Today's Agenda

- Color image processing

Color Representations

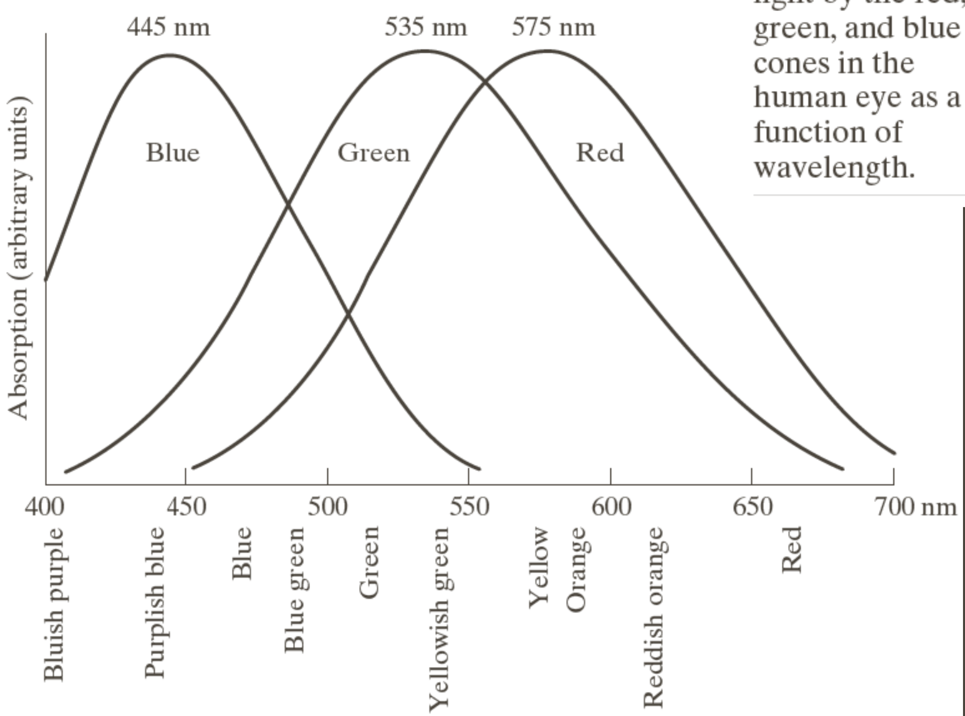
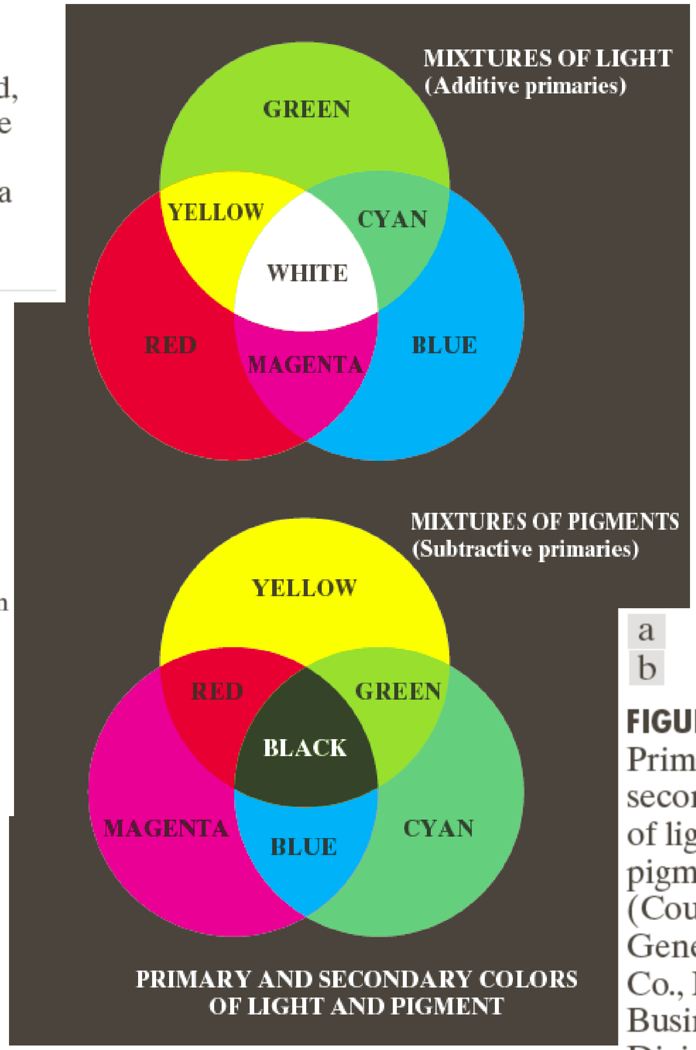


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.



a
b

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

- primary/secondary colors
- primary/secondary pigments
- all visible colors

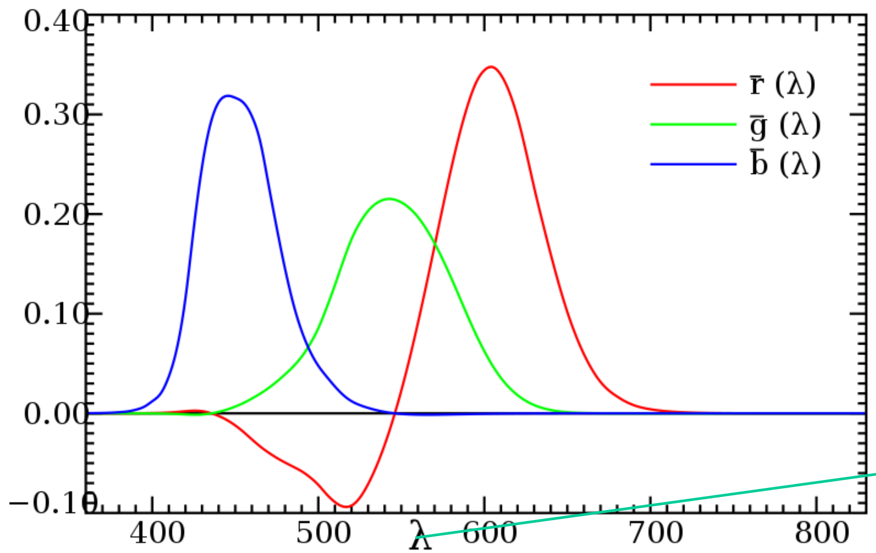
Characteristics of Color Light

- **Radiance**
- **Luminance**
- **Brightness**
- **Chromaticity**
  - Hue – dominant color/wavelength
  - Saturation – color purity

White and grey has the same chromaticity, while different brightness

Chromaticity

Tristimulus values of a color: The amounts of the three primary color to match a test color



wavelength

The CIE 1931 RGB Color matching functions.

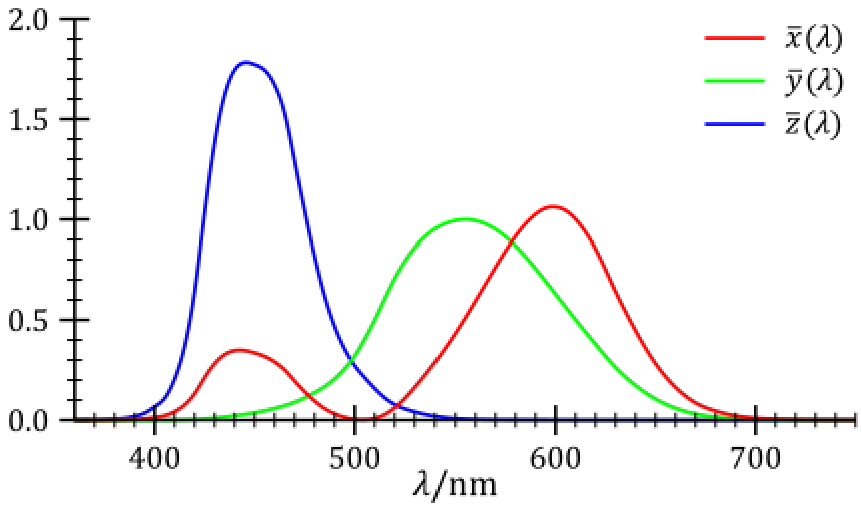
CIE (International Commission on Illumination) RGB matching function

$$R = \int_0^\infty I(\lambda)\bar{r}(\lambda)d\lambda \qquad G = \int_0^\infty I(\lambda)\bar{g}(\lambda)d\lambda \qquad B = \int_0^\infty I(\lambda)\bar{b}(\lambda)d\lambda$$

$$\int_0^\infty \bar{r}(\lambda)d\lambda = \int_0^\infty \bar{g}(\lambda)d\lambda = \int_0^\infty \bar{b}(\lambda)d\lambda$$

Chromaticity

Tristimulus values of XYZ space



CIE XYZ matching function

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$X = \int_0^\infty I(\lambda)\bar{x}(\lambda)d\lambda$$

$$Y = \int_0^\infty I(\lambda)\bar{y}(\lambda)d\lambda$$

Luminance

$$Z = \int_0^\infty I(\lambda)\bar{z}(\lambda)d\lambda$$

xy-Y space

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

Chromaticity

$$z = \frac{Z}{X+Y+Z}$$

$$\Rightarrow z = 1 - x - y$$

Chromaticity Diagram

x and y to represent colors

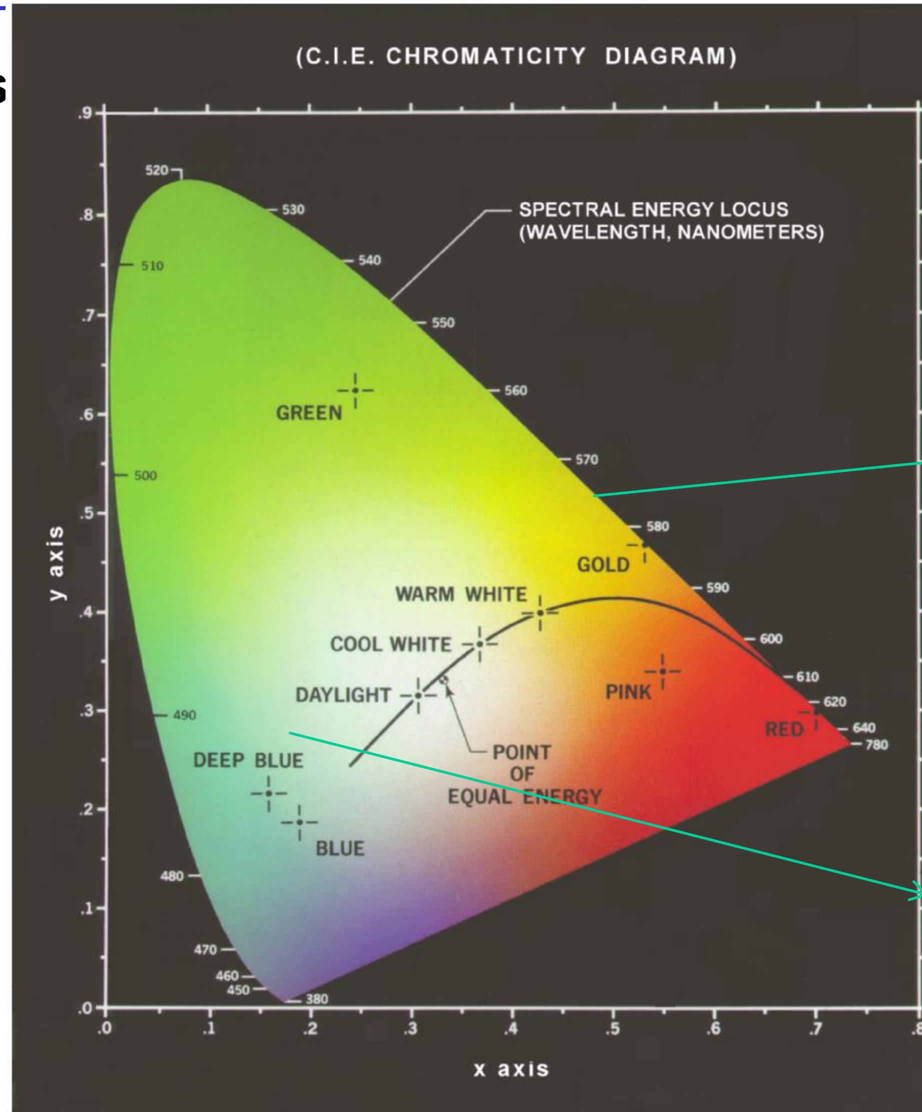


FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)

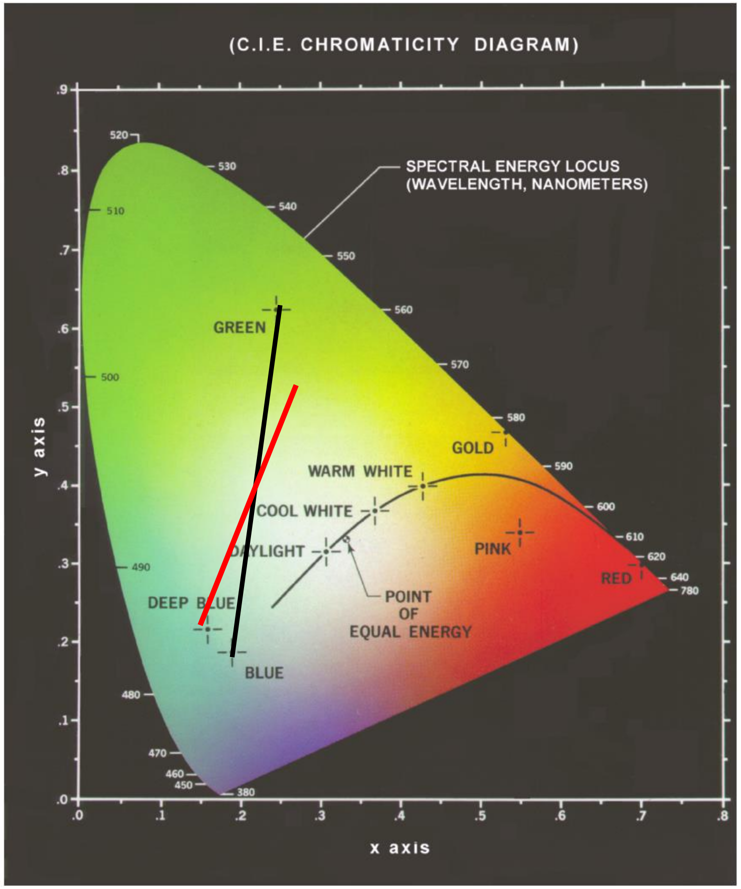
Pure color and fully saturated

Mixed color with less saturation

Chromaticity Diagram (Cont'd)

Color mixing: any color on a line segment can be generated by the two ending points in the color diagram

Metamerism: the same color can be generated with different combinations of source colors with the same tristimulus values



Color Gamut

- **Color gamut:** a complete subset of colors can be displayed on a device or represented by a color space.
- The color represented by 3 given colors resides in the triangle formed by the 3 points
- Not all colors can be represented by 3 primary colors

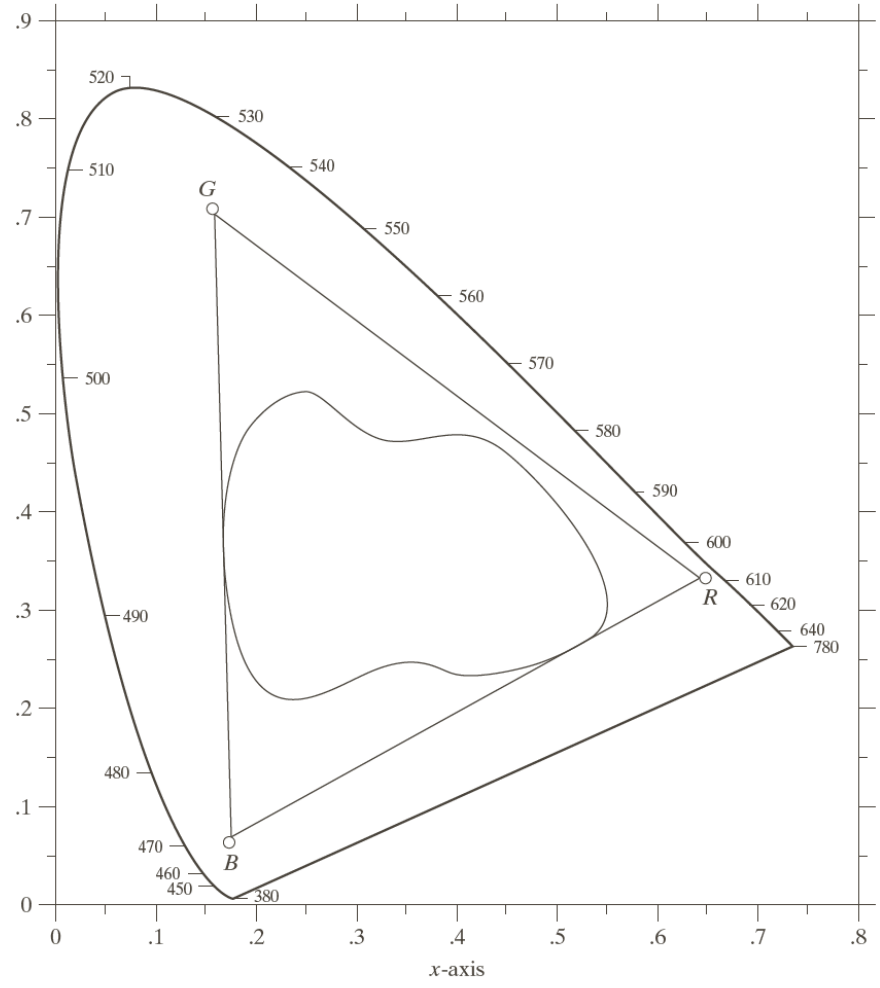


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

Color Models

Color model (space/system): a coordinate system or a subspace to represent the colors

- RGB model: monitors and cameras
- CMY (Cyan, magenta, and yellow): printing
- HSI (Hue, saturation, and intensity): separate color and gray level information

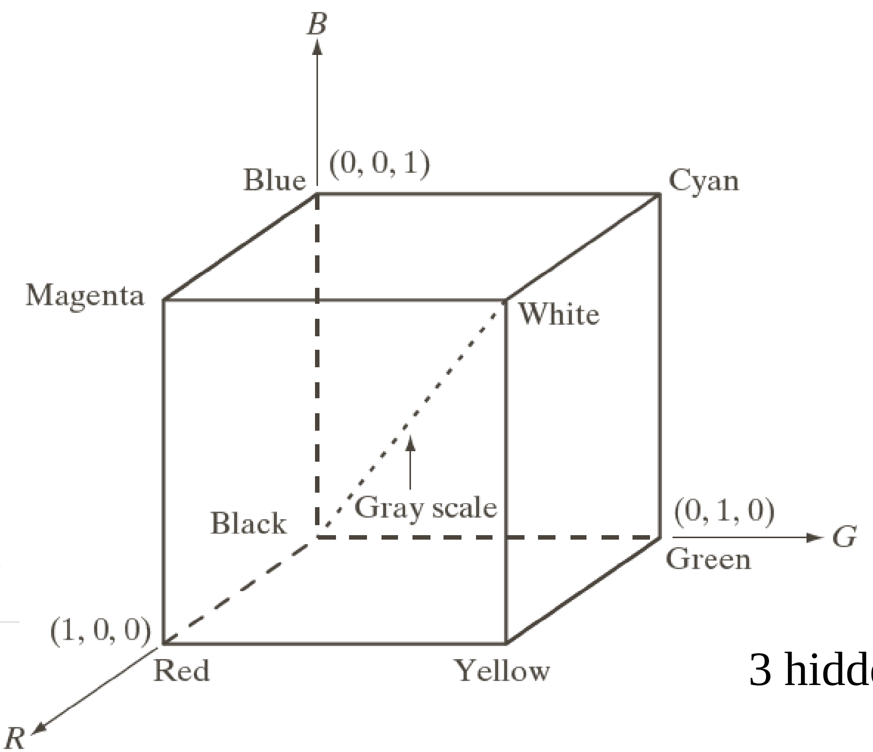
RGB Model

3D Cartesian coordinate system

All colors are normalized to [0, 1]

Pixel depth: number of bits to represent each pixel in the RGB space

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).



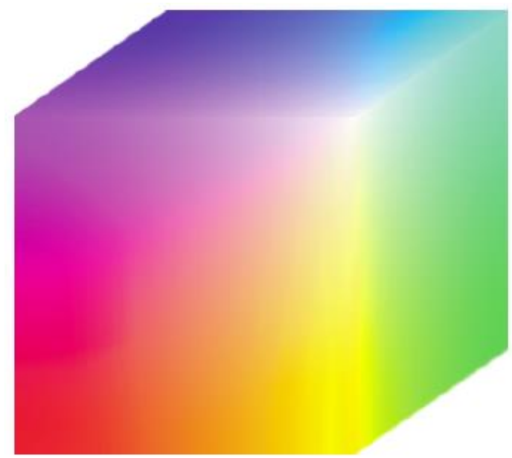
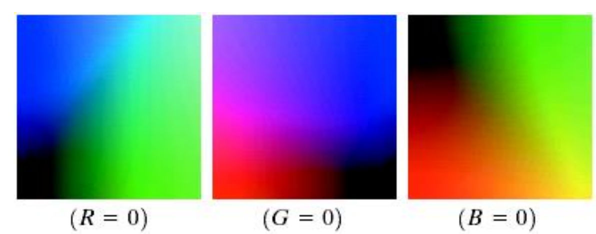


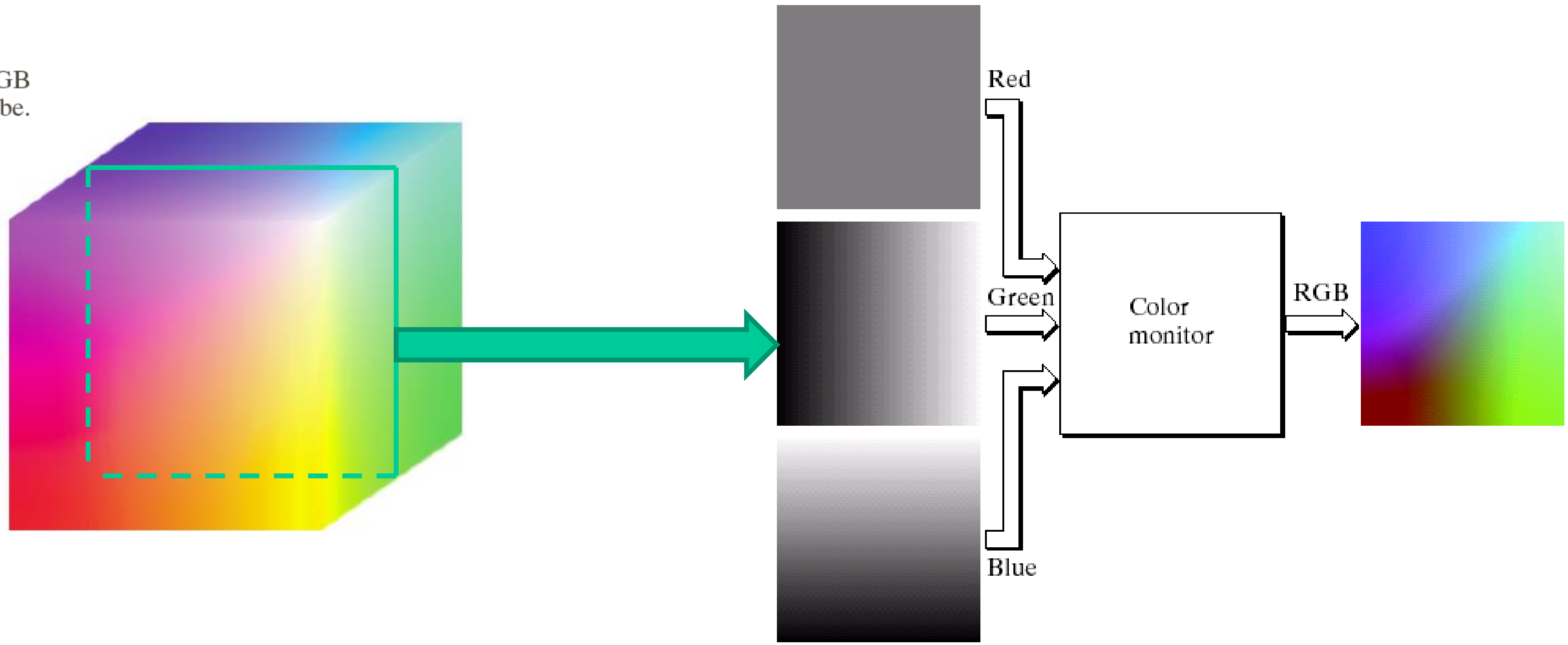
FIGURE 6.8 RGB 24-bit color cube.

3 hidden planes



RGB Model (Cont'd)

FIGURE 6.8 RGB 24-bit color cube.



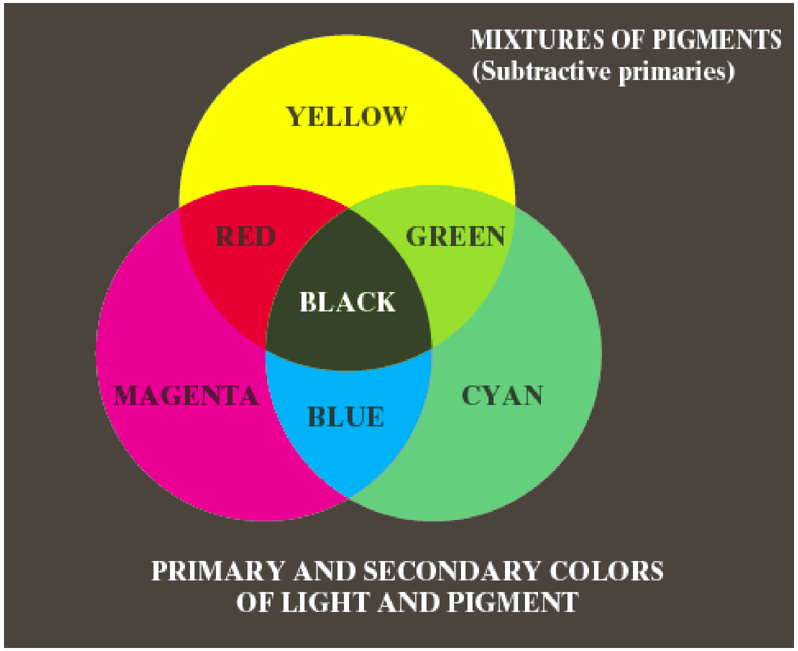
CMY/CMYK Model

CMY (Cyan, Magenta, Yellow)

- Represent the light reflected from the surface.

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

CMYK (CMY + Black)



HSI Model

A better model to describe colors.

• Hue: the dominant color observed

• Saturation: the purity of the color (how much the color is polluted by white color)

• Value/Intensity: intensity level

HSI Model

A better model to describe colors.

- Hue: the dominant color observed
- Saturation: the purity of the color (how much the color is polluted by white color)
- Value/Intensity: intensity level

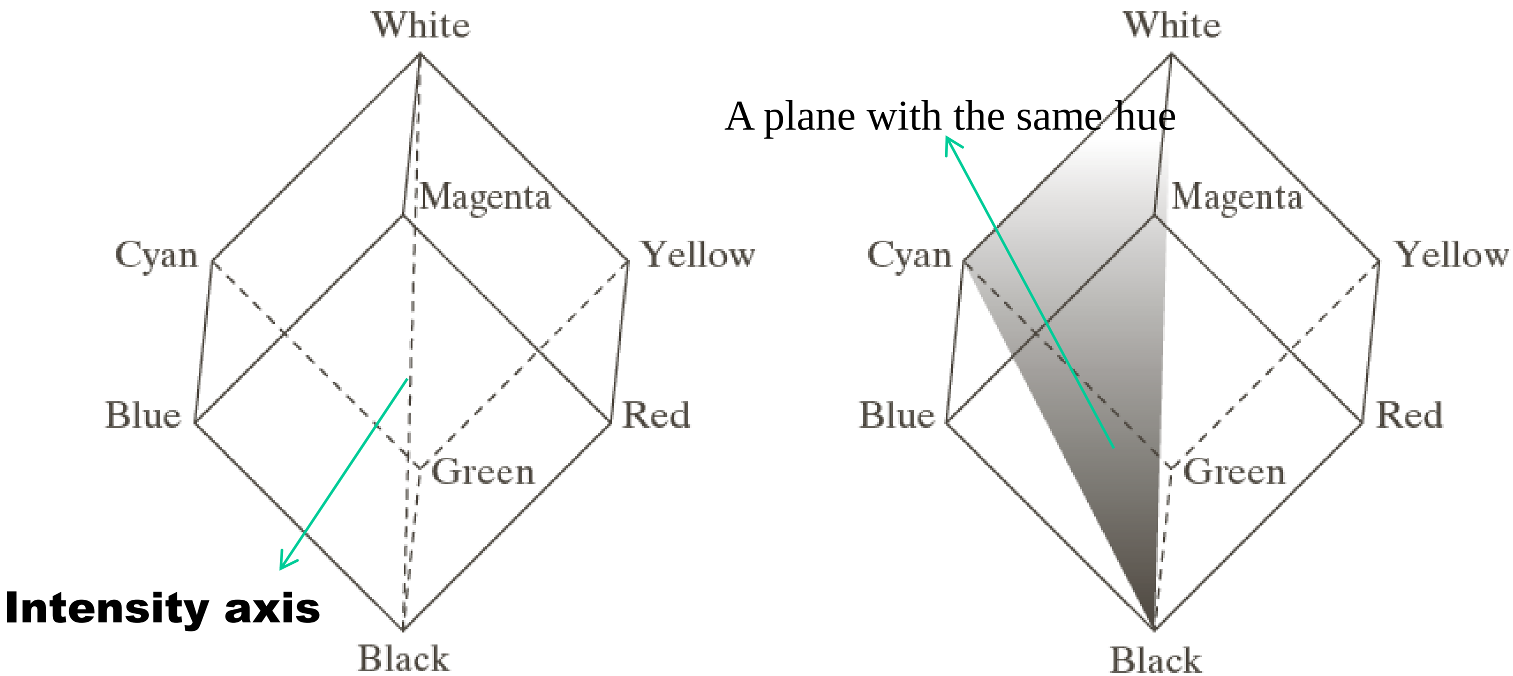
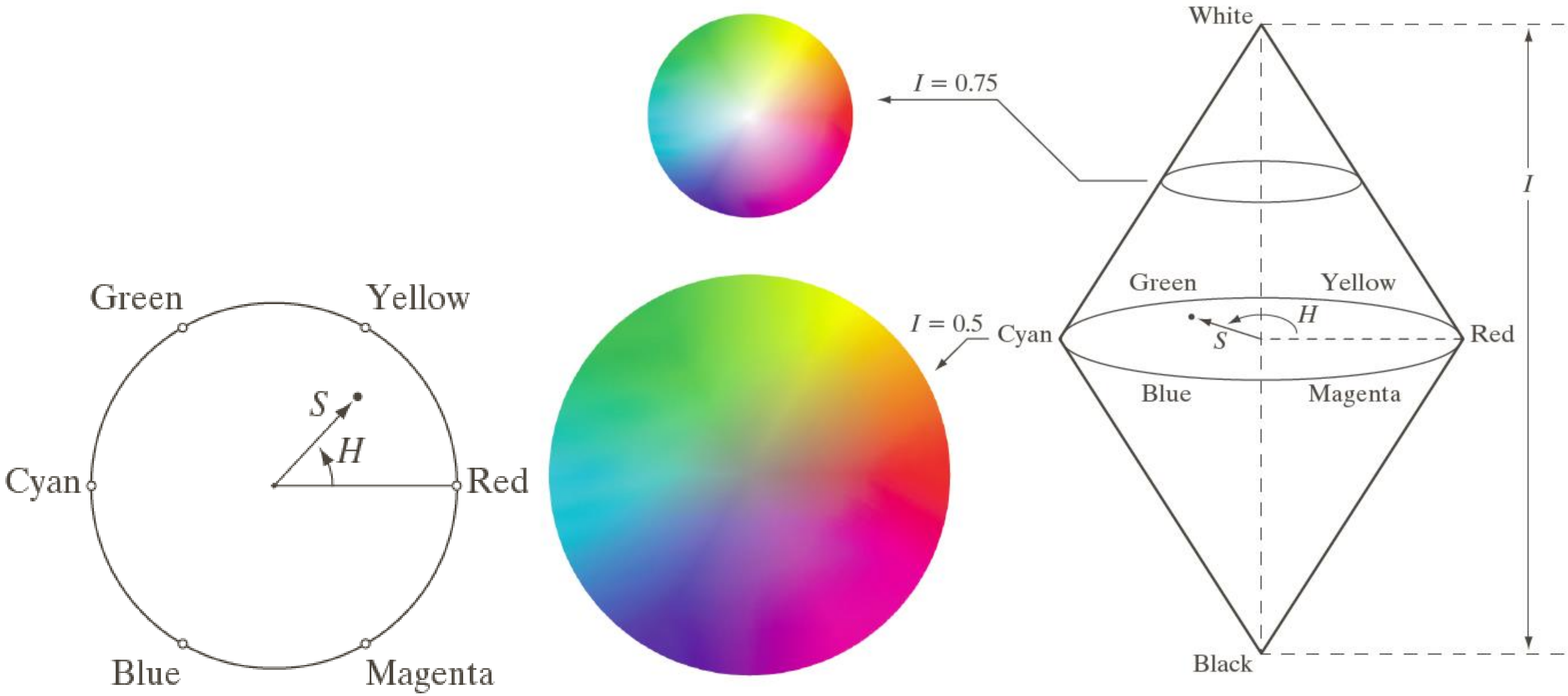


FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.

HSI Model



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

HSI to RGB

Assume RGB values have been normalized to [0,1]

$$H = \begin{cases} \theta/360 & \text{if } B \le G \\ 1-\theta/360 & \text{if } B > G \end{cases} \quad \text{where} \quad \theta = \cos^{-1}\left\{ \frac{0.5\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\}$$

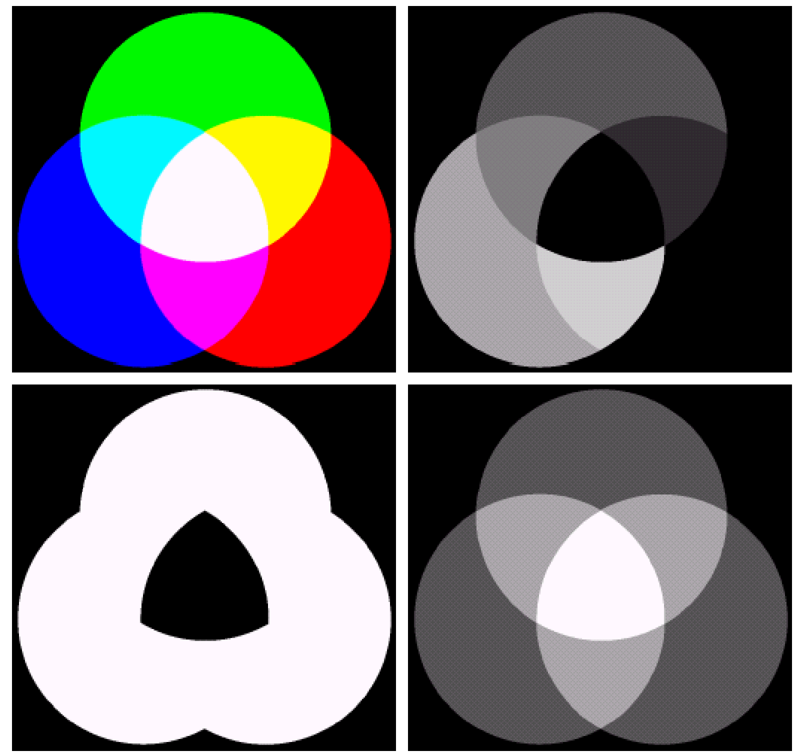
$$S = 1 - \frac{3}{R+G+B}\min(R,G,B) \qquad I = \frac{R+G+B}{3}$$

HSI values are in [0,1]

Case Study for RGB-HSI

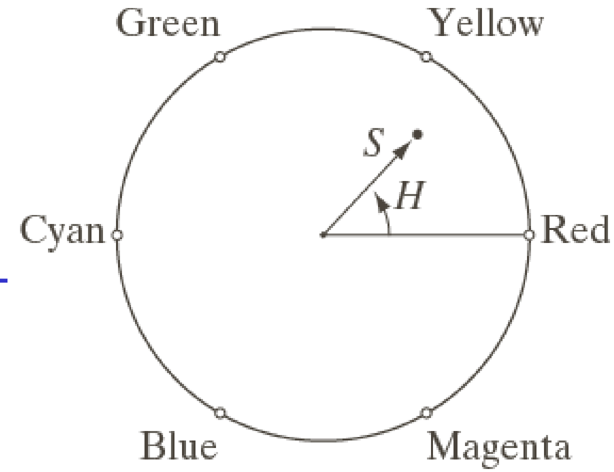
$$\begin{bmatrix}0\\0\\0\end{bmatrix} \quad \begin{bmatrix}1\\0\\0\end{bmatrix} \quad \begin{bmatrix}0\\1\\0\end{bmatrix} \quad \begin{bmatrix}0\\0\\1\end{bmatrix} \begin{bmatrix}1\\1\\0\end{bmatrix} \quad \begin{bmatrix}1\\0\\1\end{bmatrix} \quad \begin{bmatrix}0\\1\\1\end{bmatrix} \quad \begin{bmatrix}1\\1\\1\end{bmatrix}$$

Original RGB Hue



Saturation Intensity

HSI to RGB



Recover H to [0 360]

RG sector ($0 \le H < 120$ **):**

$$B = I(1-S) \qquad R = I\left[1 + \frac{S\cos H}{\cos(60-H)}\right] \qquad G = 3I - (R+B)$$

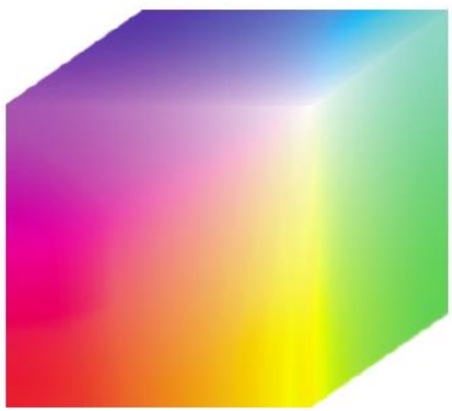
GB sector($120 \le H < 240$ **):** $H = H - 120$

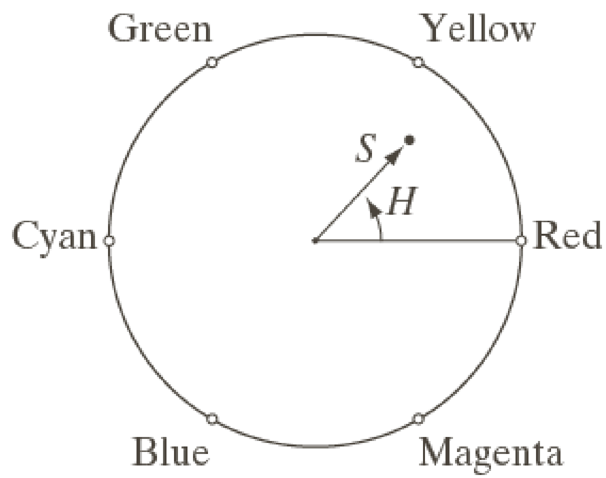
$$R = I(1-S) \qquad G = I\left[1 + \frac{S\cos H}{\cos(60-H)}\right] \qquad B = 3I - (R+G)$$

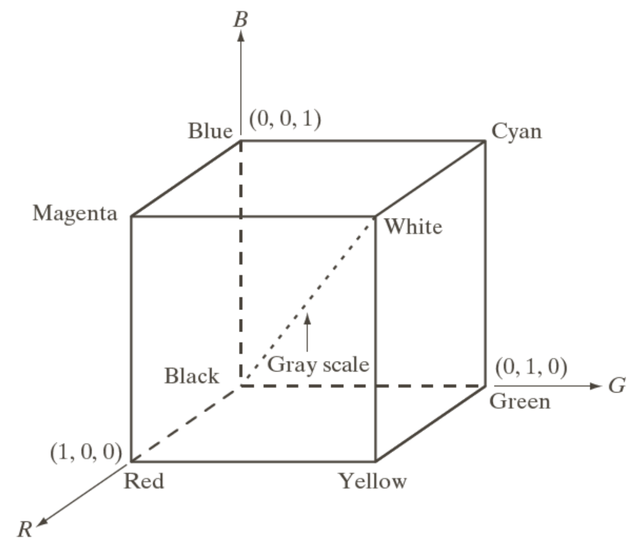
BR sector($240 \le H \le 360$ **):** $H = H - 240$

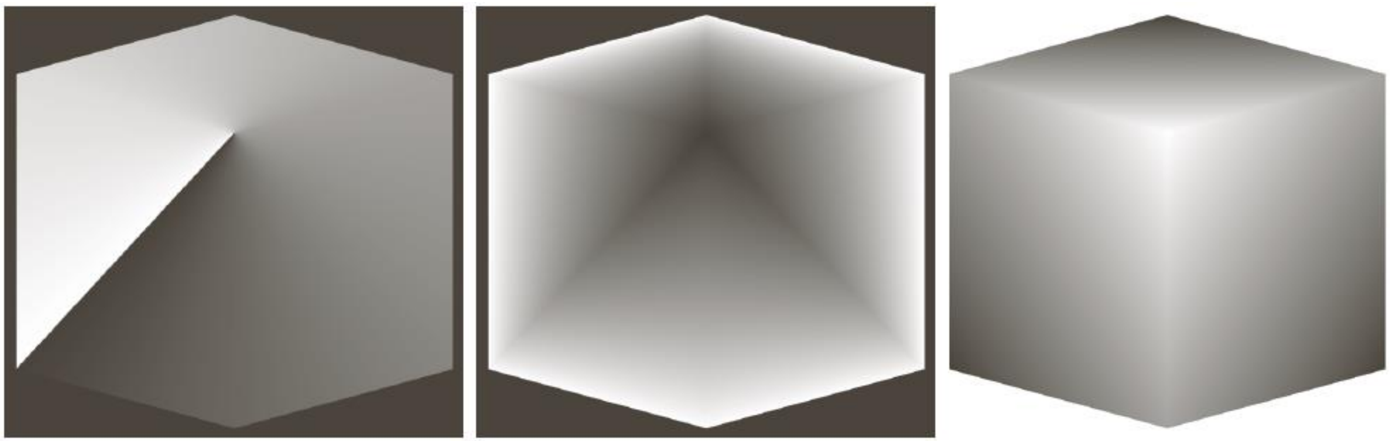
$$G = I(1-S) \qquad B = I\left[1 + \frac{S\cos H}{\cos(60-H)}\right] \qquad R = 3I - (G+B)$$

HSI Model





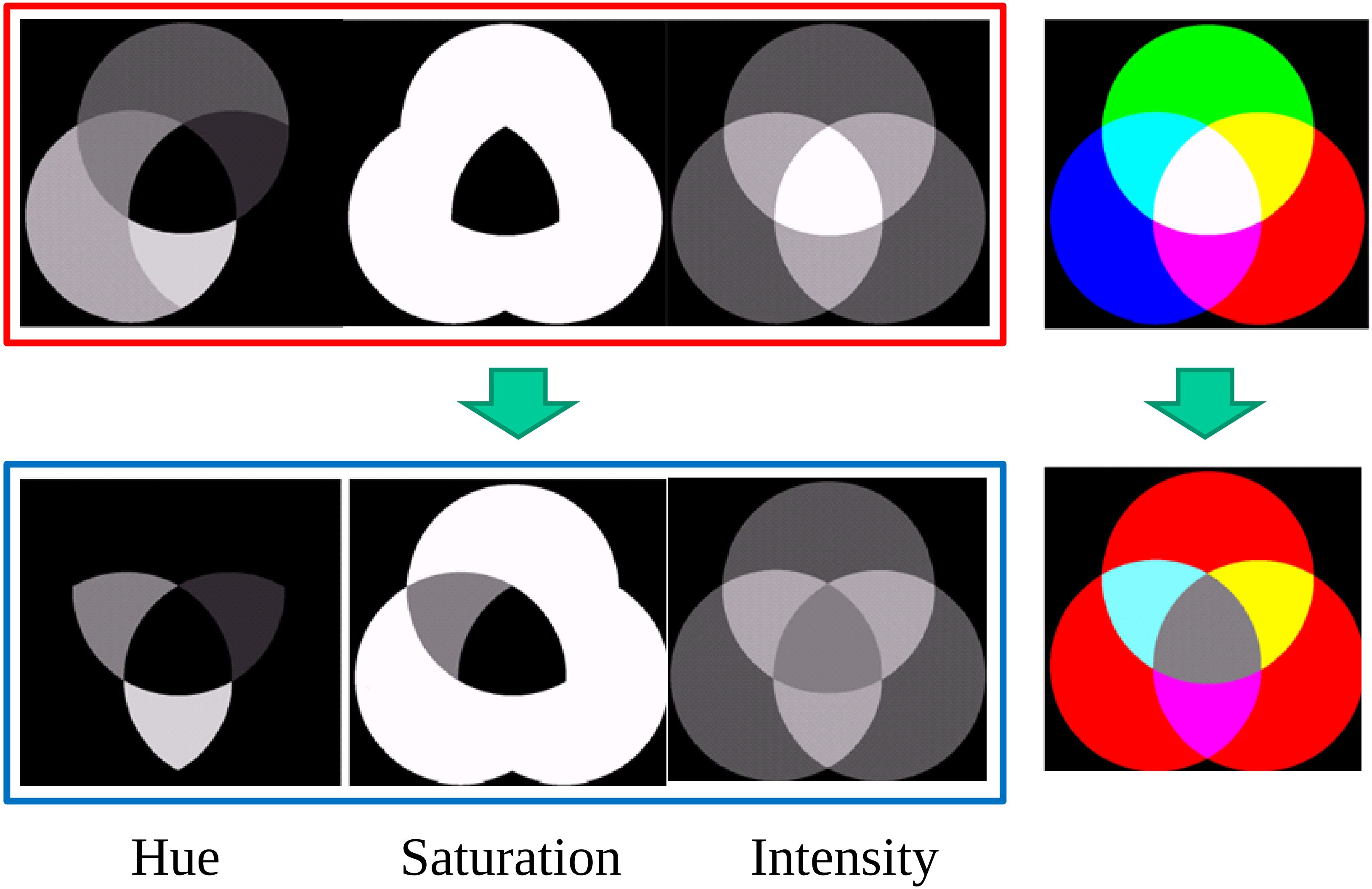




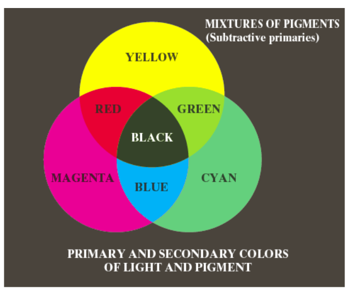
a b c

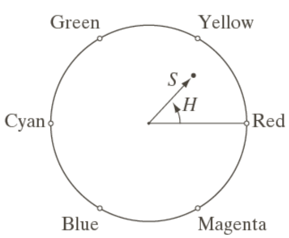
FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

Manipulate



Full Color Image in Different Color Space





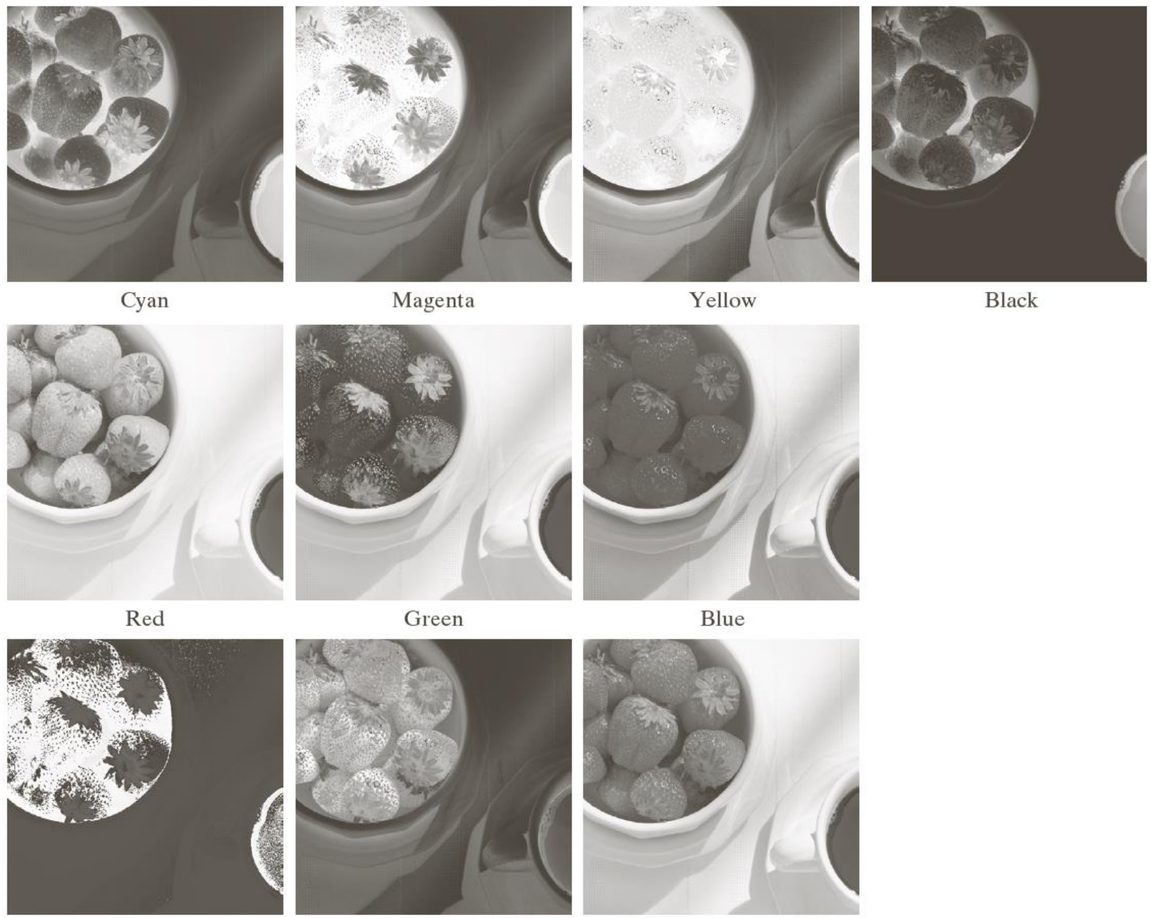


FIGURE 6.30 A full-color image and its various color-space components. Interactive.)

Pseudo Color Image Processing

Pseudo color/false color: assign colors to gray values

Enhance the visualization quality of the image

- Segmentation results
- Enhance the intensity difference

Intensity Slicing

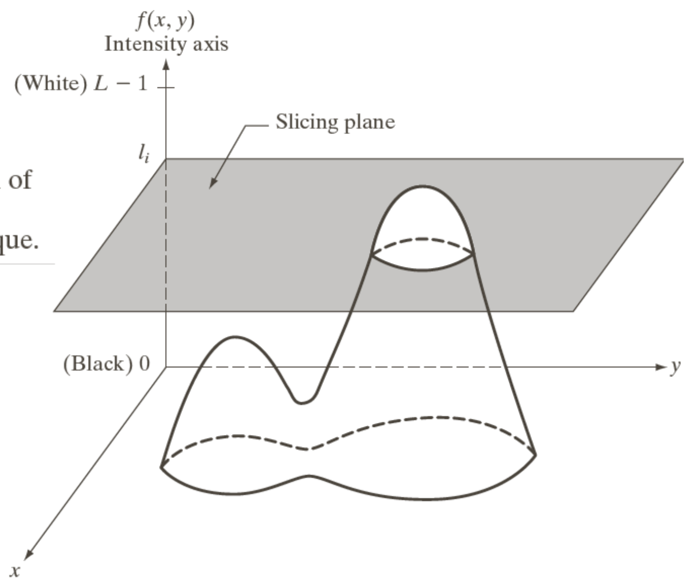


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

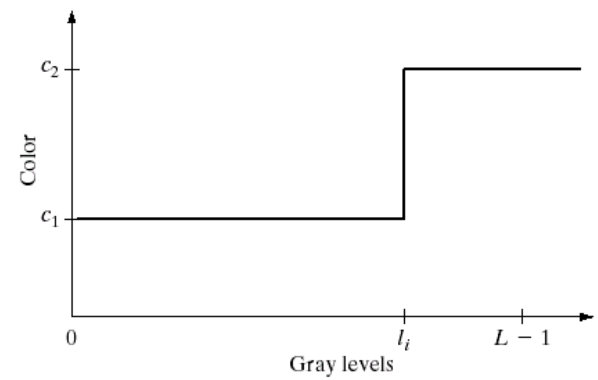
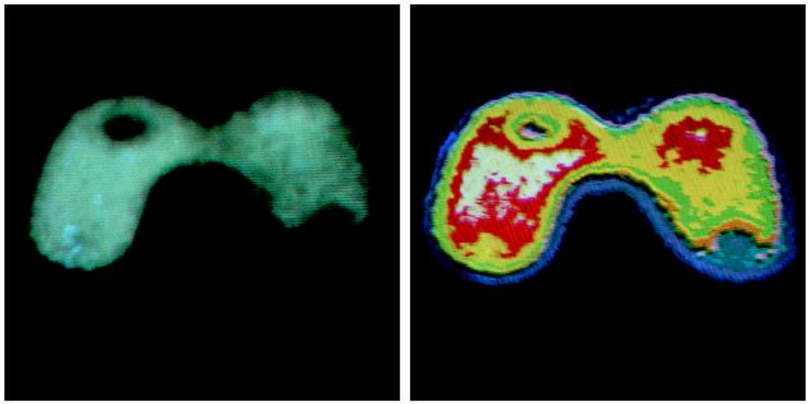


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

Examples of Intensity Slicing

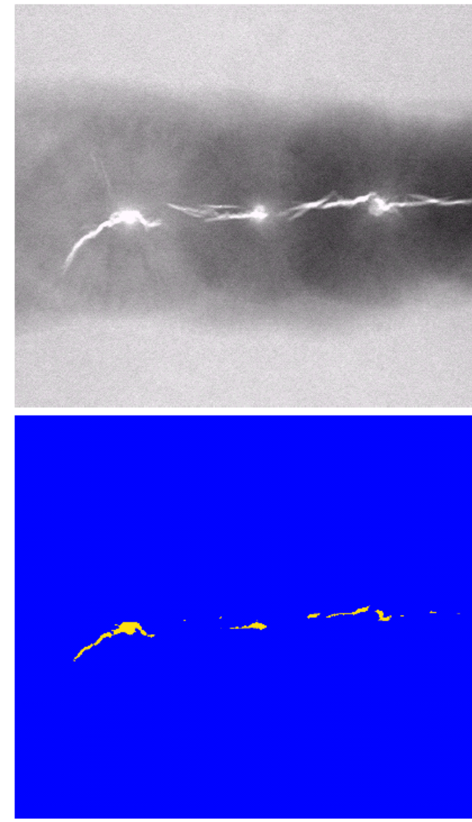


a b

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.)

a
b

FIGURE 6.21 (a) Monochrome X-ray image of a weld. (b) Result of color coding. (Original image courtesy of X-TEK Systems, Ltd.)



Examples of Intensity Slicing

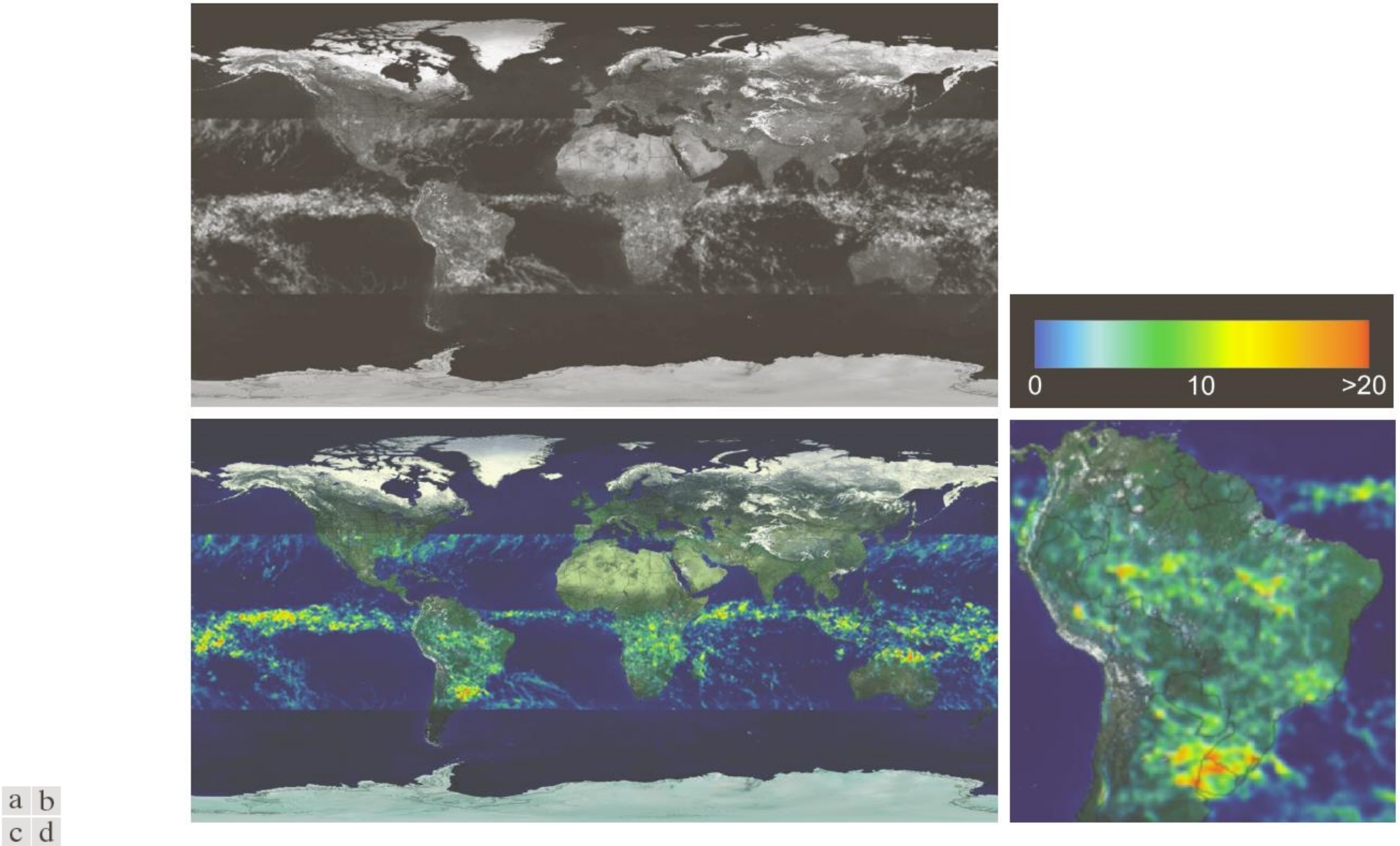
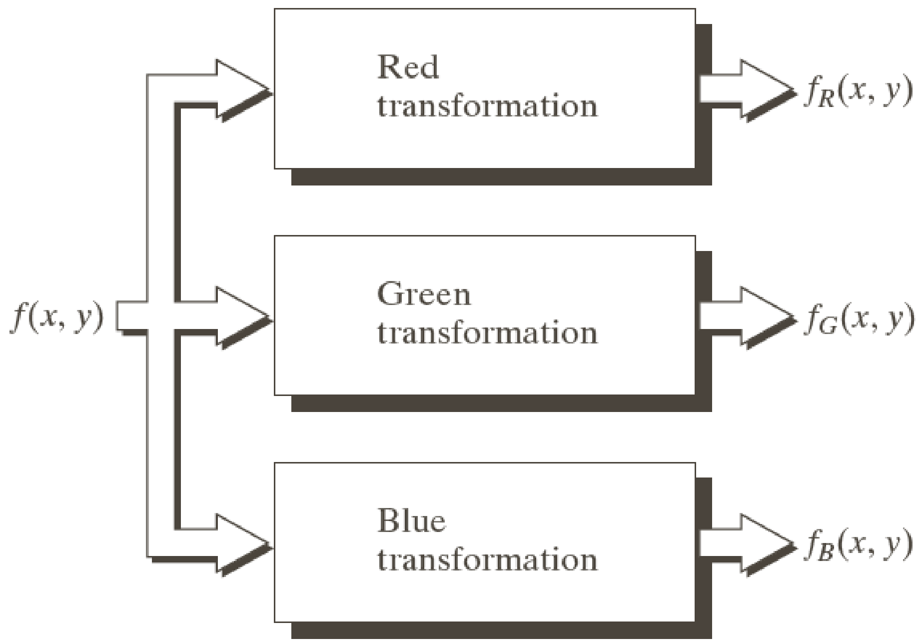


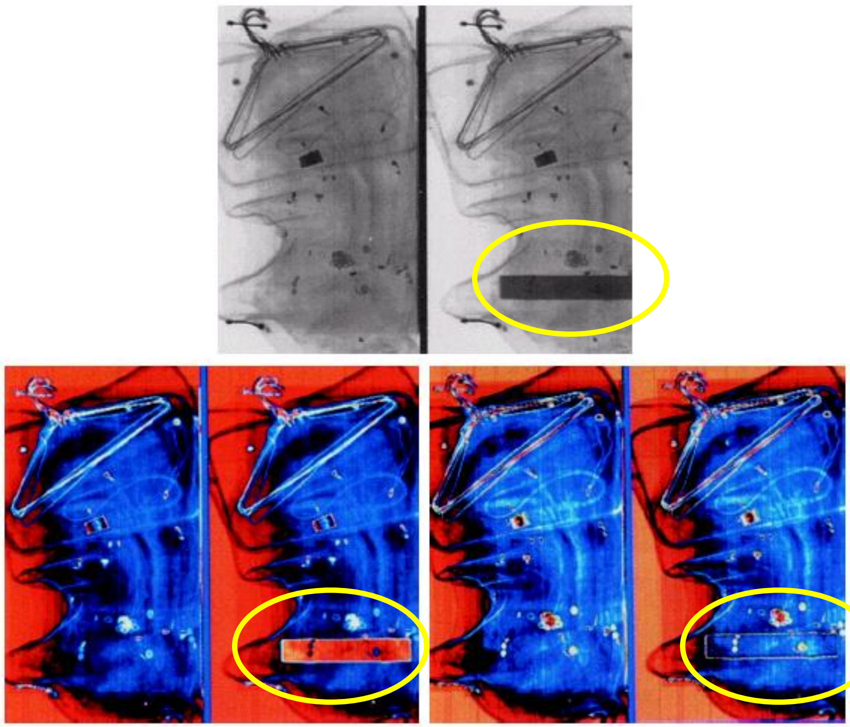
FIGURE 6.22 (a) Gray-scale image in which intensity (in the lighter horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South American region. (Courtesy of NASA.)

Intensity to Color Transformation

FIGURE 6.23 Functional bl diagram for pseudocolor image process f_R, f_G, and f_B fed into the correspondin red, green, an blue inputs of RGB color monitor.

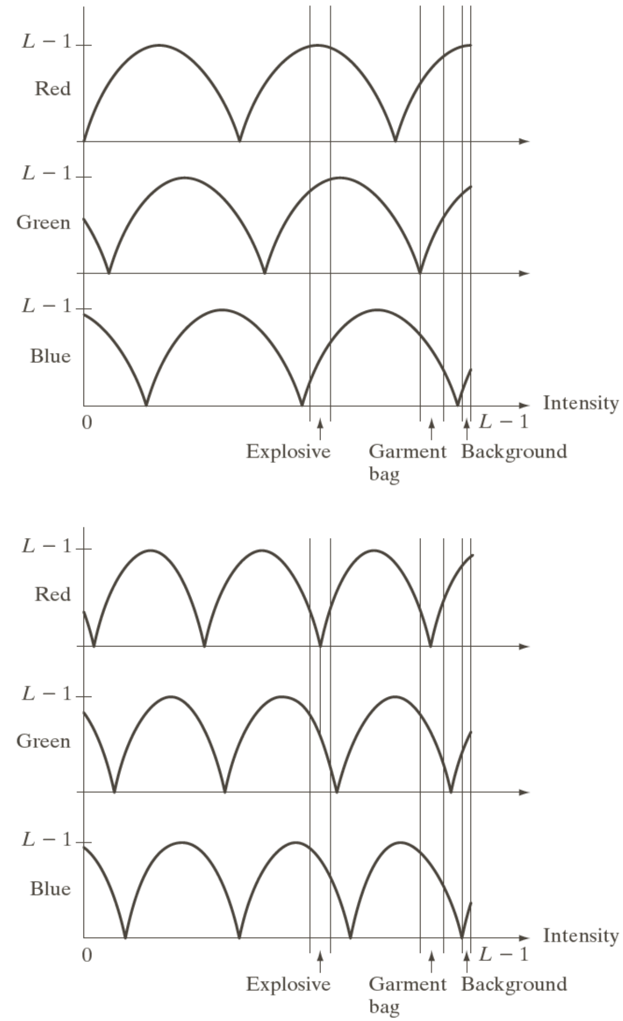


Example



a
b c

FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)



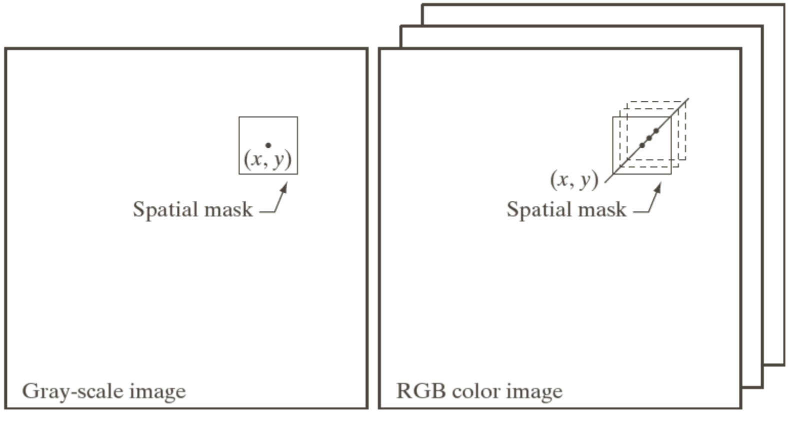
a
b

FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.

Full-color Image Processing

Pixel in color image $\mathbf{p}(x,y) = \begin{bmatrix} p_r(x,y) \\ p_g(x,y) \\ p_b(x,y) \end{bmatrix}$

- **Process each component/channel individually, then generate the composite image**
- **Work on each pixel individually**



Color Transformation

For a color image with n components

input values for all components

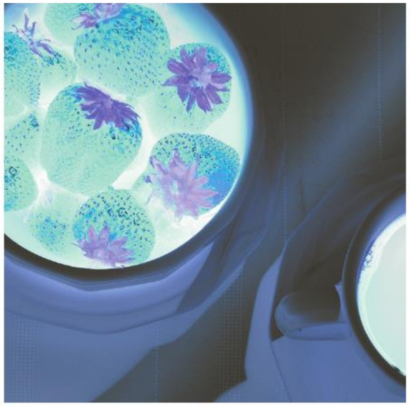
$$s_i = T_i(\underbrace{r_1, r_2, \cdots, r_n}), \qquad i = 1, 2, \cdots, n$$

Output value for i^th component   Transformation functions

- Modify intensity
- Color complement ("negative" color image)
- Color slicing
- Tonal correction
- Color balancing
- Histogram processing

Examples of Color Image Transformation






Original image	Intensity modification	Complement color	Color slicing
	HSI	RGB	RGB

Tonal Correction

Correct the tonal range (distribution of color intensities)

- Recall the intensity transformation in the gray level images

- For RGB model, each component has the same transformation function

- For HSI model, the transformation is applied on the intensity component only

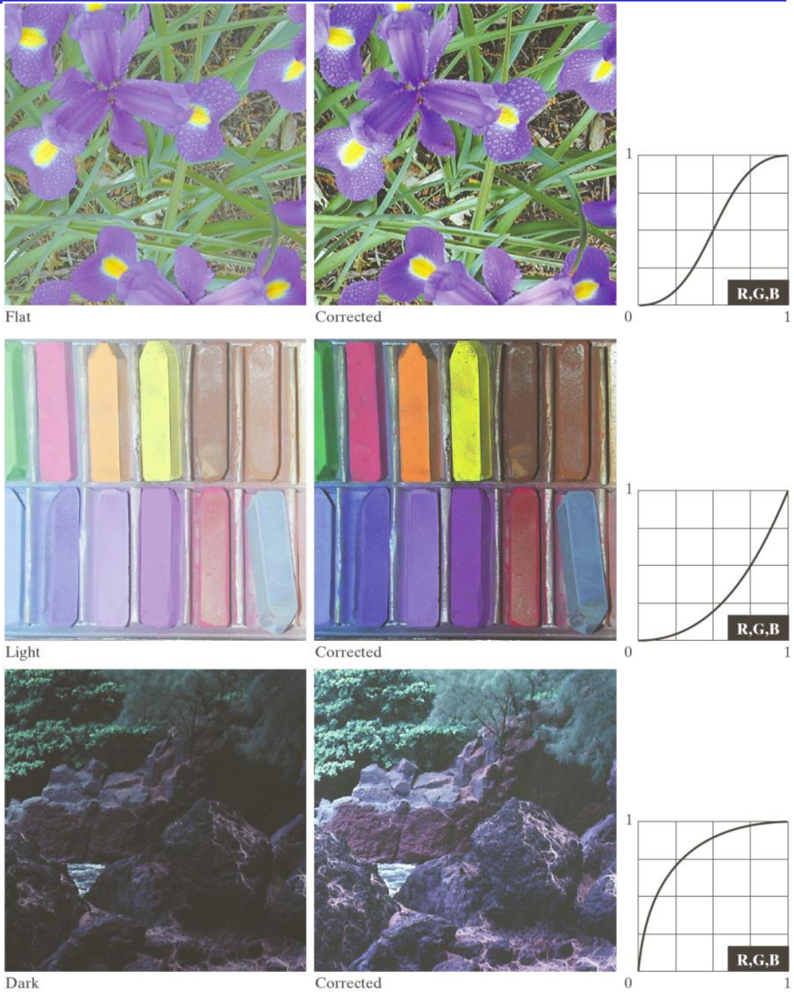
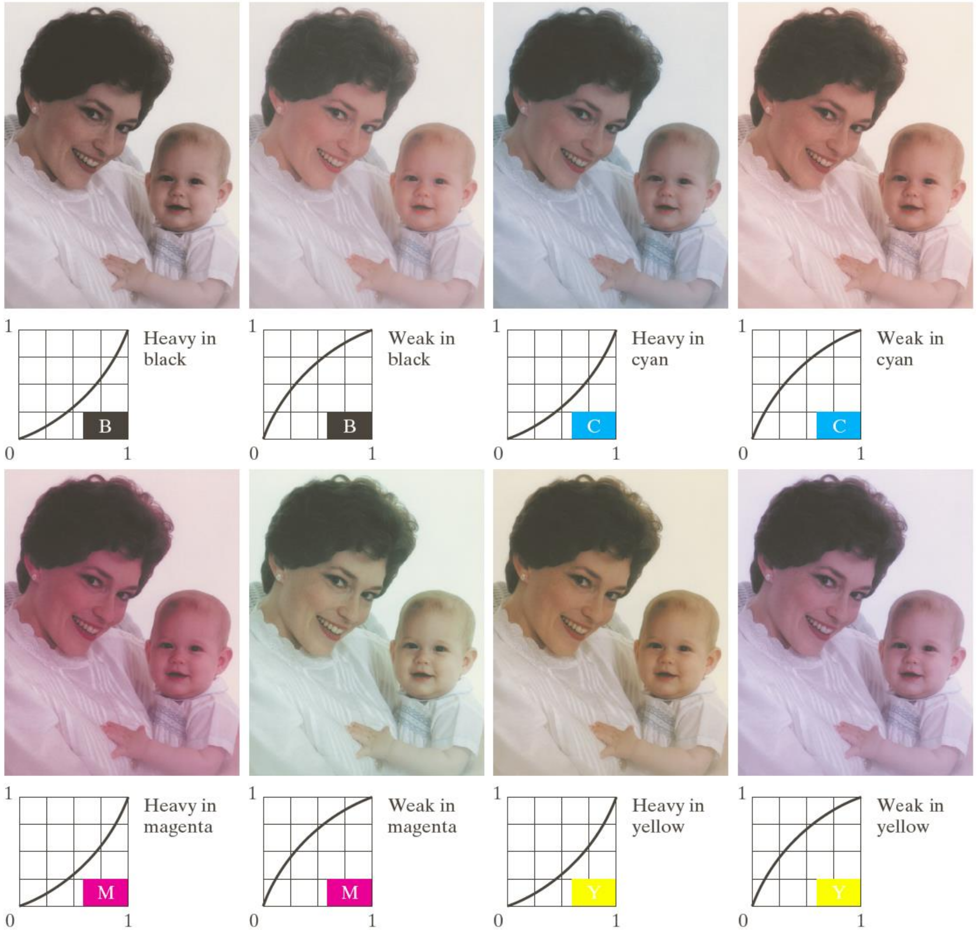


FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.

Color Balancing

Correct color unbalance by analyzing a known color in image

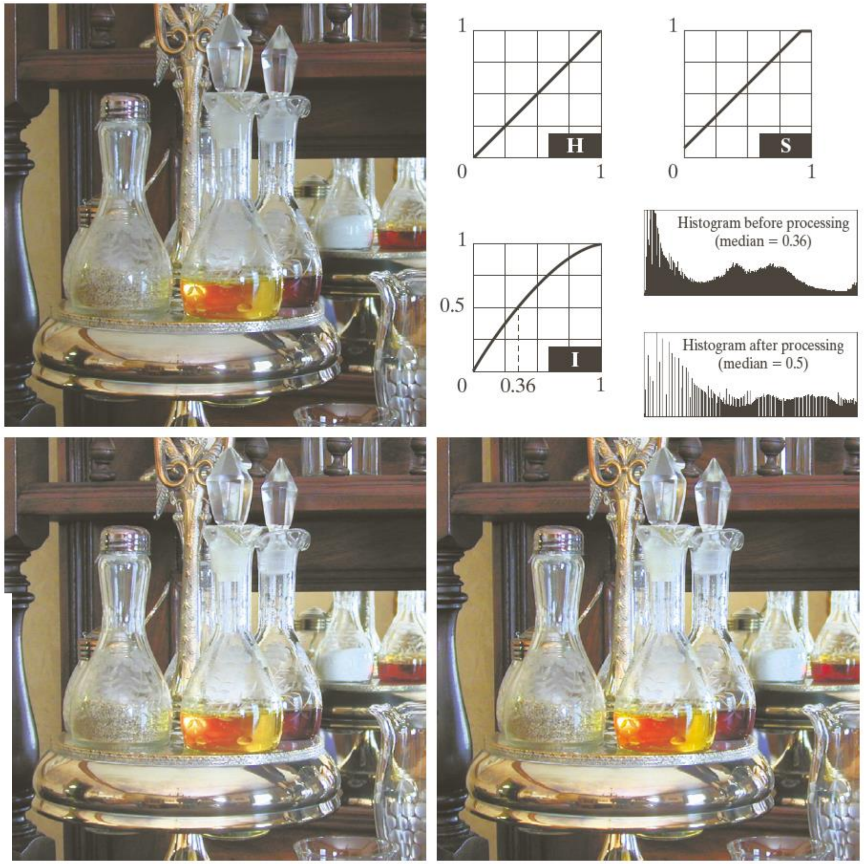
Original/Corrected



Histogram Processing

Step 1: Histogram equalization

Step 2: Saturation adjustment



a b
c d

FIGURE 6.37 Histogram equalization (followed by saturation adjustment) in the HSI color space.

Reading Assignment

- Reading Chapter 6.6, 6.7, 6.8
- Read Chapter 7 (Wavelets and Multiresolution Processing)