Color Image Processing

Color Fundamentals

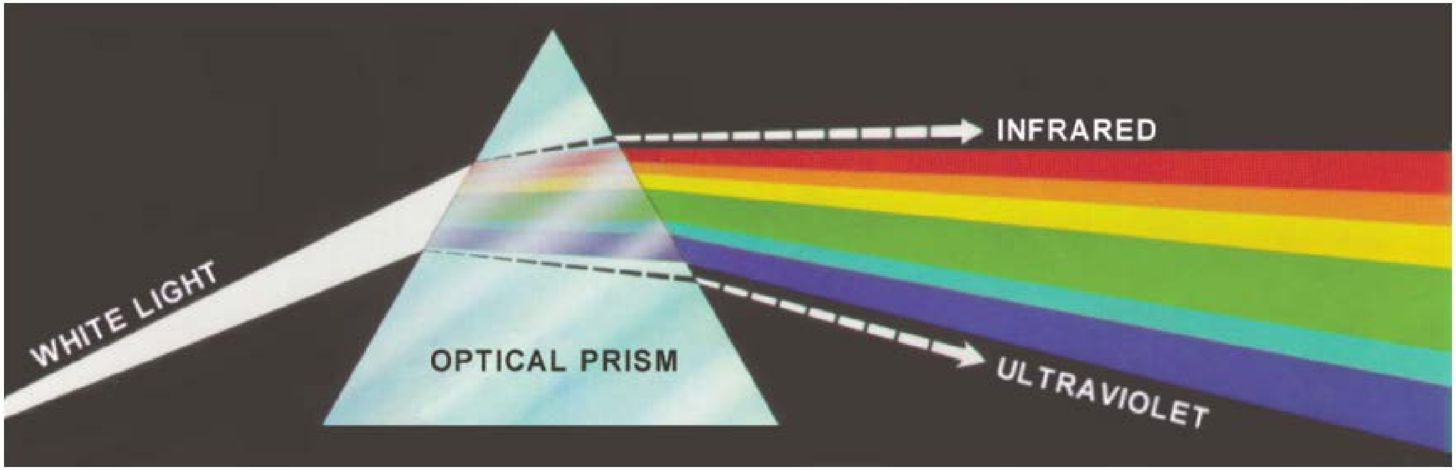


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

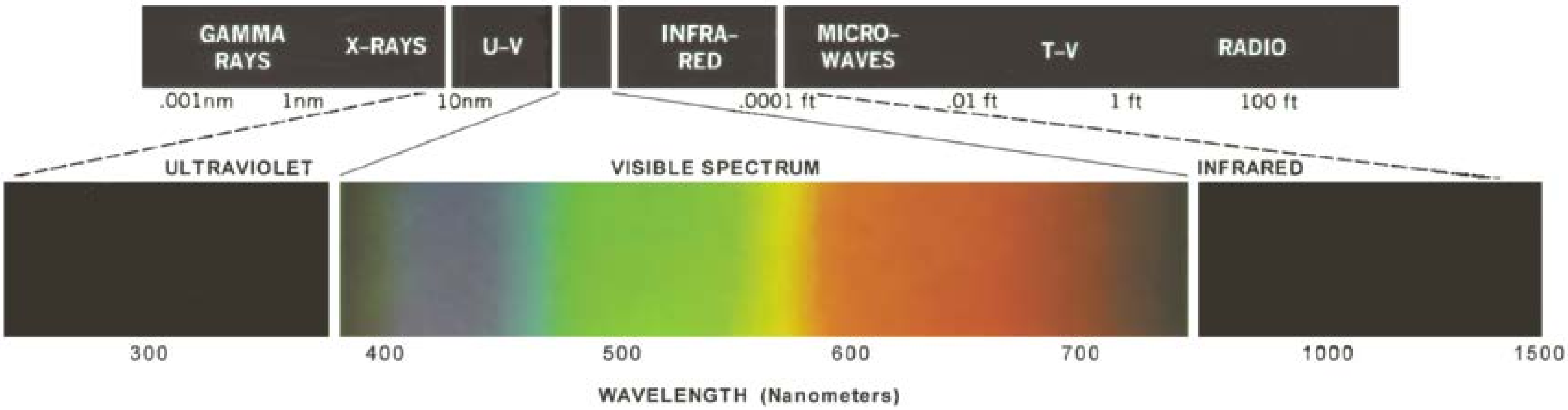


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

- 6 to 7 million cones in the human eye can be divided into three principal sensing categories, corresponding roughly to red, green, and blue.

65%: red 33%: green 2%: blue (blue cones are the most sensitive)

Color Fundamentals

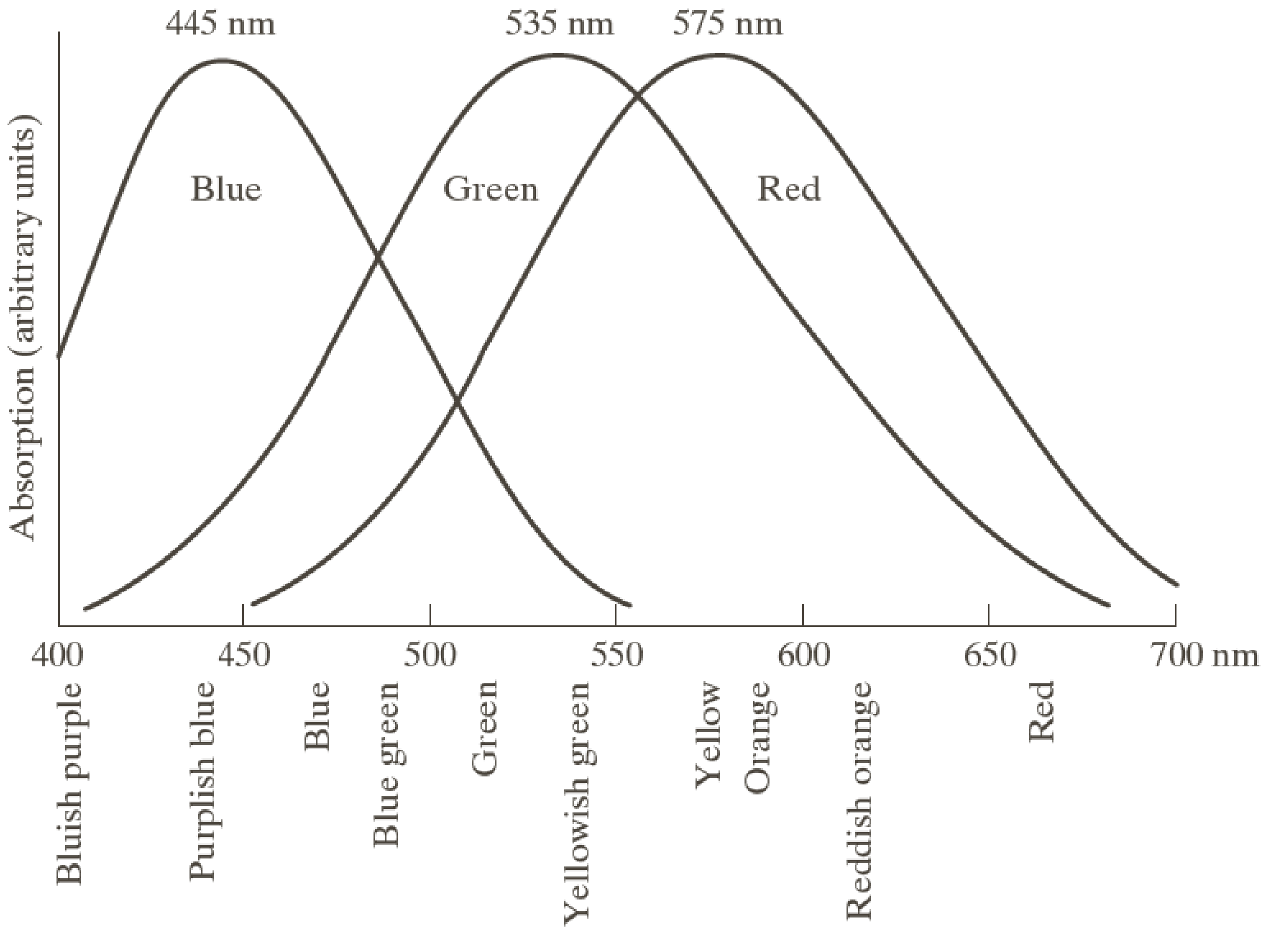


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

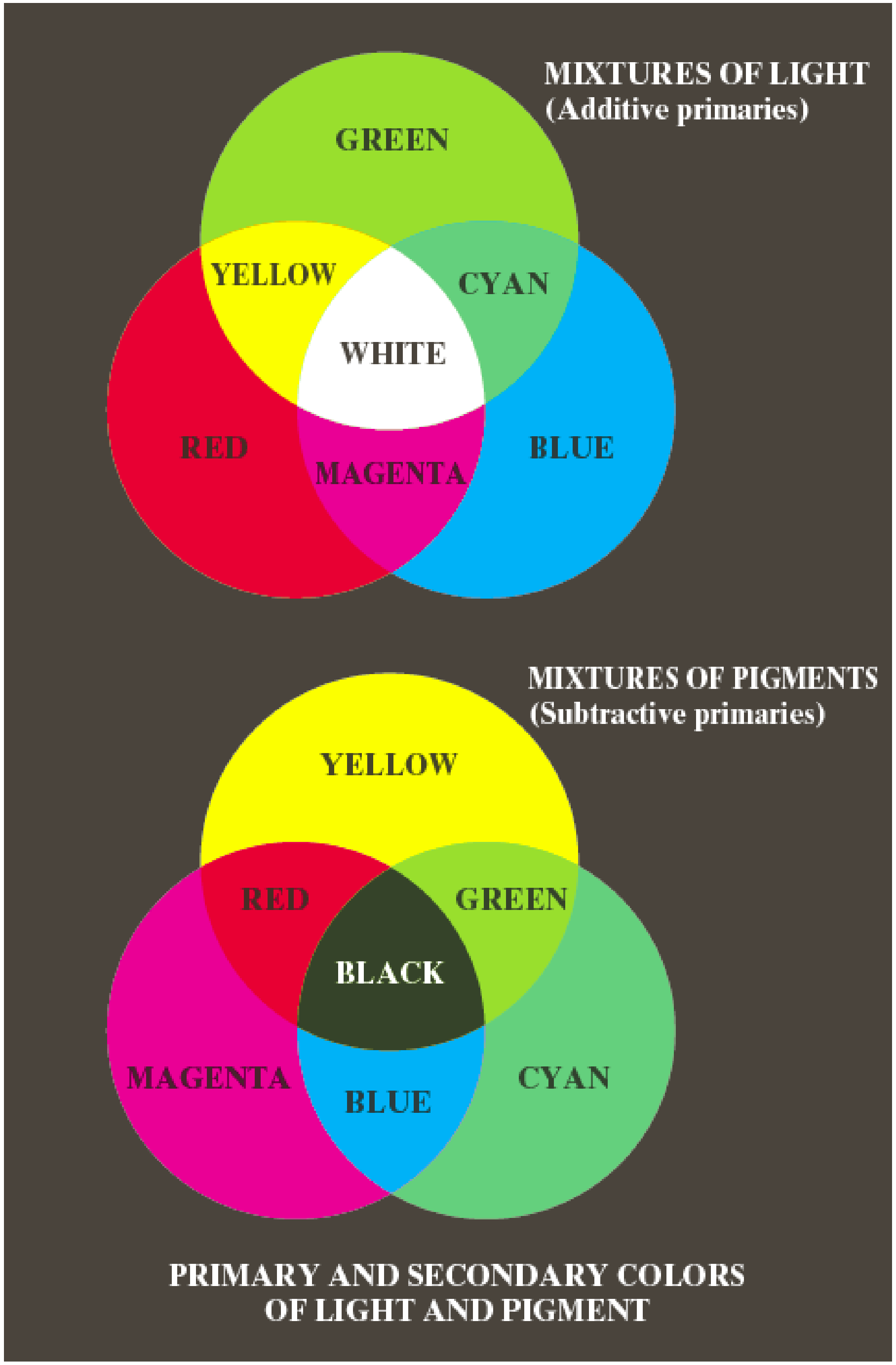


FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

- The characteristics generally used to distinguish one color from another are brightness, hue, and saturation

brightness: the achromatic notion of intensity.

hue: dominant wavelength in a mixture of light waves, represents dominant color as perceived by an observer.

saturation: relative purity or the amount of white light mixed with its hue.

Color Fundamentals

- Tristimulus

  Red, green, and blue are denoted X, Y, and Z, respectively. A color is defined by its trichromatic coefficients, defined as

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

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

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

CIE Chromaticity Diagram

It shows color composition as a function of x (red) and y (green)

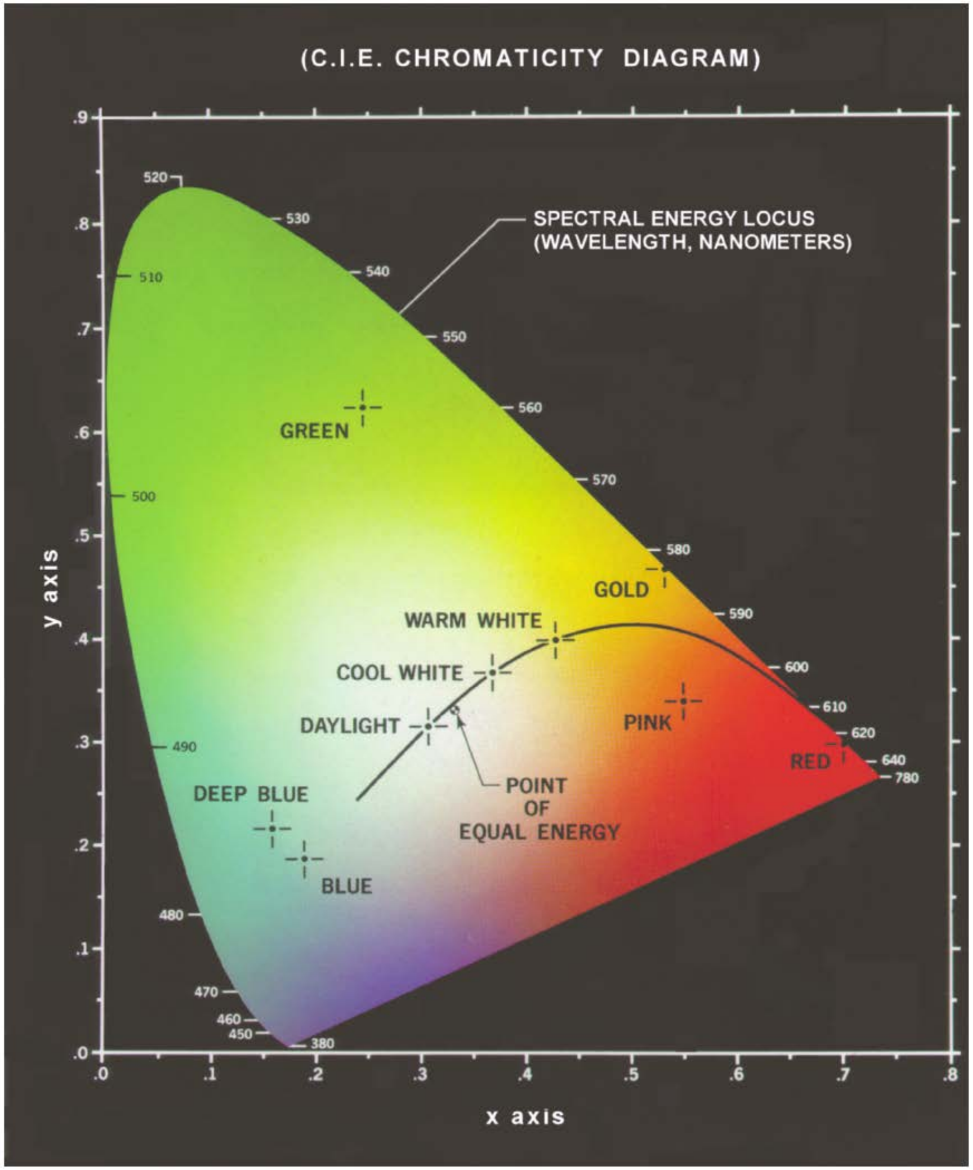


FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)

RGB Color Model

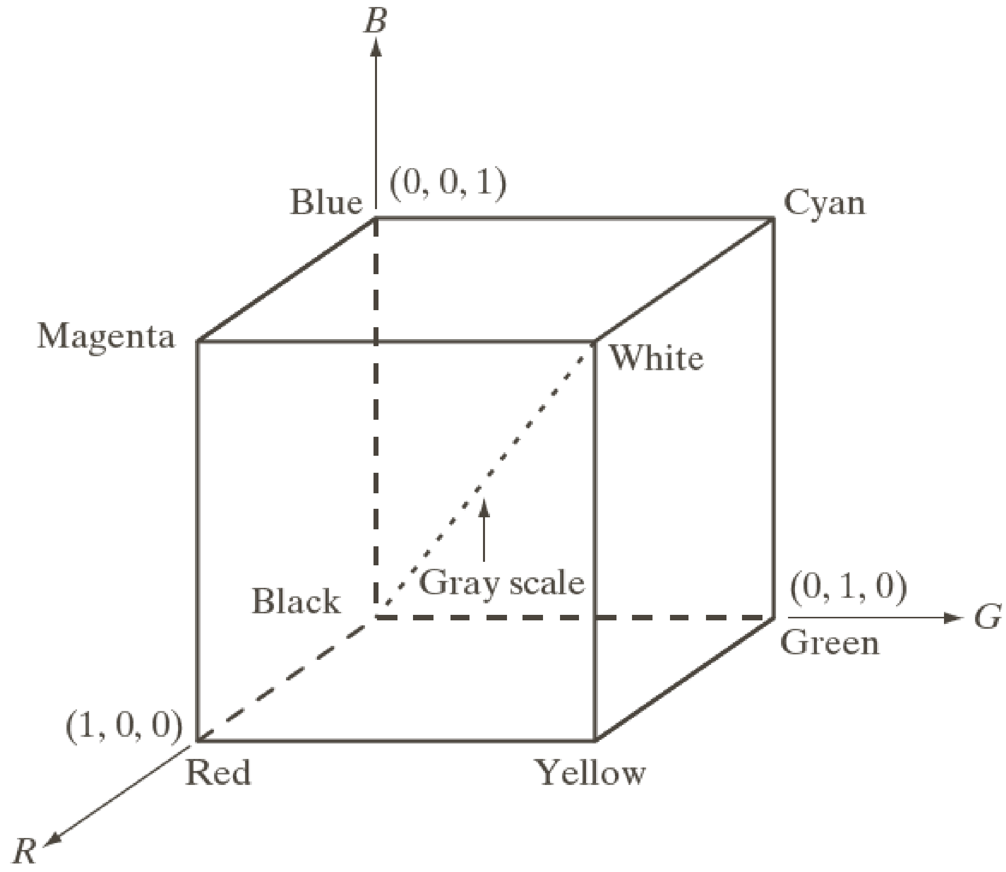


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

RGB Color Model

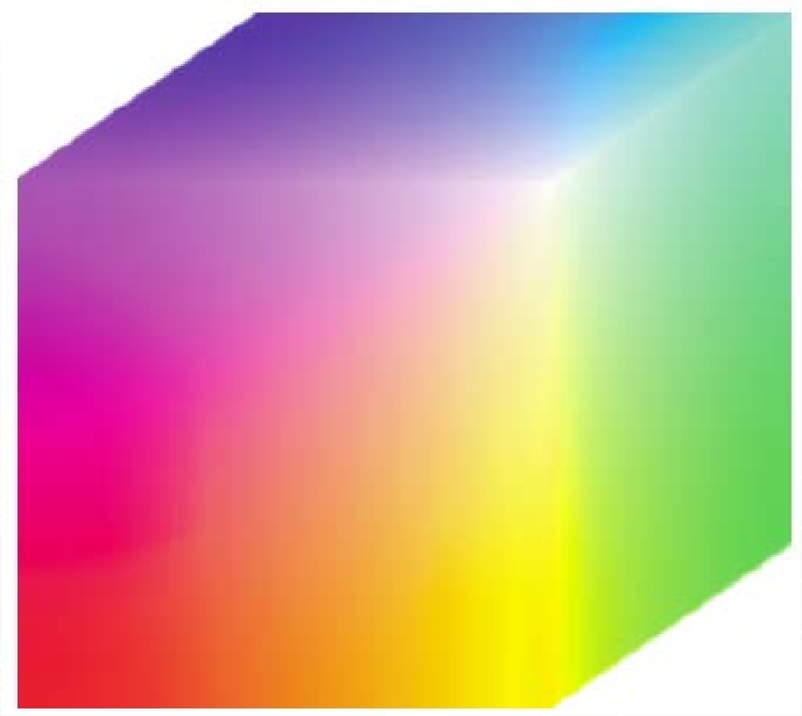


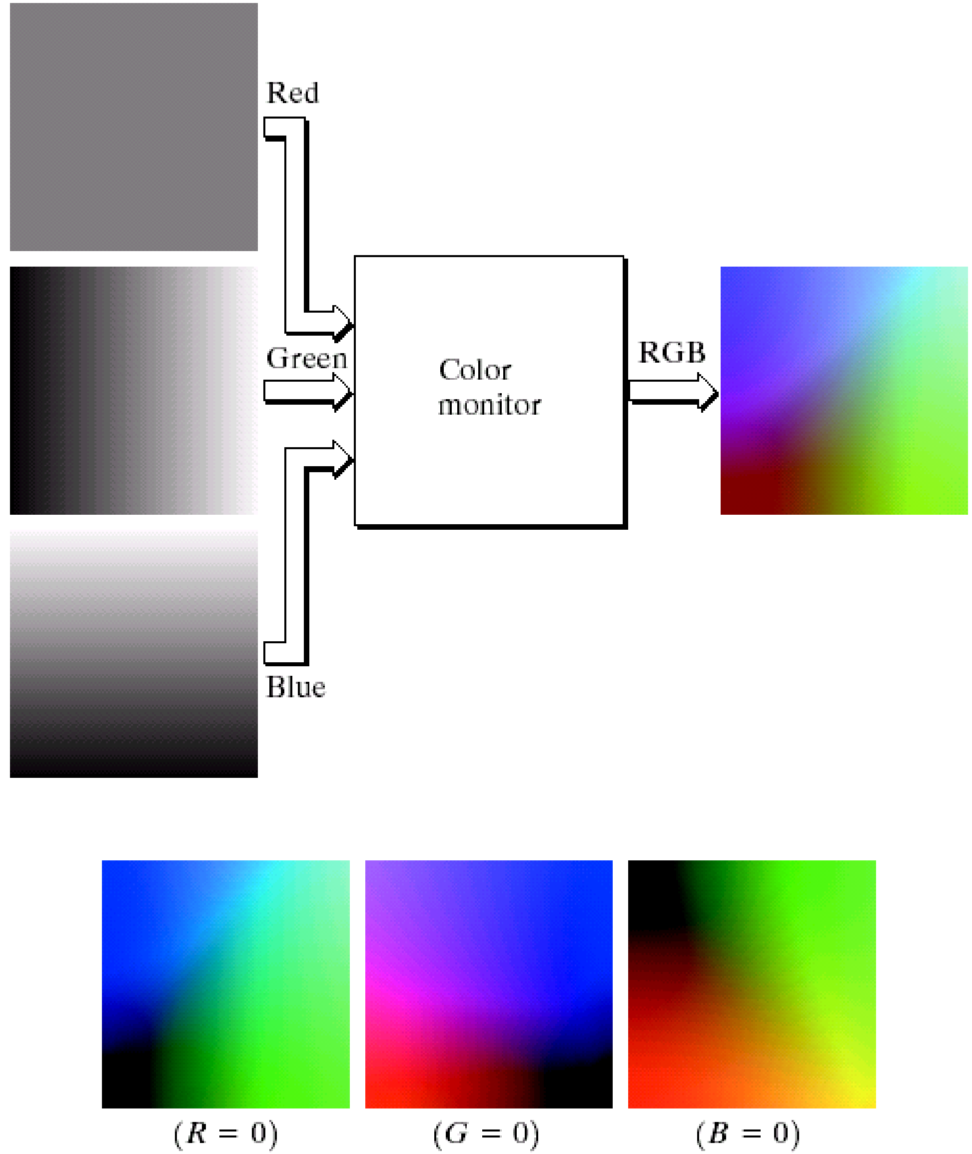
FIGURE 6.8 RGB 24-bit color cube.

Pixel depth

The total number of colors in a 24-bit RGB image is $(2^8)^3$ = 16,777,216

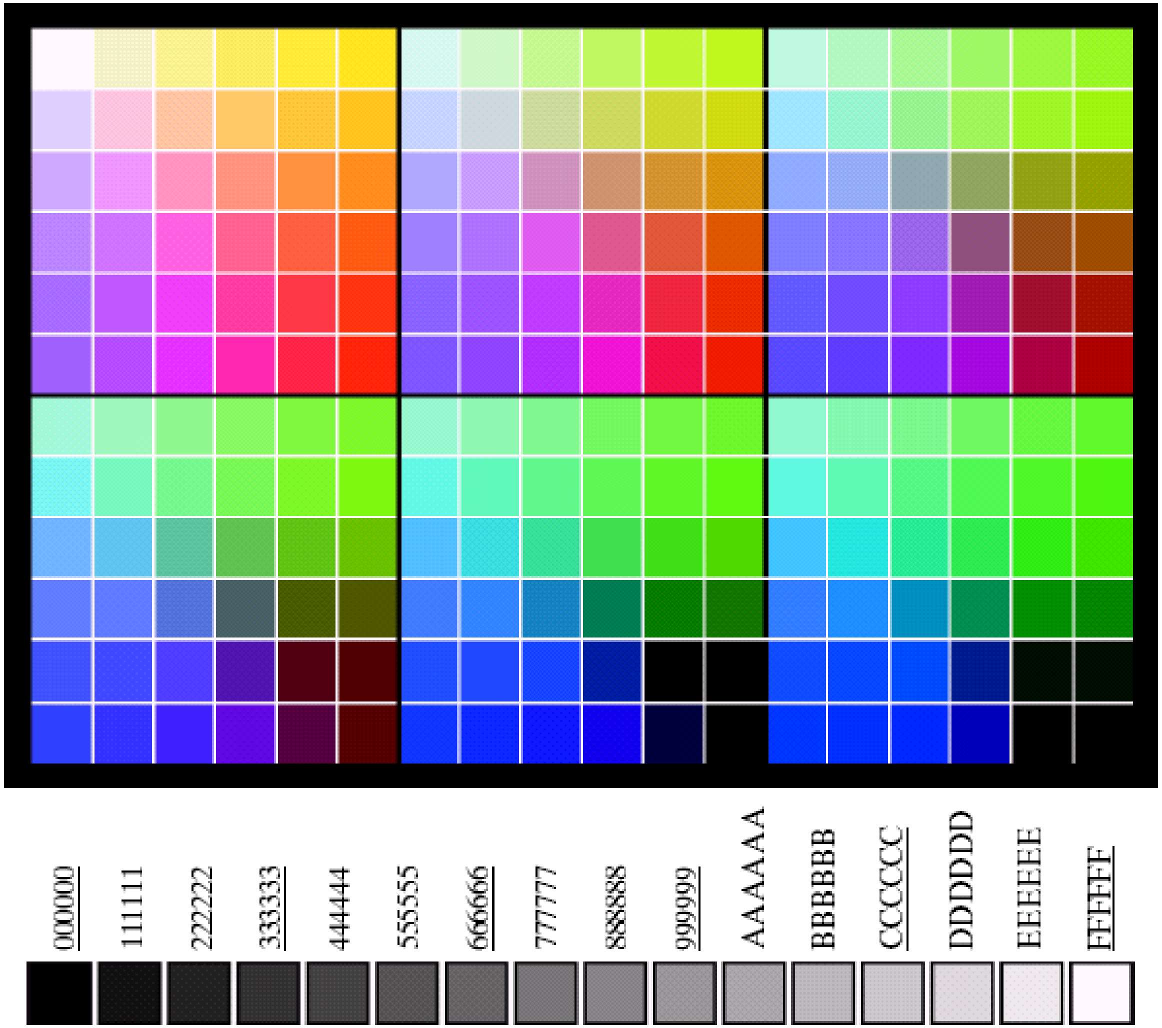
a
b

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.



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.



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).

Safe RGB colors (or **safe Web colors**) are reproduced faithfully, reasonably independently of viewer hardware capabilities

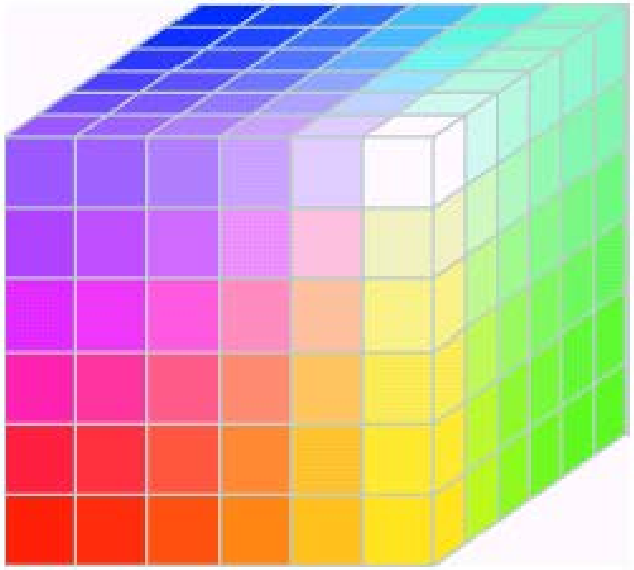


FIGURE 6.11 The RGB safe-color cube.

The CMY and CMYK Color Models

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

Equal amounts of the pigment primaries, cyan, magenta, and yellow should produce black. In practice, combining these colors for printing produces a muddy-looking black.

To produce true black, the predominant color in printing, the fourth color, black, is added, giving rise to the CMYK color model.

CMY vs. CMYK

http://en.wikipedia.org/wiki/CMYK

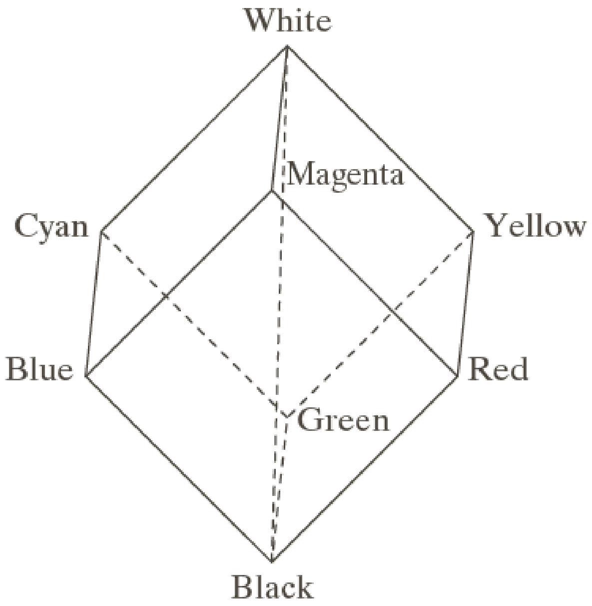
HSI Color Model

brightness: the achromatic notion of **intensity**.

hue: dominant wavelength in a mixture of light waves, represents dominant color as perceived by an observer.

saturation: relative purity or the amount of white light mixed with its hue.

HSI Color Model



a b

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

HSI Color Model

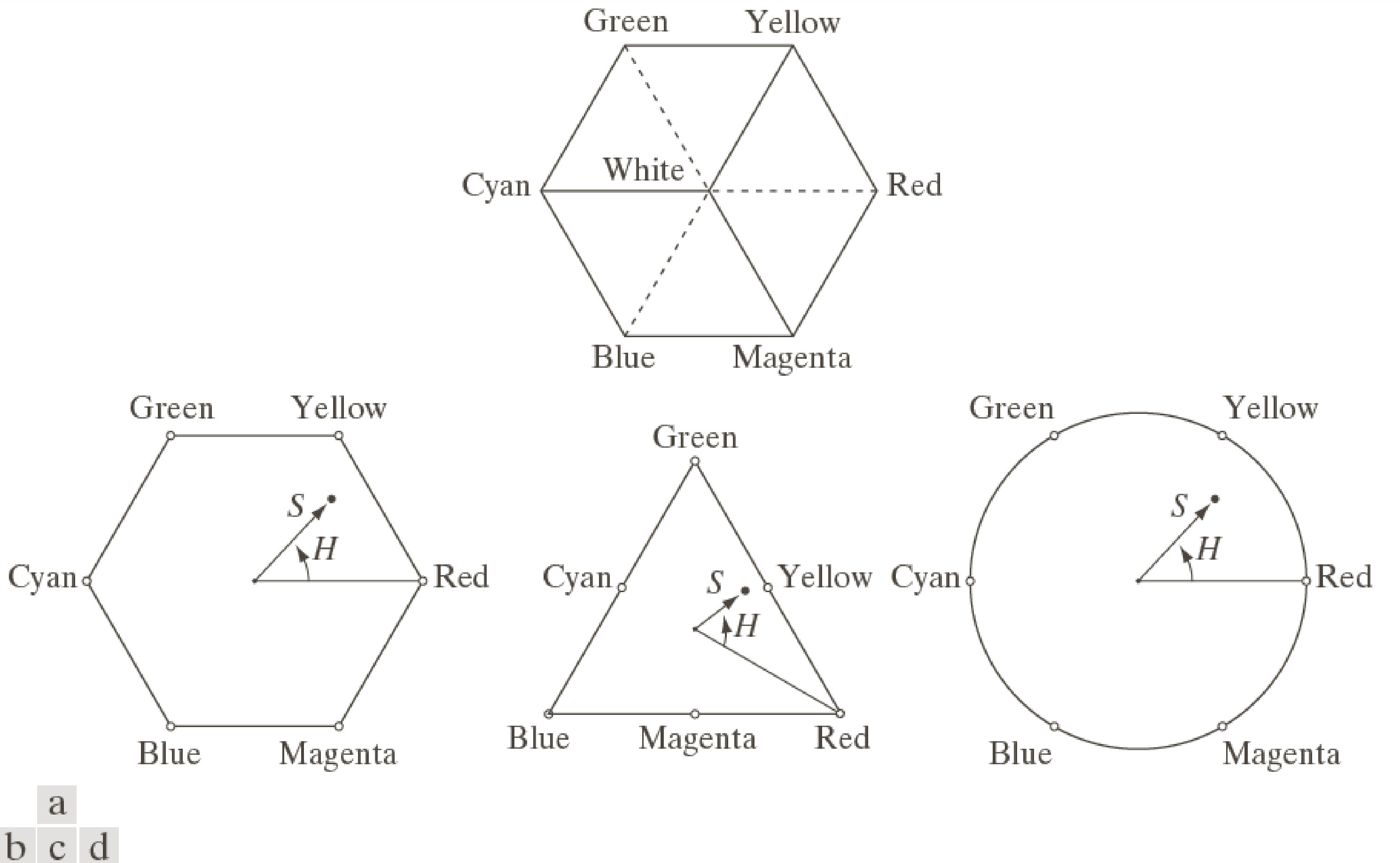
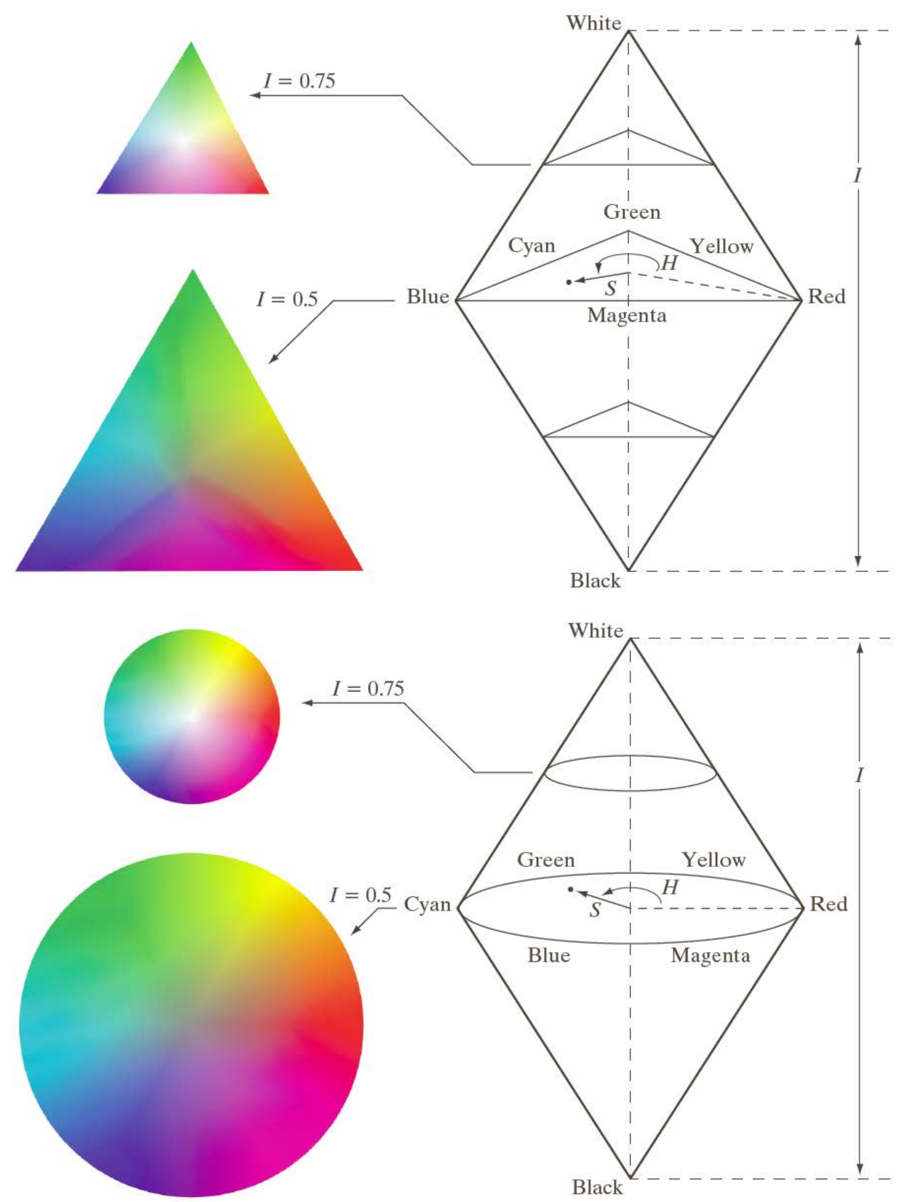


FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

HSI Color Model



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.

Converting Colors from RGB to HSI

- Given an image in RGB color format, the H component of each RGB pixel is obtained using the equation

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

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

Converting Colors from RGB to HSI

- Given an image in RGB color format, the saturation component is given by

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

Converting Colors from RGB to HSI

- Given an image in RGB color format, the intensity component is given by

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

Converting Colors from HSI to RGB

- RG sector $(0^\circ \le H < 120^\circ)$

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

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

and

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

Converting Colors from HSI to RGB

- RG sector $(120^\circ \le H < 240^\circ)$

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

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

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

and

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

Converting Colors from HSI to RGB

- RG sector $(240^\circ \le H \le 360^\circ)$

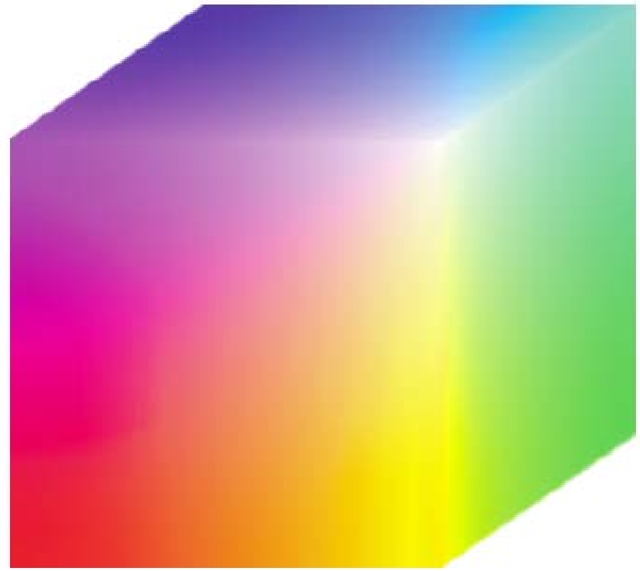
$$H = H - 240^\circ$$

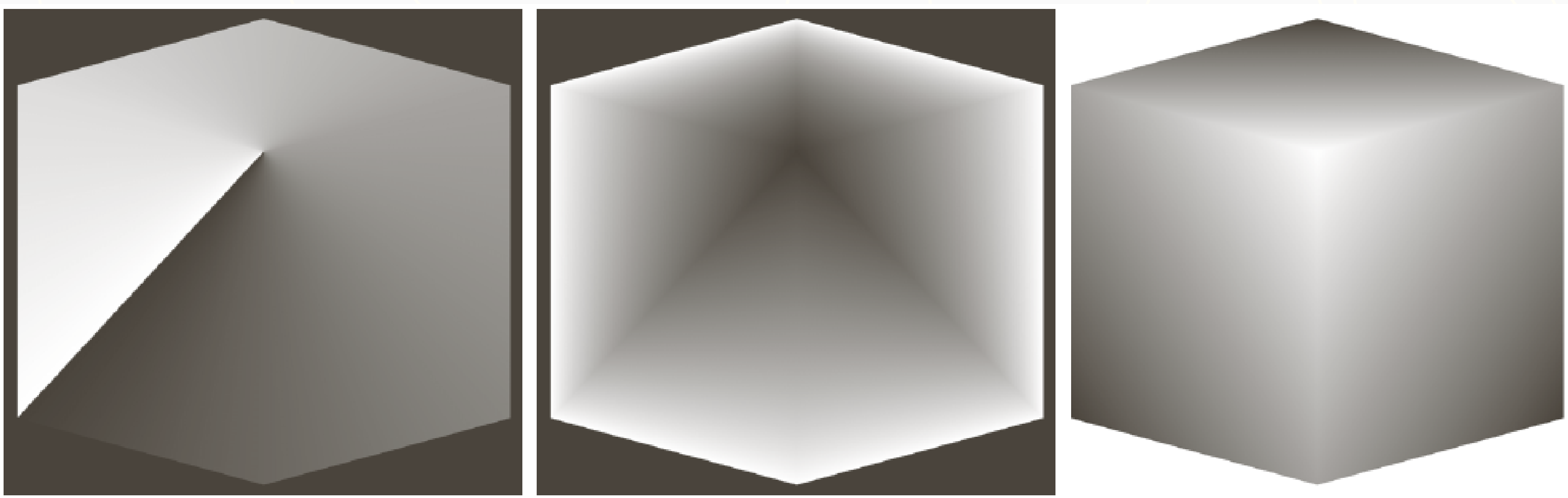
$$G = I(1 - S)$$

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

and

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





a b c

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

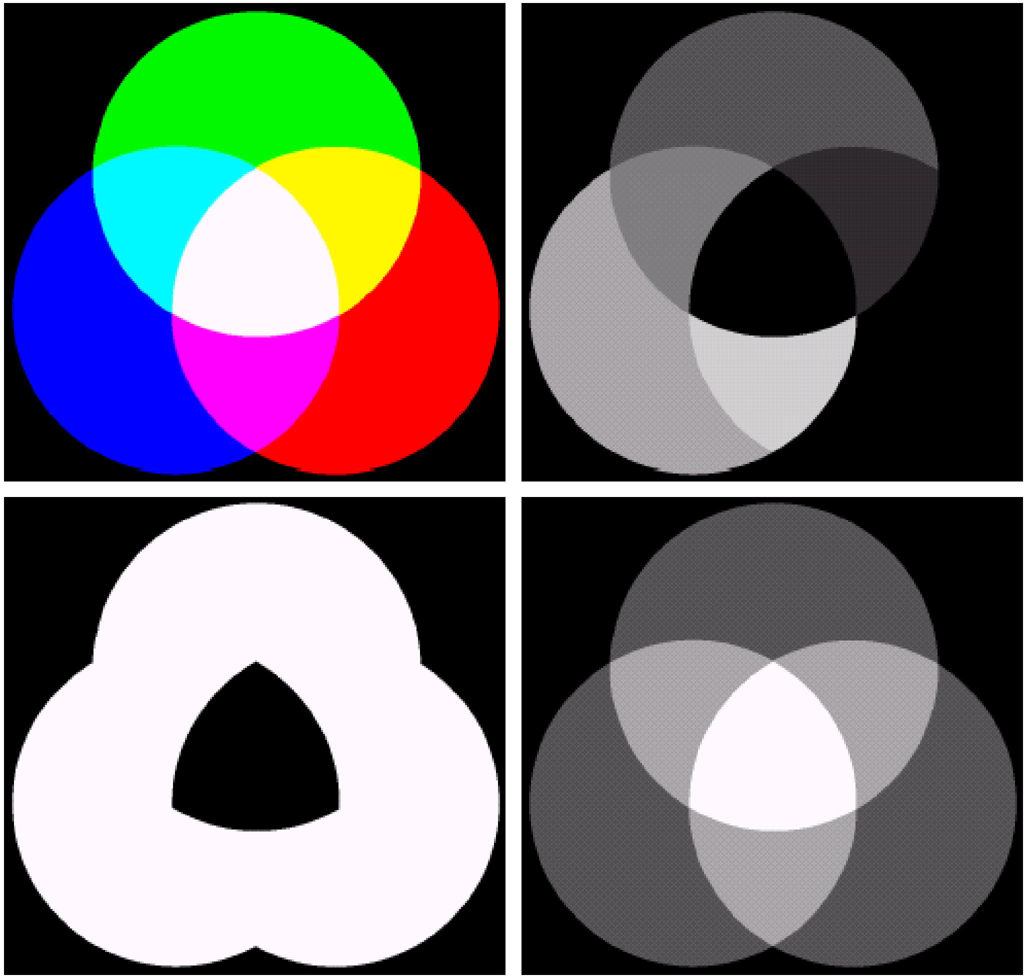
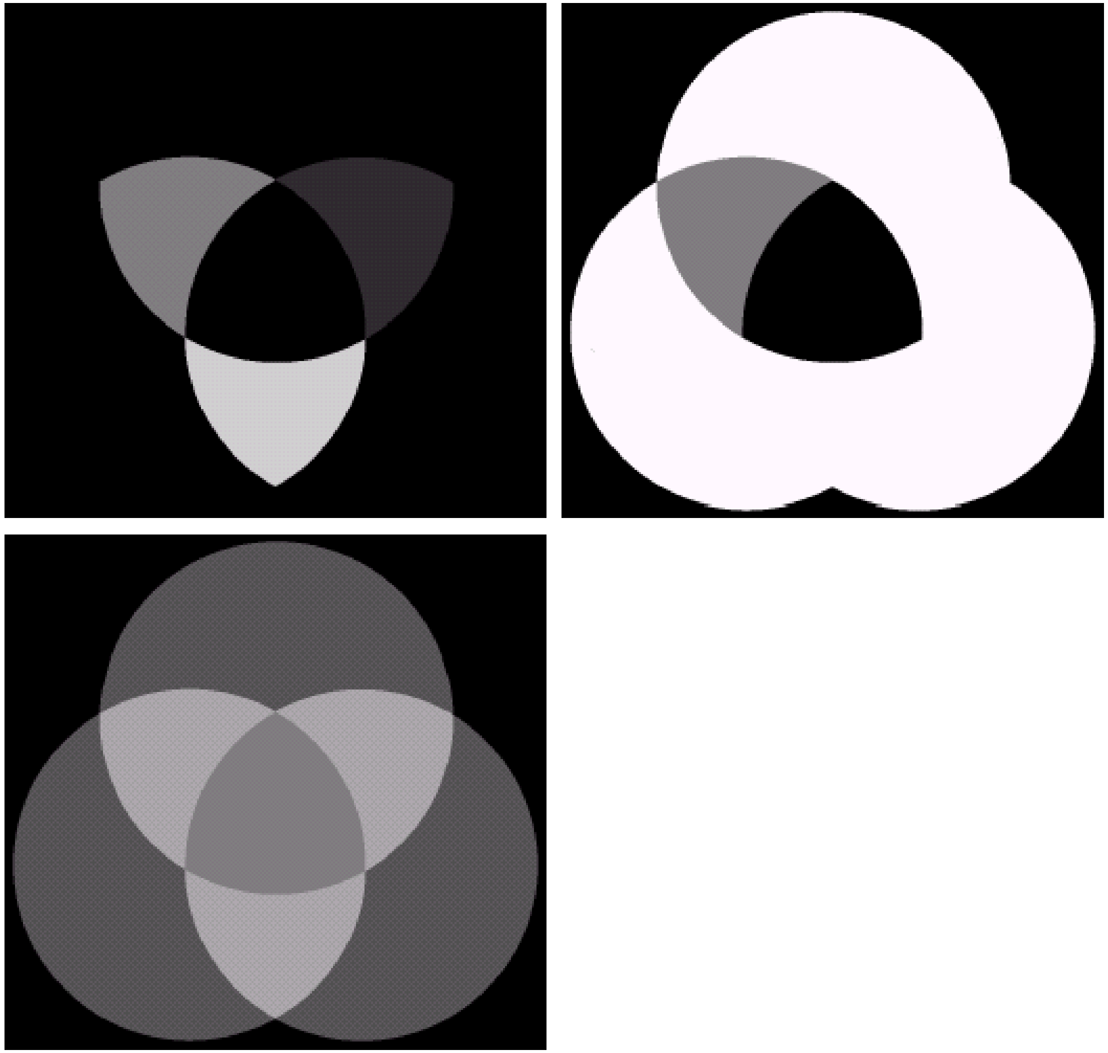


FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.



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.)

Pseudocolor Image Processing

- The process of assigning colors to gray values based on a specified criterion.

- Intensity Slicing

$$f(x,y) = c_k \qquad \text{if } f(x,y) \in V_k$$

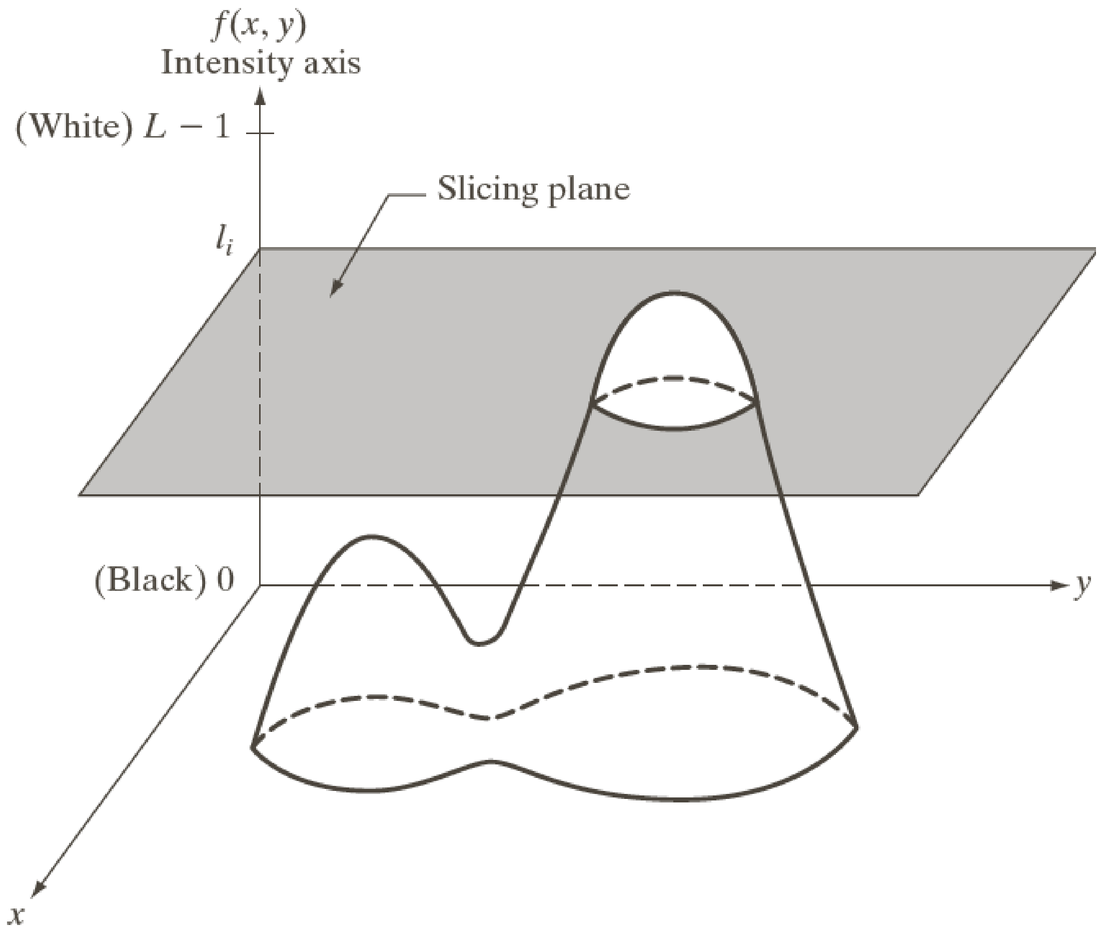


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

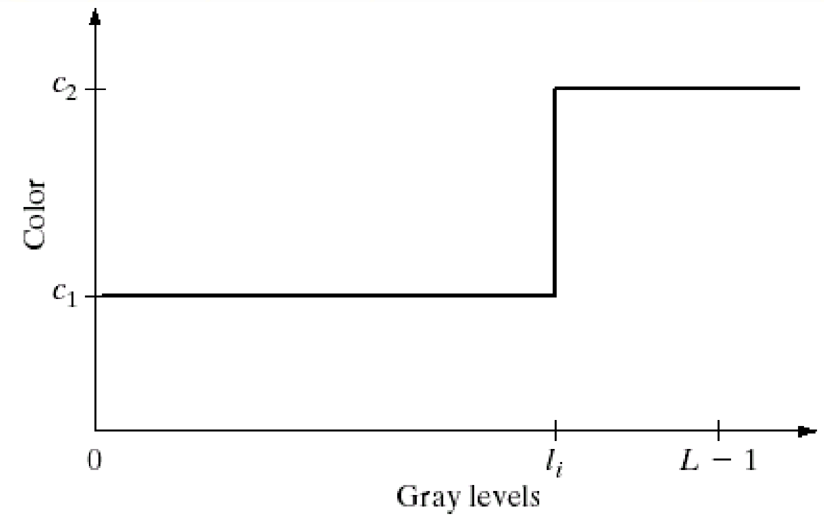
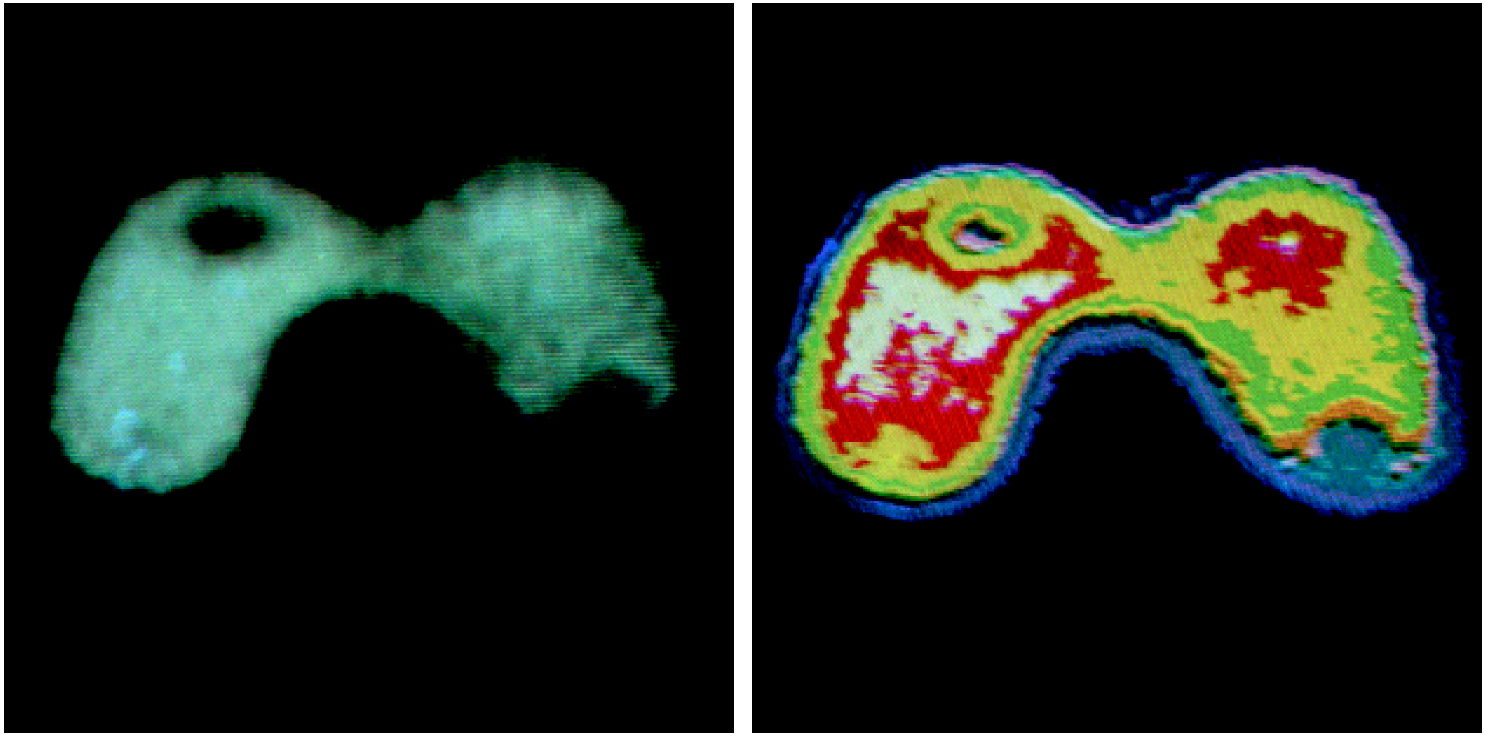


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

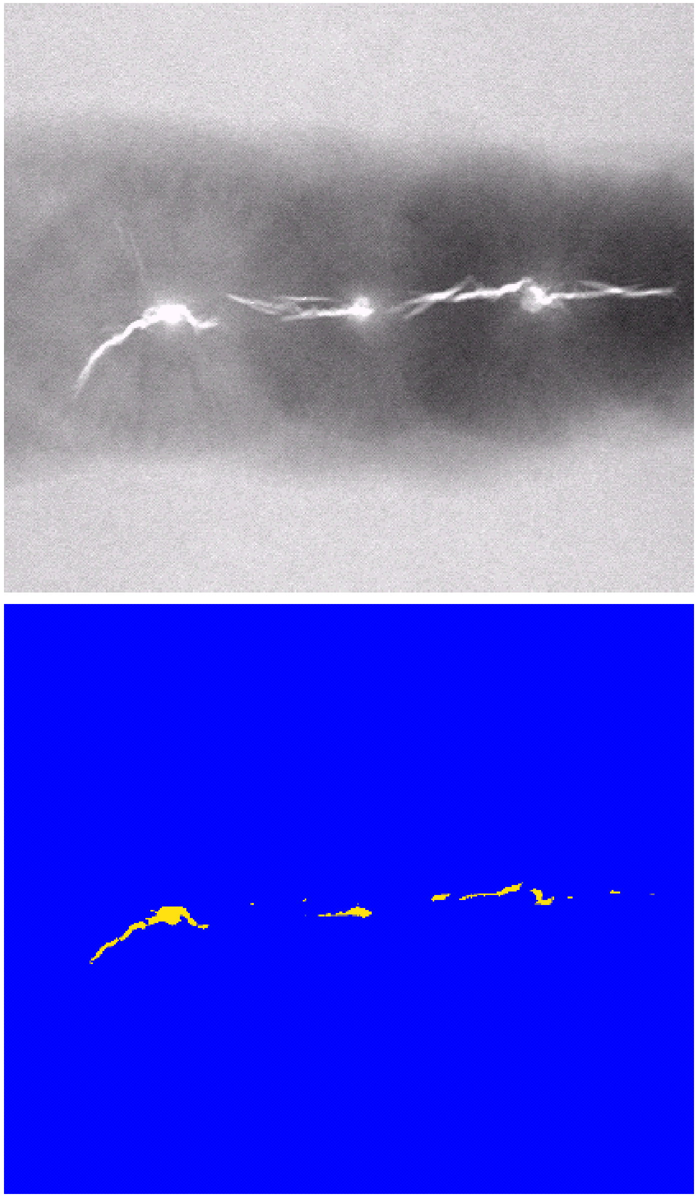


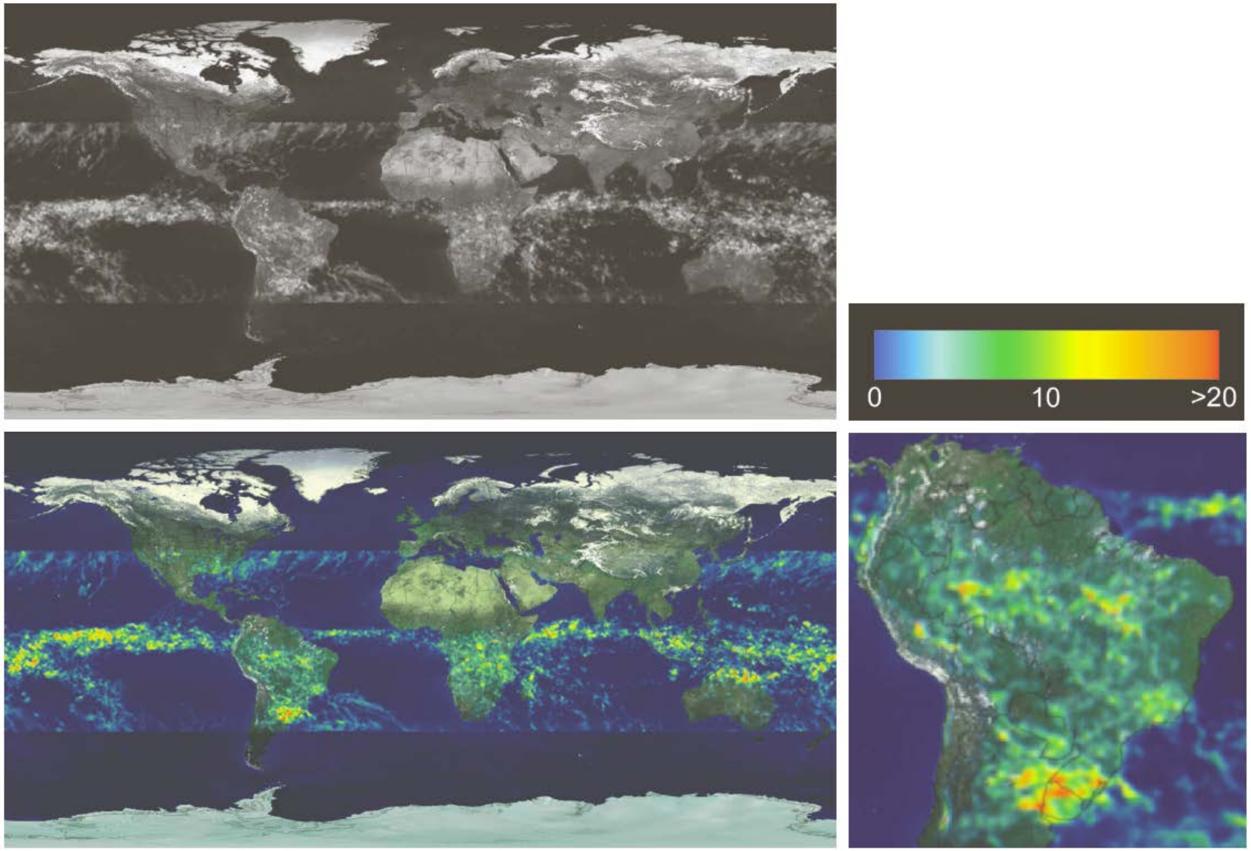
a b

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.)





a b
c d

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.)

Pseudocolor Image Processing

- Intensity to Color Transformation

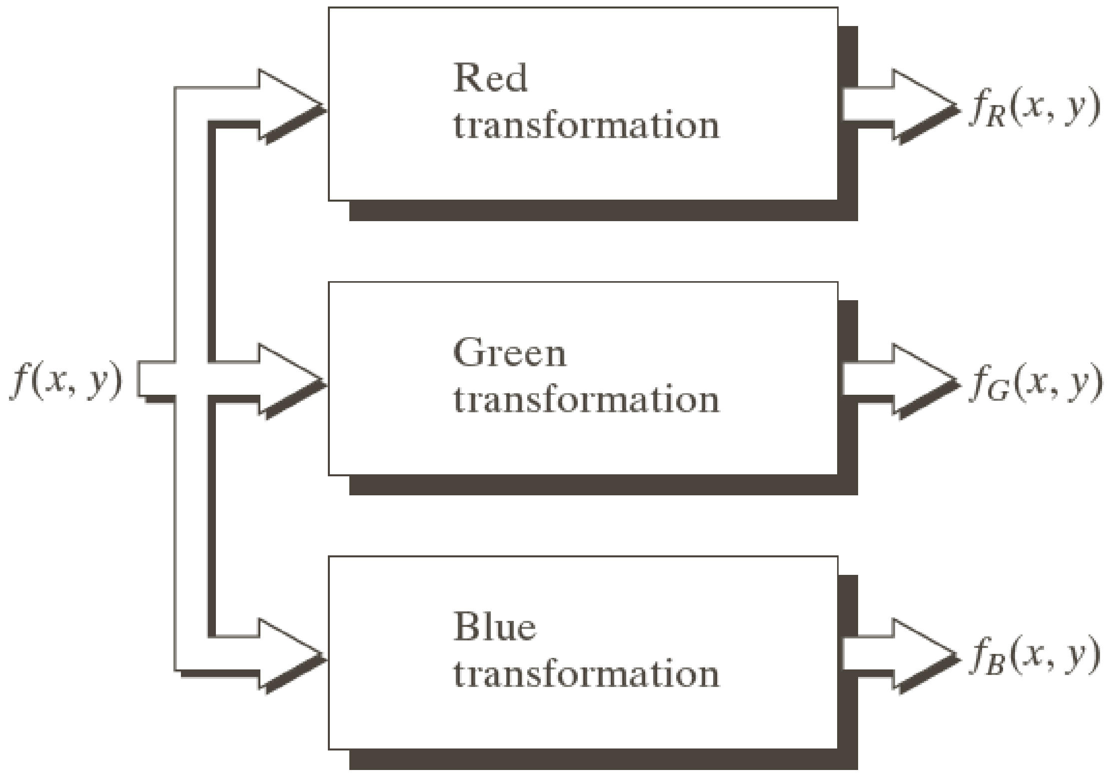
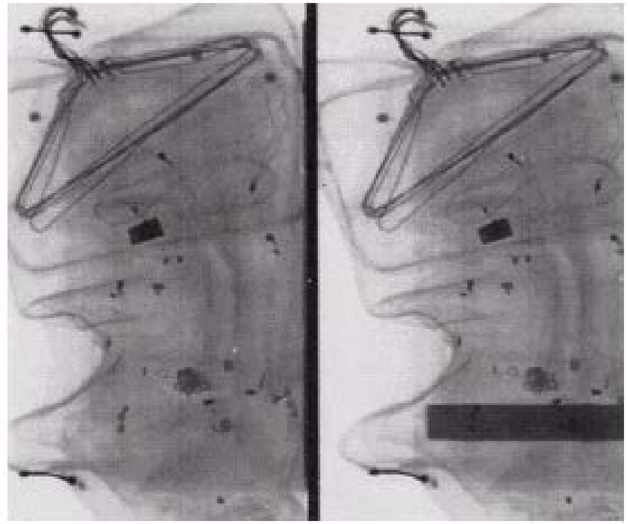


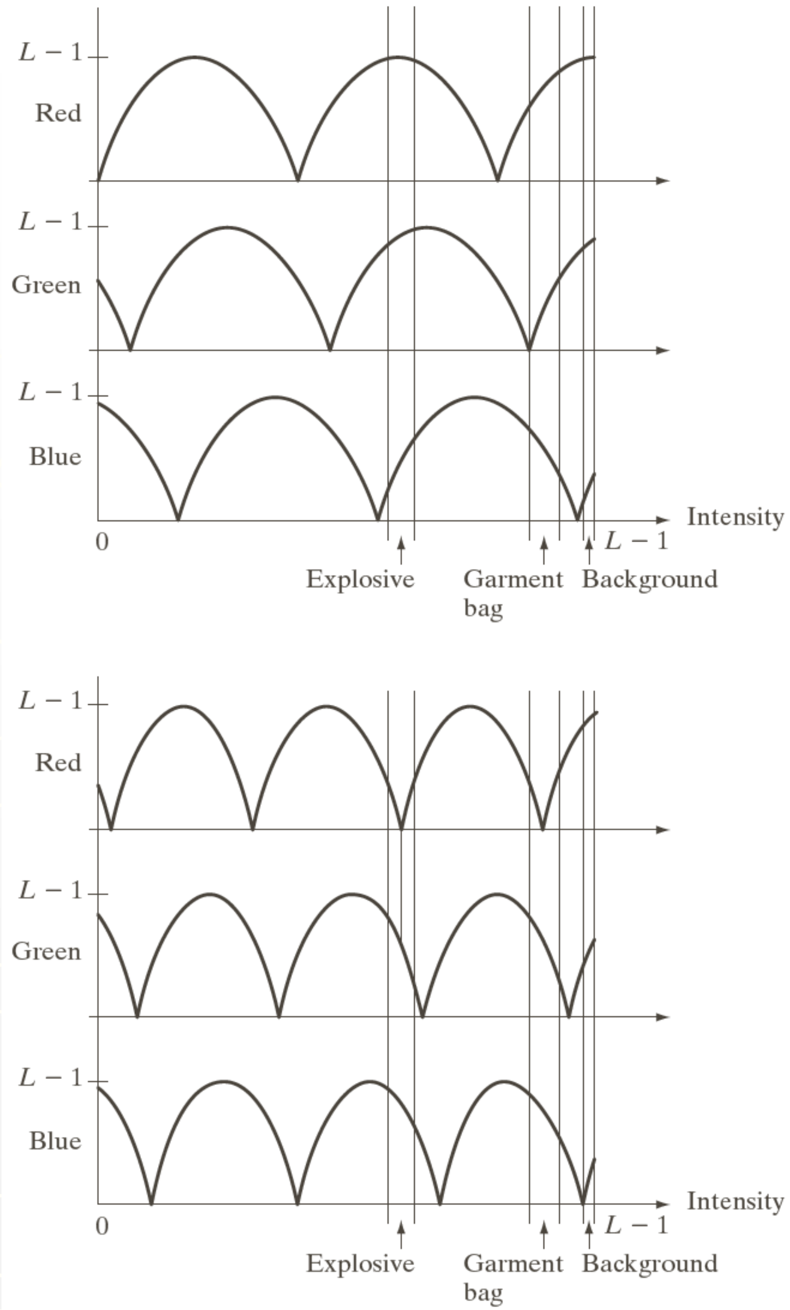
FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

The images are obtained from an airport X-ray scanning system.
The left contains ordinary articles and the right contains the same articles as well as a block of simulated plastic explosives.



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.

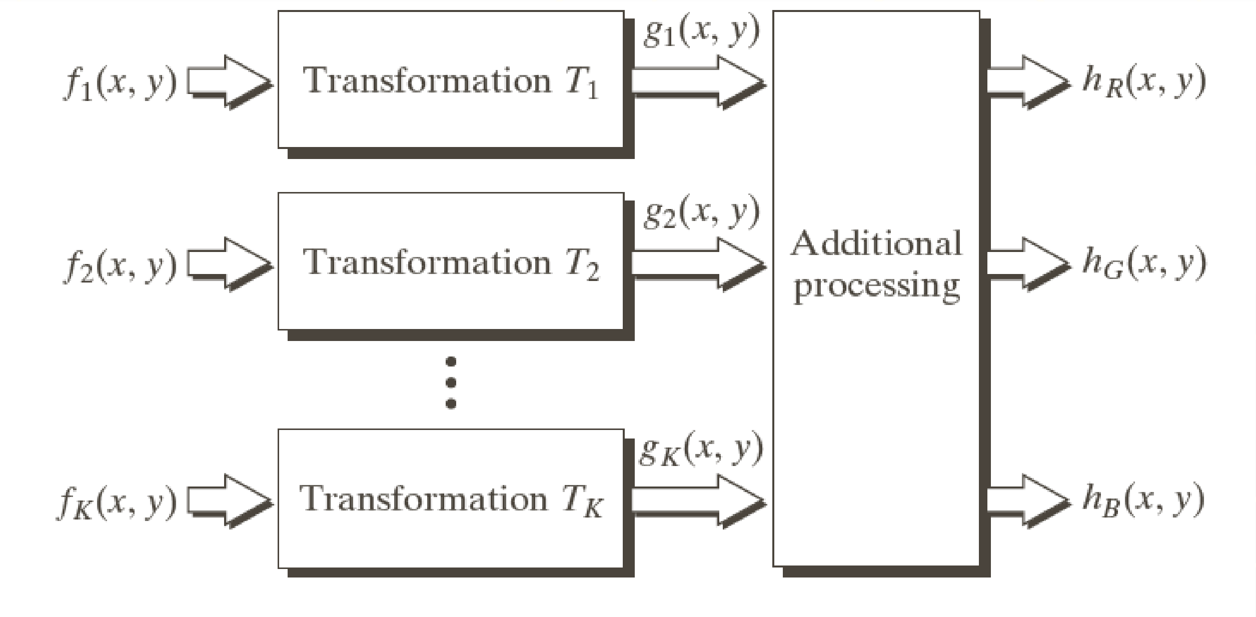


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

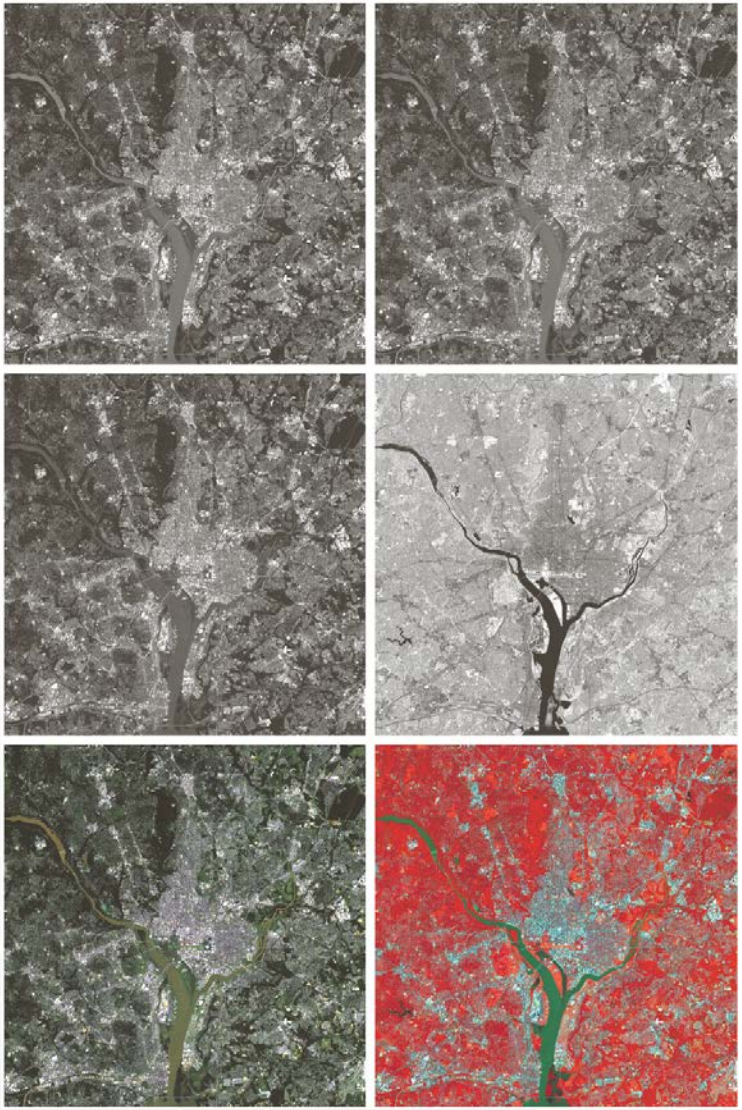
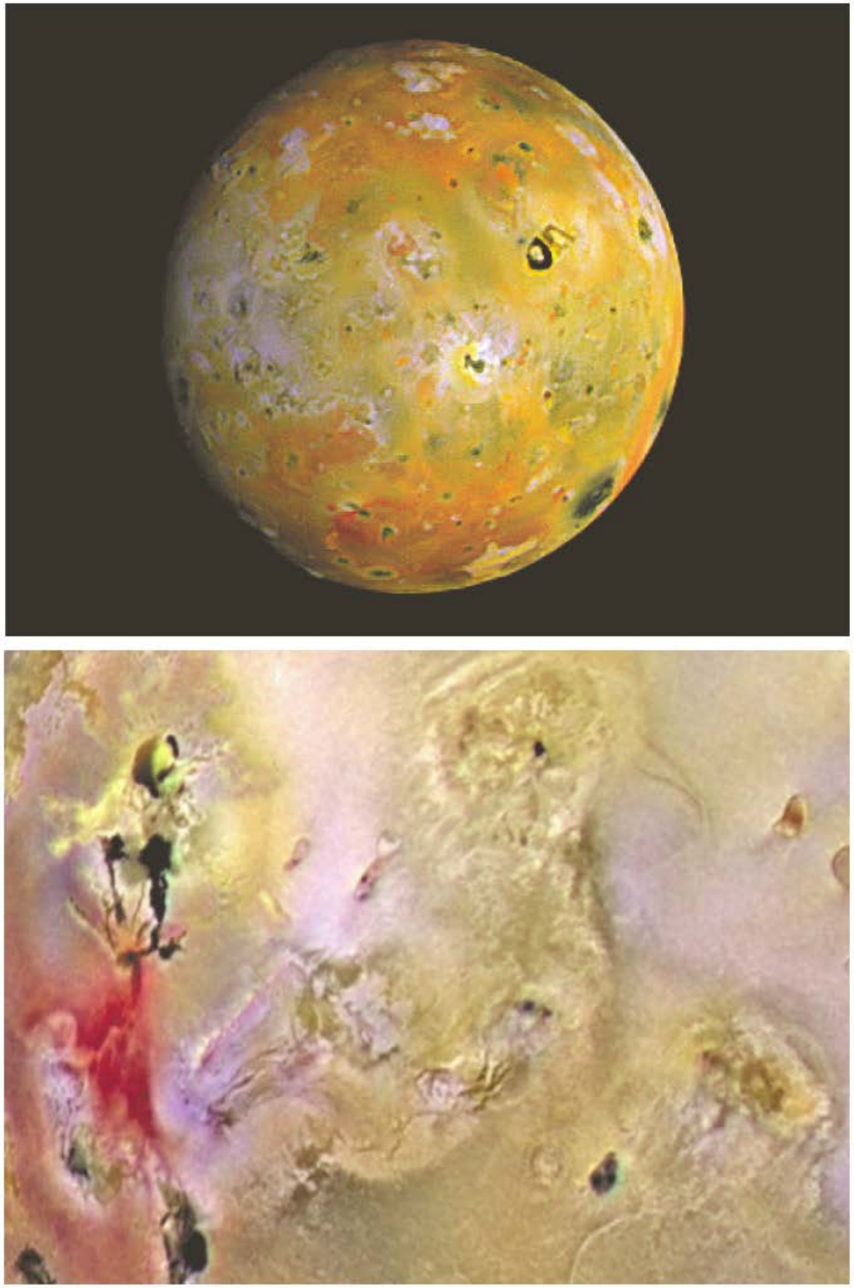


FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral images courtesy of NASA.)

a b
c d
e f

Pseudocolor by combining several of the sensor images from the Galileo spacecraft, some of which are in spectral regions not visible to the eye.

Bright red depicts materials newly ejected from an active volcano on Io, and the surrounding yellow materials are older sulfur deposits.



a
b

FIGURE 6.28
(a) Pseudocolor rendition of Jupiter Moon Io. (b) A close-up. (Courtesy of NASA.)

Basics of Full-Color Image Processing

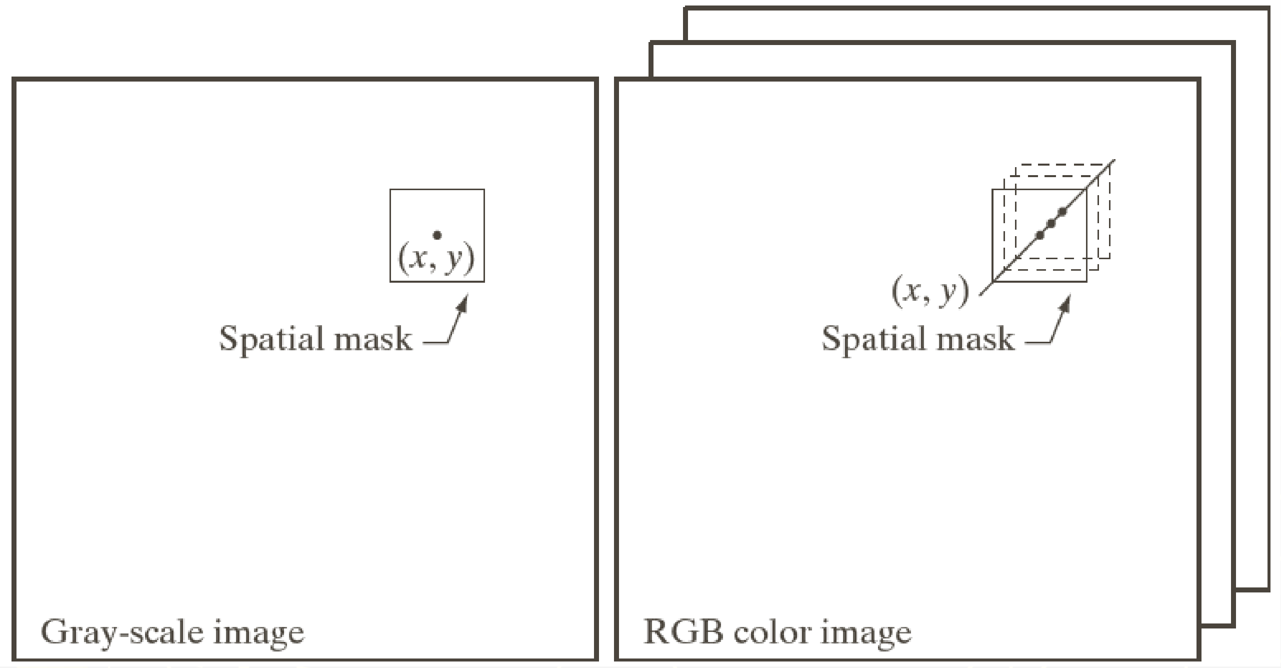
Let c represent an arbitrary vector in RGB color space:

$$c = \begin{bmatrix} c_R \\ c_G \\ c_B \end{bmatrix} = \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

At coordinates (x, y),

$$c(x, y) = \begin{bmatrix} c_R(x, y) \\ c_G(x, y) \\ c_B(x, y) \end{bmatrix} = \begin{bmatrix} R(x, y) \\ G(x, y) \\ B(x, y) \end{bmatrix}$$

Basics of Full-Color Image Processing



a b

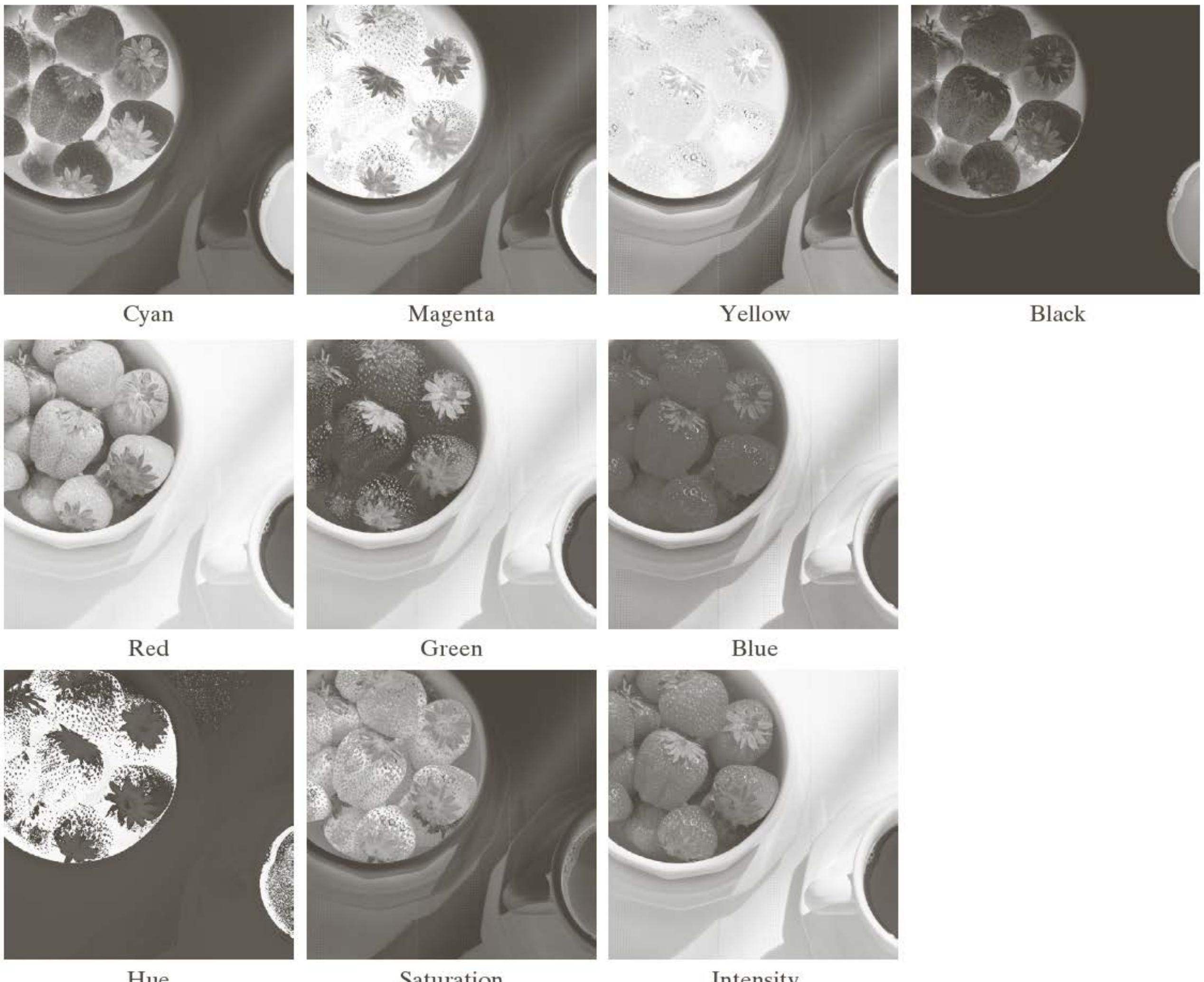
FIGURE 6.29 Spatial masks for gray-scale and RGB color images.

Color Transformations

$$g(x, y) = T\left[f(x, y) \right]$$

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

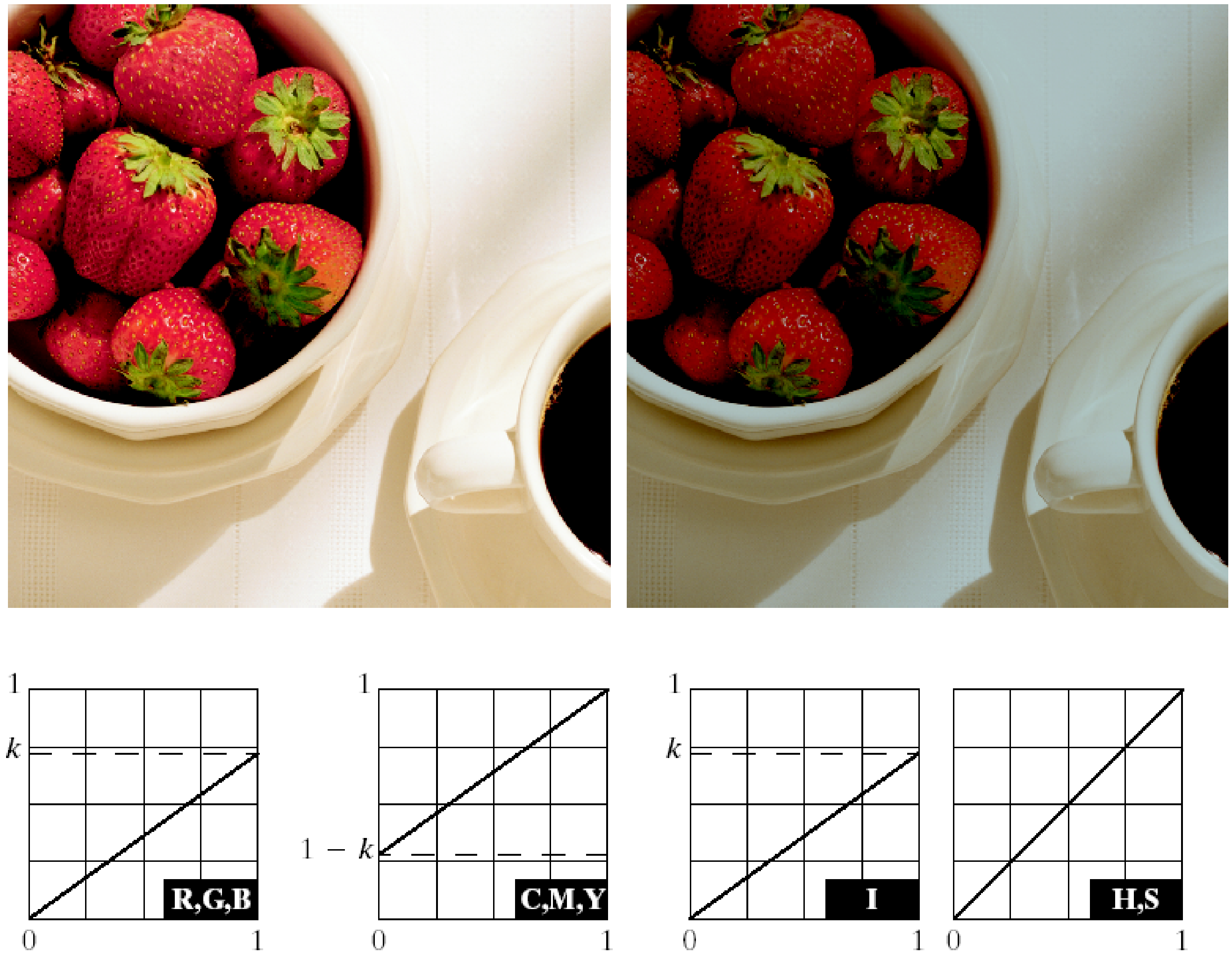
FIGURE 6.30 A full-color image and its various color-space components. Interactive.)



$$g(x,y) = kf(x,y)$$

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.)



$$s_i = kr_i, \quad i = 1, 2, 3.$$

$$s_i = kr_i + (1-k), \quad i = 1, 2, 3.$$

$$s_3 = kr_3$$

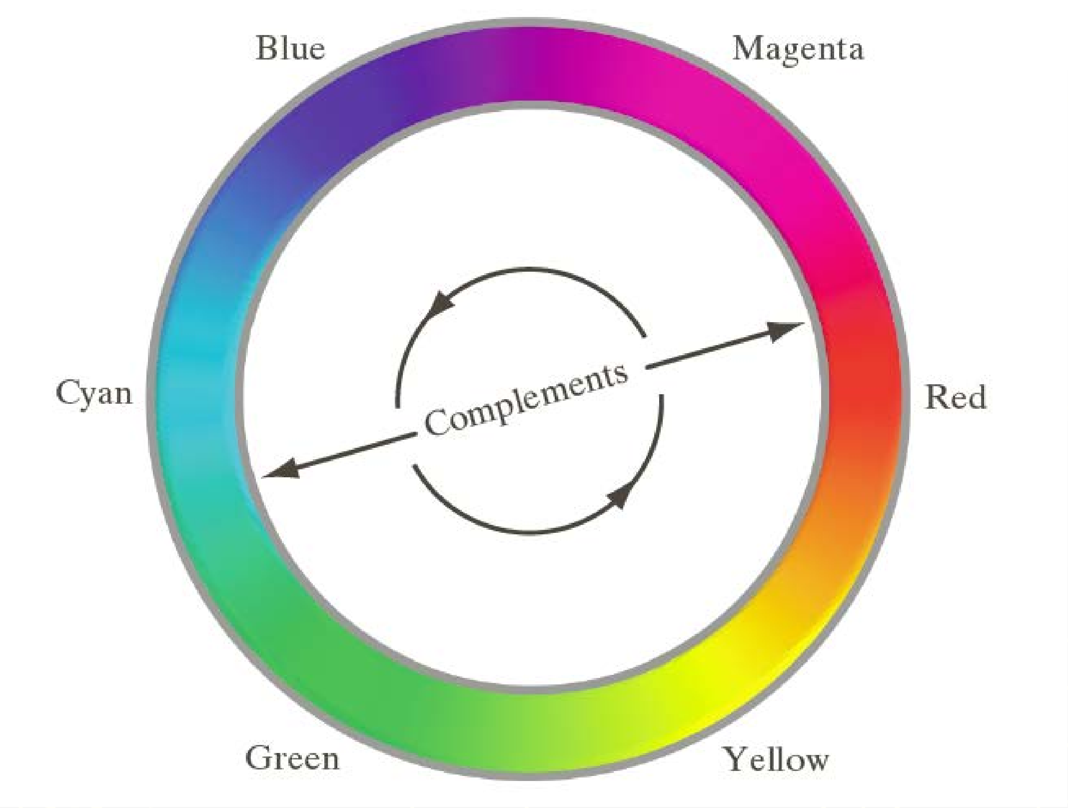
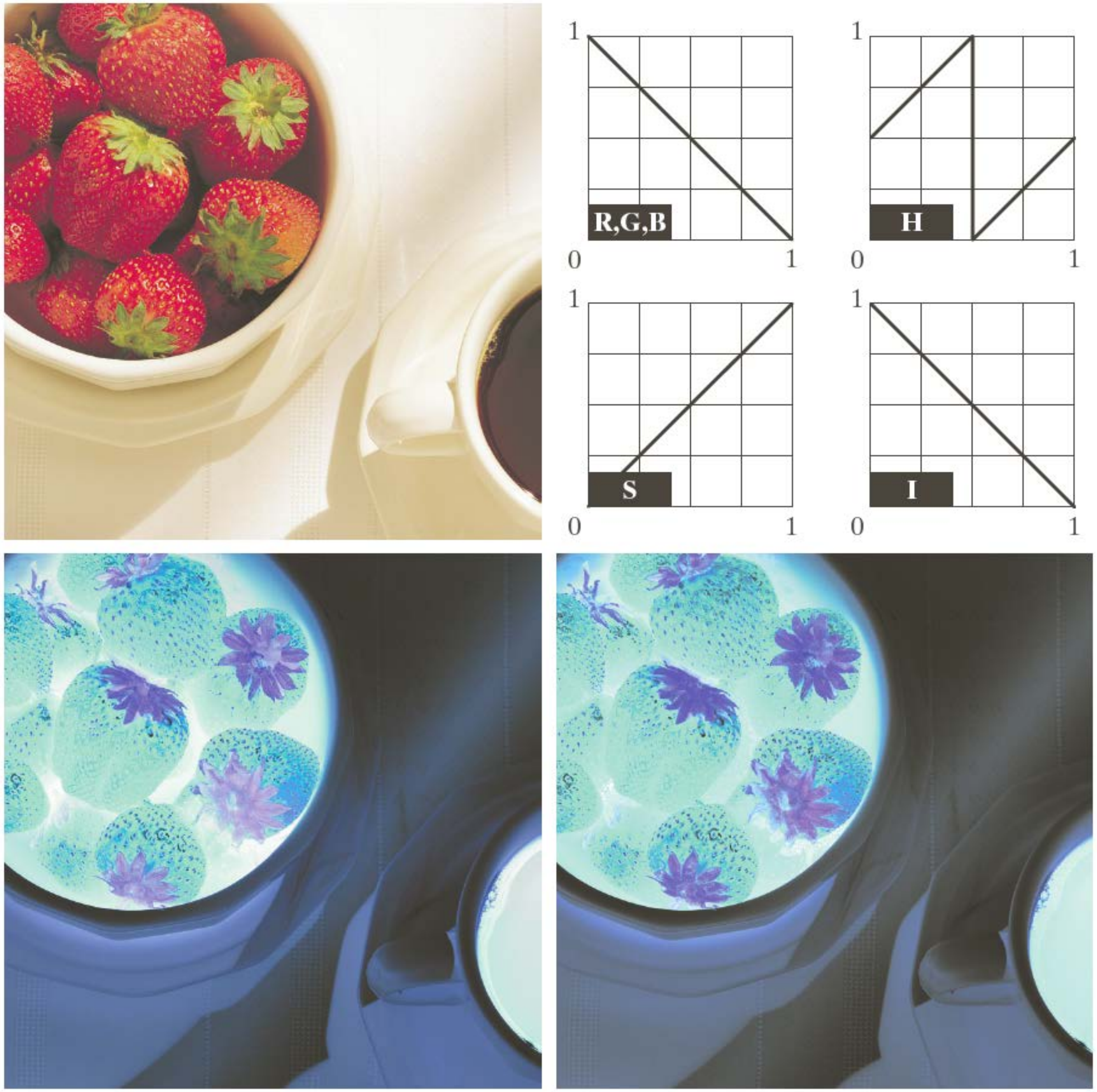


FIGURE 6.32 Complements on the color circle.



a b
c d

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

- Highlighting a specific range of colors in an image

If the colors of interest are enclosed by a cube of width W and centered at a protypical color with components $(a_1, a_2, \ldots, a_n)$, the necessary set of transformations is

$$s_i = \begin{cases} 0.5 & \text{if } \left[|r_j - a_j| > W/2 \right]_{\text{any } 1 \le j \le n} \\ r_i & \text{otherwise} \end{cases}$$

Color slicing

If a sphere is used to specify the colors of interest,

R_0 is the radius of the enclosing of its center.

The transformations is

$$s_i = \begin{cases} 0.5 & \text{if } \sum_{j=1}^{n} \left(r_j - a_j\right)^2 > R_0^2 \\ r_i & \text{otherwise} \end{cases}$$

Color slicing

a b

FIGURE 6.34 Color-slicing transformations that detect (a) reds within an RGB cube of width $W = 0.2549$ centered at (0.6863, 0.1608, 0.1922), and (b) reds within an RGB sphere of radius 0.1765 centered at the same point. Pixels outside the cube and sphere were replaced by color (0.5, 0.5, 0.5).

Tone and Color Corrections

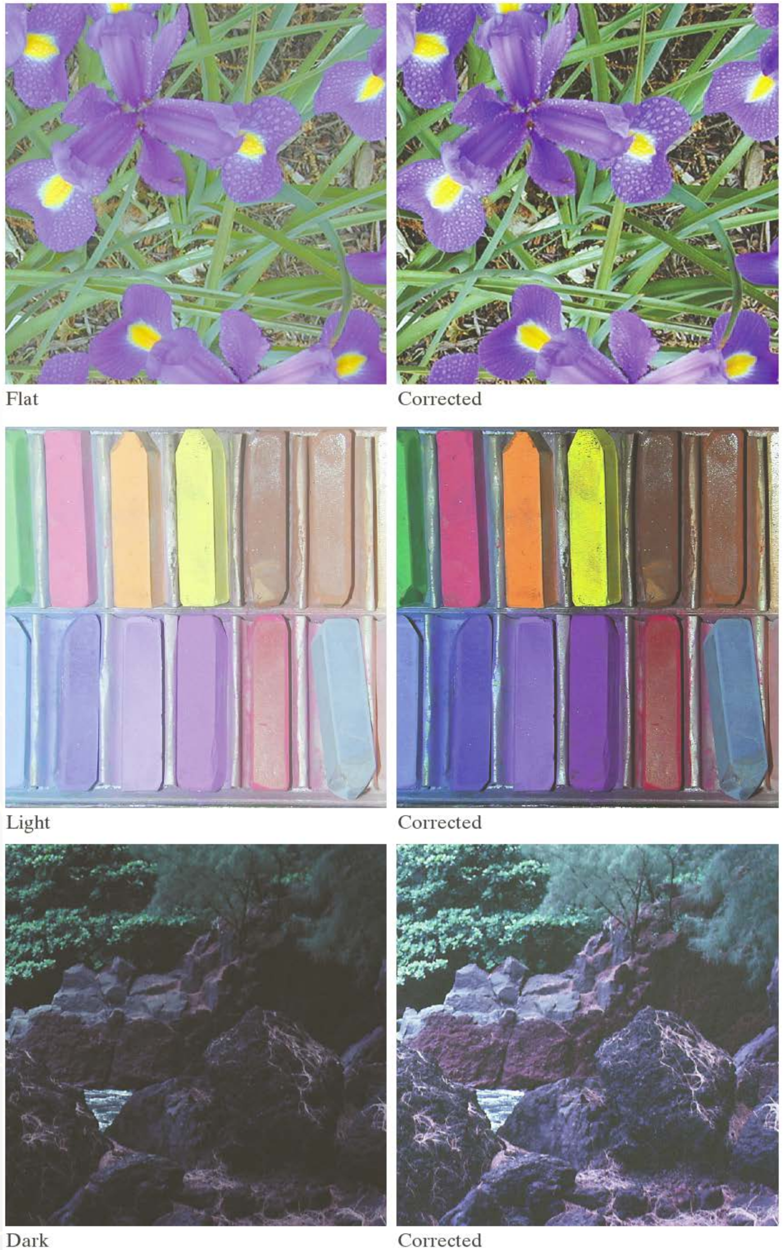
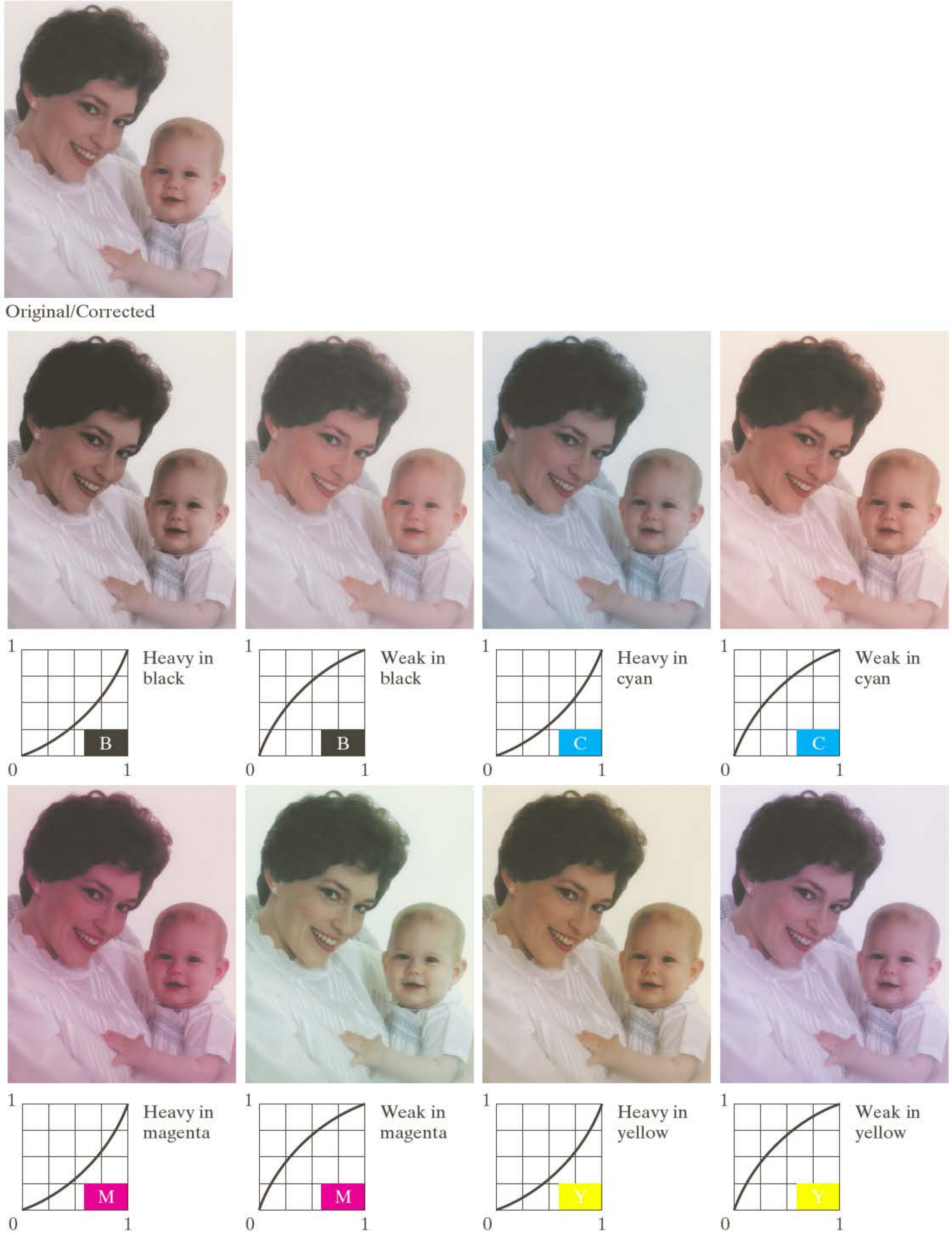
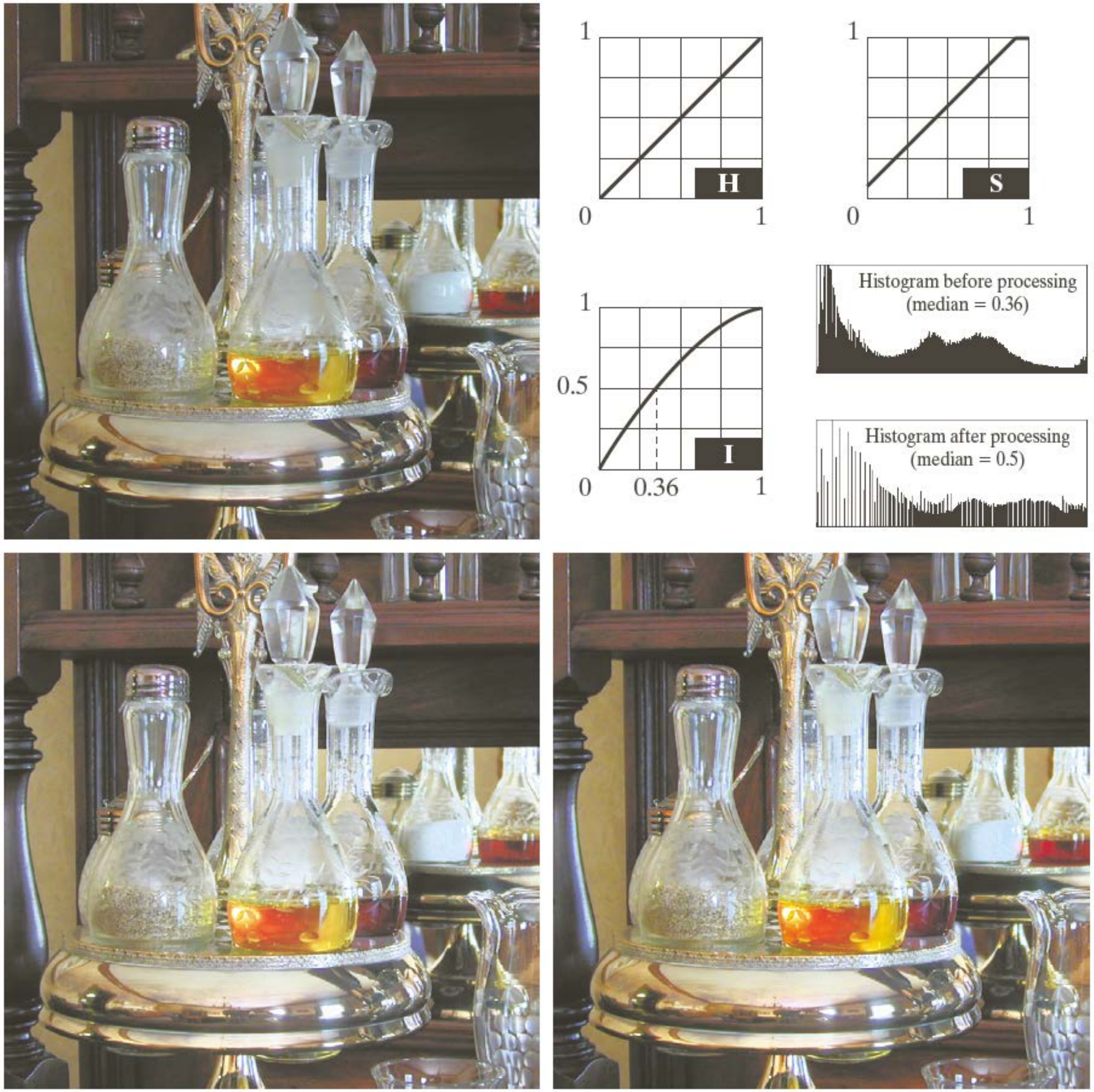


FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.


Original/Corrected
Heavy in black
Weak in black
Heavy in cyan
Weak in cyan
Heavy in magenta
Weak in magenta
Heavy in yellow
Weak in yellow
B
C
M
Y
0
1



a b
c d

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

Color Image Smoothing

Let S_{xy} denote the set of coordinates defining a neighborhood centered at (x, y) in an RGB color image. The average of the RGB component vectors in this neighborhood is

$$\bar{c}(x,y) = \frac{1}{K}\sum_{(s,t)\in S_{xy}} c(s,t) = \begin{bmatrix} \frac{1}{K}\sum_{(s,t)\in S_{xy}} R(s,t) \\ \frac{1}{K}\sum_{(s,t)\in S_{xy}} G(s,t) \\ \frac{1}{K}\sum_{(s,t)\in S_{xy}} B(s,t) \end{bmatrix}$$

| a | b |
| c | d |

FIGURE 6.38 (a) RGB image. (b) Red component image. (c) Green component. (d) Blue component.

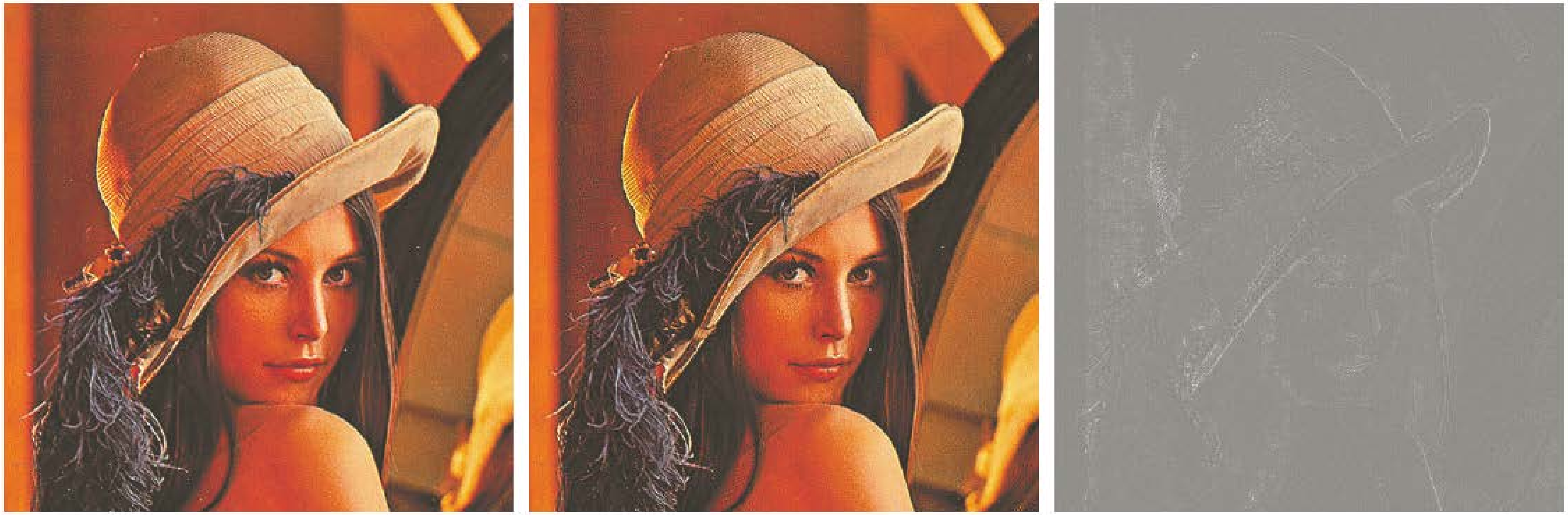
a b c

FIGURE 6.39 HSI components of the RGB color image in Fig. 6.38(a). (a) Hue. (b) Saturation. (c) Intensity.

Color Image Sharpening

The Laplacian of vector c is

$$\nabla^2\left[c(x,y)\right] = \begin{bmatrix} \nabla^2 R(x,y) \\ \nabla^2 G(x,y) \\ \nabla^2 B(x,y) \end{bmatrix}$$

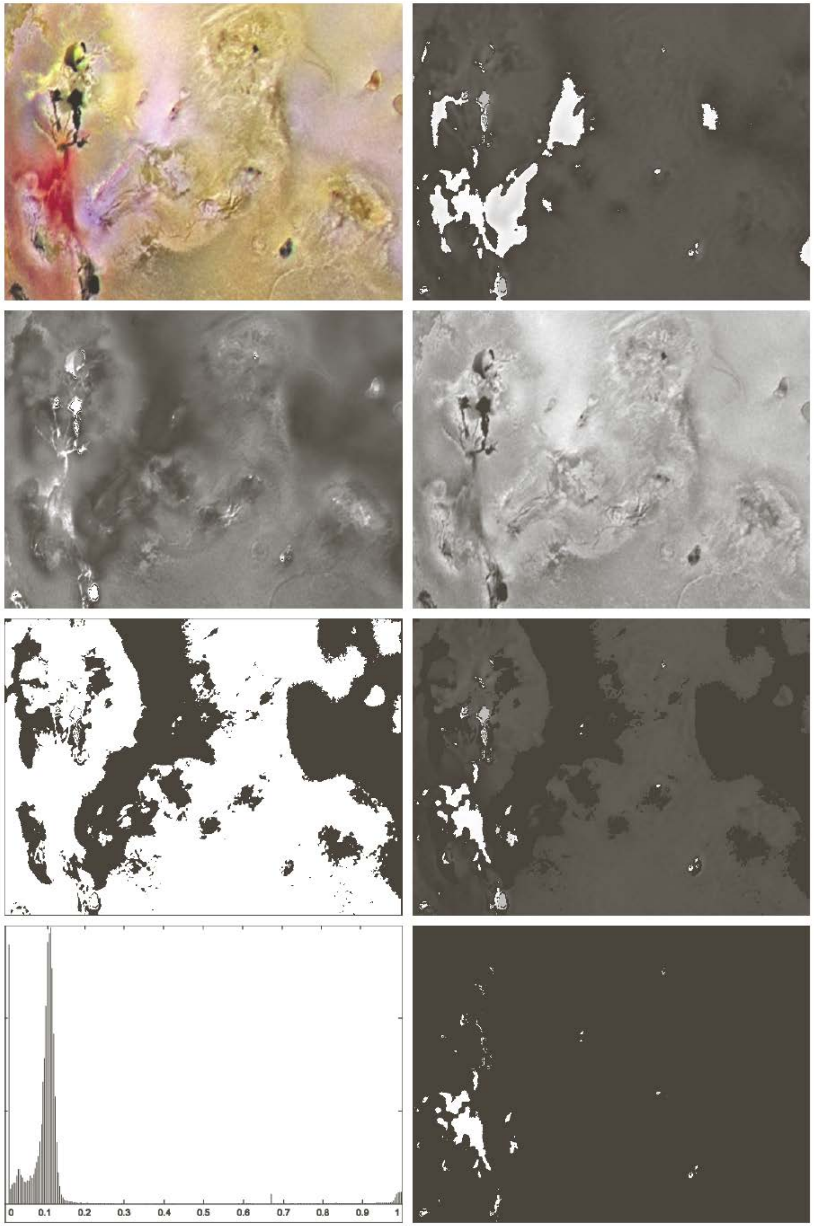


a b c

FIGURE 6.41 Image sharpening with the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the HSI intensity component and converting to RGB. (c) Difference between the two results.

Image Segmentation Based on Color:

Segmentation in HSI Color Space



a	b
c	d
e	f
g	h

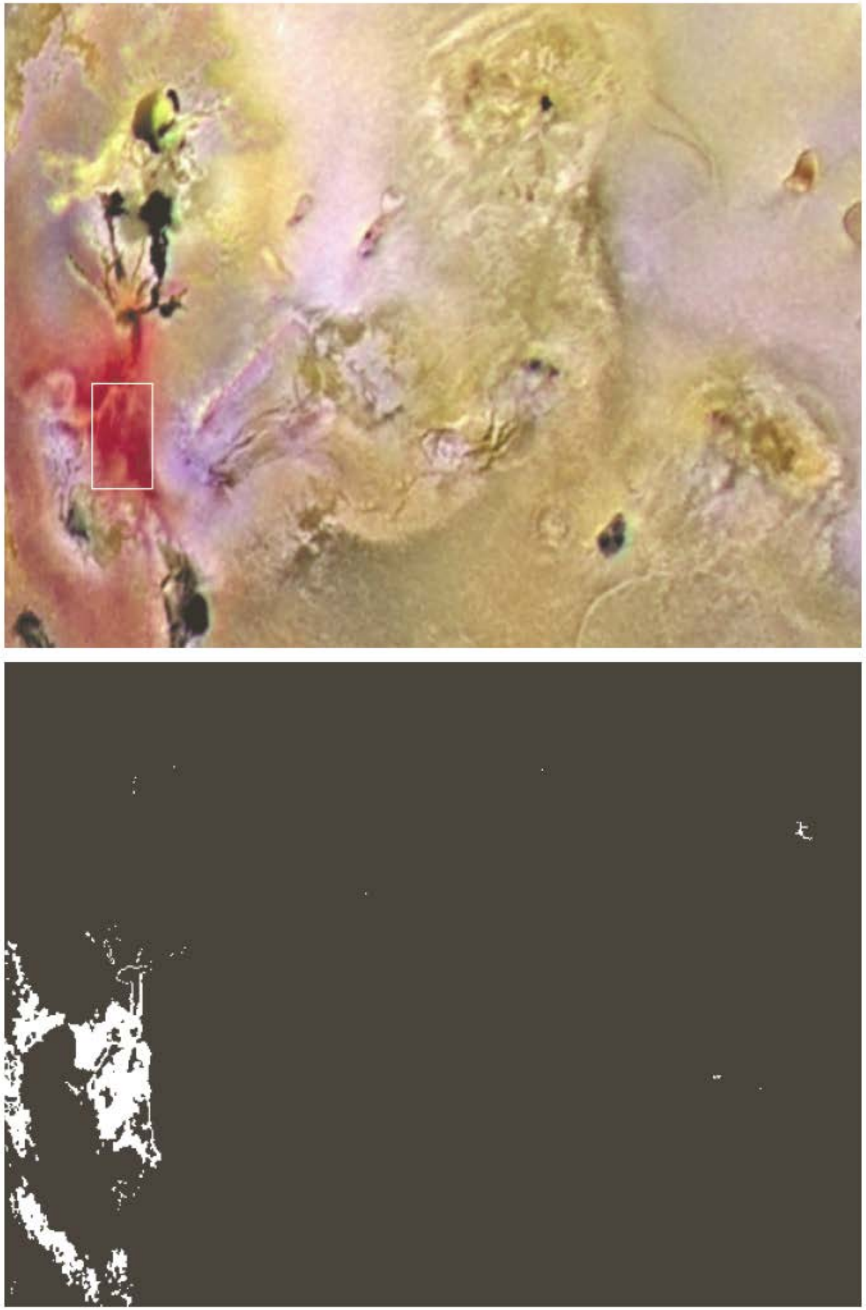
FIGURE 6.42 Image segmentation in HSI space. (a) Original. (b) Hue. (c) Saturation. (d) Intensity. (e) Binary saturation mask (black = 0). (f) Product of (b) and (e). (g) Histogram of (f). (h) Segmentation of red components in (a).

Segmentation in RGB Vector Space

Let the average color of interest is denoted by the RGB vector *a*. Let *z* denote an arbitrary point in RGB space.

$$D(z,a) = \|z-a\| = \left[(z-a)^T(z-a)\right]^{1/2}$$

$$= \left[(z_R-a_R)^2 + (z_G-a_G)^2 + (z_B-a_B)^2\right]^{1/2}$$



a
b

FIGURE 6.44 Segmentation in RGB space. (a) Original image with colors of interest shown enclosed by a rectangle. (b) Result of segmentation in RGB vector space. Compare with Fig. 6.42(h).

Color Edge Detection (1)

Let r, g, and b be unit vectors along the R, G, and B axis of RGB color space, and define vectors

$$\mathrm{u} = \frac{\partial R}{\partial x}\mathrm{r} + \frac{\partial G}{\partial x}\mathrm{g} + \frac{\partial B}{\partial x}\mathrm{b}$$

and

$$\mathrm{v} = \frac{\partial R}{\partial y}\mathrm{r} + \frac{\partial G}{\partial y}\mathrm{g} + \frac{\partial B}{\partial y}\mathrm{b}$$

Color Edge Detection (2)

$$g_{xx} = \mathrm{u} \cdot \mathrm{u} = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2$$

$$g_{yy} = \mathrm{v} \cdot \mathrm{v} = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2$$

and

$$g_{xy} = \mathrm{u} \cdot \mathrm{v} = \frac{\partial R}{\partial x}\frac{\partial R}{\partial y} + \frac{\partial G}{\partial x}\frac{\partial G}{\partial y} + \frac{\partial B}{\partial x}\frac{\partial B}{\partial y}$$

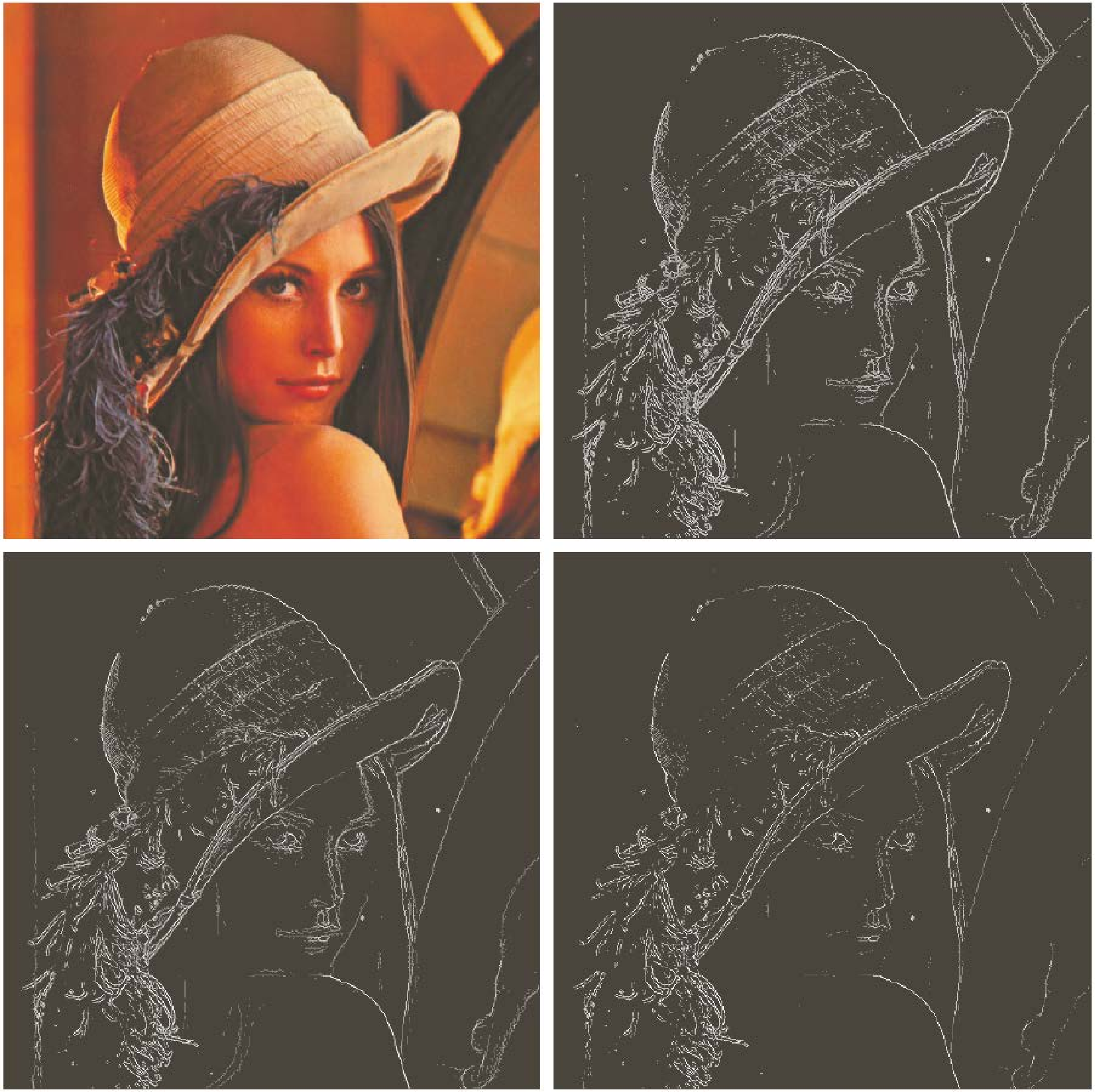
Color Edge Detection (3)

The direction of maximum rate of change of c(x, y) is given by the angle

$$\theta(x,y) = \frac{1}{2}\tan^{-1}\left[\frac{2g_{xy}}{g_{xx}-g_{yy}}\right]$$

The value of the rate of change at (x, y) in the direction of $\theta(x, y)$, is given by

$$\mathrm{F}_{\theta}(x,y)=\left\{\frac{1}{2}\left[\left(g_{xx}+g_{yy}\right)+\left(g_{xx}-g_{yy}\right)\cos 2\theta(x,y)+2g_{xy}\sin 2\theta(x,y)\right]\right\}^{1/2}$$



a	b
c	d

FIGURE 6.46
(a) RGB image.
(b) Gradient computed in RGB color vector space.
(c) Gradients computed on a per-image basis and then added.
(d) Difference between (b) and (c).

a b c

FIGURE 6.47 Component gradient images of the color image in Fig. 6.46. (a) Red component, (b) green component, and (c) blue component. These three images were added and scaled to produce the image in Fig. 6.46(c).