Lecture 6
Color Image Processing

Dr. Raj Tissainayagam

Broadband Systems Division
NEC Australia Pty Ltd

raj@tns.nec.com.au

Color Fundamentals

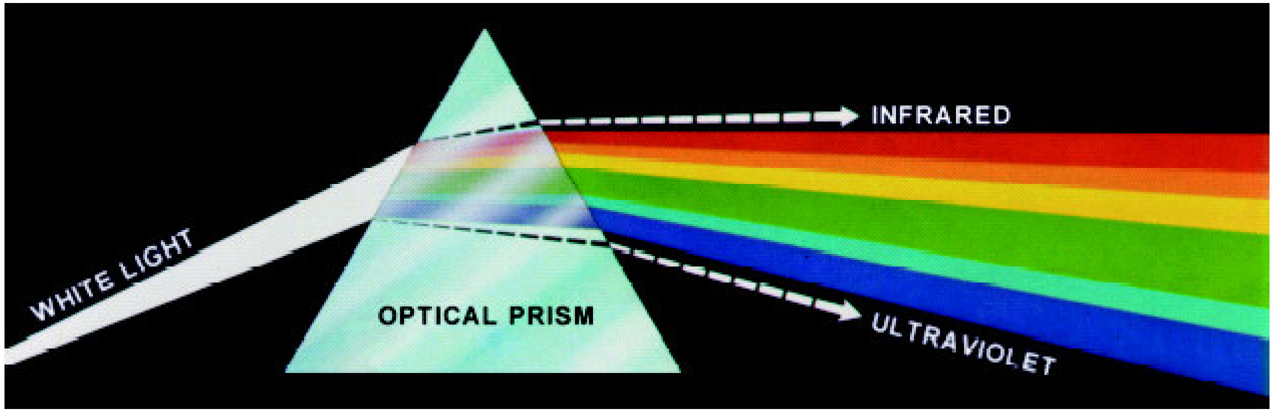


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

White light split into individual colors using a prism

Full color – Image acquired with a full color sensor

Pseudo-color – Color assigned to an intensity value or range

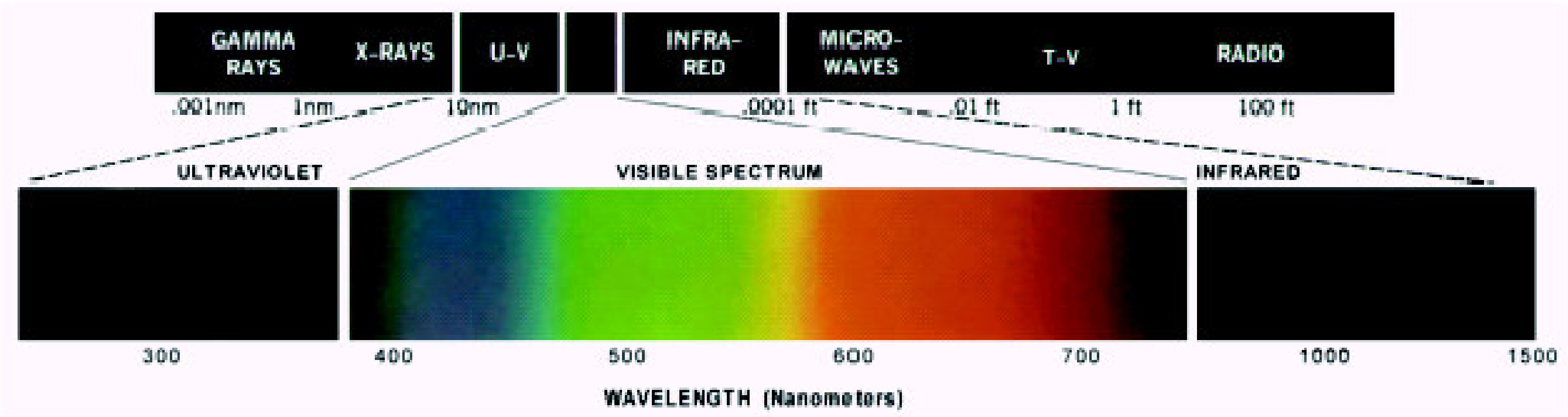


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Physical units

Radiance (Watts): Total energy emitted by a light source

Luminance (lumens): Incoming energy as measured by the detector

Brightness: Subjective units (can’t measure!!)

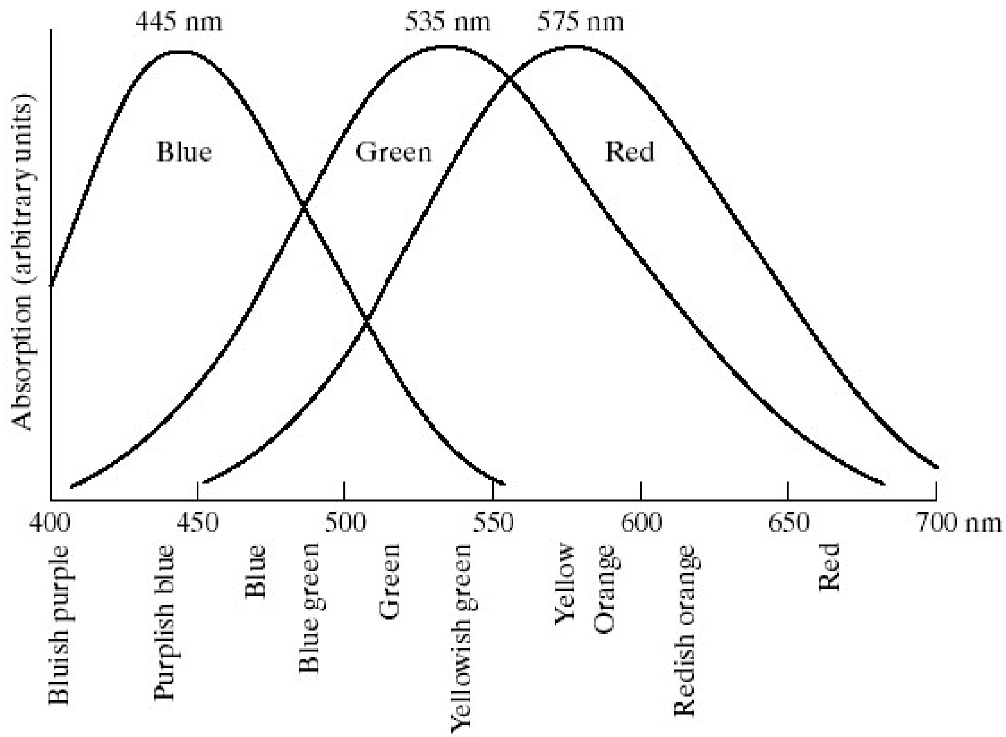


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Spectral response of human eye

primary colors do not quite correspond to human eye sensitivity

red (700nm) — 65% of all cones sensitive to red

green (546.1nm) — 33% " green

blue (435.8nm) — 2% " blue

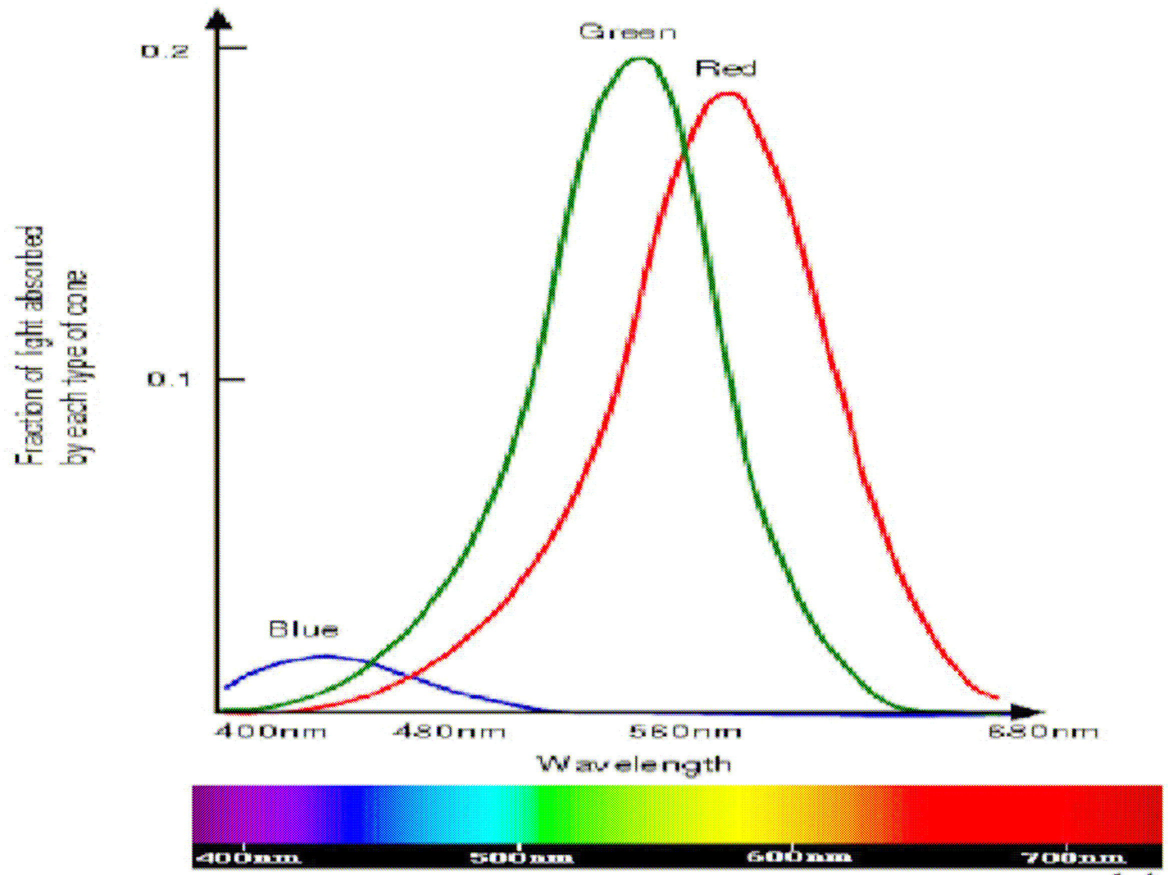
Color

- How do we perceive color?
  - Eye has different types of cells (cones)sensitive to different wavelengths
  - Filter peaks:

    Blue: 440

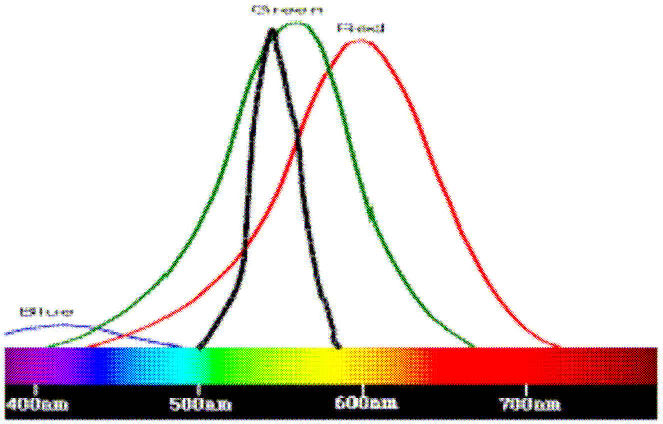
    Green: 545

    red: 580

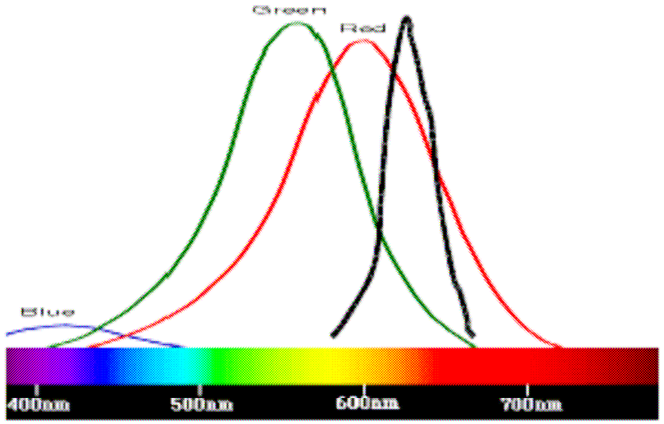


Color

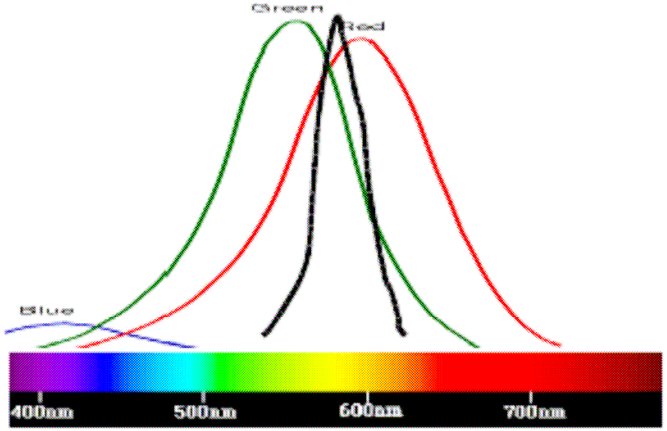
- The mixture of wavelengths determines the sensation of color
- Any perceived color could be created by many different observed spectrums



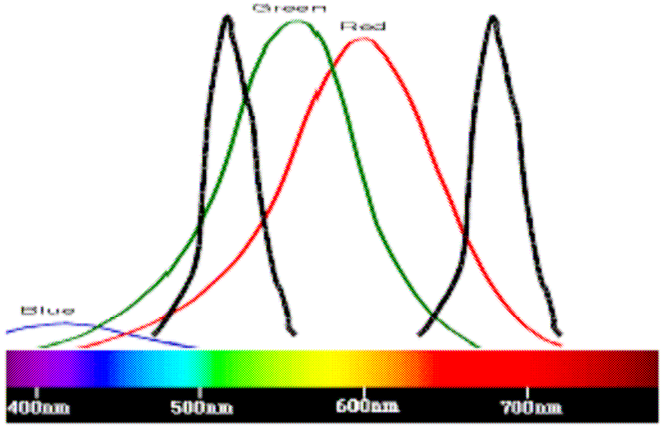
Perceived as green



Perceived as red



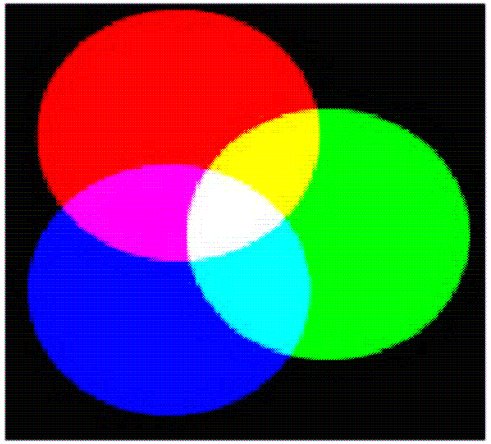
Perceived as yellow

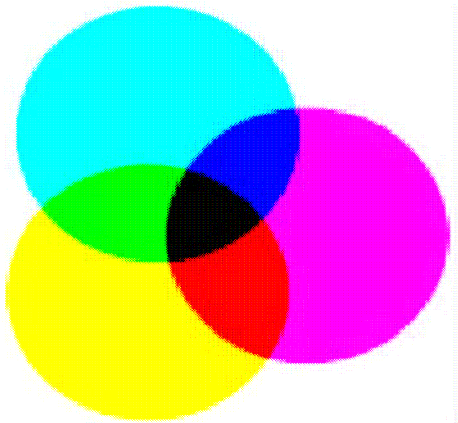


Perceived as yellow

Color

- Tristimulus theory
  - We can recreate a color by changing the mixing ratio of 3 colors
- Additive (primary) colours:
  - Red, green, blue (RGB)
  - Three colours add to make white.
  - eg. CRT, LCD
- Subtractive (secondary) colours:
  - Cyan, magenta, Yellow (CMY)
  - Three colours subtract to make black.
  - eg. Painting, printing.





(Primary)

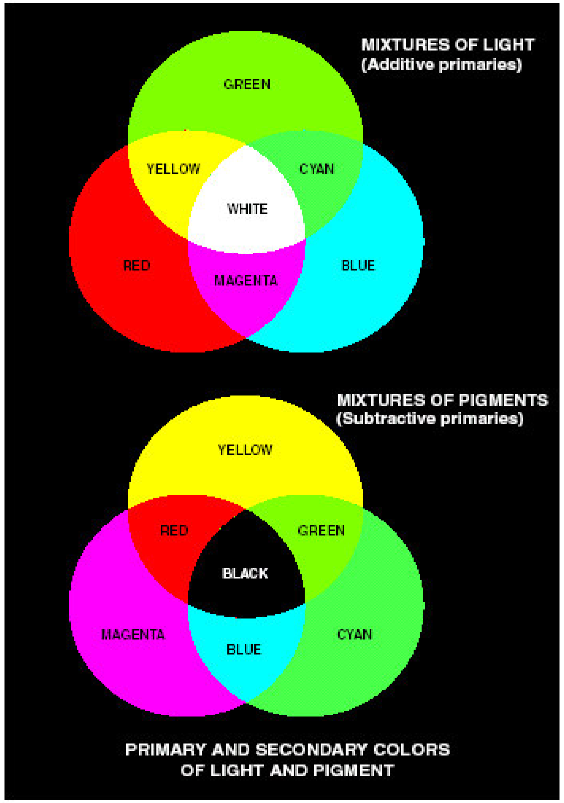
additive colors

transmission

Subractive colors

(secondary)

Reflection absorbs a primary color



R-G-B

-TV monitors

Cyan-Magenta-Yellow

-Printing

Need Black also

a
b

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

yellow - absorbs blue
and transmits
red + green = yellow

characteristics of color

brightness

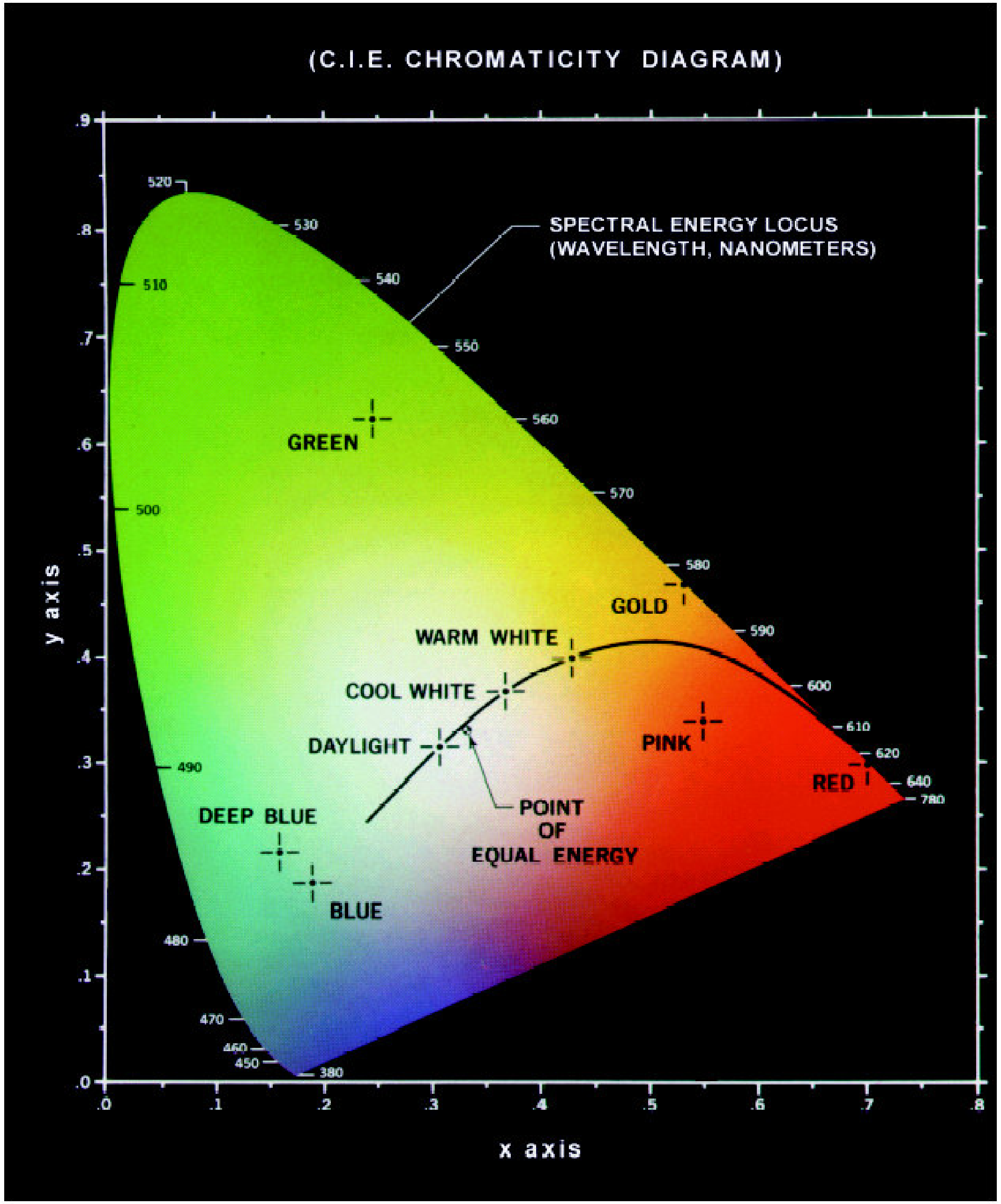
chromaticity { hue — dominant color seen by an observer

saturation — amount of white light mixed with The color

FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)

Any point on boundary is fully saturated (saturation=1)

green



+green ~ (.25 red, .62 green)

Point of equal energy – white (0.33 red, 0.33 green)

Several kinds of white

Warm – more red

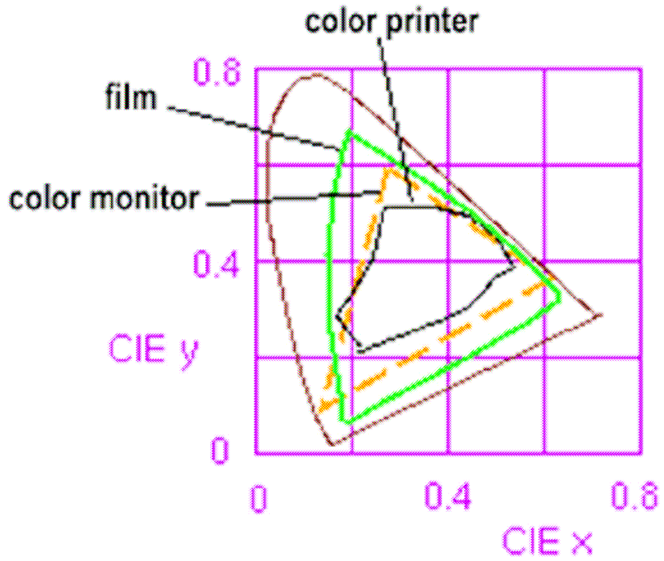
Cool-

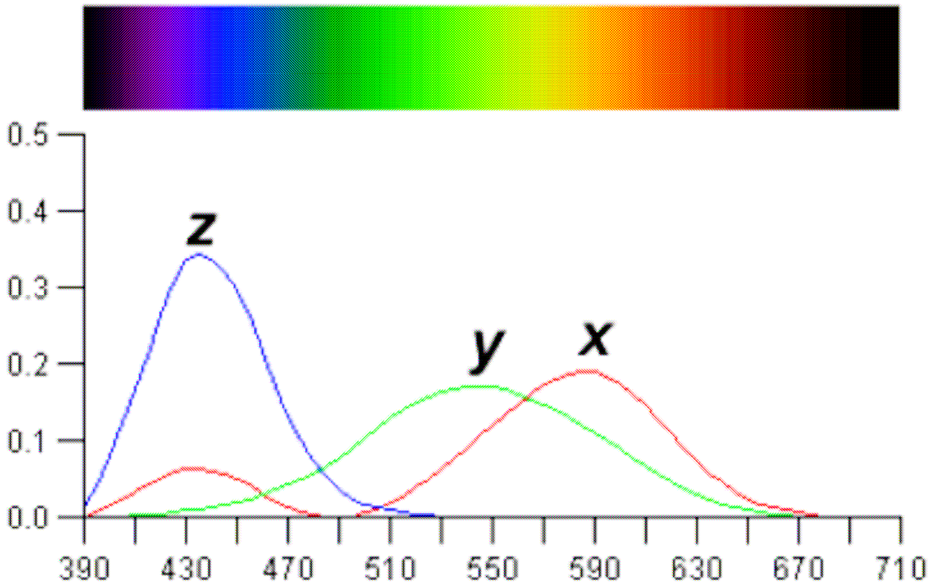
Natural – (daylight)

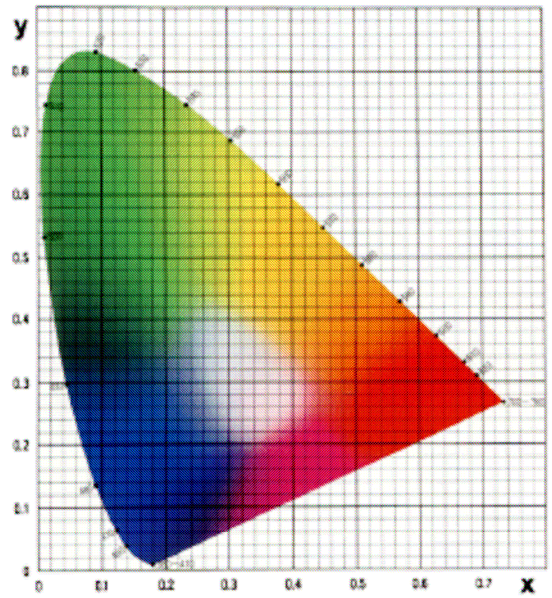
red

Color

- CIE-colorspace
  - Defined standard light sources which allow to reproduce colors as additive mixtures
  - Carefully designed, but cannot be reproduced on practical devices







A color can be specified by its tristimulus values

red $x = \dfrac{X}{X+Y+Z}$

green $y = \dfrac{Y}{X+Y+Z}$

blue $z = \dfrac{Z}{X+Y+Z}$

$\left.\right\}$ where $x+y+z=1$

where X, Y, Z are the amounts of red, green, and blue needed to form a color

CIE chromaticity diagram
just specify x, y (red, green) since blue is then determined by $1-x-y$.

point of equal energy = CIE standard for white light (saturation = 0 here)

Irregular area is typical color printing area

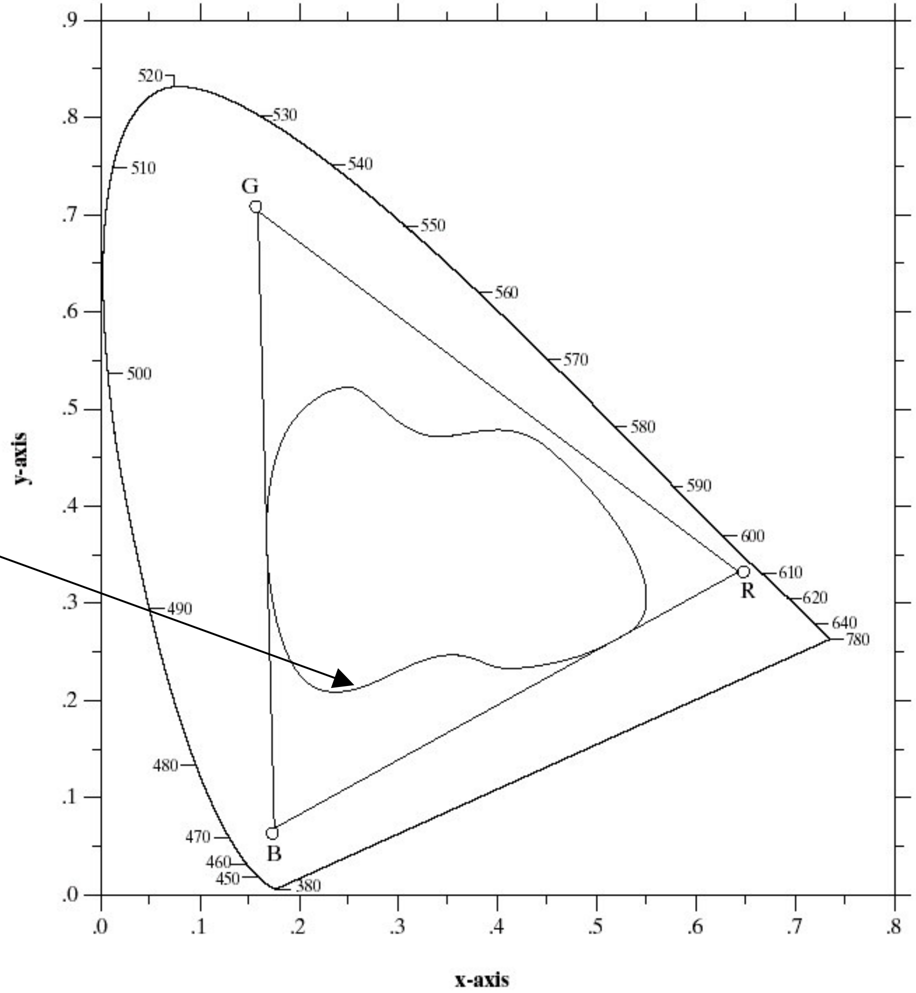


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

The RGB points represent the maximum RGB values of an RGB monitor. Since a monitor is an additive process this RGB monitor can create any color within the triangle.

Color Models

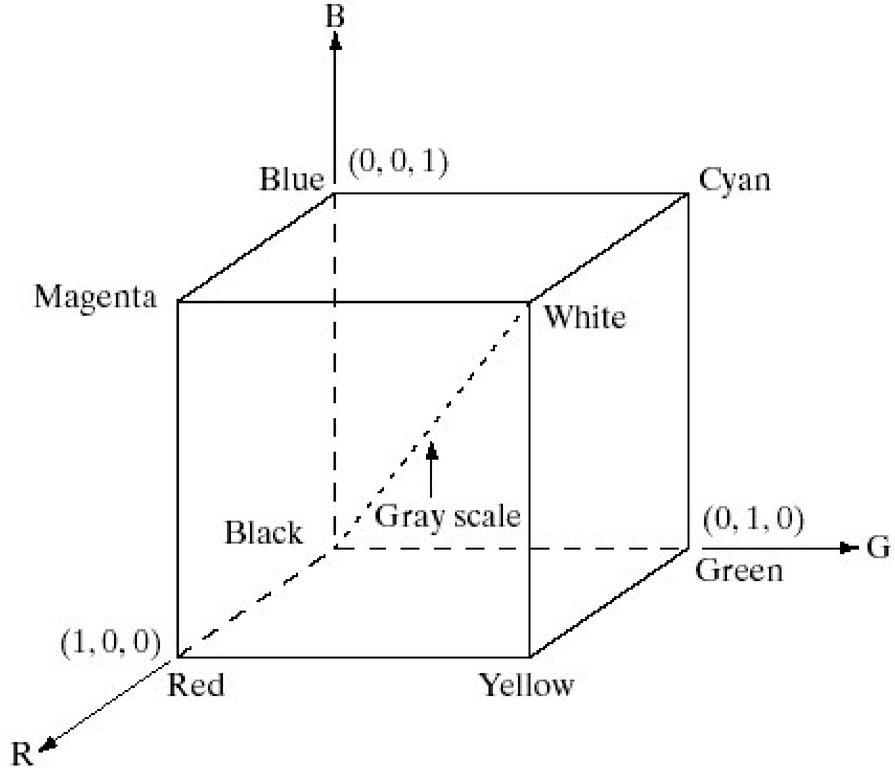
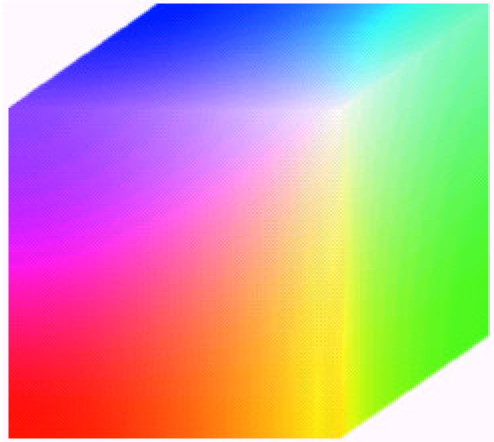


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

RGB color model

depth is the number of bits used in total
For example, 8-bit RGB is $8 \times 3 = 24$ bit depth.

Top is (R,G,255) surface



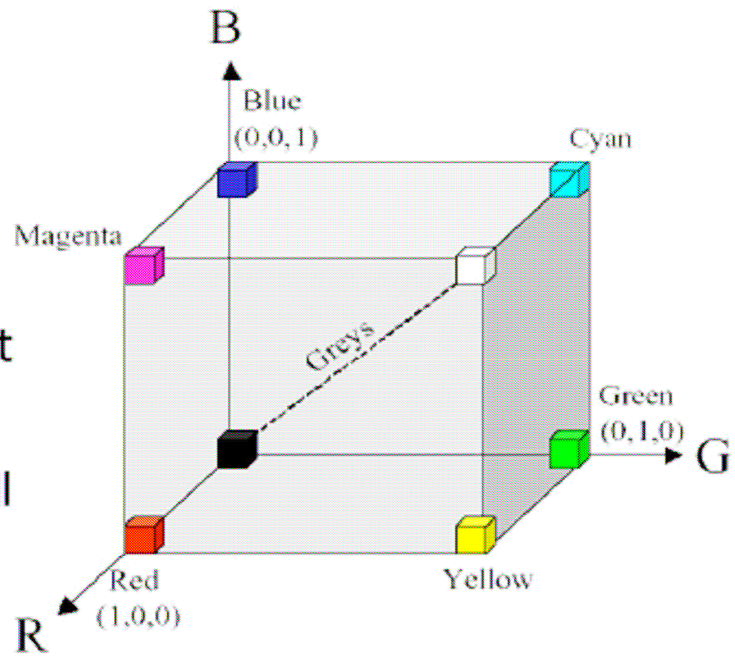
Can be represented as [0,255] or [0,1]

FIGURE 6.8 RGB 24-bit color cube.

Bottom is (R,G,0) surface

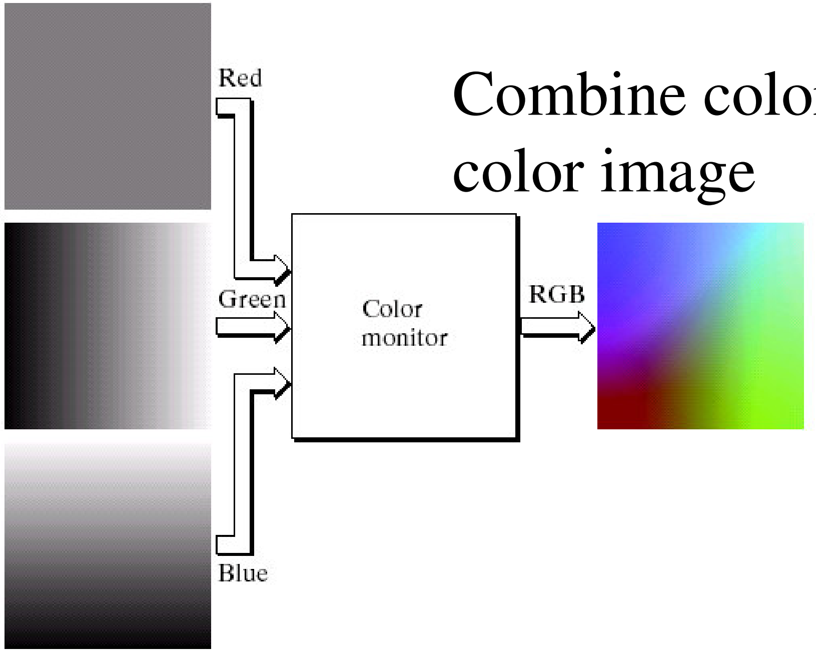
Color

- Pros
  - RGB corresponds to the way our eyes sense
  - Convenient for image display on CRT, LCD etc.
  - CMYK (inverse RGB) is convenient for printing processes.
- Cons
  - RGB corresponds to the way we sense colour but not the way we perceive colour
  - For example, consider an object moving from full sunlight to shade.
    - Intensity across whole spectrum reduces.
    - We sense reduced RGB
    - However we perceive a change in brightness, not 3 changes in RGB

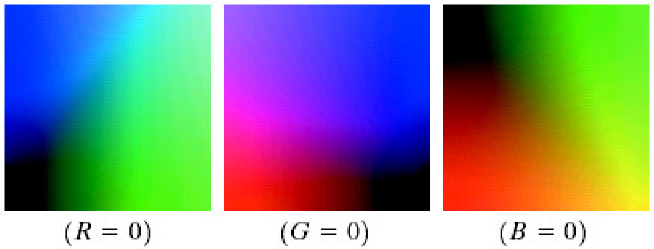


a
b

FIGURE 6.9 (a) Generating the RGB image of the cross-sectional color plane $(127, G, B)$. (b) The three hidden surface planes in the color cube of Fig. 6.8.



Combine color planes into color image

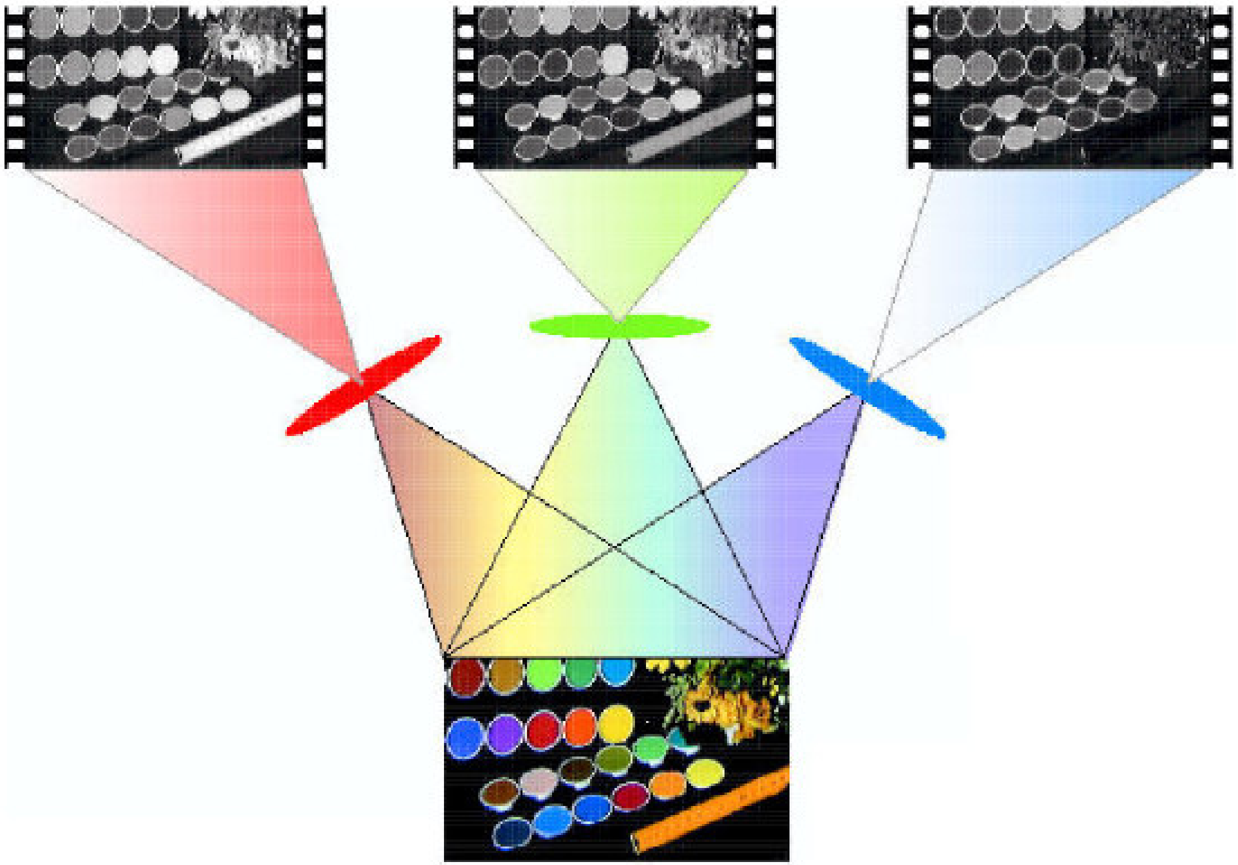


(R,G,B) (0,G,B) (R,0,B) (R,G,0)

back planes looking inside out

Color

- Representing color
  - Straight-forward generalization of gray-value images: record several images for different wave-lengths and overlay them => RGB



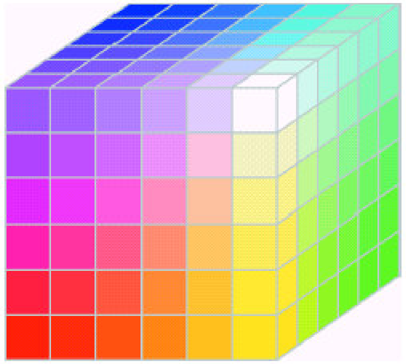


FIGURE 6.11 The RGB safe-color cube.

"safe" colors are only on the surfaces (faces).
No interior colors are "safe".

CMY Color Model

Color printers & copiers convert RGB to CMY

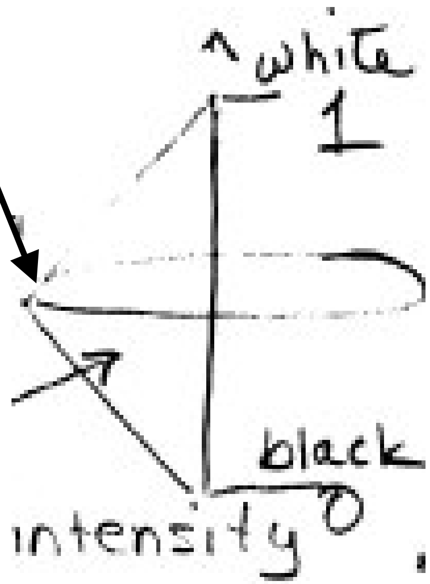
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

To get a good black on color printers we add "black" as a fourth color.

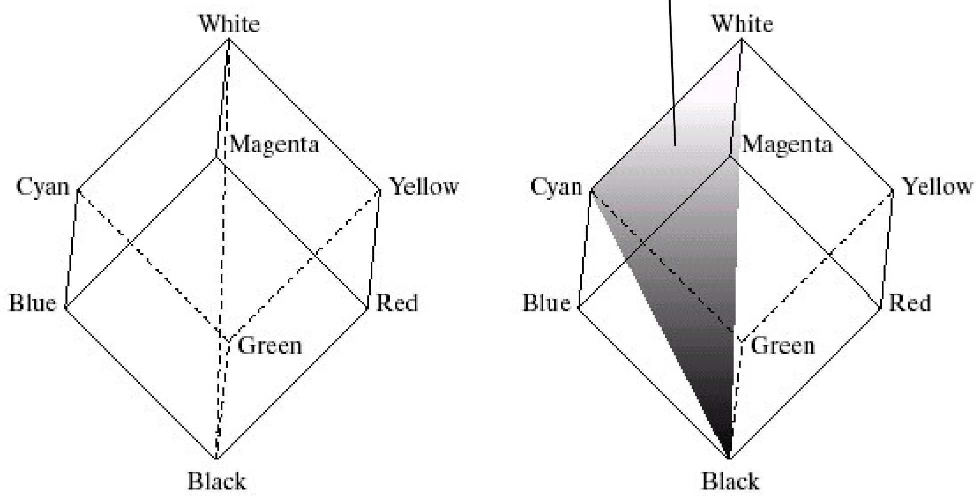
HSI Color Model

Same saturation place

Same hue plane



Plane of constant hue (cyan)



a b

FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.

Although RGB is good for generating colors it is not good for describing colors as humans interpret them.

H - hue
S - saturation
} color information decoupled from intensity

I - intensity } gray scale image

For an RGB color cube the intensity I is the diagonal from (0,0,0) black to (1,1,1) white. The intensity of any RGB color is its projection onto this intensity diagonal.

The plane perpendicular to the gray diagonal in the RGB cube will contain all colors of the same saturation since white does not change.

The plane defined by the gray diagonal and the cube boundaries will contain all colors of the same hue.

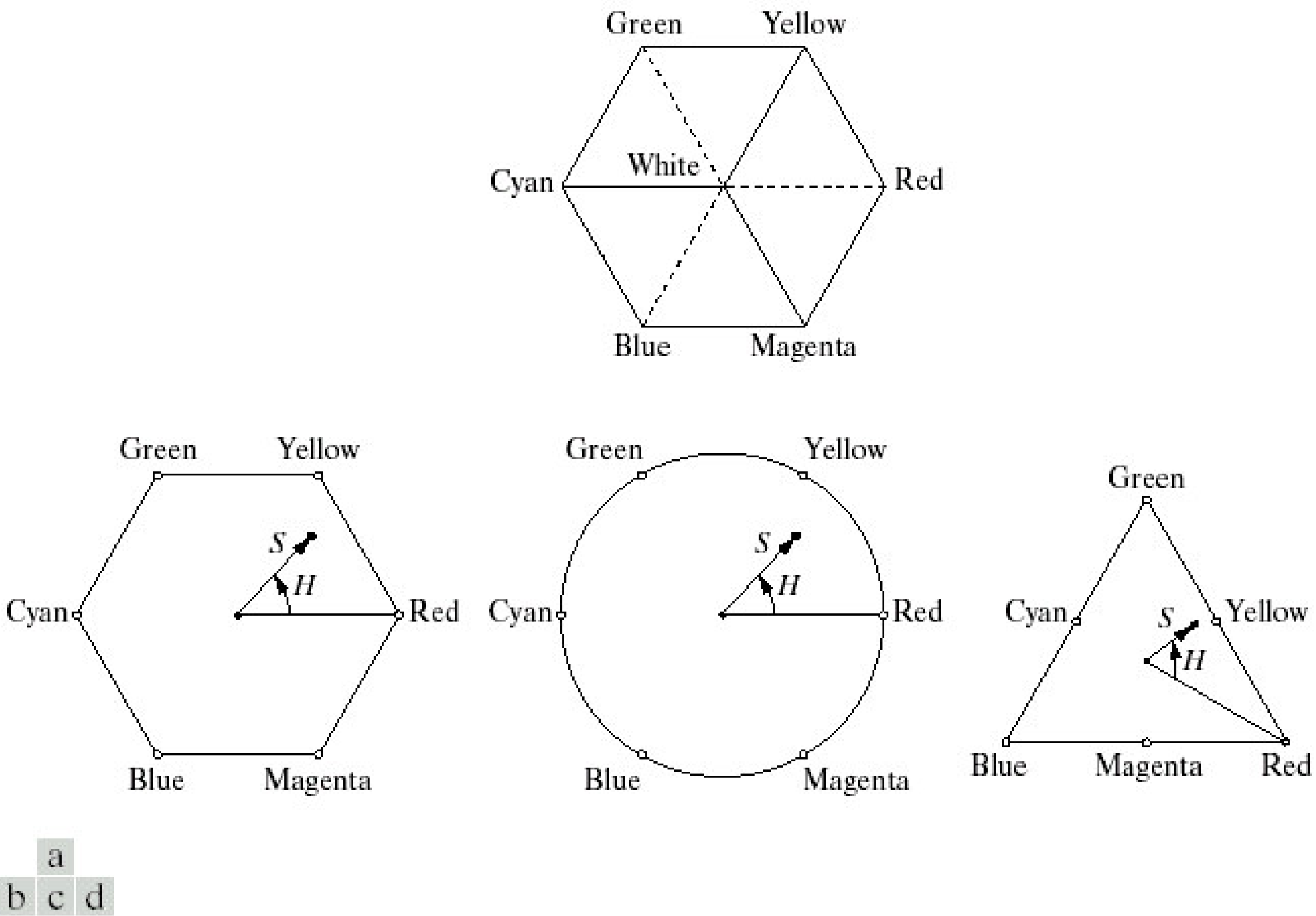
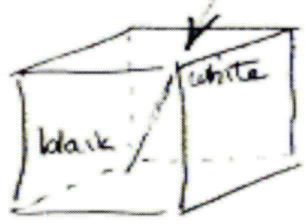
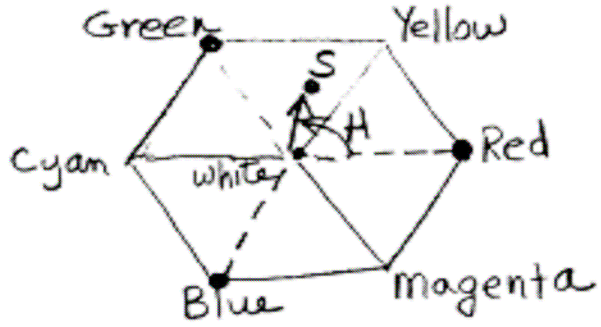


FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

looking at diagonal perpendicular planes are hexagonal.



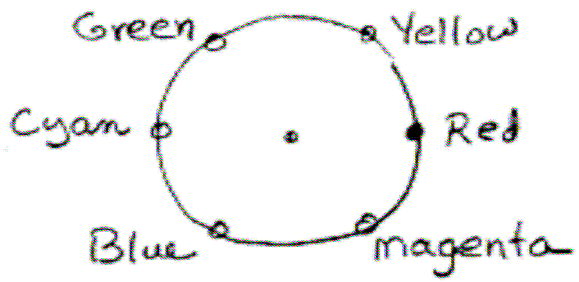
looking along axis

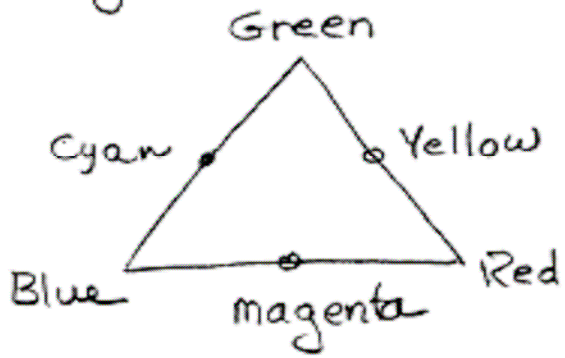


The hue of any point in each plane is it's angle from a reference point.

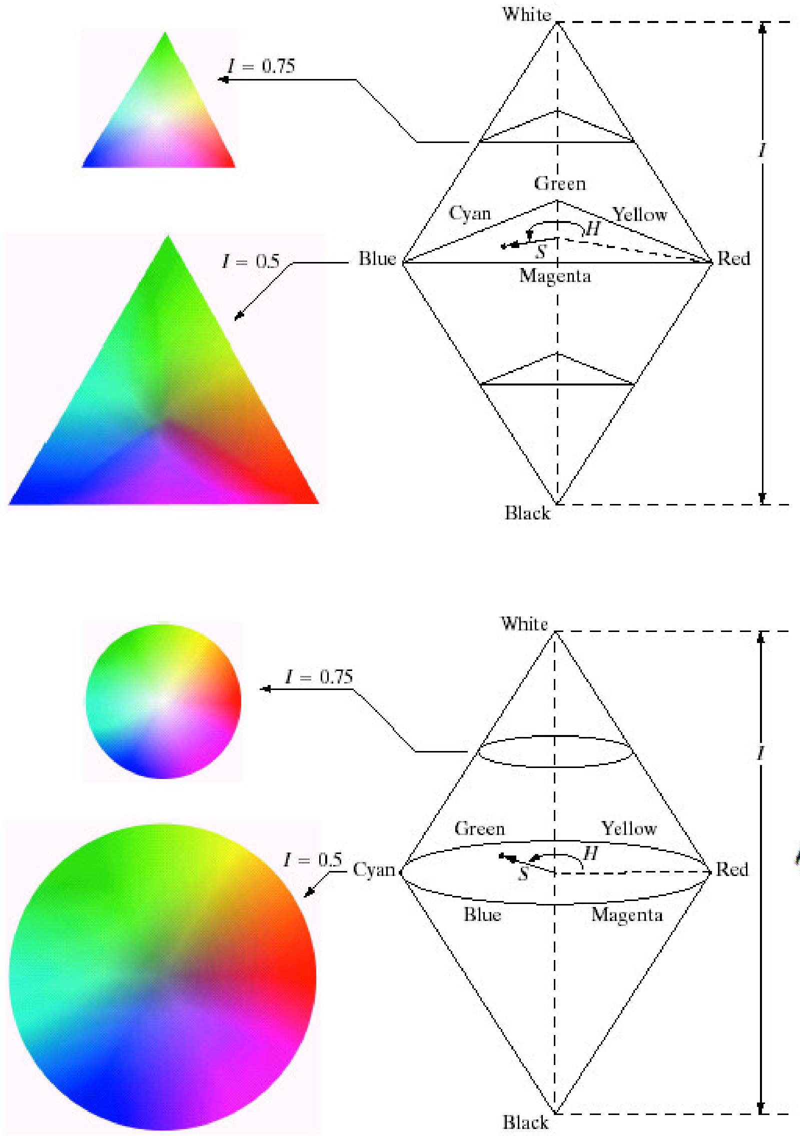
The saturation is the distance from the origin.

Various simplifications of this hexagon are circles and triangles.





Coverting from RGB to HSI



a
b

FIGURE 6.14 The HSI color model based on (a) triangular and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

From Figure 6.13 we can use trigonometry to derive the relationships between RGB and an HSI point.

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

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

saturation $S = 1 - \dfrac{3}{R+G+B} \min(R,G,B)$

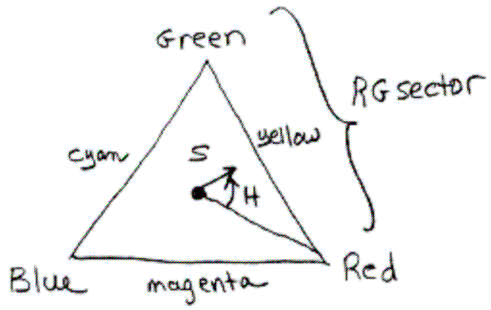
intensity $I = \frac{1}{3}(R+G+B)$

See book's web site for derivation

This is the gray diagonal, i.e. the intensity axis.

Converting colors from HSI to RGB

Multiply H by 360° to convert it back to an angle. H is usually normalized to [0,1].



RG Sector $(0° \leq H \leq 120°)$

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

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

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

GB sector $(120° \leq H \leq 240°)$

compute $H = H - 120°$

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

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

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

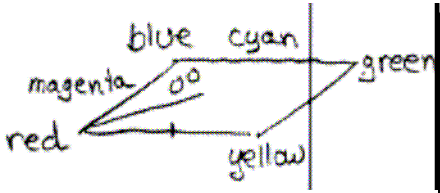
BR Sector $(240° \leq H \leq 360°)$

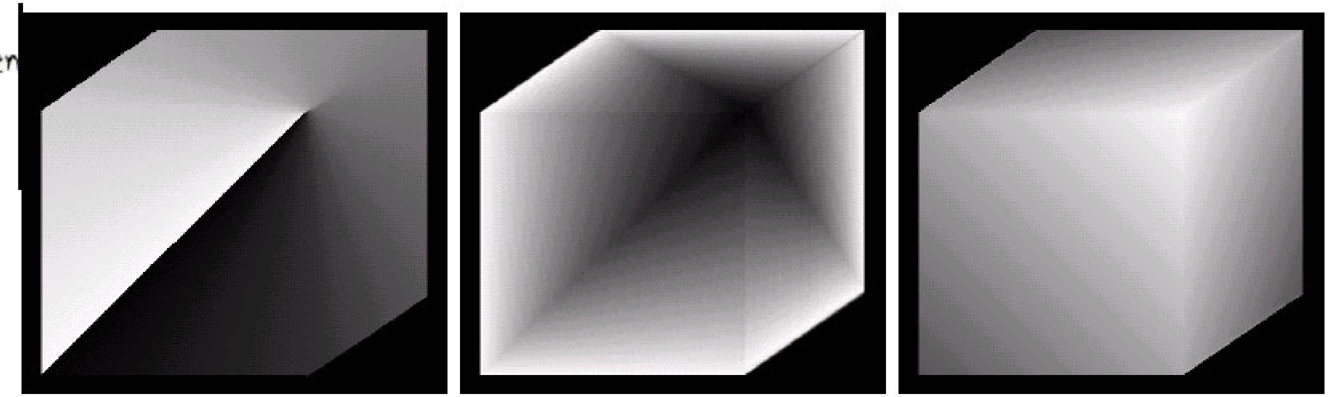
compute $H = H - 240°$

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

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

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





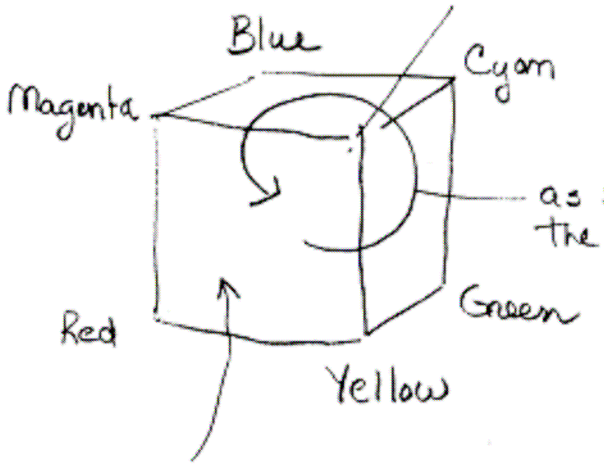
a b c

FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

discontinuity because H is going from 1 (bright) to 0 (dark)

shows decreasing value, i.e. less saturation as you approach white

$I = \frac{1}{3}(R+G+B)$ is just average of R,G,B values



as seen looking back along the gray axis we have a discontinuity from 1 to zero along the red-white line.

this is the H=0 plane where H switches from 0°(black) to 360° (white)

Manipulating HSI component images

Black and white have zero hue

Primary - secondary colors

H component

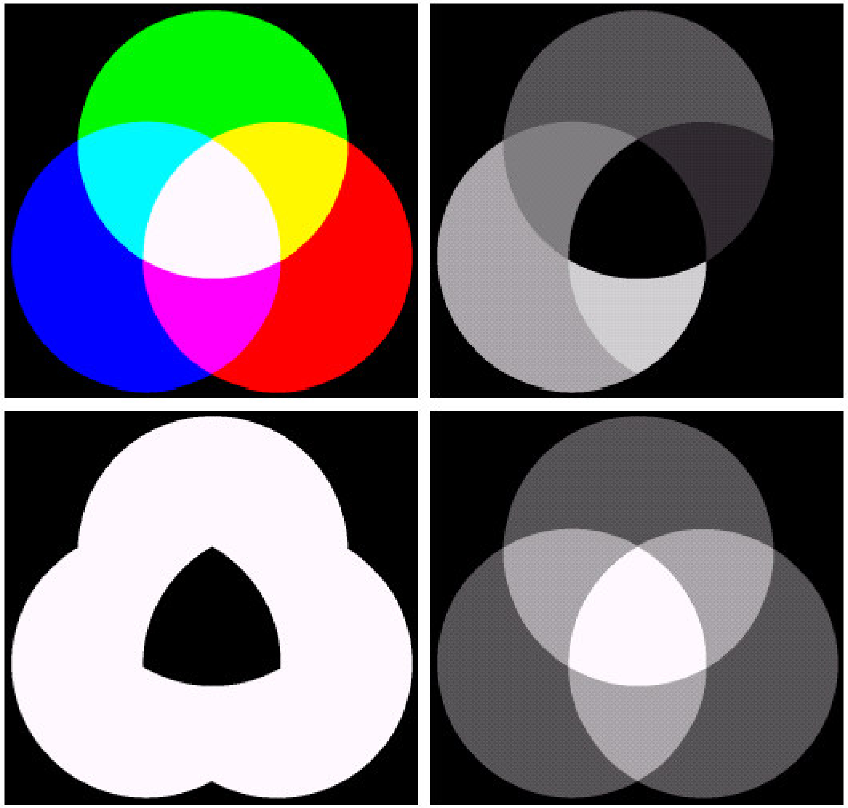
(angles)

S Component [0,255]

Colors are fully saturated

I component

Average intensities

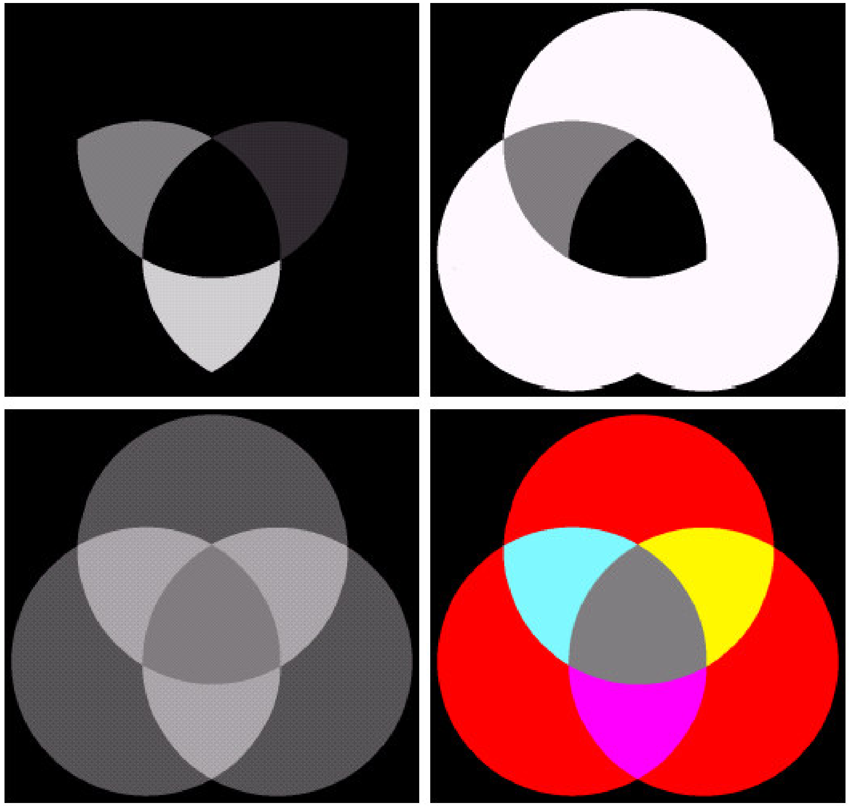


a b
c d

FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.

H: change blue and green to 0,ie red

Reduce cyan saturation by 50%



I: reduce intensity of white by 50%

Transformed colour image

B,G become R

Cyan looks washed out white

White is now 50% grey

a b
c d

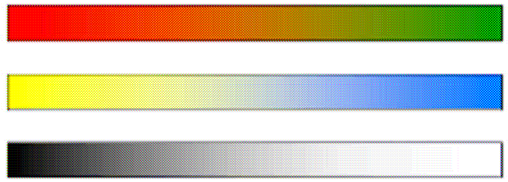
FIGURE 6.17 (a)–(c) Modified HSI component images. (d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)

To change color in HSI simply change the hue value and convert back to RGB without changing S and I.

To change saturation modify only S,

Color

- YUV color space – used for PAL broadcast television system
- Uses reduced bandwidth for UV (same trick in MPEG)
- Color vector is described in terms of difference between color pairs



Red-green
yellow-blue
black-white (brightness)

RGB-to-YUV

Y = .299R + .587G + .114B
U = -.147R - .289G + .437B
V = .615R - .515G - .100B

YUV-to-RGB

R = 1.00Y + .000U + 1.403V
G = 1.00Y - .344U - .714V
B = 1.00Y + 1.773U + .000V

Color

- Other color spaces
  - Attempts to linearize CIE: Lab, Luv

$$L^* = 116 * (Y/Yn)^{1/3} - 16 \quad \text{for } Y/Yn > 0.008856$$
$$L^* = 903.3 * Y/Yn \quad \text{otherwise}$$

$$a^* = 500 * (\, f(X/Xn) - f(Y/Yn) \,)$$
$$b^* = 200 * (\, f(Y/Yn) - f(Z/Zn) \,)$$
$$\text{where } f(t) = t^{1/3} \quad \text{for } t > 0.008856$$
$$f(t) = 7.787 * t + 16/116 \quad \text{otherwise}$$

  - YIQ: adapted by NTSC for television system

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$