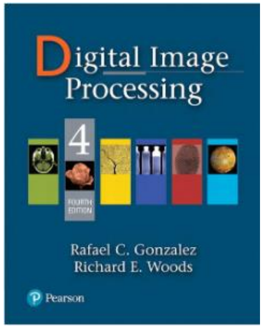


Digital Image Processing

Color Image Processing (I)

Dr. Tun-Wen Pai

1) **Understand fundamental of color and color spectrum**
2) **Understand color models used in DIP**
3) **Pseudo-color image processing**
4) **Grayscale methods for color images?**

Color Image Processing

- In automated image analysis, color is a powerful descriptor, which simplified 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 consists of two part: Pseudo-color processing and Full color processing.

- In pseudo-color processing, (false) colors are assigned to a monochrome image. For example, objects with different intensity values may be assigned different colors, which would enable easy identification/ recognition by humans.

- In full-color processing, images are acquired with full color sensors/cameras. This has become common in the last decade or so, due to the easy and cheap availability of color sensors and hardware.

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 lsaac Newton, 1666)
- The color spectrum can be divided into six broad regions: violet, blue, green, yellow, orange, and red.

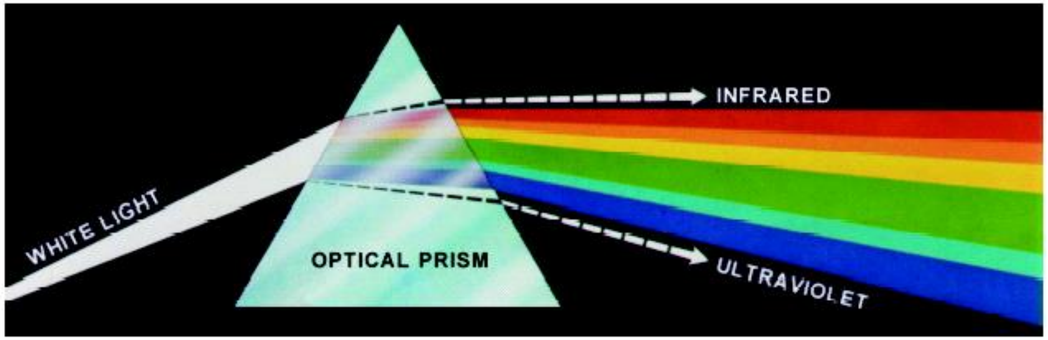


FIGURE 6.1 Color Spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

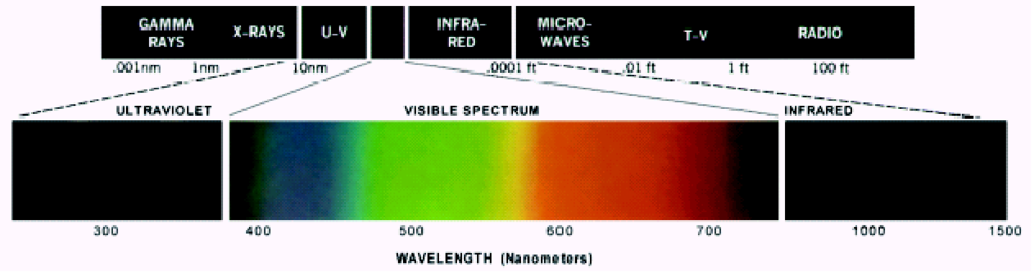


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Divisoin.)

- The different colors in the spectrum do not end abruptly but each color blends smoothly into the next.
- Color perceived by the human eye depends on the nature of light reflected by an object. Light that is relatively balanced in all visible wavelengths is perceived as white. Objects that appear green reflect more light in the 500-570 nm range (absorbing other wavelengths of light).
- Characterization of light is important for the understanding of color.
- If the light is **achromatic** (devoid of color), its only attribute is its **intensity** (amount of light). This is what we have been dealing with so far. The term graylevel refers to the scalar measure of the intensity of light --- black to grays to white.
- **Chromatic** light spans the electromagnetic (EM) spectrum from approximately 400 nm to 700 nm.
- Three basic quantities are used to describe the quality of a chromatic source of light:
- **Radiance** is the total amount of light that flows from a light source (measured in Watts)
- **Luminance** gives a measure of the amount of energy an observer perceives from a light source (measured in lumens).
- **Brightness** is a subjective descriptor that is impossible to measure.

- 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.
- Absorption of light by the three types of cones is illustrated in the figure below:

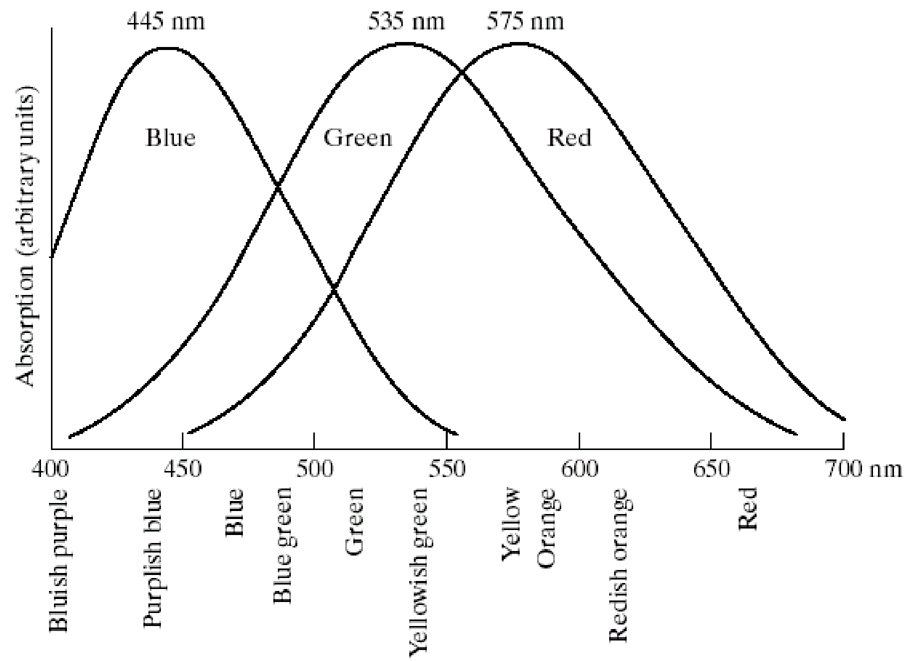
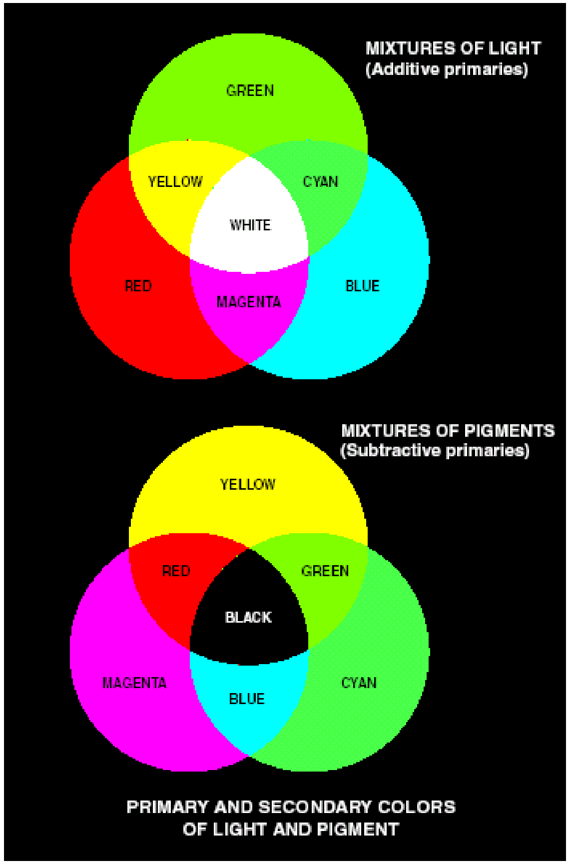


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

- Due to the absorption characteristics of the human eye, all colors perceived by the human can be considered as a variable combination of the so called three primary colors:
  - Red (R) (700 nm)
  - Green (G) (546.1 nm)
  - Blue (B) (435.8 nm)

- The wavelengths for three primary colors are established by standardization by the **CIE (International Commission on Illumination, 國際照明委員會)**. They correspond to the experimental curve only approximately.

- Note that the specific color wavelengths are used mainly for standardization. It is not possible to produce all colors purely by combining these specific wavelengths.



a
b

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

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

- Mixing the three primaries, or a secondary with its opposite primary, in the right intensities produces white light.

- A primary color of pigment is defined as one that subtracts or absorbs a primary color of light and reflects or transmits the other two.

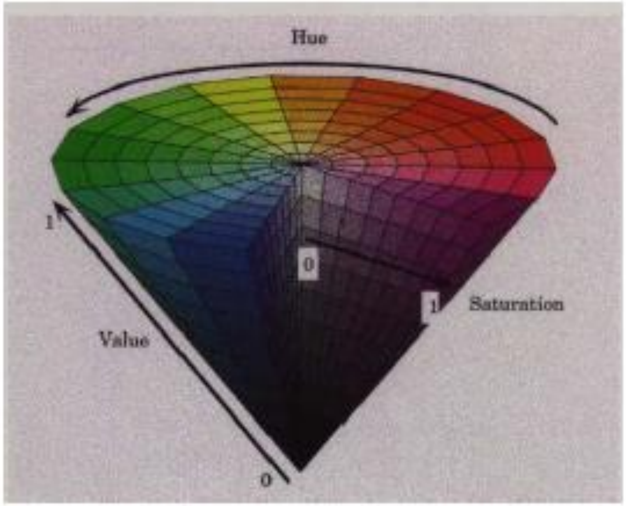
- Therefore, the primary colors of pigments are magenta, cyan, and yellow, and the secondary pigment colors are red, green, and blue.

- Mixing the three pigment primaries, or a secondary with its opposite primary, in the right intensities produces black.

- Color television or a computer monitor is an example of additive nature of the color of light. The inside of the screen is coated with dots of phosphor, each being capable of producing one of the three primary colors. A combination of light of the three primary colors produces all the different color we see.

- Printing is an example of the subtractive nature of color pigments. For example, a pigment of red color actually absorbs light of all wavelengths, except that corresponding to red color.

- The characteristics used to distinguish one color from another are:
  - Brightness (or 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).
  - Saturation 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 lavender (violet + white) are less saturated, with the saturation being inversely proportional to the amount of white light added.
- Hue and saturation together are called **chromaticity**. A color can be described in terms of its brightness and chromaticity.



Tristimulus values

- The amounts of red, green, and blue needed to form any particular color are called the **tristimulus** values and are denoted by *X*, *Y*, and *Z*, respectively.

- In general, color is specified by its three **trichromatic coefficients:**

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

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

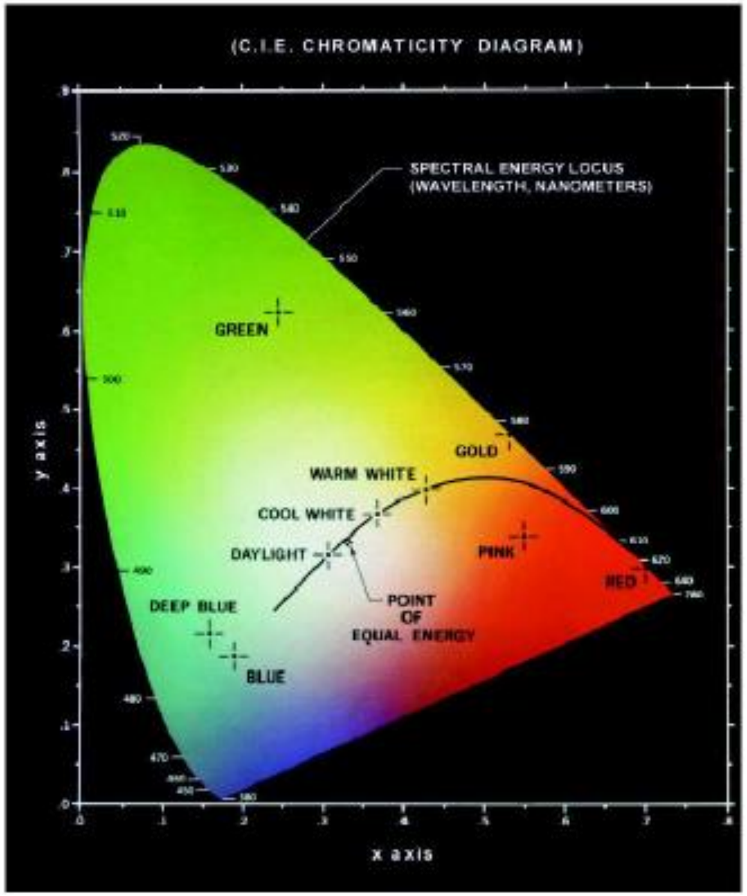
$$z = \frac{Z}{X + Y + Z}$$

- Naturally, x + y + z = 1.

Chromaticity diagram (CIE 1931色彩空間色度圖)

- Another approach to specifying colors is via the CIE **chromaticity diagram**, which represents color composition by means of x (red) and y (green) values.
- For any value of x (red) and y (green), the corresponding value of z (blue) is given by z = 1-(x + y)

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



- The positions of various spectrum colors (completely saturated or “pure” colors) are indicated along the boundary of the tongue-shaped chromaticity diagram.
- Points inside this region represent some mixture of the pure colors

- Point of equal energy corresponds to equal fractions of the three primary colors. It represents the *Commission Internationale de l’Eclairge* --- *The International Commission on Illumination* (CIE) standard for white light.

- As a point leaves the boundary and moves towards the center, more white light is added to the color and it becomes less saturated.

- The point of equal energy corresponds to zero saturation.
- 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.
- A line joining the point of equal energy to any point on the boundary represents different shades of that color.
- Similarly, the triangular region enclosed by the line segments joining three point in the chromaticity diagram represents all the colors that can be obtained by combing the three colors.
- This is consistent with the remark made earlier that the three pure primary colors by themselves cannot produce all the colors (unless we change the wavelengths as well)

- The triangular region shown in the figure below represents the typical range of colors (gamut of colors) produced by RGB monitors.
- The irregular region inside the triangular region represents the color gamut of modern high-quality color printer.

- Color printing is a complicated process and it is more difficult to control the color of printed object than it is to control the color displayed on a monitor.

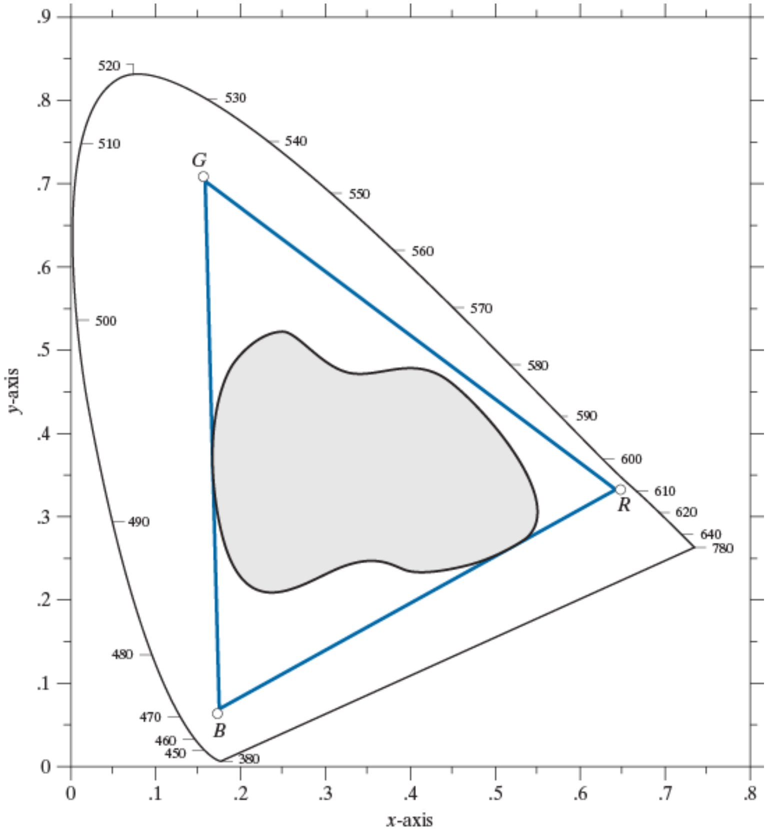


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

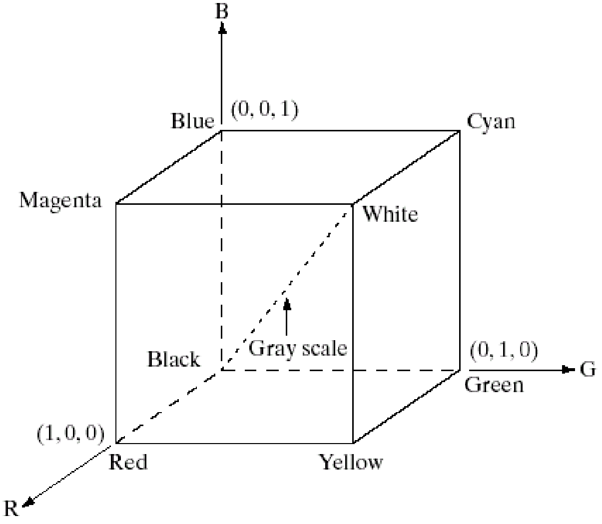
Color Models

- 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.
- Most color models in use today are either based on hardware (color camera, printer) or on applications involving color manipulation (computer graphics, animation).
- In image processing, the hardware base color models mainly used are: RGB, CMYK, and HSI.
- The RGB (red, green, blue) color system is used mainly in color monitors and video cameras.
- The CMYK (cyan, magenta, yellow, black) color system is used in printing devices.
- The HSI (hue, saturation, intensity) is base 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** (R), **green** (G), and **blue** (B)
- Mainly used for hardware such as color monitors and color video camera.

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)



- It is based on a Cartesian coordinate system. All color values are normalized 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.
- The primary colors red, green, and blue correspond to three corners of the cube, whereas the secondary colors cyan, magenta, and yellow correspond to three other corners. Origin (0, 0, 0) represents black and (1, 1, 1) represents white.
- Grayscale (monochrome) is represented by the diagonal joining black to white.

- Different points on or inside the cube correspond to different colors and can be represents as vector or three values or coordinates. Each coordinate represents the amount of that primary color present in the given color.
- Images in the RGB model consist of three independent component images, one for each primary color.
- When fed to into an RGB monitor, these three images combine on the phosphor screen to produce a composite color image.
- The number of bits used to represent each pixel in RGB space is called **pixel depth**.
- For example, if eight bits are used to represent each of the primary components, each RGB color pixel would have a depth of 24 bits. This is usually referred to as a **full color** image.
- There are 2^{24} = 16,777,216 unique colors possible in this system.

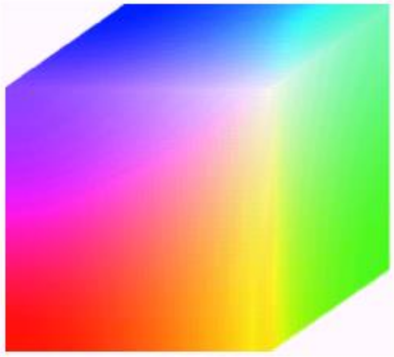


FIGURE 6.8 RGB 24-bit color cube

- Although high-end monitors can display true 24-bit colors, more modest display devices are limited to smaller (typically 256) set of colors.

- Given the variety of display devices, it is useful to have a small subset of colors that are reproduced reliably and faithfully, independently of the display hardware specifics. This subset of colors in referred to as **safe RGB colors** or the set of **all-systems-safe colors**. They are also referred to **as safe web colors** or **safe browser colors** in internet applications.

- Assuming 256 distinct colors as the minimum capability of any color display device, a standard notation to refer to these “safe” colors is necessary.

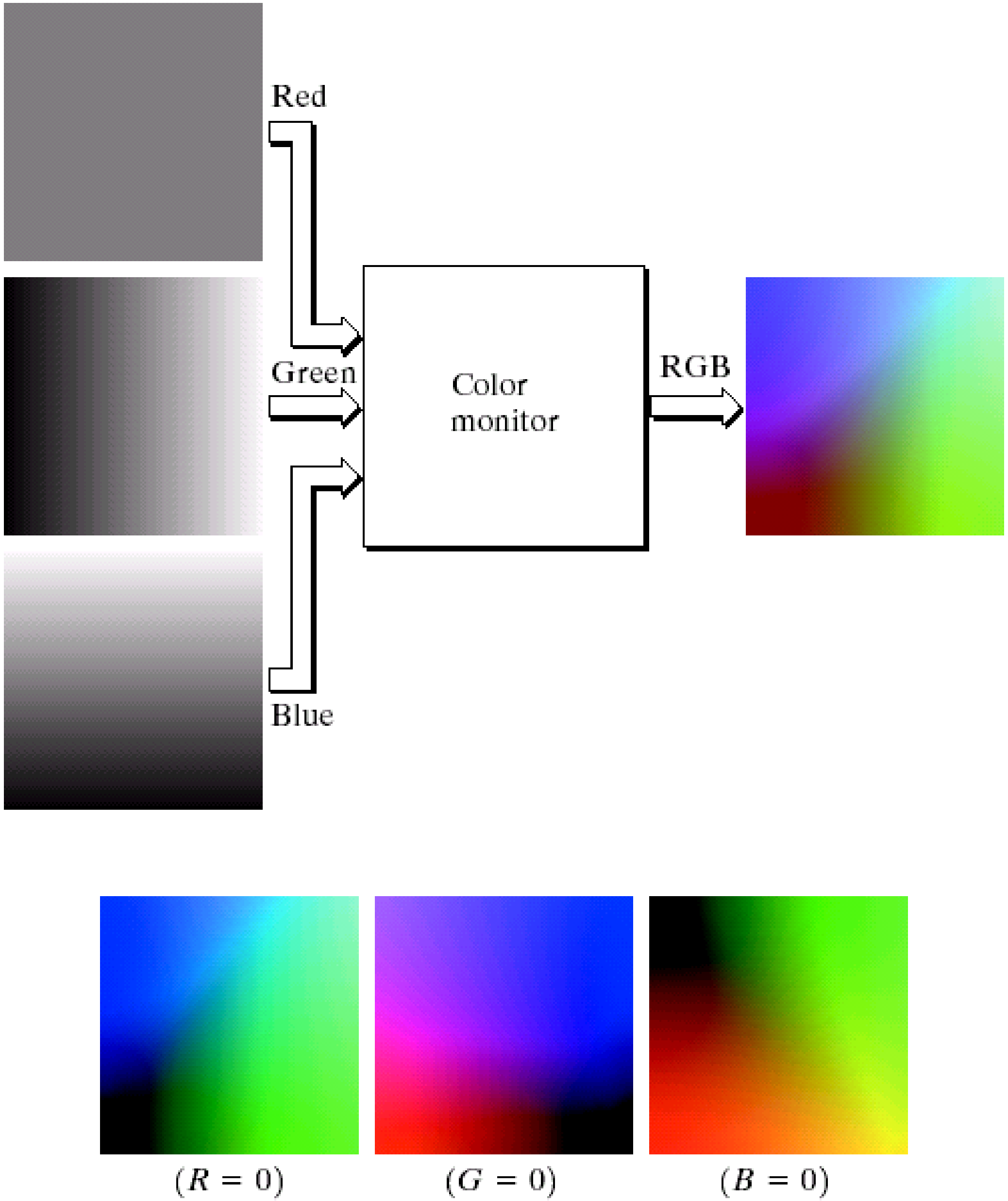
- Forty of these 256 colors are known to be processed differently by various operating systems, leaving 216 colors that are common to most systems.

- These 216 colors are formed by a combination of RGB values , where each component is restricted to be one of possible six values in the set {0, 51, 102, 153, 204, 255} or using hexadecimal notation {00, 33, 66, 99, CC, FF}. Note that all the values are divisible by 3.

- These $2^6 = 216$ colors have become de facto standard for safe colors, especially in internet applications. They are commonly used, whenever it is desired that the colors viewed by most people appear the same.

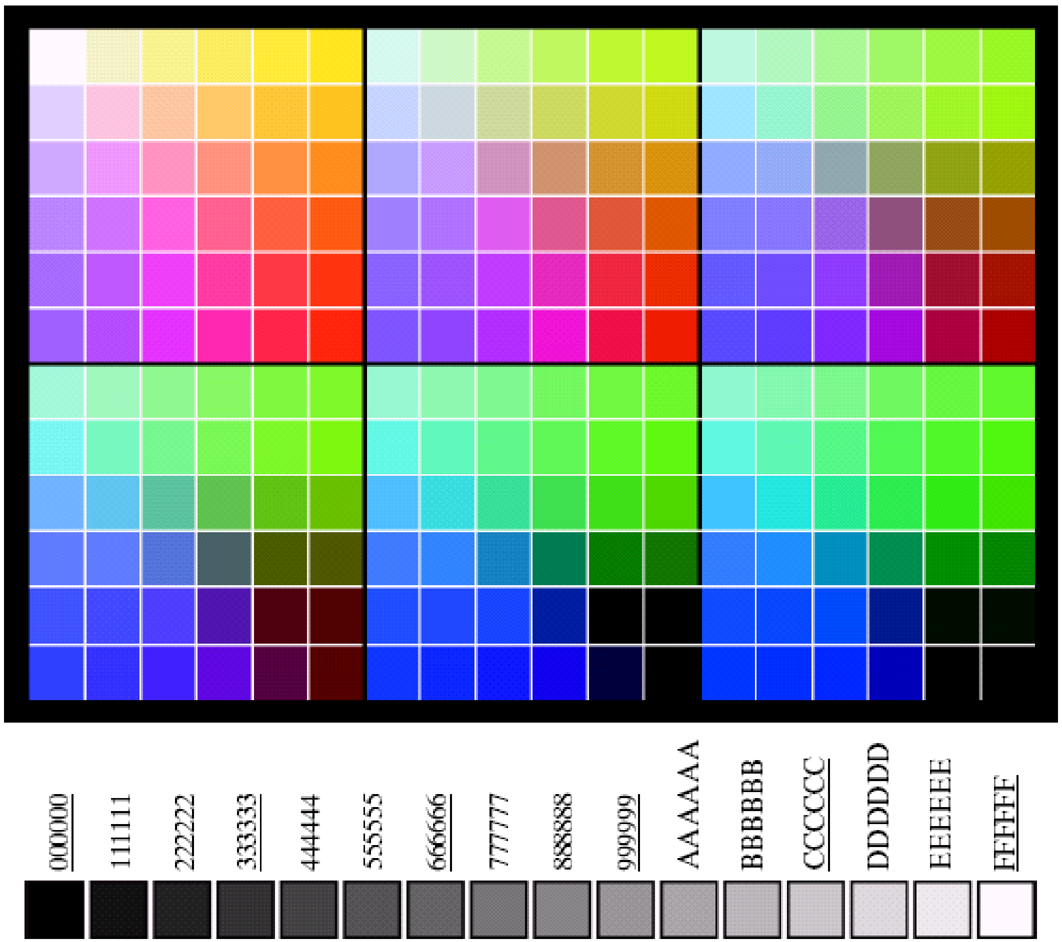
a
b

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.



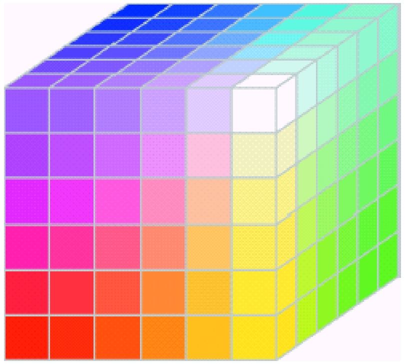
Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

TABLE 6.1 Valid values of each RGB component in a safe color.



a
b

FIGURE
(a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (gray that are part of the safe color group are shown underlined).



The RGB safe-color cube.

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 by the following:

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

YIQ color model

- Each color is represented in terms of a **luminance** component (*Y*) and two **chrominance** or color components: **in-phase** (*I*) and **quadrature** (*Q*) components.
- Used in United Sates commercial TV broadcasting (NTSC system).
- The *Y* component provided all the video information required by a monochrome TV receiver/monitor.
- It is related to the RGB model by:

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

- The main advantage of the YIQ model is that the luminance and chrominance components are decoupled and can be processed separately.

HSI or HSV color model

- Each color is specified in terms of its **Hue** (*H*), **Saturation** (*S*) and **intensity** (*I*) or **value** (*V*)
- Note that the *I* in HSI model is different than the *I* in YIQ model. This model is sometimes referred to as HSV instead of HSI.
- 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.
- In short, the RGB model is suited for image color generation, whereas the HIS model is suited for image color description.
- It is related to the RGB model as follows:

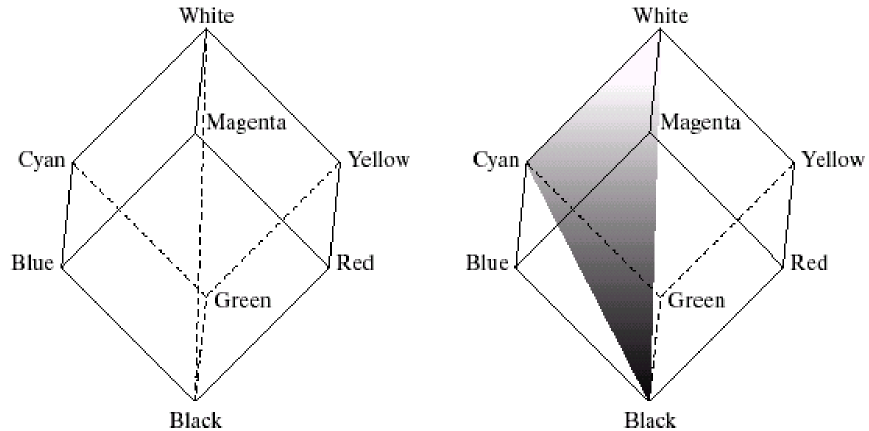
$$I = V = \frac{1}{3}(R+G+B)$$

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

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

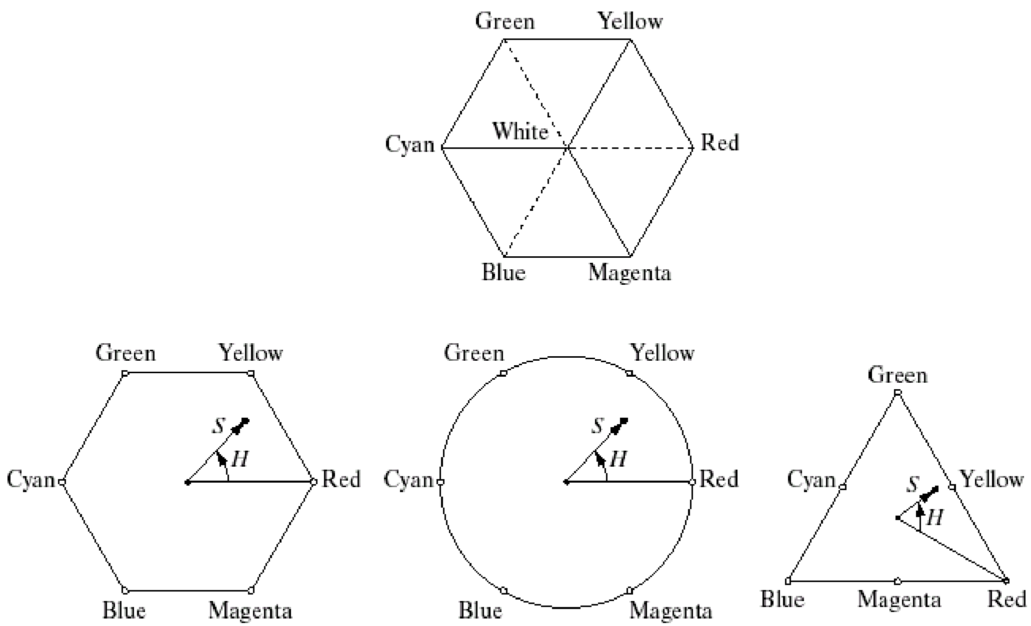
$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\}$$

- Equation for inverse transformations are given in the text .



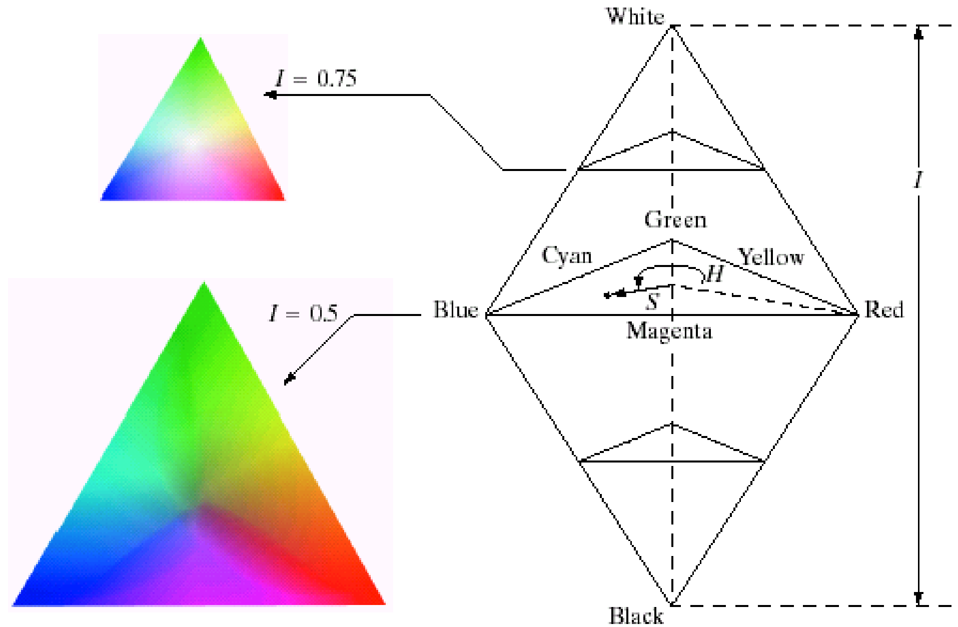
a b

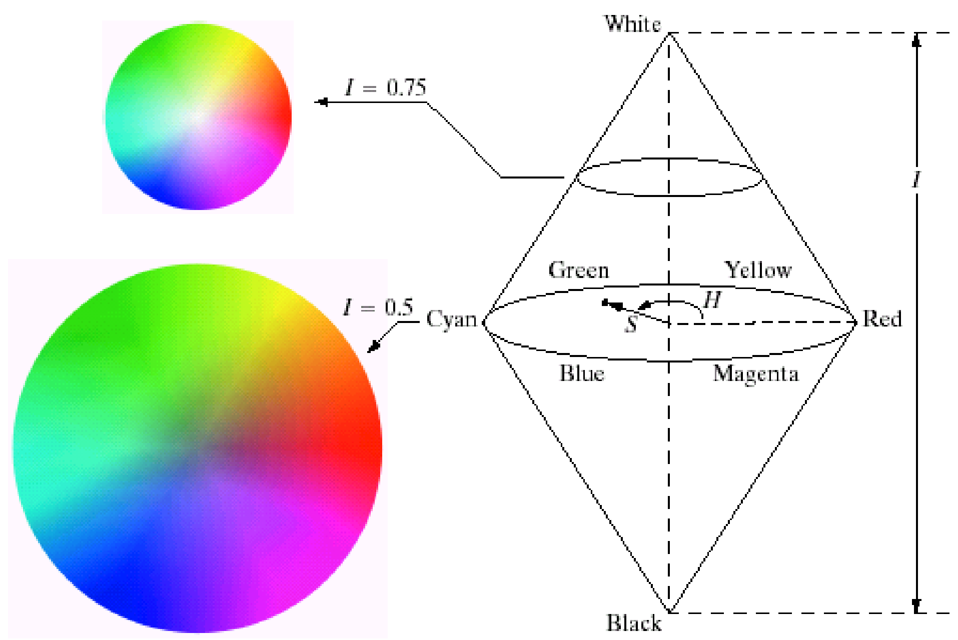
FIGURE 6.10 Conceptual relationships between the RGB and HSI color models.



a
b c d

FIGURE 6.11 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.





a
b

FIGURE 6.12 The HSI color model based on (a) triangular and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

Manipulation of HSI components

- Consider the primary colors char below and the corresponding HIS component images.

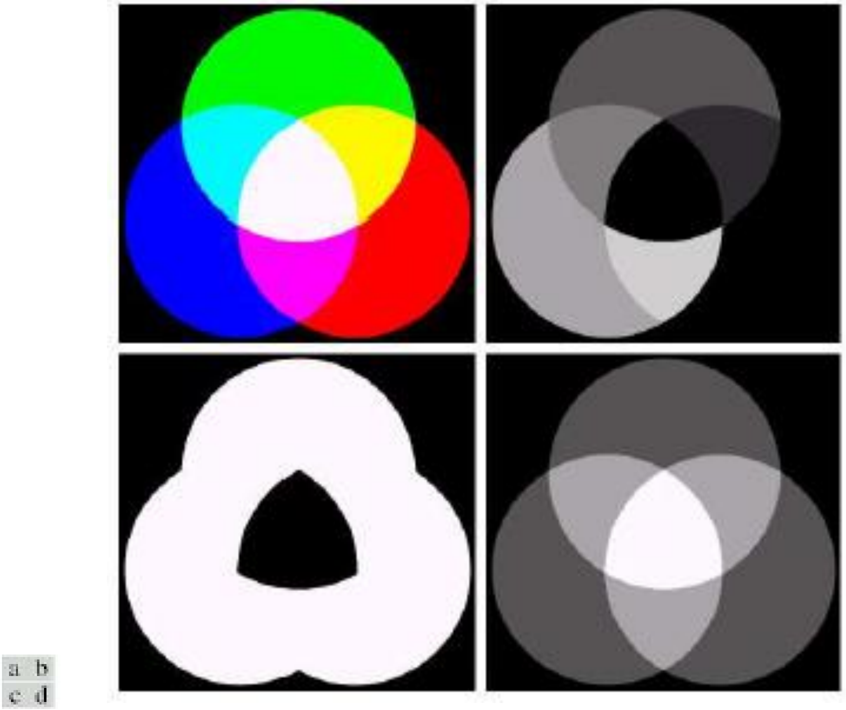
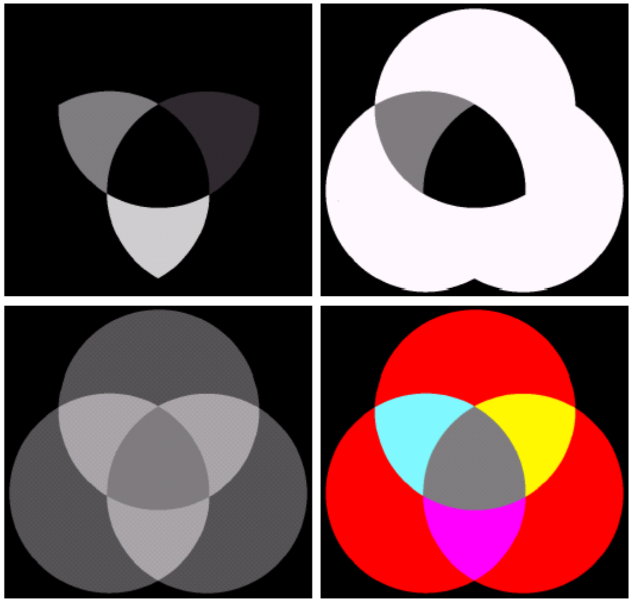


FIGURE 6.14 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.

- To change the individual color of any region in the RGB image, we change the value of the corresponding region in the Hue image. Then we convert the new H image with the original S and I images to get the transformed RGB image.

- We can modify saturation and intensity like-wise, by manipulating the corresponding component image in the HSI model.

- For example, we can manipulate the RGB color chart as follows:
  - Change all the green and blue regions into red by setting to 0 the corresponding regions in the H component image.
  - Reduce the saturation of the Cyan region by ½ by manipulating the corresponding region in the S component image.
  - Reduce by ½ the intensity of the white region by manipulating the corresponding region in the I component image.
- The resulting H, S, and I images are converted back to RGB and displayed below.



a b
c d

FIGURE 6.15 (a)-(c) Modified HSI component images (d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)

Pseudo Coloring

- Assign colors to monochrome images, base on various properties of their graylevel content.
- It is mainly used for human visualization and interpretation.
- Several transformations can be used for this purpose.
- For example, we may use a different enhancement technique to highlight different features and color code them appropriately.

Intensity Slicing

- View an image as a 2-D intensity function. Slice the intensity (or density) function by a plane parallel to the coordinate axes.
- Pixel with grayvalues above the plane are color coded with one color and those below are coded with a different color.

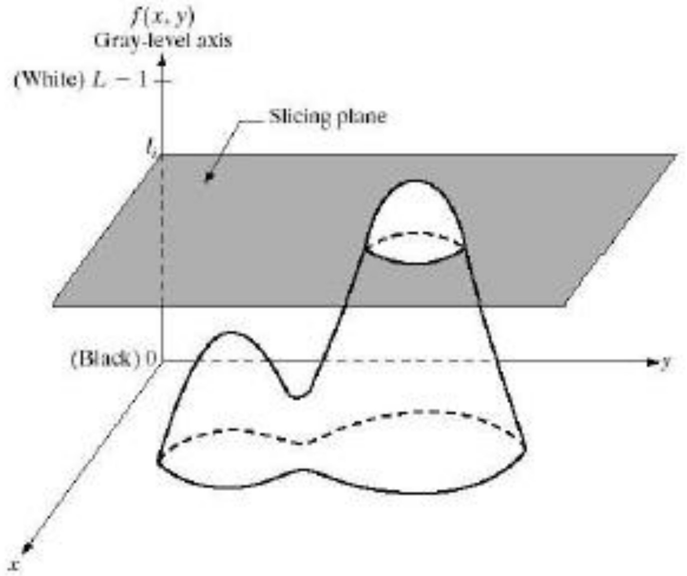
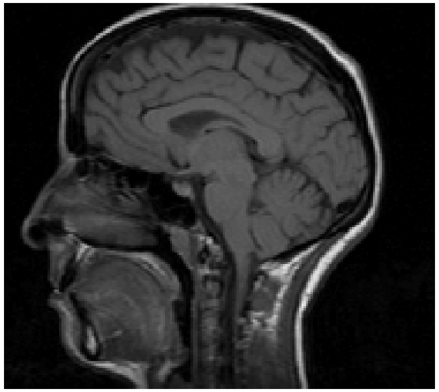


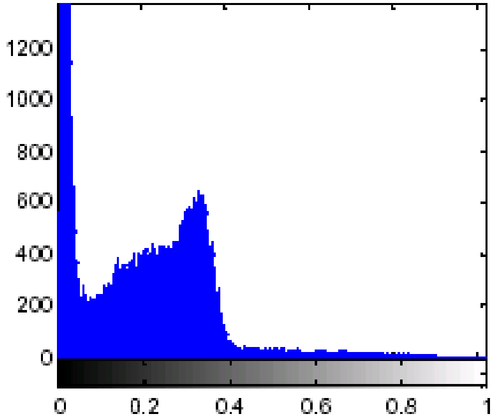
FIGURE 6.16 Geometric interpretation of the intensity-slicing technique.

- This gives a two-color image. Similar to thresholding but with colors.
- Technique can be easily extended to more than one plane.

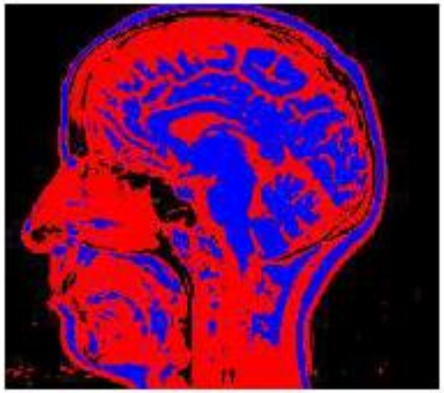
Example



Monochrome Image



Histogram



Intensity Slicing:
Two colors

Intensity Slicing:
Three colors

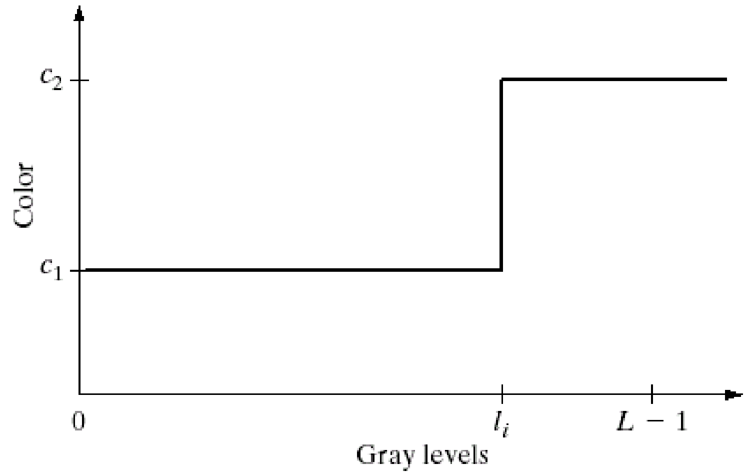
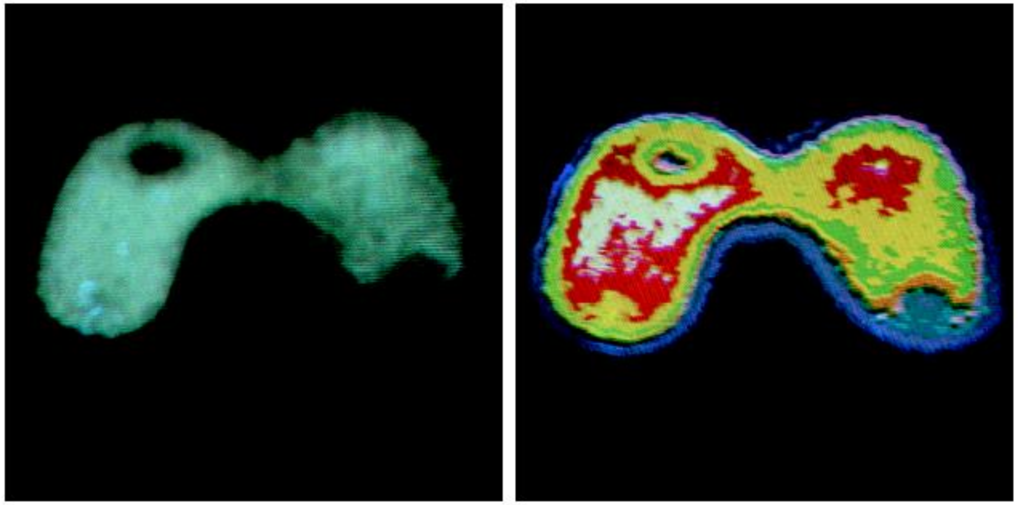
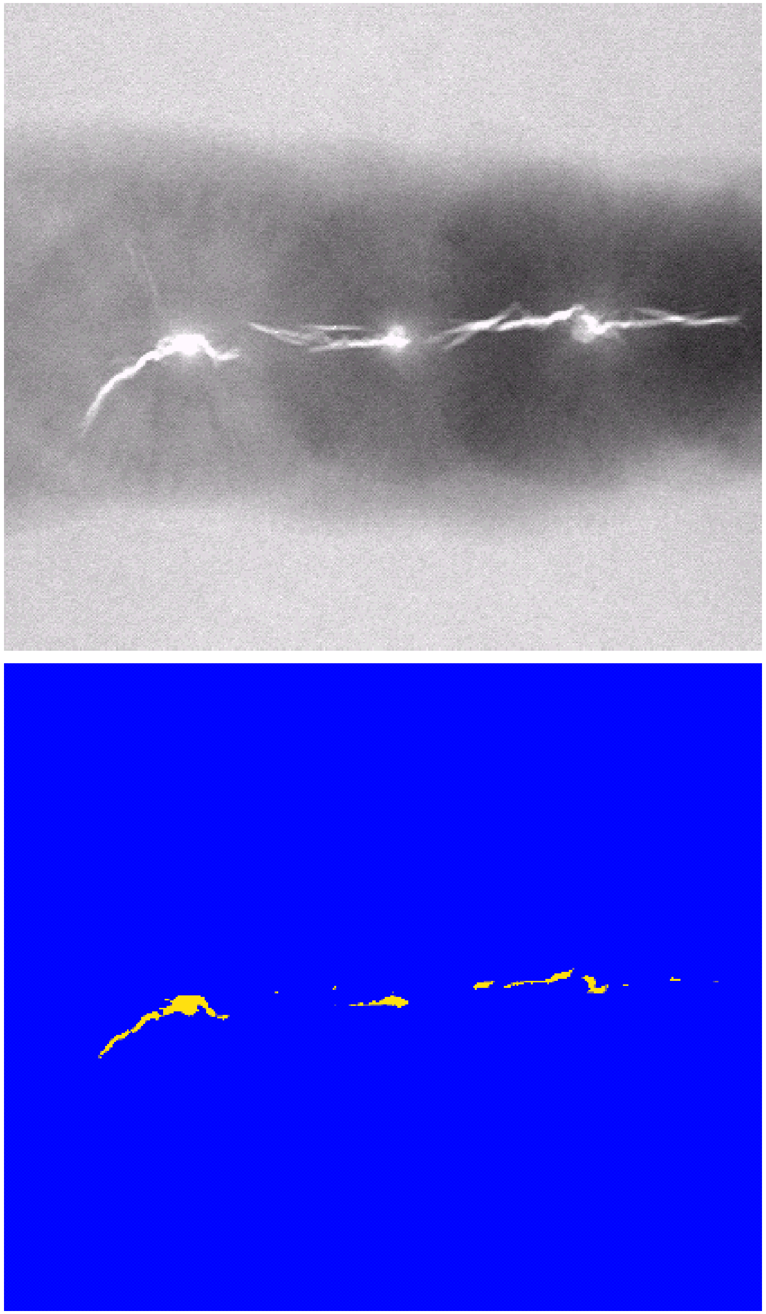


FIGURE 6.17 An alternative representation of the intensity-slicing technique.



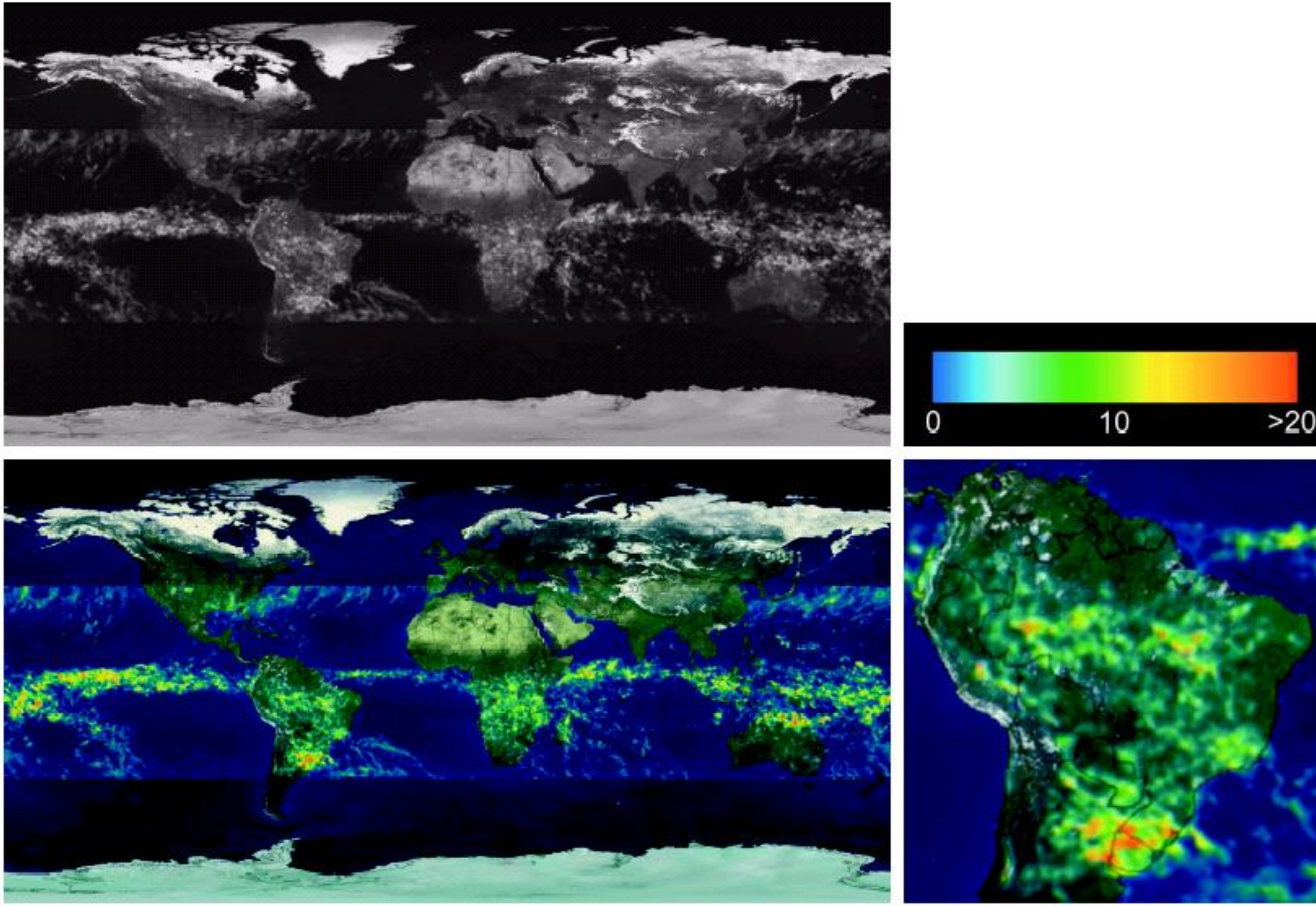
a b

FIGURE 6.18 (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 6.19 (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 6.20 (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 America region. (Courtesy of NASA.)

Gray Level to Color transformations

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

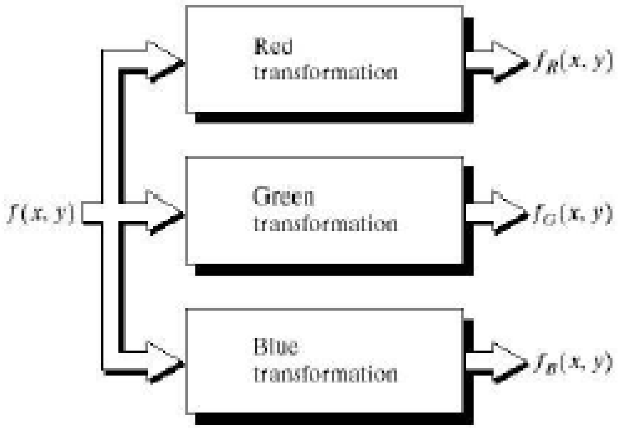


FIGURE 6.21 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

- This technique can also be used to combine several monochrome images into a single composite color image.

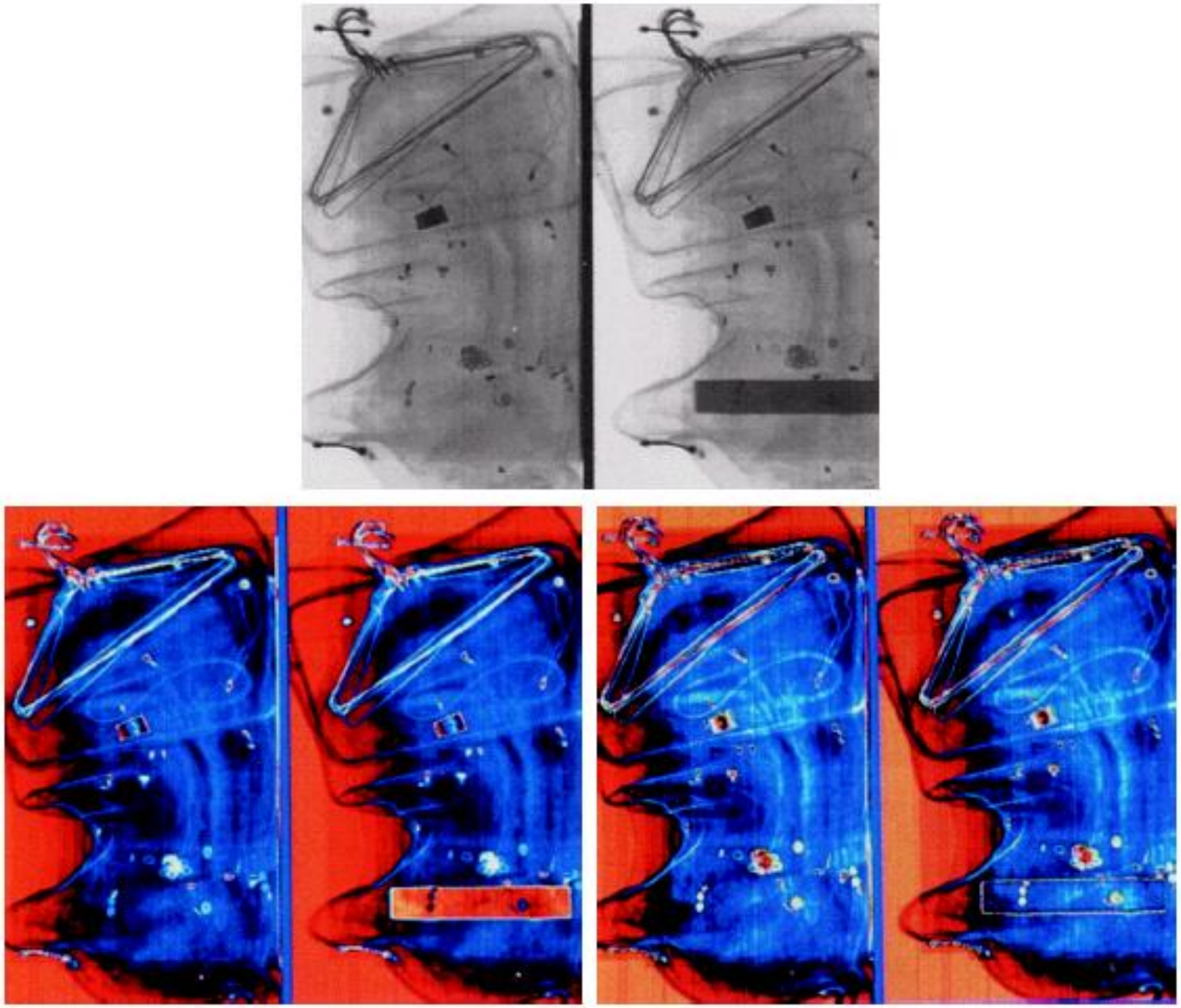


FIGURE 6.22 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25 (Origianl image courtesy of Dr. Mike Hurwitz, Westinghouse.)

a
b

FIGURE 6.23 Transformation function used to obtain the images in Fig. 6.24.

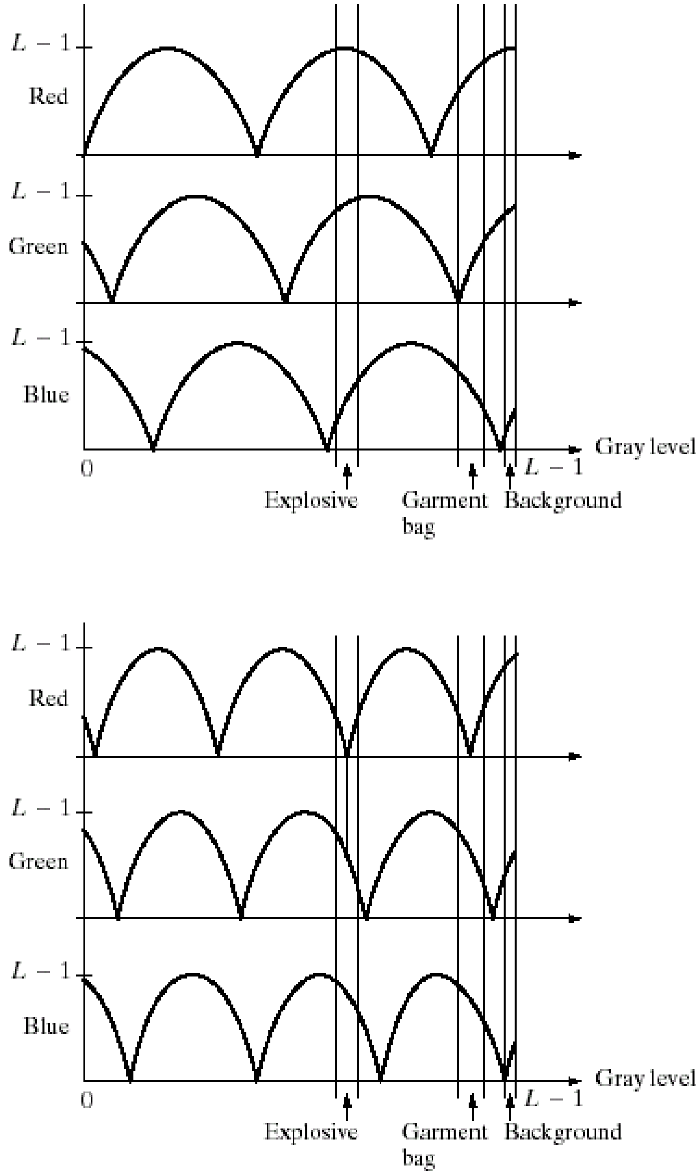
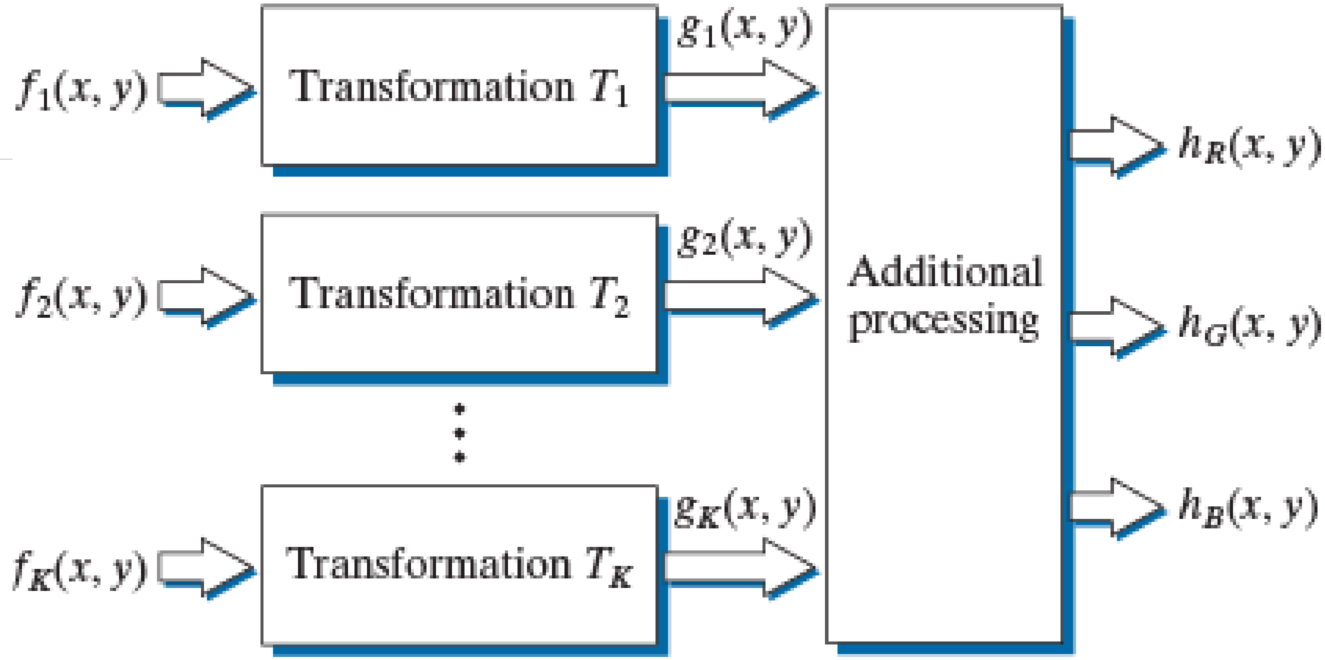
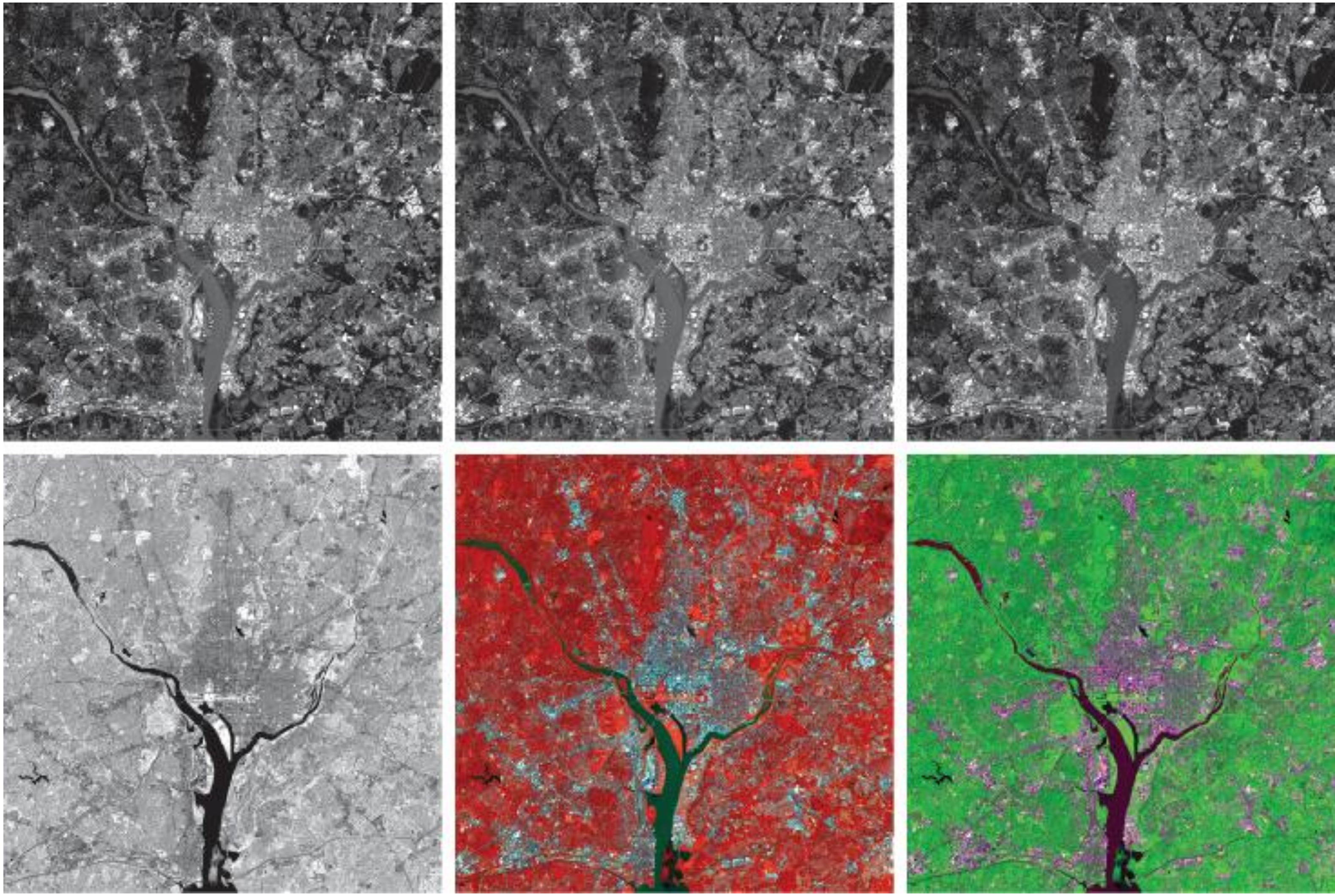


FIGURE 7.24 A pseudocolor coding approach using multiple grayscale images. The inputs are grayscale images. The outputs are the three components of an RGB composite image.



- This is frequently used in multispectral imaging, where different sensors produce individual monochrome images, each in a different spectral band.



a b c
d e f

FIGURE 7.25 (a)–(d) Red (R), green (G), blue (B), and near-infrared (IR) components of a LANDSAT multispectral image of the Washington, D.C. area. (e) RGB color composite image obtained using the IR, G, and B component images. (f) RGB color composite image obtained using the R, IR, and B component images. (Original multispectral images courtesy of NASA.)