CPE409 Image Processing

Part 7
Color Image Processing

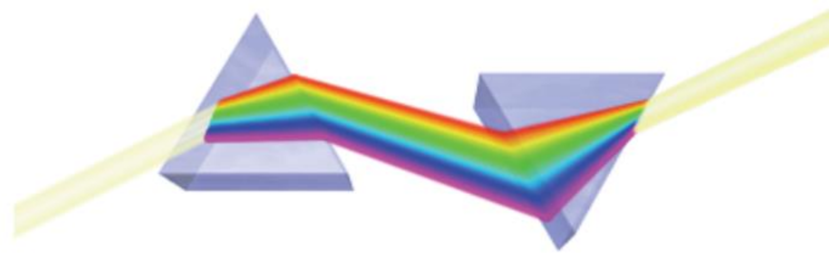
Assist. Prof. Dr. Caner ÖZCAN

It is only after years of preparation that the young artist should touch color—not color used descriptively, that is, but as a means of personal expression. ~Henri Matisse

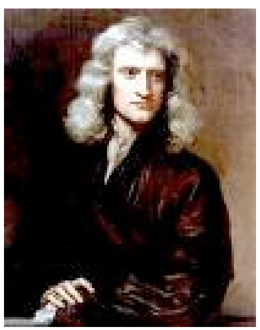
Outline

6. Color Image Processing
    - Color Fundamentals
    - Color Models
    - Pseudocolor Image Processing
    - Basics of Full-Color Image Processing
    - Color Transformations
    - Smoothing and Sharpening
    - Image Segmentation Based on Color
    - Noise in Color Images
    - Color Image Compression

Renk Temelleri

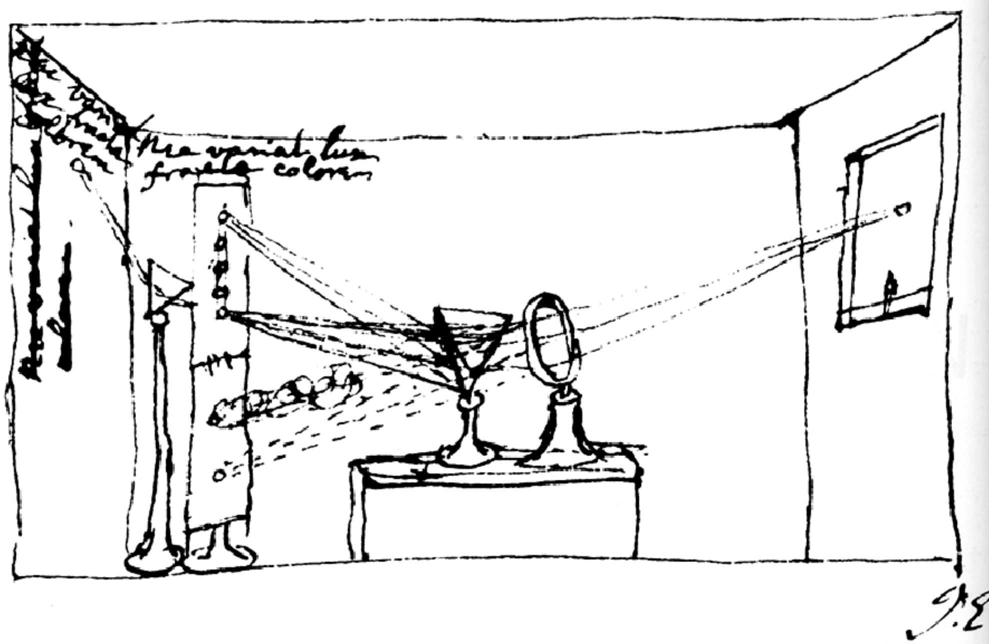


- White light



Newton 1665

Color



4.1 NEWTON'S SUMMARY DRAWING of his experiments with light. Using a point source of light and a prism, Newton separated sunlight into its fundamental components. By reconverging the rays, he also showed that the decomposition is reversible.

From Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

Slide credit: B. Freeman, A. Torralba, K. Grauman

Color Fundamentals

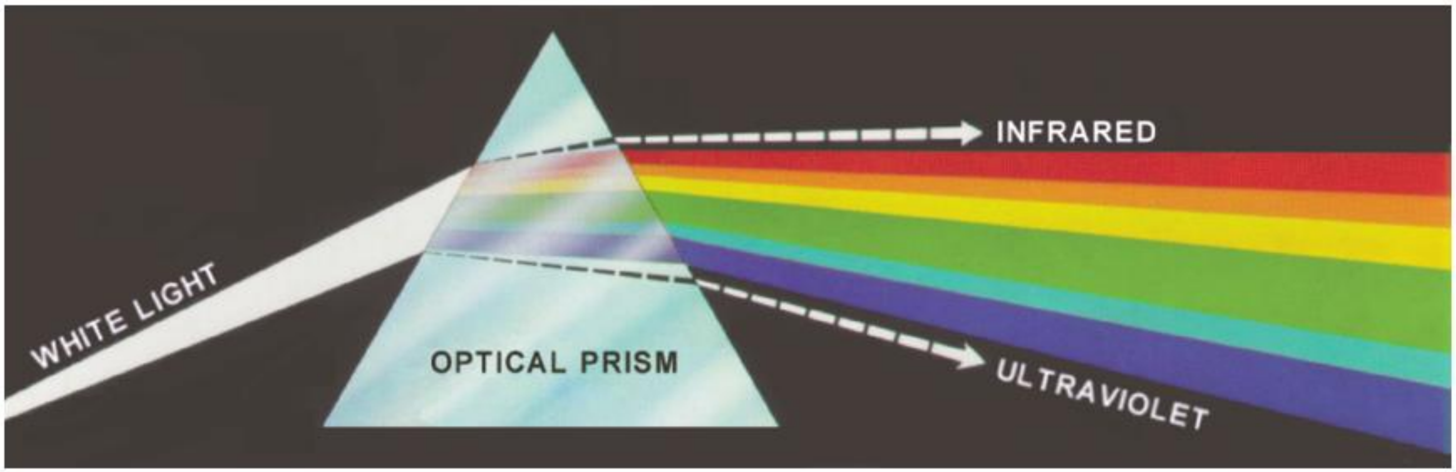


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

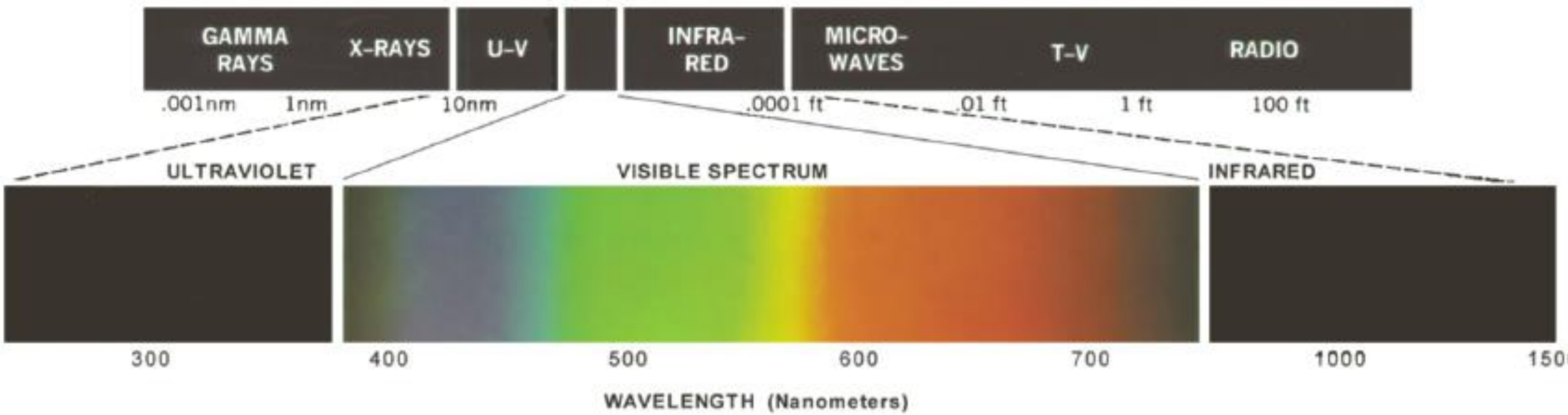


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Renk Temelleri

Three basic parameters are used to express the property of colored light:

1. Radiance: It is the total amount of energy emitted from the light source and is measured in Watt (W).
2. Luminance: It is the total amount of energy that the observer perceives from the light source and is measured in Lumen (lm).
3. Brightness: It is a subjective descriptive parameter that is practically impossible to measure. It indicates colorlessness of intensity.

Color Fundamentals

- Cone cells are responsible for color vision in the eye.

- 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

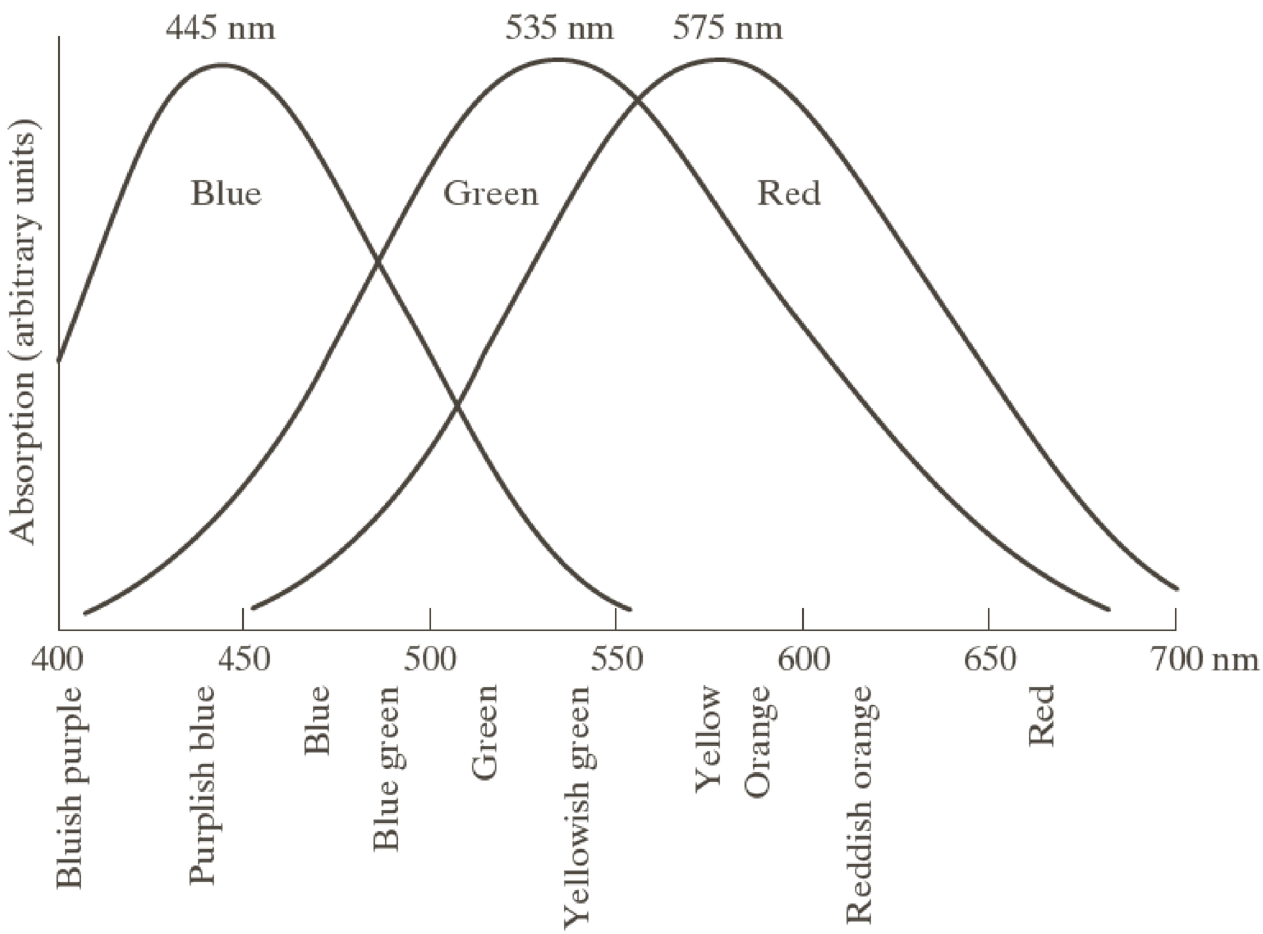
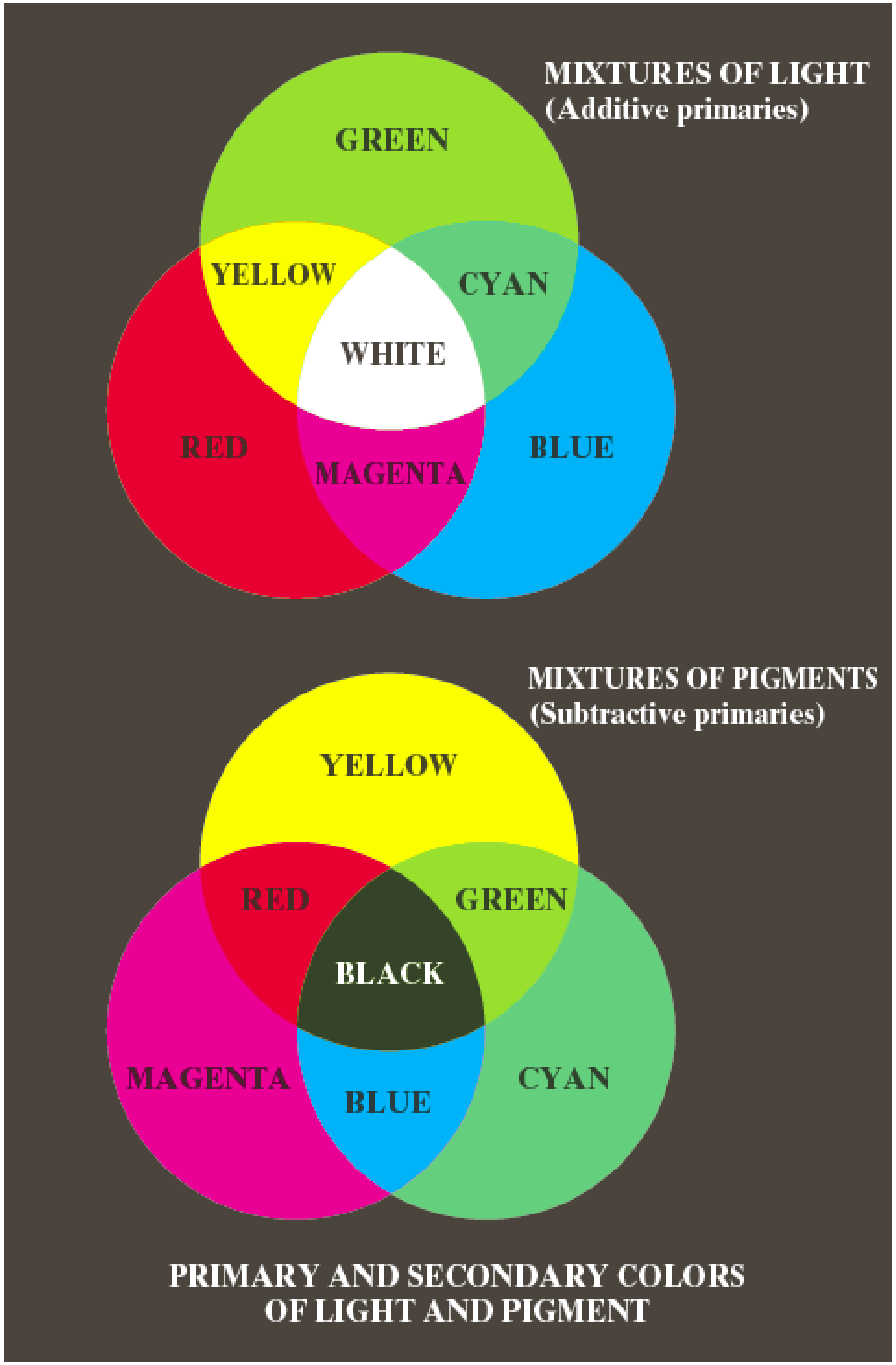


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.



a
b

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)

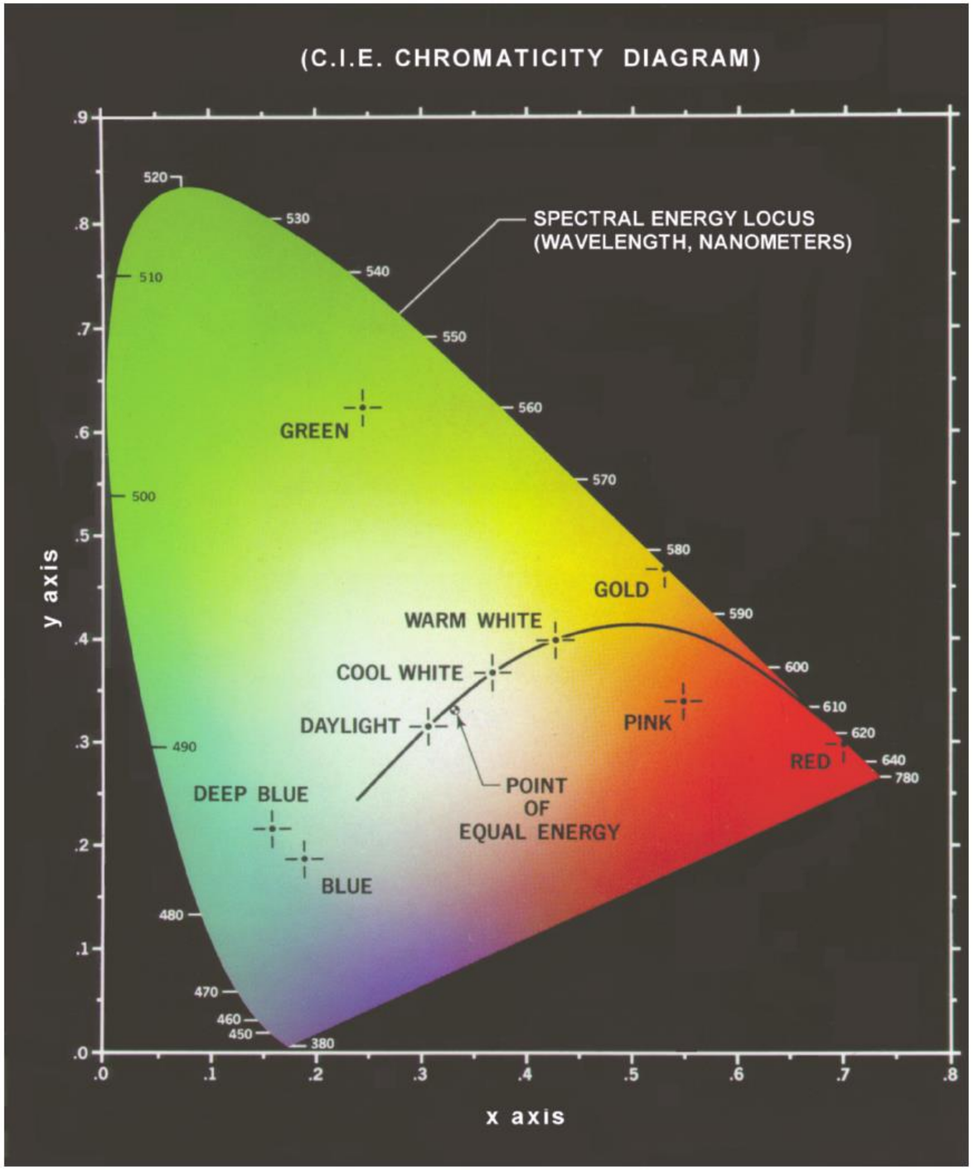


FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)

RGB Color Model

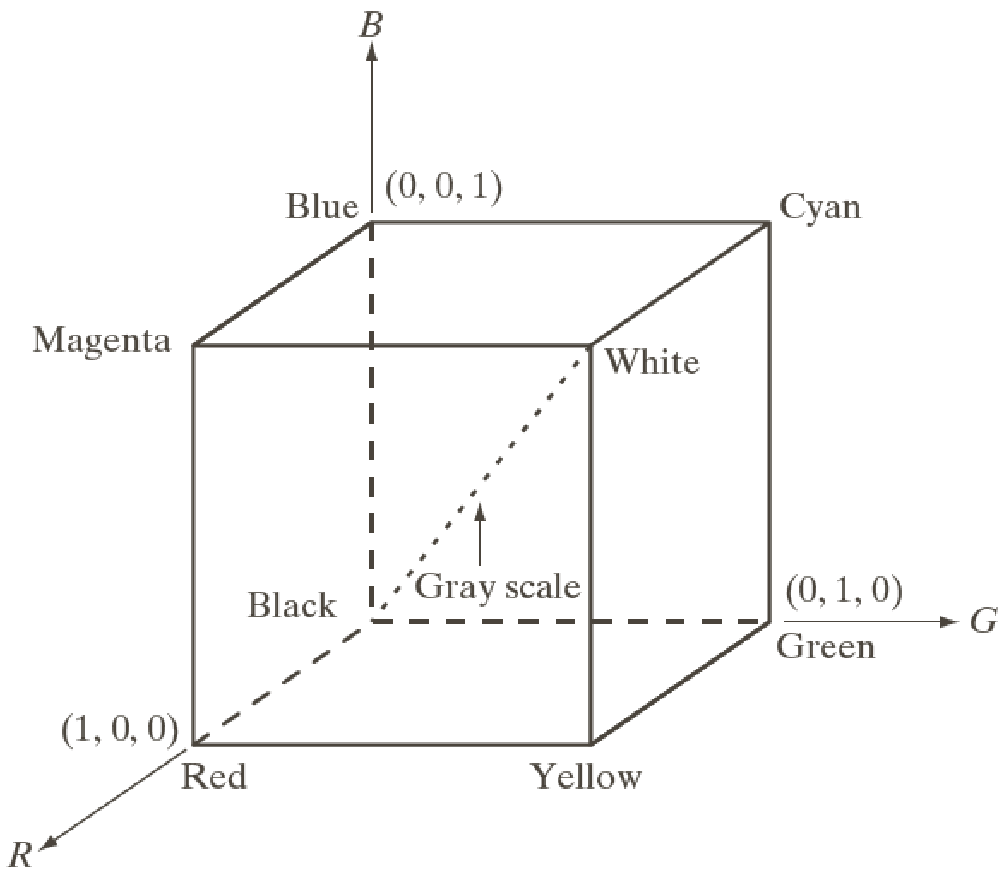


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

RGB Color Model

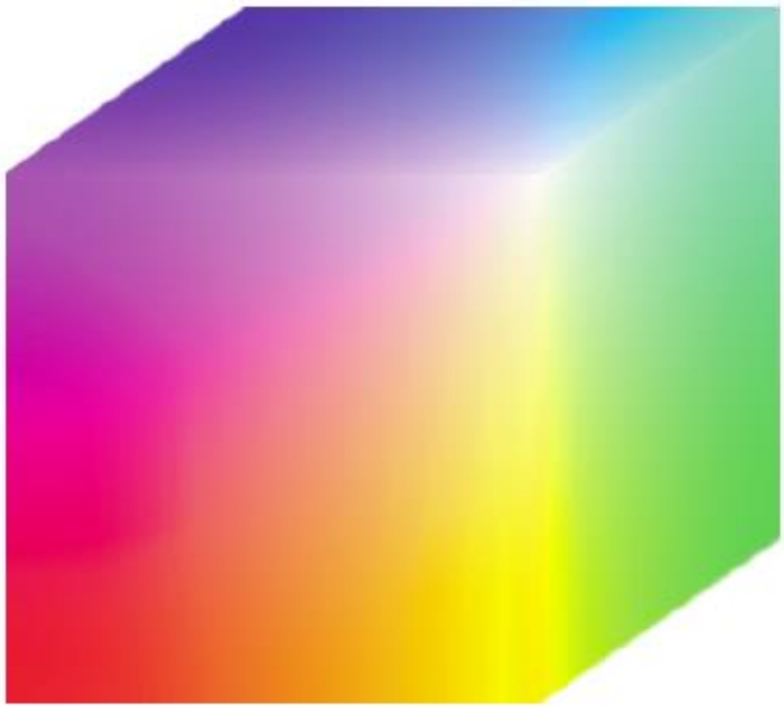


FIGURE 6.8 RGB 24-bit color cube.

Pixel depth

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

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

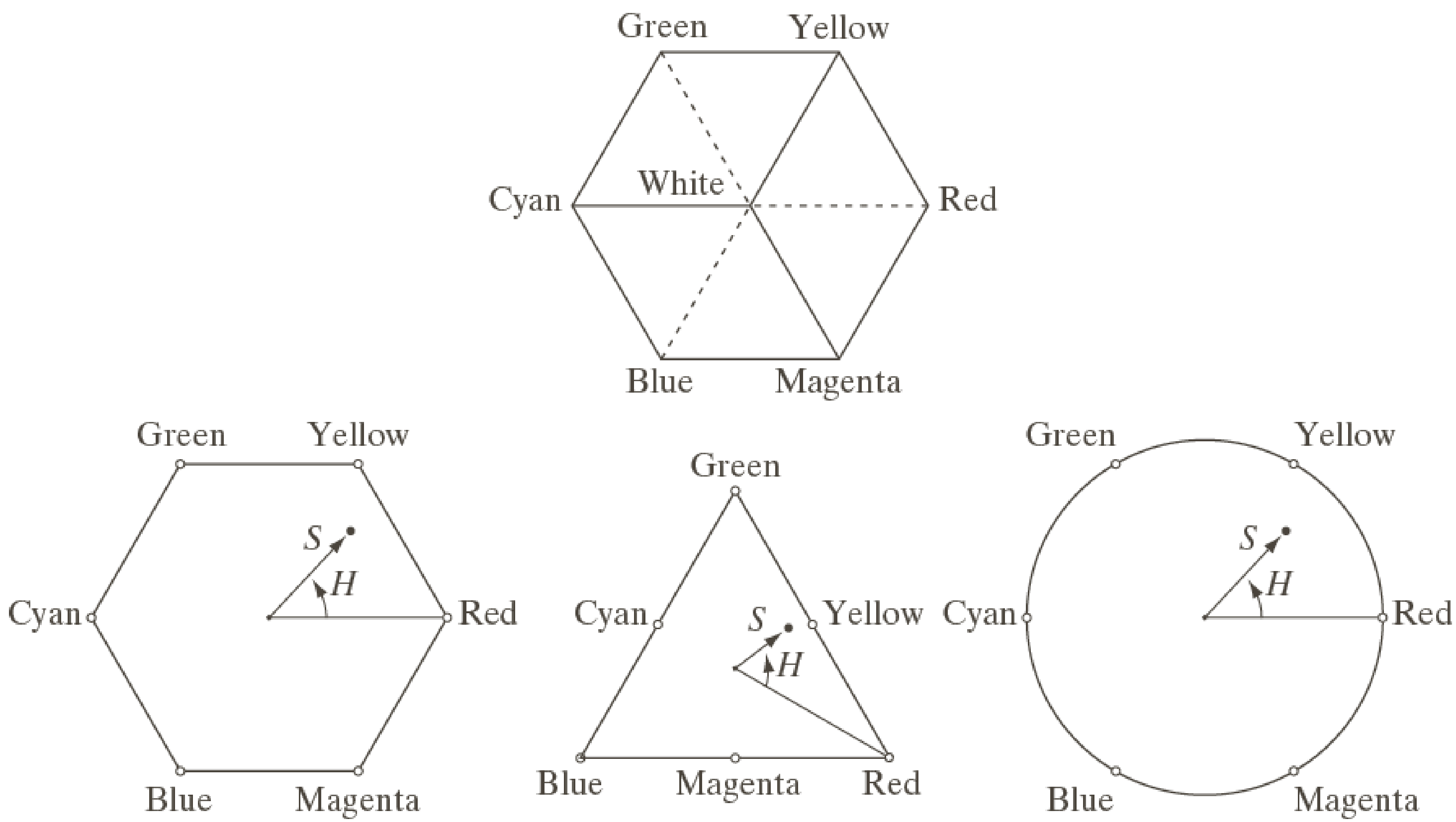
HIS Color Model

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.

HIS Color Model



a
b c d

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.

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

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

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

Converting Colors from RGB to HSI

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

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

Note: All color values are normalized to the range [0-1].

Converting Colors from RGB to HSI

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

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

Note: All color values are normalized to the range [0-1].

Converting Colors from RGB to HSI

- For an image in RGB color format, the intensity component is given as:

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

Python code:

```
hsvImage = cv2.cvtColor(image, cv2.COLOR_RGB2HSV)
```

Note: All color values are normalized to the [0-1] range.

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

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

Note: All color values are normalized to the range [0-1].

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

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

Note: All color values are normalized to the range [0-1].

Converting Colors from HSI to RGB

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

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

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

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

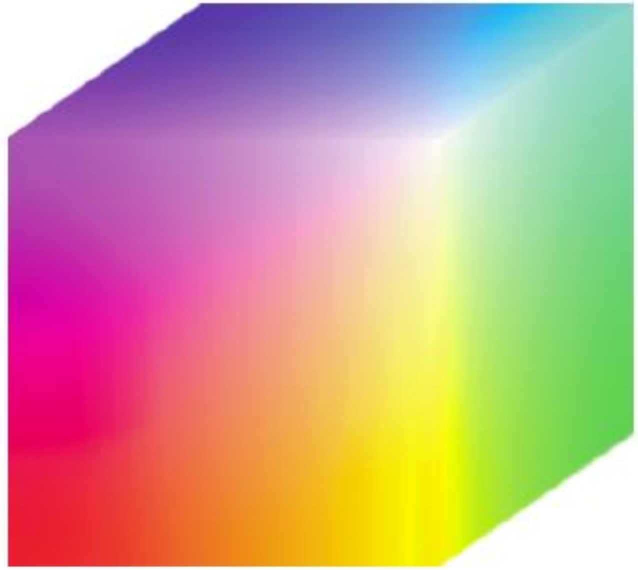
and

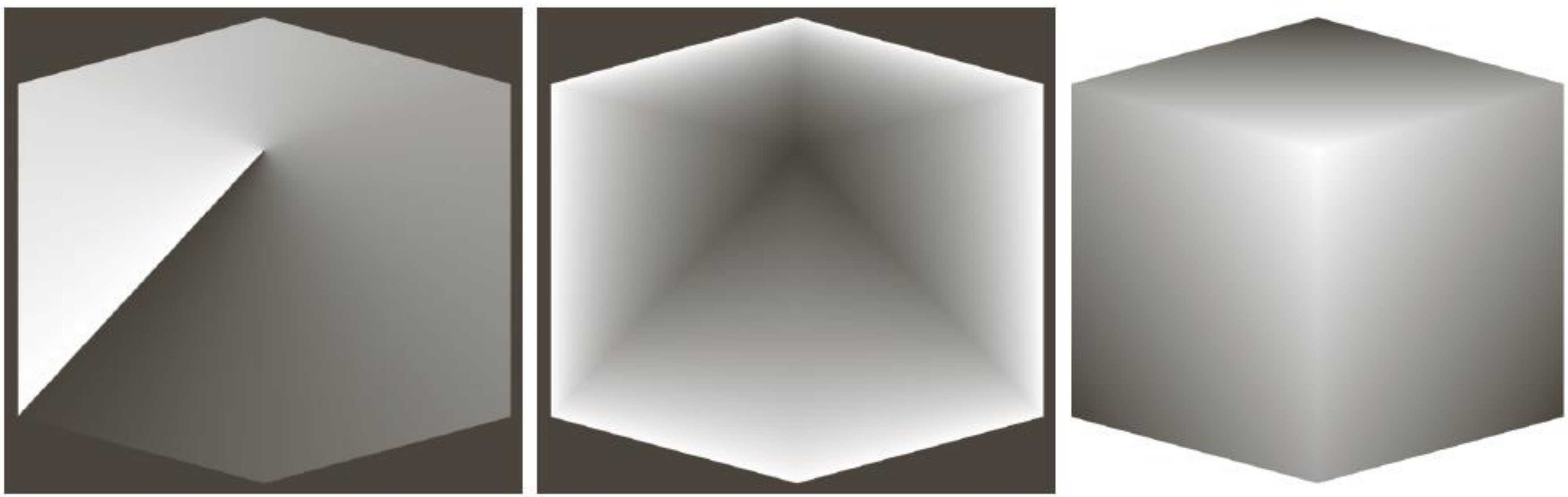
$$R = 3I - (G + B)$$

Note: All color values are normalized to the range [0-1].

Python Code:

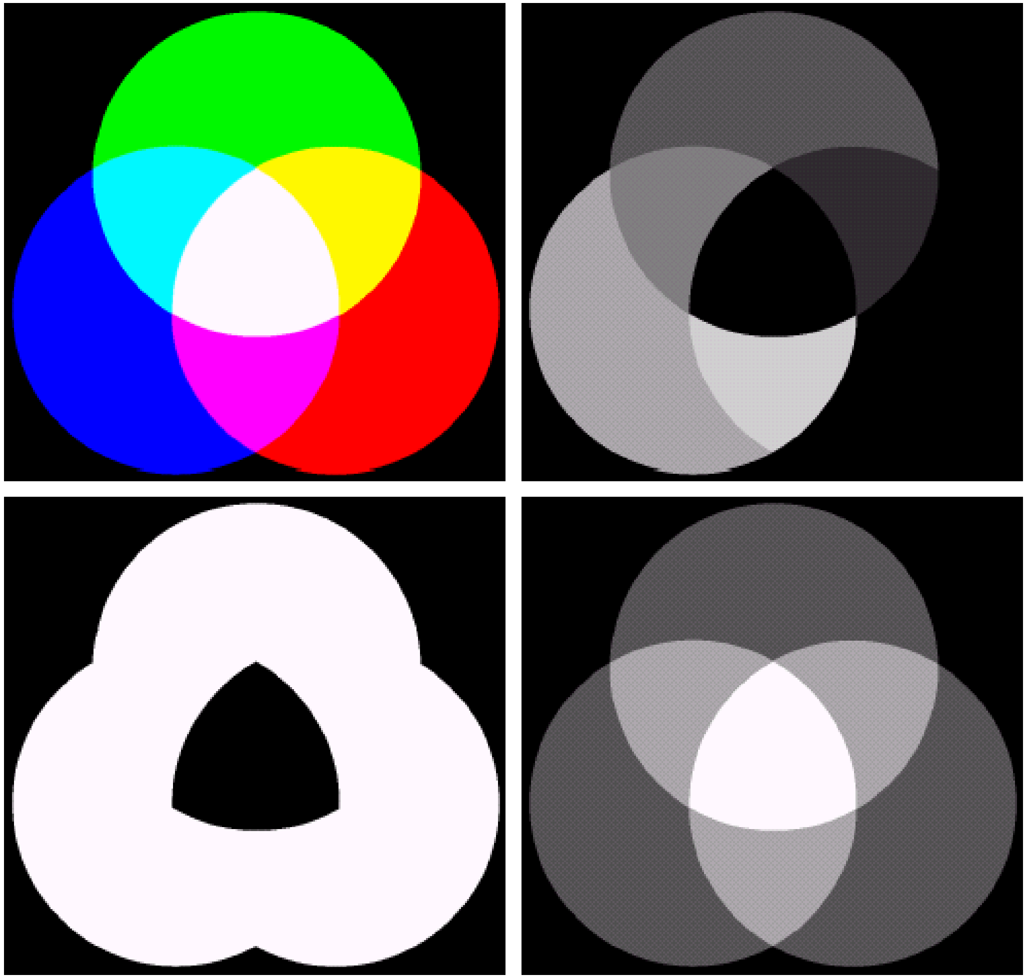
```
rgbImage = cv2.cvtColor(image, cv2.COLOR_HSV2RGB)
```





a b c

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



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.

Pseudocolor Image Processing

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

- Intensity Slicing

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

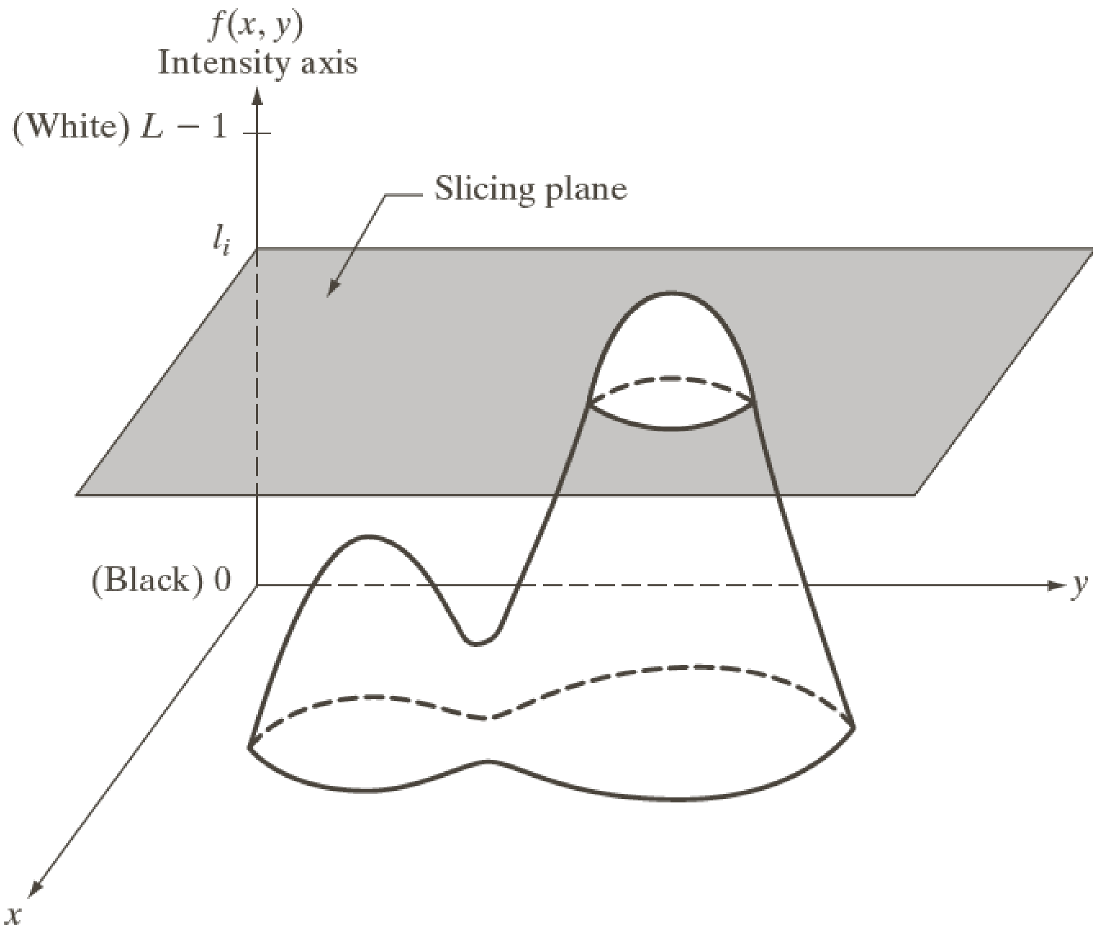


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

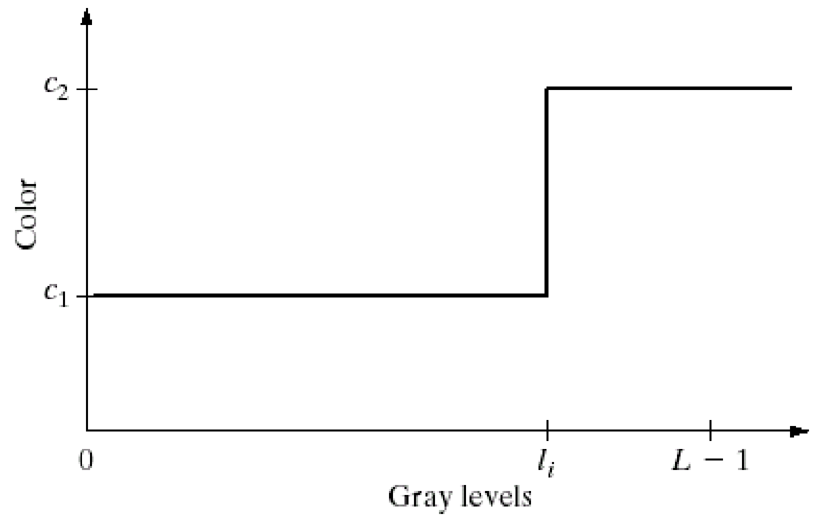
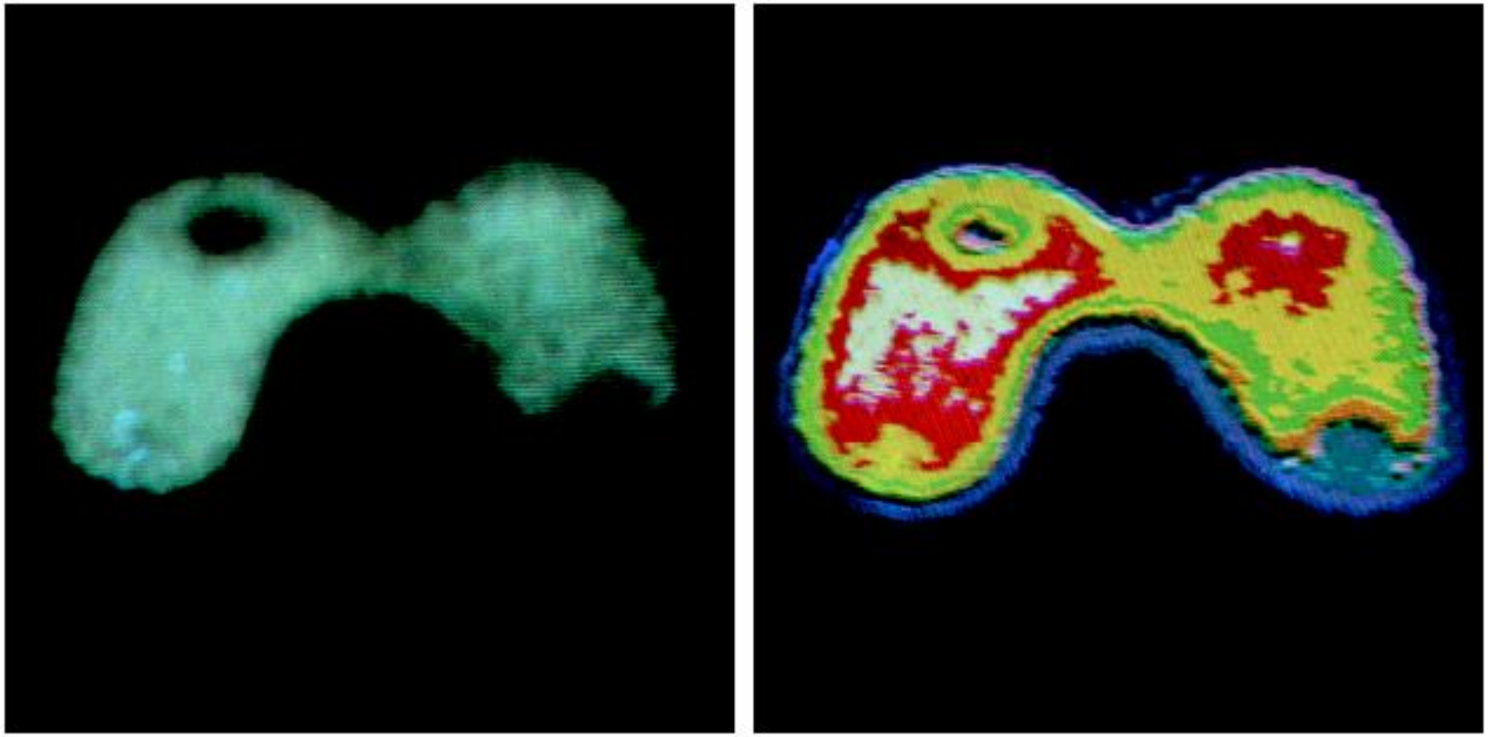


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

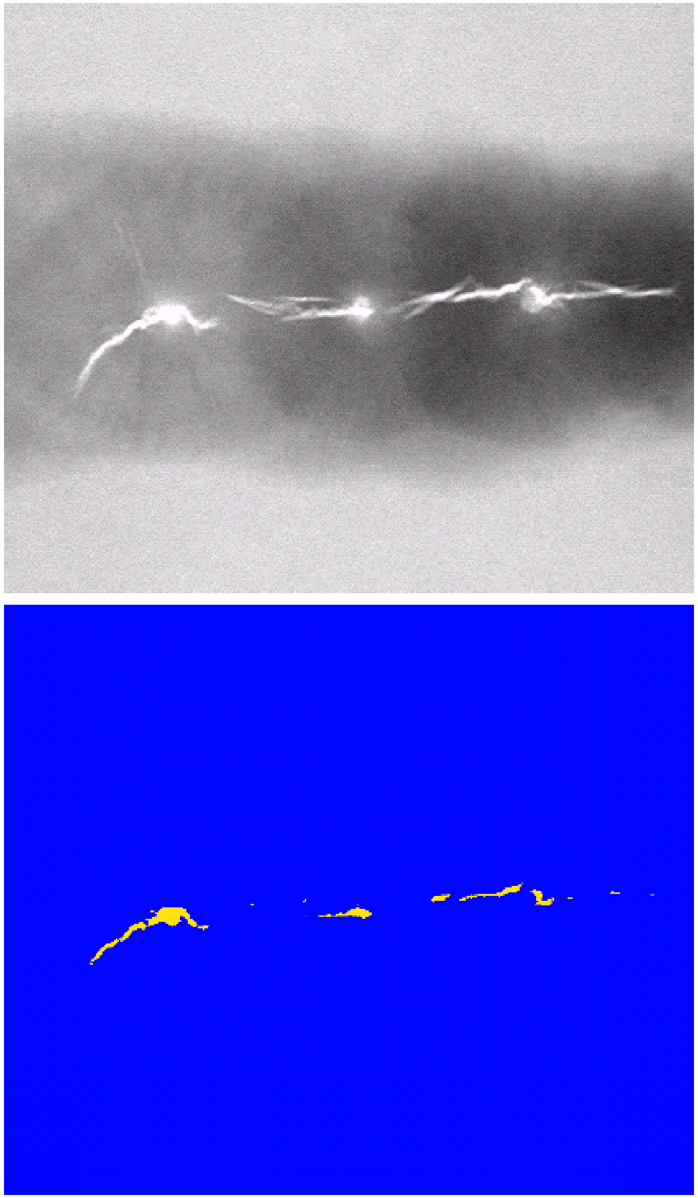


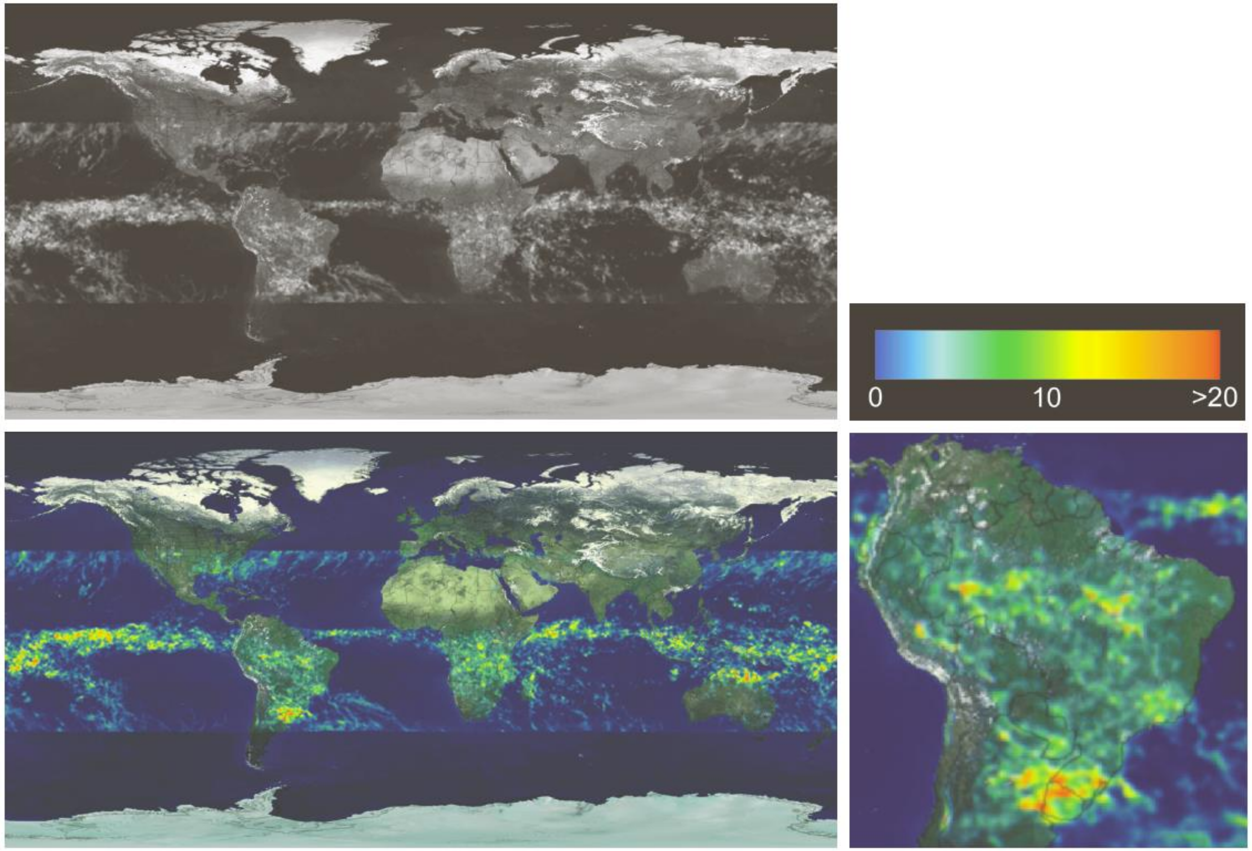
a b

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.)

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

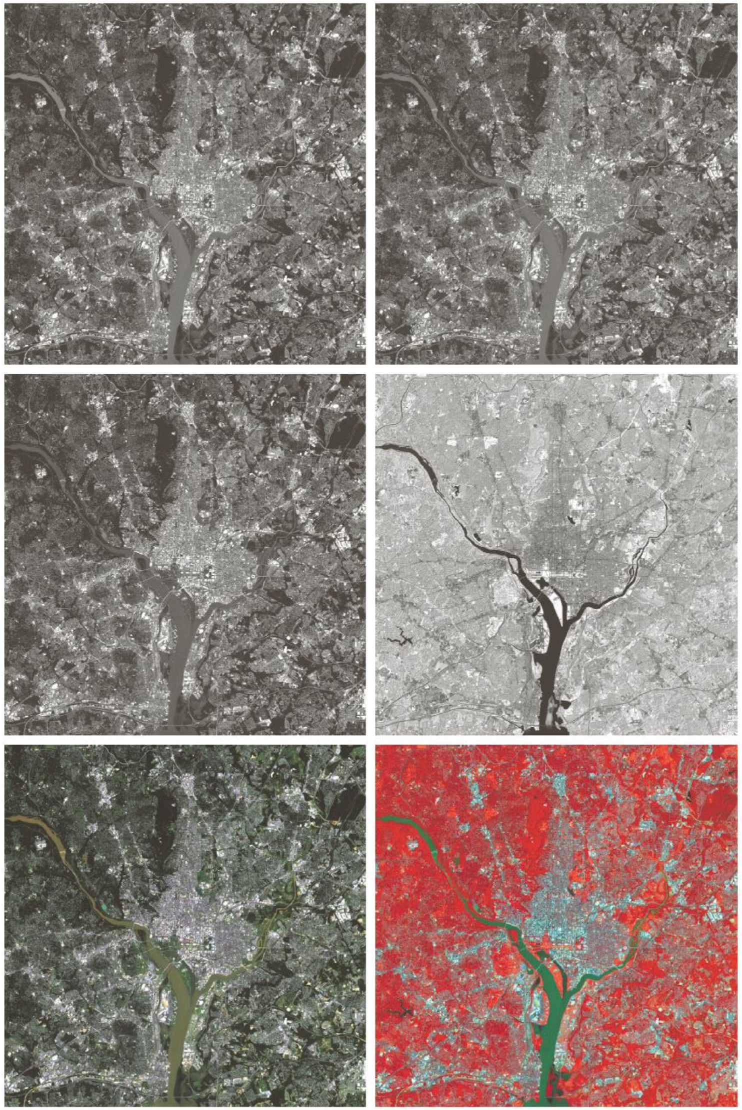
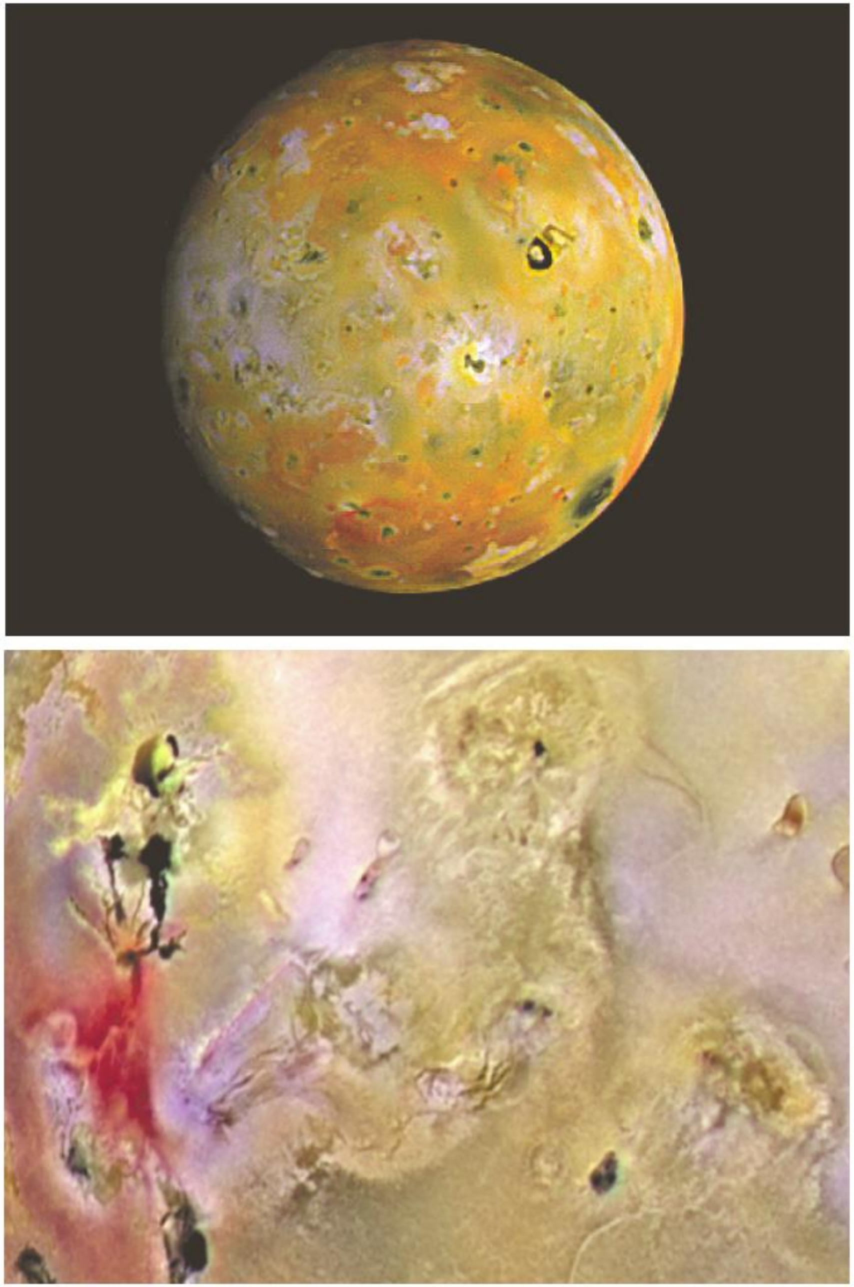


FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral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

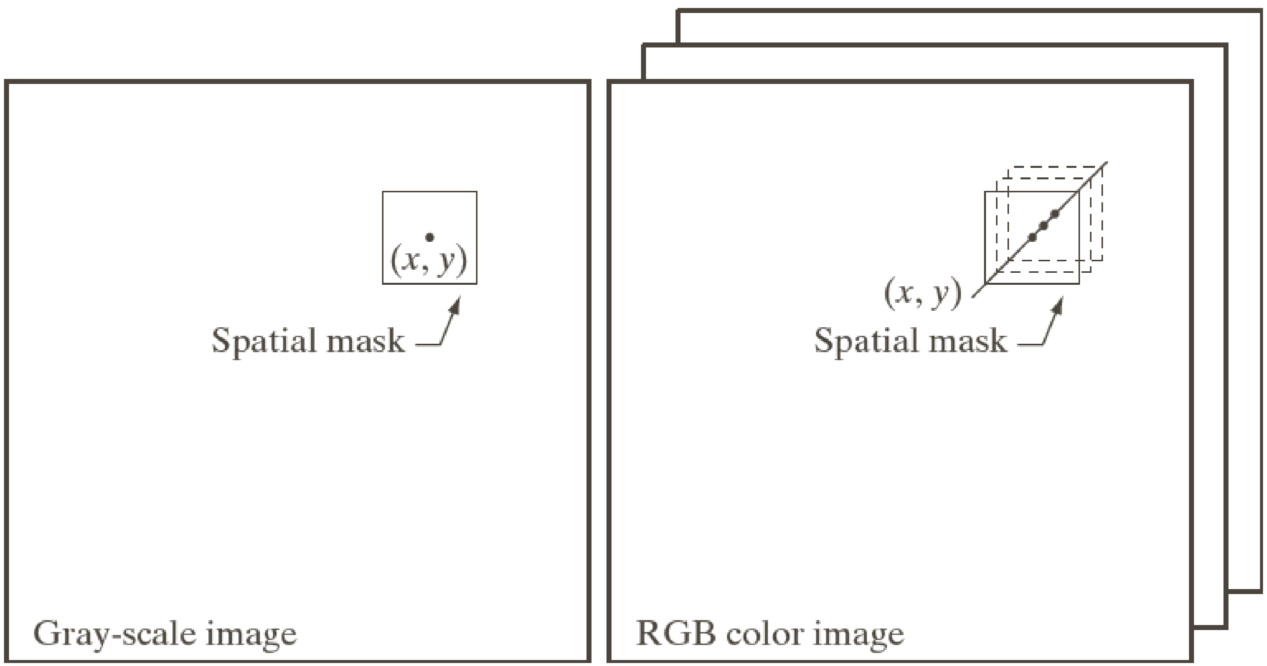
Let c represent an arbitrary vector in RGB color space:

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

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.

References

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- Lecture Notes, EBM537-Image Processing, F.Karabiber
- https://docs.opencv.org/
- Bekir Aksoy, Python ile İmgeden Veriye Görüntü İşleme ve Uygulamaları, Nobel Akademik Yayıncılık