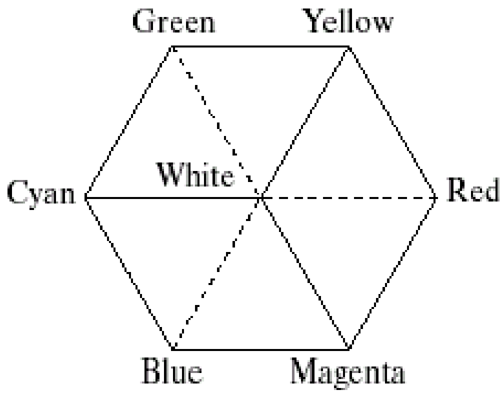


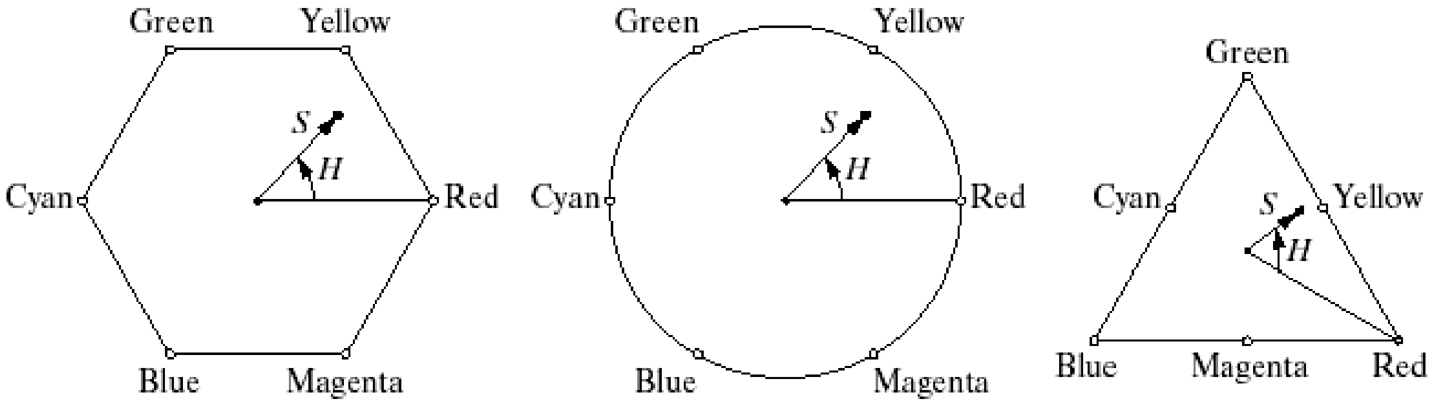
RGB

HSI

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

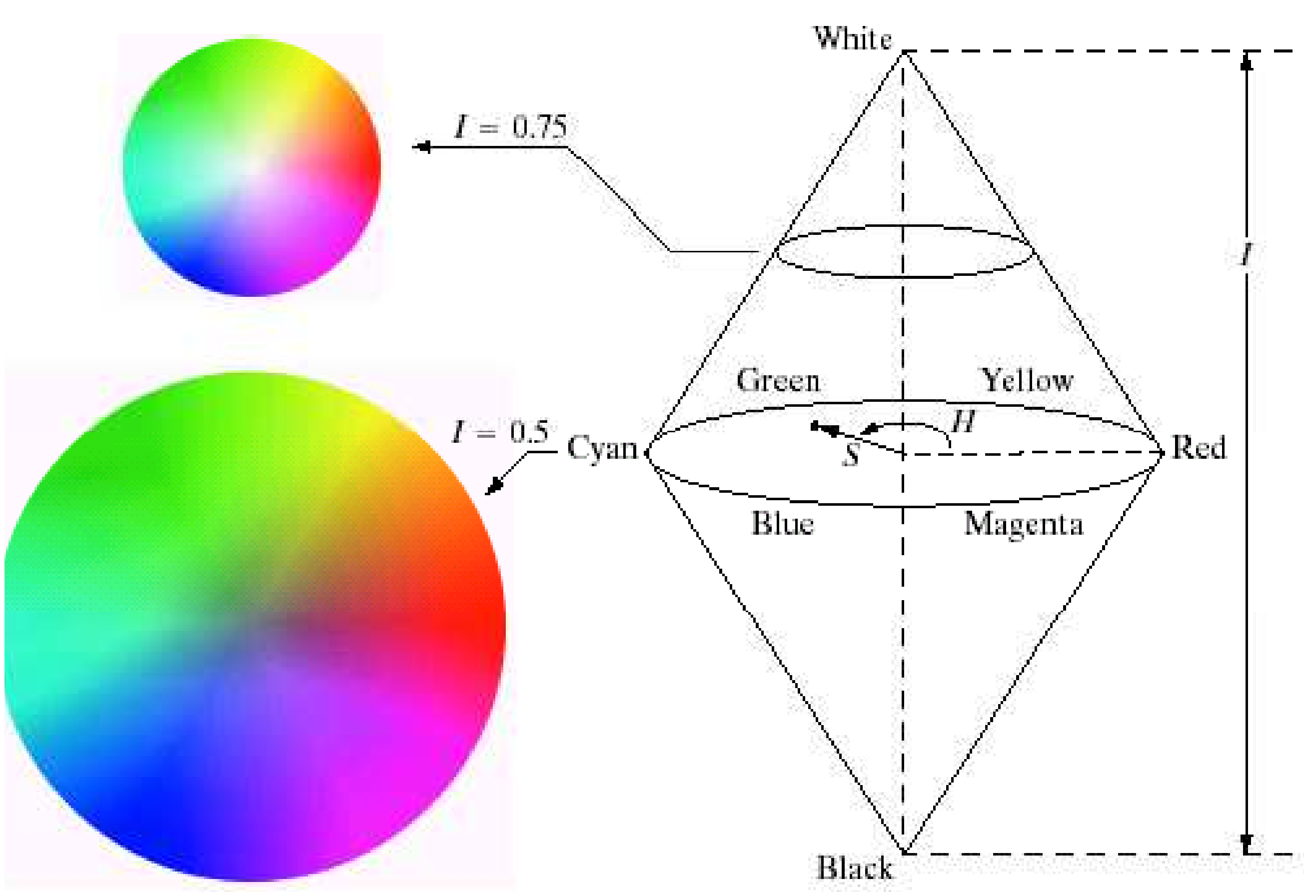
Hue and Saturation on Color Planes

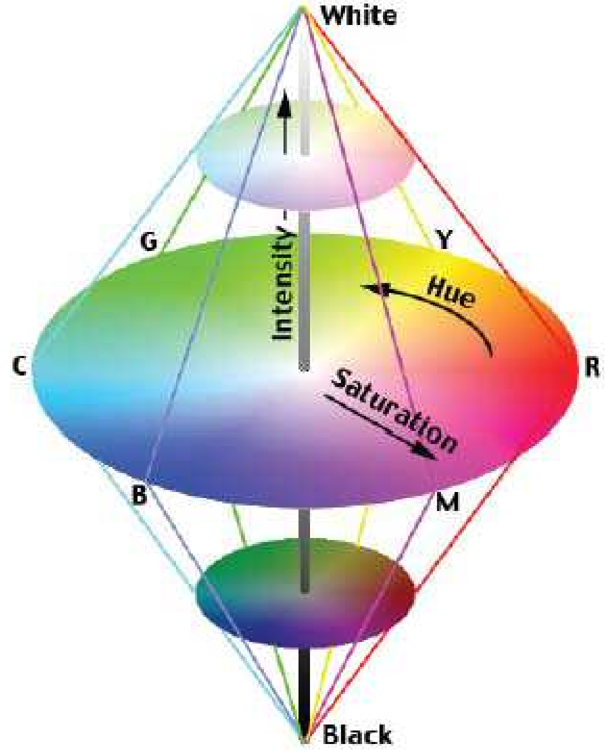




1. A dot is the plane is an arbitrary color
2. Hue is an angle from a red axis.
3. Saturation is a distance to the point.

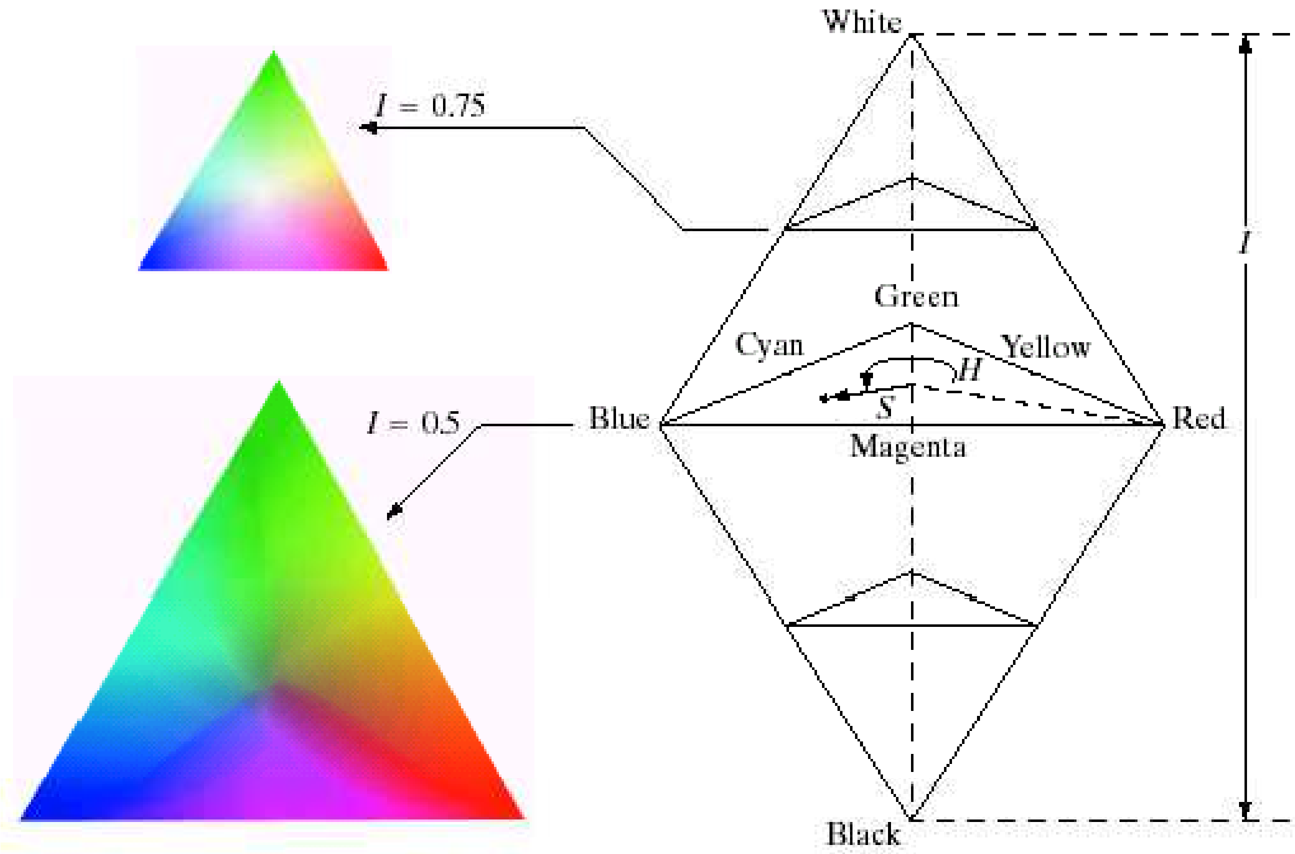
HSI Color Model (cont.)





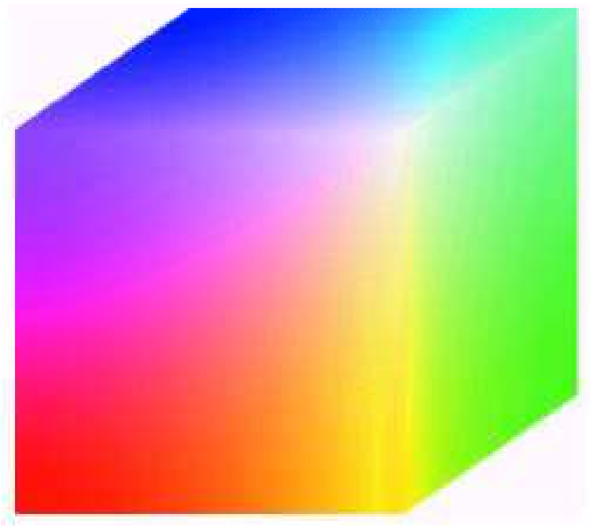
Intensity is given by a position on the vertical axis.

HSI Color Model

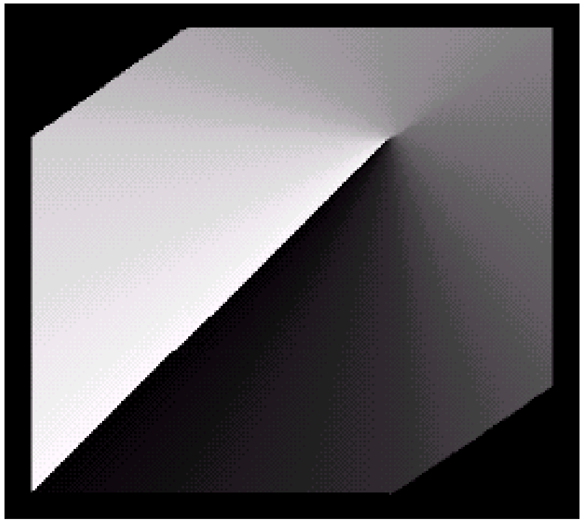


Intensity is given by a position on the vertical axis.

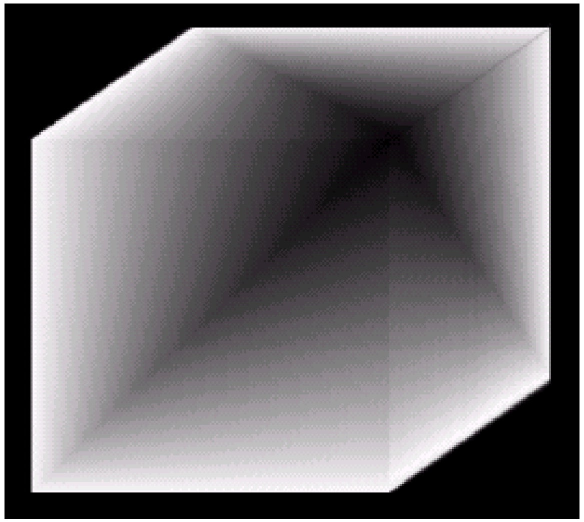
Example: HSI Components of RGB Cube



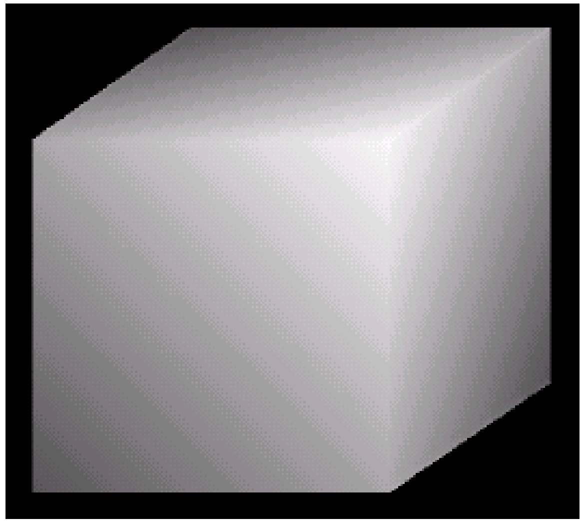
RGB Cube



Hue



Saturation



Intensity

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Converting Colors from RGB to HSI

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

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

$$S = 1 - \frac{3}{R+G+B}$$

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

Converting Colors from HSI to RGB

RG sector: $0 \le H < 120$

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

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

$$G = 1 - (R + B)$$

GB sector: $120 \le H < 240$

$$H = H - 120$$

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

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

$$B = 1 - (R + G)$$

BR sector: $240 \le H \le 360$

$$H = H - 240$$

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

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

$$R = 1 - (G + B)$$

FORMULAE

RGB to HSI Conversion:

First, we convert RGB color space image to HSI space beginning with normalizing RGB values:

$$r = \frac{R}{R+G+B}, \; g = \frac{G}{R+G+B}, \; b = \frac{B}{R+G+B}.$$

Each normalized H, S and I components are then obtained by,

$$h = \cos^{-1}\left\{ \frac{0.5 \cdot [(r-g)+(r-b)]}{\left[(r-g)^2+(r-b)(g-b)\right]^{1/2}} \right\} \qquad h \in [0, \pi] \text{ for } b \le g$$

$$h = 2\pi - \cos^{-1}\left\{ \frac{0.5 \cdot [(r-g)+(r-b)]}{\left[(r-g)^2+(r-b)(g-b)\right]^{1/2}} \right\} \qquad h \in [\pi, 2\pi] \text{ for } b > g$$

$$s = 1 - 3 \cdot \min(r, g, b)\,; \qquad s \in [0,1]$$

$$i = (R+G+B)/(3 \cdot 255)\,; \qquad i \in [0,1].$$

For convenience, h, s and i values are converted in the ranges of [0,360], [0,100], [0, 255], respectively , by:

$$H = h \times 180/\pi\,; \quad S = s \times 100 \text{ and } \quad I = i \times 255.$$

HSI to RGB Conversion:

$$h = H \cdot \pi / 180\,; \qquad s = S/100\,; \qquad i = I/255$$

$$x = i \cdot (1-s)$$

$$y = i \cdot \left[1 + \frac{s \cdot \cos(h)}{\cos(\pi/3 - h)} \right]$$

$$z = 3i - (x + y);$$

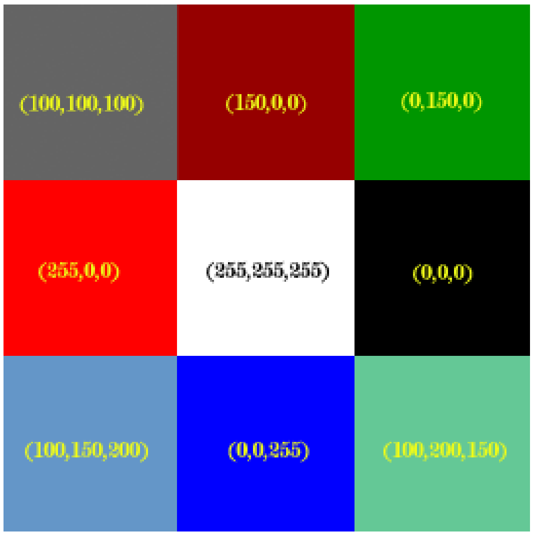
when $h < 2\pi/3$, $b = x$; $r = y$ and $g = z$.

when $2\pi/3 \le h < 4\pi/3$, $h = h - 2\pi/3$, and $r = x$; $g = y$ and $b = z$.

when $4\pi/3 \le h < 2\pi$, $h = h - 4\pi/3$, and $g = x$; $b = y$ and $r = z$.

The result r, g and b are normalized values, which are in the ranges of [0,1], therefore, they should be multiplied by 255 for displaying.

Example: An image is shown here:



With RGB values as:

$$\begin{pmatrix} (100,100,100) & (150,0,0) & (0,150,0) \\ (255,0,0) & (255,255,255) & (0,0,0) \\ (100,150,200) & (0,0,255) & (100,200,150) \end{pmatrix}$$

RGB to HSI Conversion:

To compute HSI value of pixel (100,150,200)

1. Normalize:

$$r = \frac{R}{R+G+B} = 0.222\text{, } g = \frac{G}{R+G+B} = 0.333\text{, } b = \frac{B}{R+G+B} = 0.444$$

2. Here b > g, so we compute H value by equation:

$$h = 2\pi - \cos^{-1}\left\{ \frac{0.5 \cdot [(r-g)+(r-b)]}{\left[(r-g)^2 + (r-b)(g-b)\right]^{1/2}} \right\} = 1.167\pi$$

Compute S value by:

$$s = 1 - 3 \cdot \min(r, g, b) = 0.333$$

3. Represent H,S,I values in the ranges of [0,360], [0,100] and [0, 255]:
4.

$$H = h \times 180 / \pi = 210$$

$$S = s \times 100 = 33.3$$

$$I = (R+G+B)/3 = 150$$

HSI to RGB Conversion

5. $h = H \cdot \pi / 180 = 7\pi / 6$; $s = S/100 = 0.333$; $i = I/255 = 0.588$

6. When $2\pi/3 \le h < 4\pi/3$, we use following formulae

$$h = h - 2\pi/3 = \pi/2,$$

$$r = x = i \cdot (1 - s) = 0.392$$

$$g = y = i \cdot \left[1 + \frac{s \cdot \cos(h)}{\cos(\pi/3 - h)}\right] = 0.588$$

$$b = z = 3i - (x + y)$$

7. To represent R,G,B values in the ranges of [0,255], [0,255] and [0, 255]:
8.

$$R = 255 \cdot r = 100$$
$$G = 255 \cdot g = 150$$
$$B = 255 \cdot b = 200$$