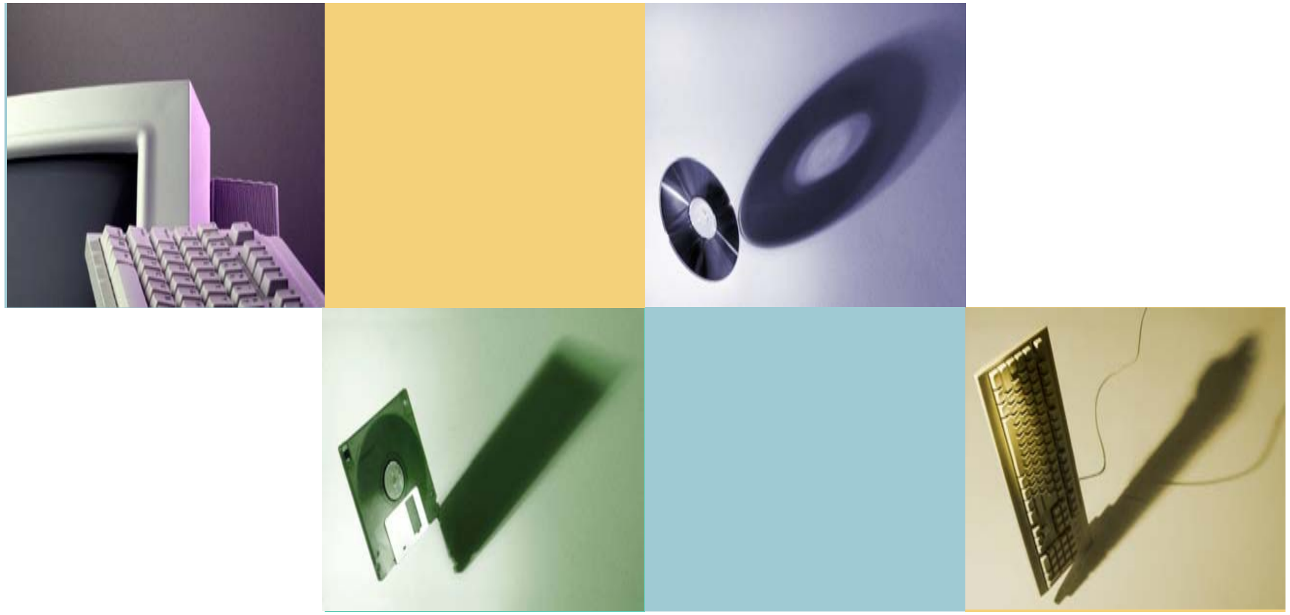
Chapter 6
Color Image Processing



Preview

- Color image processing is divided into two major areas
  - Full color
  - Pseudo color

Color Fundamentals

- The Color spectrum may be divided into six broad regions. (1666)
  - As Fig 6.1 shows
- Visible light is composed of a relative narrow band of frequencies.
  - As illustrated in Fig 6.2

Color fundamentals

- 1666, Isaac Newton 三稜鏡

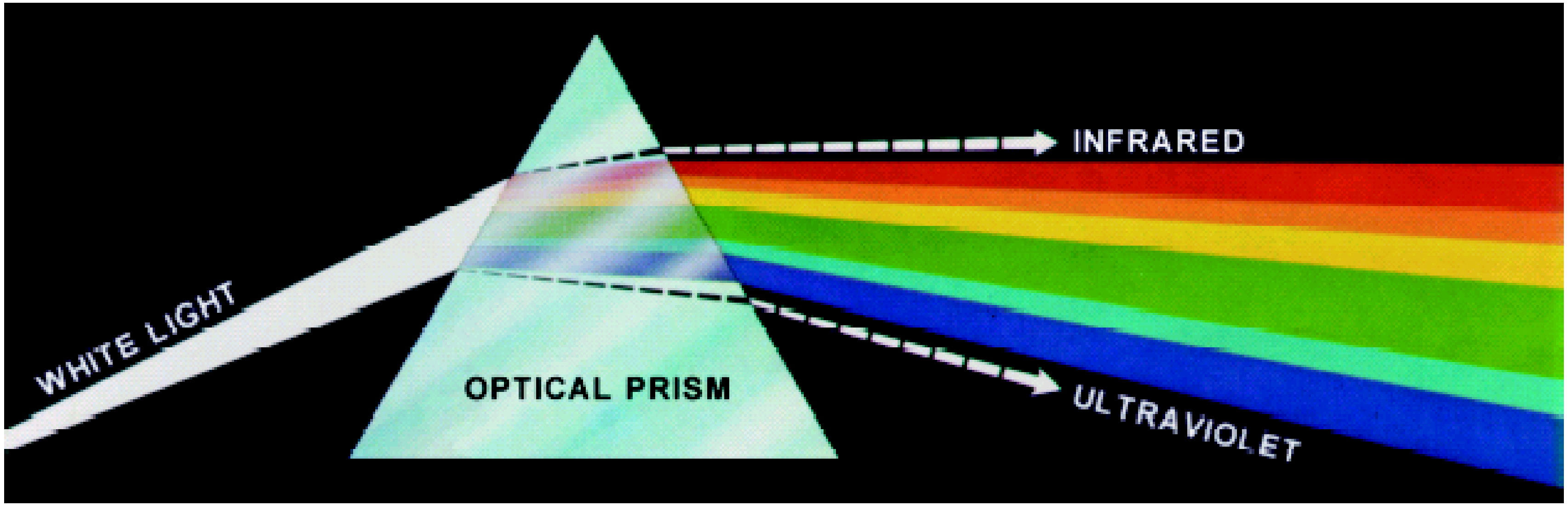
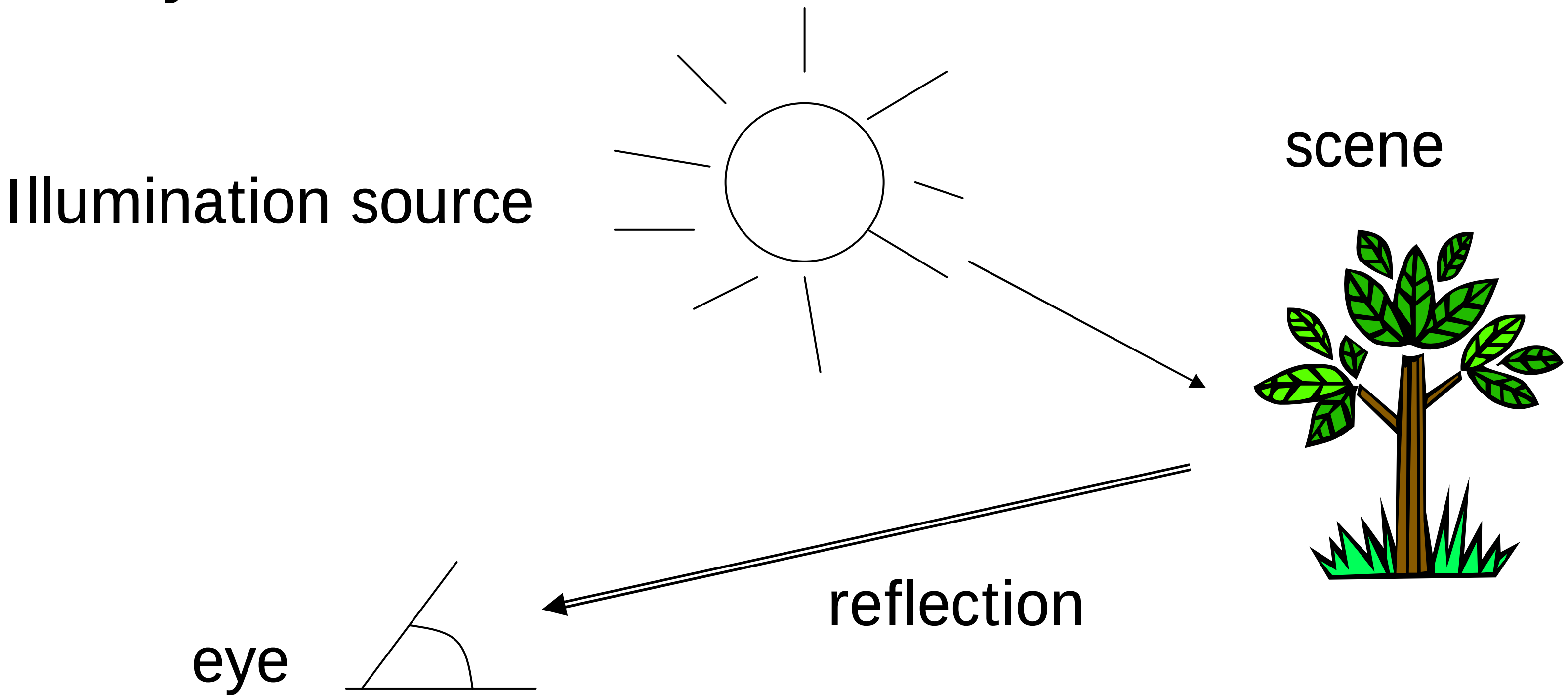


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Color fundamentals (cont.)

- The color that human perceive in an object = the light reflected from the object



Visible light

- Chromatic light span the electromagnetic spectrum (EM) from 400 to 700 nm

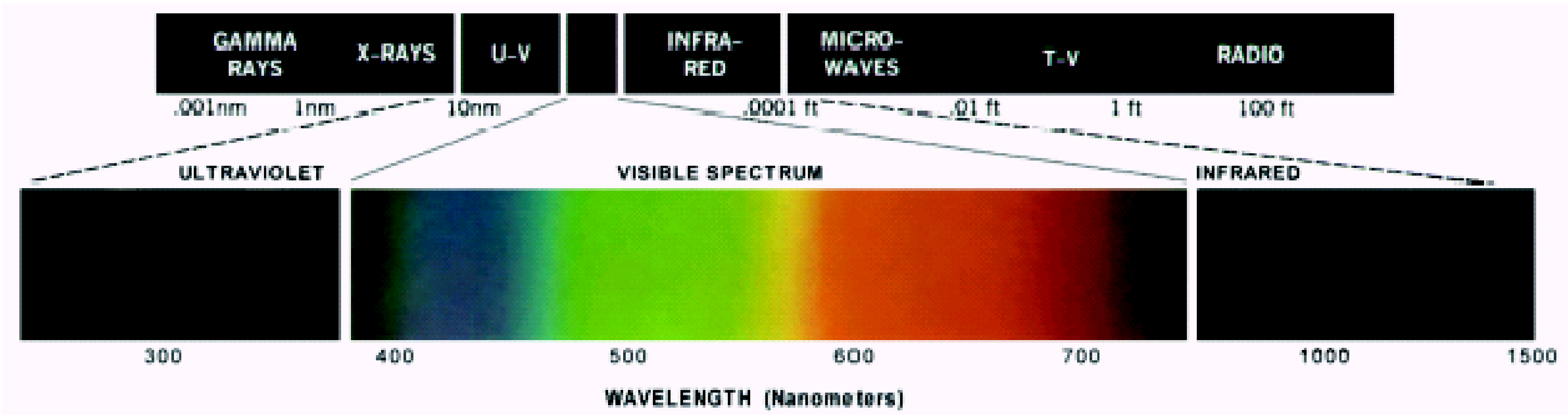


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

- For human eye
  - – Approximately 65% of all cone are sensitive to red light
  - – 33% are sensitive to green light
  - – 2% are sensitive to blue light
    - But blue cones are the most sensitive.
  - – Fig 6.3 shows average experimental curves detailing the absorption of light by the red, green, and blue cones in the eye.

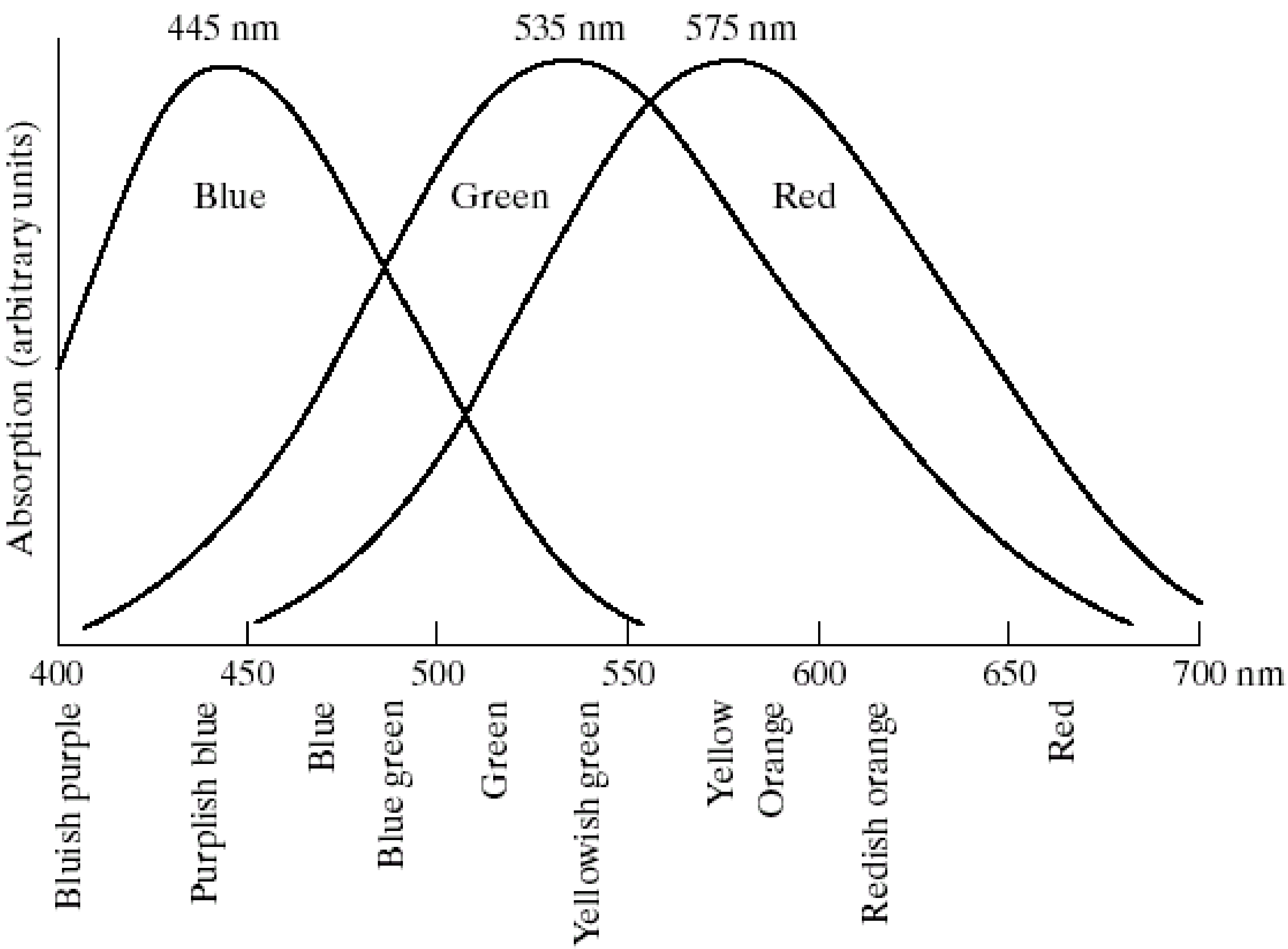
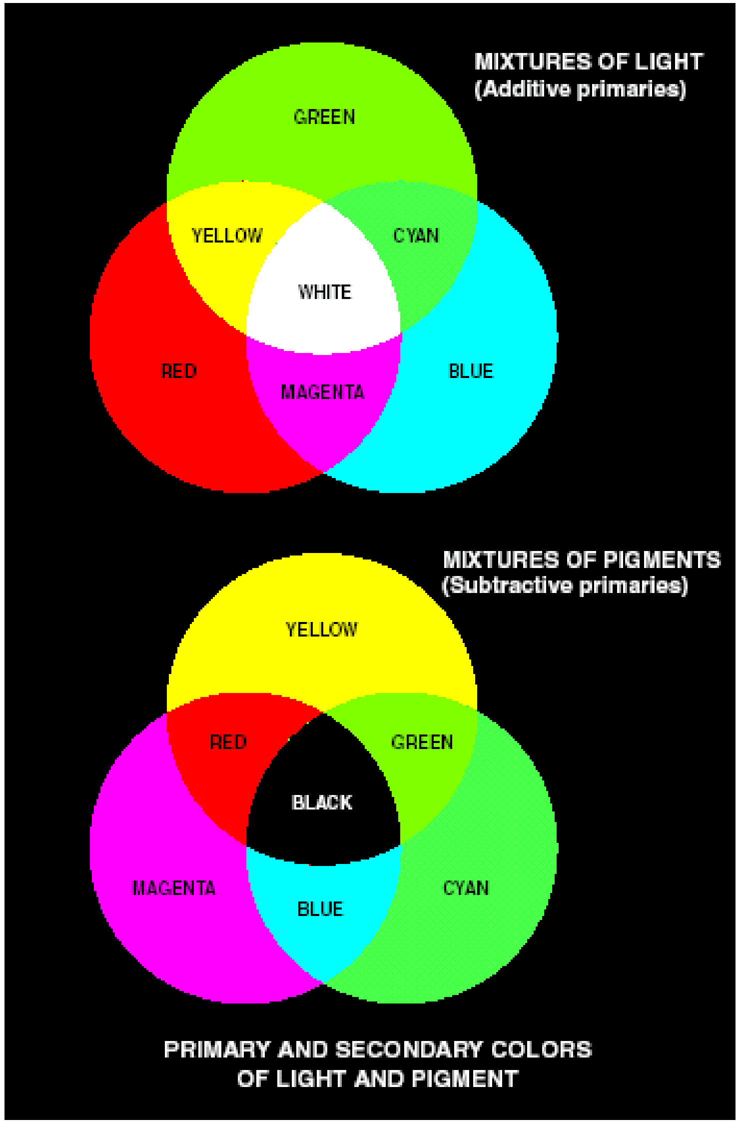


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Primary and secondary colors

- CIE(International Commission on Illumination) defines specific wavelength values to the primary colors
  - R = 435.8 nm, G = 546.1 nm, B = 700 nm
  - Not that no single color may be called red, green, or blue
- Secondary colors: G+B=Cyan, R+G=Yellow, R+B=Magenta



a
b

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

Primary colors of light v.s. primary colors of pigments

- Primary color of pigments
  - Color that subtracts or absorbs a primary color of light and reflects or transmits the other two

Color of light:	R	G	B
	↓	↓	↓
Color of pigments:	absorb R Cyan	absorb G Magenta	absorb B Yellow

6.1 Color Fundamentals

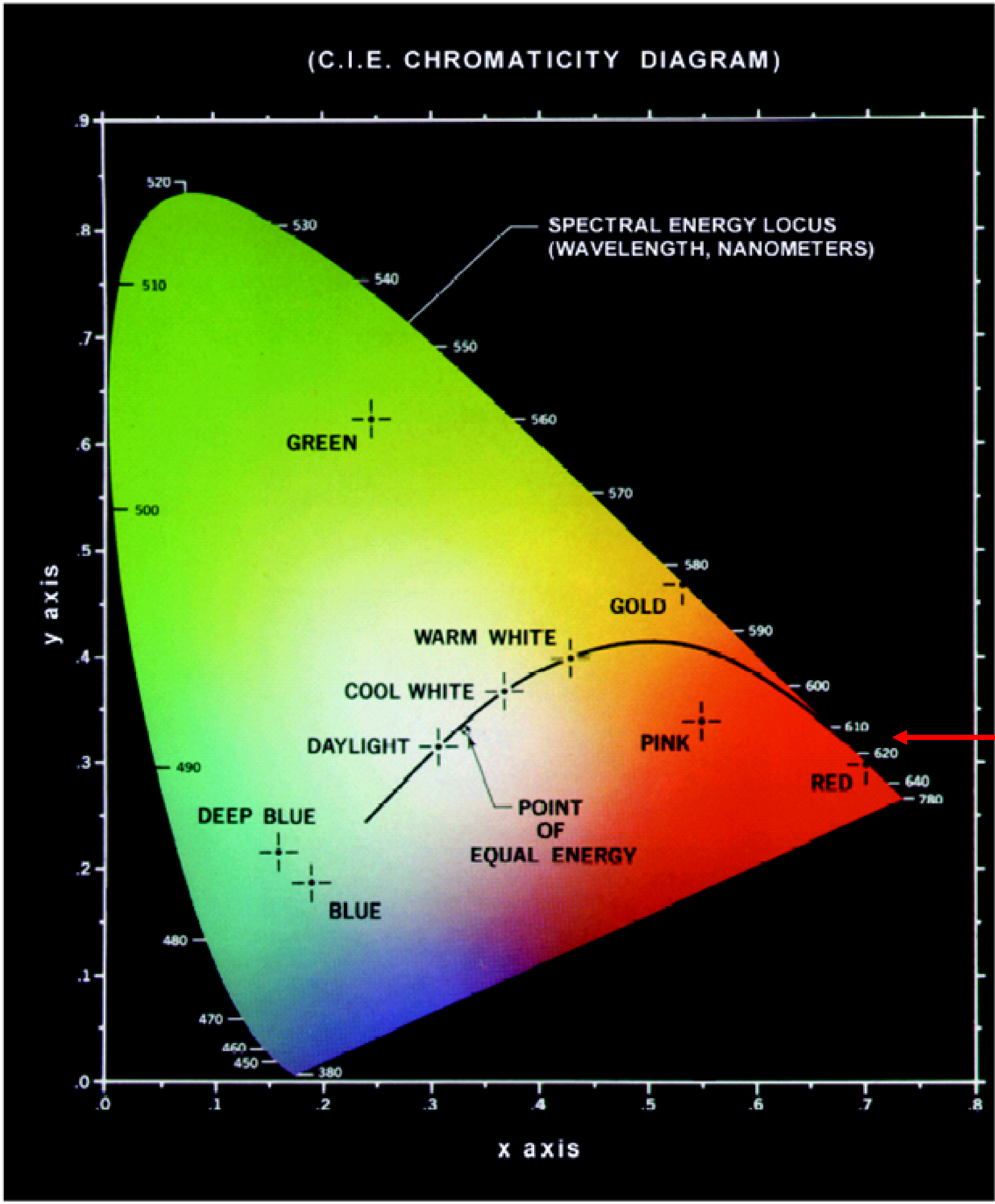
- Another color characteristics
  - Brightness
    - Chromatic notation of intensity
  - Hue
    - Dominant wavelength in a mixture of light waves
  - Saturation
    - The mount of white light mixed with hue

Color Fundamentals

- Chromaticity – Hue and Saturation
- CIE chromaticity diagram
  - Fig. 6.5
- Typical range of colors (color gamut 色階) produced by RGB monitors
  - Fig. 6.6

g

$\boxed{b=1-r-g}$



Colors in the boundary are full saturated

r

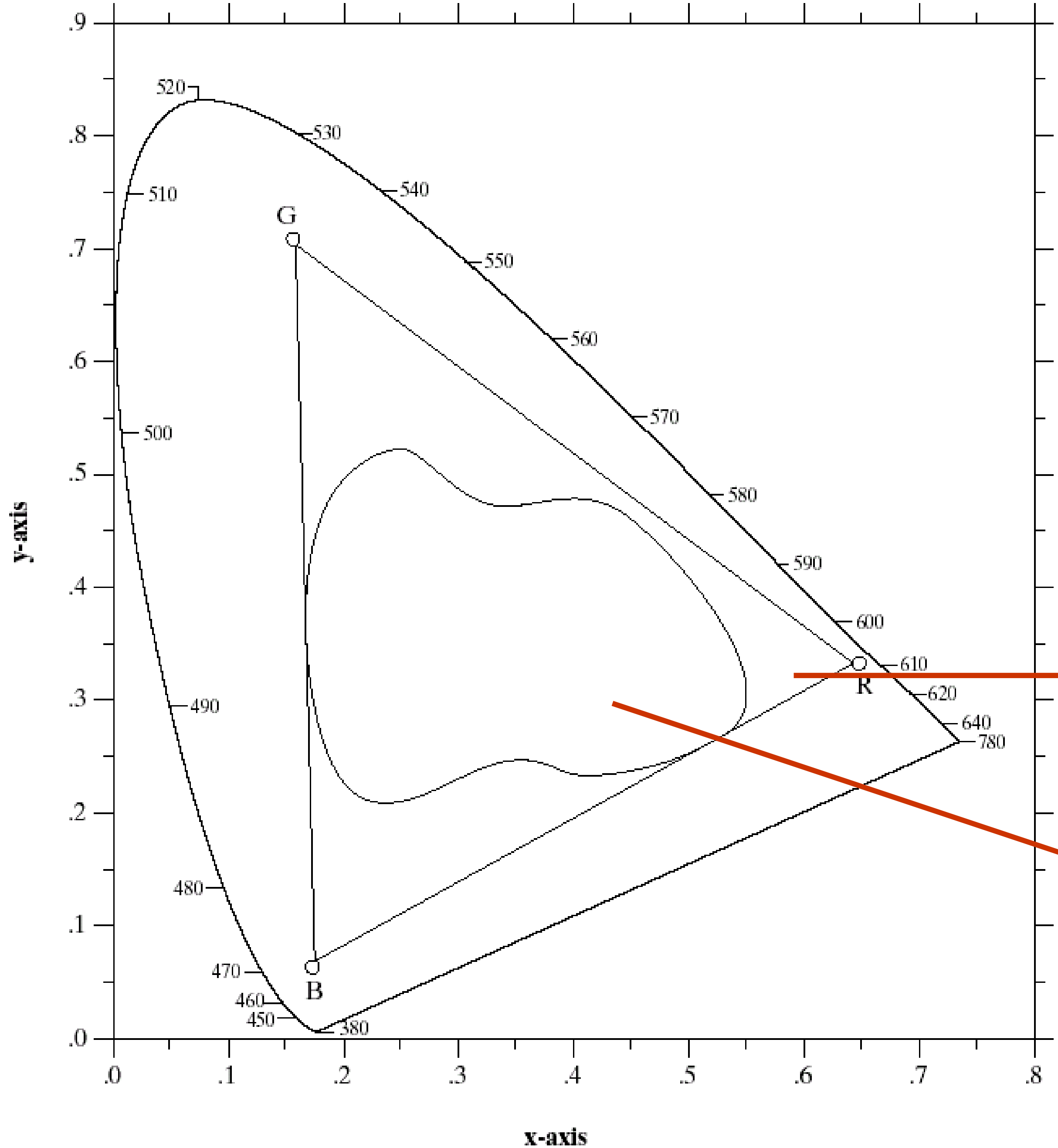


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

By additivity of colors: Any color inside the triangle can be produced by combinations of the three initial colors

Color gamut of monitors

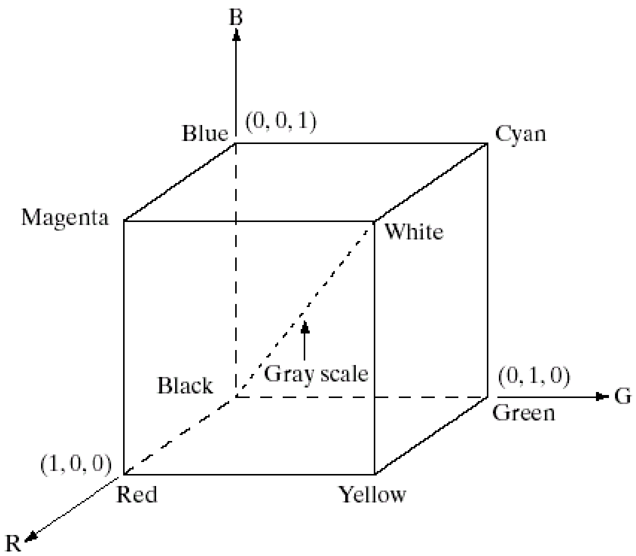
Color gamut of printers

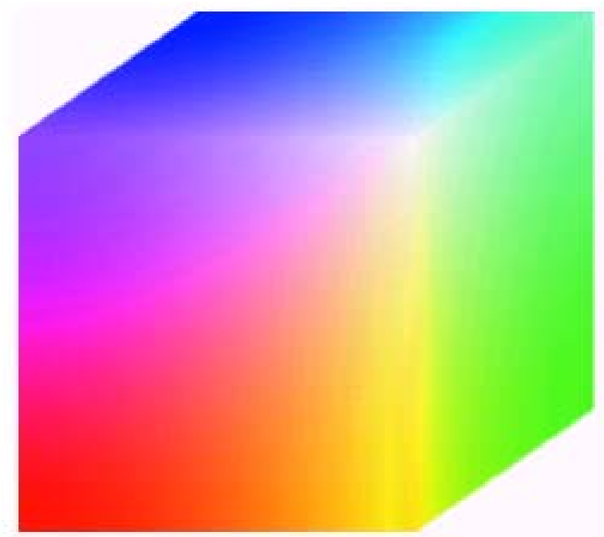
Color Models

- Color model also called
  - Color space
  - Color system
- The RGB Color Model
  - The color subspace of interest is the cube shown in Fig. 6.7.
  - Fig. 6.8 - RGB 24-bit color cube
  - A color image can be acquire by using three filters – Fig. 6.9.

Pixel depth

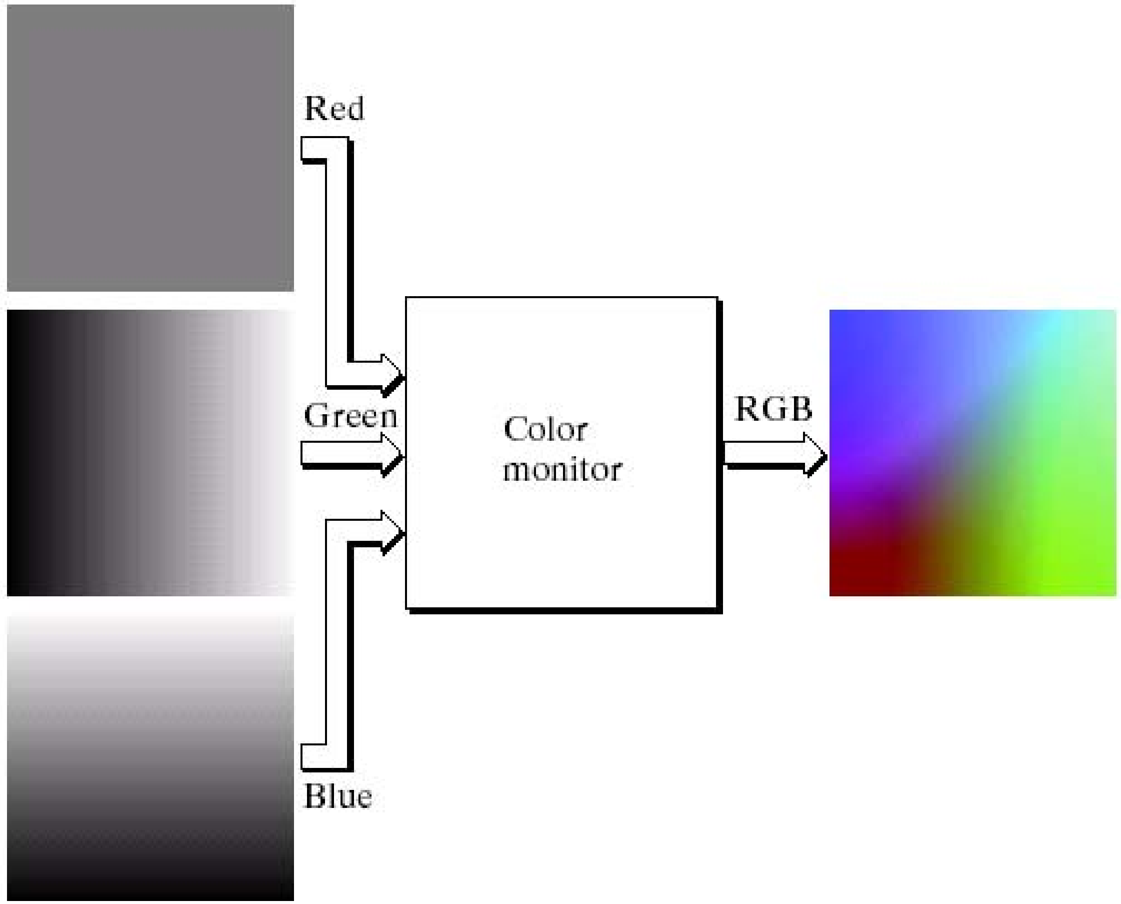
- Pixel depth: the number of bits used to represent each pixel in RGB space
- Full-color image: 24-bit RGB color image
  - (R, G, B) = (8 bits, 8 bits, 8 bits)

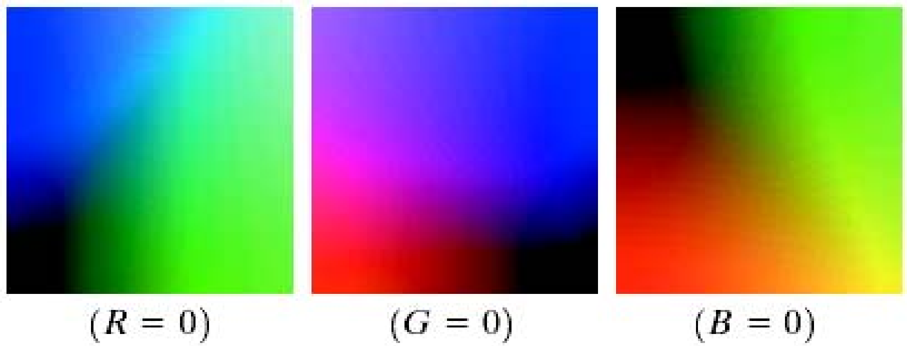




a
b

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.





6.2 Color Models

- The set of safe RGB colors
  - Many systems in the use today are limited to 256 colors.
  - Also call the set of all-system-safe colors
  - In Internet application – safe Web colors or safe browser colors
  - 40 colors are processed differently by various O.S.
  - 216 colors – each RGB value can only be 0, 51, 102, 153, 204, or 255. ($6^3 = 216$)
  - Table 6.1, Fig. 6.10, and 6.11

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.

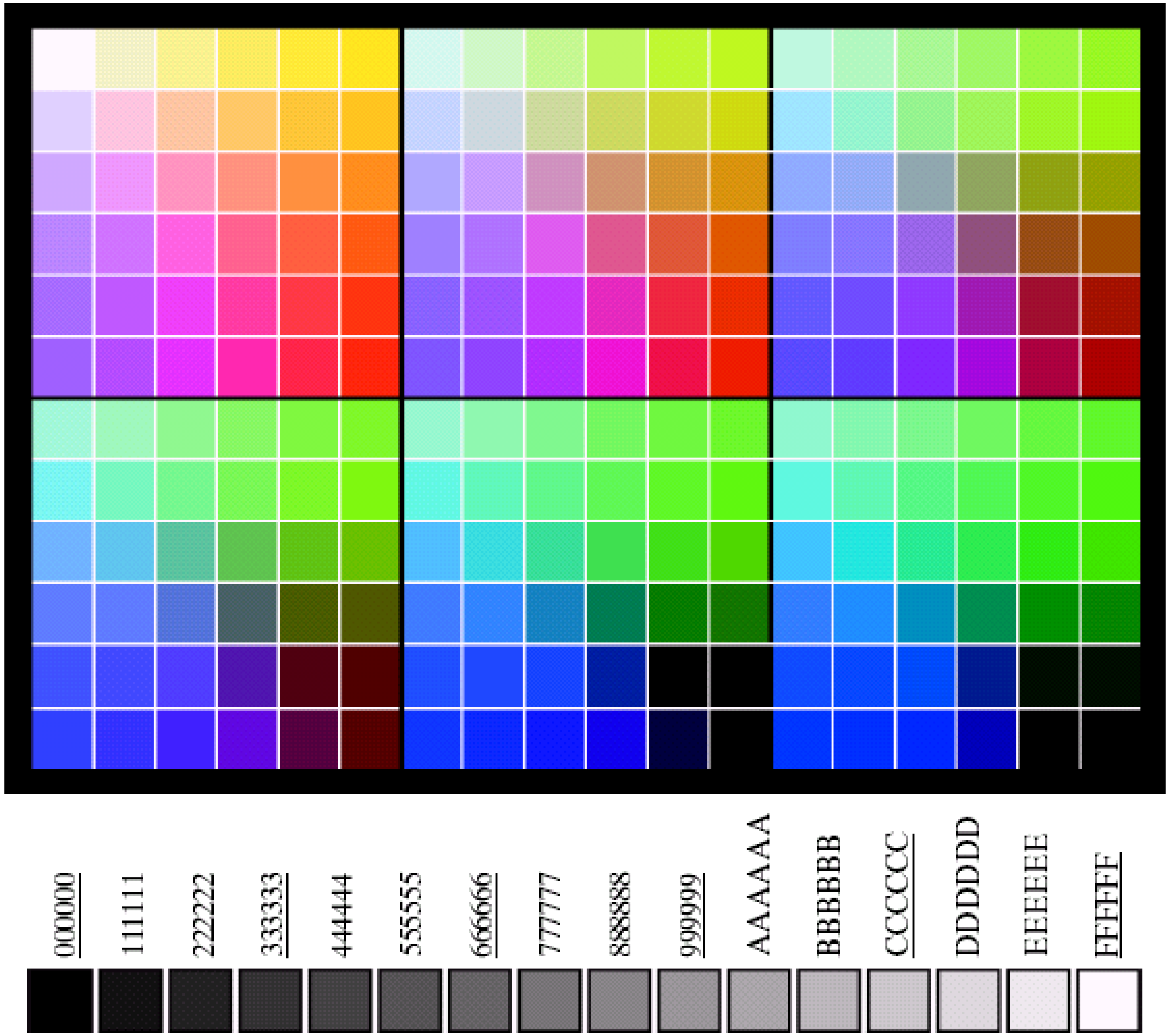


FIGURE 6.10 (a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

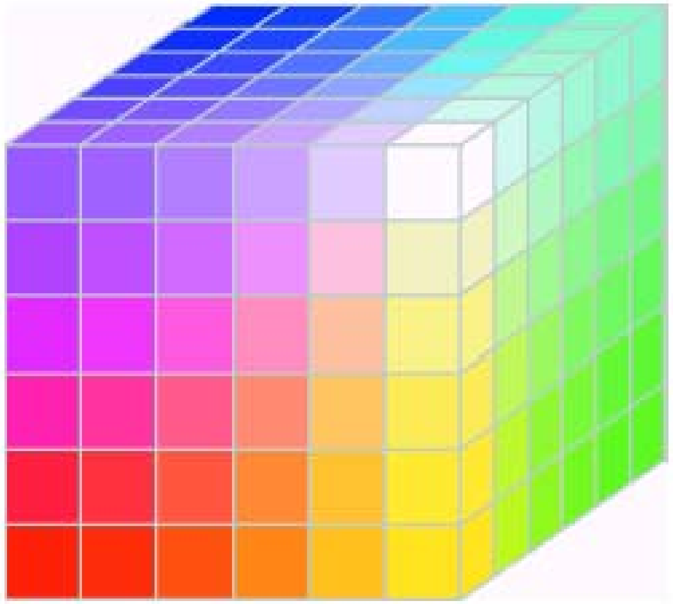
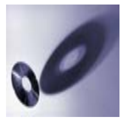
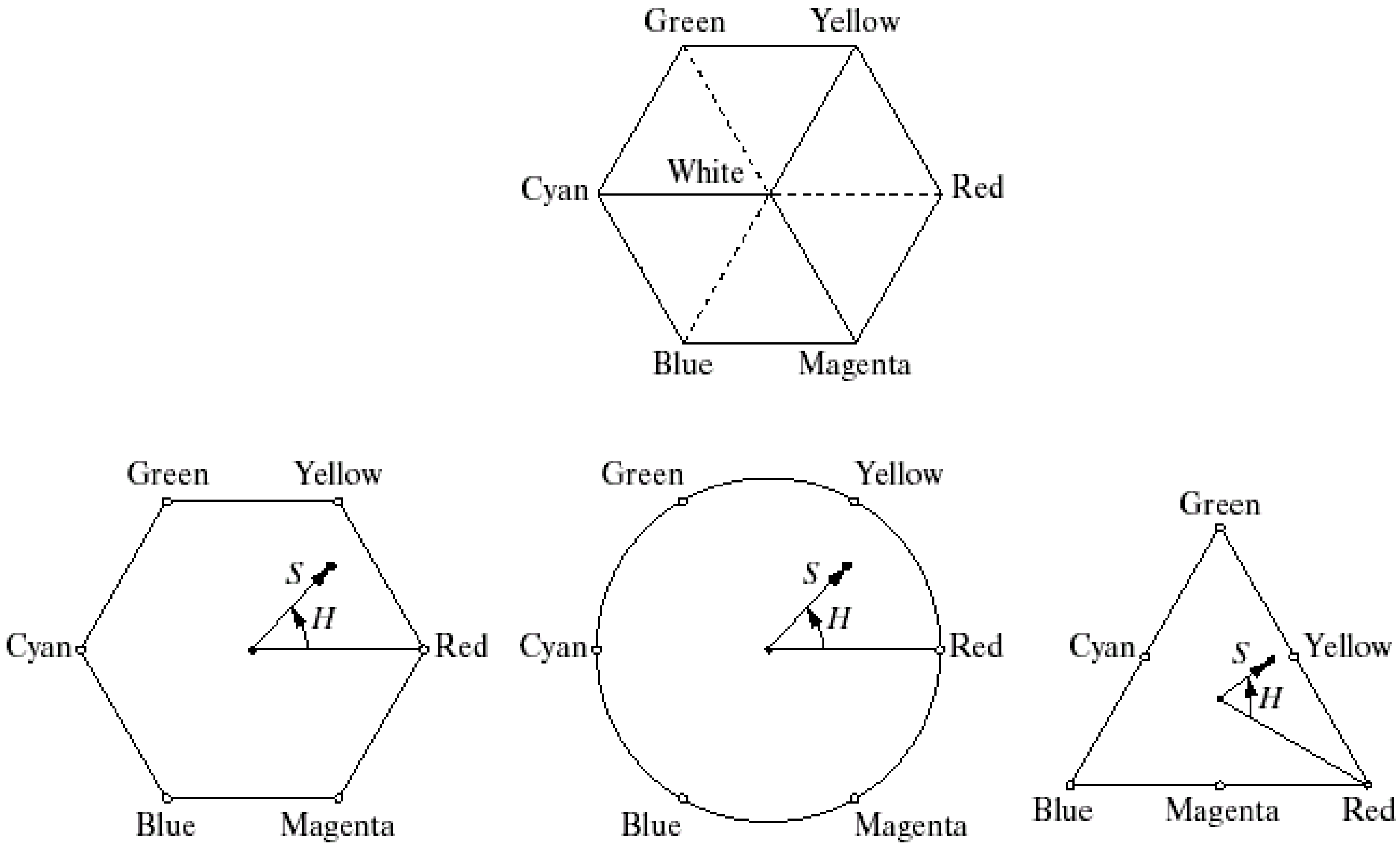


FIGURE 6.11 The RGB safe-color cube.

Color Models

- The CMY and CMYK Color Models
  - RGB to CMY – Eq. 6.2-1 (pp.294)
  - K – is the added color, black
- The HIS Color Model – Fig 6.13 and 6.14
  - When human view a color object
    - Hue (H)
    - Saturation (S)
    - Brightness or intensity (I)

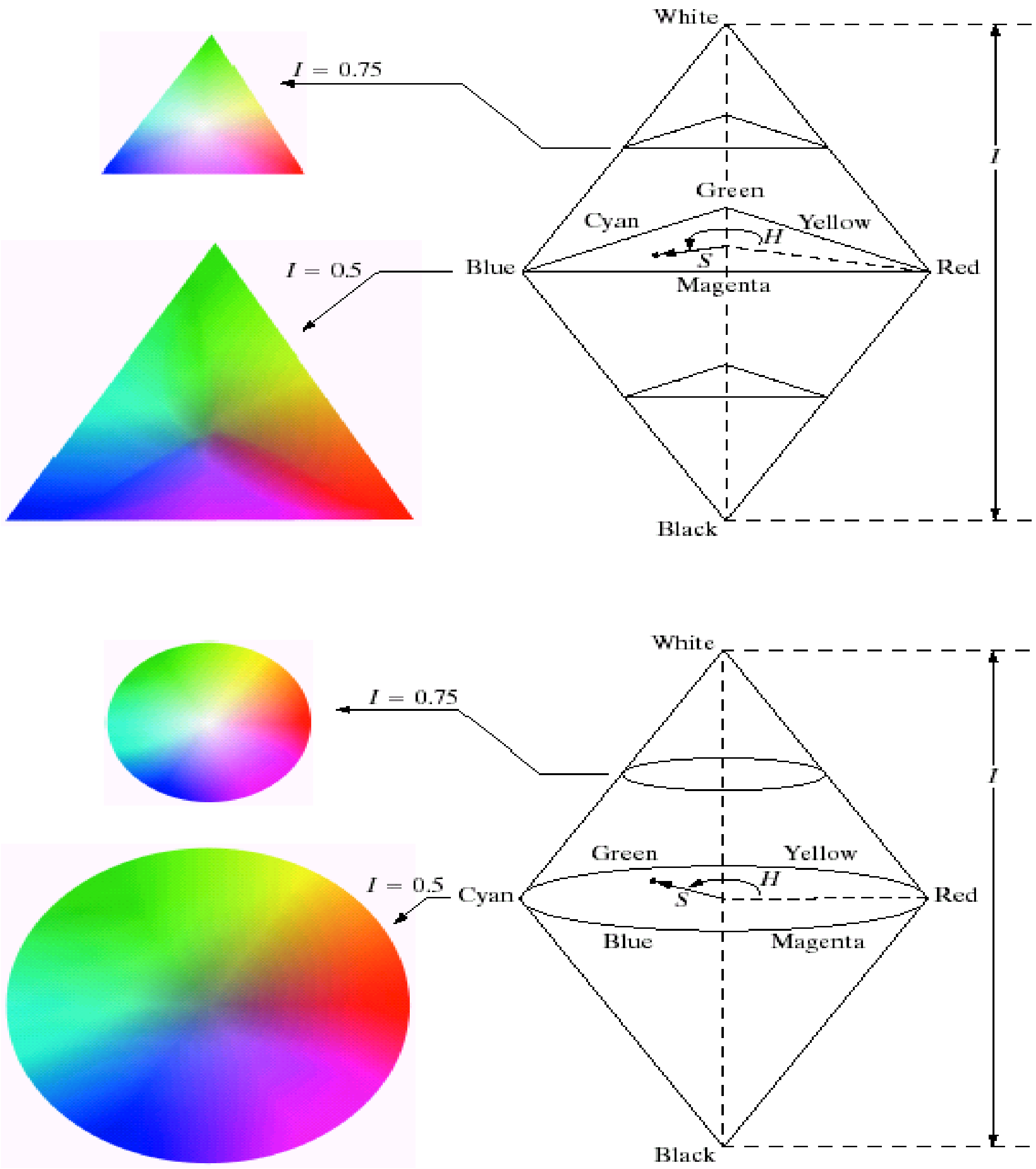



a
b c d

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.

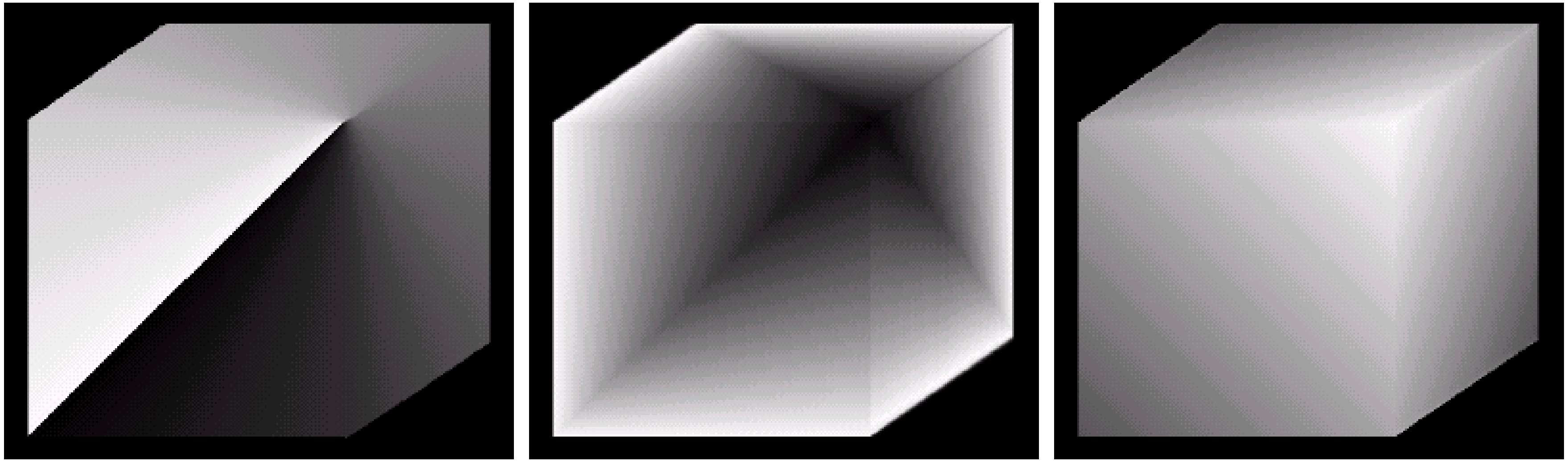
a
b

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.



Color Models

- Converting color from RGB to HSI
  – Eq. 6.2-2 ~ Eq. 6.2-4
- Converting color from HSI to RGB
  – Eq. 6.2-5 ~ Eq. 6.2-15
- Example 6.2
  – The HIS values corresponding to the image of the RGB color cube – Fig. 6.15.
- Manipulating HIS component image
  – Fig. 6.16 and 6.17

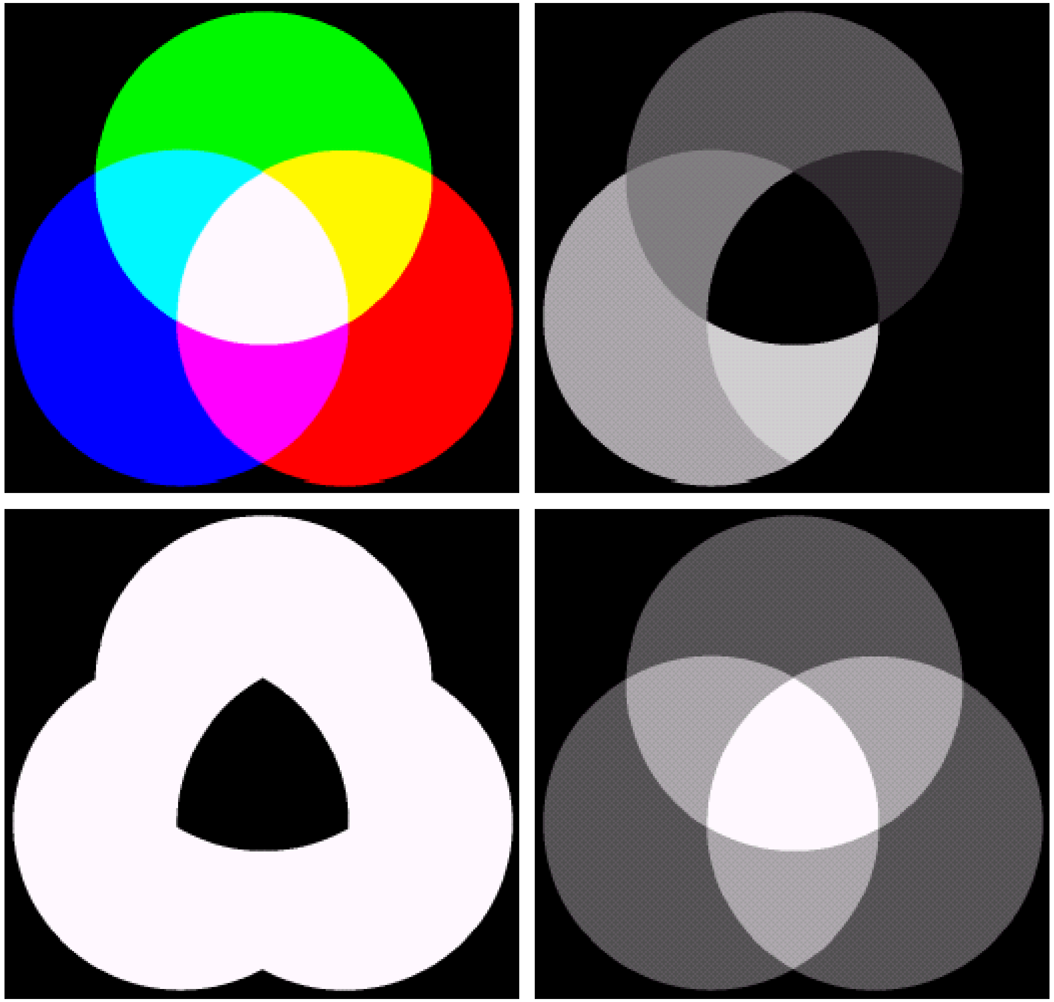


a b c

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

HSI component images

R,G,B



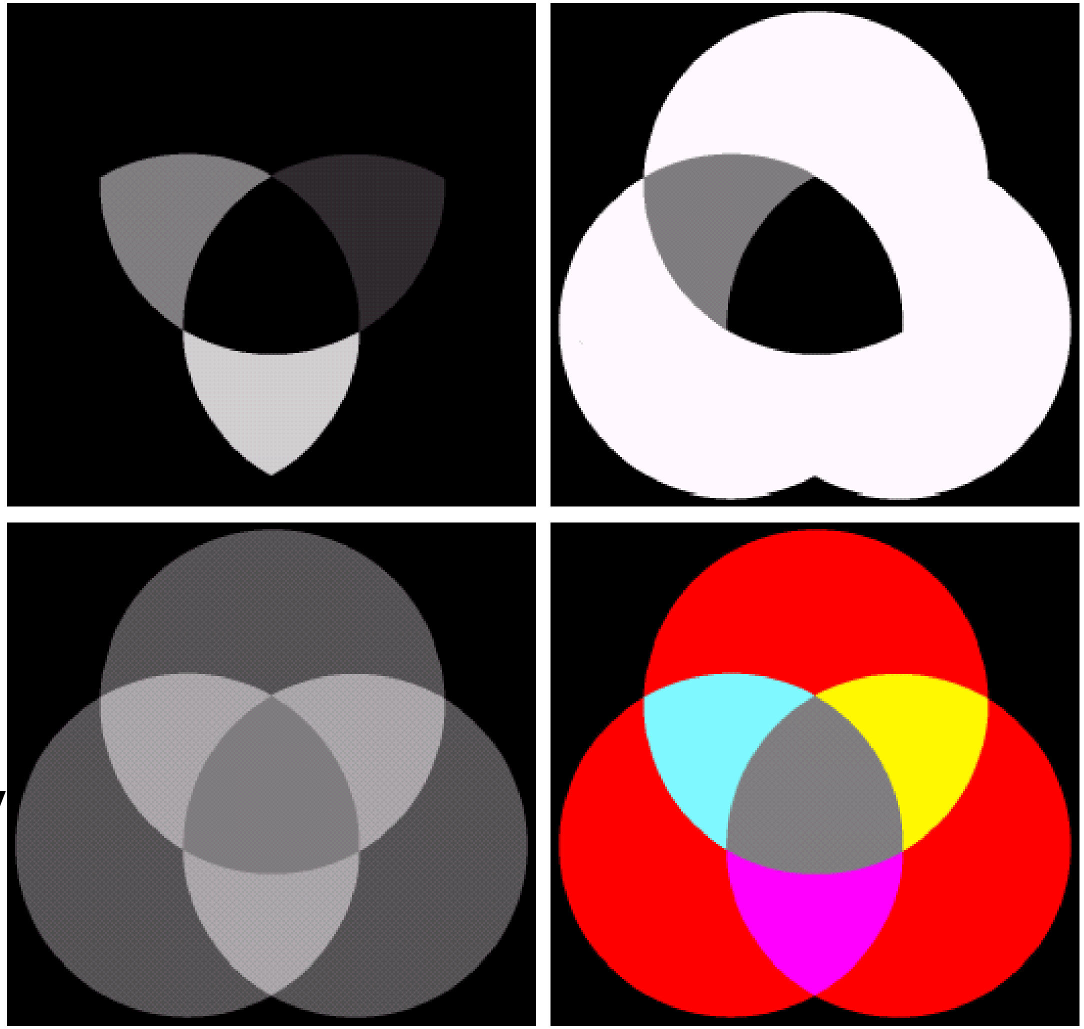
Hue

saturation

intensity

Modify the HSI component images

Hue



saturation

intensity

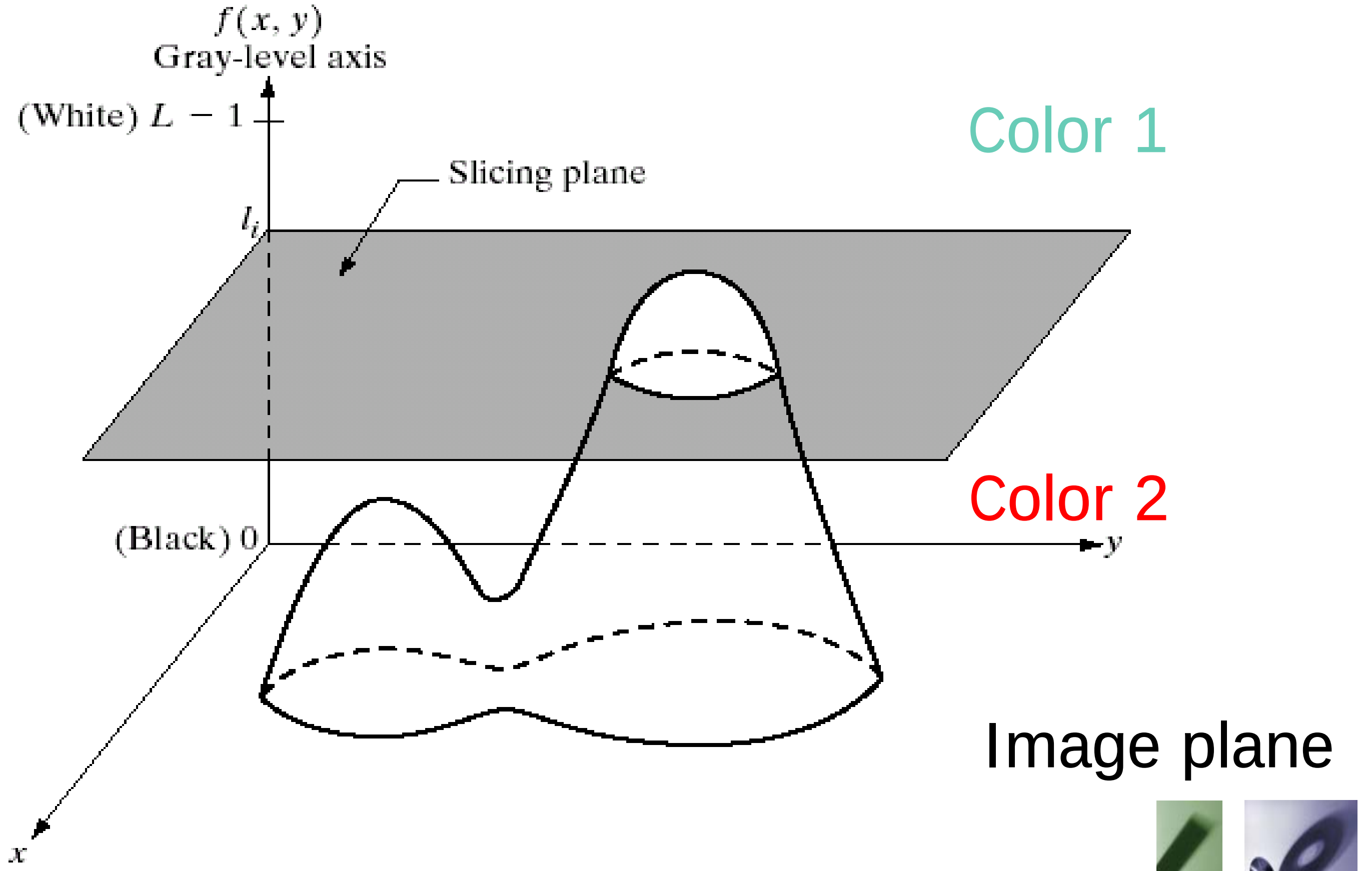
reconstructed

Pseudo-color Image Processing

- Also called false color
- Intensity slicing
  - Assigned different color to each side of the intensity plane
  - Fig. 6.18
  - Fig. 6.19

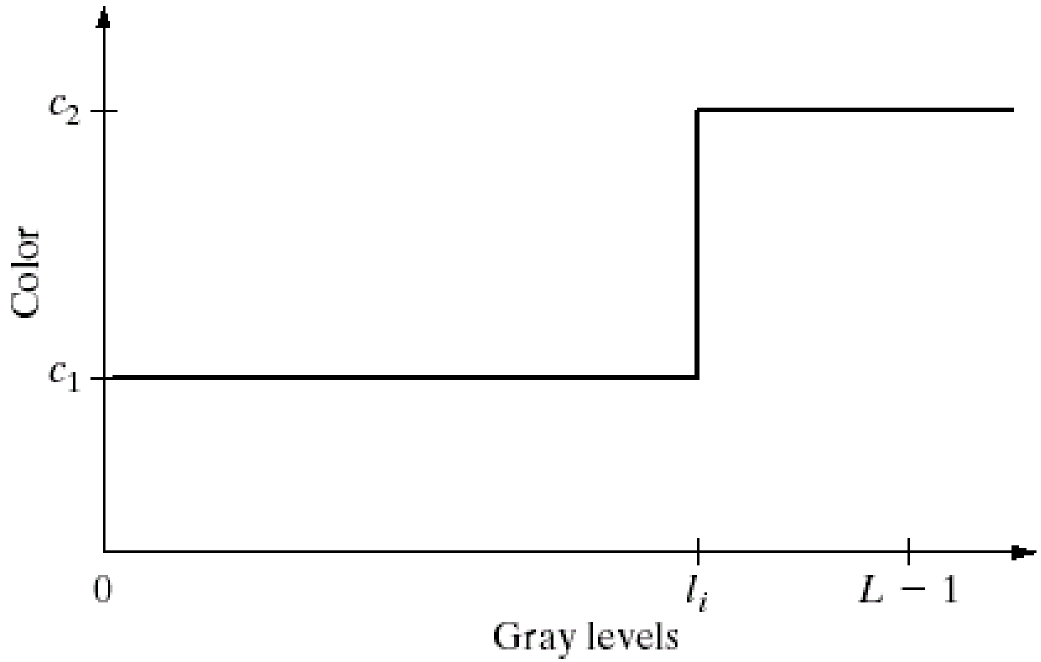
Intensity slicing

- 3-D view of intensity image



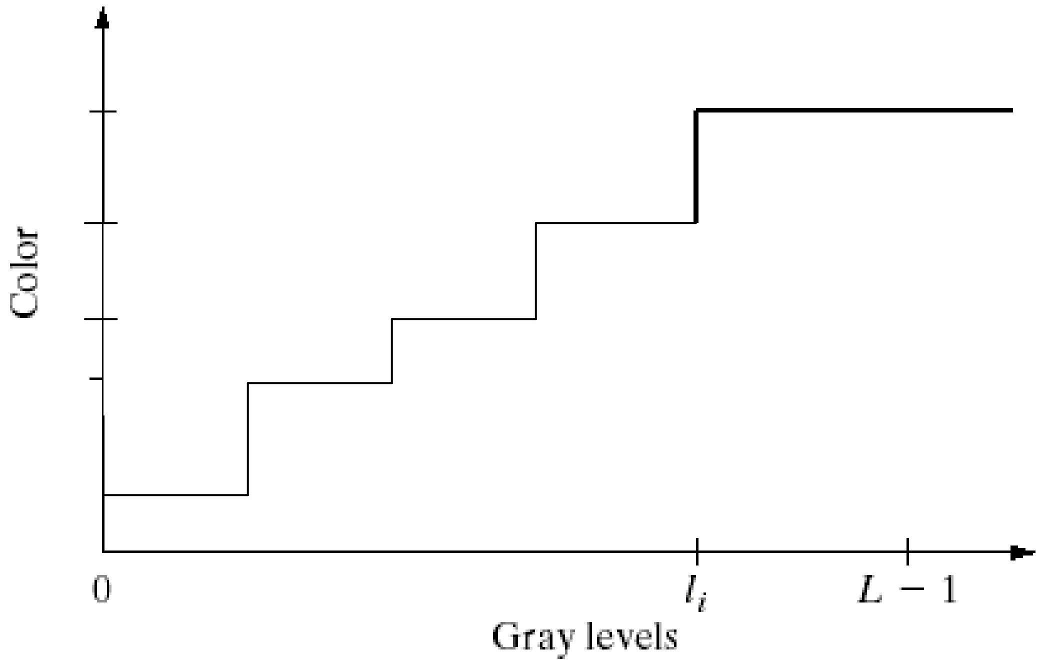
Intensity slicing (cont.)

- Alternative representation of intensity slicing



Intensity slicing (cont.)

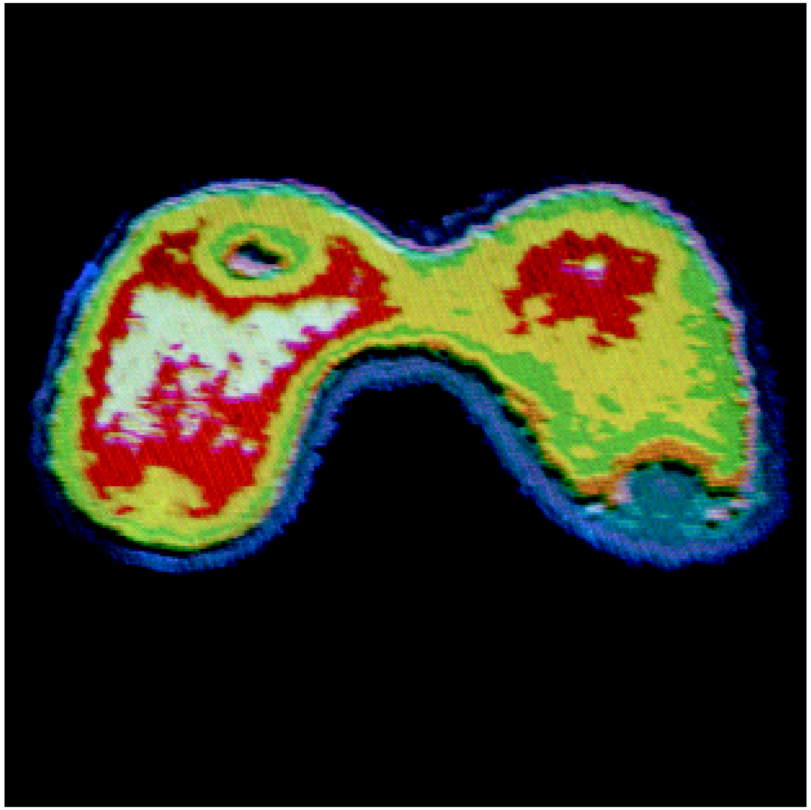
- More slicing plane, more colors



Pseudo-color Image Processing

- Example 6.3
  - Medical monochrome image - Fig. 6.20
  - X-ray monochrome image - Fig. 6.21
- Example 6.4
  - Use of color to highlight rainfall levels
  - Fig. 6.22

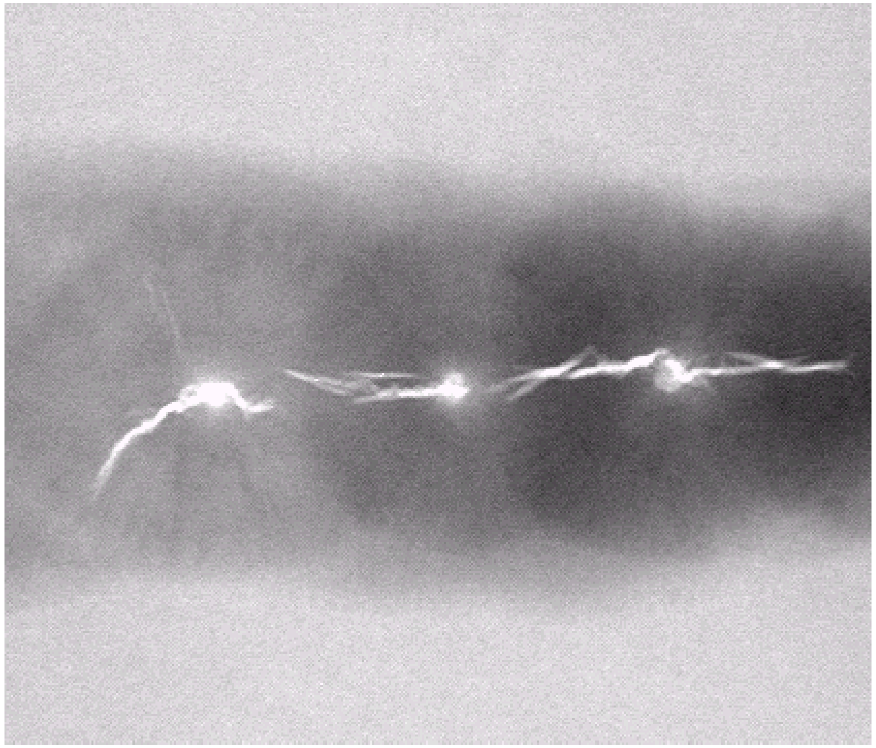
Application 1

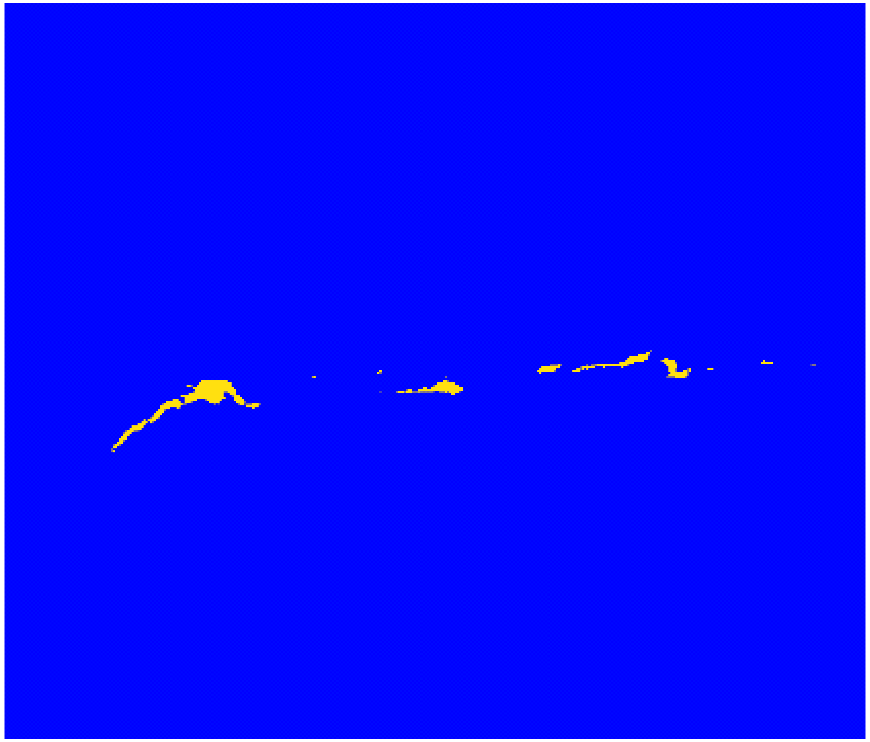


Radiation test pattern → 8 color regions

* See the gradual gray-level changes

Application 2

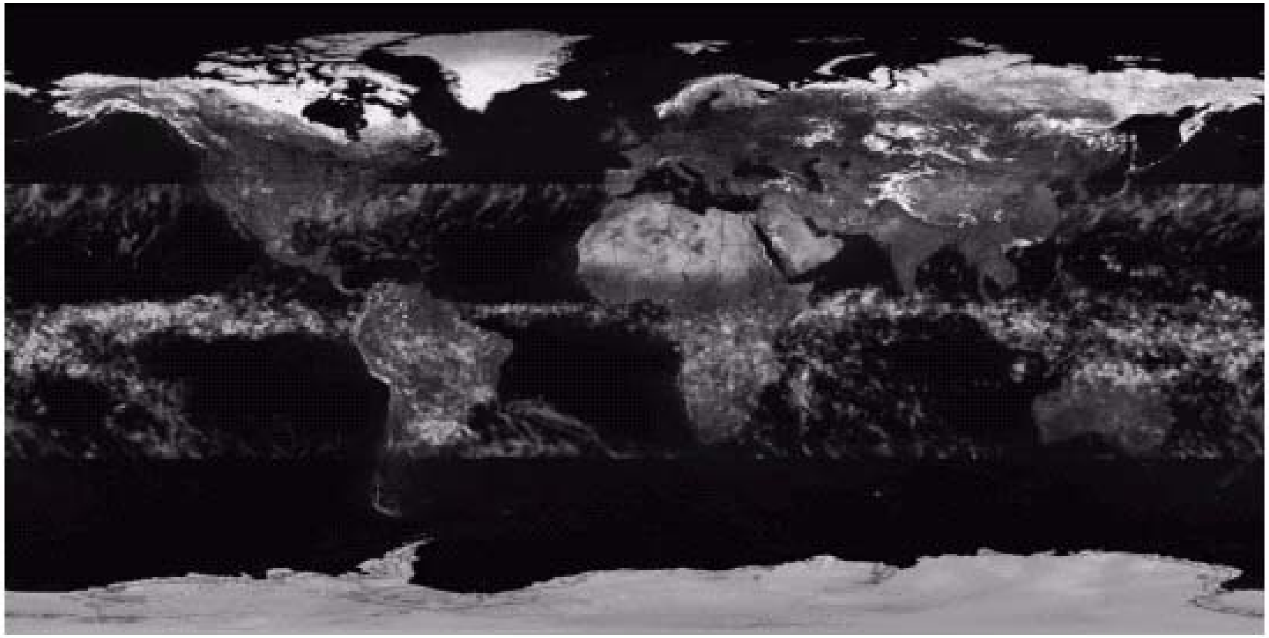




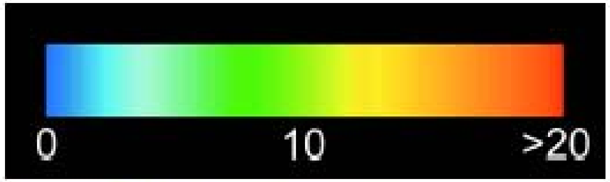
X-ray image of a weld

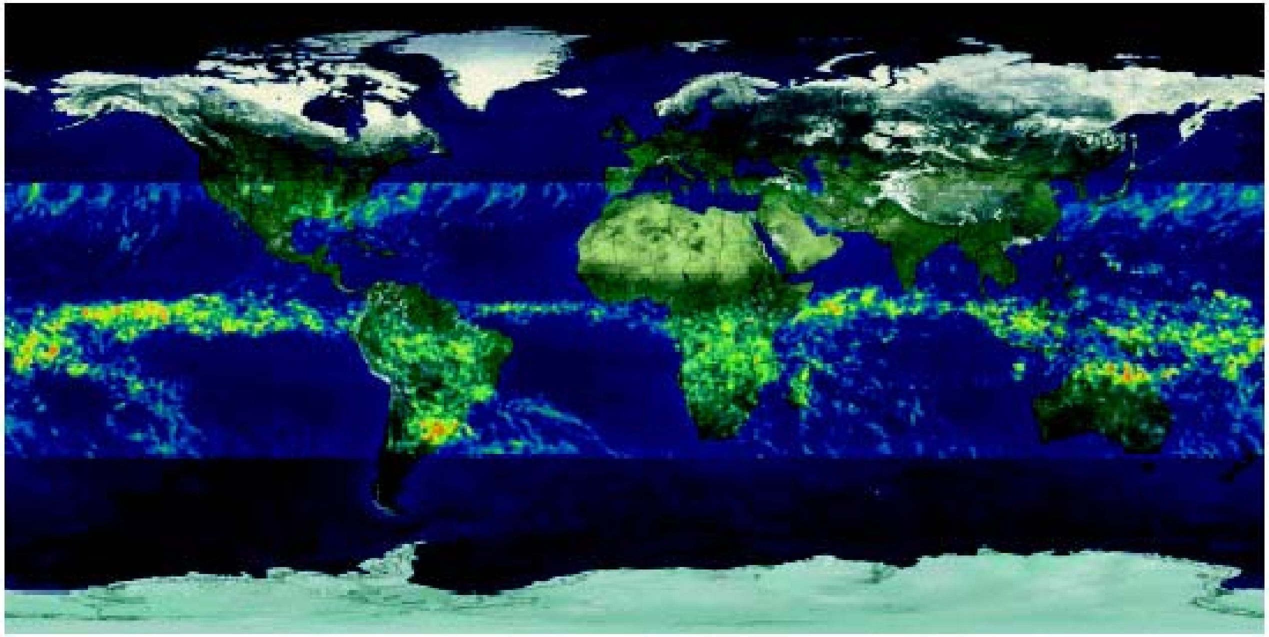
焊接物

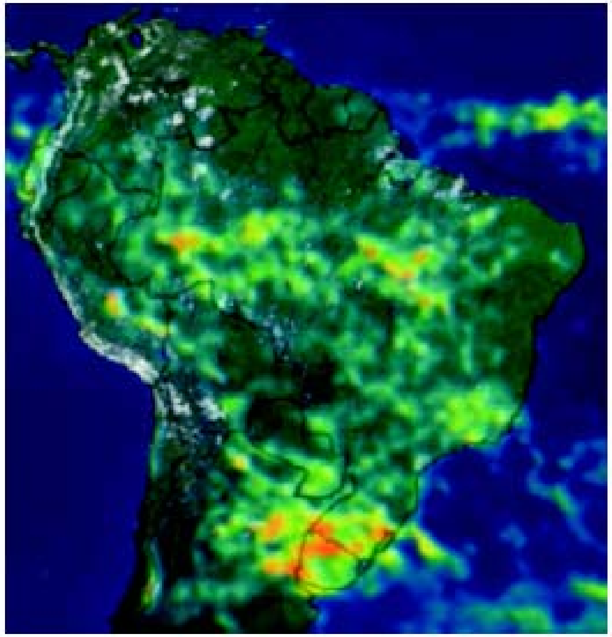
Application 3



Rainfall statistics

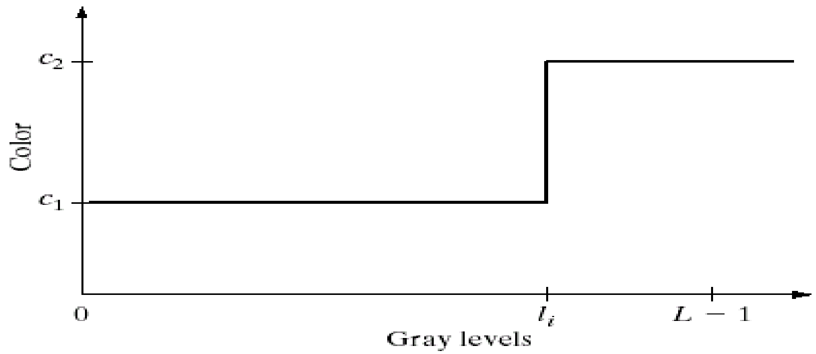




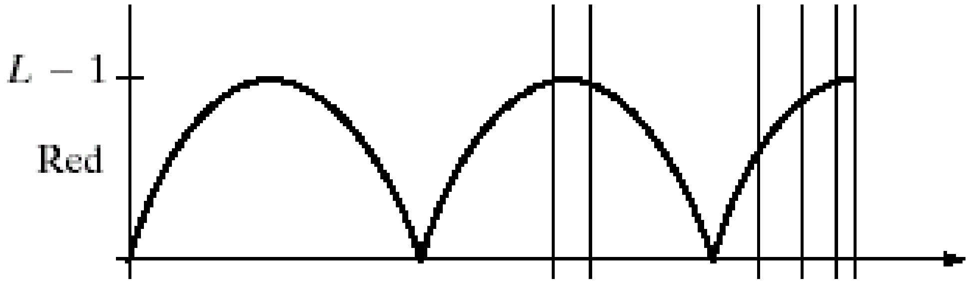


Gray level to color transformation

- Intensity slicing: piecewise linear transformation



- General Gray level to color transformation



Gray level to color transformation

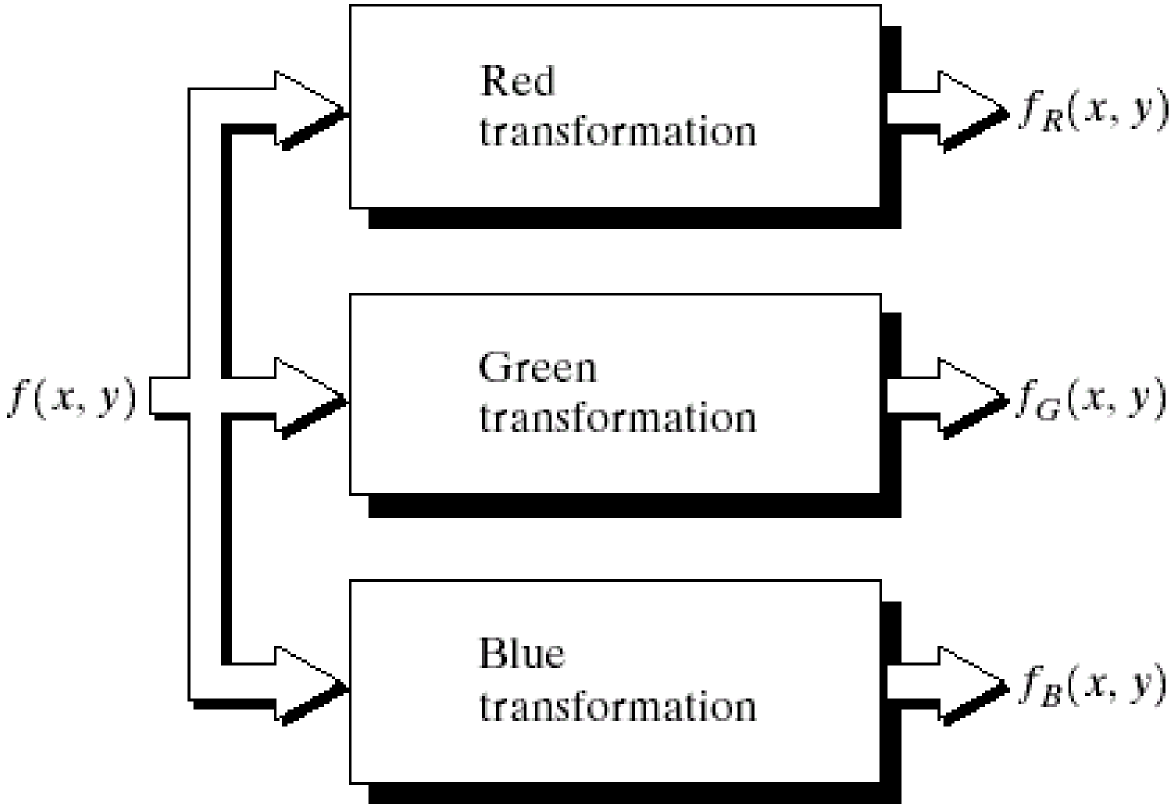
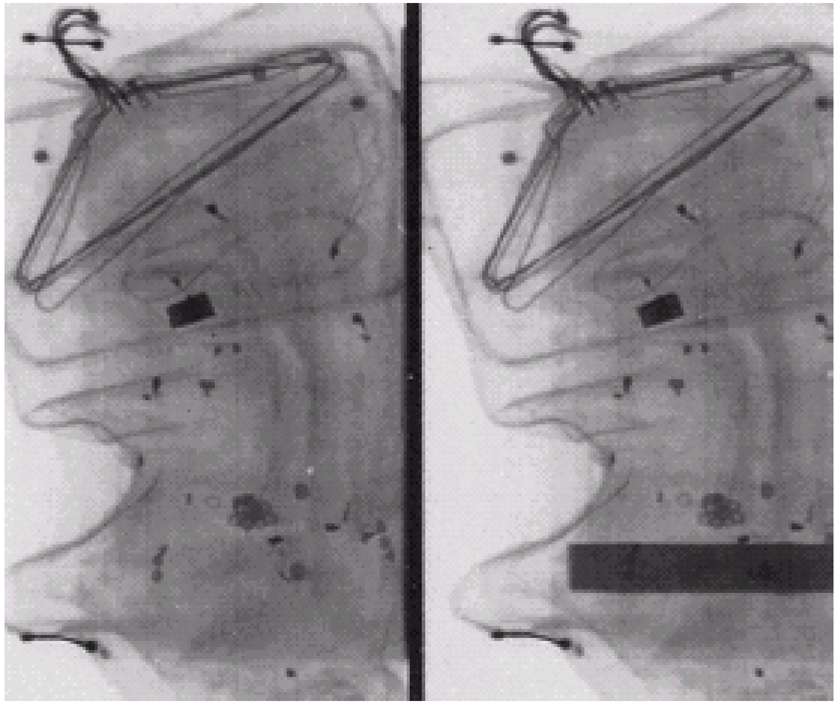
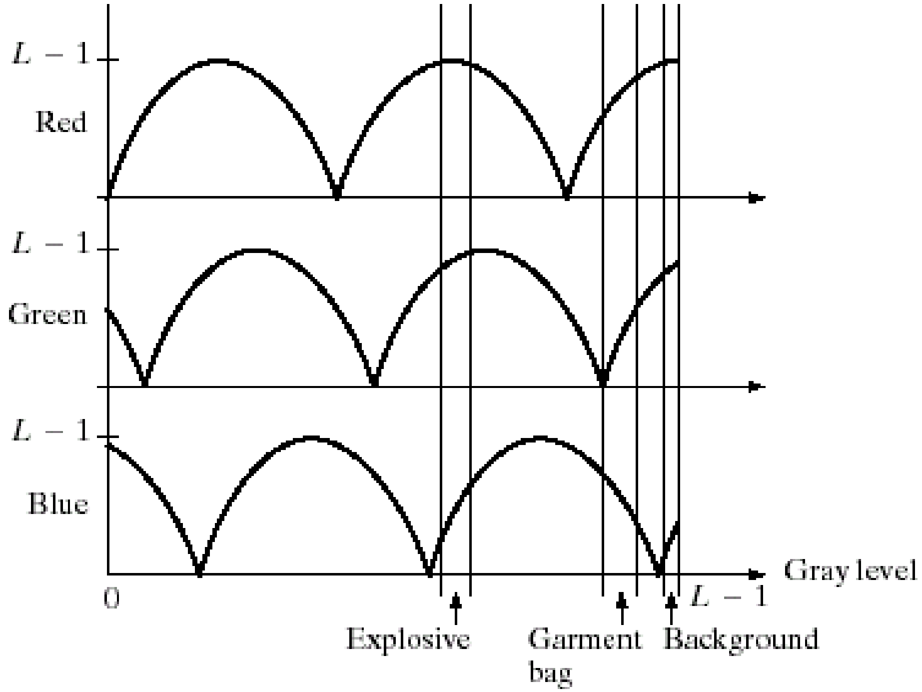
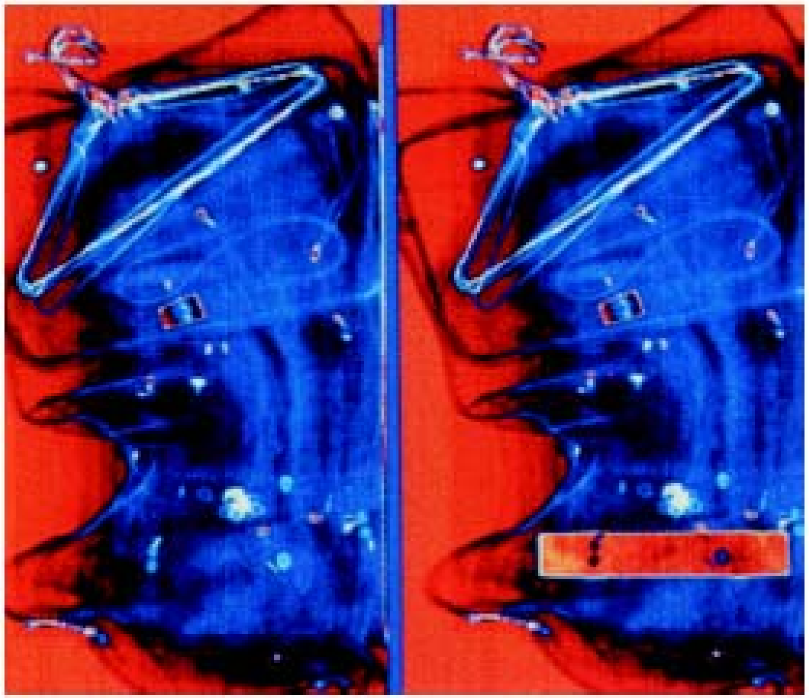


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

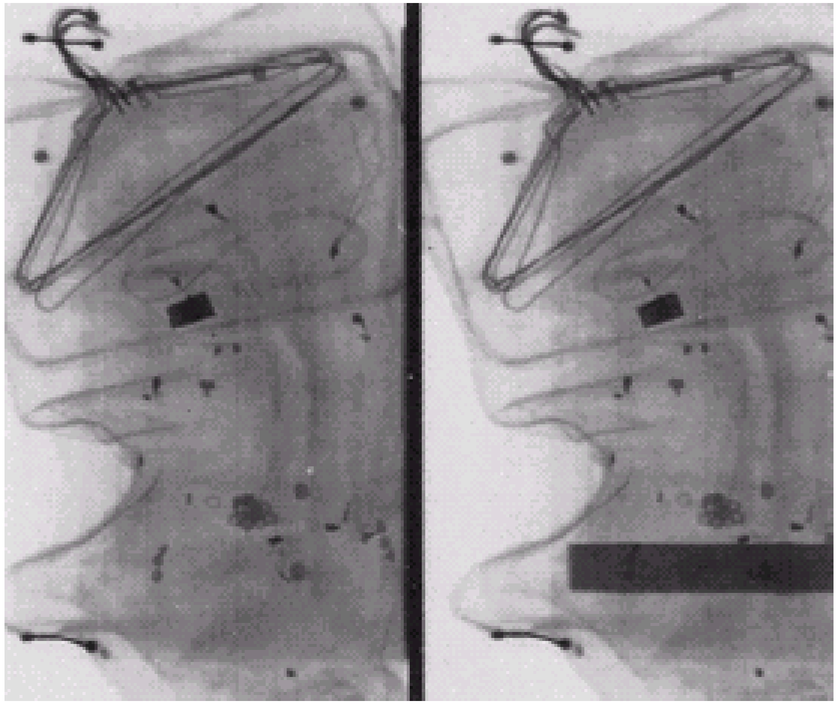
Application 1

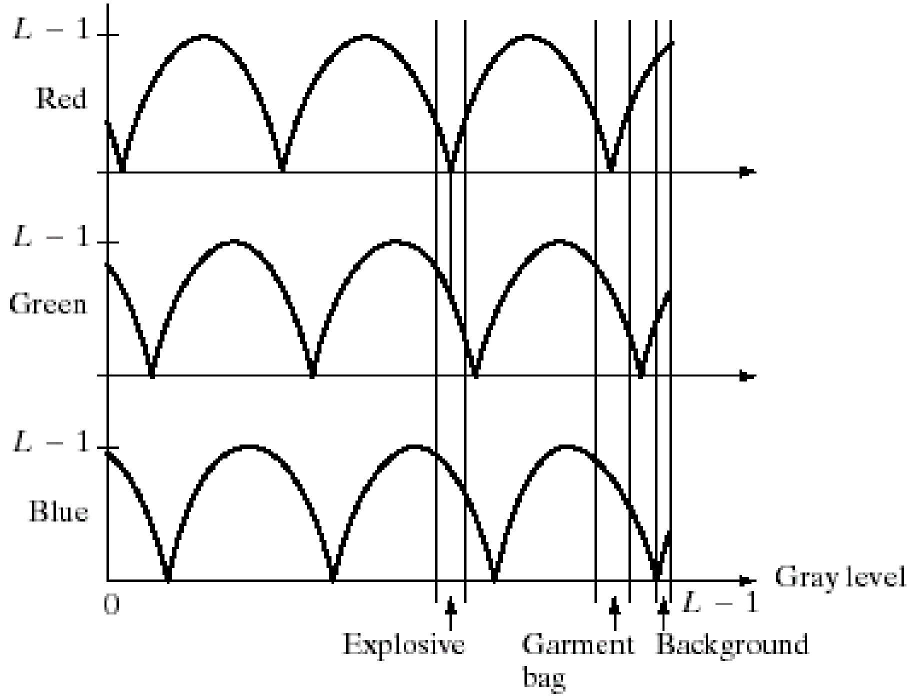


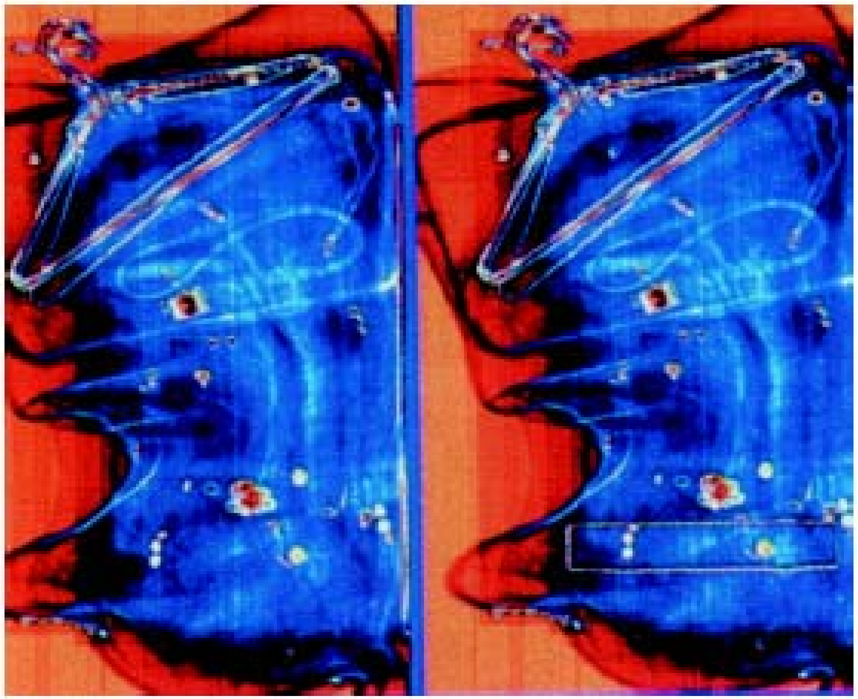




Application 1

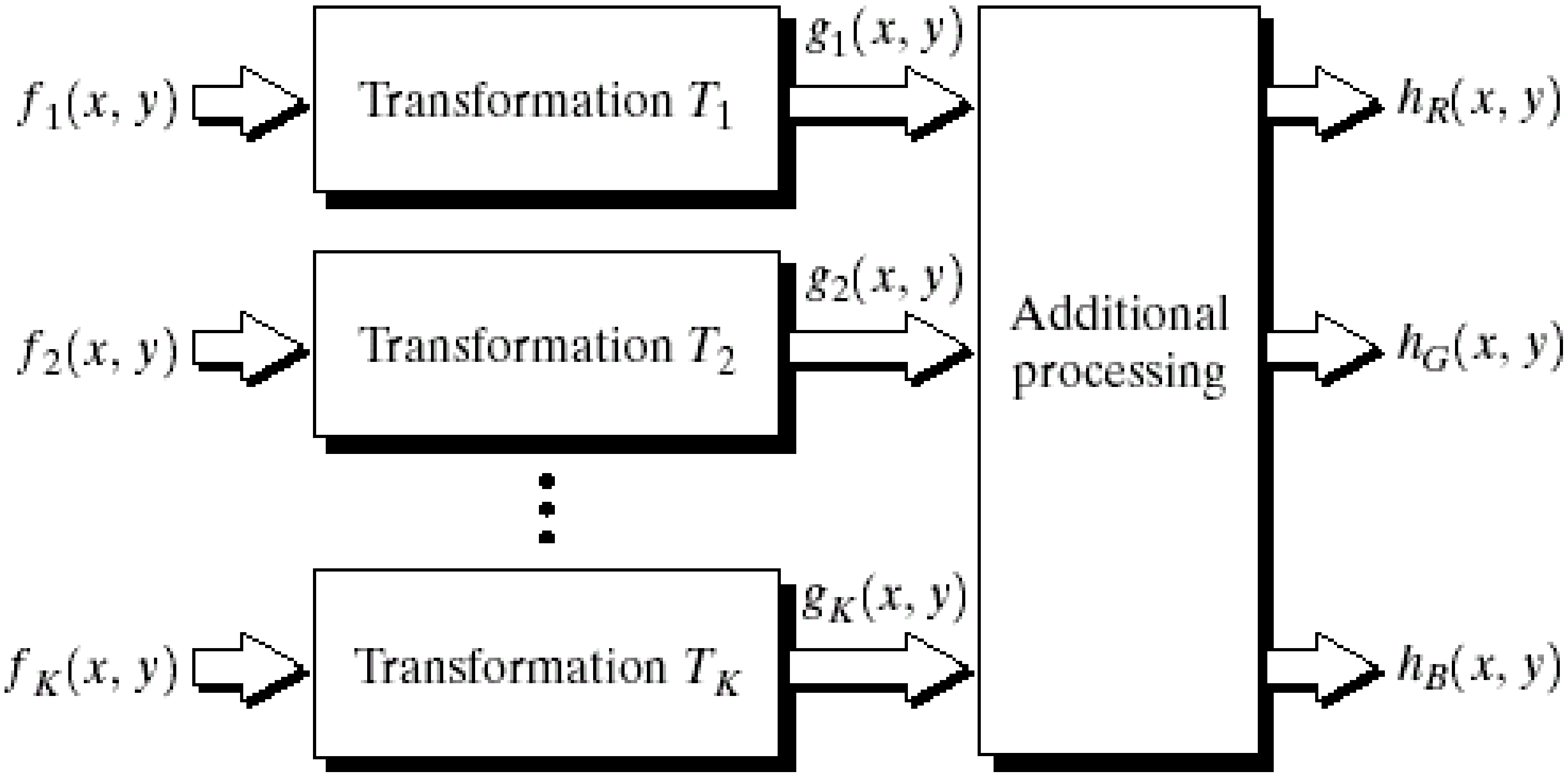




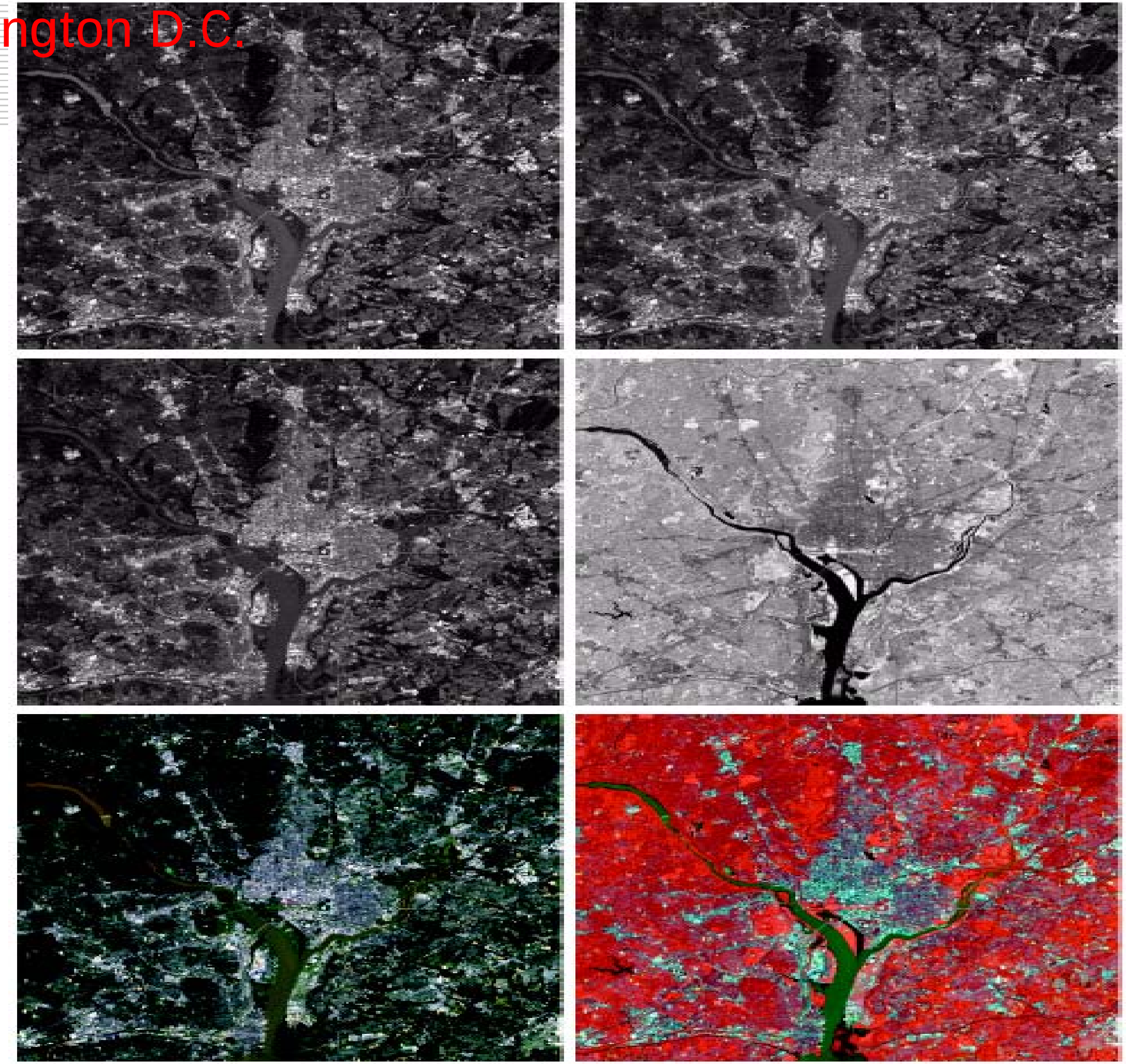


Combine several monochrome images

Example: multi-spectral images



Washington D.C.



R

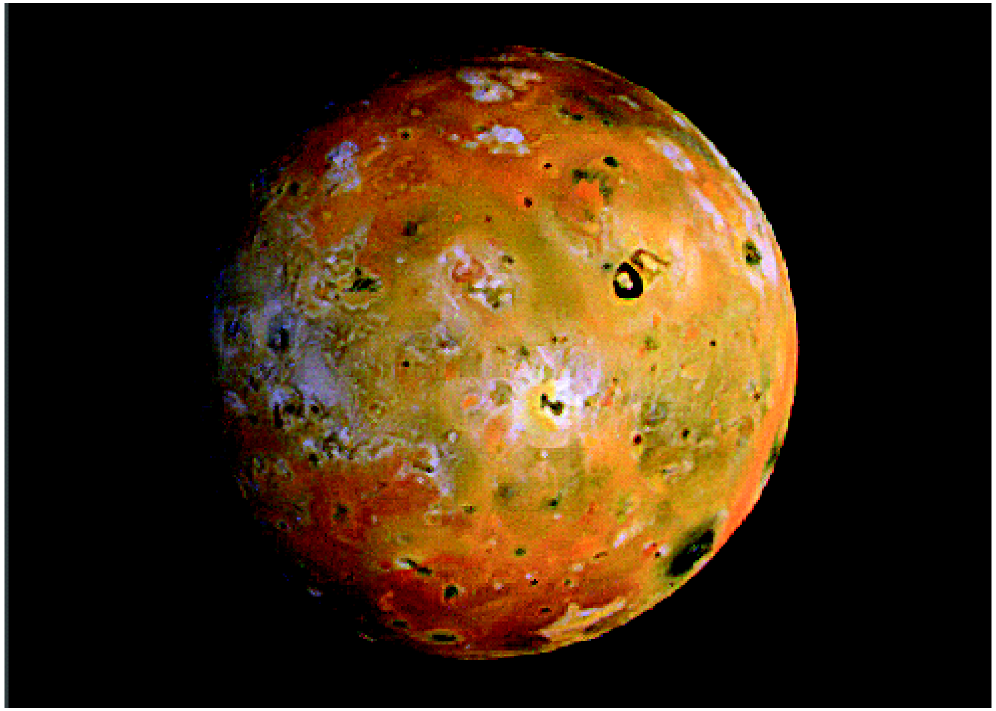
G

B

Near Infrared (sensitive to biomass)

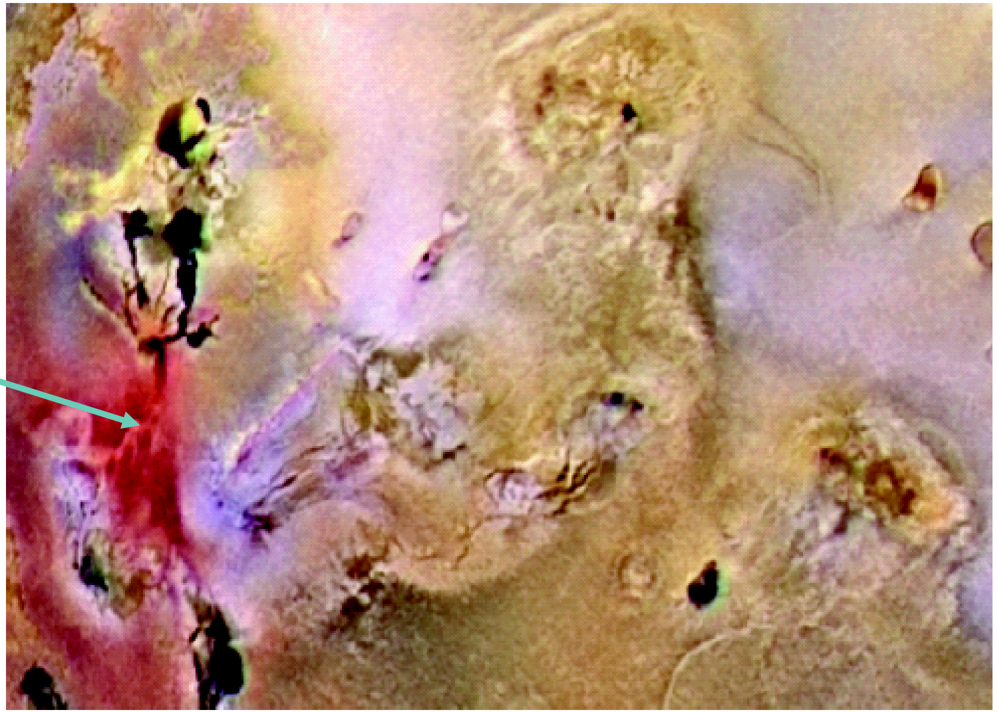
R+G+B

near-infrared+G+B



Jupiter Moon Io

volcano



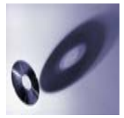
Basics of full-color image processing

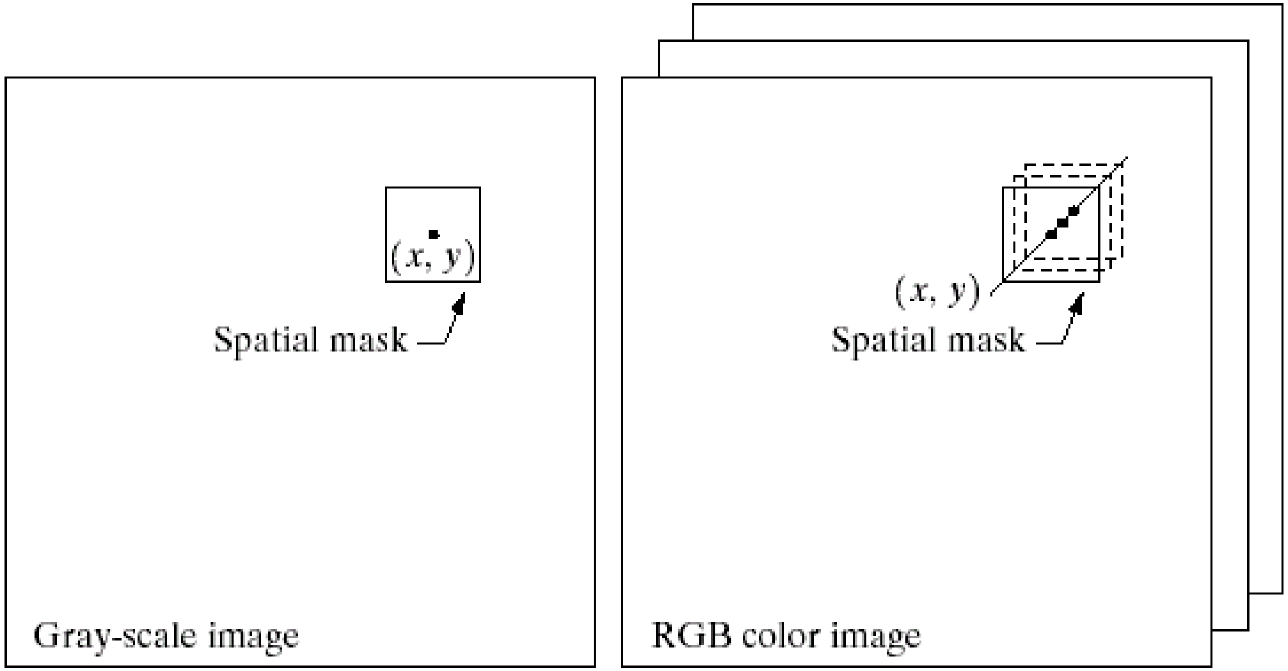
- A pixel at (x,y) is a vector in the color space
  - RGB color space

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

c.f. gray-scale image

f(x,y) = I(x,y)

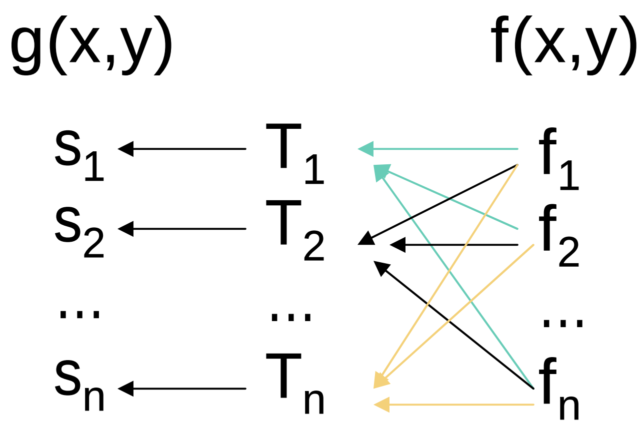
a b

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

Color transformation

- Similar to gray scale transformation
  - g(x,y)=T[f(x,y)]
- Color transformation

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



Color Transformations

- Same as the gray-level transformation techniques of Chapter 3
- Use color mapping functions for each color component
  - See Eq. 6.5-2 (pp.315)
  - Color-space components – Fig 6.30
  - Adjusting the intensity of an image using color transformations – Fig. 6.31

Use which color model in color transformation?

- RGB ⇔CMY(K) ⇔ HSI
- Theoretically, any transformation can be performed in any color model
- Practically, some operations are better suited to specific color model

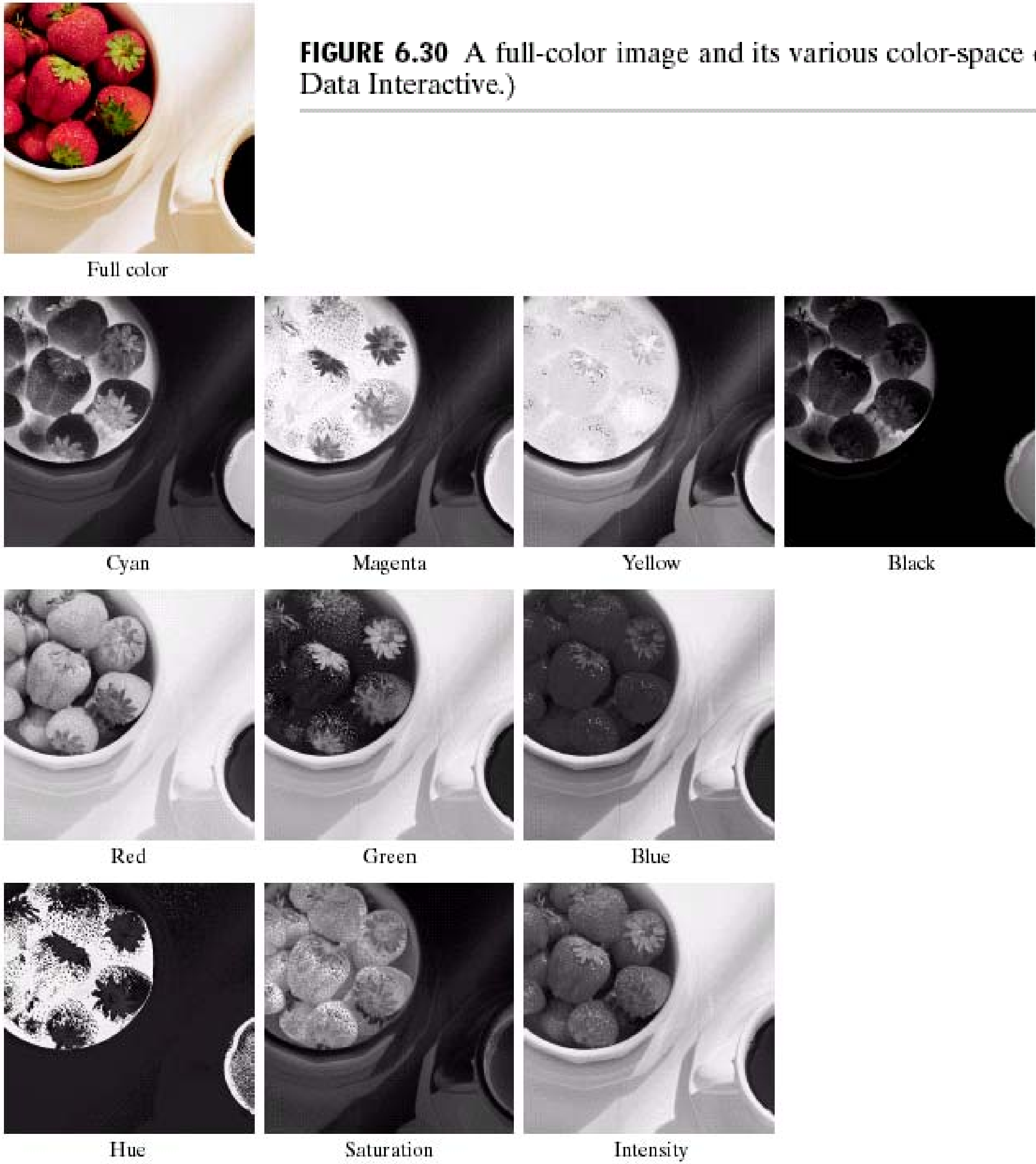
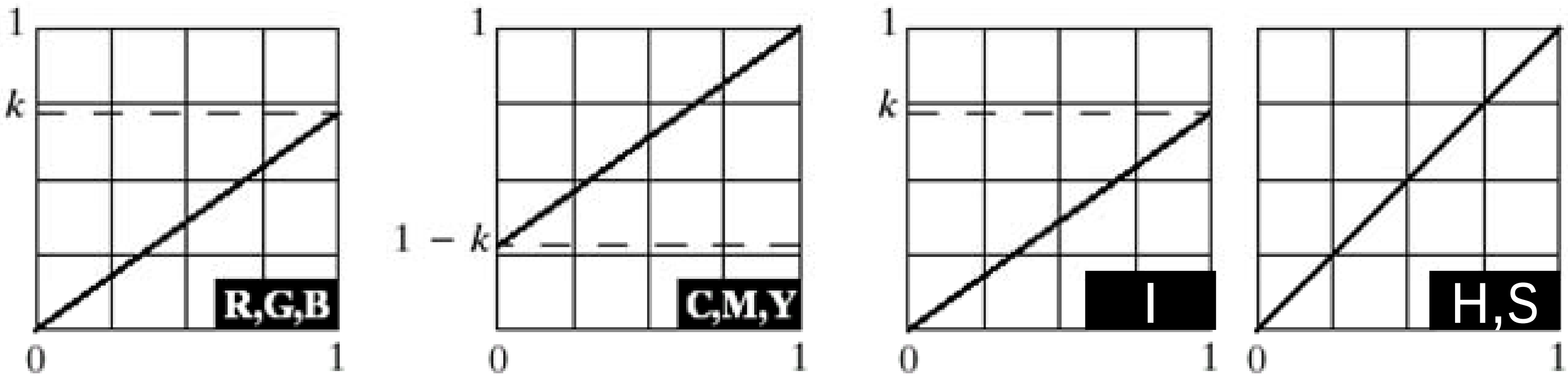


FIGURE 6.30 A full-color image and its various color-space components. (Original image courtesy of Med-Data Interactive.)


1
k
R,G,B
0
1
1
1 − k
C,M,Y
0
1
1
k
I
0
1
H,S
0
1

6.5 Color Transformations

- Color Complements
  - The Hues directly opposite one another on the color circle
  - Fig. 6.32
  - Example 6.7
    - Computing color image complements.
    - Fig. 6.33

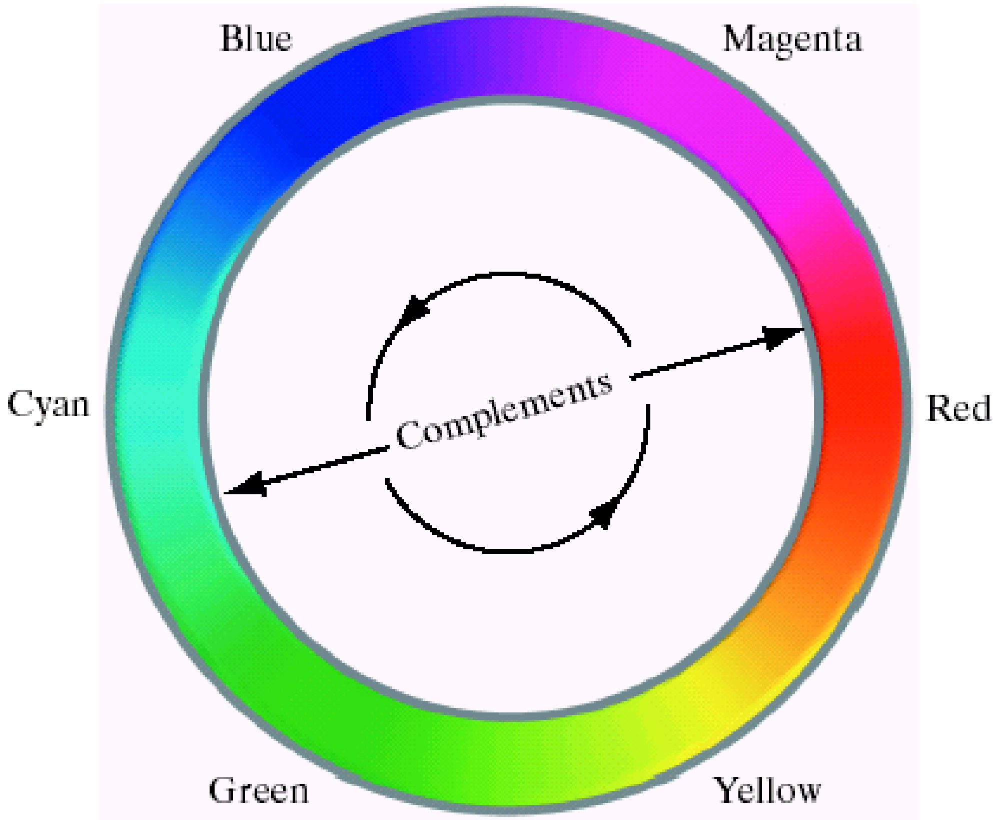
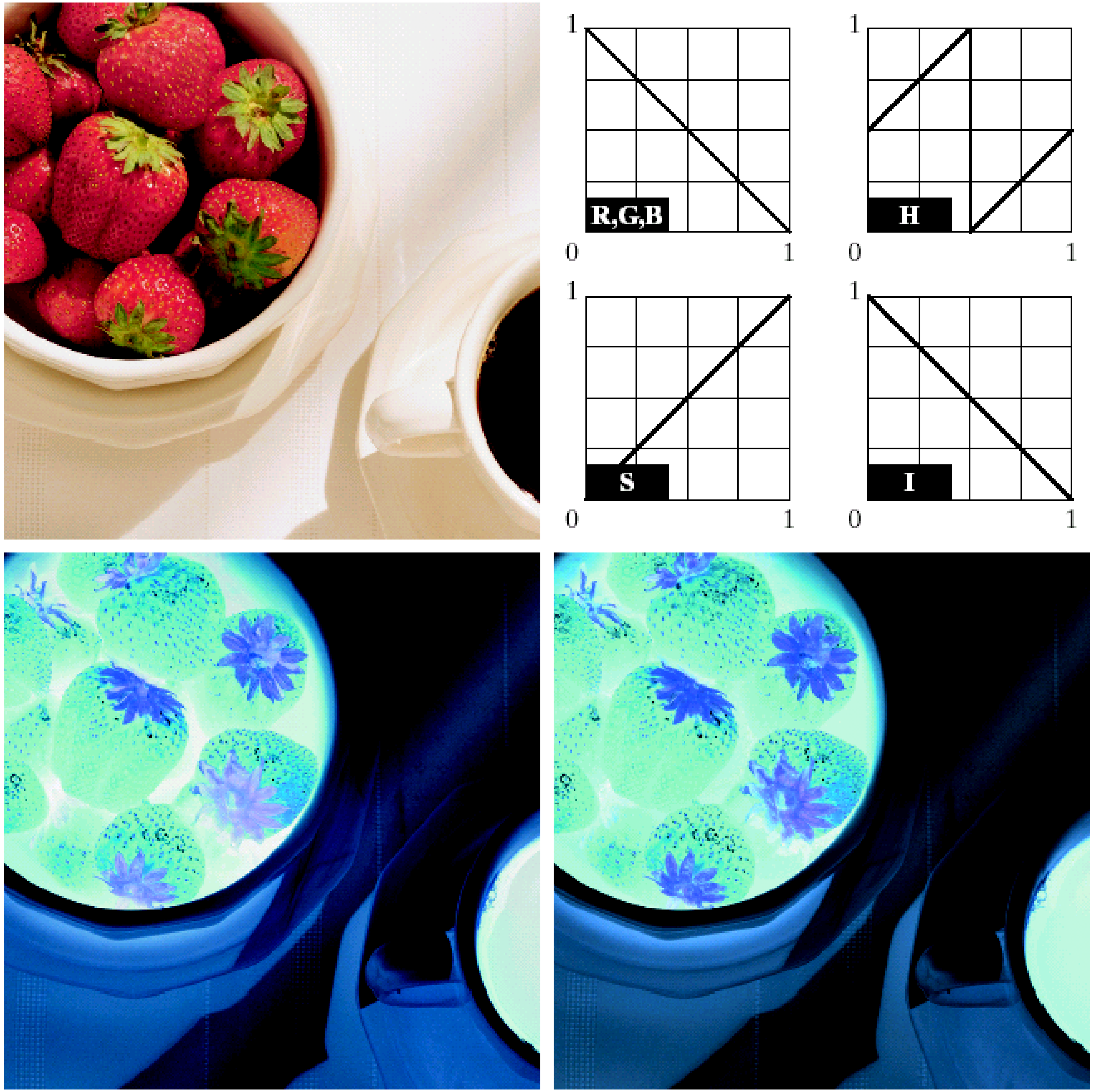


FIGURE 6.32
Complements on the color circle.

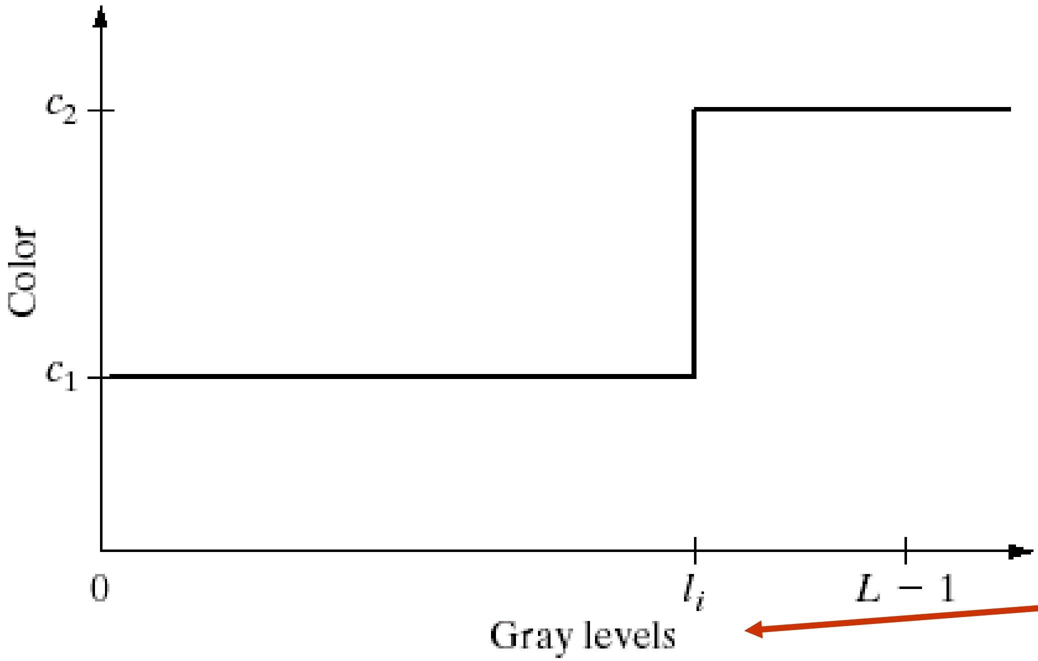


a b
c d

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.

Purpose of color slicing

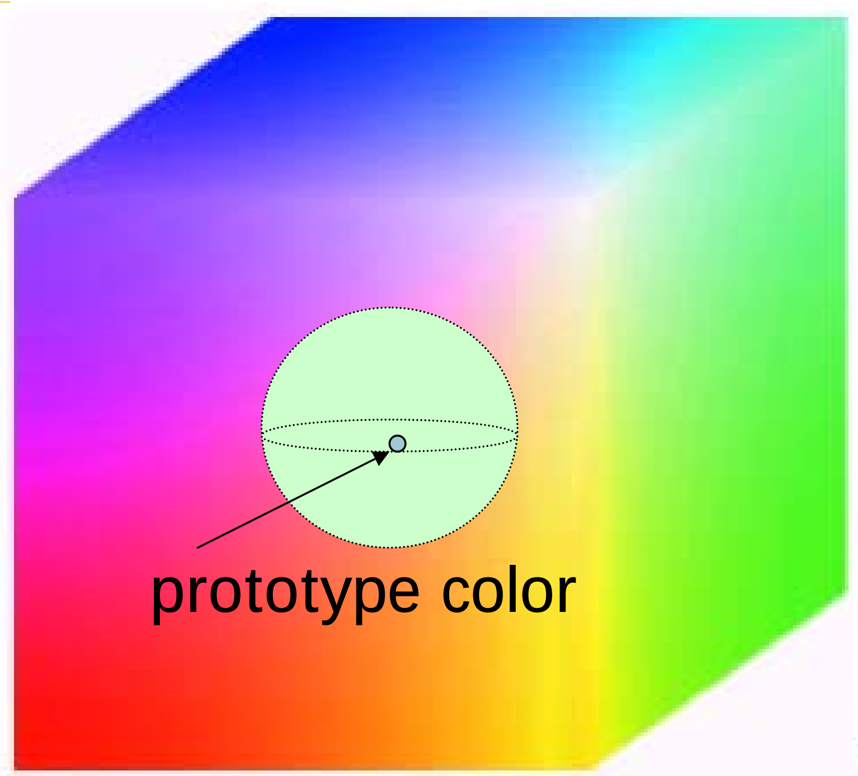
- Highlight a specific range of colors of interest
  - Recall the pseudo-color intensity slicing



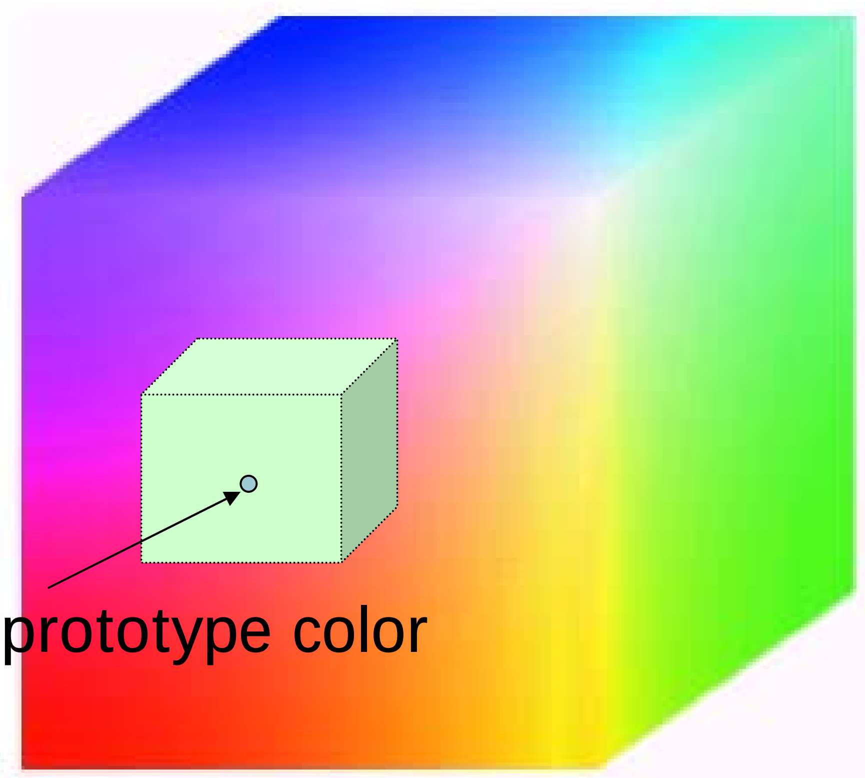
1-D intensity

Implementation of color slicing

- How to take a region of colors of interest?

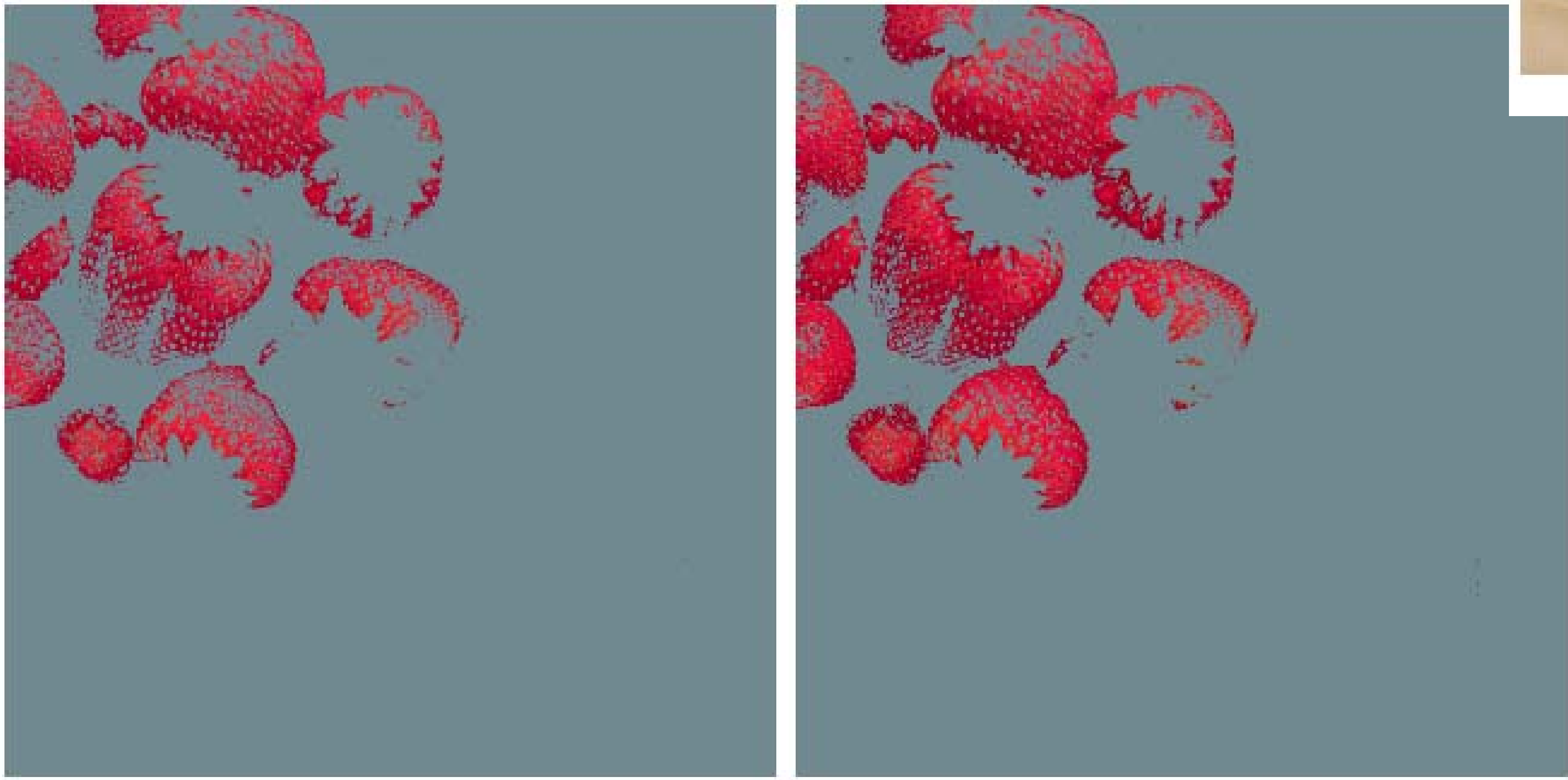


Sphere region



Cube region

Full color



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 $(0.5, 0.5, 0.5)$.

General color transformation

- Component independent transformations

g(x,y) f(x,y)

$$
\begin{array}{ccccc}
s_1 & \leftarrow & T_1 & \leftarrow & f_1 \\
s_2 & \leftarrow & T_2 & \leftarrow & f_2 \\
\ldots & & \ldots & & \ldots \\
s_n & \leftarrow & T_n & \leftarrow & f_n
\end{array}
$$

- **Digital darkroom**
  - Photo enhancement
  - Color reproduction

Color Transformations

– L*a*b* color space is
  - Colorimetric
  - Perceptually uniform
  - Device independent
  - Not a directly displayable format
– L*a*b* color components
  - Lightness (L*)
  - Red – green (a*)
  - Green – blue (b*)

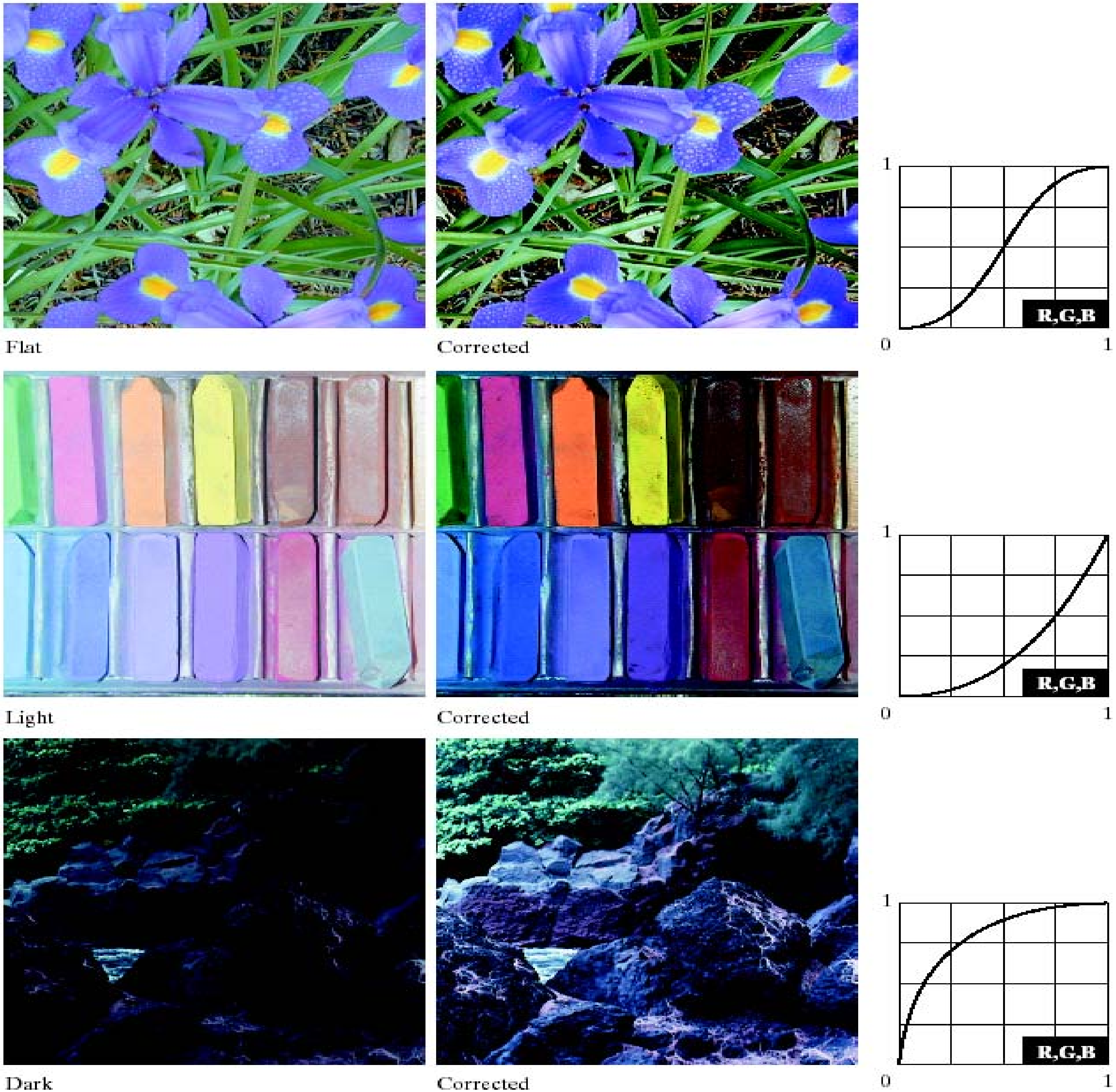
Tone correction

- Tone adjustment: does not change hue
  - Tone range of an image, key type: general distribution of color **intensity**
  - **High-key:** image concentrates at high intensity
  - **Middle-key:** middle
  - **Low-key:** image concentrates at low intensity

flat

High-key

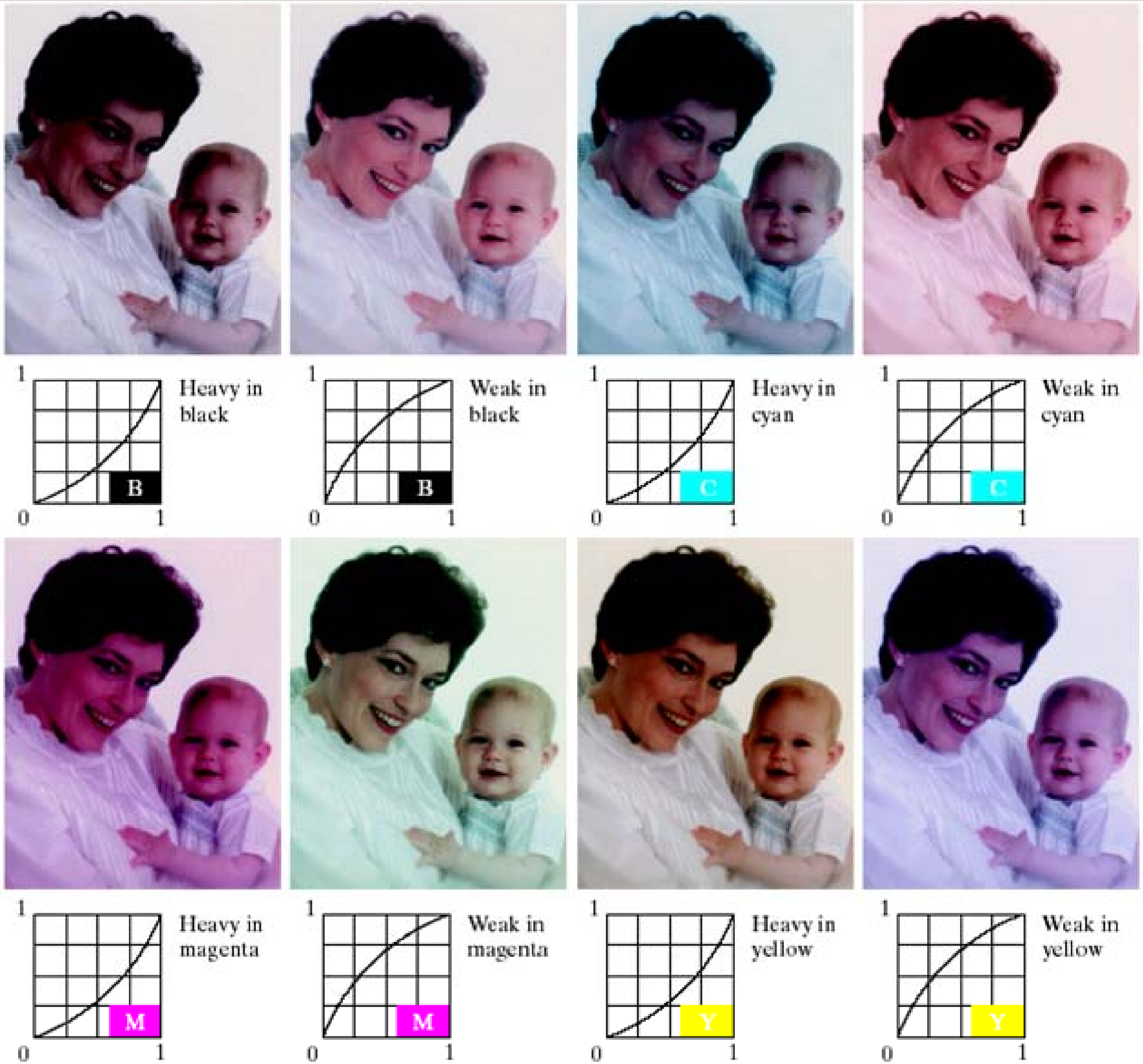
Low-key



Color corrections

- Visual assessment on certain regions
  - Ex. Skin tones

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

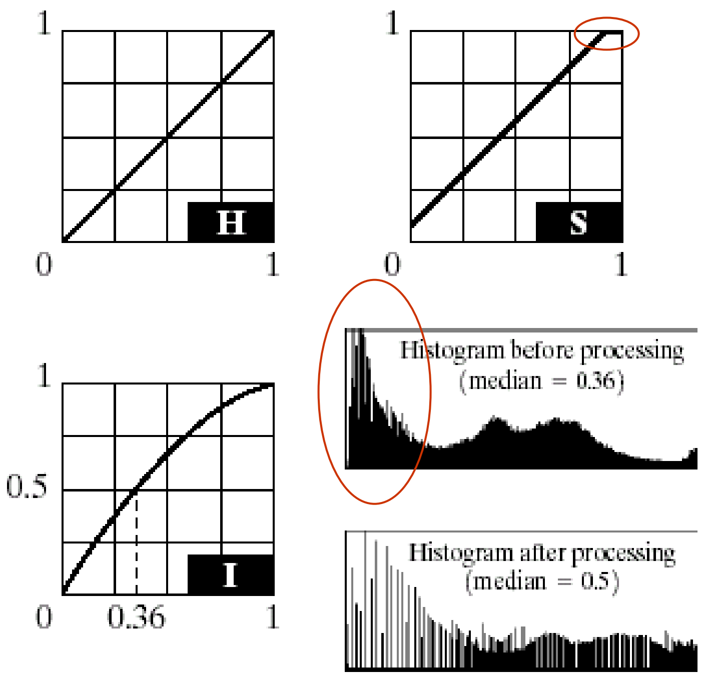
Histogram processing

- Histogram processing can be done automatically
  - Ex. Histogram equalization
- Compared to gray images, it is unwise to do histogram equalization on each component of a color image
  - Change of one color component will affect the visual results of the other compnents

Histogram processing (cont.)

- Histogram processing on color images
  - Does not change the hue first
  - Spread the color intensity uniformly
  - HSI model

original

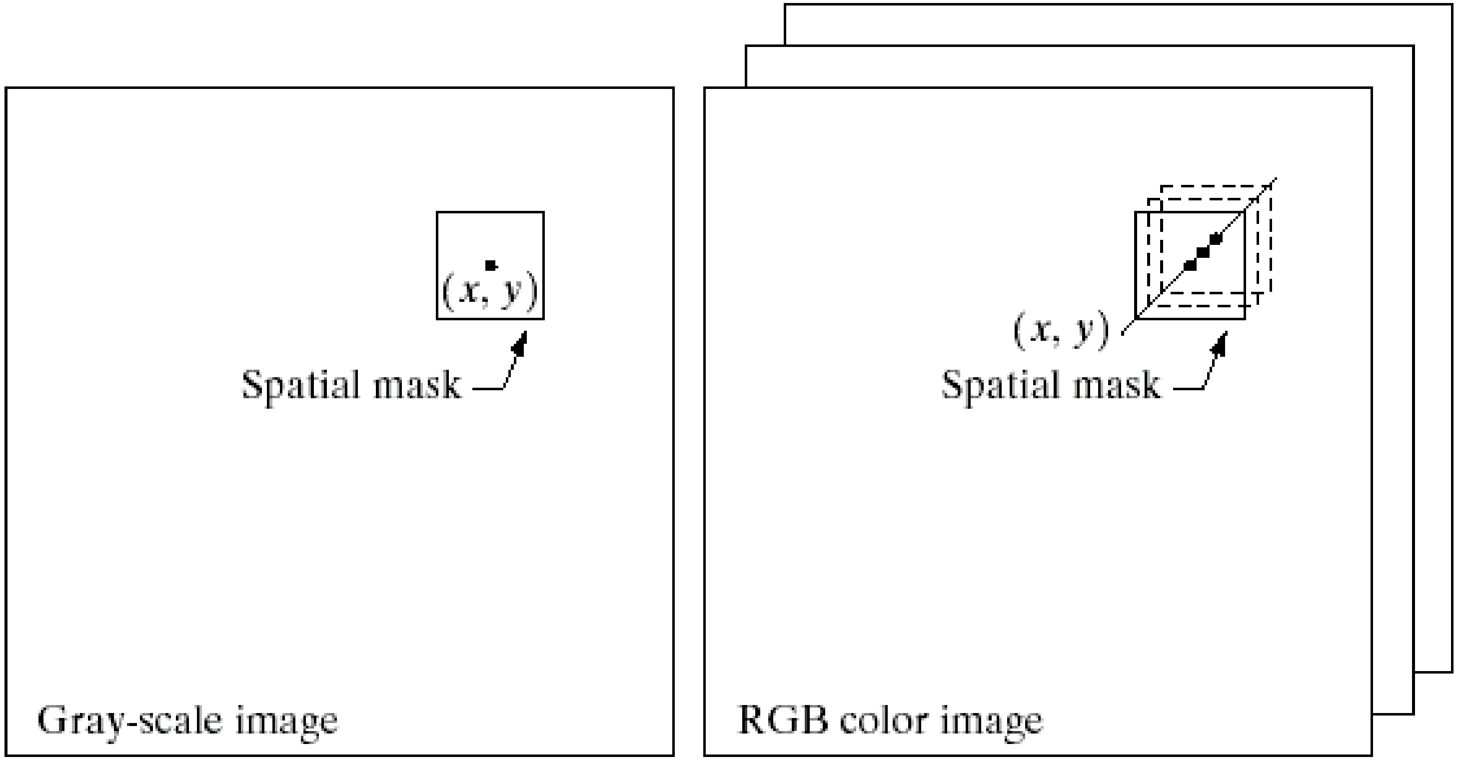


Spread intensity

Adjust saturation

Color image smoothing

- Neighborhood processing



Color image smoothing: averaging mask

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

vector processing

Neighborhood
Centered at (x,y)

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

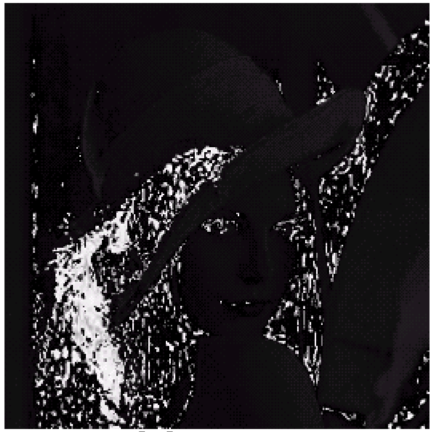
per-component processing

original

R

G

G



H

S

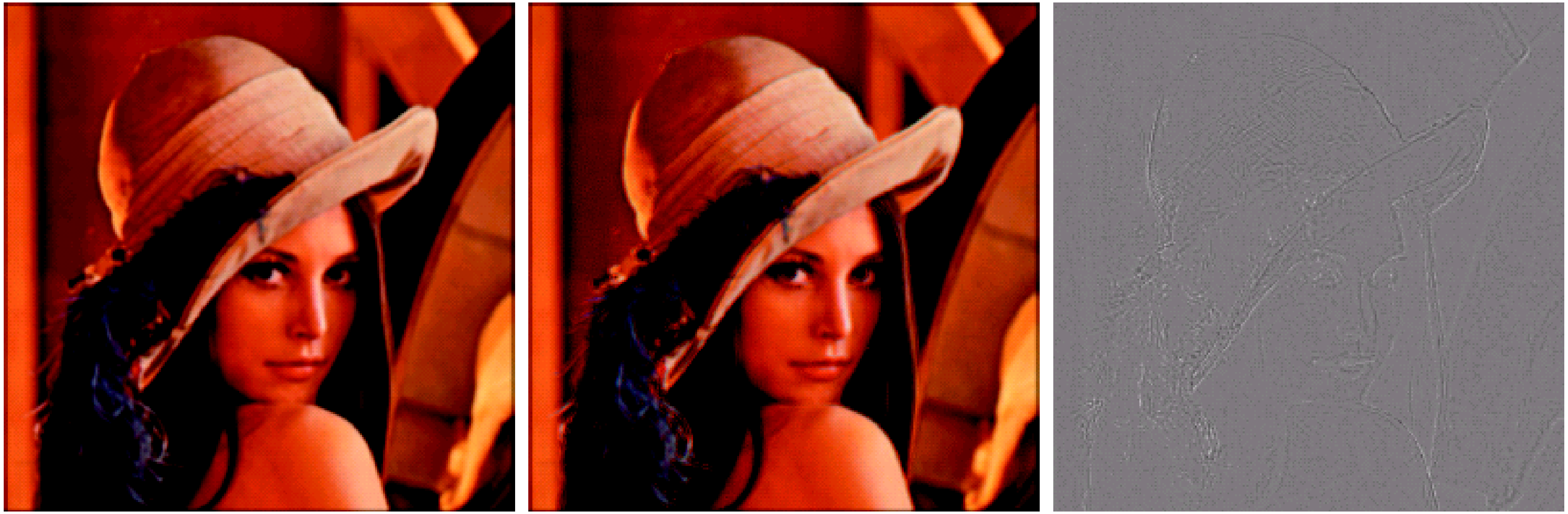
I

Example: 5x5 smoothing mask

RGB model

Smooth I
in HSI model

difference



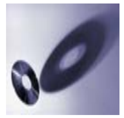
a b c

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.

Color image sharpening

- Example: Laplacian

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

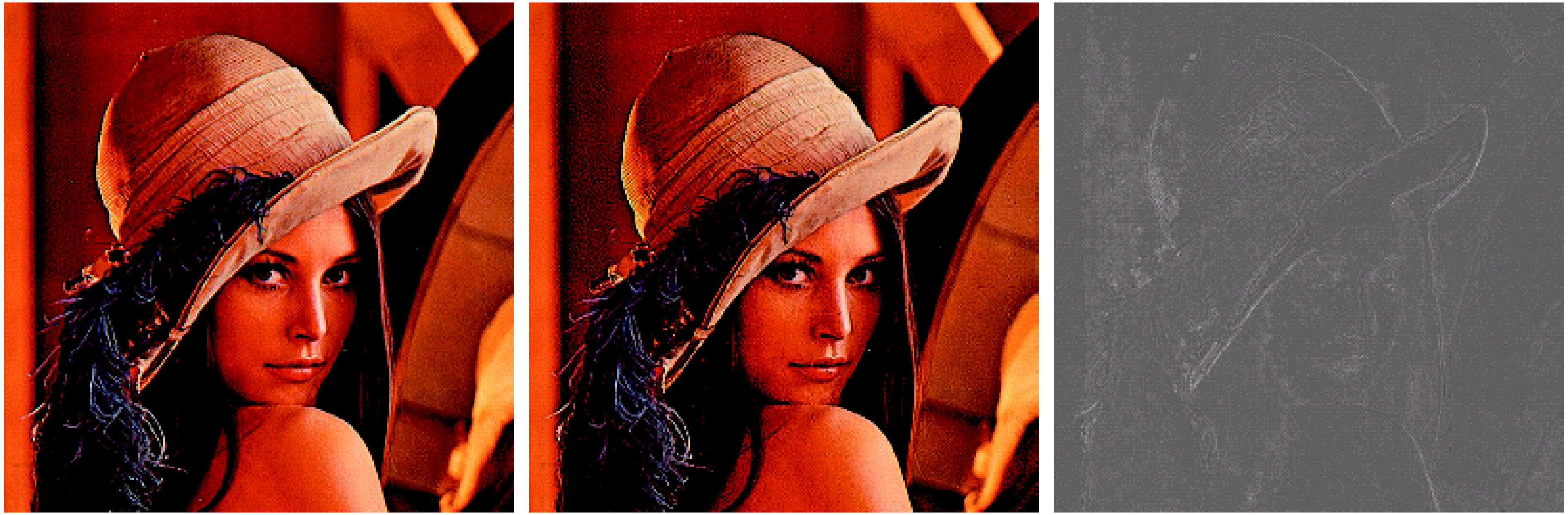




Example: Laplacian sharpening

RGB

Sharpen intensity of HSI model

difference

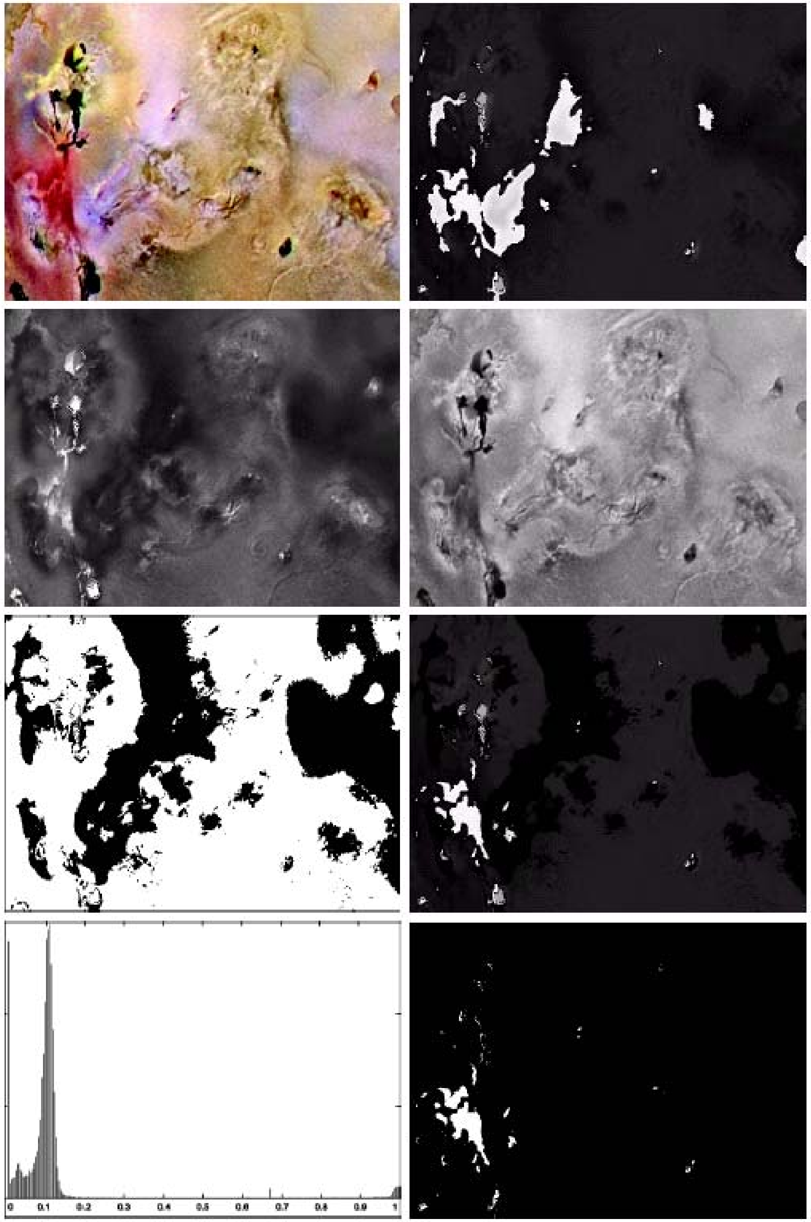


a b c

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.

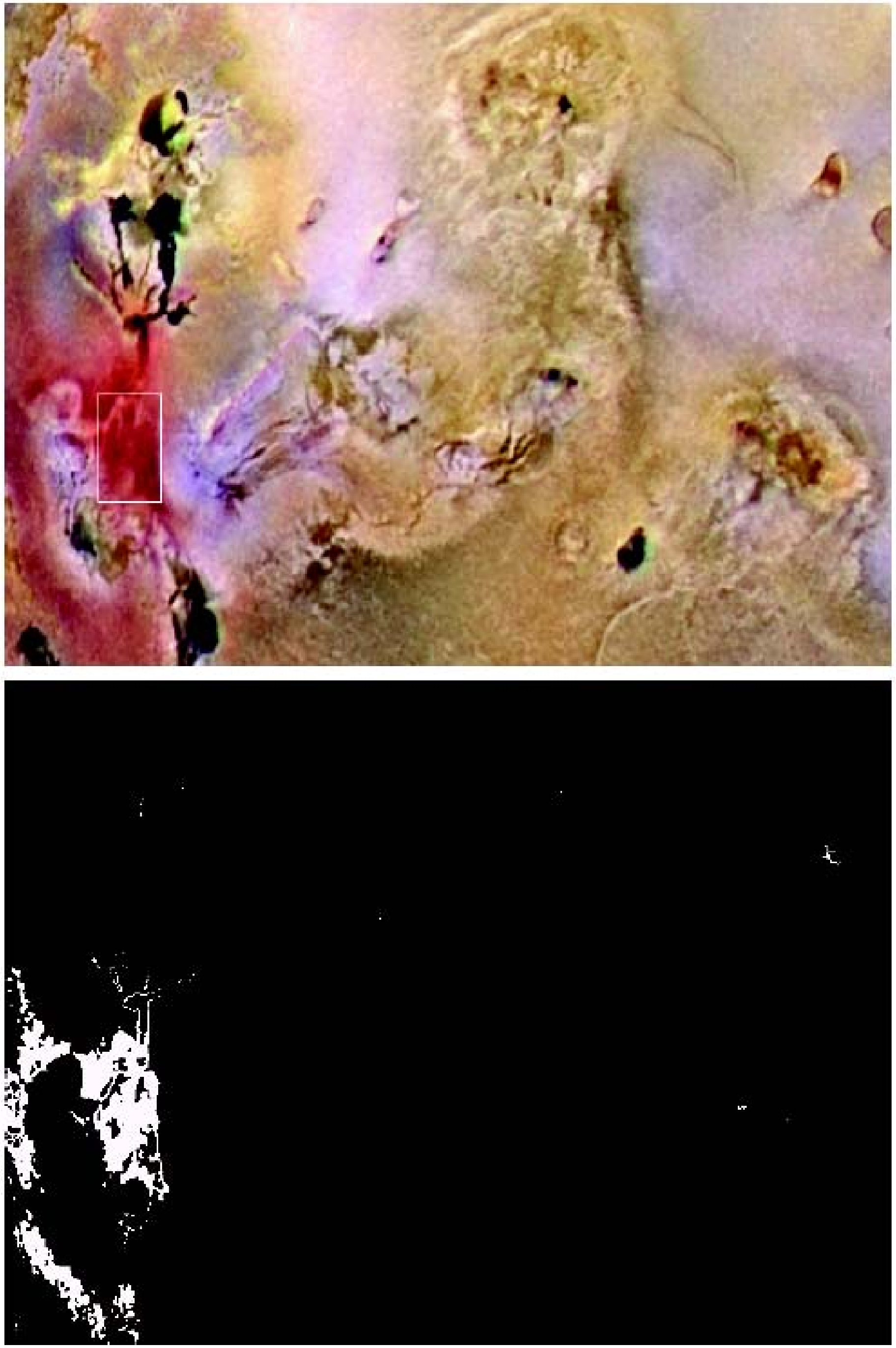
6.7 Color Segmentation

- Segmentation in HSI Color Space
  - Example 6.14
    - Fig. 6.42
- Segmentation in RGB Color Space
  - Example 6.15
    - Fig. 6.44
- Color Edge Detection
  - Consider Fig. 6.45
  - Example 6.16 – RGB color image
    - Fig. 6.46 and 6.47



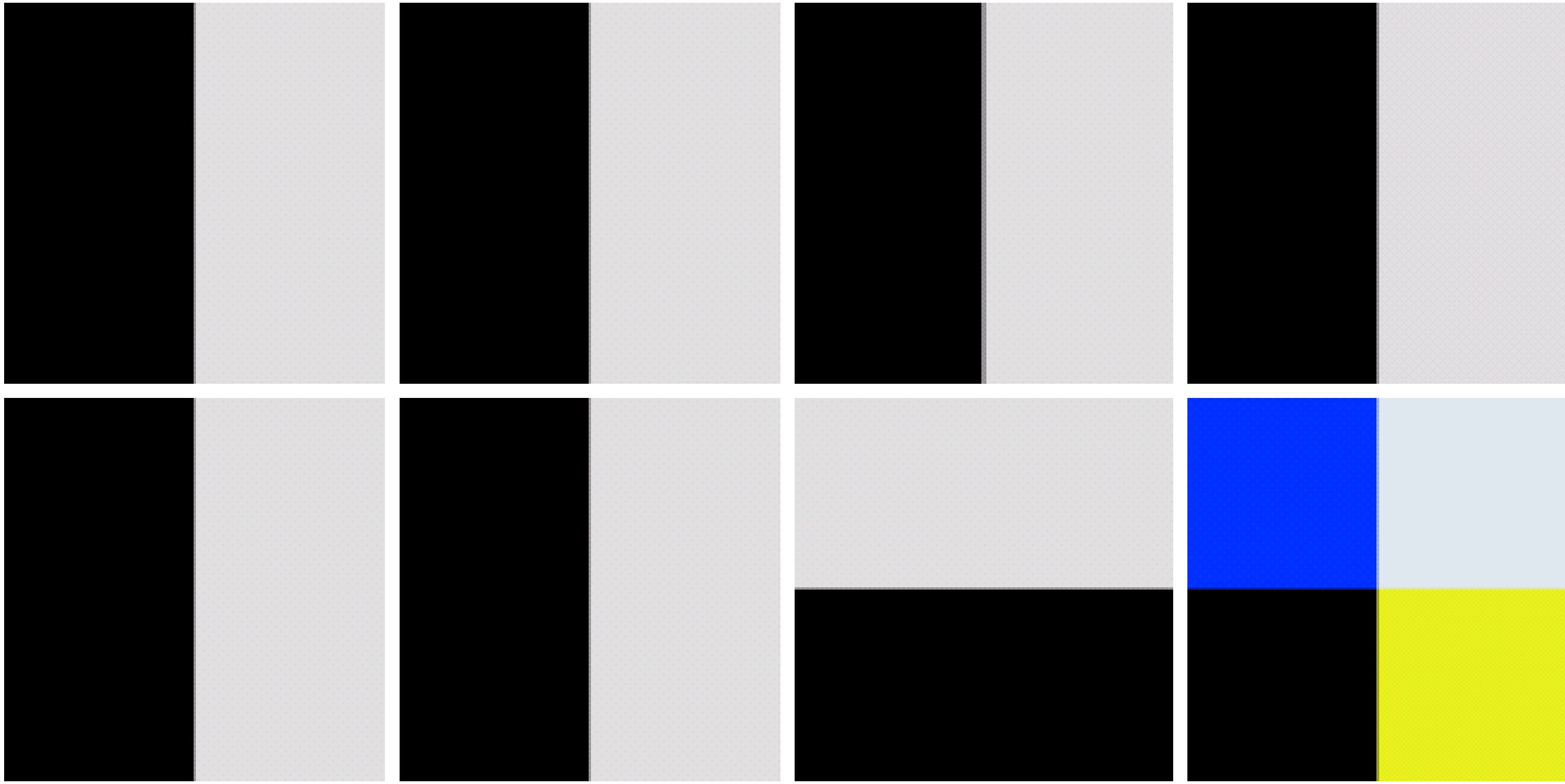
a b
c d
e f
g h

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).



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).



a b c d
e f g h

FIGURE 6.45 (a)–(c) R, G, and B component images and (d) resulting RGB color image. (f)–(g) R, G, and B component images and (h) resulting RGB color image.

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).

6.8 Noise in Color Image

- Usually, the noise content of a color image has the same characteristics in each color channel.
- Example 6.17
  - Illustration of the effects of converting noisy RGB images to HSI
  - Fig. 6.48, 6.49, and 6.50

a b
c d

FIGURE 6.48 (a)–(c) Red, green, and blue component images corrupted by additive Gaussian noise of mean 0 and variance 800. (d) Resulting RGB image. [Compare (d) with Fig. 6.46(a).]

a b c

FIGURE 6.49 HSI components of the noisy color image in Fig. 6.48(d). (a) Hue. (b) Saturation. (c) Intensity.

a	b
c	d

FIGURE 6.50
(a) RGB image with green plane corrupted by salt-and-pepper noise.
(b) Hue component of HSI image.
(c) Saturation component.
(d) Intensity component.

Color Image Compression

- RGB
- HSI
- CMY(K)

- Example 6.18
  - JPEG 2000 image compression
  - Fig. 6.51

a b
c d

FIGURE 6.51 Color image compression. (a) Original RGB image. (b) Result of compressing and decompressing the image in (a).