Color image processing

莊子肇 副教授
中山電機系

Introduction

- In automated image analysis, color is a powerful descriptor, which simplifies object identification and extraction.
- The human eye can distinguish between thousands of color shades and intensities but only about 20-30 shades of gray. Hence, use of color in human image processing would be very effective.
- Color image processing
  - Pseudo-color processing
  - Full-color processing.

Color Fundamentals

- When a beam of sunlight is passed through a glass prism, the emerging beam of light is not white but consists of a continuous spectrum of colors (Sir Isaac Newton, 1666).

- The different colors (violet, blue, green, yellow, orange, and red) in the spectrum do not end abruptly but each color blends smoothly into the next.

Color spectrum

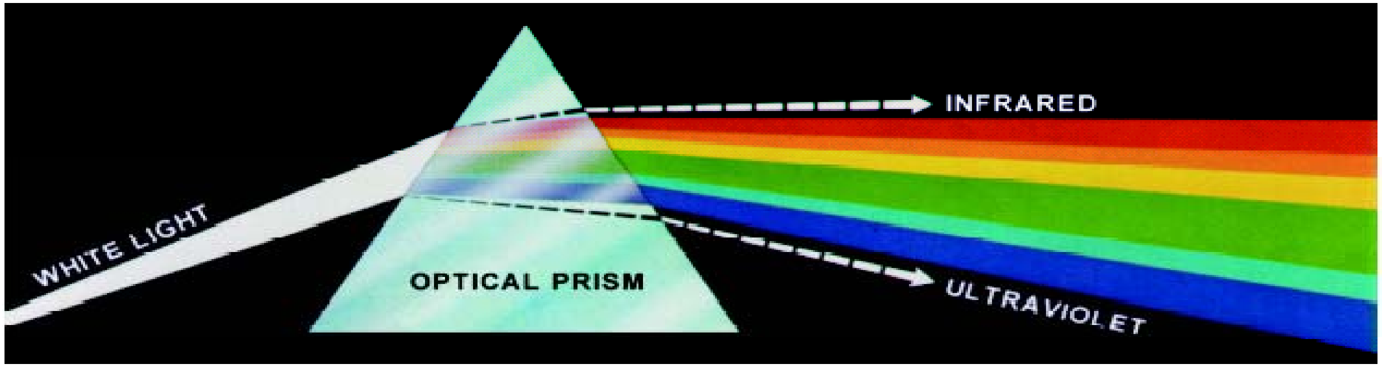


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

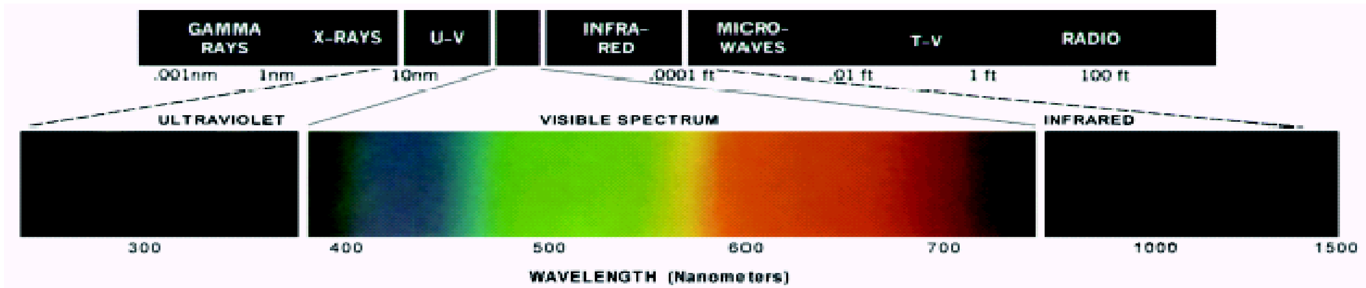


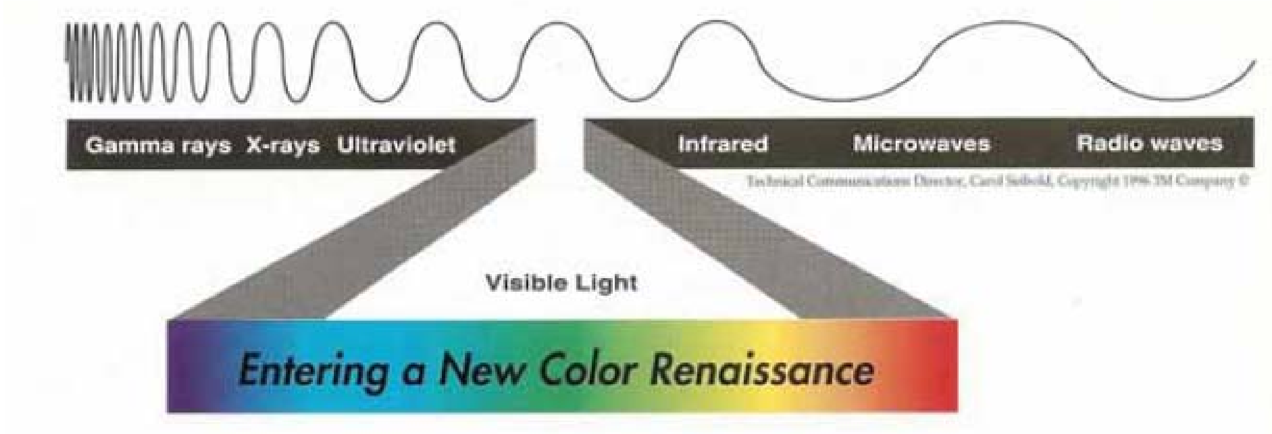
FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

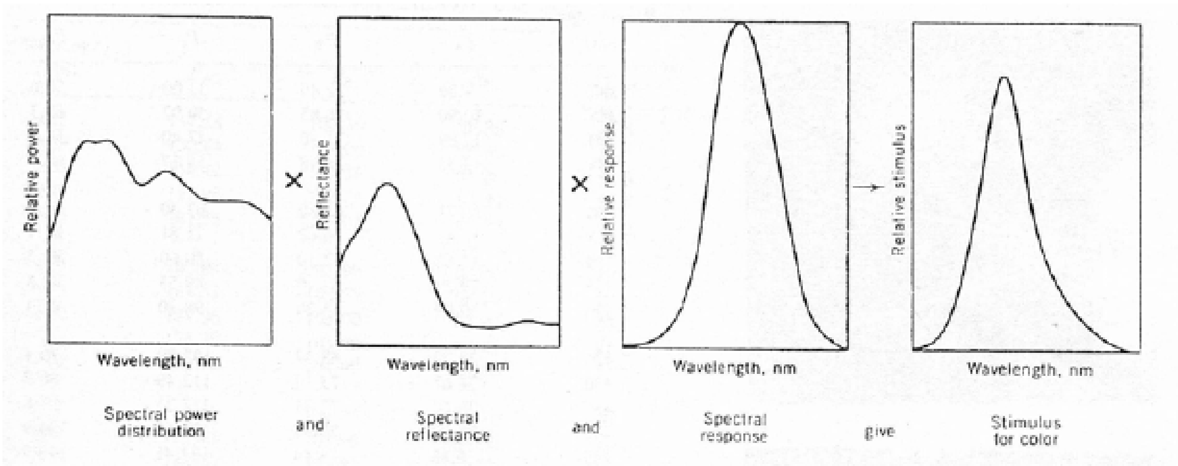
- Light that is relatively balanced in all visible wavelengths is perceived as white.
  - Achromatic
  - Gray scale
  - Chromatic light spans the electromagnetic (EM) spectrum from approximately 400 nm to 700 nm.

- Color perceived by the human eye depends on the nature of light reflected by an object.
  - Objects that appear green reflect more light in the 500-570 nm range (absorbing other wavelengths of light).

Color perception



Wavelength between 380nm to 780nm

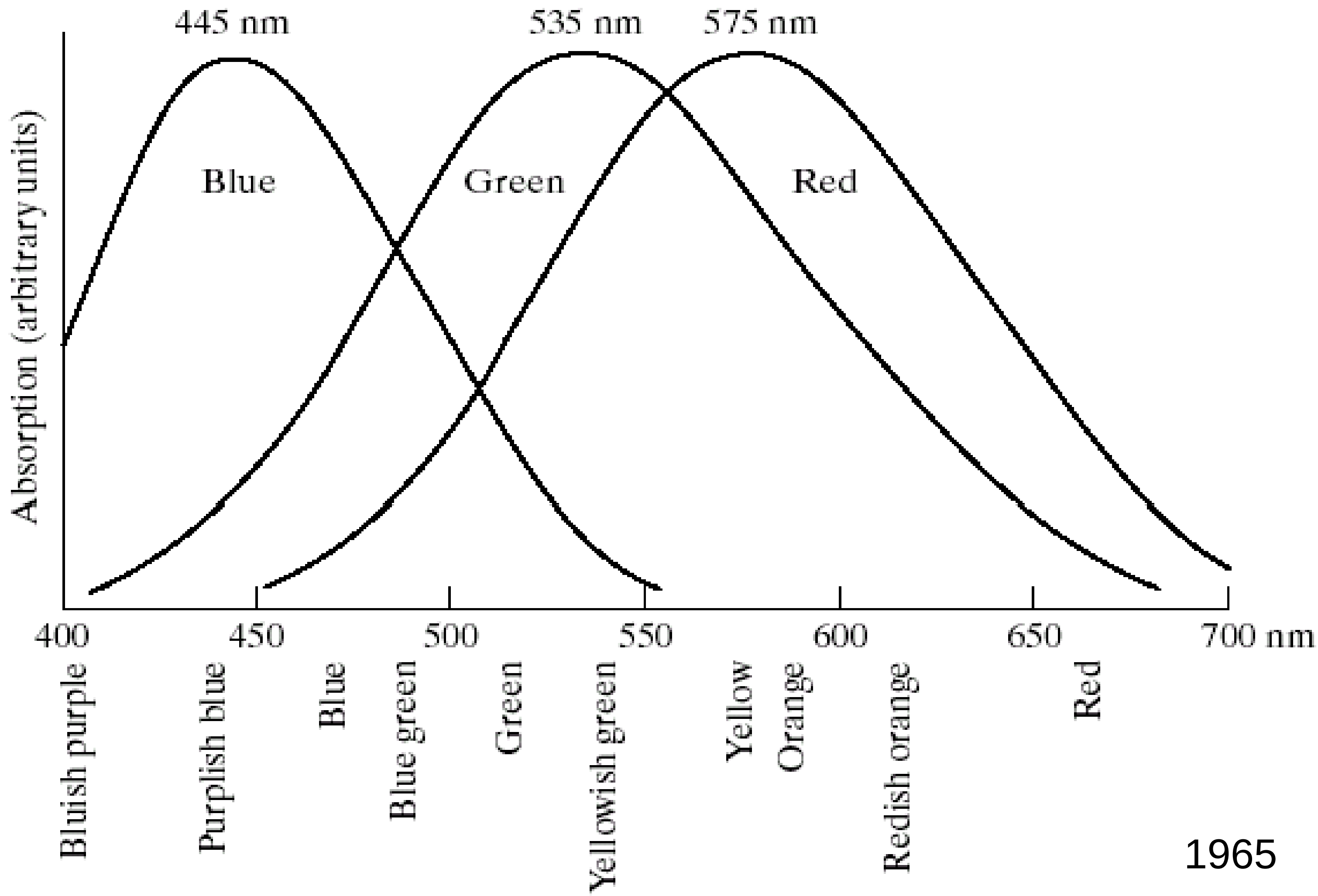


Light source	Reflectance	Eye's Responsivity	Color

Human eyes v.s. color image

- Cones in the retina are responsible for color perception in the human eye.
- Six to seven million cones in the human eye can be divided into three categories: red light sensitive cones (65%), green light sensitive cones (33%) and blue light sensitive cones (2%). The latter cones are the most sensitive ones.
  - Three primary colors: RGB

Absorption of light by cones



1965

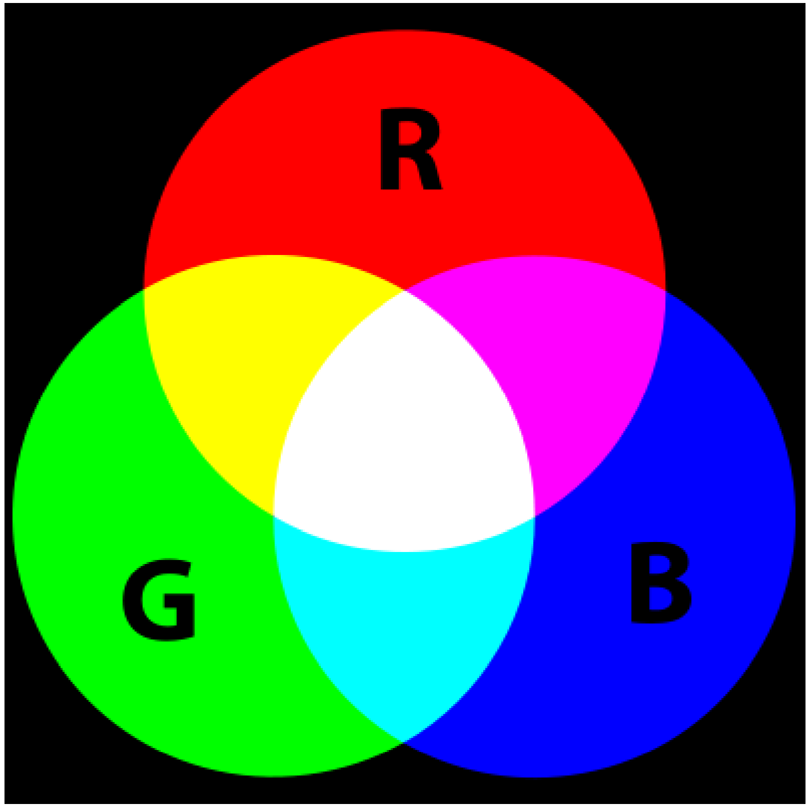
Standardization: CIE primary colors

- Red (R) (700 nm)
  Green (G) (546.1 nm)
  Blue (B) (435.8 nm)

- The wavelengths for the three primary colors are established by standardization by the CIE (International Commission on Illumination) in 1931. (only approximately correspond to the experimental curves in last slide)

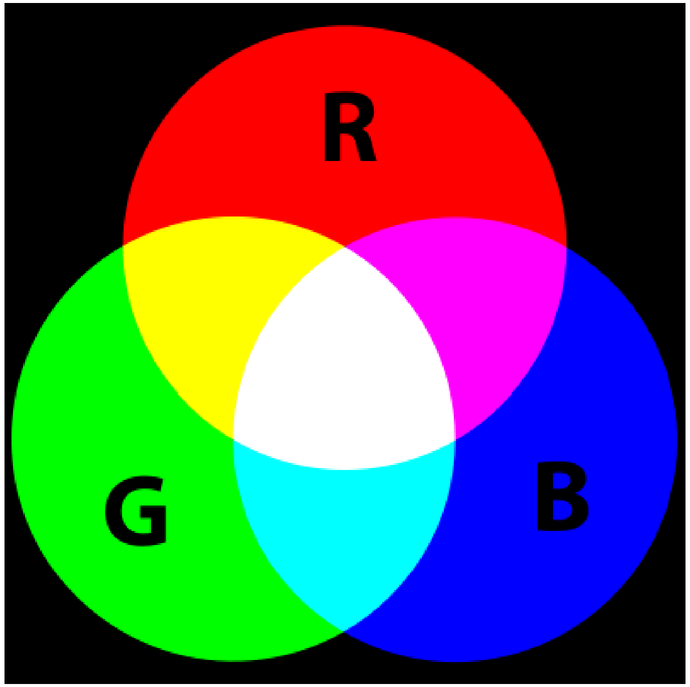
Primary and secondary colors

- Primary colors are added to produce secondary colors:
  - Magenta (red + blue)
  - Cyan (green + blue)
  - Yellow (red + green)

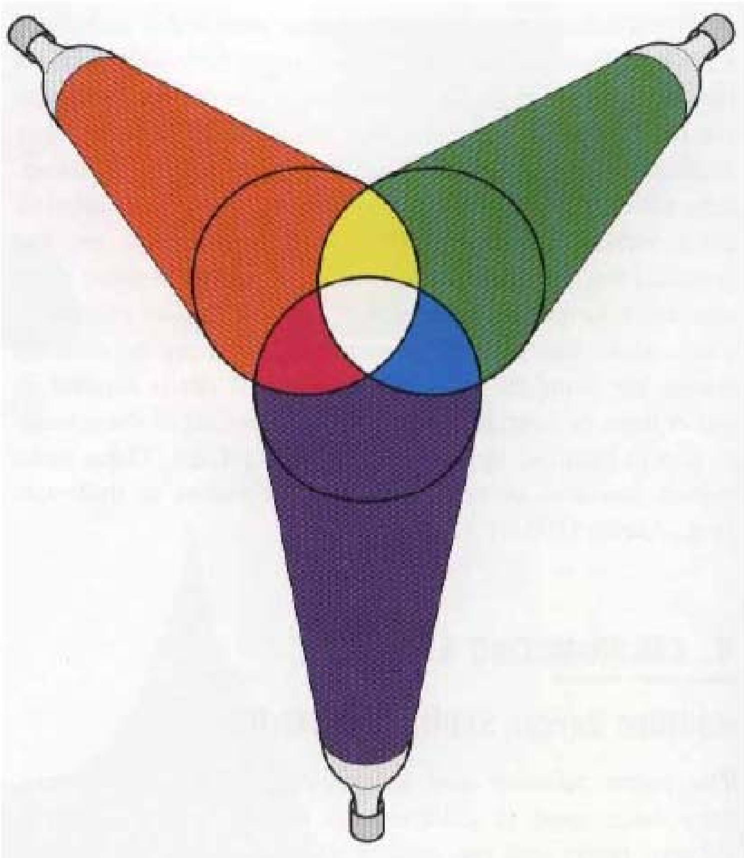


Additive color mixing

- Mixing the three primaries, or a secondary with its opposite primary, in the right intensities produces white light.
- Mixture of lights
    - TV, computer monitor



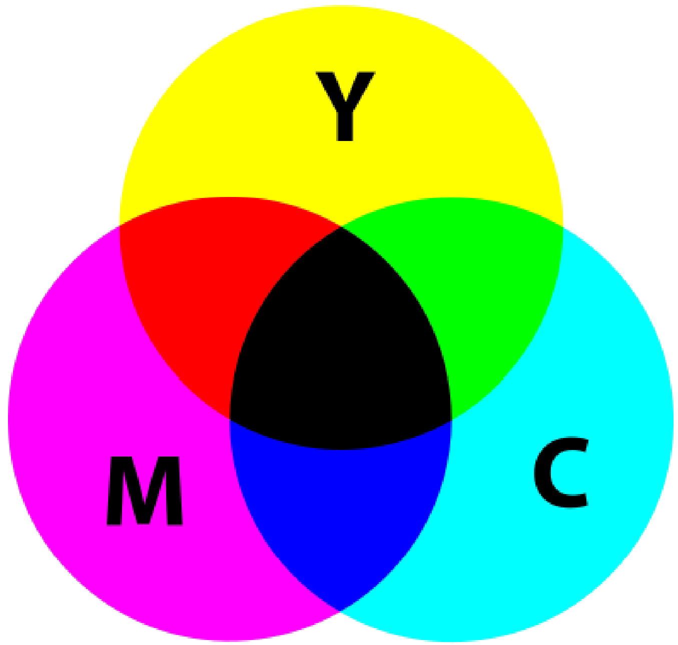
Color mixing


Additive primaries red, green, and blue


Subtractive primaries cyan, magenta, and yellow

Subtractive color mixing

- The primary colors of pigments are magenta, cyan, and yellow, and the secondary pigment colors are red, green, and blue.
- Mixture of pigments
    - Printer



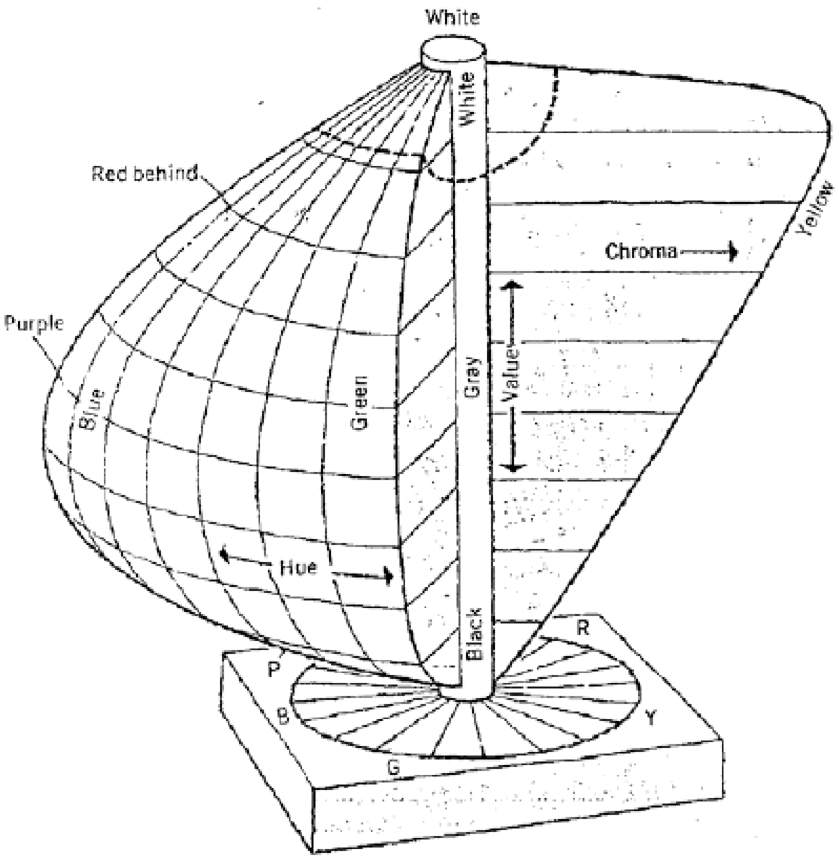
Characteristics of Color

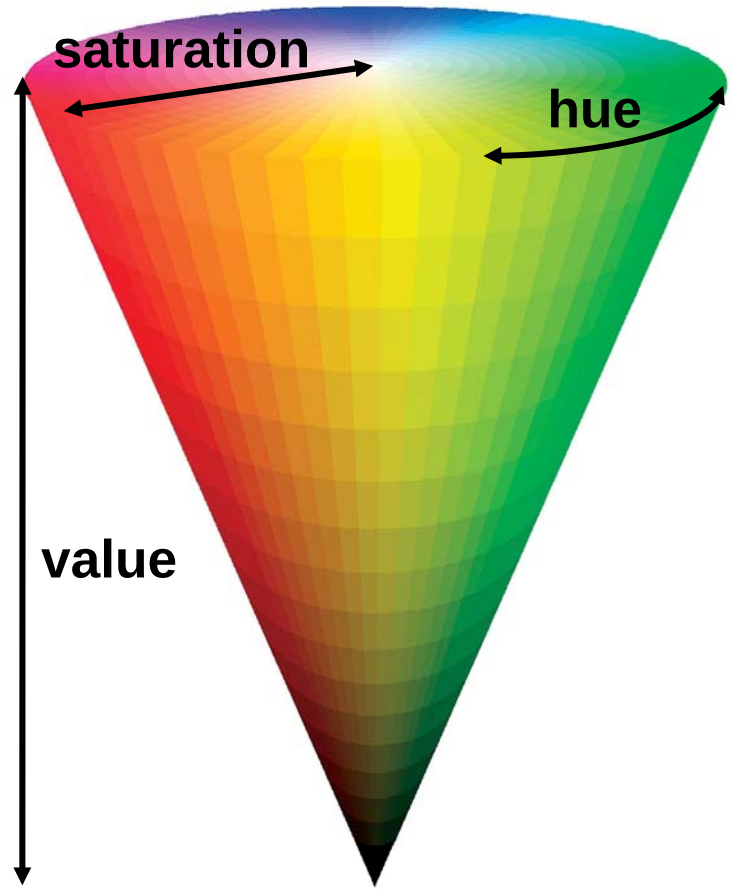
- Brightness (Intensity, value)
  - embodies the chromatic notion of intensity.
- Hue
  - is an attribute associated with the dominant wavelength in a mixture of light waves. It represents the dominant color as perceived by an observer (ex. orange, red, violet).

Characteristics of Color

- Saturation (chroma)
  - refers to the relative purity or the amount of white light mixed with a hue.
  - Pure colors are fully saturated.
  - Colors such as pink (red + white) and lavendar (violet + white) are less saturated, with the saturation being inversely proportional to the amount of white light added.

Hue, Saturation, Intensity



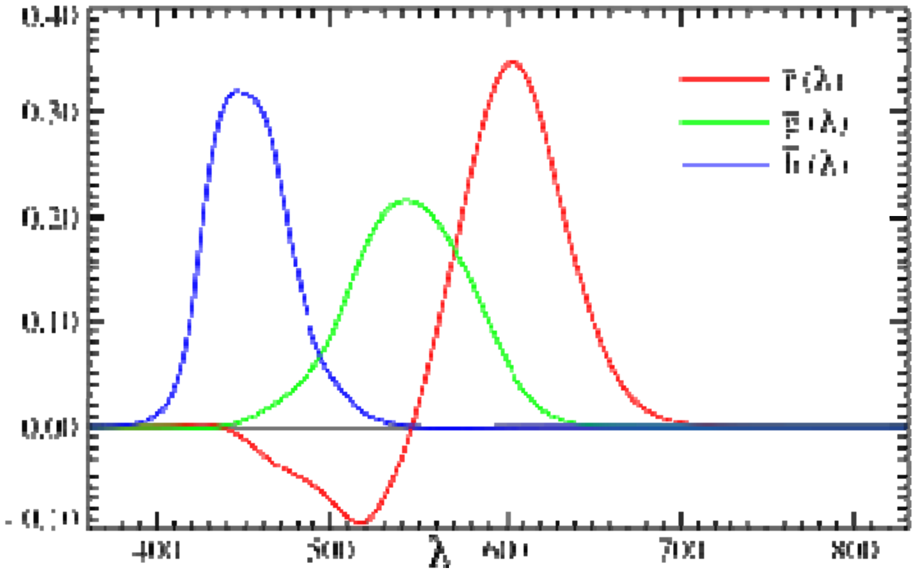


CIE RGB color space

- The amounts of red, green, and blue (primary colors) needed to form any particular color are called the tristimulus values
  - Red (R): 700 nm
    Green (G): 546.1 nm
    Blue (B): 435.8 nm
  - Can we reproduce single-wavelength EM wave by mixing these three primary colors?

RGB matching function

The CIE RGB Color matching functions



- Given these functions, the RGB tristimulus values for a color with a spectral power distribution *I*(*λ*) can be obtained by:

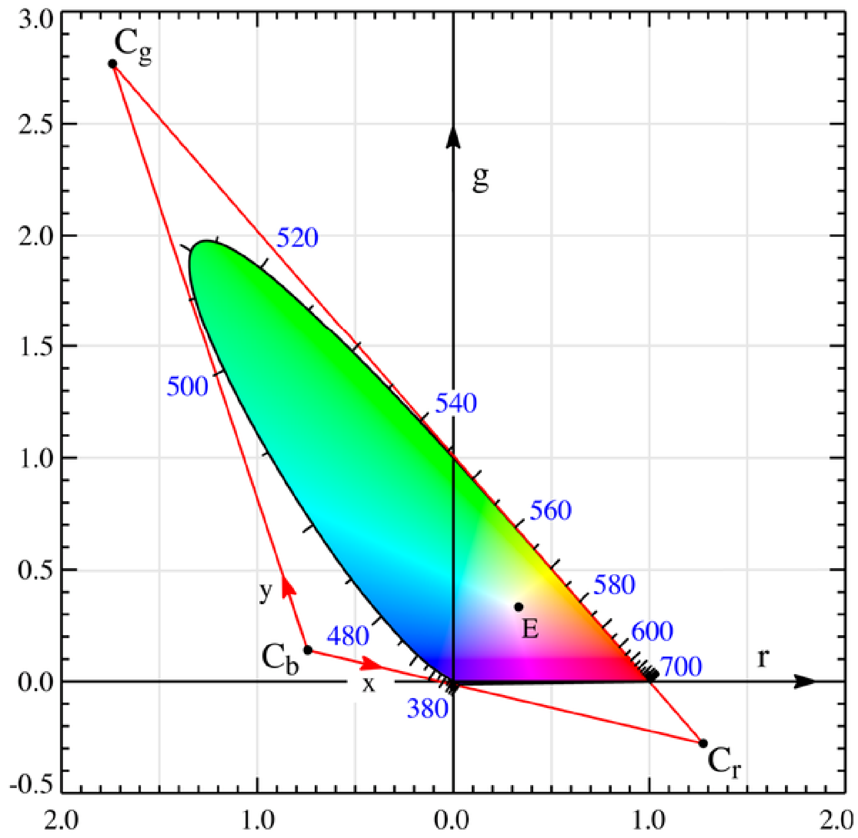
$$R = \int I(\lambda)\bar{r}(\lambda)d\lambda \quad G = \int I(\lambda)\bar{g}(\lambda)d\lambda \quad B = \int I(\lambda)\bar{b}(\lambda)d\lambda$$

CIE rg chromaticity diagram

- The chromaticity diagram can be used for color mixing, since a line joining two points in the diagram represents all the colors that can be obtained by mixing the two colors additively.

$$r = \frac{R}{R+G+B}$$

$$g = \frac{G}{R+G+B}$$



XYZ color space

- A new color space (*XYZ,* which are <u>roughly</u> red, green, and blue) was developed so that
  - Positive color matching functions:

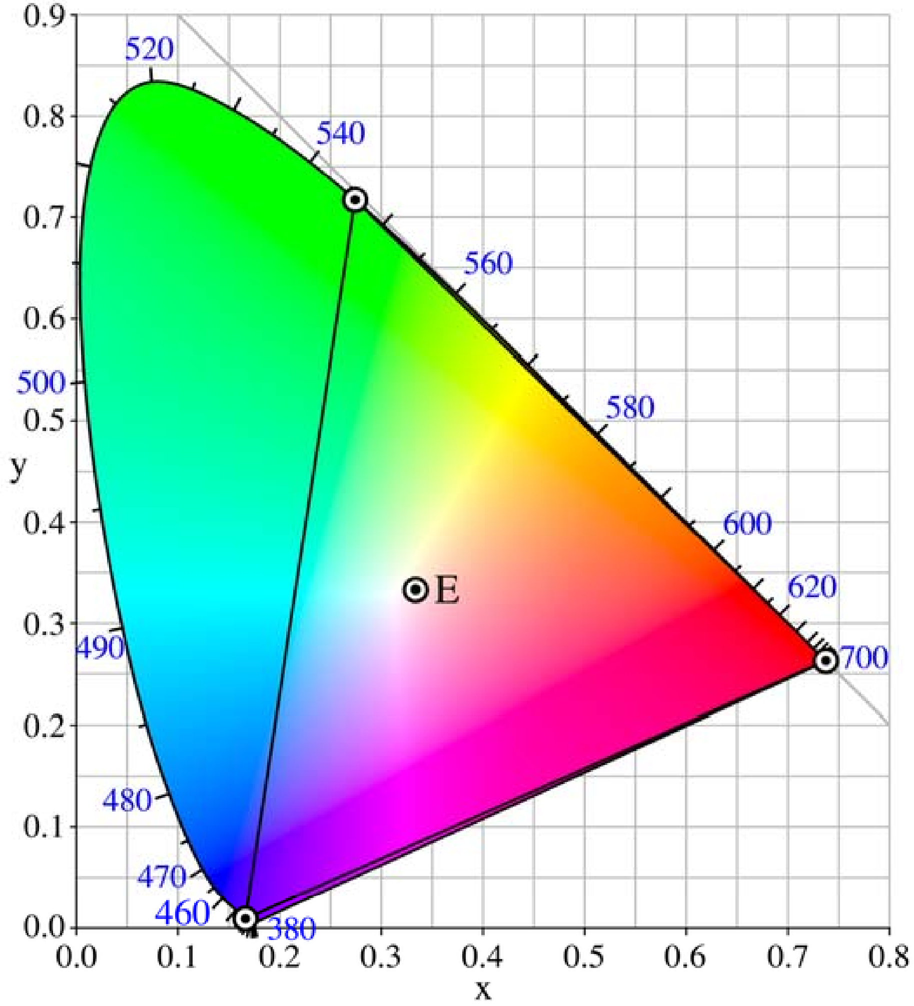
$$X = \int I(\lambda)\bar{x}(\lambda)d\lambda \quad Y = \int I(\lambda)\bar{y}(\lambda)d\lambda \quad Z = \int I(\lambda)\bar{z}(\lambda)d\lambda$$

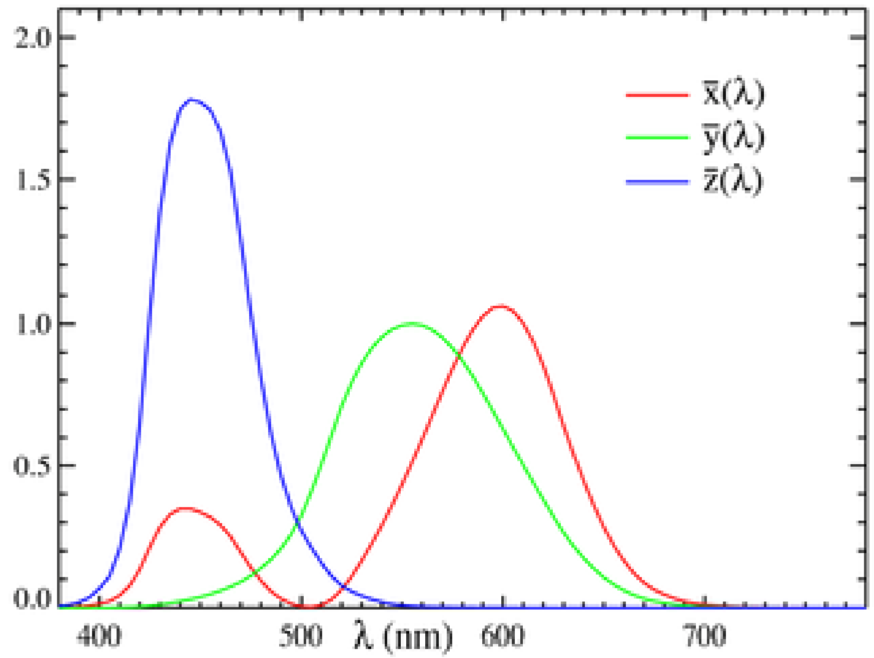
  - Three trichromatic coefficients

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

  - White point: $x = y = z = 0.333$

CIE xy chromaticity diagram





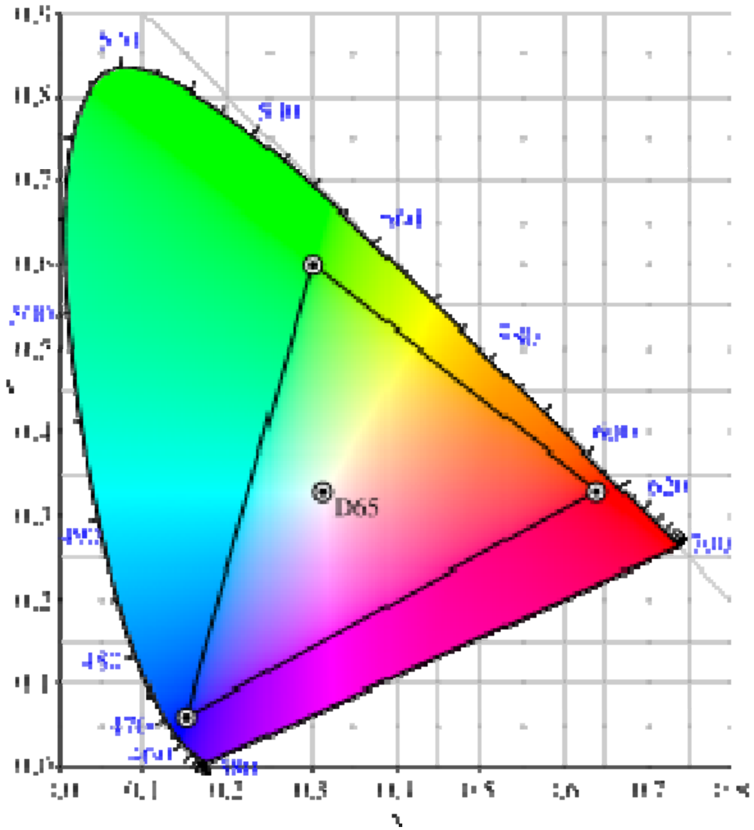
The CIE 1931 standard observer
Color matching functions

Chromaticity diagram

- The triangular region in the chromaticity diagram represents all the colors that can be obtained by combining the three primary colors.
  - Color gamut produced by three colors
  - The gamut of human vision is not a triangle

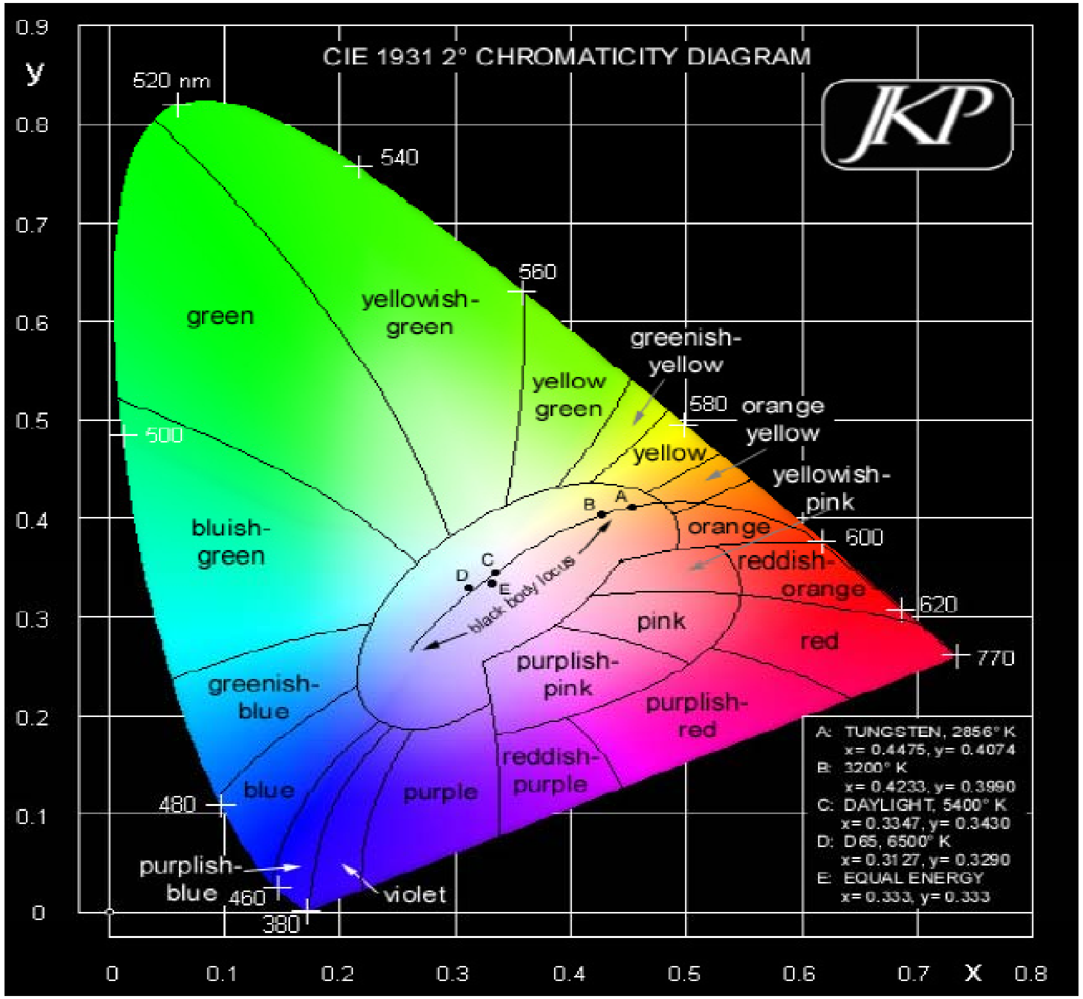
Standard RGB (sRGB) space

- Created by HP and Microsoft in 1996for use on monitors, printers, and the internet.
- Areas outside the triangle cannot be accurately colored, because they are out of the gamut of computer displays.



CIE Chromaticity diagram

- Boundary: completely saturated or “pure” colors (or the light with single wavelength)
- Inside the tongue-shaped region: mixture of the pure colors.



Color models

Color Models

- The purpose of a color model (or color space or color system) is to facilitate the specification of color in some standard fashion.

- A color model is a specification of a 3-D coordinate system and a subspace within that system where each color is represented by a single point.

Color Models

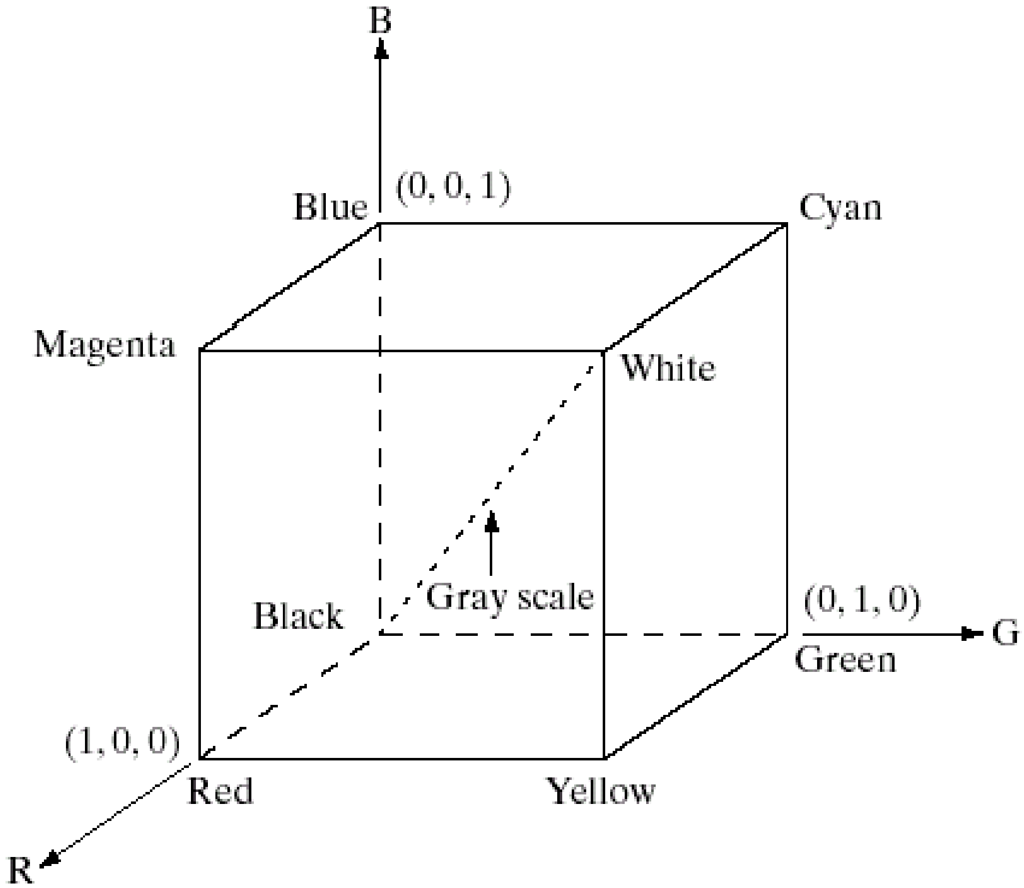
- In image processing, the hardware based color models mainly used are: RGB, CMYK, and HSI.
- RGB (red, green, blue) color system
  - mainly in color monitors and video cameras.
- CMYK (cyan, magenta, yellow, black)
  - is used in printing devices.
- HSI (hue, saturation, intensity)
  - based on the way humans describe and interpret color.
  - It also helps in separating the color and grayscale information in an image.

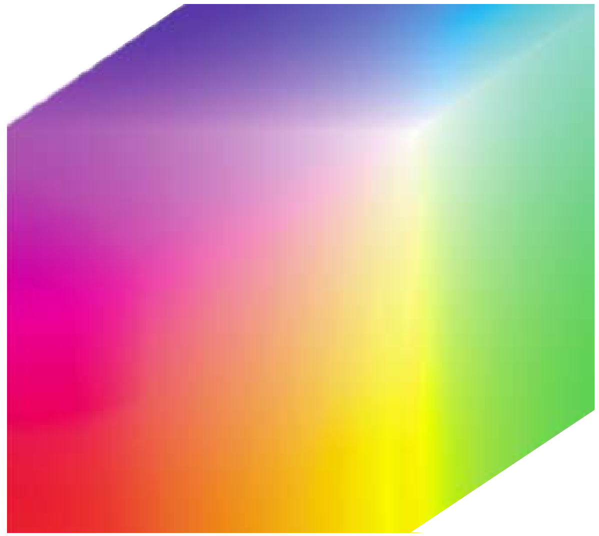
RGB Color model

- Each color appears in its primary spectral components of red, green, and blue.

- It is based on a Cartesian coordinate system. All color values are <u>normalized</u> so that the values of *R*, *G*, and *B* are in the range [0,1]. Thus, the color subspace of interest is the unit cube.

RGB Color model

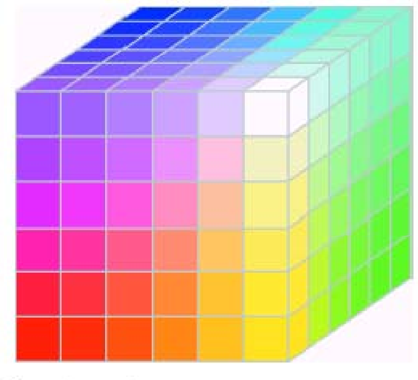




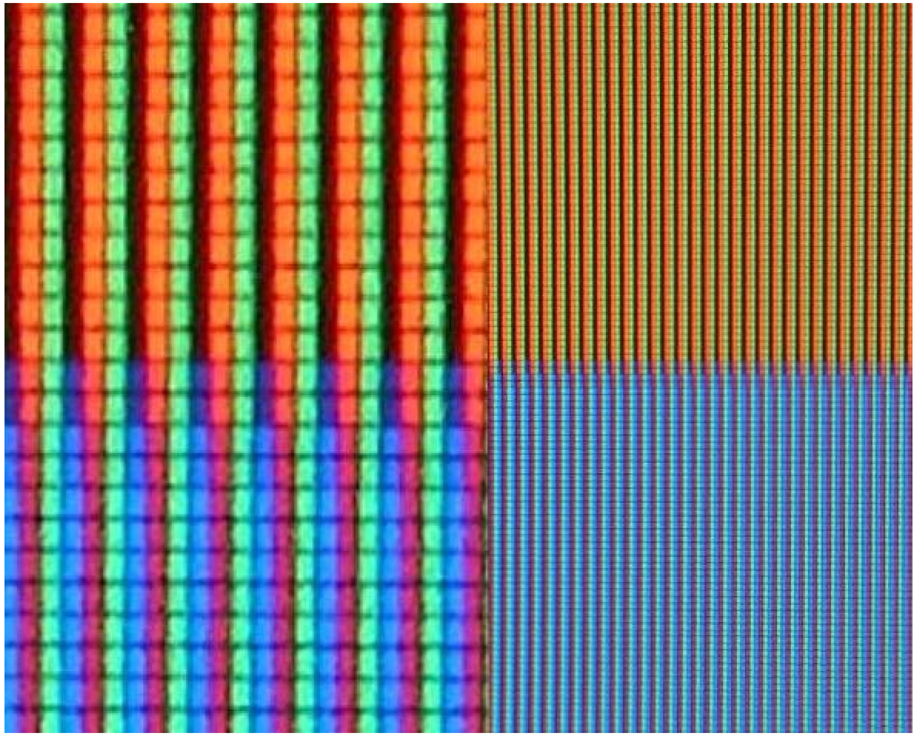
24-bit RGB color cube

RGB Color model

- Images in the RGB model consist of three independent component images, one for each primary color.
- The number of bits used to represent each pixel in RGB space is called *pixel depth*.
    - True color: 24 bits
    - Safe RGB color (safe web color): 216 colors





RGB pixels in an LCD TV
Right: an orange and a blue color
Left: a close-up of pixels

A single pixel in a large scale LED screen composed of red, green, blue LEDs.

Color Models

- In image processing, the hardware based color models mainly used are: RGB, CMYK, and HSI.
- RGB (red, green, blue) color system
  - mainly in color monitors and video cameras.
- CMYK (cyan, magenta, yellow, black)
  - is used in printing devices.
- HSI (hue, saturation, intensity)
  - based on the way humans describe and interpret color.
  - It also helps in separating the color and grayscale information in an image.

CMY color model

- Each color is represented by the three secondary colors --- cyan (C), magenta (M), and yellow (Y).
- It is mainly used in devices such as color printers that deposit color pigments.
- It is related to the RGB color model:

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

Color Models

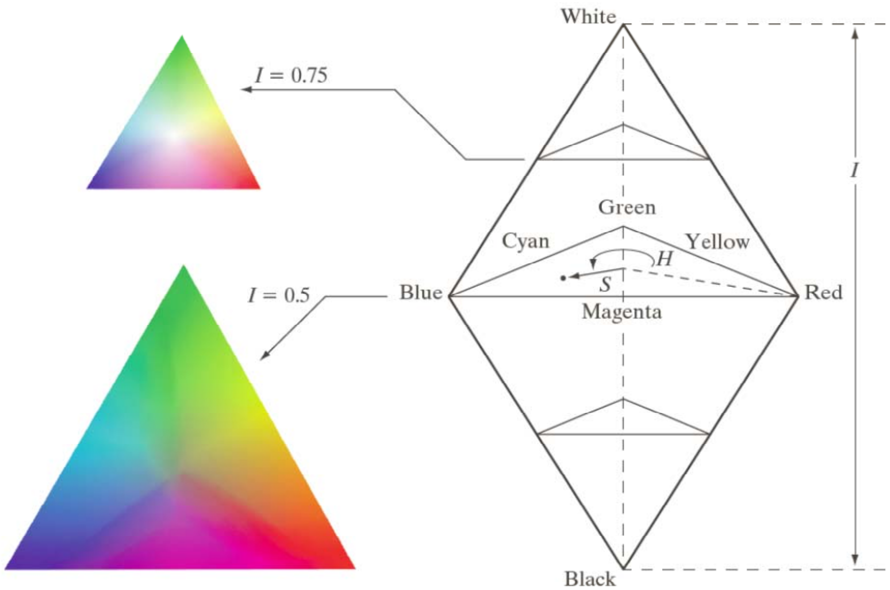
- In image processing, the hardware based color models mainly used are: RGB, CMYK, and HSI.
- RGB (red, green, blue) color system
  - mainly in color monitors and video cameras.
- CMYK (cyan, magenta, yellow, black)
  - is used in printing devices.
- HSI (hue, saturation, intensity)
  - based on the way humans describe and interpret color.
  - It also helps in separating the color and grayscale information in an image.

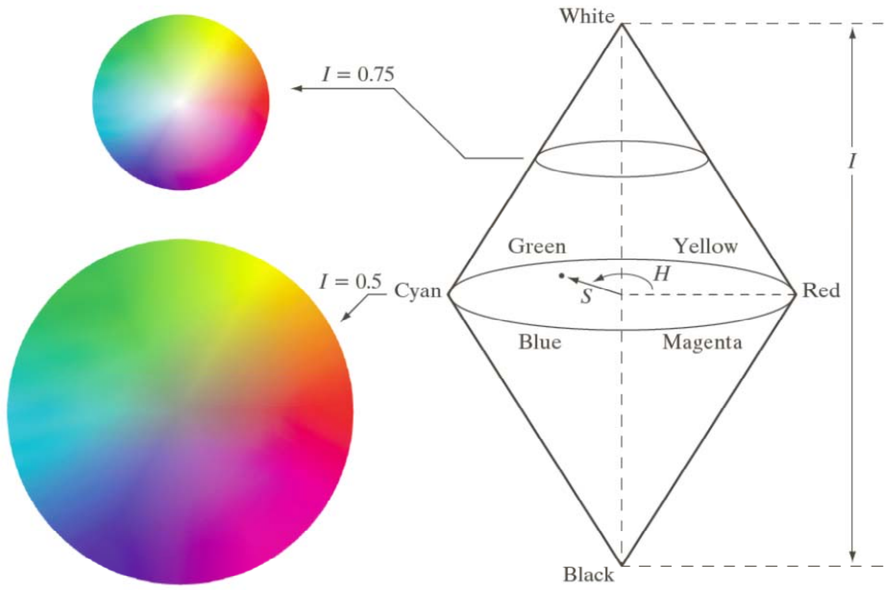
HSI or HSV color model

- Each color is specified in terms of its Hue (H), Saturation (S) and intensity (I) or value (V).

- The main advantages of this model is that:
  - Chrominance (H, S) and luminance (I) components are decoupled.
  - Hue and saturation is intimately related to the way the human visual system perceives color.

HIS color model





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

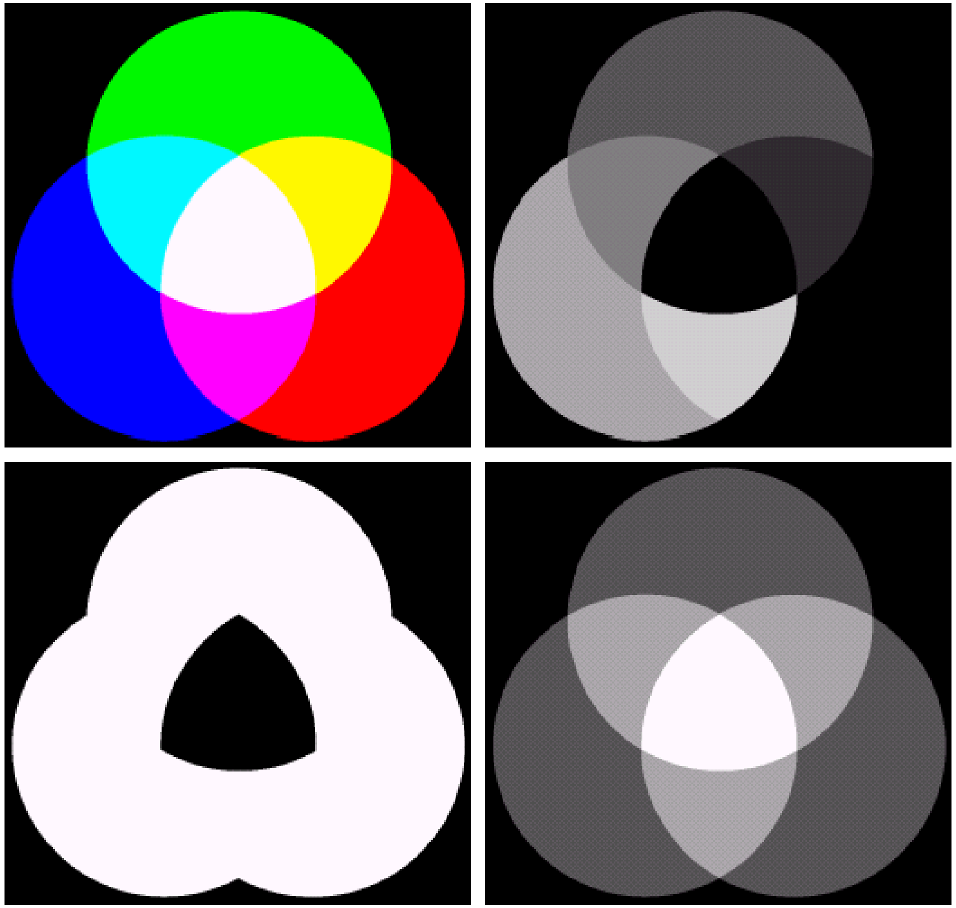
(Assume R, G, and B are normalized to [0, 1].)

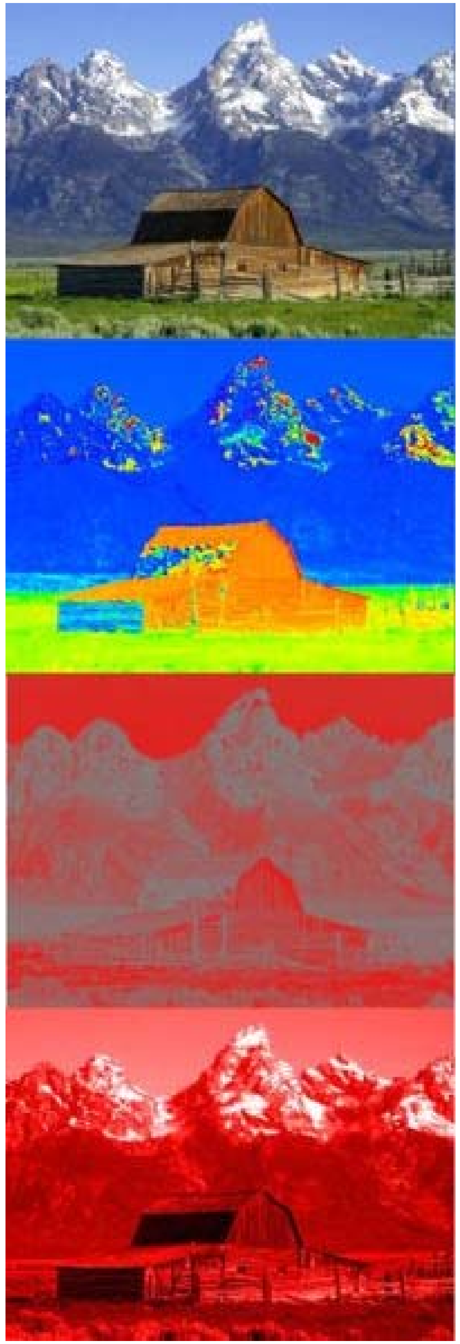
$$S = 1 - \frac{3}{(R+G+B)} \cdot \min(R,G,B)$$

$$H = \begin{cases} \theta & ,if \quad B \le G \\ 360-\theta, & else. \end{cases}$$

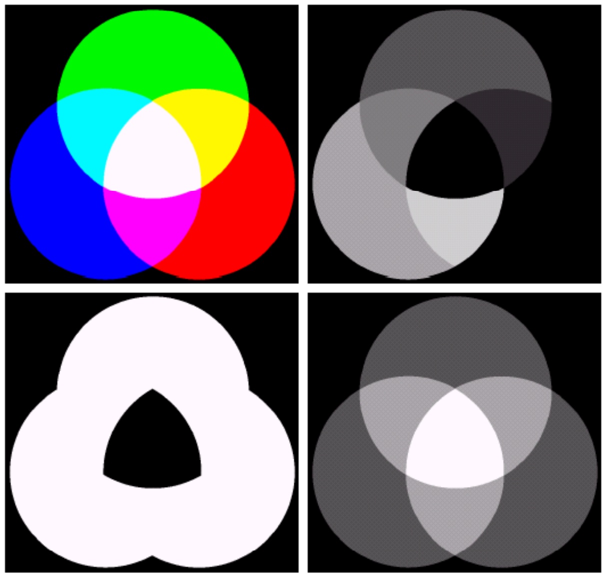
$$\theta = \cos^{-1}\left\{ \frac{[(R-G)+(R-B)]/2}{[(R-G)^2+(R-B)(G-B)]^{1/2}} \right\}$$

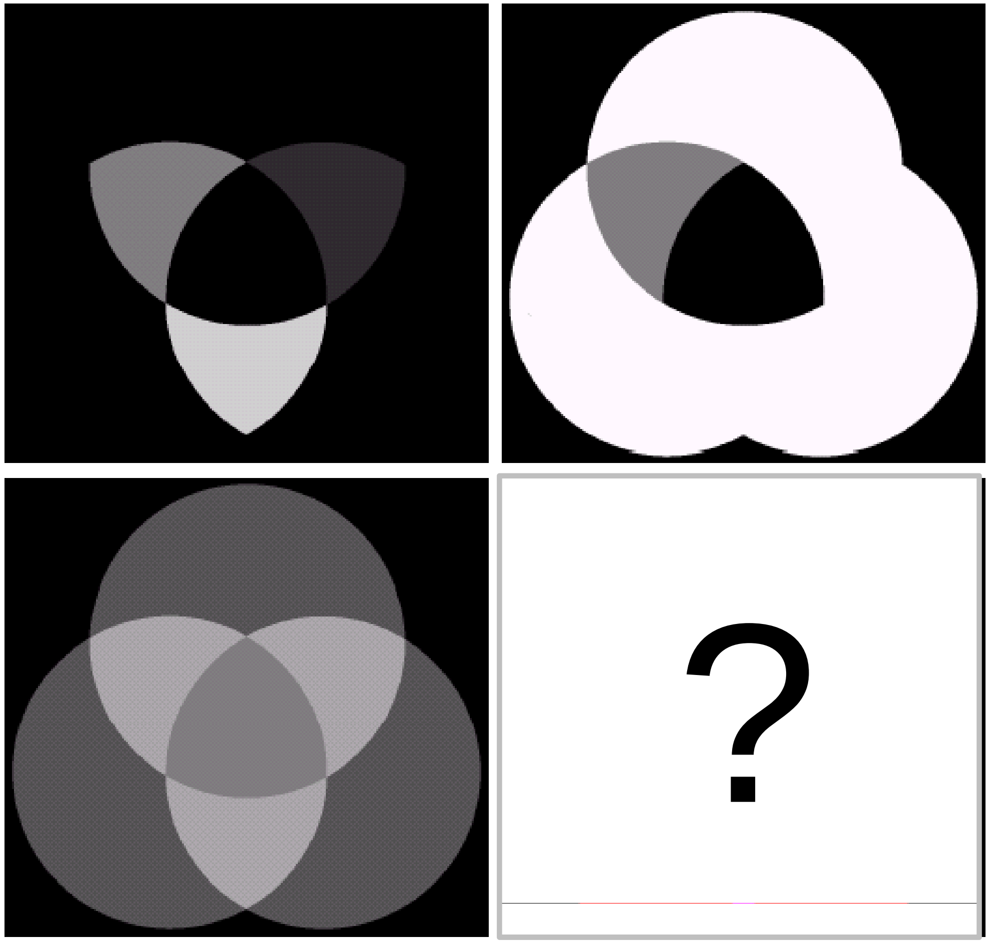
HIS color model





What color is it?





Manipulation of HSI components

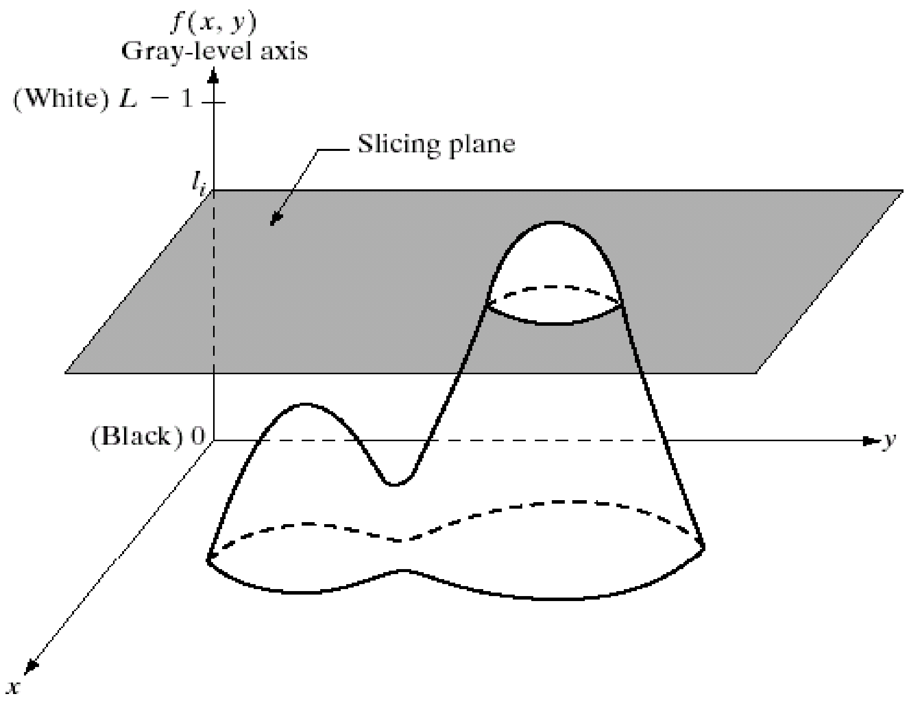
- To change color → Hue
- To change brightness → Intensity
- To change the purity of color → Saturation

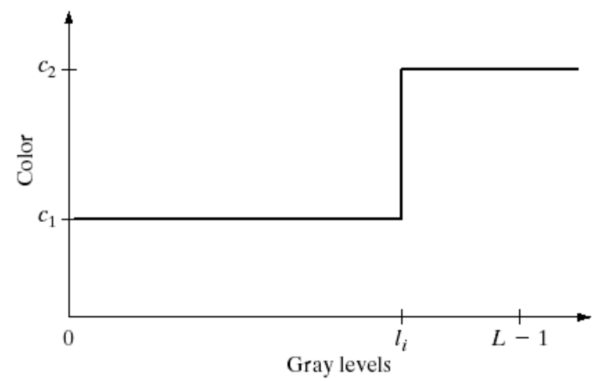
Pseudo color processing

Pseudo Coloring

- Assign colors to monochrome images, based on various properties of their gray-level content.
- It is mainly used for human visualization and interpretation.
  - Intensity slicing
  - Intensity to color transformation

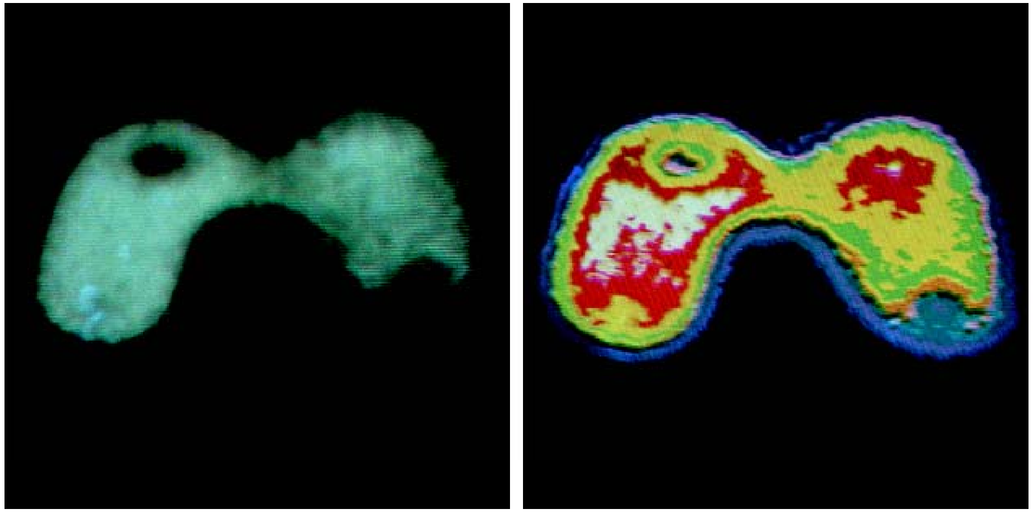
Intensity Slicing





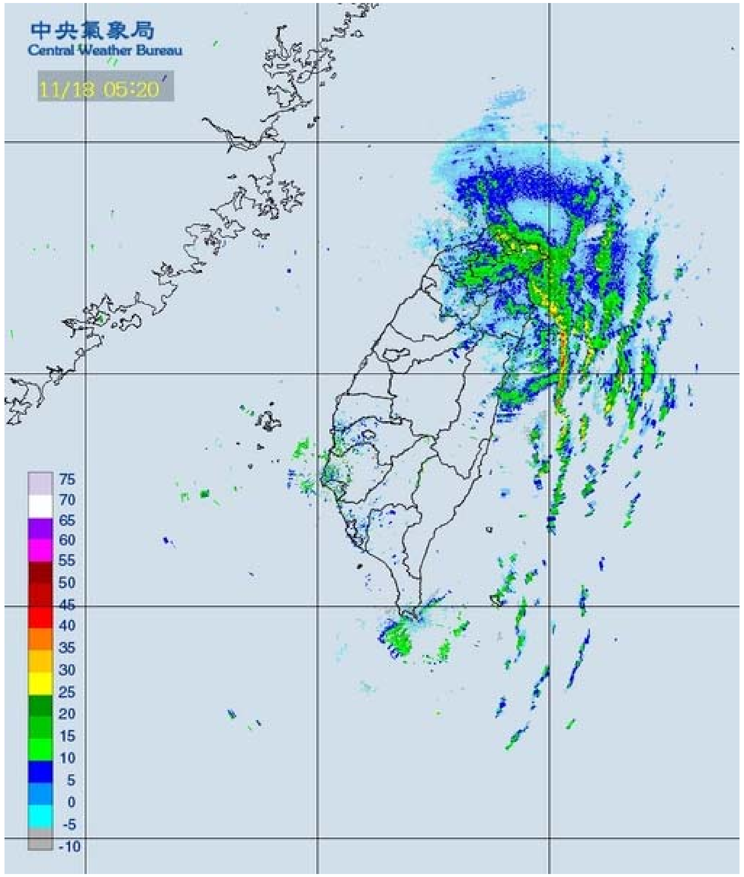
- Thresholding with colors
- Extending to more than one plane?   - Sure!

Intensity Slicing



a b

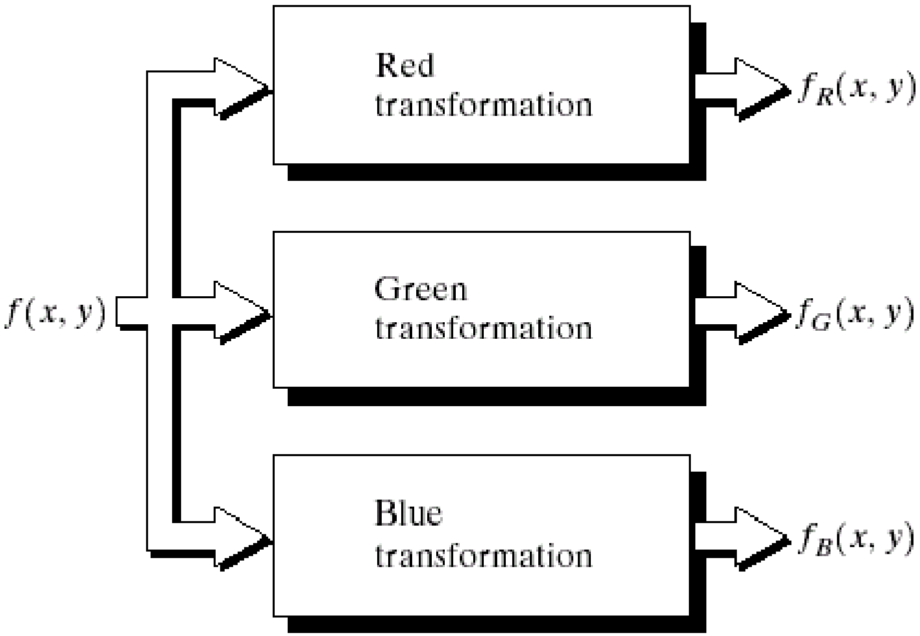
FIGURE 6.20 (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)



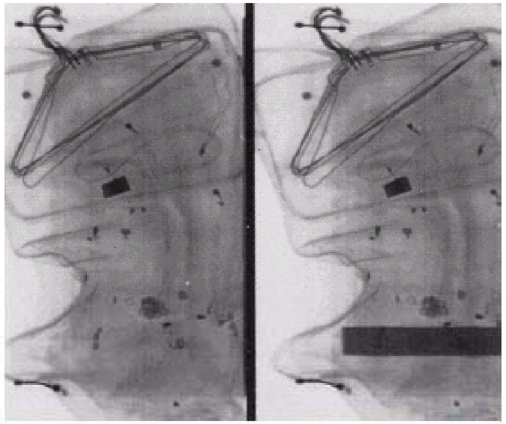
雷達回波圖

Intensity to color transformations

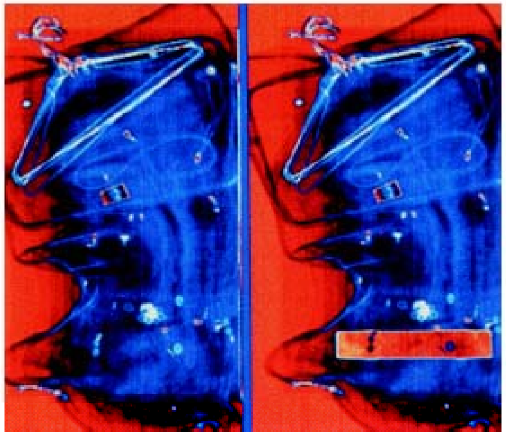
- Perform three independent transformations on the gray-level of an input monochrome image.
- The outputs of the three transformations are fed to the Red, Green, and Blue channels of a color monitor.



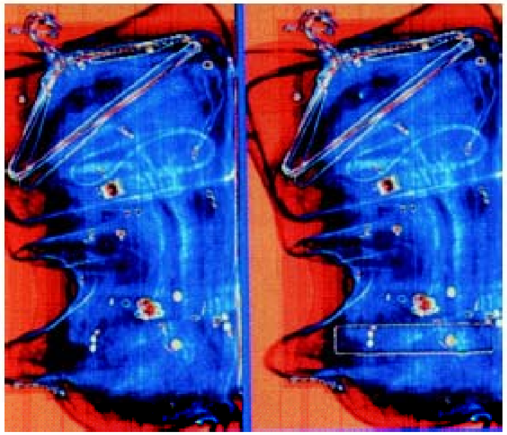
Normal luggage



With explosives

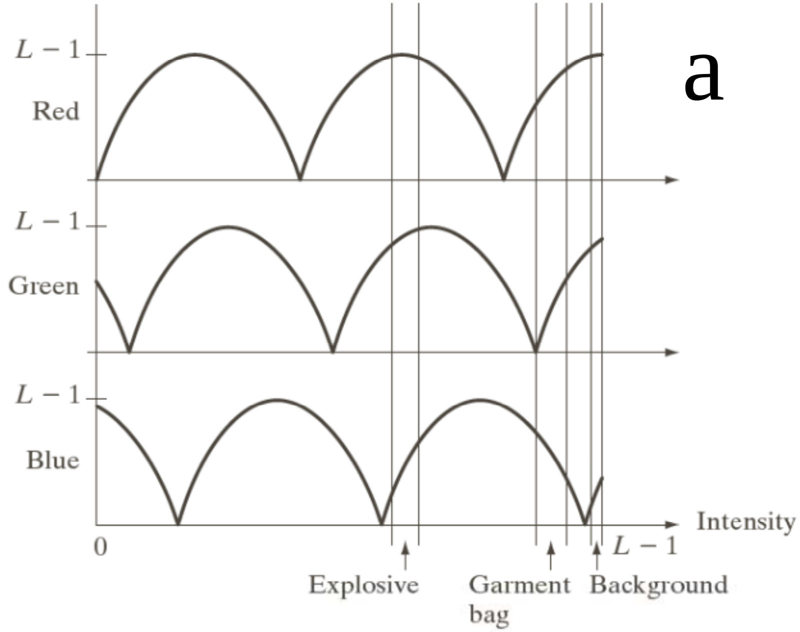


Transformed by function **a**

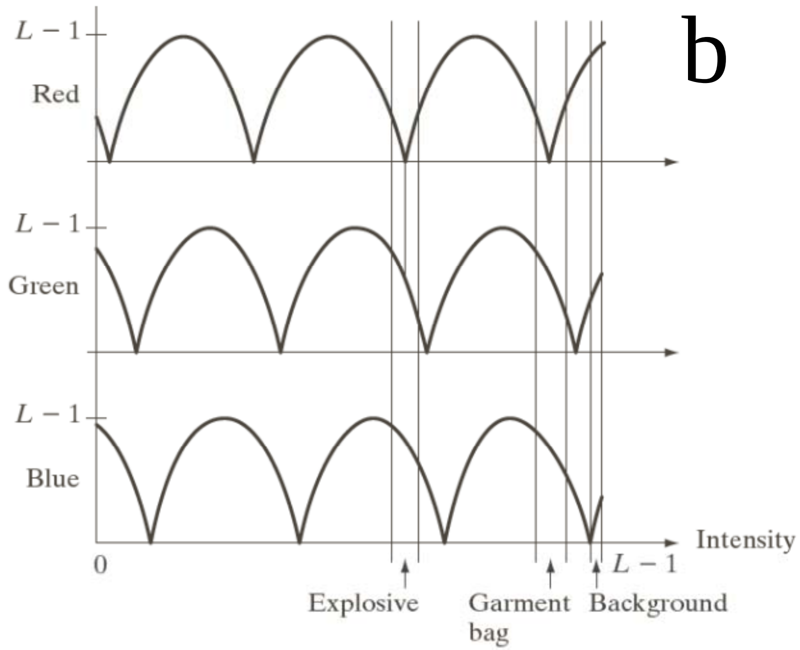


Transformed by function **b**

a

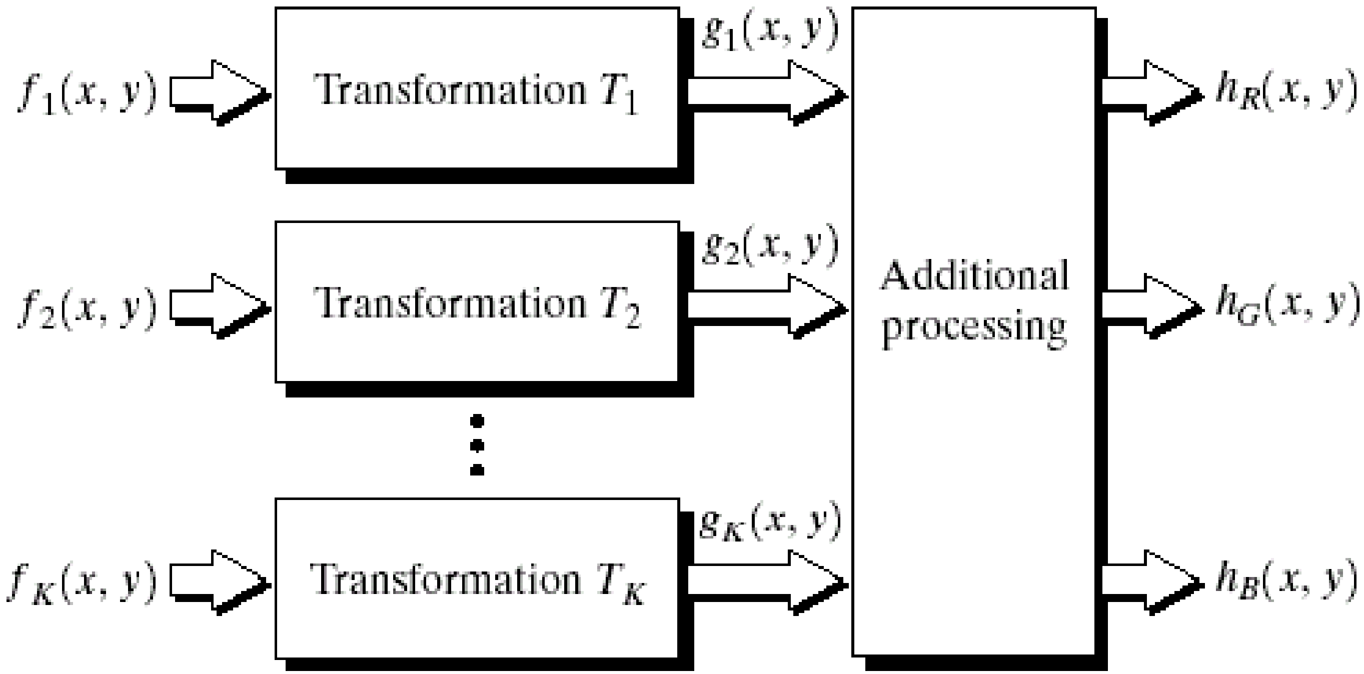


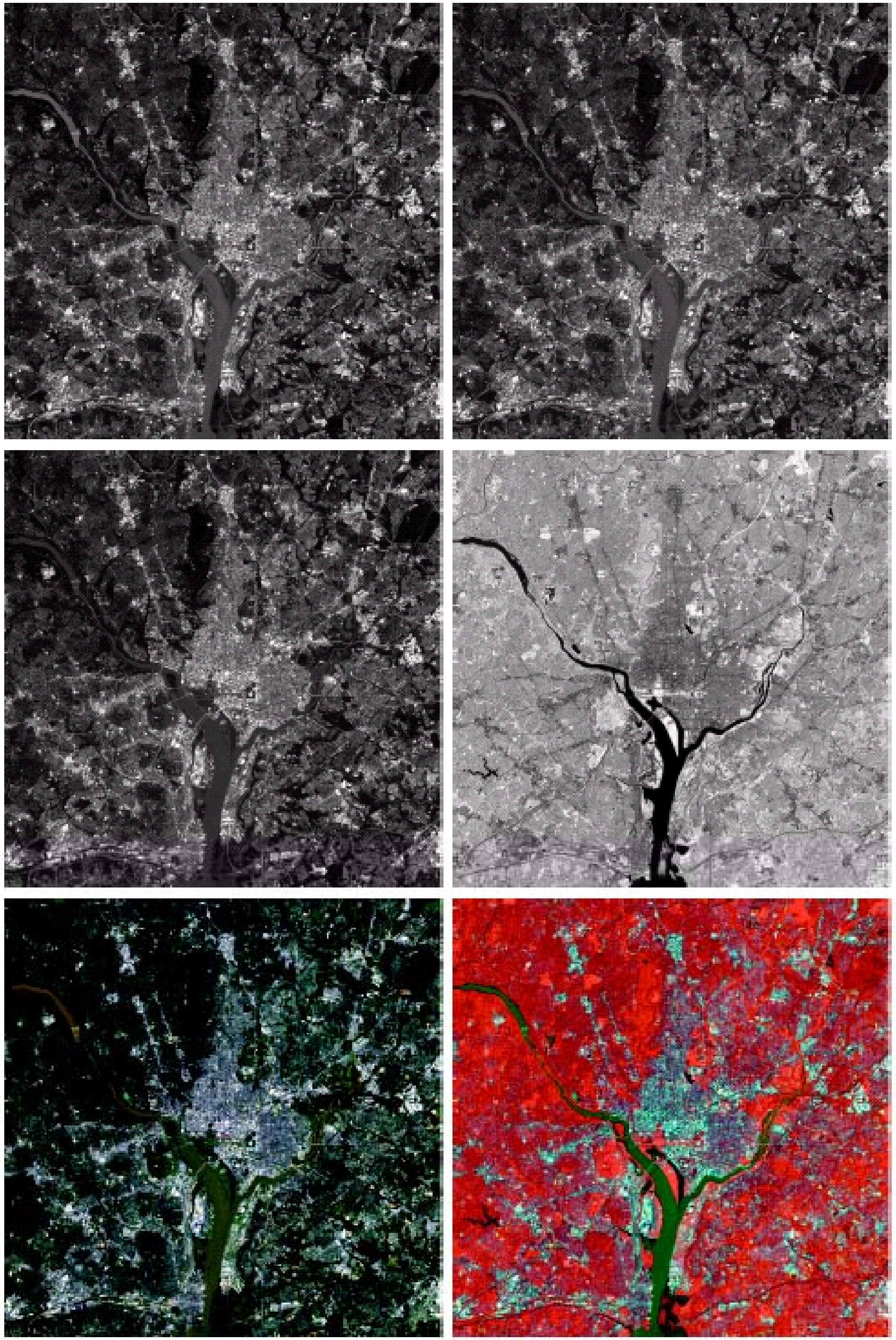
b



Advanced color transformations

- Frequently used in multispectral imaging





(a) Visible red

(b) Visible green

(c) Visible blue

(d) Near infrared

Combining (a), (b), (c)

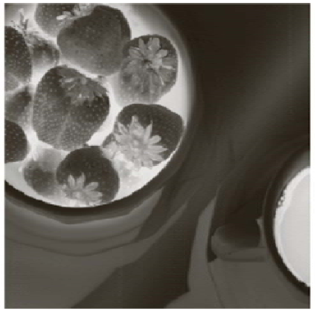
Combining (d), (b), (c)

Full color processing

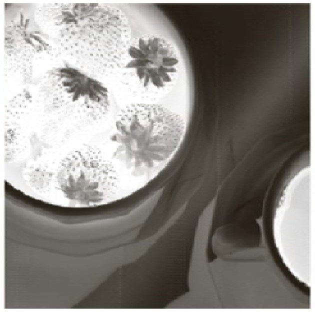
Color Transformations

- It is useful to think of a color image as a vector valued image, where each pixel has associated with it, as vector of three values.
- Each components of this vector corresponds to a different aspect of color, depending on the color model being used.
  - [R, G, B], [H, S, I]

Full color

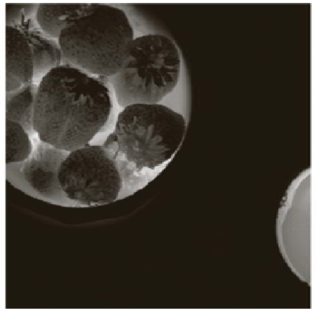


Cyan



Magenta

Yellow

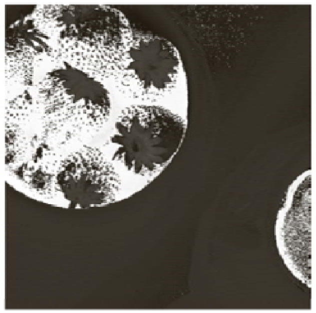


Black

Red

Green

Blue



Hue

Saturation

Intensity

Color Transformations

- Intensity transformation function (gray-scale)

  s = T(r)

- Color transformation (color mapping function)

$$s_i = T_i(r_1, r_2, \ldots, r_n) \qquad i = 1, 2, \ldots, n$$

n: the number of color components

Example: Modifying intensity

$$g(x, y) = k \cdot f(x, y)$$

HSI space

$$\begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix} = \begin{bmatrix} r_1 \\ r_2 \\ kr_3 \end{bmatrix}$$

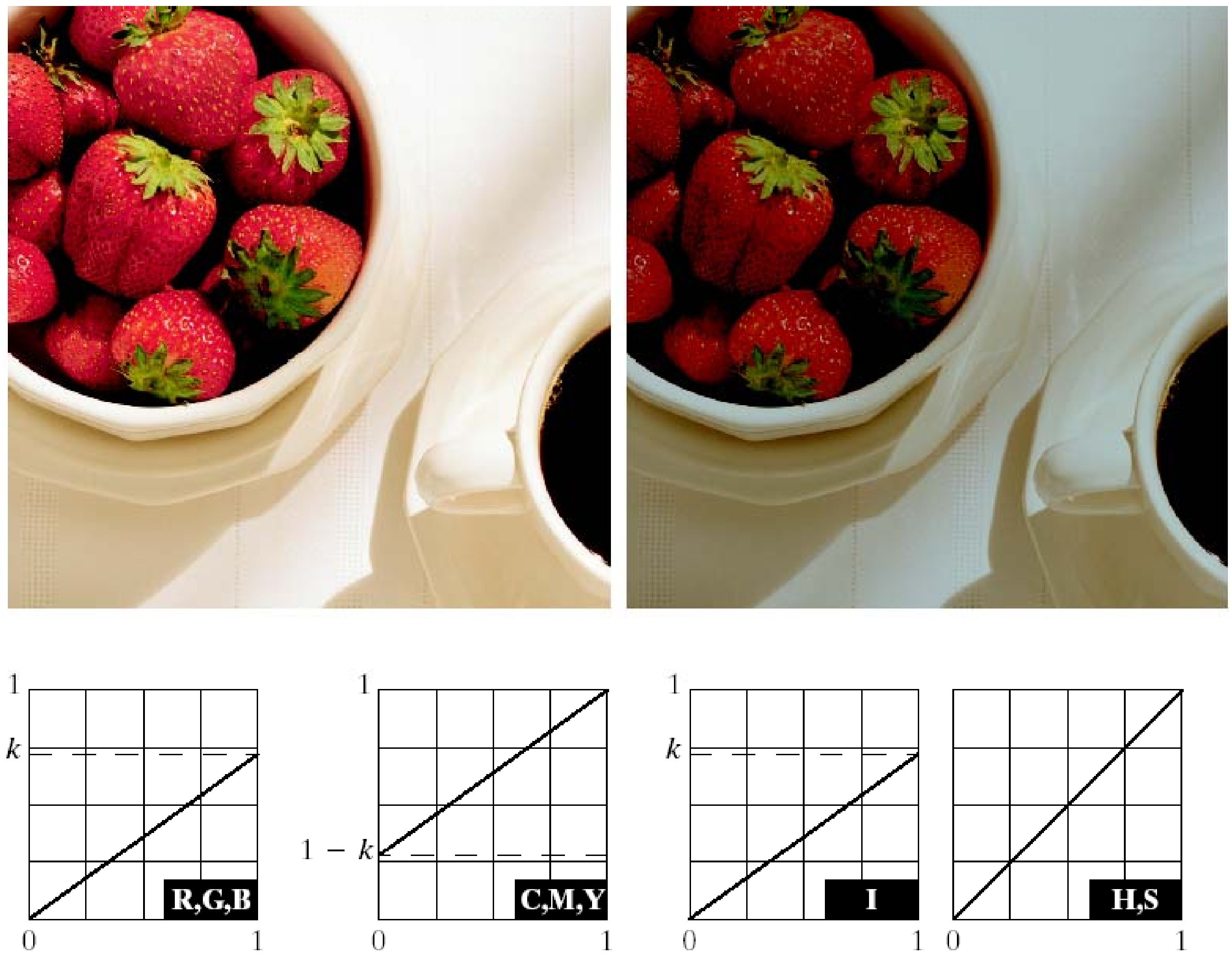
RGB space

$$\begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix} = \begin{bmatrix} kr_1 \\ kr_2 \\ kr_3 \end{bmatrix}$$

CMY space

$$\begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix} = \begin{bmatrix} kr_1 \\ kr_2 \\ kr_3 \end{bmatrix} + (1 - k)$$

Example: Modifying intensity



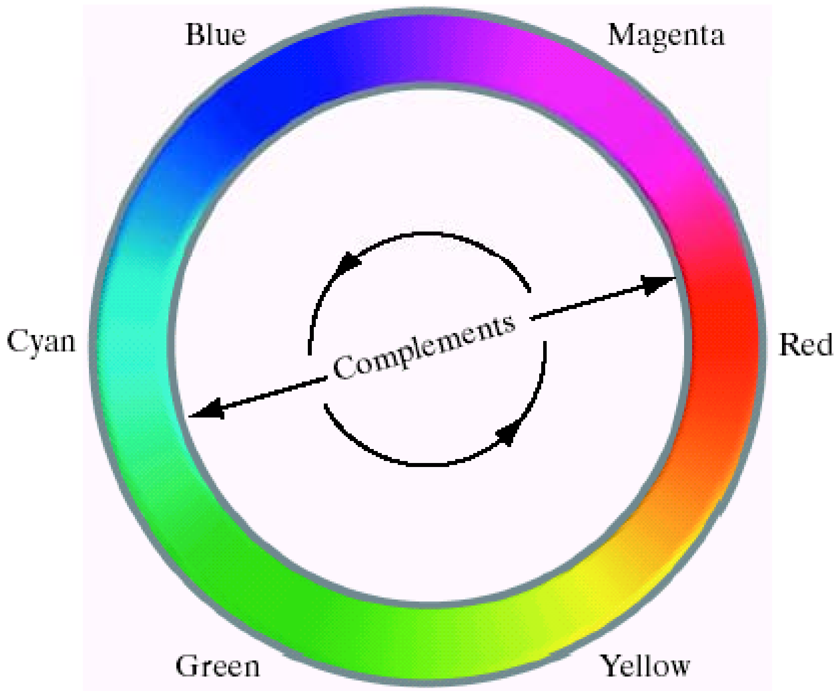
a b
c d e

FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)

Color complements

- Hues opposite one another in a color circle are called complements.

- Negative images
  - – enhancing details embedded in dark regions



Example: Color complement

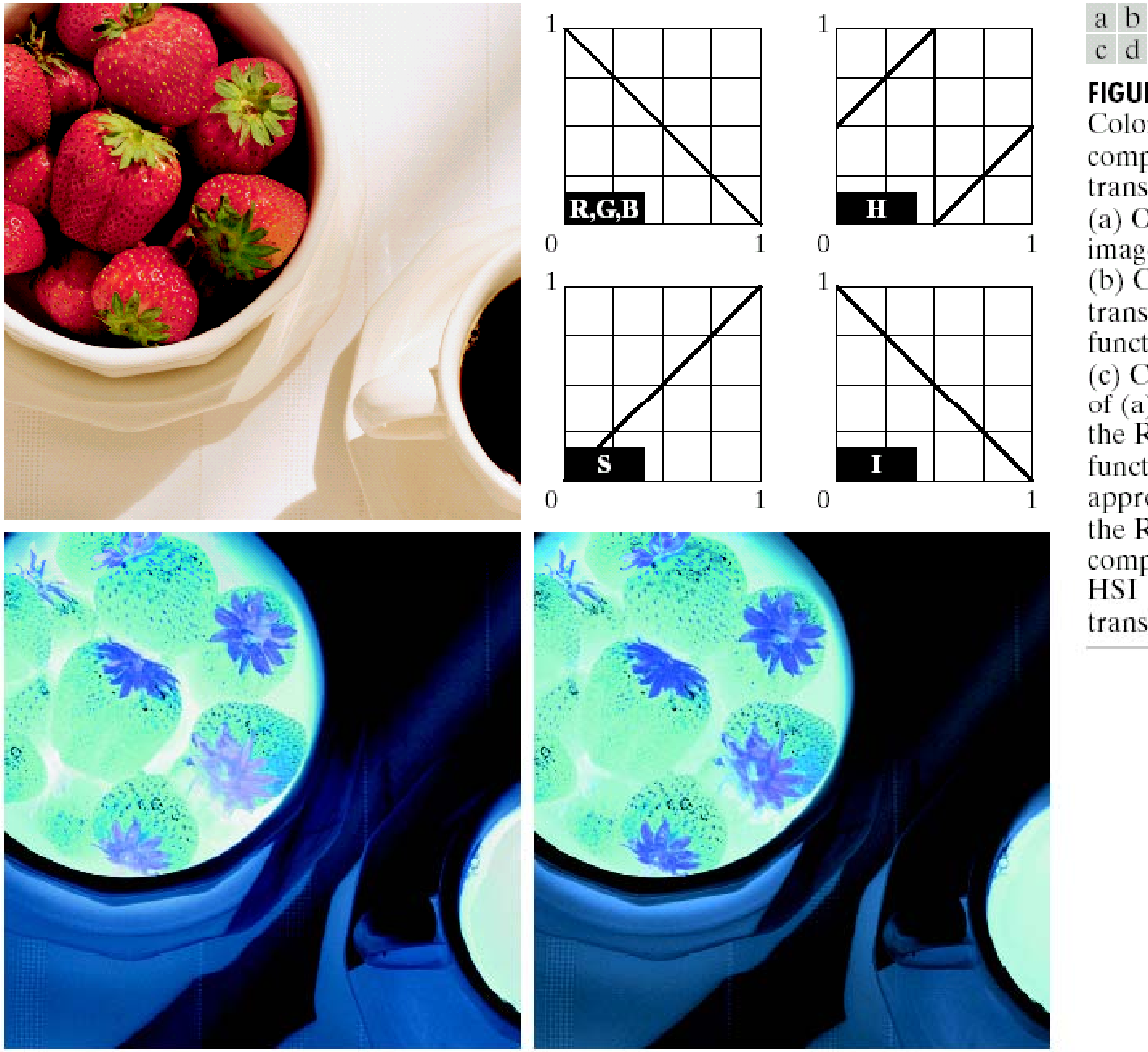


FIGURE 6.33 Color complement transformations. (a) Original image. (b) Complement transformation functions. (c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.

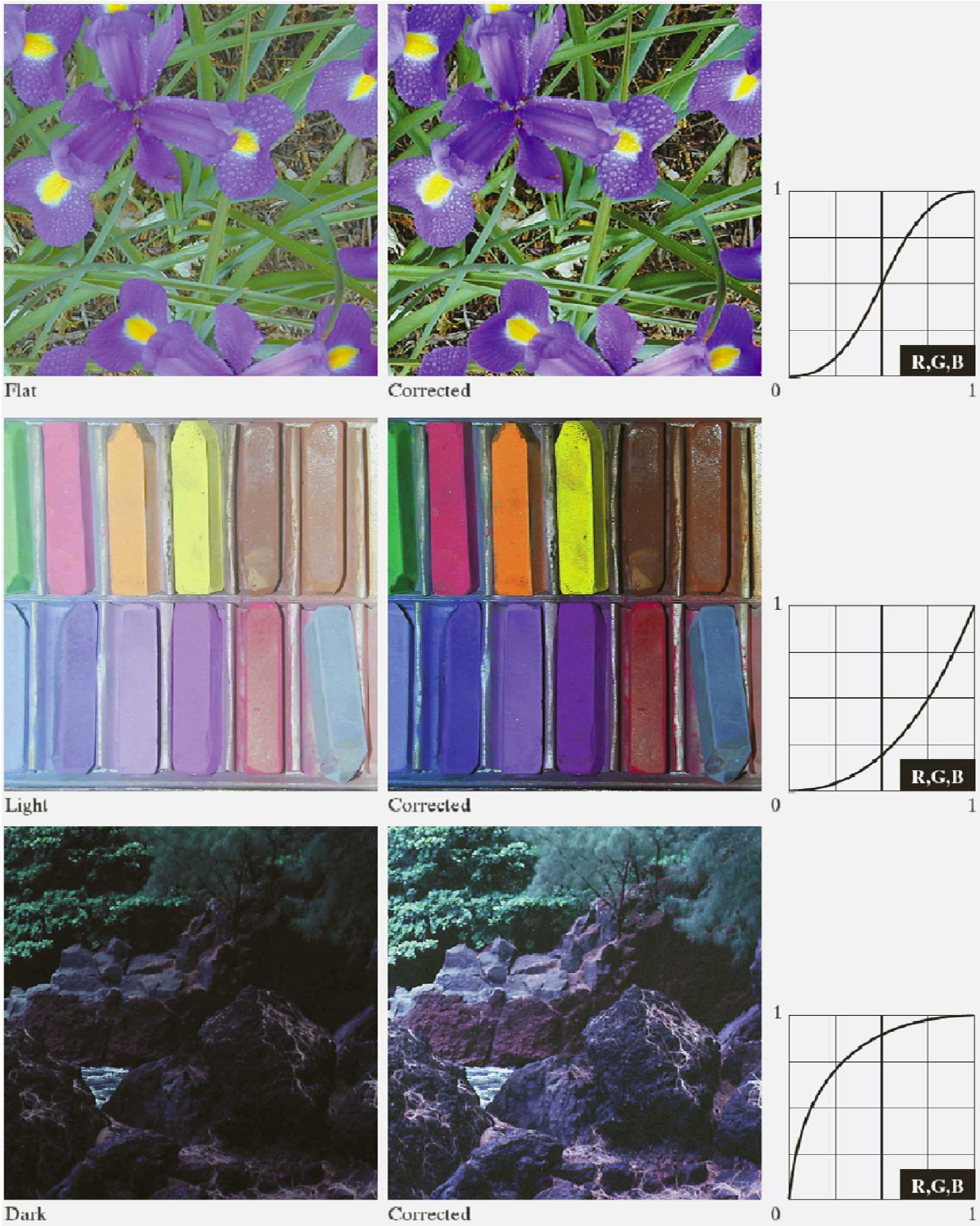
Color Slicing

- Color slicing is similar to intensity slicing

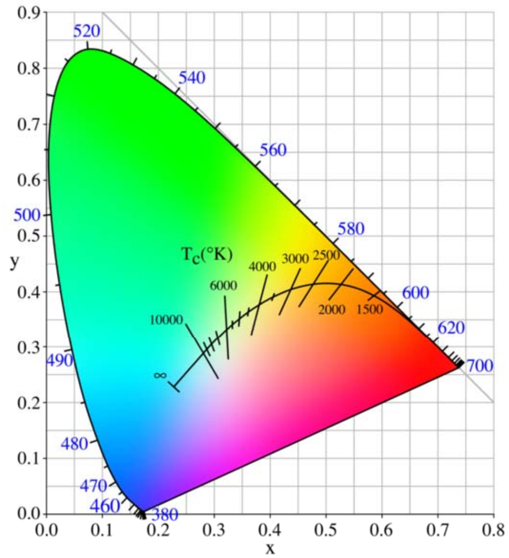
Detect reds centered at RGB = (0.6863, 0.1608, 0.1922).
(pixels else were replaced by color (0.5,0.5,0.5).)

Tone and color correction

What if red, green, and blue have different transformations?
- tonal/color adjustment

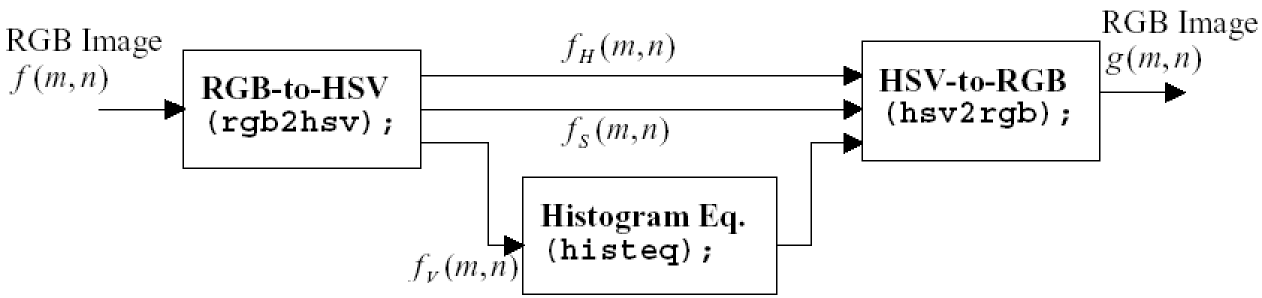


Color balance

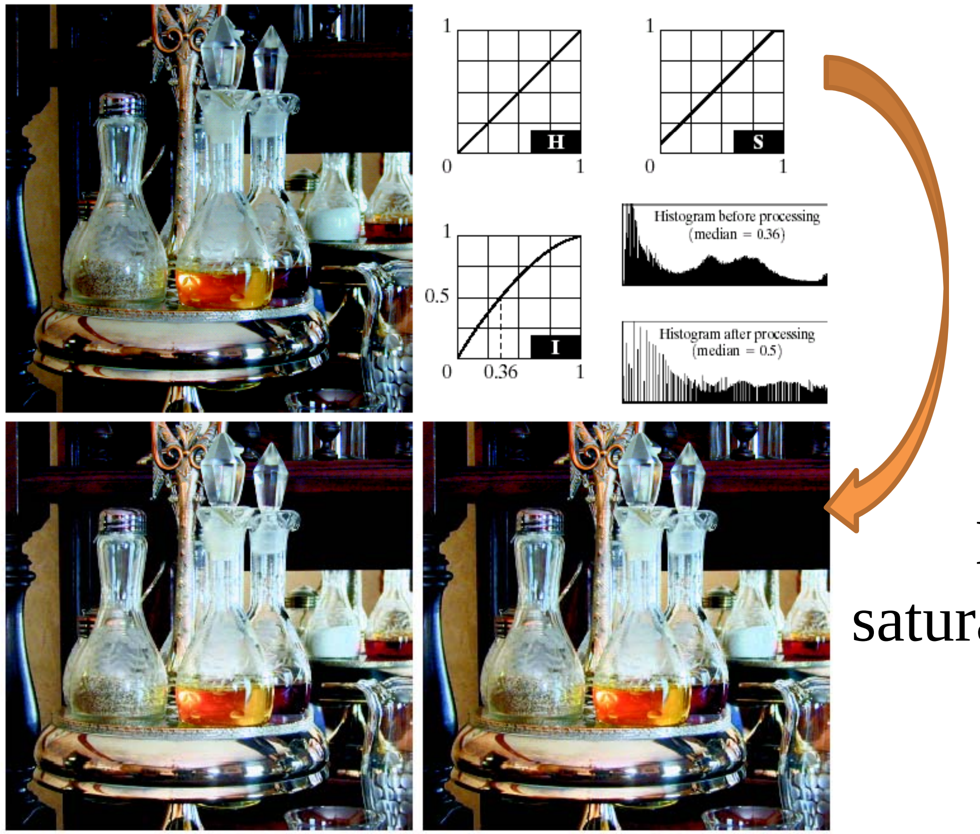


Color Temperature	Light Source
1000-2000 K	Candlelight
2500-3500 K	Tungsten Bulb (household variety)
3000-4000 K	Sunrise/Sunset (clear sky)
4000-5000 K	Fluorescent Lamps
5000-5500 K	Electronic Flash
5000-6500 K	Daylight with Clear Sky
6500-8000 K	Moderately Overcast Sky
9000-10000 K	Shade or Heavily Overcast Sky

Color Histogram Equalization



Original



After equalization

Increase saturation slightly

Color Image smoothing

- RGB: all components individually transformed by an appropriate smoothing mask
- HSI: only I component transformed

- Any difference in the results?
  - Colors not presenting in the original image might be introduced in the RGB method.


R
G
B
H
S
I

Color Image smoothing

Image smoothed with a 5x5 averaging mask.

RGB

HSI

difference

Color image sharpening

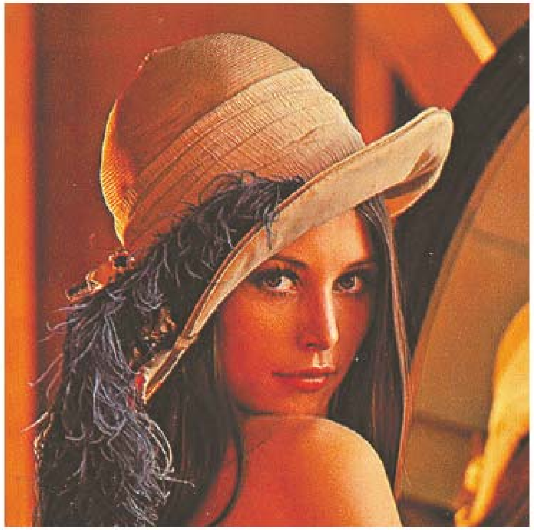
- Sharpening of color images can be performed in a manner analogous to smoothing, using appropriate masks, say the Laplacian mask

0	1	0
1	-4	1
0	1	0

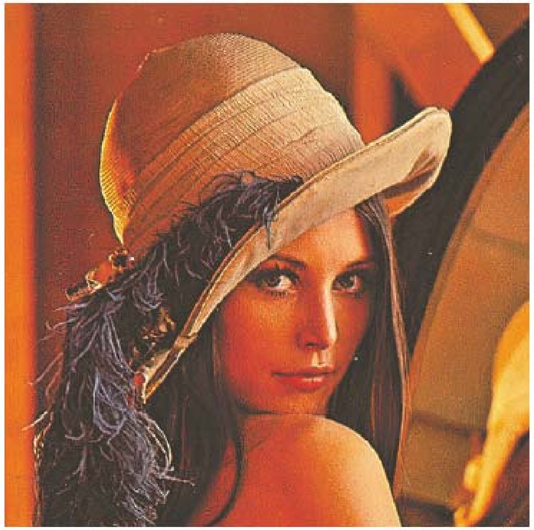
1	1	1
1	-8	1
1	1	1

Color image sharpening

Image sharpened with a Laplacian mask.



RGB



HSI

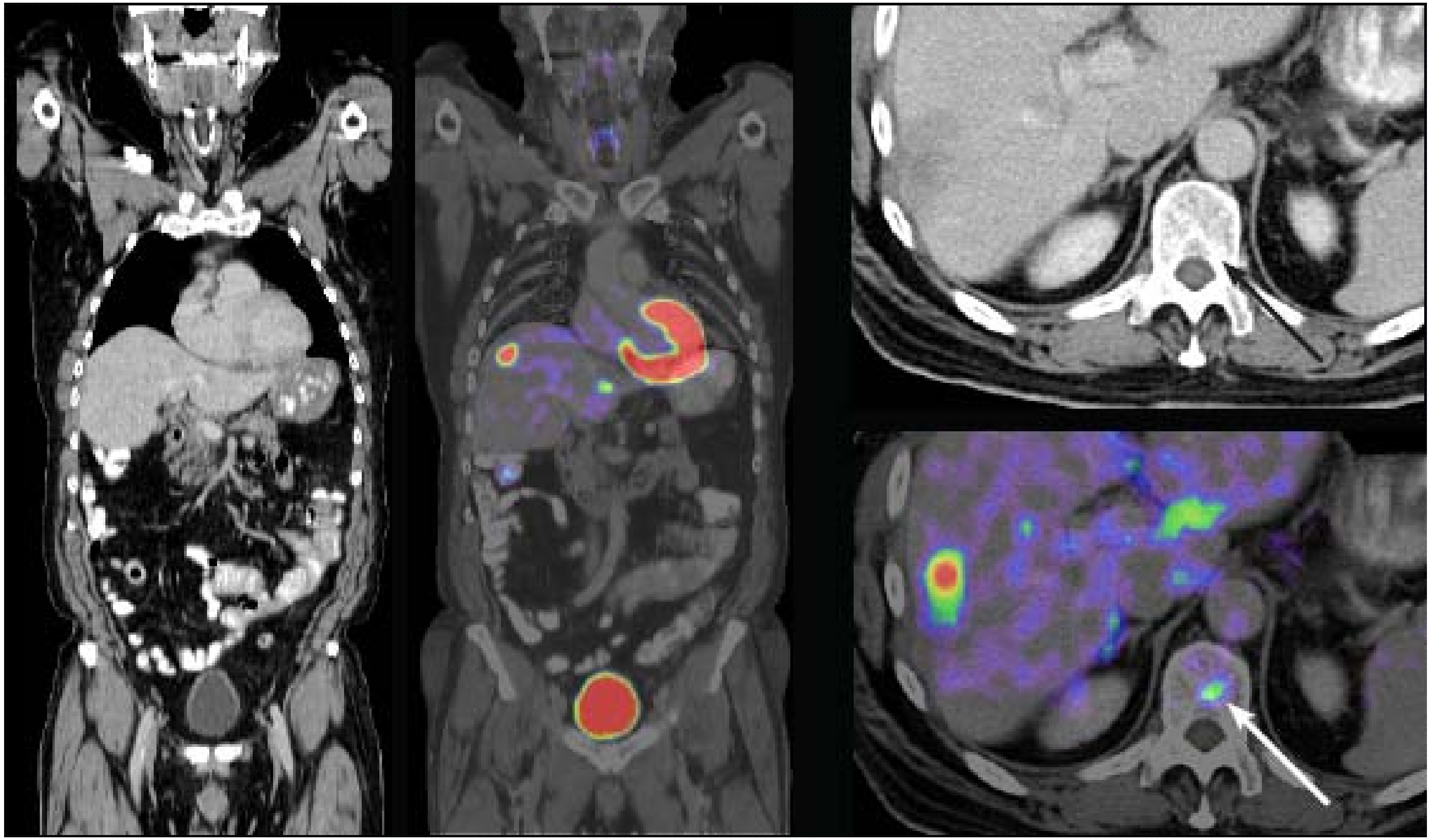
difference

Possible medical applications

- In fact, not many…

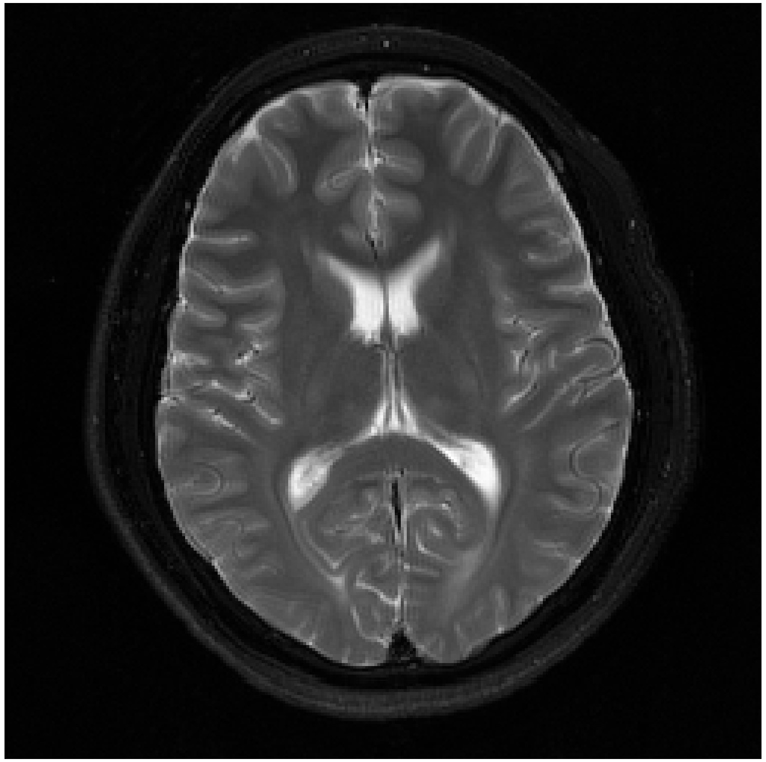
- Image fusion between different imaging modalities
- Demonstration of neural/muscular fiber orientation

Medical image fusion

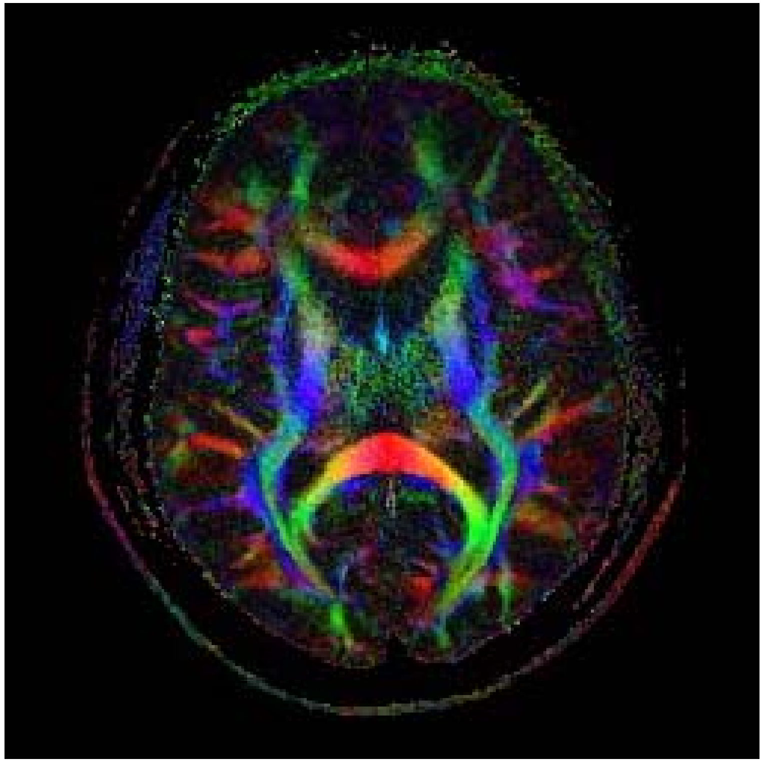


CT(gray-level) + PET (color) fusion

Neural fiber by diffusion MRI



T2WI of human brain



colored FA map

Review

- Fundamentals of colors
- Color models: RGB, CMYK, HSI
- Pseudo color processing
- Full color processing
  - 基本上灰階能做的事，彩色影像通通能做！
- Medical applications

生醫影像研究方法：影像色彩學