Digital Image Processing

COSC 6380/4393

Lecture – 30

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Acknowledgment: Slides from Pourreza

What is color?

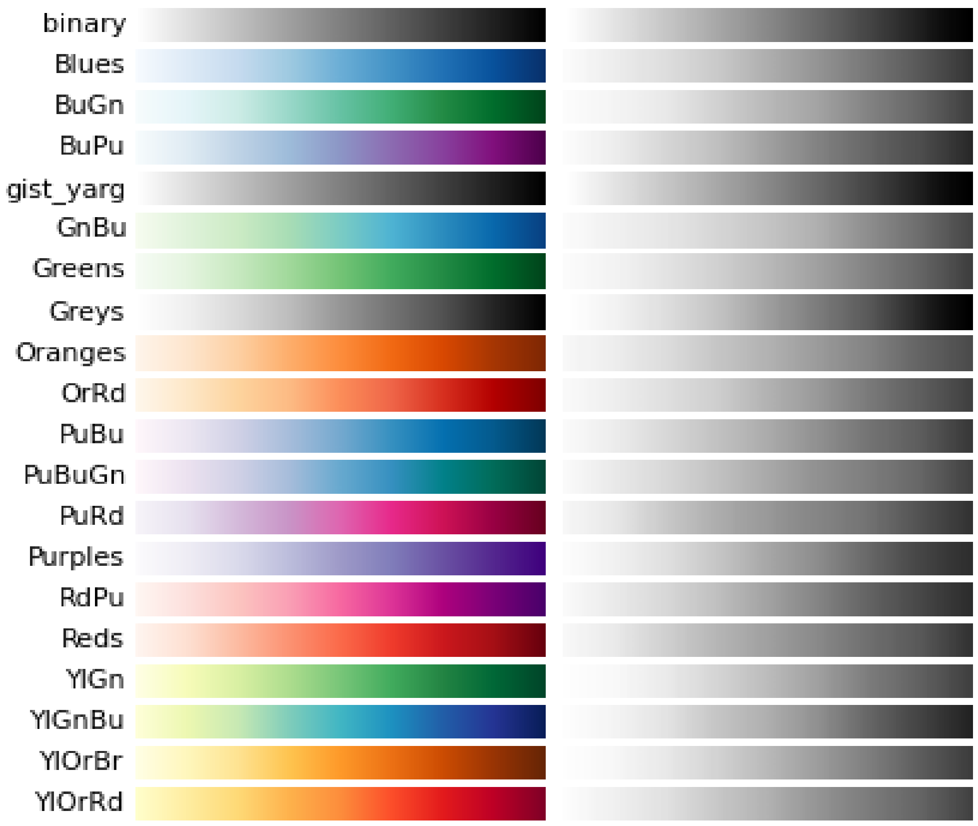
- Color is a psychological property of our visual experiences when we look at objects and lights,
  not a physical property of those objects or lights
  (S. Palmer, *Vision Science: Photons to Phenomenology*)
- Color is the result of interaction between physical light in the environment and our visual system

Wassily Kandinsky (1866-1944), Murnau Street with Women, 1908

Principal Descriptor

- Visual Descriptor
  - **SHAPE**
  - **COLOR**
  - **TEXTURE**
  - **MOTION**

Discerning Color



~1000 ~24

Color Fundamentals

- Cones are the sensors in the eye that are responsible for color vision
- 6 to 7 million cones in the human eye

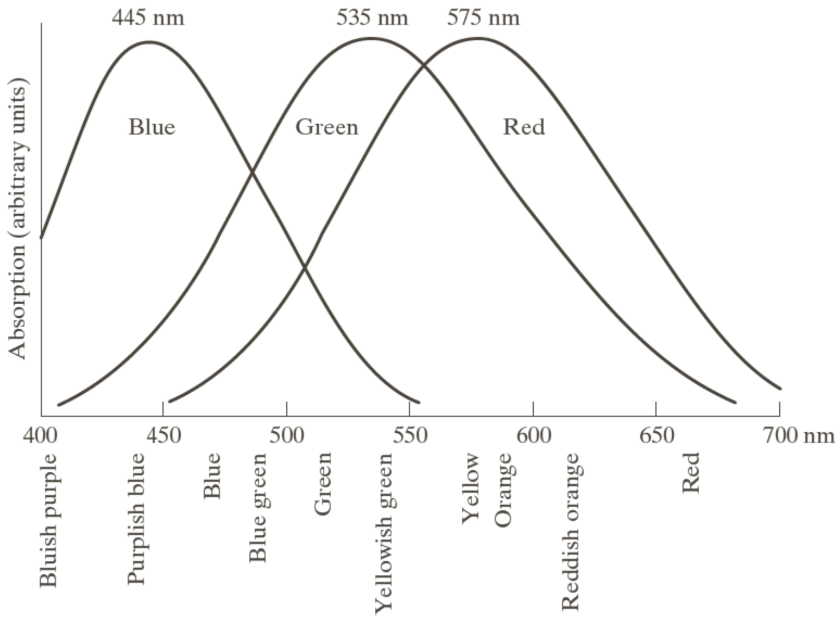
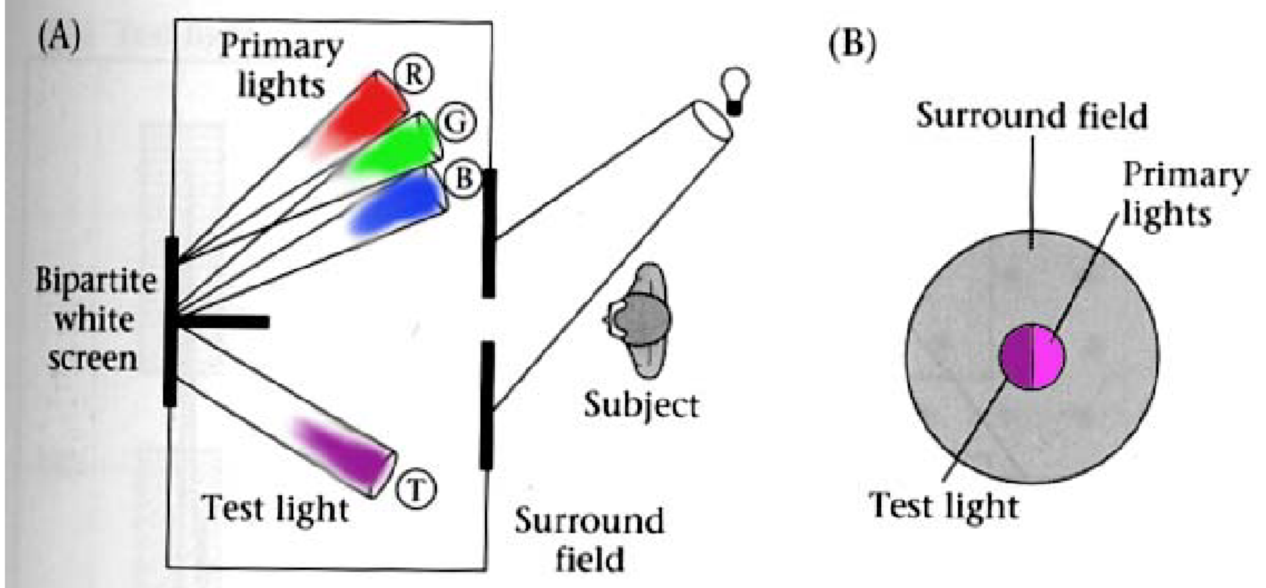


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Primary colors

- Due to the absorption characteristics of human eye,
- Primary colors:
  - Red
  - Green
  - Blue
- Color: described as a variable combination of the primary colors
- In 1931, CIE(International Commission on Illumination) defines specific wavelength values to the primary colors
  - B = 435.8 nm, G = 546.1 nm, R = 700 nm
  - However, we know that <u>no single color</u> may be called red, green, or blue

Color matching experiment



4.10 THE COLOR-MATCHING EXPERIMENT. The observer views a bipartite field and adjusts the intensities of the three primary lights to match the appearance of the test light. (A) A top view of the experimental apparatus. (B) The appearance of the stimuli to the observer. After Judd and Wyszecki, 1975.

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

slide from T. Darrel

CIE RGB

- Tri-stimulus values: Color defined by three value **(R,G,B)**
- The amount of Red, Green and Blue needed to form any particular color

CIE XYZ

- New color matching functions were to be everywhere greater than or equal to zero.
- For the constant energy white point, it was required that $x = y = z = 1/3$.

CIE XYZ model

- RGB -> CIE XYZ model

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.431 & 0.342 & 0.178 \\ 0.222 & 0.707 & 0.071 \\ 0.020 & 0.130 & 0.939 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Normalized tristimulus values

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

=> x+y+z=1. Thus, x, y (chromaticity coordinate) is enough to describe all colors

Color models

- Color model, color space, color system
  - Specify colors in a standard way
  - A coordinate system that each color is represented by a single point

- RGB model
- CYM model
- CYMK model
- HSI model

Suitable for hardware or applications

- match the human description

RGB Color Model

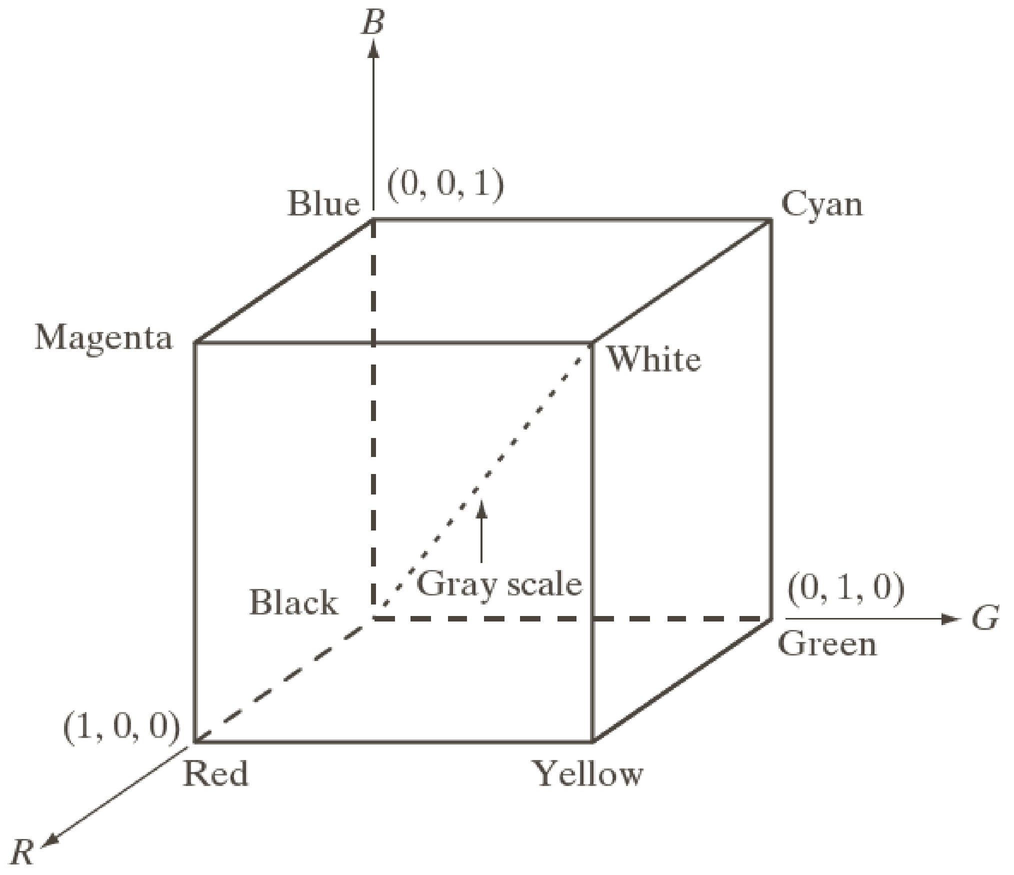


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

RGB Color Model

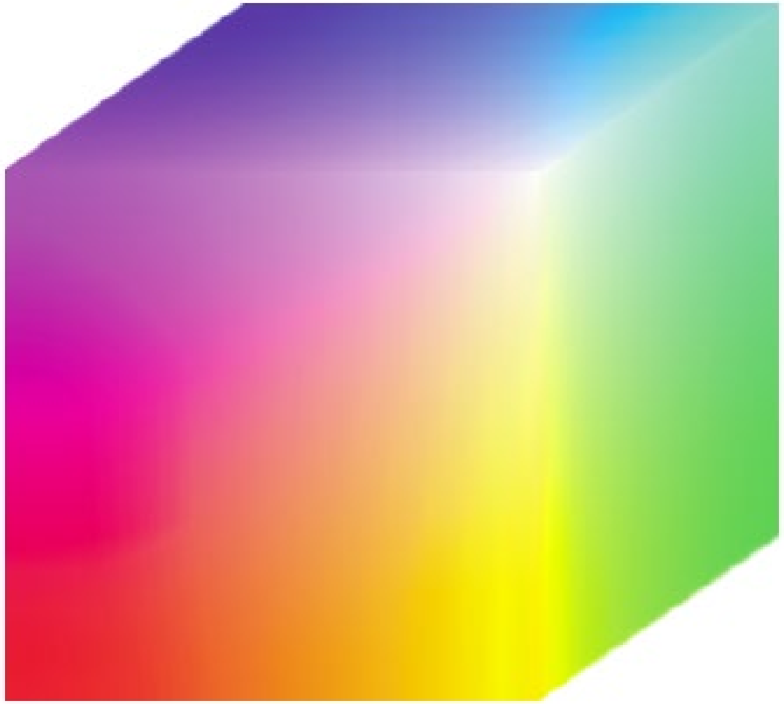


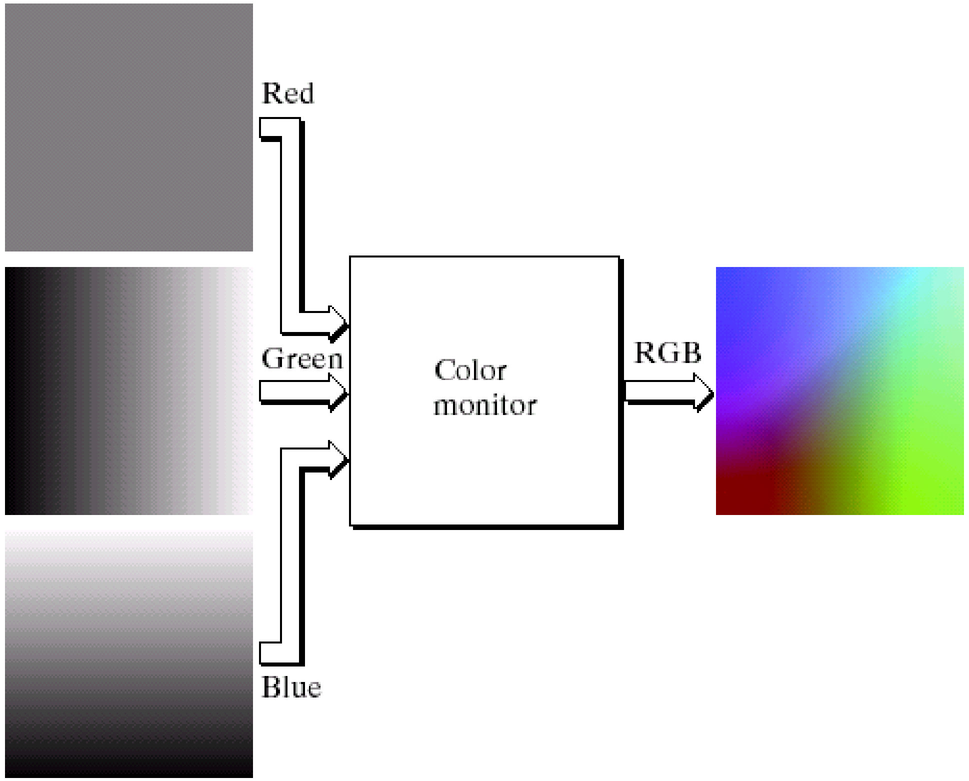
FIGURE 6.8 RGB 24-bit color cube.

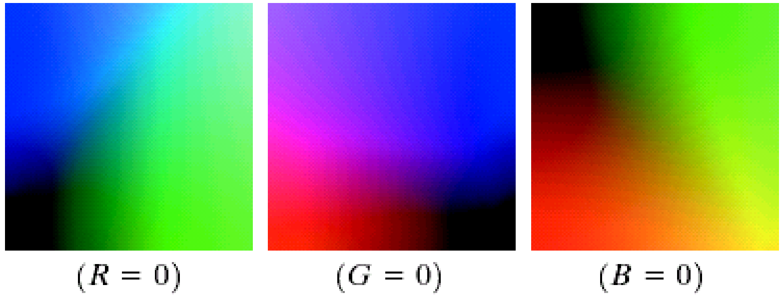
Pixel depth

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

a
b

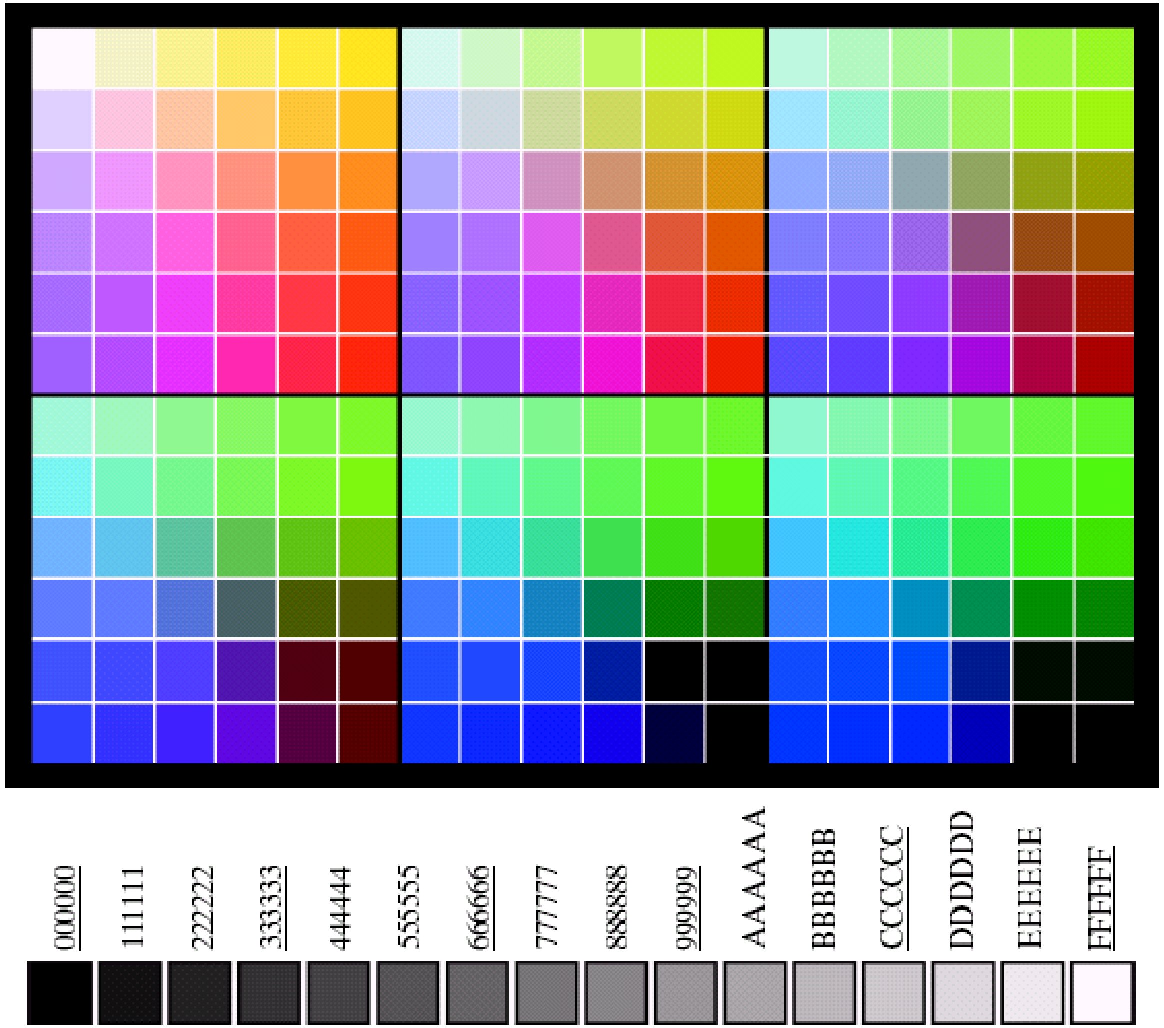
FIGURE 6.9
(a) Generating the RGB image of the cross-sectional color plane $(127, G, B)$.
(b) The three hidden surface planes in the color cube of Fig. 6.8.





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

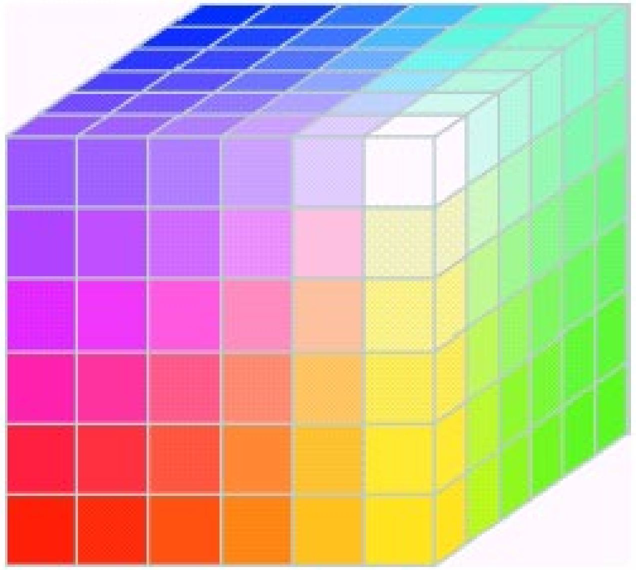
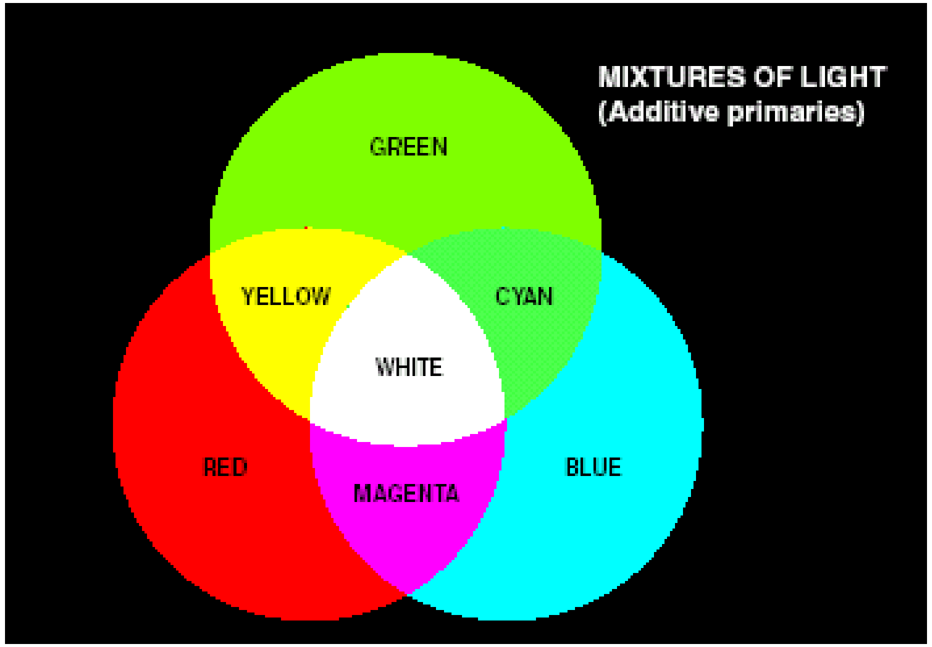


FIGURE 6.11 The RGB safe-color cube.

CMY model (+Black = CMYK)

- CMY: secondary colors of light, or primary colors of pigments
- Used to generate hardcopy output

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



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

- Will you describe a color using its R, G, B components?
- Human describe a color by its hue, saturation, and brightness
  - Hue: color attribute
  - Saturation: purity of color (white->0, primary color->1)
  - Brightness: achromatic notion of intensity

RGB Color Model

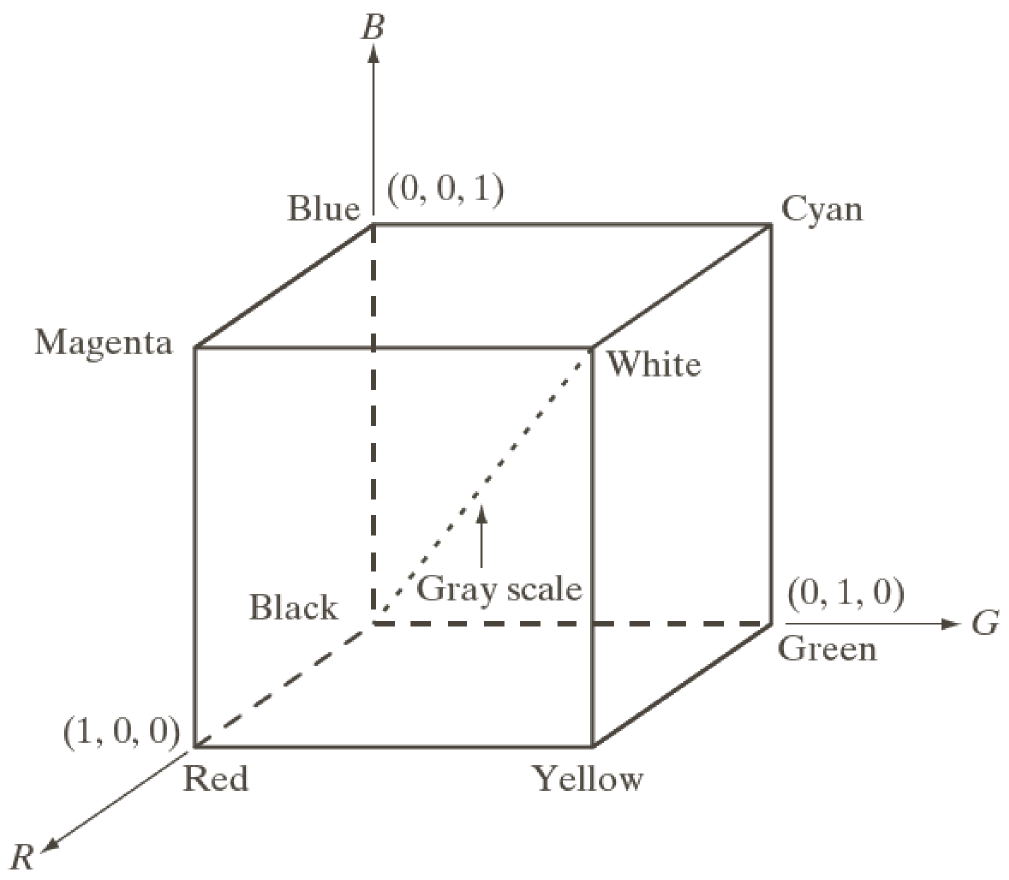
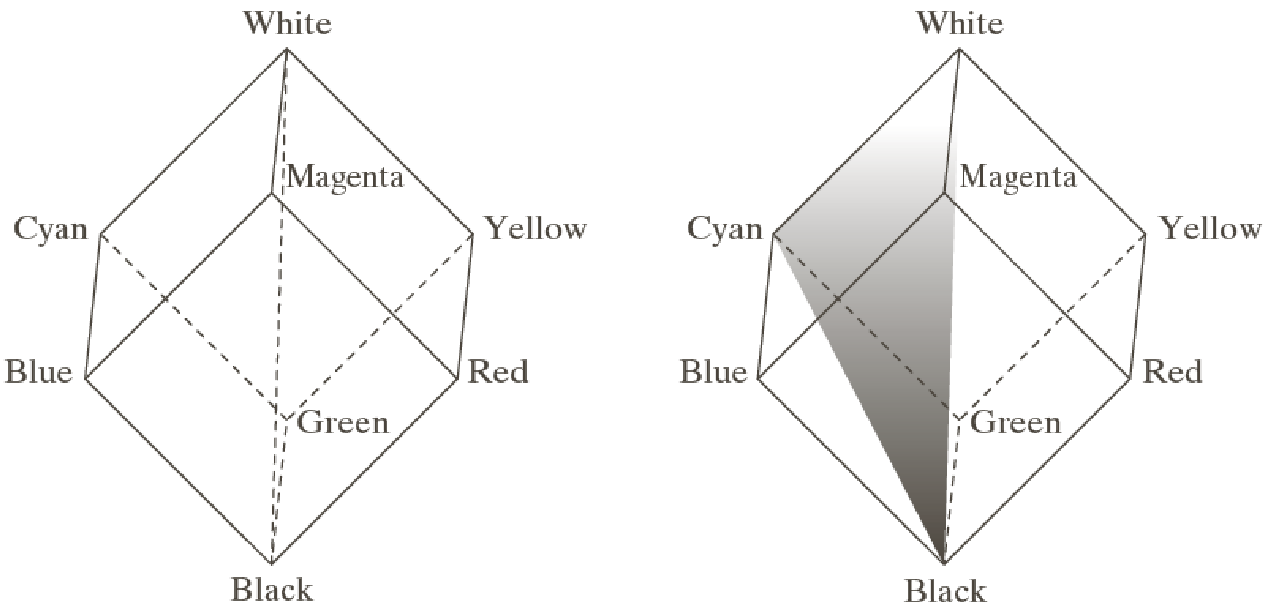


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

HIS Color Model



a b

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

HIS Color Model

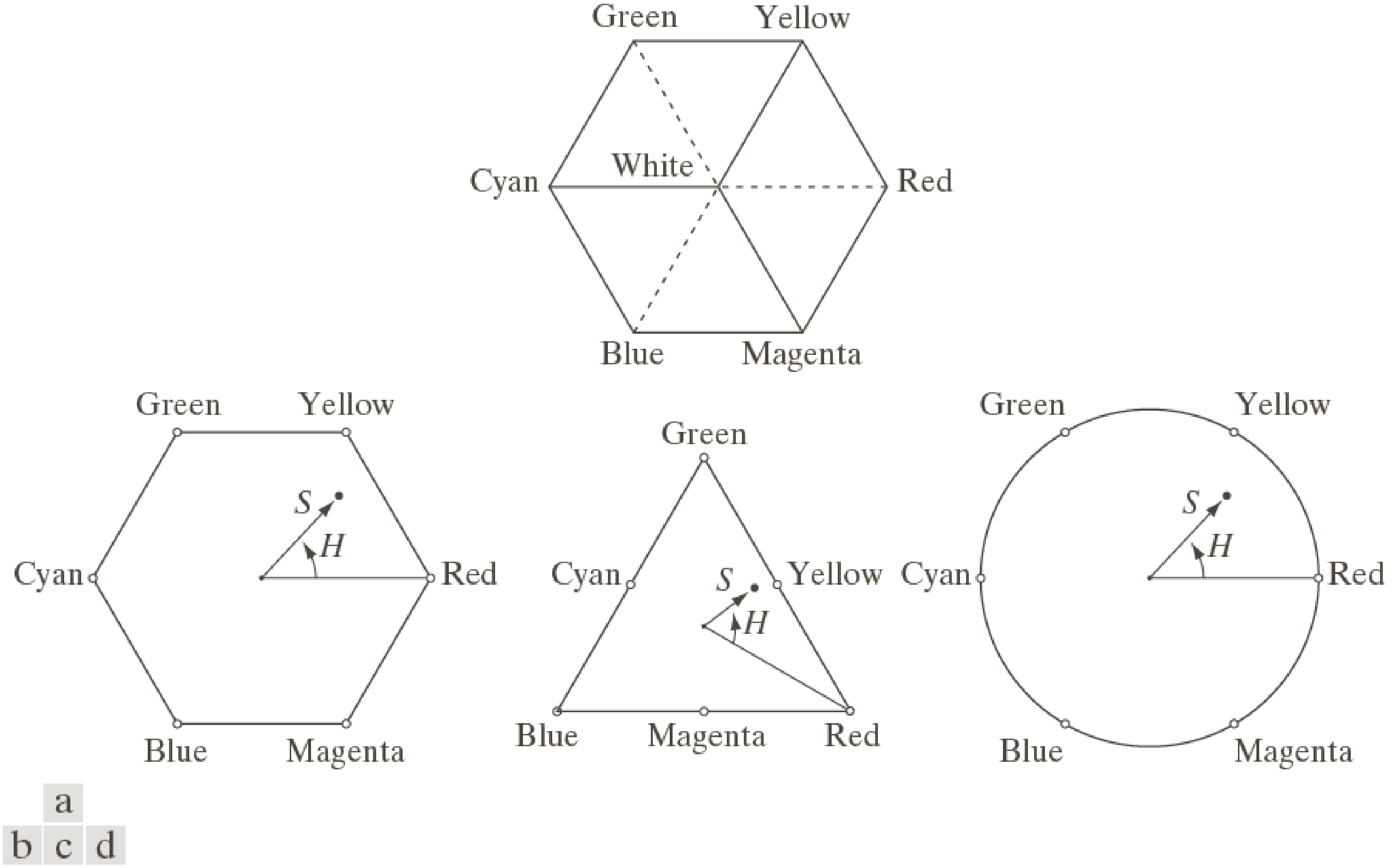
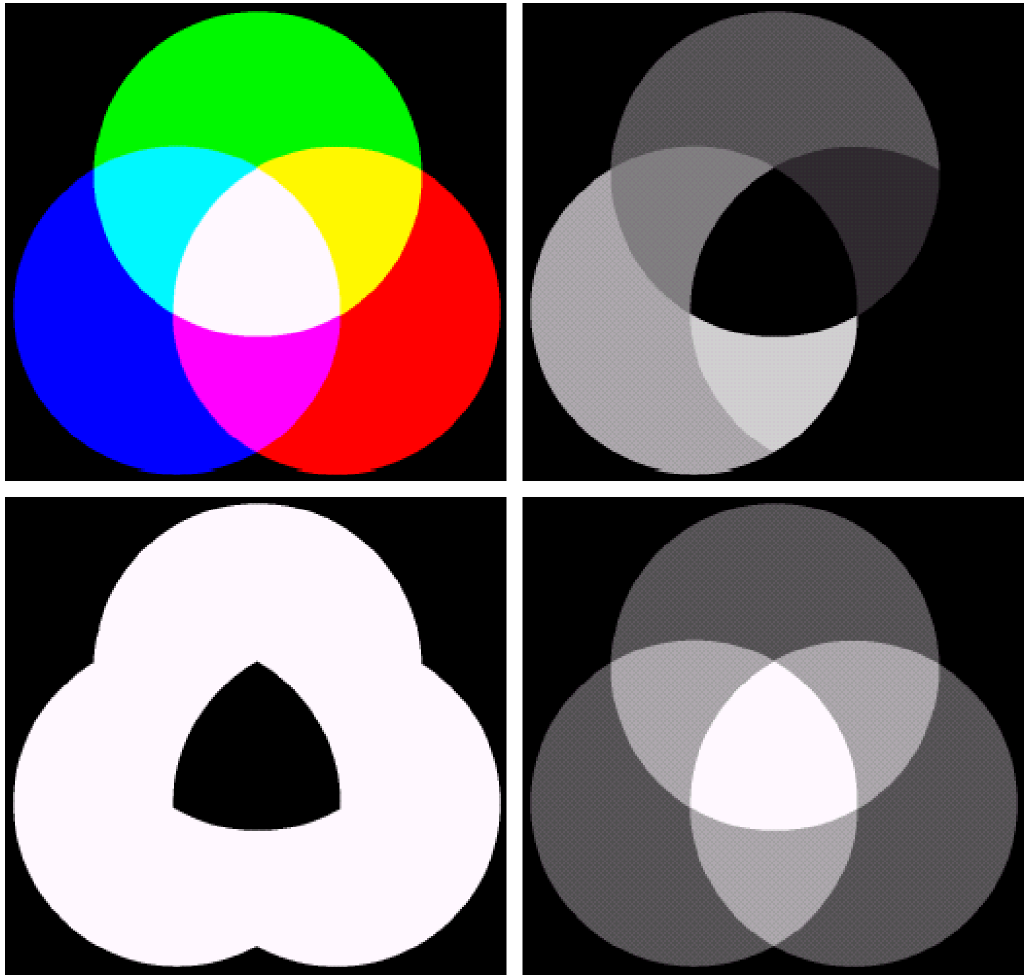


FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.



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.

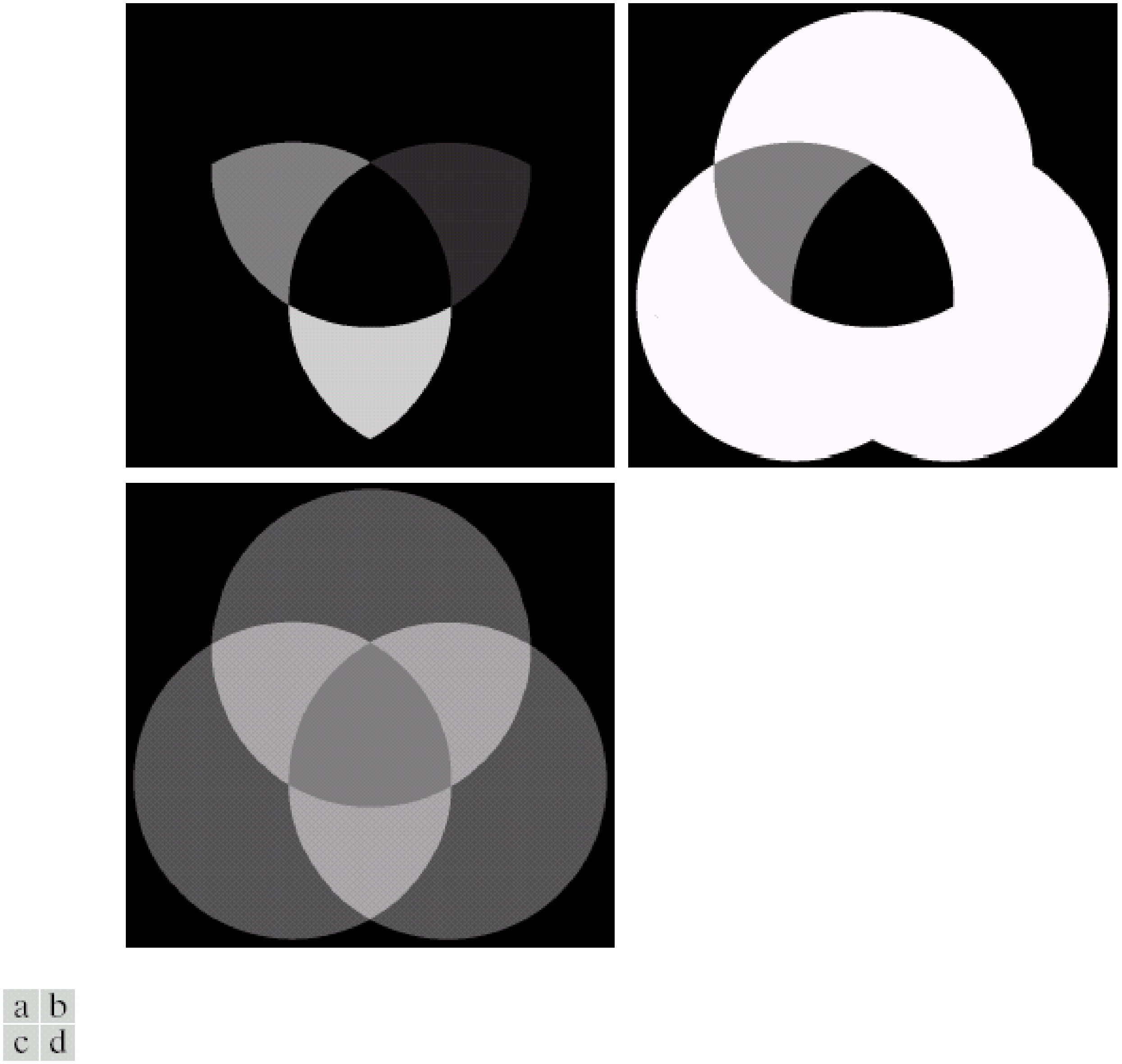


FIGURE 6.17 (a)–(c) Modified HSI component images. (d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)

Pseudocolor Image Processing

- **Pseudocolor (also called false color) image processing consists of assigning colors to gray values based on a specified criterion.**

- **The principal use of pseudocolor is for human visualization and interpretation of gray-scale events in an image or sequence of images.**

1. **Intensity Slicing**
2. **Gray Level to Color Transformations**

Intensity Slicing

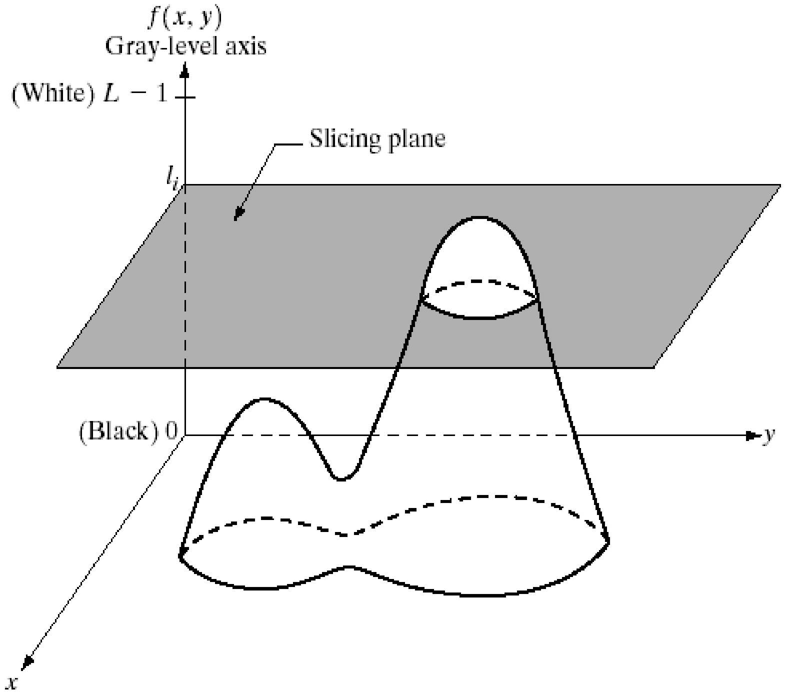


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

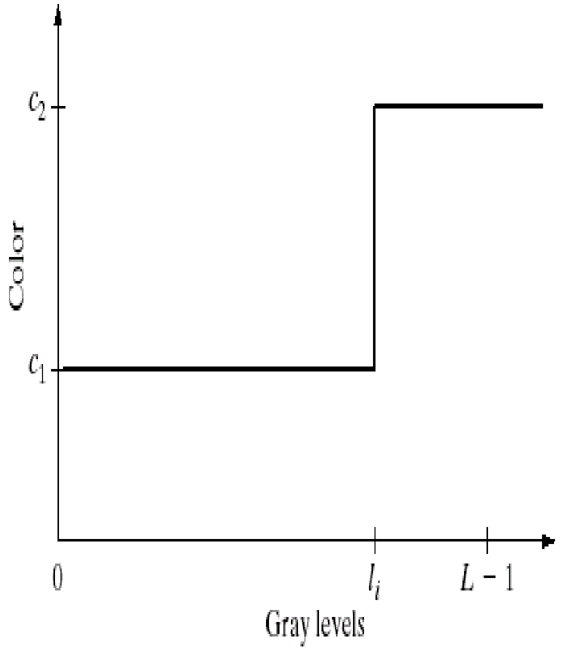
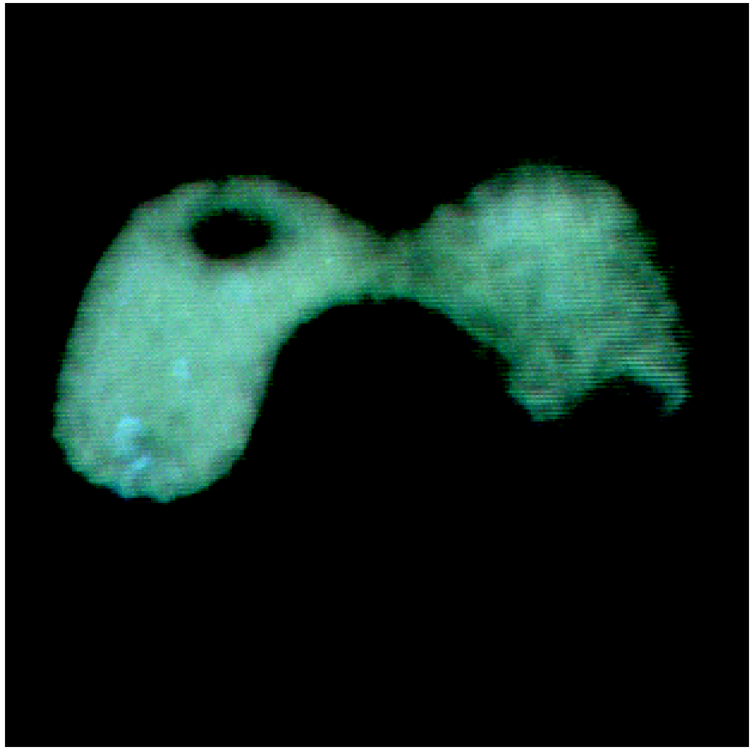


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

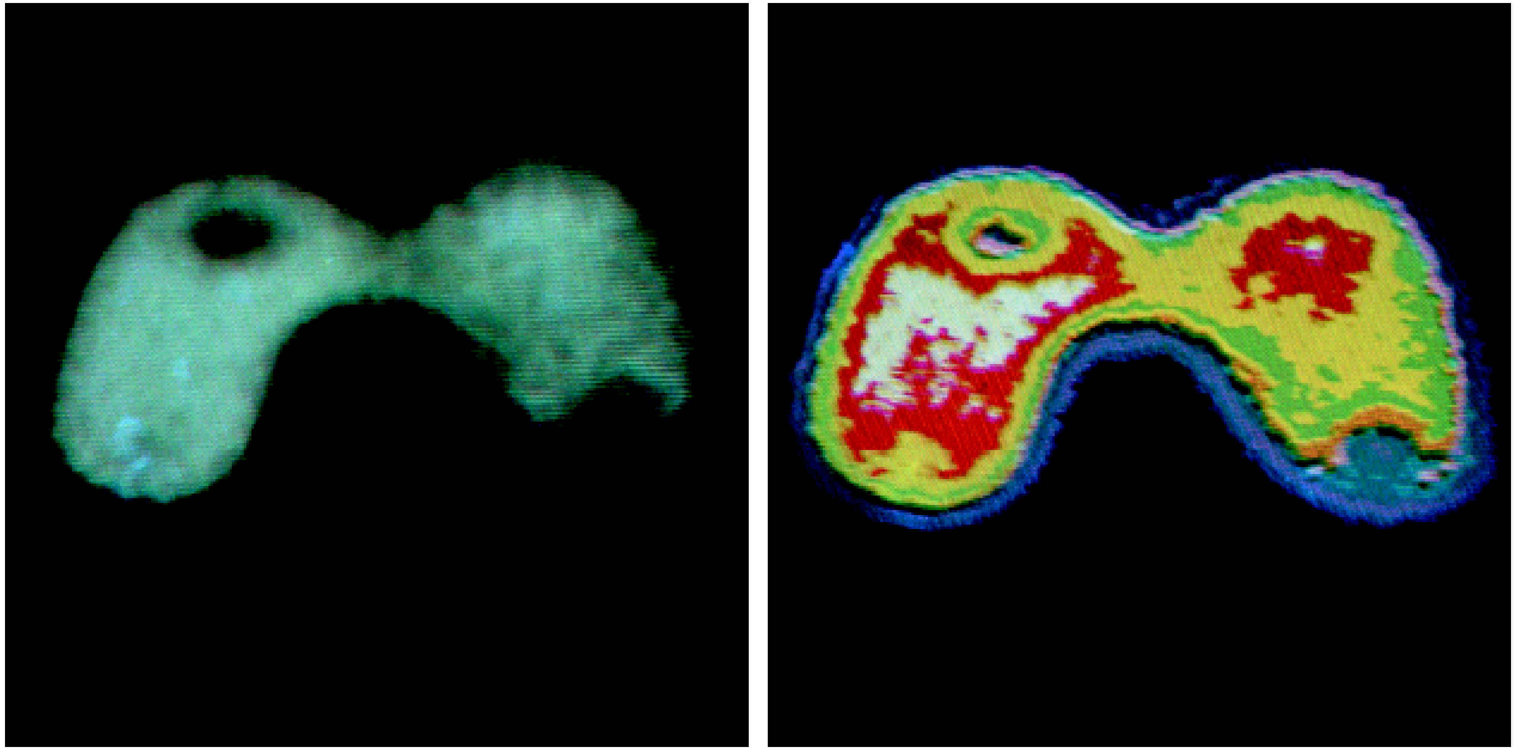
Intensity Slicing (con't)



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.)

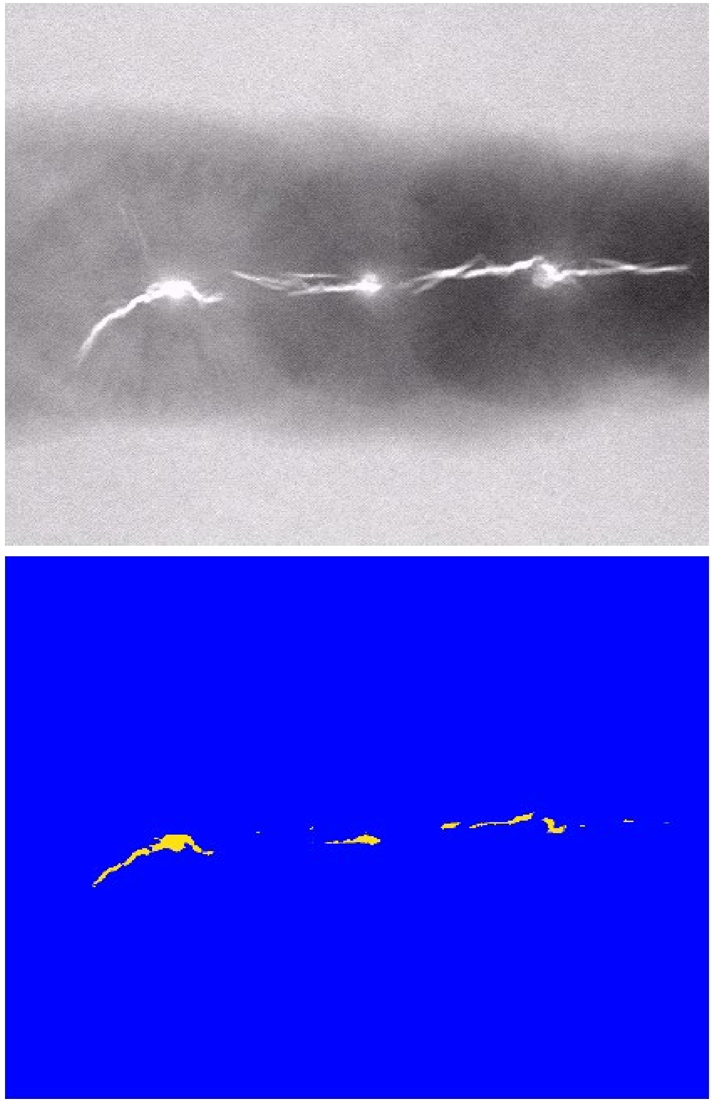
Intensity Slicing (con't)



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.)

Intensity Slicing (con't)



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.)

Gray Level to Color Transformations

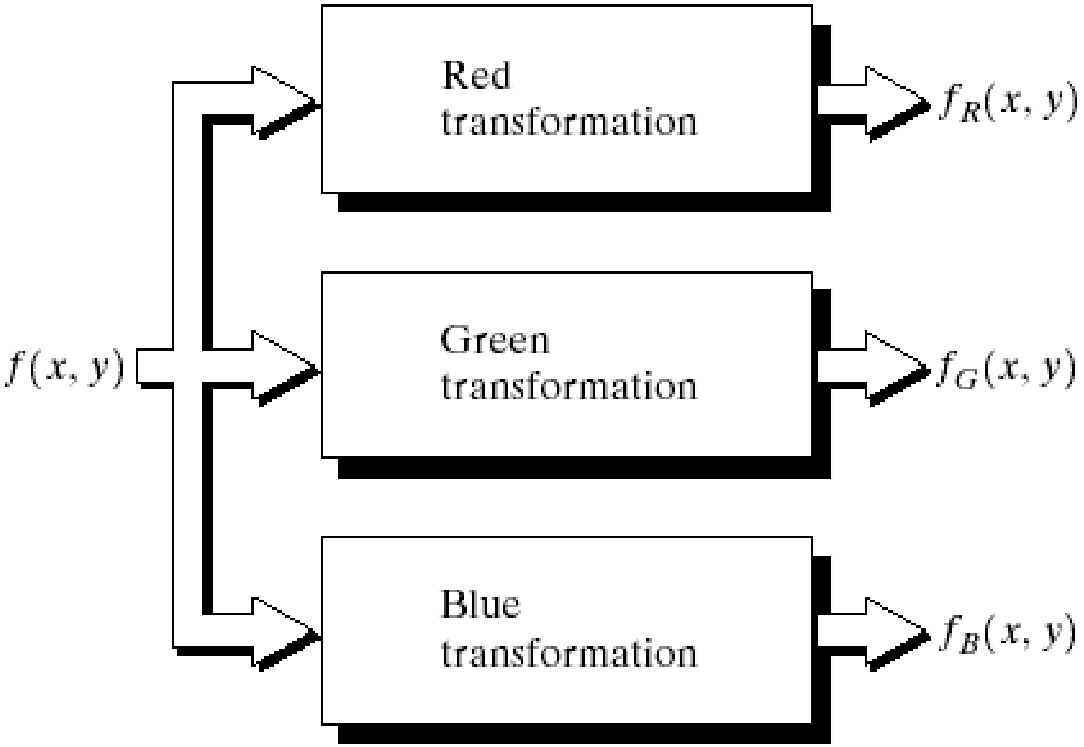
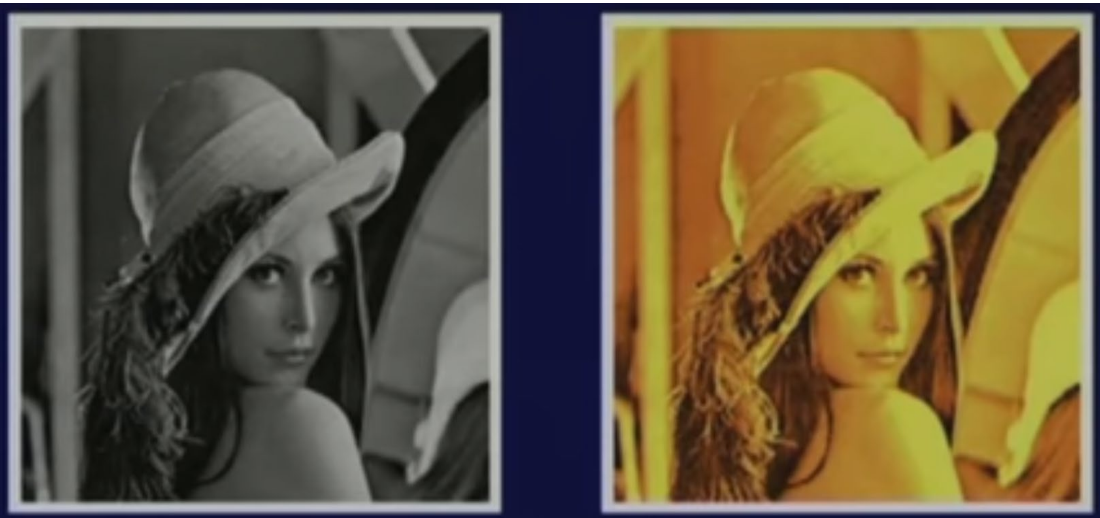


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

Gray Level to Color Transformations



$$f_R(x, y) = f(x, y)$$

$$f_G(x, y) = 0.33\, f(x, y)$$

$$f_B(x, y) = 0.11\, f(x, y)$$

Slide: nptelhrd

Gray Level to Color Transformations

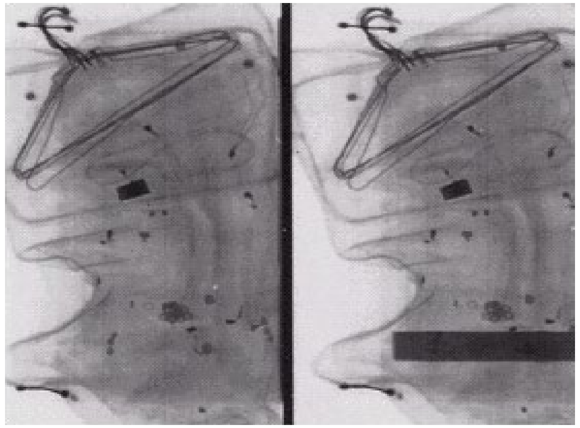
$$f_R(x, y) = 0.33\, f(x, y)$$

$$f_G(x, y) = f(x, y)$$

$$f_B(x, y) = 0.11\, f(x, y)$$

Slide: nptelhrd

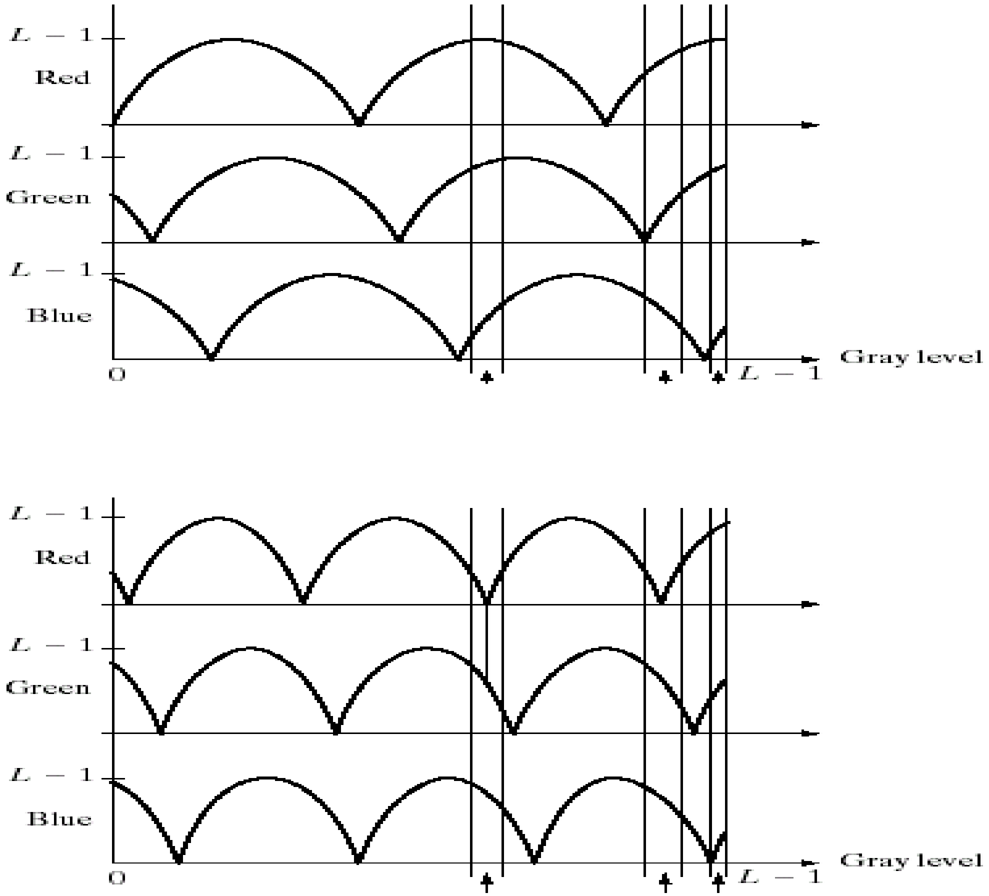
Gray Level to Color Transformations



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.)

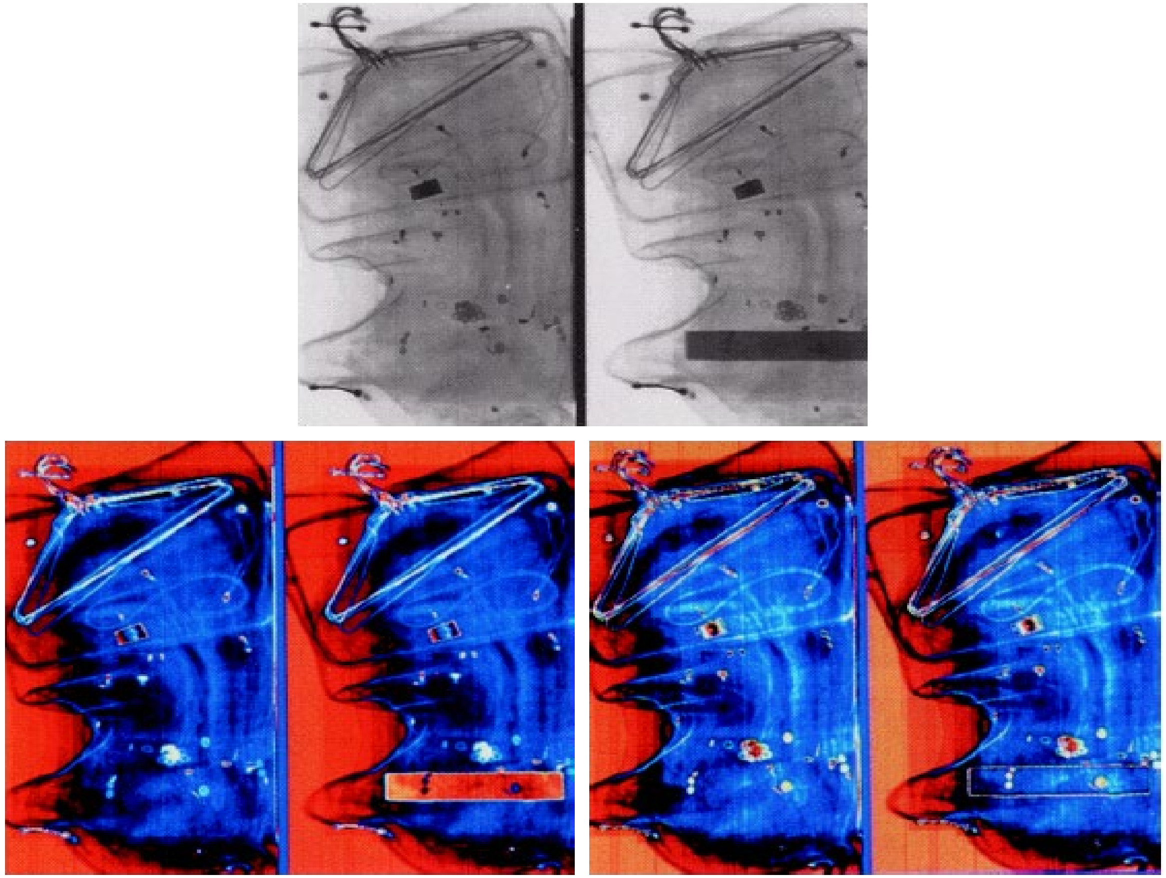
Gray Level to Color Transformations



a
b

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

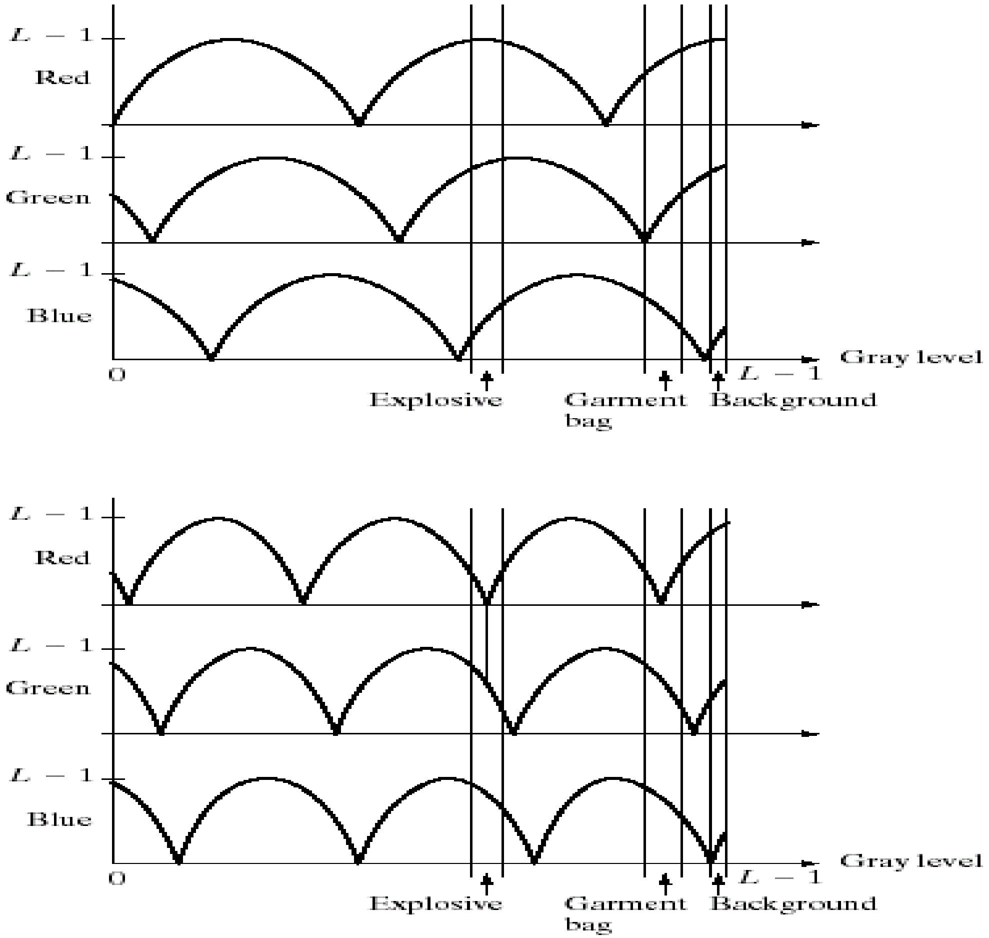
Gray Level to Color Transformations



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.)

Gray Level to Color Transformations



a
b

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

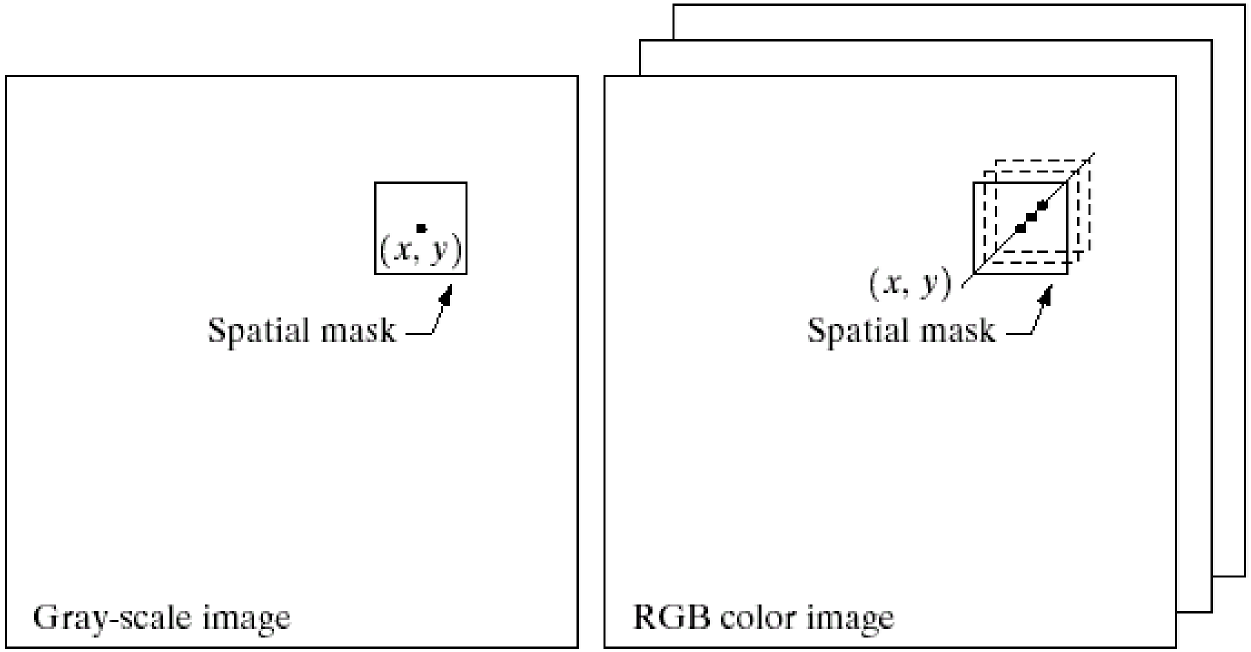
Basic of Full-Color Image Processing

- **Major categories of full-color Image processing:**
  - **Per-color-component processing**
  - **Vector-based processing**

Basic of Full Color Image Processing

a b

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



Basic of Full Color Image Processing

Let c represent an arbitrary vector in RGB color space

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

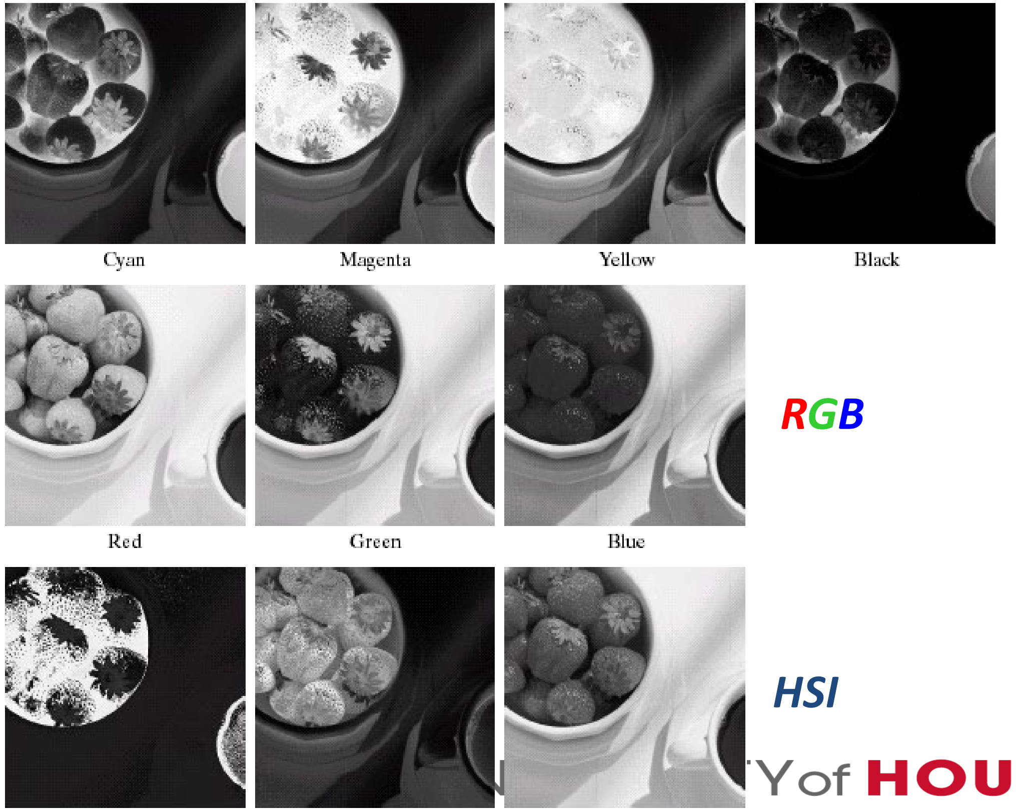
For an image of size M*N,

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

Full-Color Image Processing

Color Transformation

FIGURE 6.30 A full-color image and its various color-space components. (Original image courtesy of Med-Data Interactive.)



CMYK

RGB

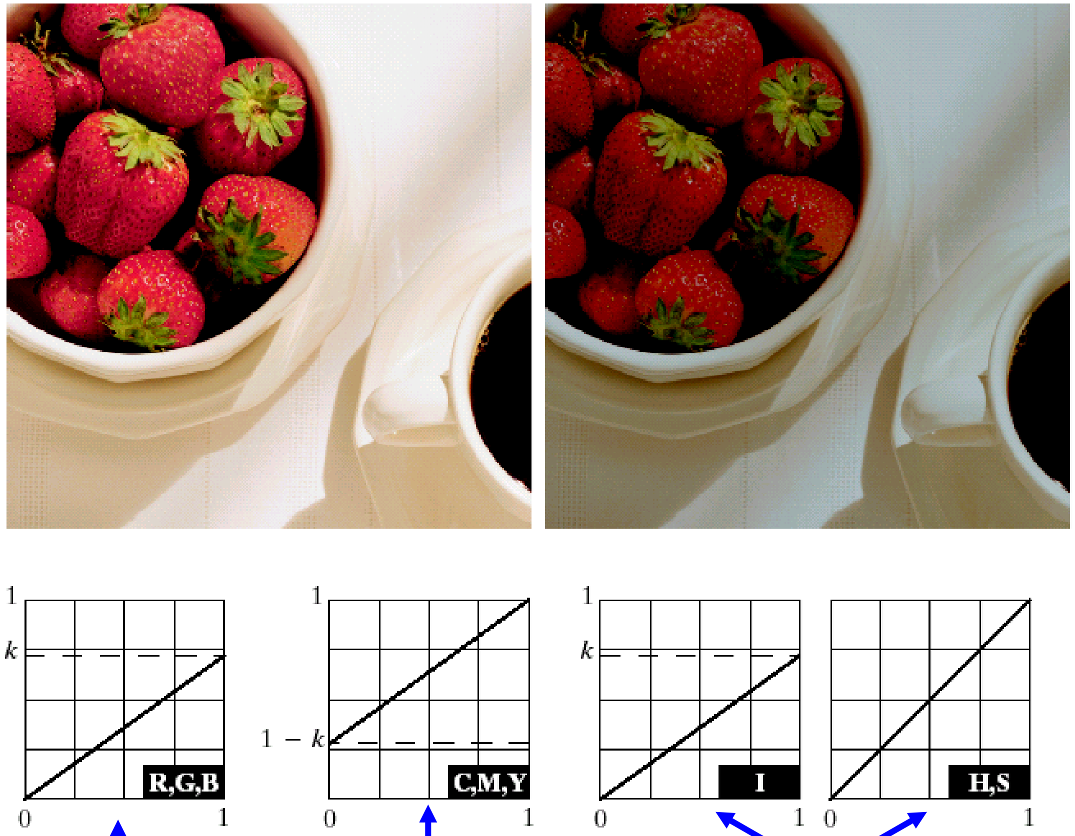
HSI

Full-Color Image Processing

Color Transformation: Modify the 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.)



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

$$s_i = kr_i \qquad i = 1,2,3$$

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

$$s_1 = r_1$$
$$s_2 = r_2$$
$$s_3 = kr_3$$

Full-Color Image Processing

Color Transformation: Color Complement

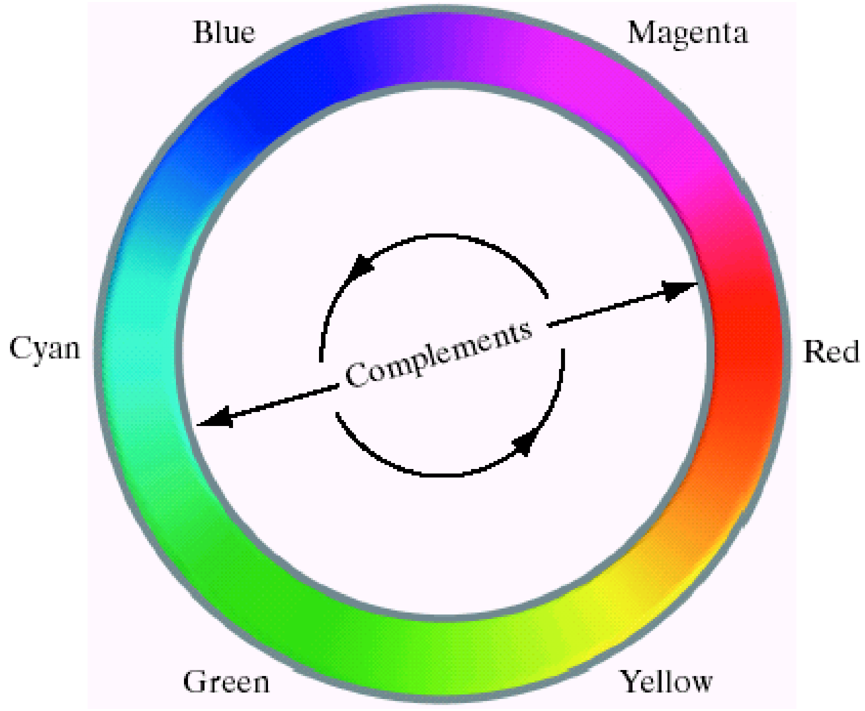
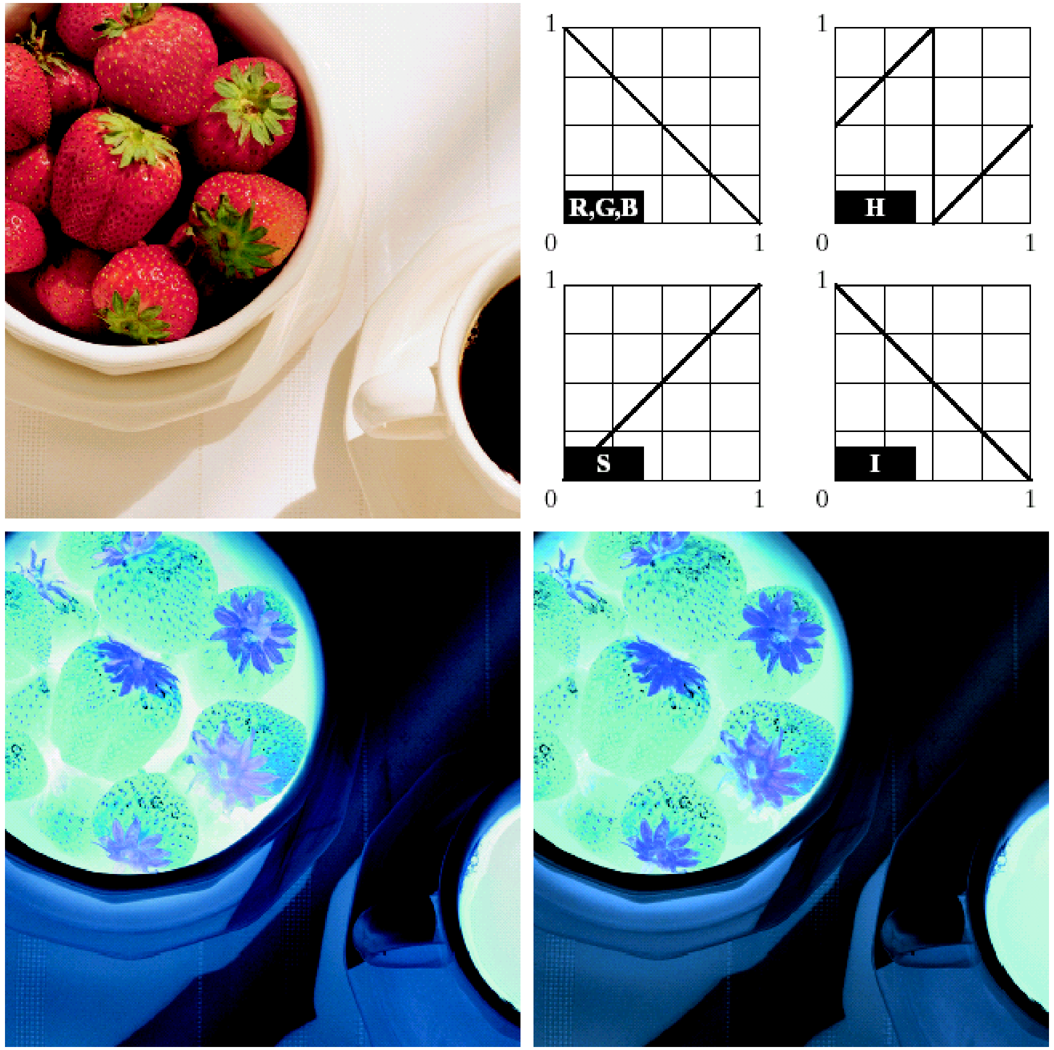


FIGURE 6.32 Complements on the color circle.

Full-Color Image Processing

Color Transformation: Color Complement



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.

Full-Color Image Processing

Color Transformation: Color Slicing

Motive: Highlighting a specific range of colors in an image

Basic Idea:

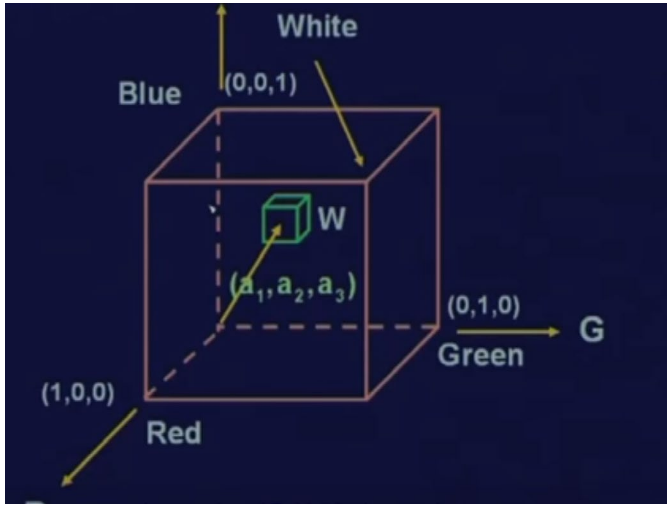
- **Display the color of interest so that they stand out from background**
- **Use the region defined by the colors as a mask for further processing**

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

Full-Color Image Processing
Color Transformation: Color Slicing

1. Colors of interest are enclosed by ***cube*** (or ***hypercube*** for n>3)

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



Full-Color Image Processing

Color Transformation: Color Slicing

1. Colors of interest are enclosed by ***cube*** (or ***hypercube*** for n>3)

$$s_i = \begin{cases} 0.5 & if \left[\left| r_j - a_j \right| > \dfrac{W}{2} \right]_{any\, 1 \le j \le n} \\ r_i & otherwise \end{cases} \quad , \qquad i = 1,2,\ldots,n$$

2. Colors of interest are enclosed by ***Sphere***

$$s_i = \begin{cases} 0.5 & if \sum_{j=1}^{n} (r_j - a_j)^2 > R_0^2 \\ r_i & otherwise \end{cases} \quad , \qquad i = 1,2,\ldots,n$$

Full-Color Image Processing

Color Transformation: Color Slicing

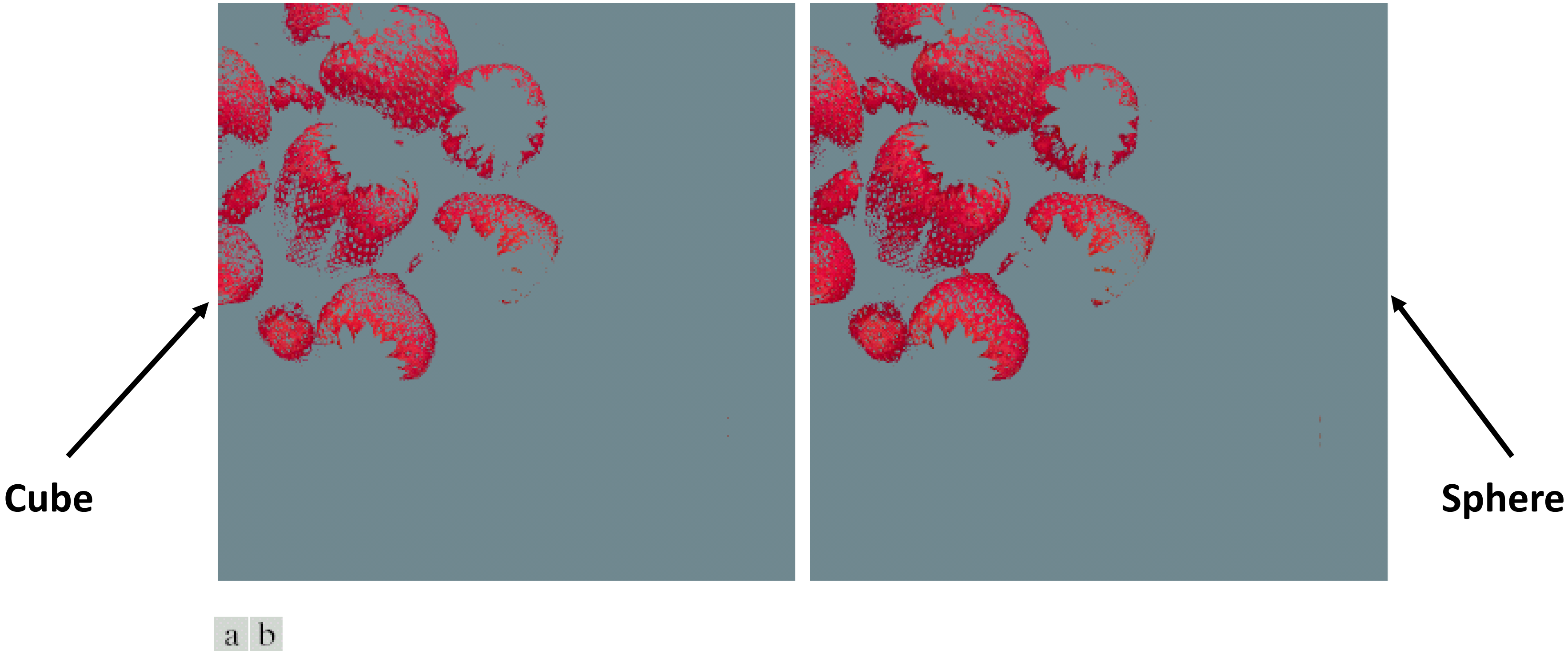


FIGURE 6.34 Color slicing transformations that detect (a) reds within an RGB cube of width $W = 0.2549$ centered at (0.6863, 0.1608, 0.1922), and (b) reds within an RGB sphere of radius 0.1765 centered at the same point. Pixels outside the cube and sphere were replaced by color (0.5, 0.5, 0.5).

Full-Color Image Processing

Color Image Smoothing

Averaging:

$$\bar{\mathbf{c}}(x, y) = \frac{1}{K} \sum_{(x,y)\in S_{xy}} \mathbf{c}(x, y)$$

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

Full-Color Image Processing

Color Image Smoothing

a b
c d

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

Red

Green

Blue

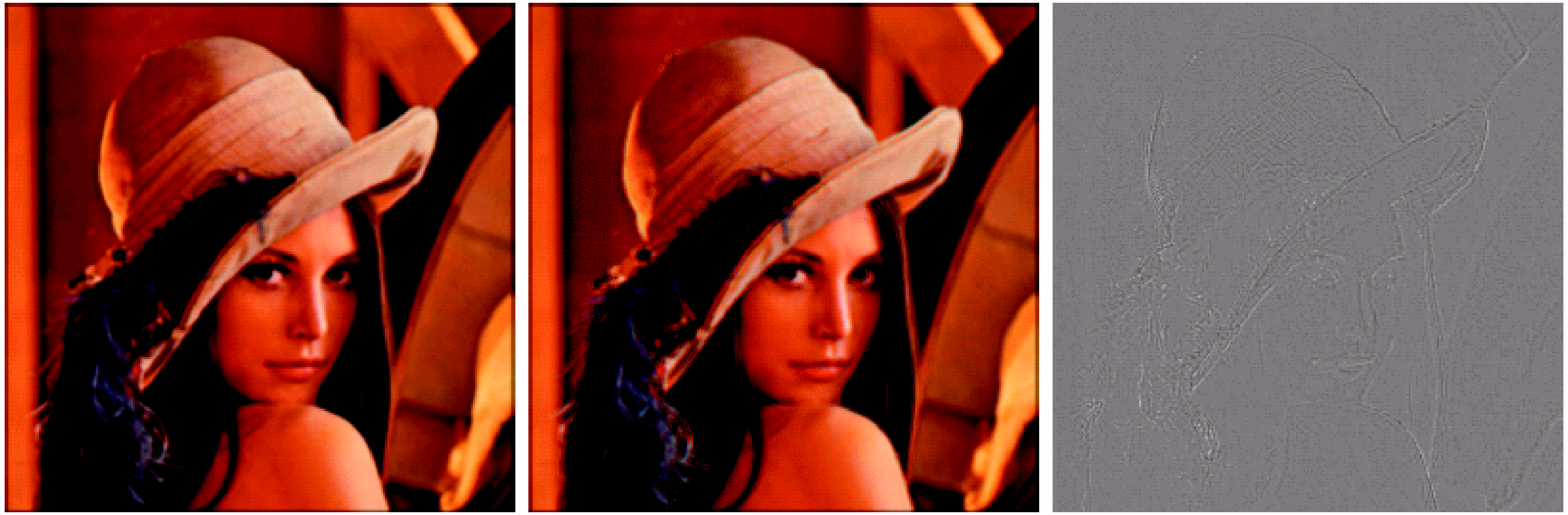
Full-Color Image Processing
Color Image Smoothing

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

Full-Color Image Processing

Color Image Smoothing

Averaging R,G and B | Averaging Intensity | Difference



a b c

FIGURE 6.40 Image smoothing with a 5×5 averaging mask. (a) Result of processing each RGB component image. (b) Result of processing the intensity component of the HSI image and converting to RGB. (c) Difference between the two results.

Full-Color Image Processing

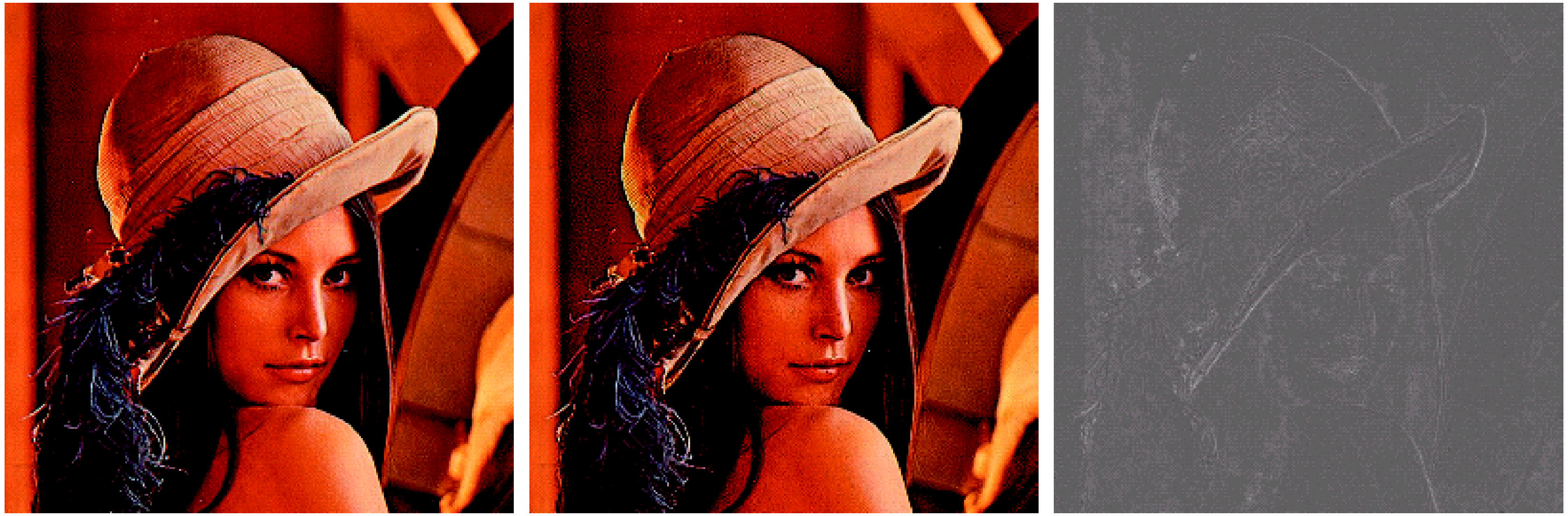
Color Image Sharpening

The Laplacian of Vector **c** :

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

Full-Color Image Processing
Color Image Sharpening

Sharpening R,G and B | Sharpening Intensity | Difference



a b c

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

Summary

1. Color Fundamentals
2. Color Spaces
3. Color Image Processing