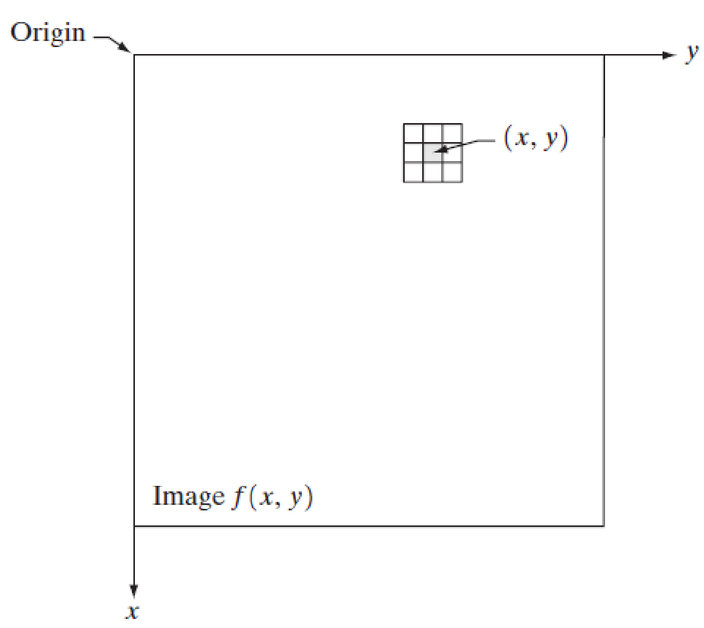
Intensity Transformations and Color Image

Intensity Transformation

Basics of Intensity Transformations and Spatial Filtering

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

FIGURE 3.1 A 3×3 neighborhood about a point (x, y) in an image.



Basics of Intensity Transformations and Spatial Filtering

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

$$f(x, y): \text{input image}$$

$$g(x, y): \text{output image}$$

$$T: \text{an operator on } f \text{ defined over}$$

$$\text{a neighborhood of point } (x, y)$$

Basics of Intensity Transformations and Spatial Filtering

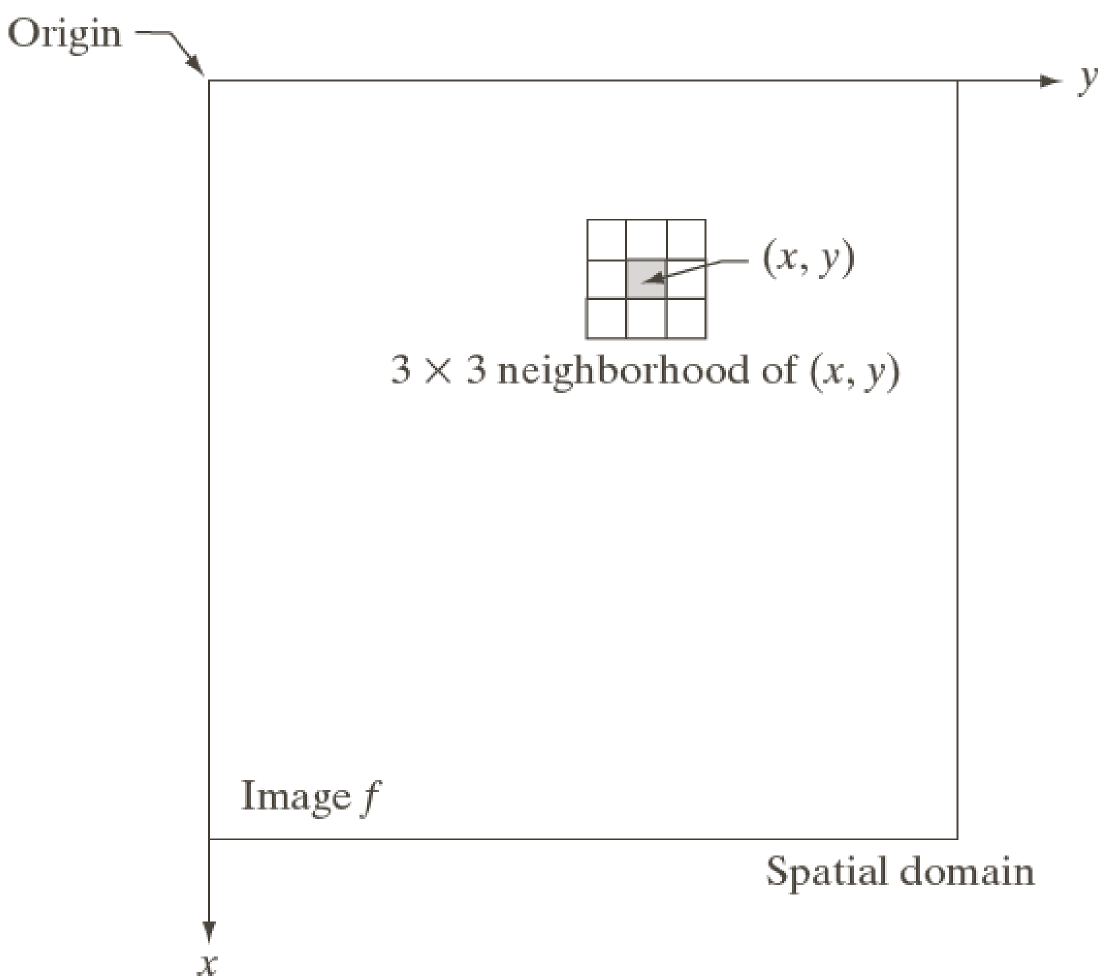
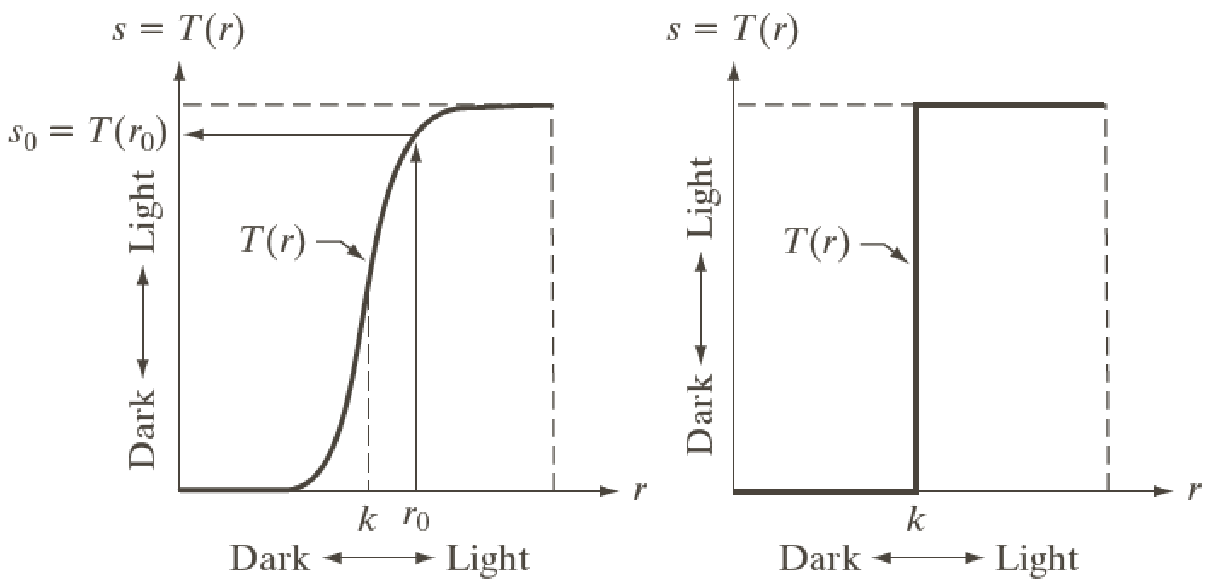


FIGURE 3.1 A 3×3 neighborhood about a point (x, y) in an image in the spatial domain. The neighborhood is moved from pixel to pixel in the image to generate an output image.

Simple Spatial Domain Processing

Intensity transformation function

$$s = T(r)$$



a b

FIGURE 3.2 Intensity transformation functions. (a) Contrast-stretching function. (b) Thresholding function.

Some Basic Intensity Transformation Functions

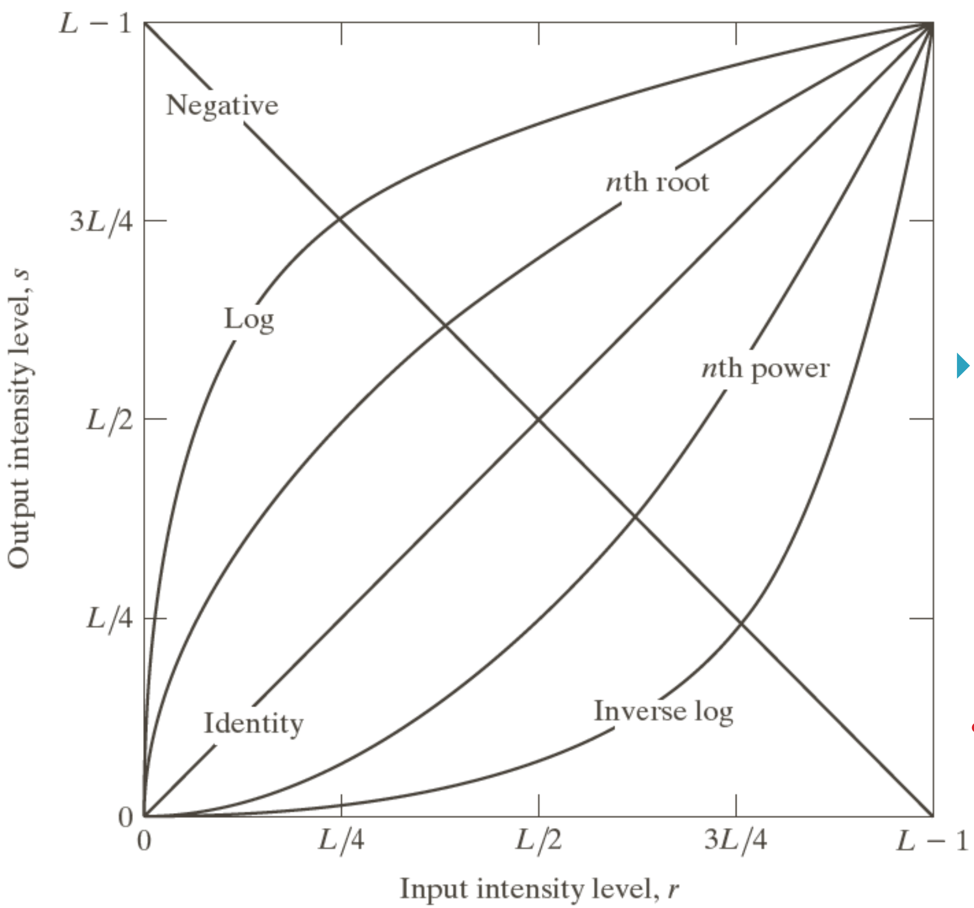
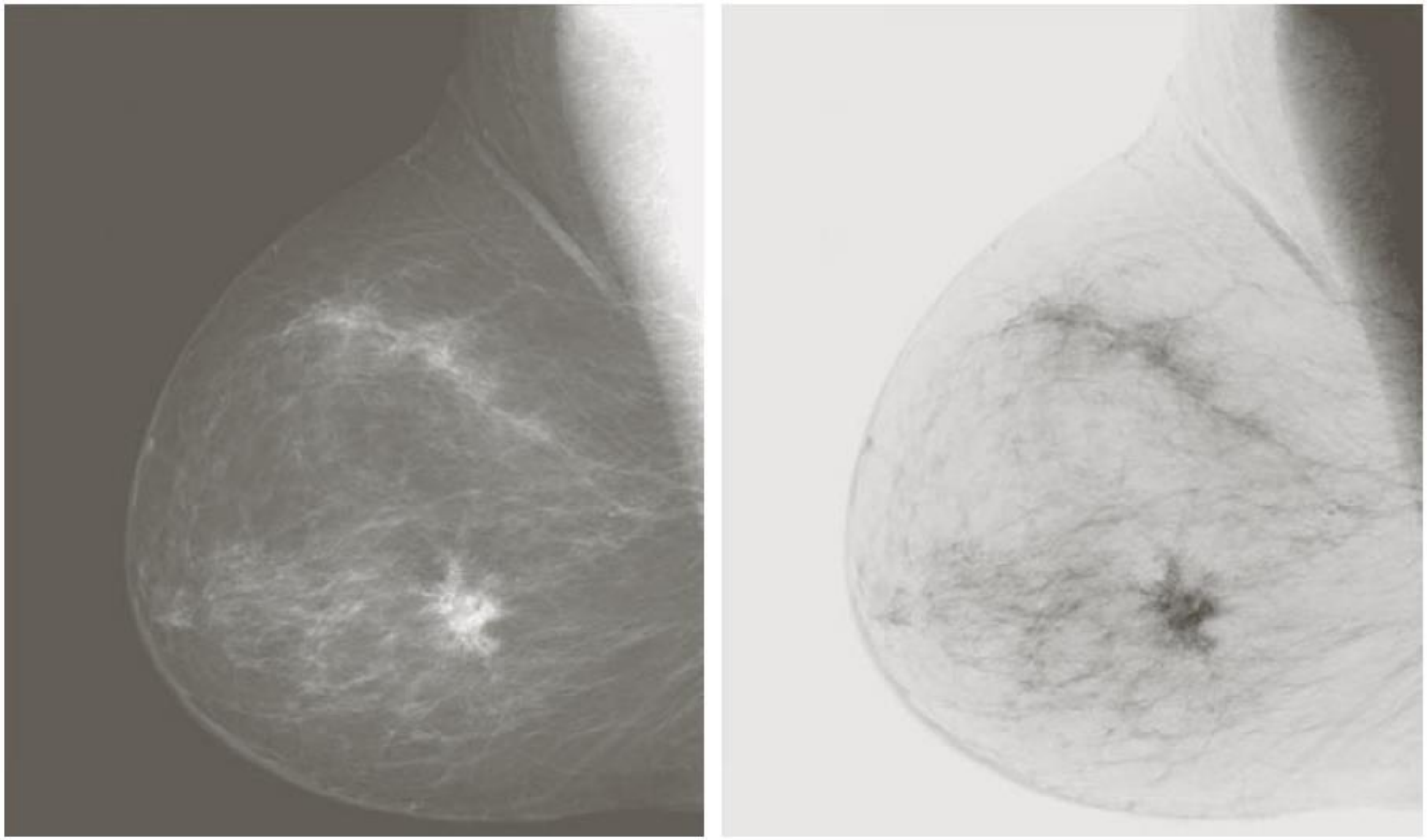


FIGURE 3.3 Some basic intensity transformation functions. All curves were scaled to fit in the range shown.

- Image Negatives
  - Intensity level: [0, L−1]
  - Negative transformation
    - $s = \text{Neg}(r) = L - 1 - r$

- Log Transformation
  - $s = c \log(1+r)$

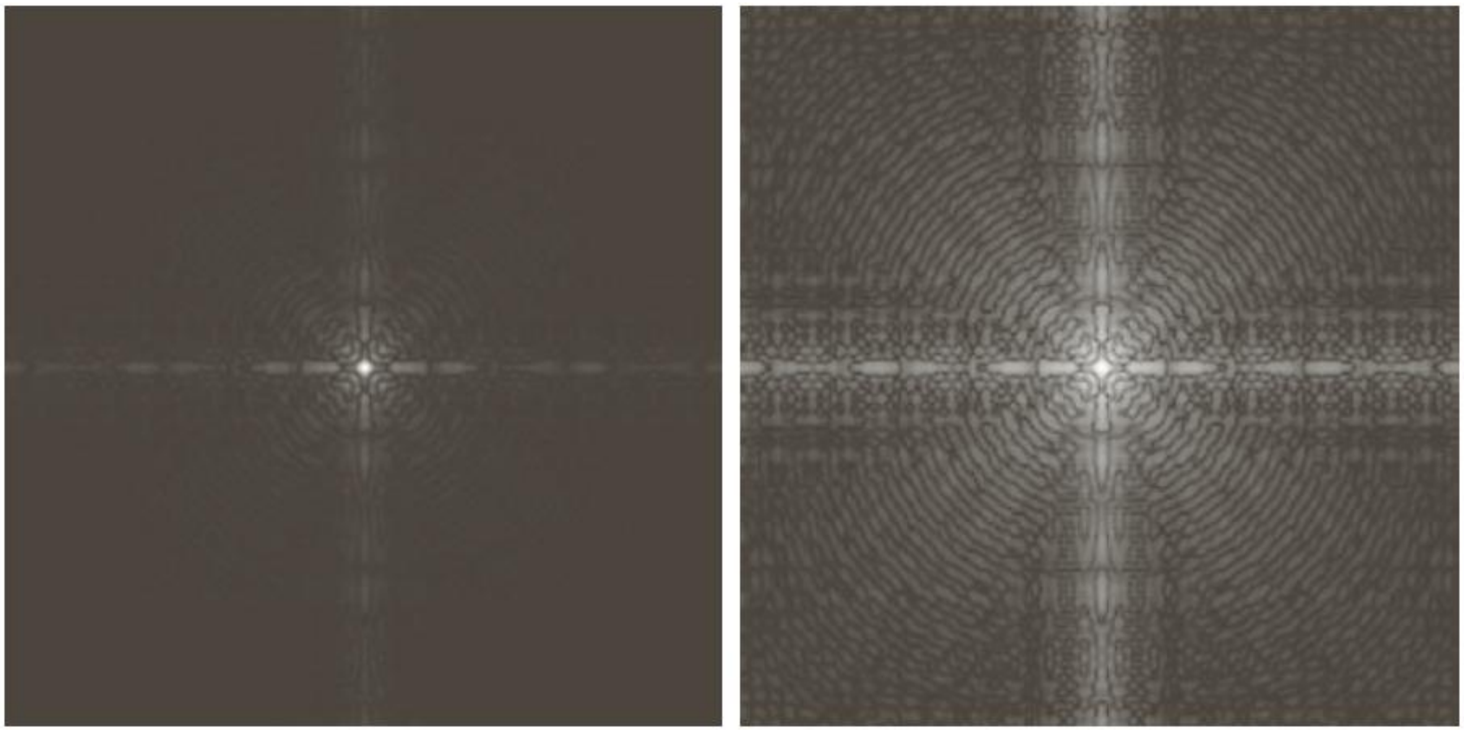
Some Basic Intensity Transformation Functions



a b

FIGURE 3.4
(a) Original digital mammogram.
(b) Negative image obtained using the negative transformation in Eq. (3.2-1).
(Courtesy of G.E. Medical Systems.)

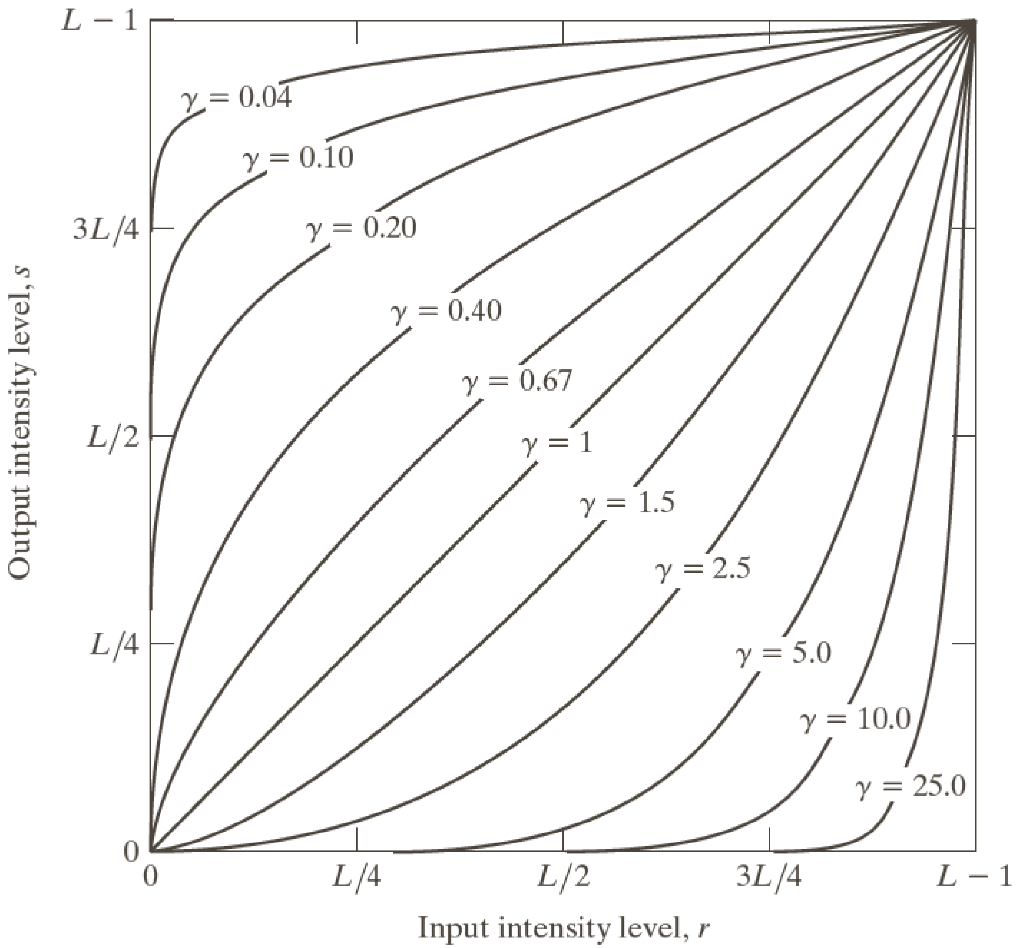
Some Basic Intensity Transformation Functions



a b

FIGURE 3.5 (a) Fourier spectrum. (b) Result of applying the log transformation in Eq. (3.2-2) with $c = 1$.

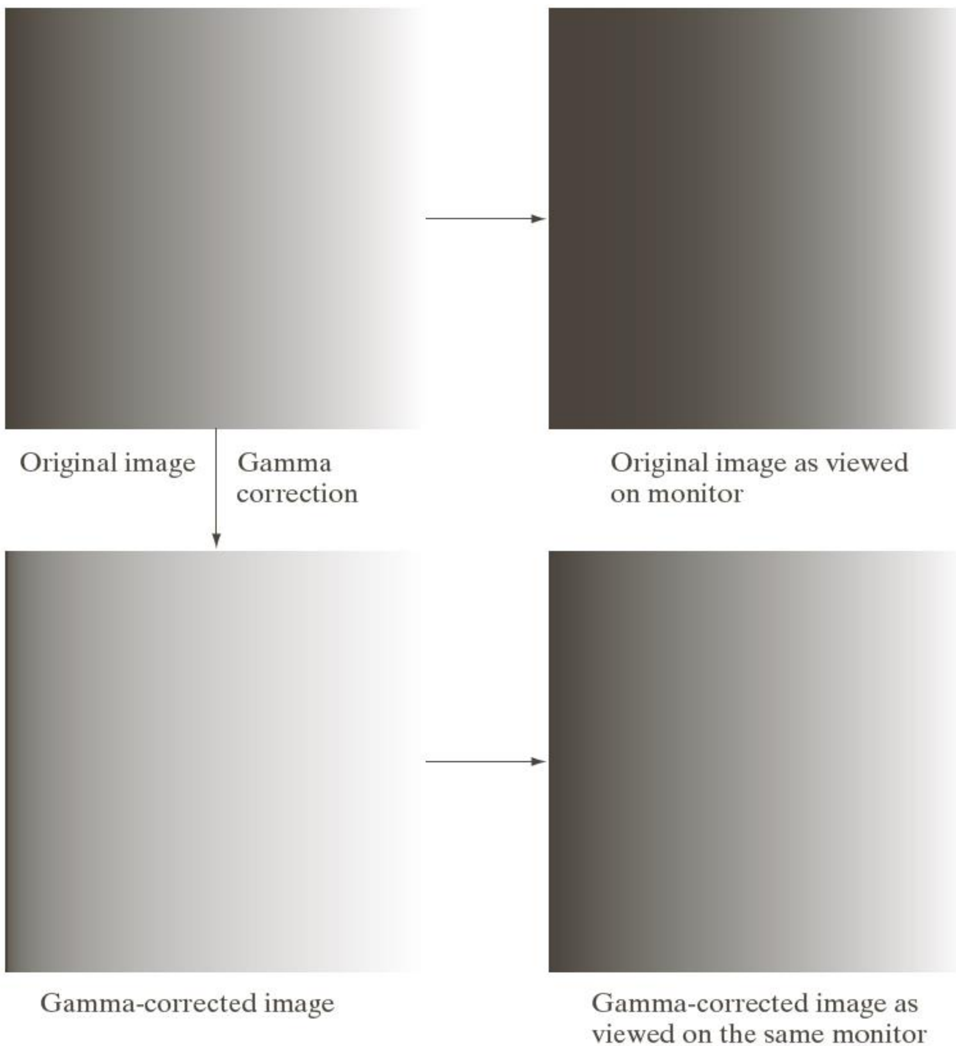
Power-Law (Gamma) Transformations



$$s = cr^{\gamma}$$

FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases). All curves were scaled to fit in the range shown.

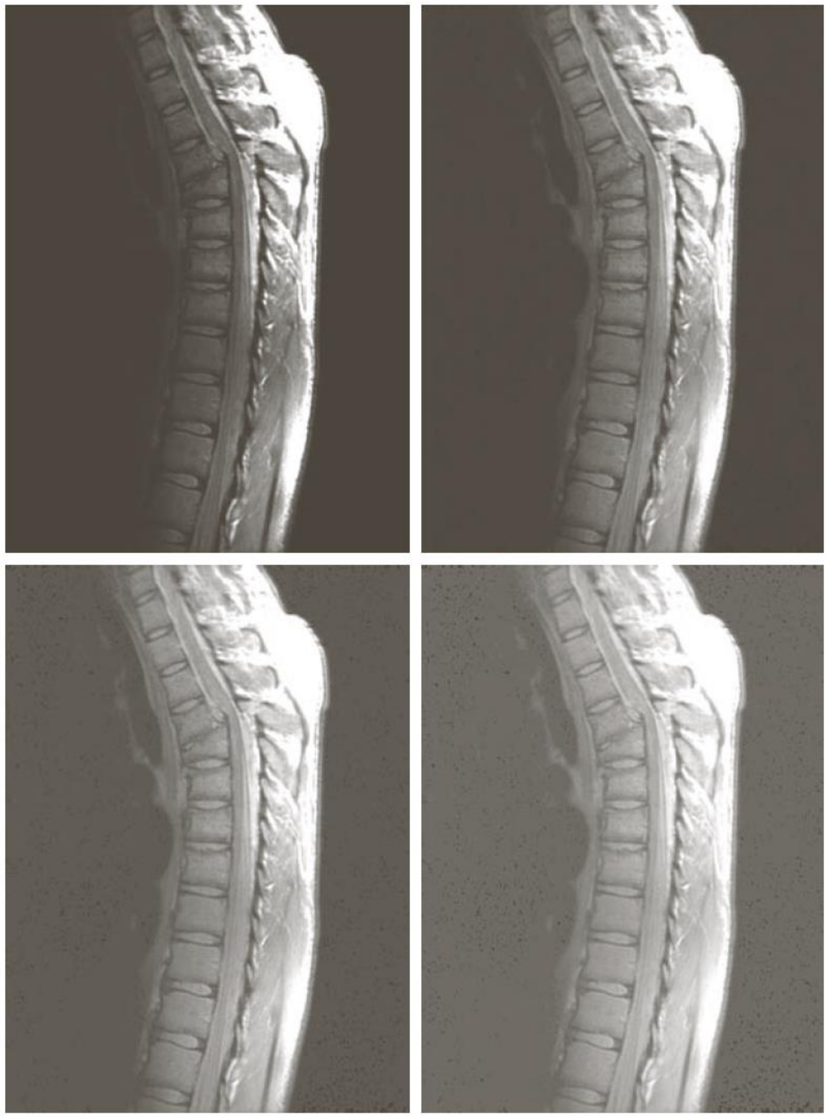
Example of Gamma Transformation



a b
c d

FIGURE 3.7 (a) Intensity ramp image. (b) Image as viewed on a simulated monitor with a gamma of 2.5. (c) Gamma-corrected image. (d) Corrected image as viewed on the same monitor. Compare (d) and (a).

Example of Gamma Transformation



a	b
c	d

FIGURE 3.8 (a) Magnetic resonance image (MRI) of a fractured human spine. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 0.6, 0.4$, and 0.3, respectively. (Original image courtesy of Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

Example of Gamma Transformation

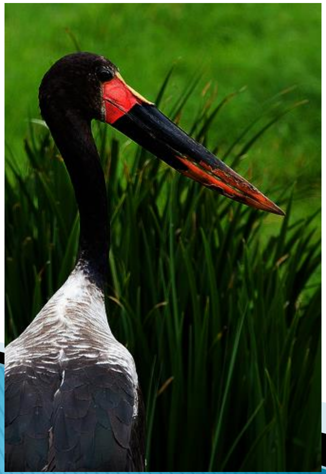
a	b
c	d

FIGURE 3.9 (a) Aerial image. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 3.0, 4.0,$ and 5.0, respectively. (Original image for this example courtesy of NASA.)

Example

$L_0^{2.2}$ L_0 $L_0^{1/2.2}$



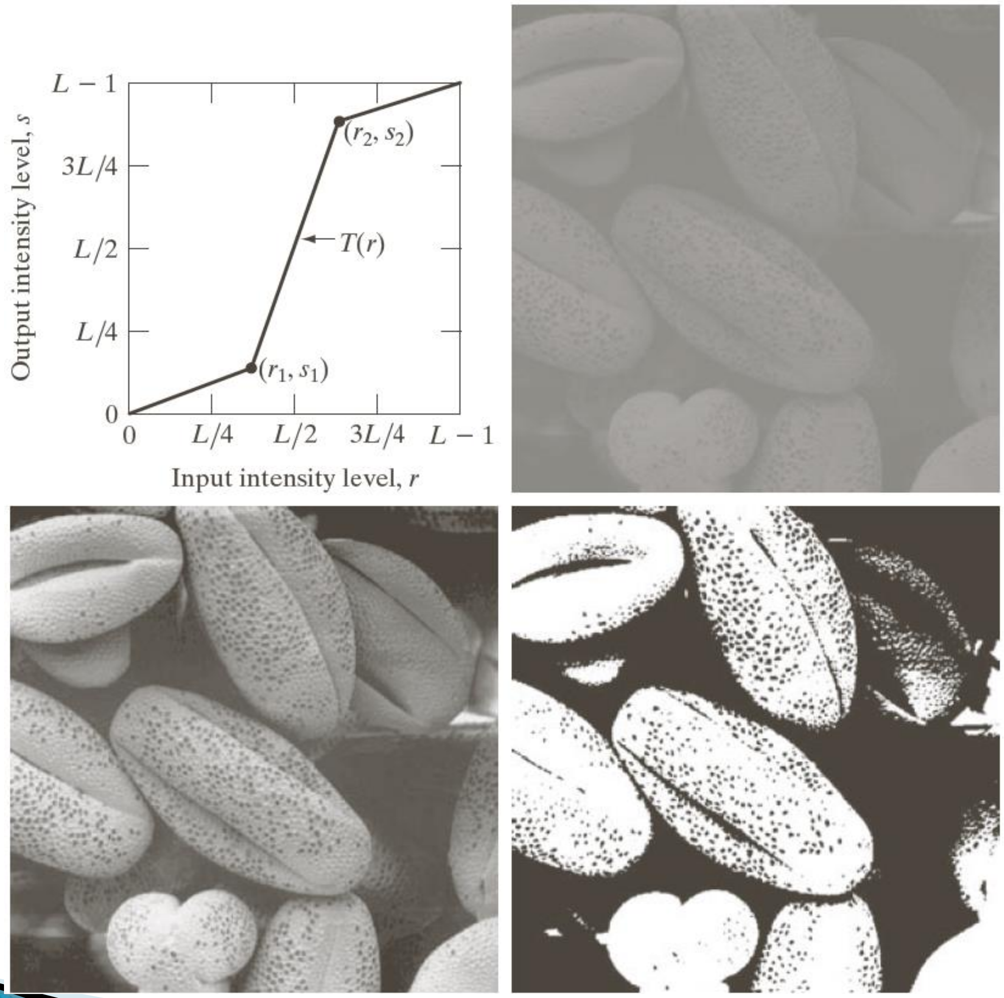



Piecewise-Linear Transformation Functions

- Contrast Stretching
  - Expands the range of intensity levels in an image.
  - Spans the full intensity range of the recording medium.

- Intensity-level Slicing
  - Highlights a specific range of intensities in an image.

Contrast Stretching



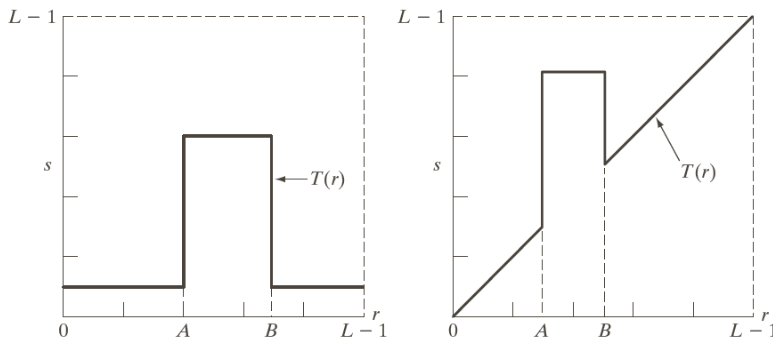
a	b
c	d

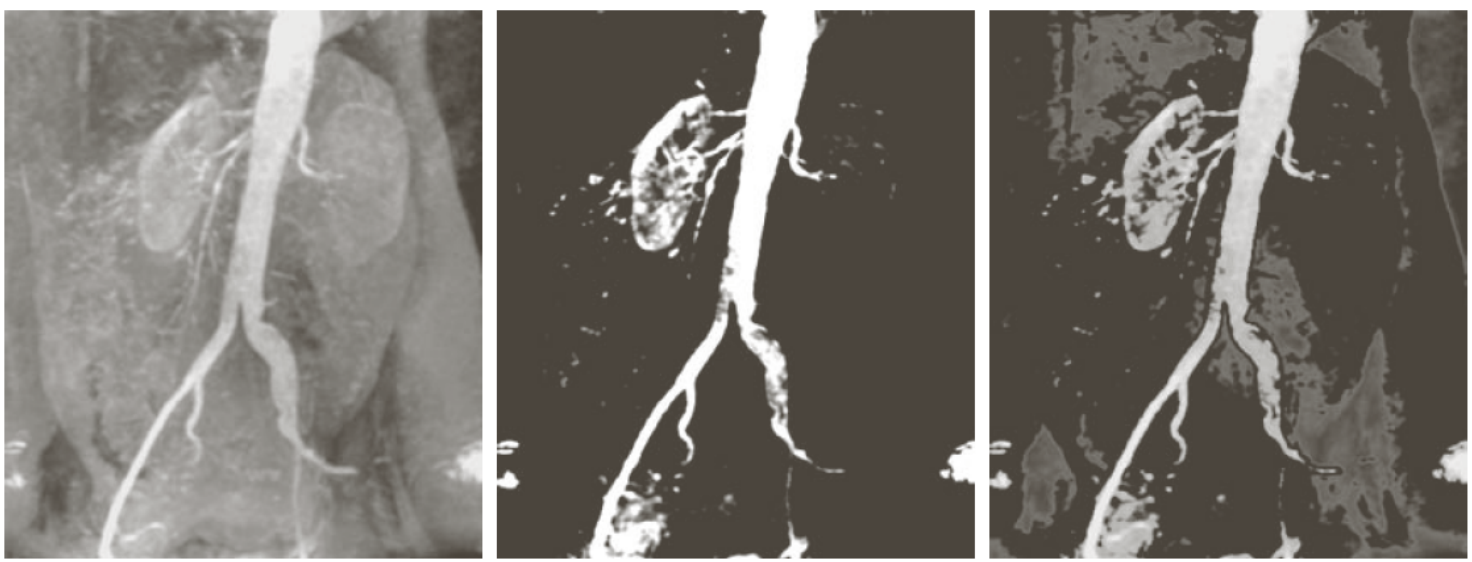
FIGURE 3.10 Contrast stretching. (a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)

Intensity-Level Slicing

a b

FIGURE 3.11 (a) This transformation highlights intensity range $[A, B]$ and reduces all other intensities to a lower level. (b) This transformation highlights range $[A, B]$ and preserves all other intensity levels.

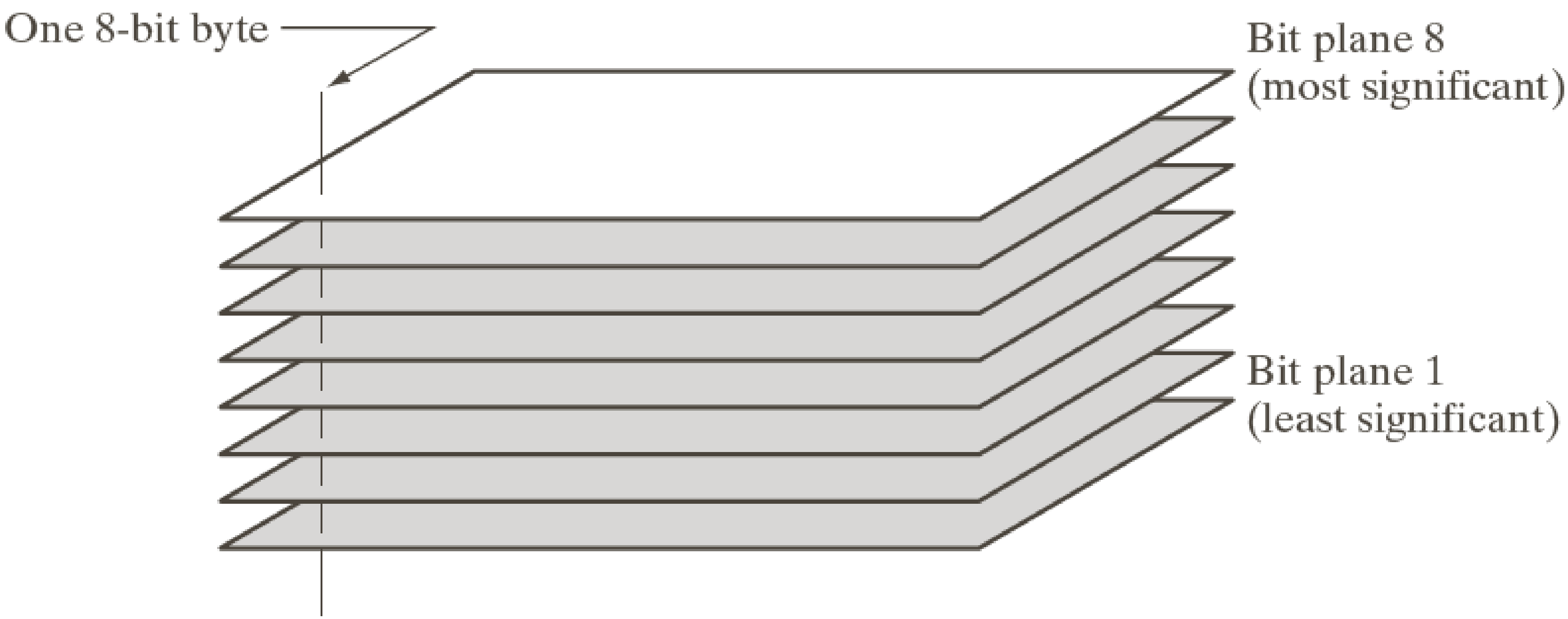




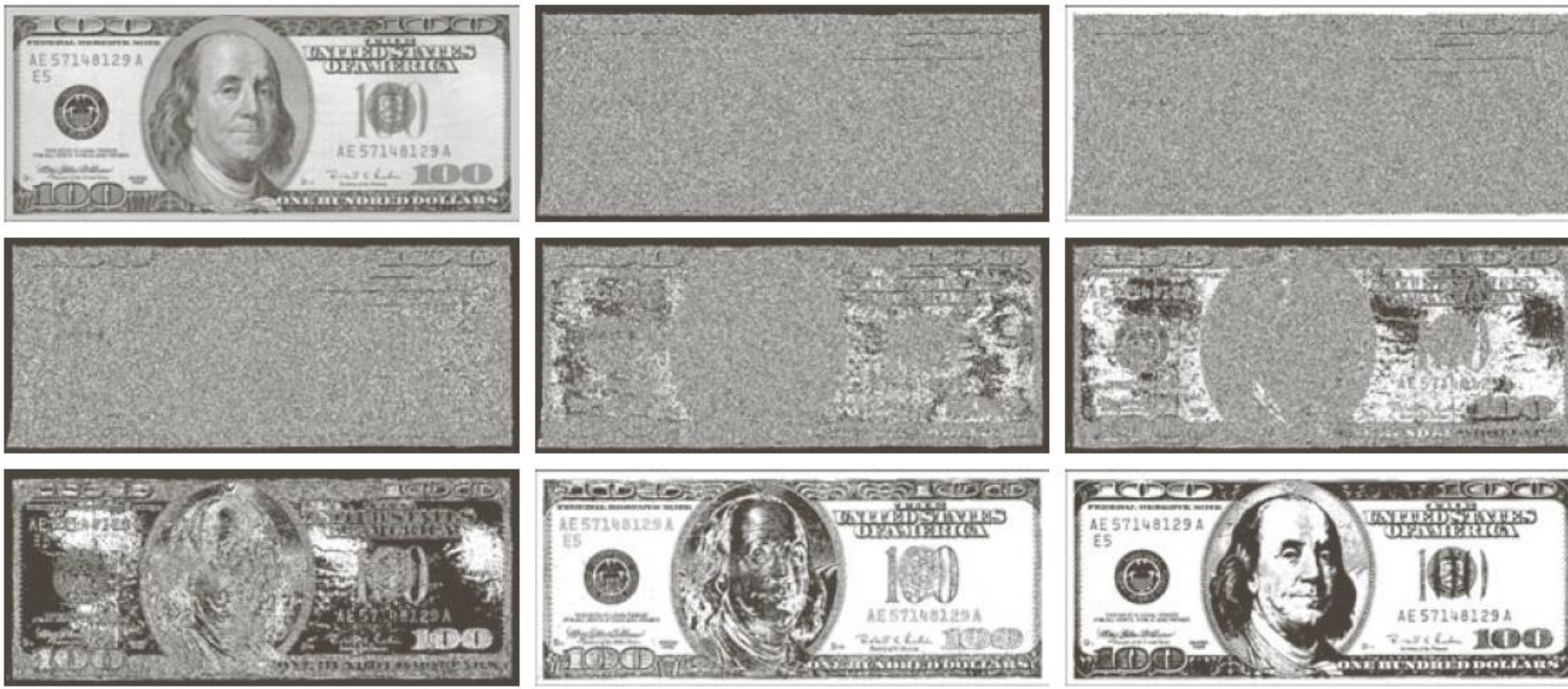
a b c

FIGURE 3.12 (a) Aortic angiogram. (b) Result of using a slicing transformation of the type illustrated in Fig. 3.11(a), with the range of intensities of interest selected in the upper end of the gray scale. (c) Result of using the transformation in Fig. 3.11(b), with the selected area set to black, so that grays in the area of the blood vessels and kidneys were preserved. (Original image courtesy of Dr. Thomas R. Gest, University of Michigan Medical School.)

Bit-Plane Slicing



Bit-Plane Slicing



a	b	c
d	e	f
g	h	i

FIGURE 3.14 (a) An 8-bit gray-scale image of size 500 × 1192 pixels. (b) through (i) Bit planes 1 through 8, with bit plane 1 corresponding to the least significant bit. Each bit plane is a binary image.

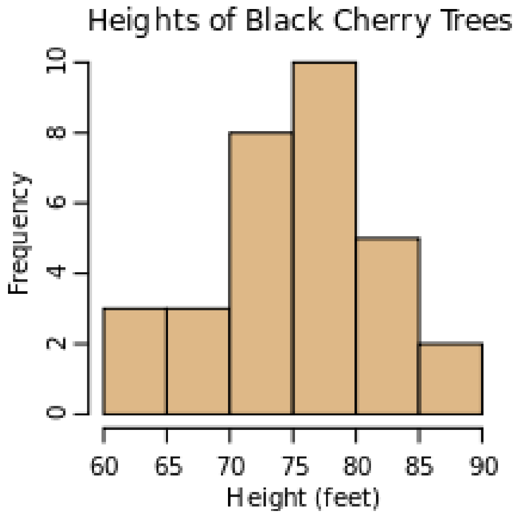
Bit-Plane Slicing

a b c

FIGURE 3.15 Images reconstructed using (a) bit planes 8 and 7; (b) bit planes 8, 7, and 6; and (c) bit planes 8, 7, 6, and 5. Compare (c) with Fig. 3.14(a).

Histogram Processing

- What is a *Histogram*?



Histogram Processing

- Histogram for image processing

$$h(r_k) = n_k$$

  - where r_k is the k–th **gray level** and n_k is the **number of pixels** in the image.

Example (8bit image)

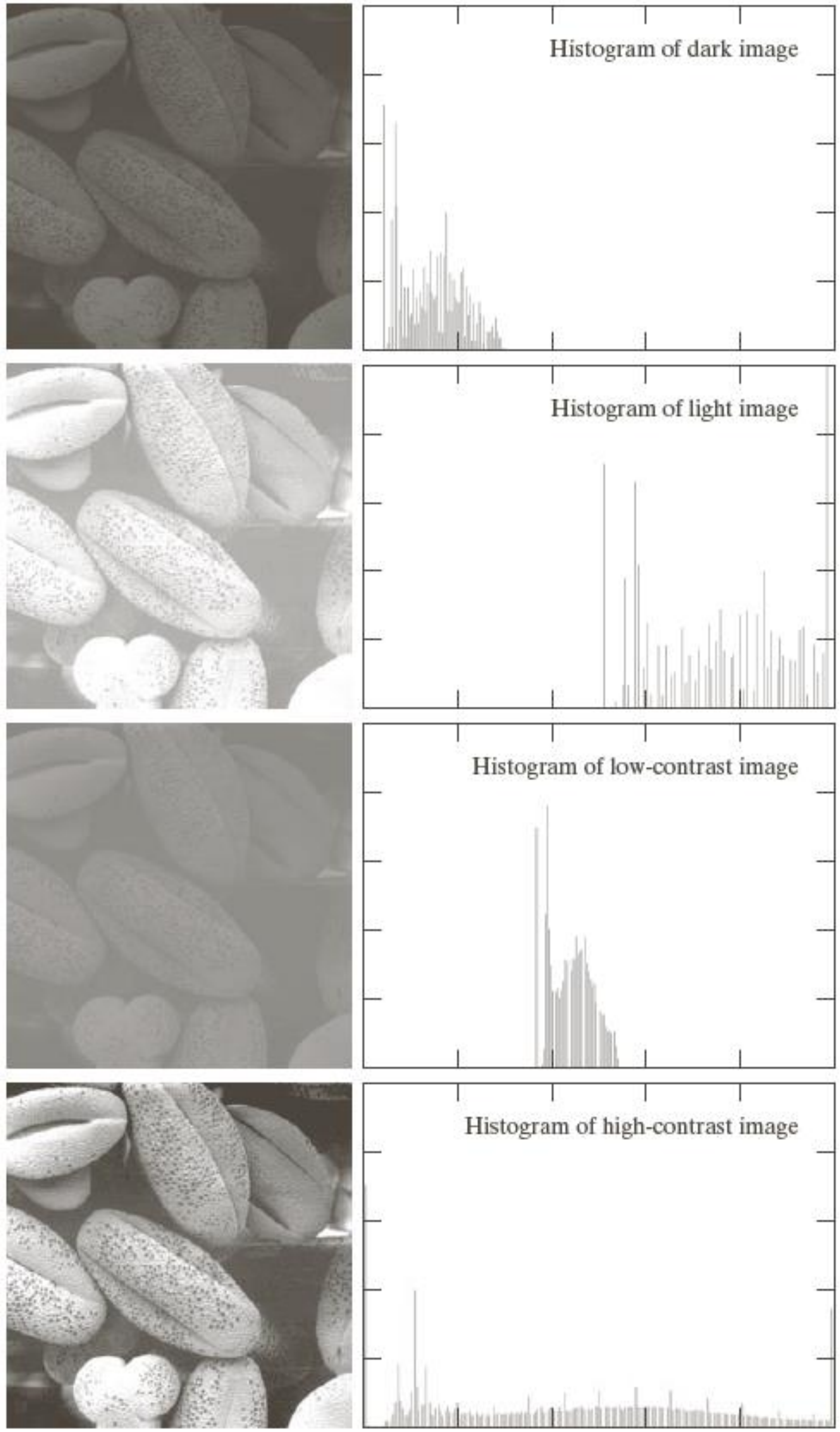
```
unsigned int Histogram[256]={0};

for(h=0;h<H;h++) for(w=0;w<W;w++){
  Histogram[  img[w][h]  ]++;
```

Histogram Processing

- Normalized histogram

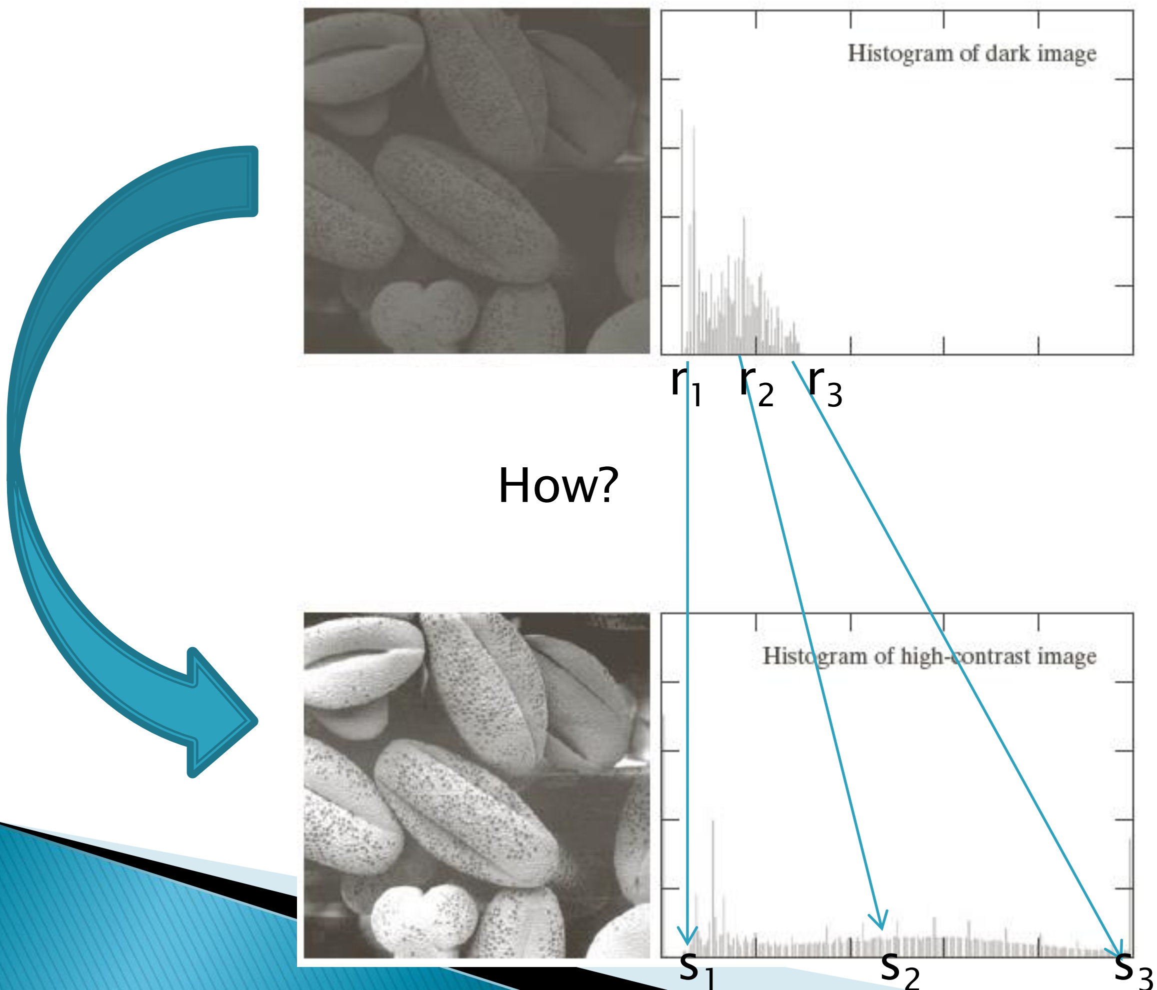
$$p(r_k) = n_k / (WH)$$

  - Estimate of the probability of occurrence of intensity level r_k .


Histogram of dark image
Histogram of light image
Histogram of low-contrast image
Histogram of high-contrast image

Histogram Processing

- What is Histogram Equalization?



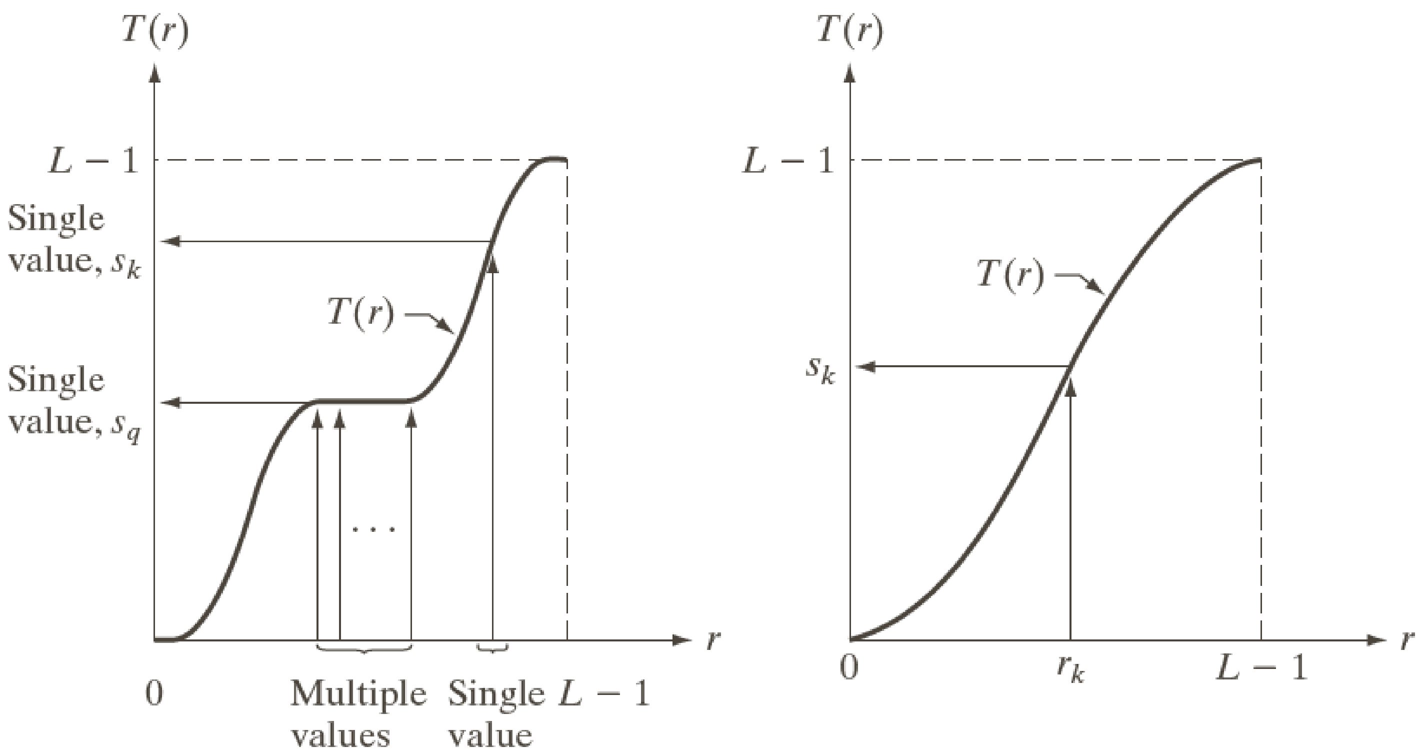
Pixel value: r → s

Find a transfer function:

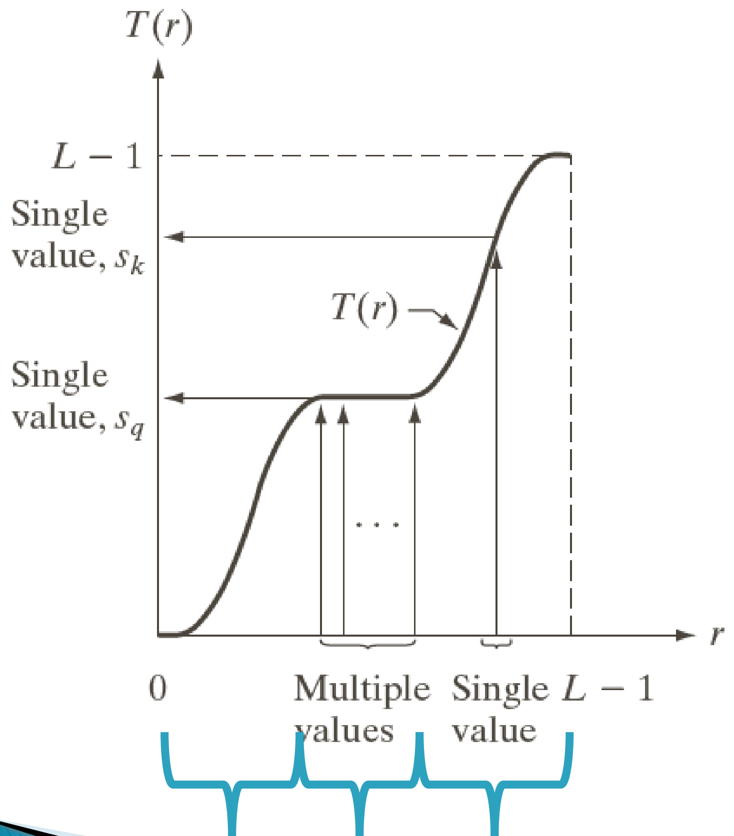
$s = T(r)$

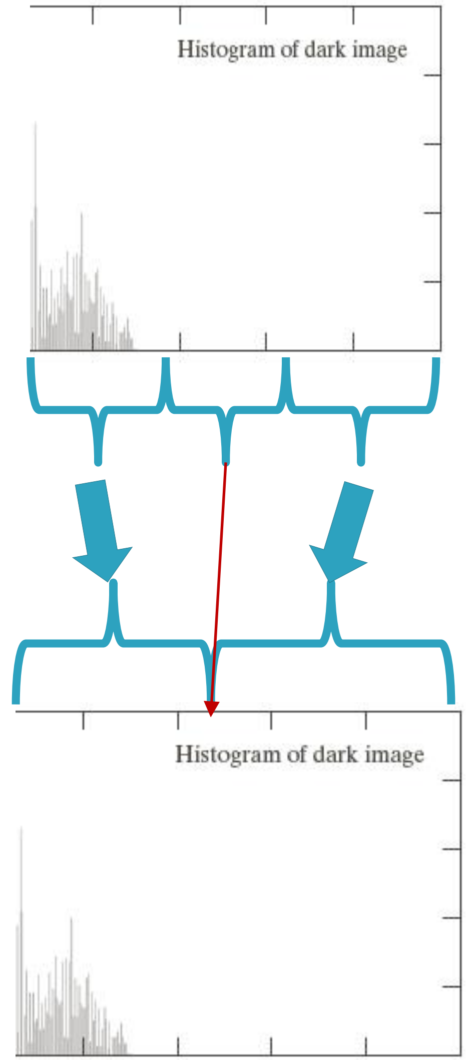
$s_1 = T(r_1)$
$s_2 = T(r_2)$
$s_3 = T(r_3)$

Examples of Transfer Functions

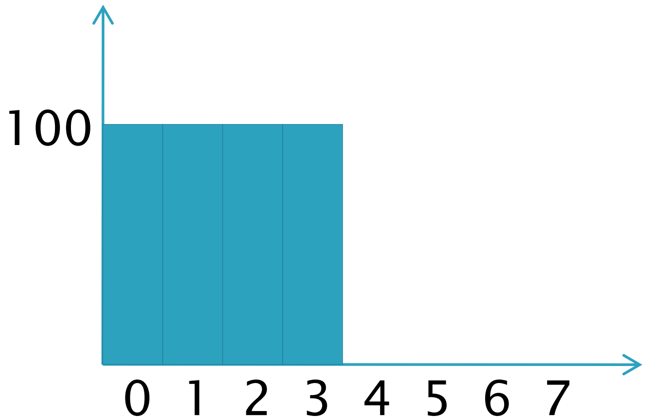


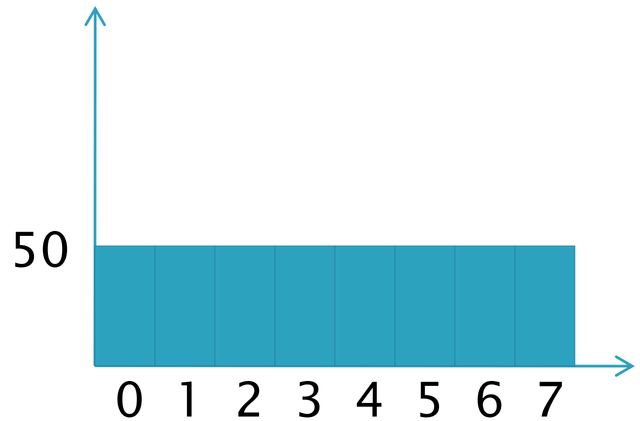
Examples of Transfer Functions



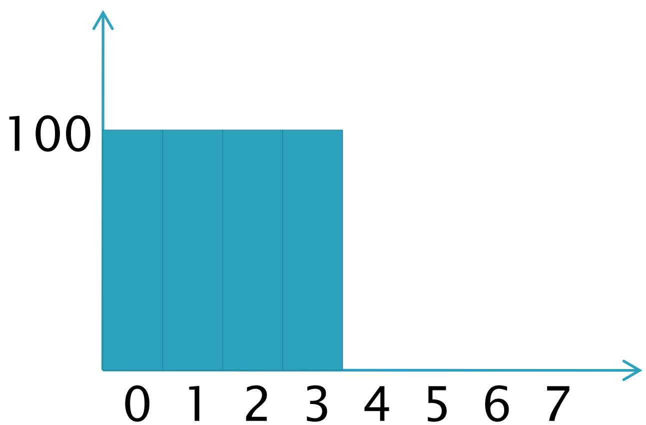


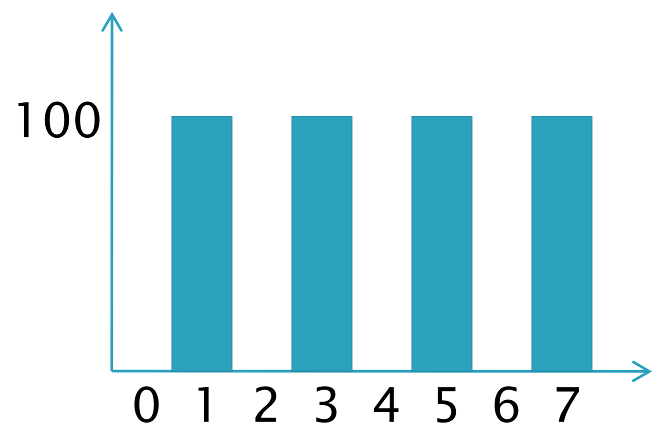
Histogram Equalization





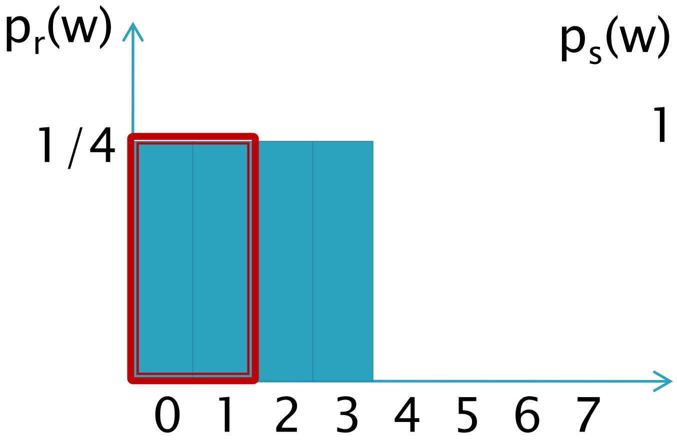
Ideal

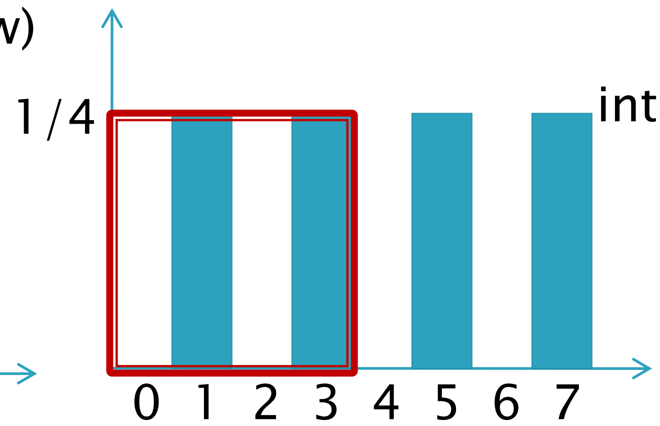




Practical

Histogram Equalization





intuitively

0 → 1
1 → 3
2 → 5
3 → 7

Practical

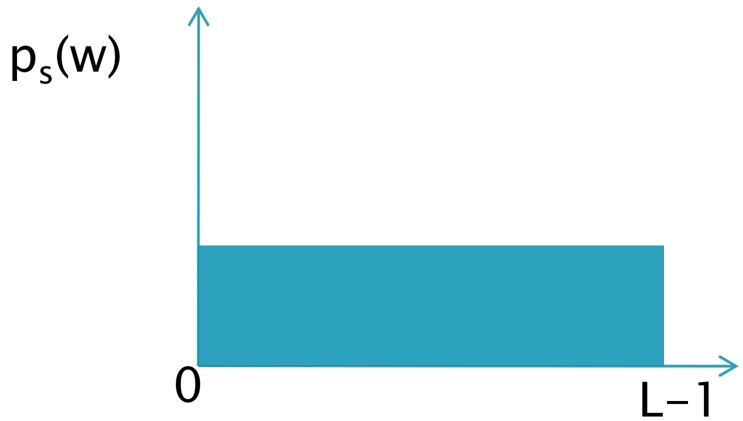
$$\sum_{i=0}^{r} p_r(i) = \sum_{i=0}^{s} p_s(i)$$

$$\sum_{i=0}^{0} p_r(i) = \sum_{i=0}^{1} p_s(i) = \frac{1}{4}$$

$$\sum_{i=0}^{1} p_r(i) = \sum_{i=0}^{3} p_s(i) = \frac{1}{2}$$

$$\int_0^r p_r(w)dw = \int_0^s p_s(w)dw$$

Histogram Equalization



Ideal probability function

$$\int_0^r p_r(w)dw = \int_0^s p_s(w)dw = \frac{s}{L-1}$$

$$s = (L-1)\int_0^r p_r(w)dw = T(r)$$

Histogram Equalization

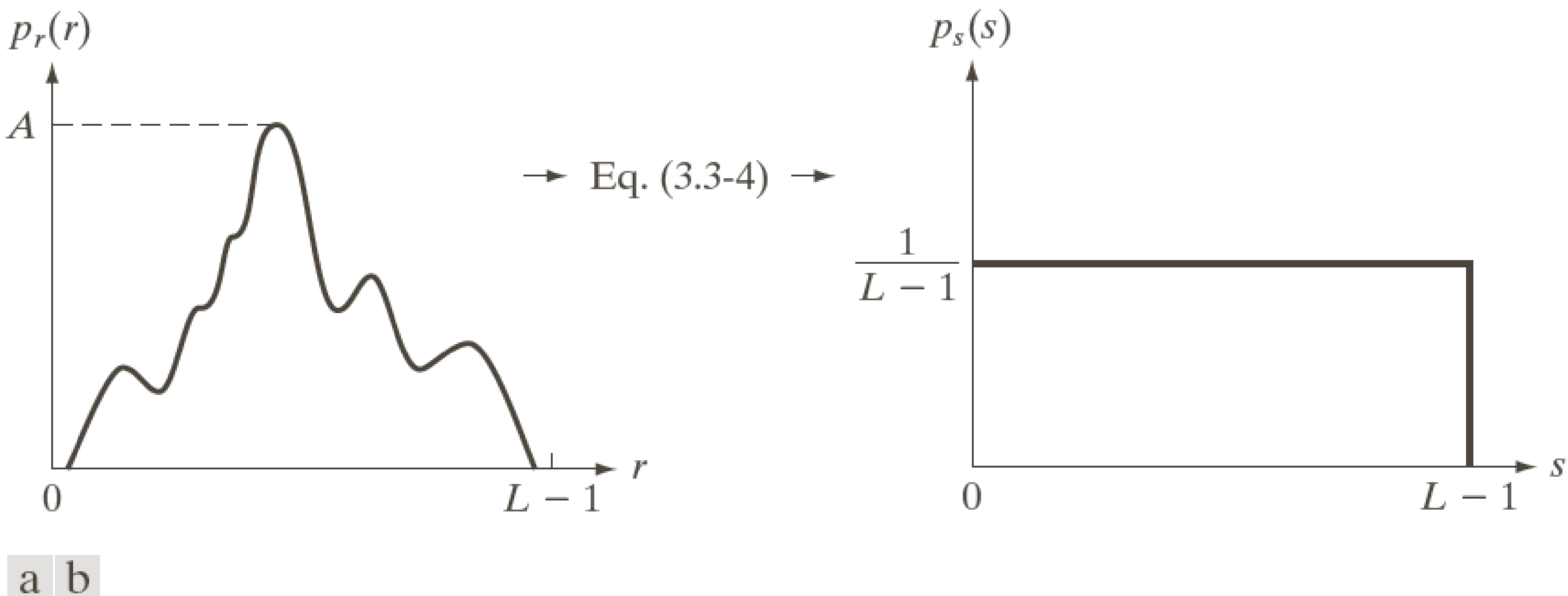


FIGURE 3.18 (a) An arbitrary PDF. (b) Result of applying the transformation in Eq. (3.3-4) to all intensity levels, r. The resulting intensities, s, have a uniform PDF, independently of the form of the PDF of the r's.

Histogram Equalization

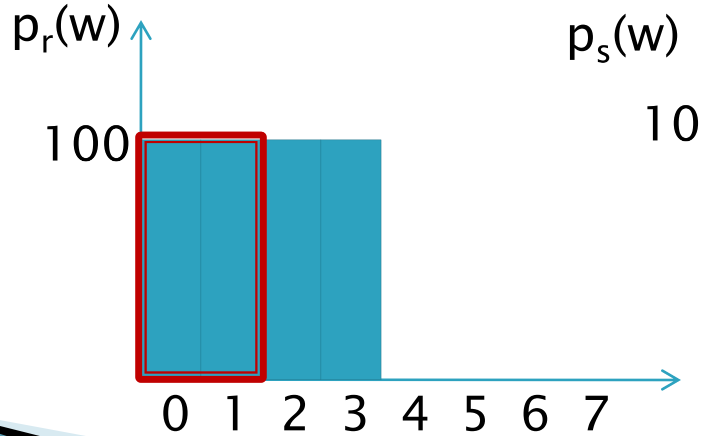
- Discrete form of transformation

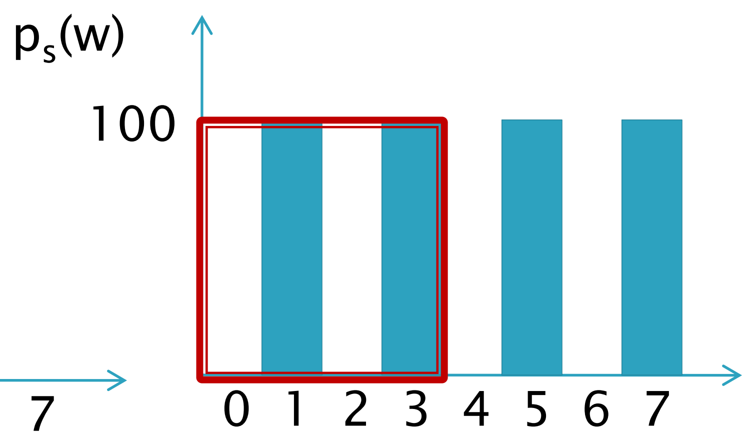
$$s_k = T(r_k) = (L-1)\sum_{j=0}^{k} p_r(r_j)$$

$$= \frac{(L-1)}{MN}\sum_{j=0}^{k} n_j, \quad k = 0,1,2,\ldots,L-1$$

$$\frac{(L-1)}{MN}\sum_{j=0}^{k} n_j = \frac{7}{400}\sum_{j=0}^{1} n_j$$

$$= \frac{7}{400}200 = 3.5$$





1.75
3.75
5.25
7.00

Histogram Equalization

r_k	n_k	$p_r(r_k) = n_k/MN$
$r_0 = 0$	790	0.19
$r_1 = 1$	1023	0.25
$r_2 = 2$	850	0.21
$r_3 = 3$	656	0.16
$r_4 = 4$	329	0.08
$r_5 = 5$	245	0.06
$r_6 = 6$	122	0.03
$r_7 = 7$	81	0.02

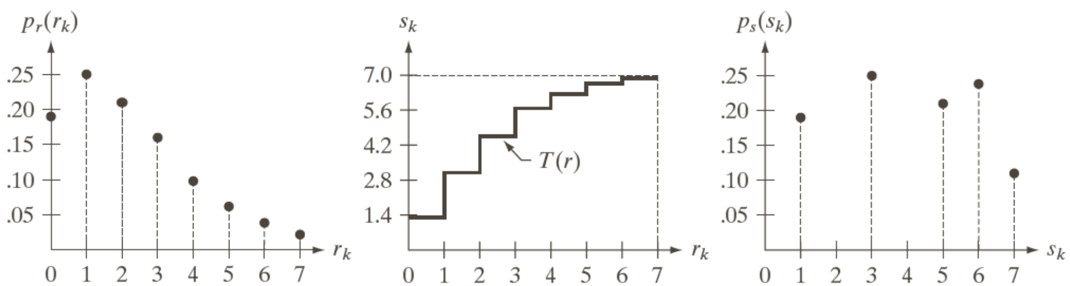
$$s_0 = T(r_0) = 7\sum_{j=0}^{0} p_r(r_j) = 7 \times 0.19 = 1.33 \quad \rightarrow 1$$

$$s_1 = T(r_1) = 7\sum_{j=0}^{1} p_r(r_j) = 7 \times (0.19 + 0.25) = 3.08 \quad \rightarrow 3$$

$$s_2 = 4.55 \quad \rightarrow 5 \qquad s_3 = 5.67 \quad \rightarrow 6$$

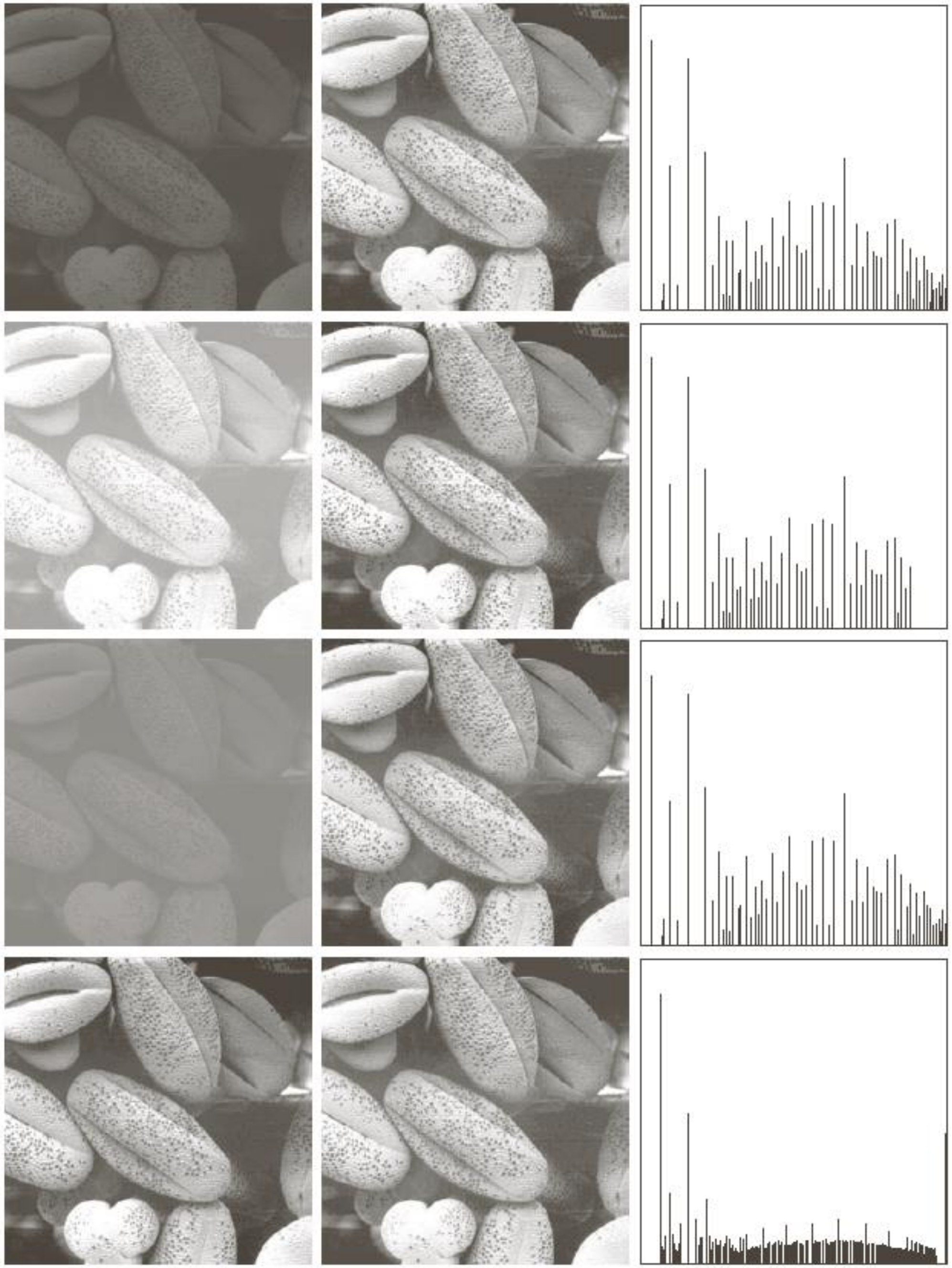
$$s_4 = 6.23 \quad \rightarrow 6 \qquad s_5 = 6.65 \quad \rightarrow 7$$

$$s_6 = 6.86 \quad \rightarrow 7 \qquad s_7 = 7.00 \quad \rightarrow 7$$



a b c

FIGURE 3.19 Illustration of histogram equalization of a 3-bit (8 intensity levels) image. (a) Original histogram. (b) Transformation function. (c) Equalized histogram.



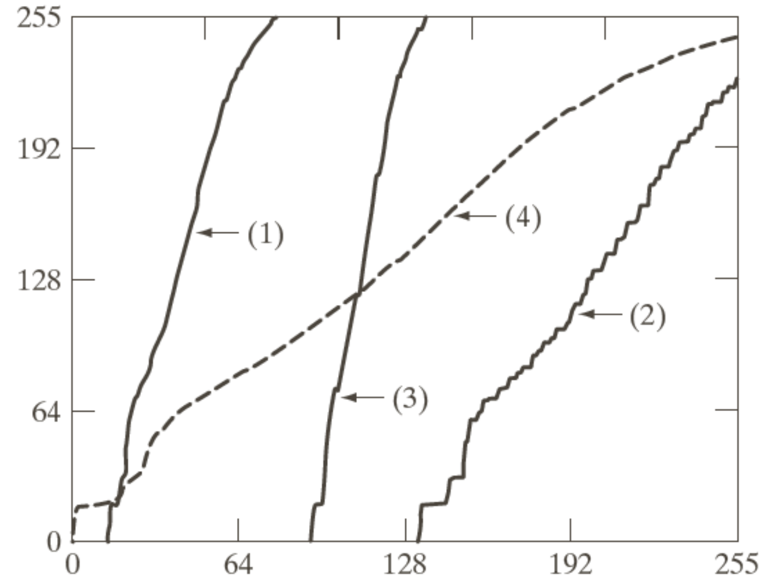


FIGURE 3.21 Transformation functions for histogram equalization. Transformations (1) through (4) were obtained from the histograms of the images (from top to bottom) in the left column of Fig. 3.20 using Eq. (3.3-8).

Histogram Specification (Matching)

- Histogram matching (specification)
  - A processed image has a specified histogram

$$p_r(t) \Rightarrow p_s(t) = \frac{1}{L-1}$$ Histogram Equalization

$$p_r(t) \Rightarrow p_z(t)$$ Histogram Specification

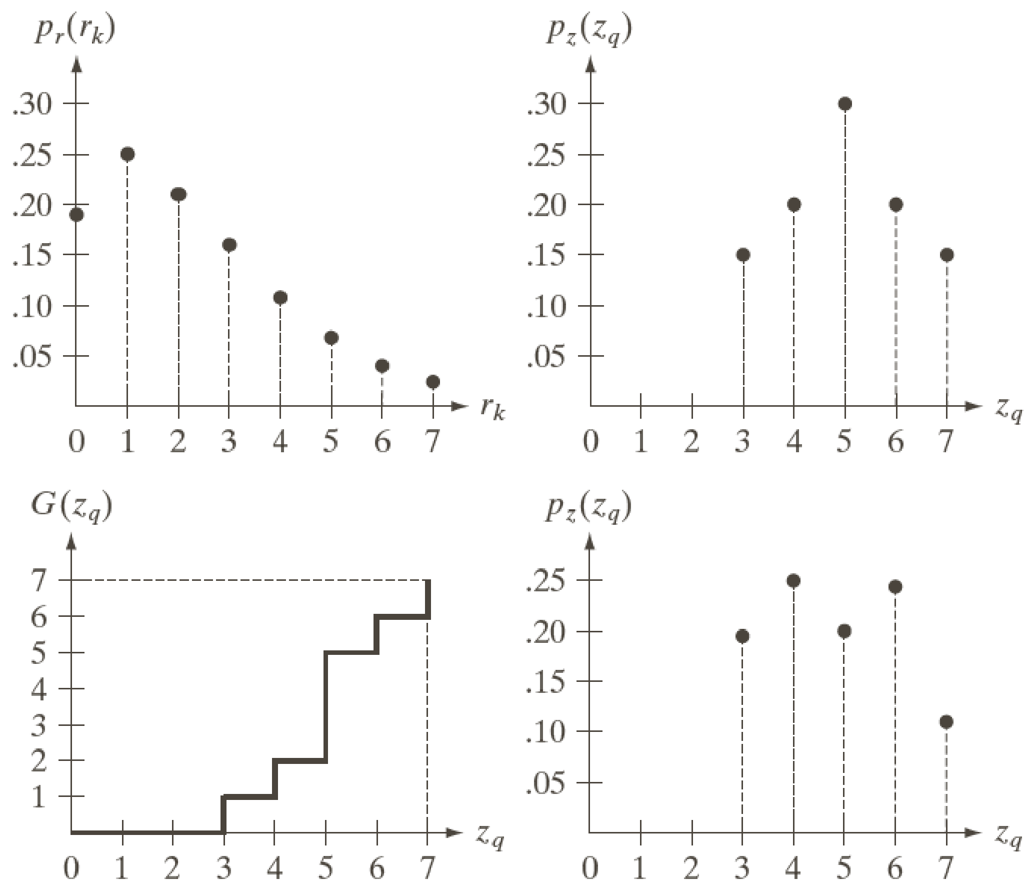
Histogram Specification (Matching)

- Histogram specification

$$p_z(z)$$: Target PDF

$$\int_0^r p_r(w)dw = \int_0^s p_z(w)dw$$

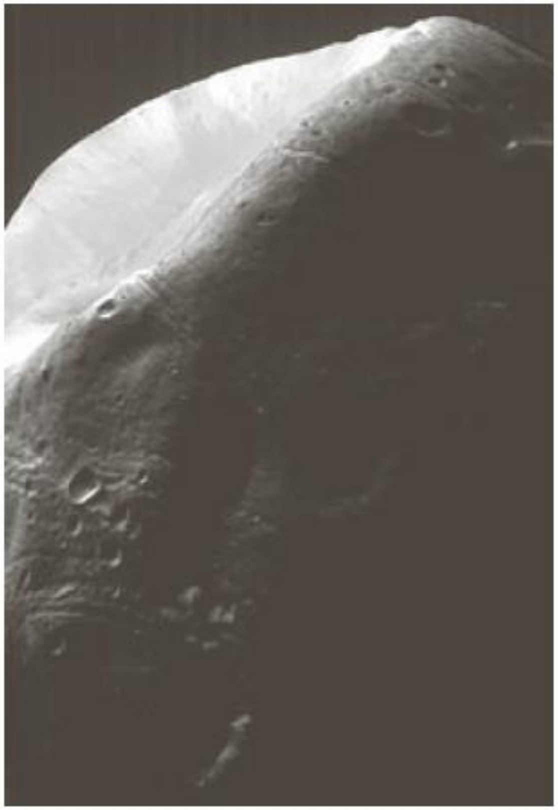
Histogram Specification (Matching)

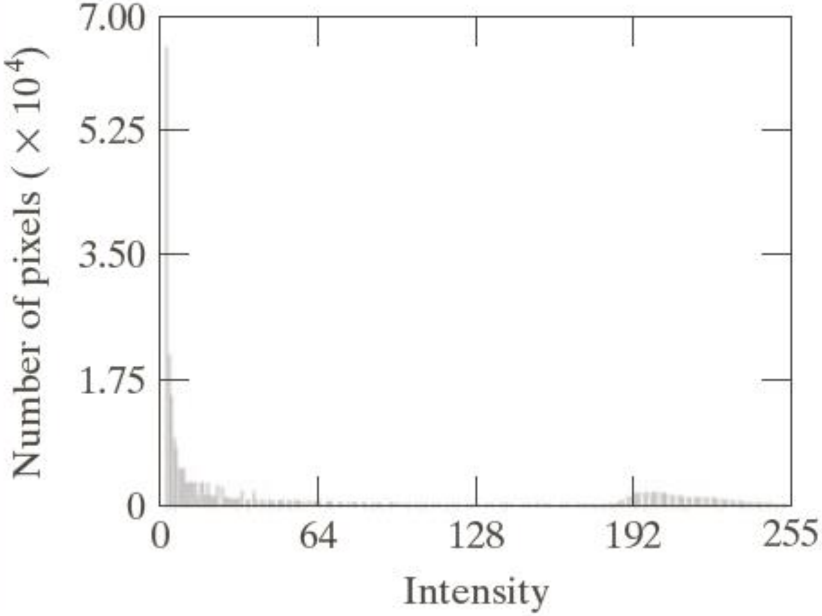


a	b
c	d

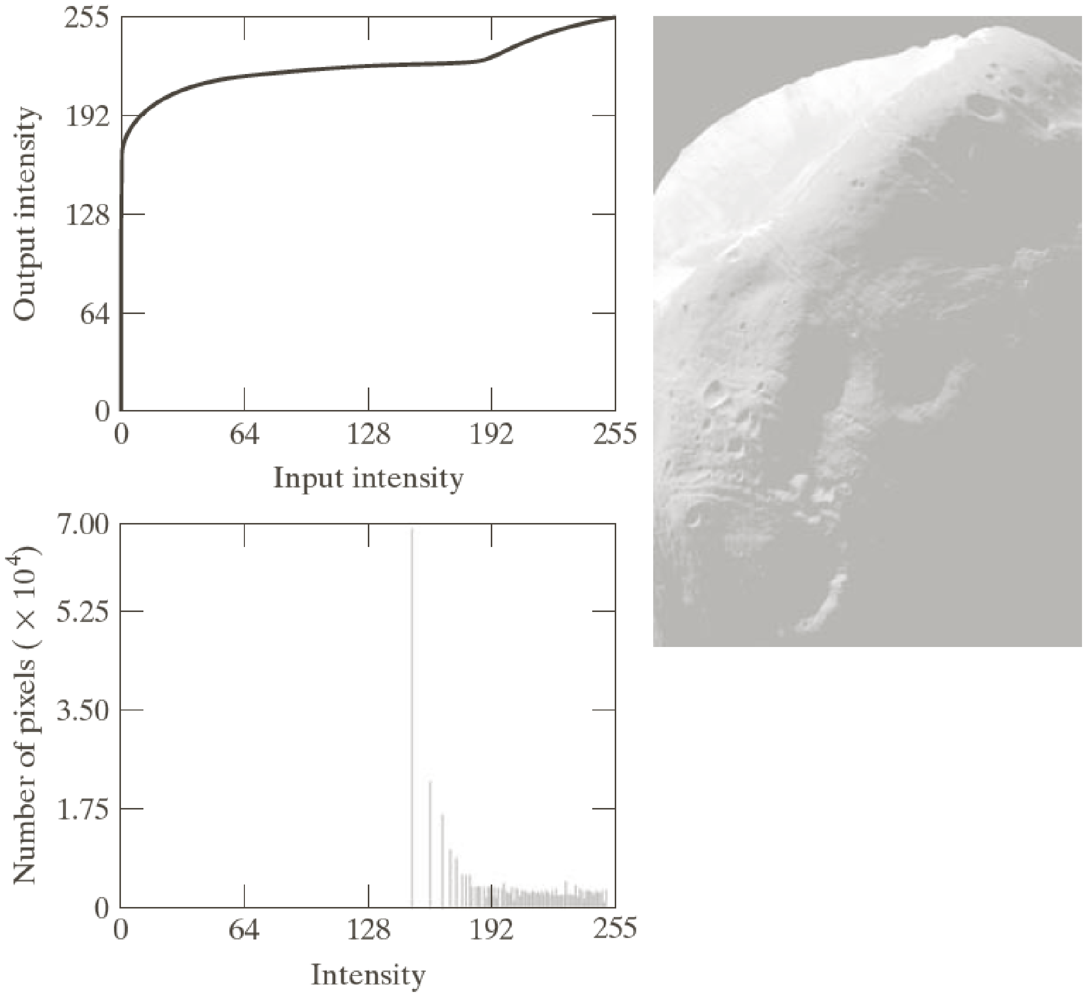
FIGURE 3.22 (a) Histogram of a 3-bit image. (b) Specified histogram. (c) Transformation function obtained from the specified histogram. (d) Result of performing histogram specification. Compare (b) and (d).

Original Image and its Histogram





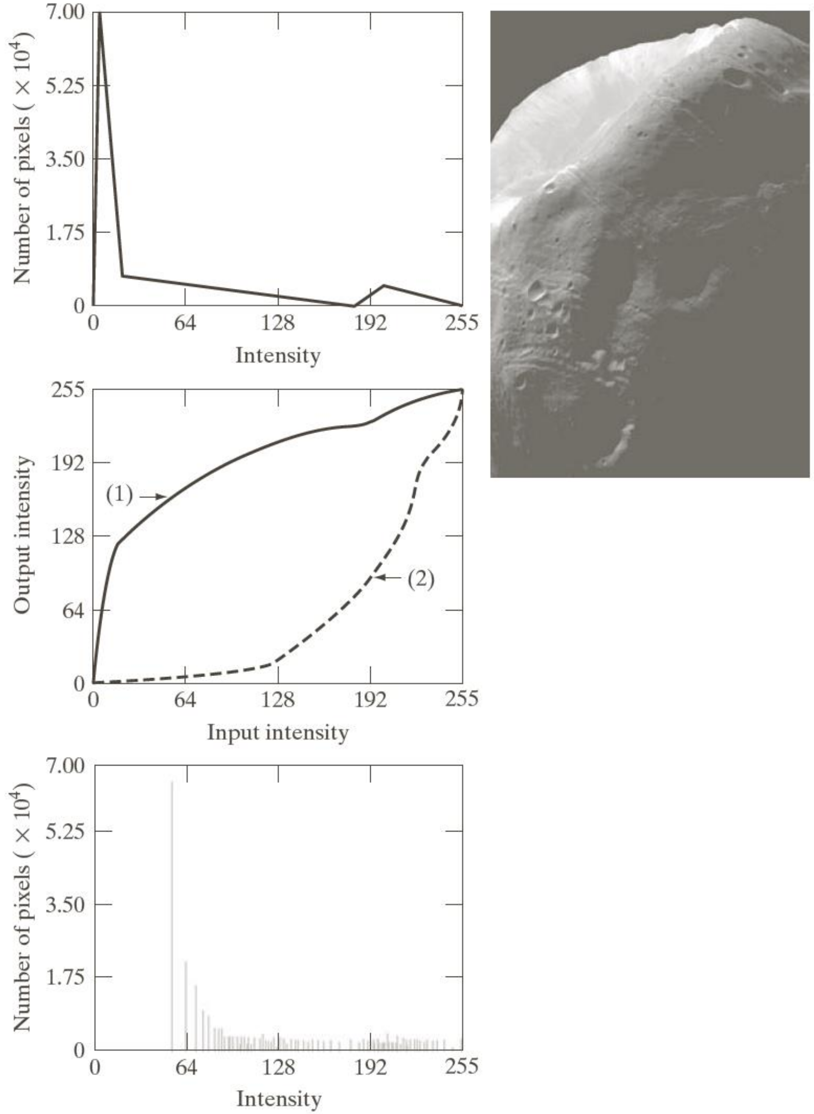
Histogram Equalization



a b
c

FIGURE 3.24
(a) Transformation function for histogram equalization.
(b) Histogram-equalized image (note the washed-out appearance).
(c) Histogram of (b).

Histogram Matching



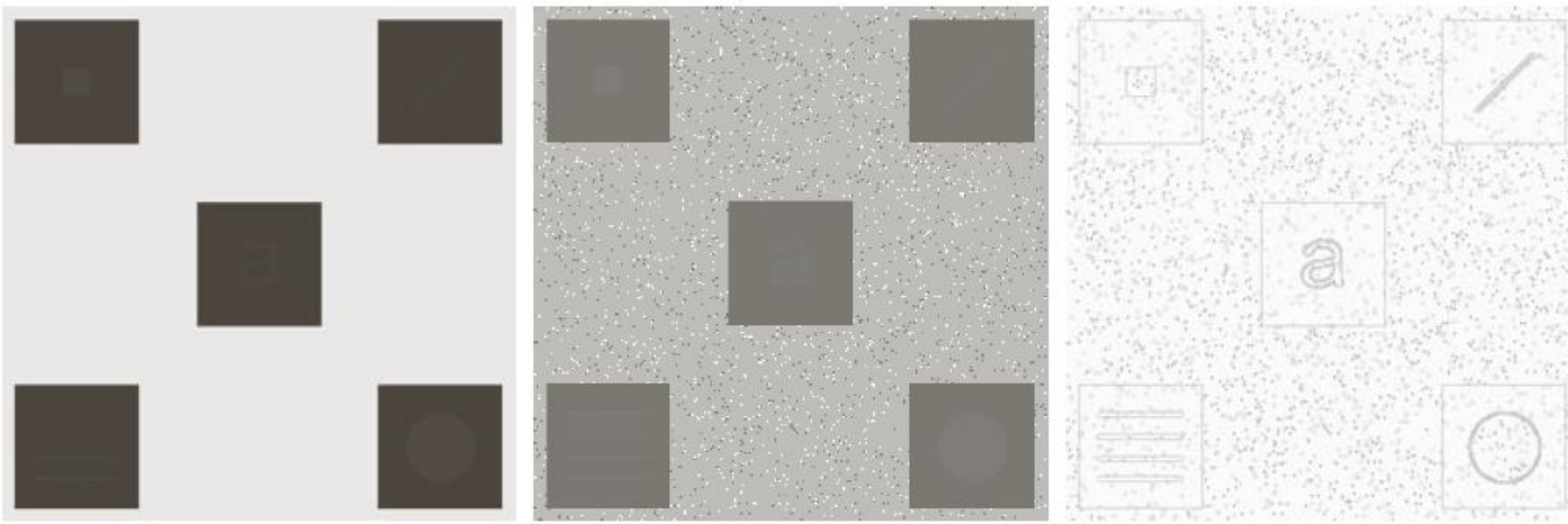
a c
b
d

FIGURE 3.25
(a) Specified histogram.
(b) Transformations.
(c) Enhanced image using mappings from curve (2).
(d) Histogram of (c).

Local Histogram Processing

- Define a neighborhood and move its center from pixel to pixel.
- At each location, the histogram of the points in the neighborhood is computed. Either histogram equalization or histogram specification transformation function is obtained.
- Map the intensity of the pixel centered in the neighborhood.
- Move to an adjacent pixel location and the procedure is repeated.

Local Histogram Processing



a b c

FIGURE 3.26 (a) Original image. (b) Result of global histogram equalization. (c) Result of local histogram equalization applied to (a), using a neighborhood of size 3×3.

Color Image

Color Fundamentals

- In 1666 Sir Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging beam is not white but consists a spectrum of colors.

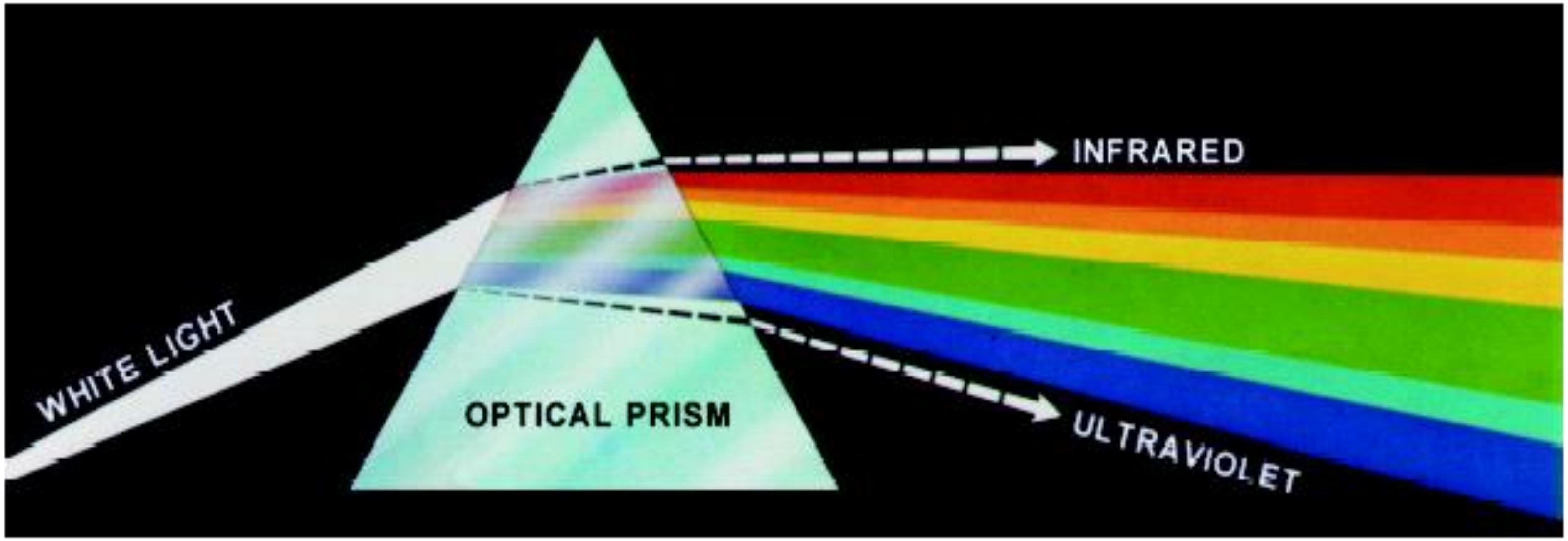


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

- The colors that humans and some other animals perceive in an object are determined by the nature of the light reflected from the object

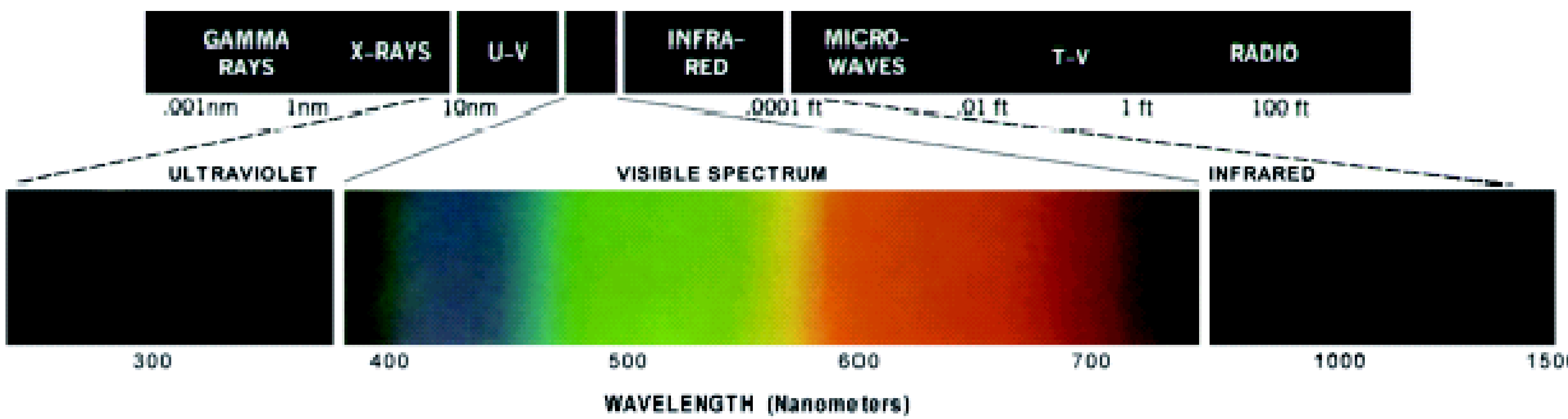


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Basic Quantities of a Chromatic Light Sources

- **Radiance**: The total amount of energy
- **Luminance**: the amount of energy an observer perceives from a light source
- **Brightness**: A subjective descriptor that embodies the achromatic notion of intensity and is practical impossible to measure.

Absorption of Light by Red, Green, and Blue Cones

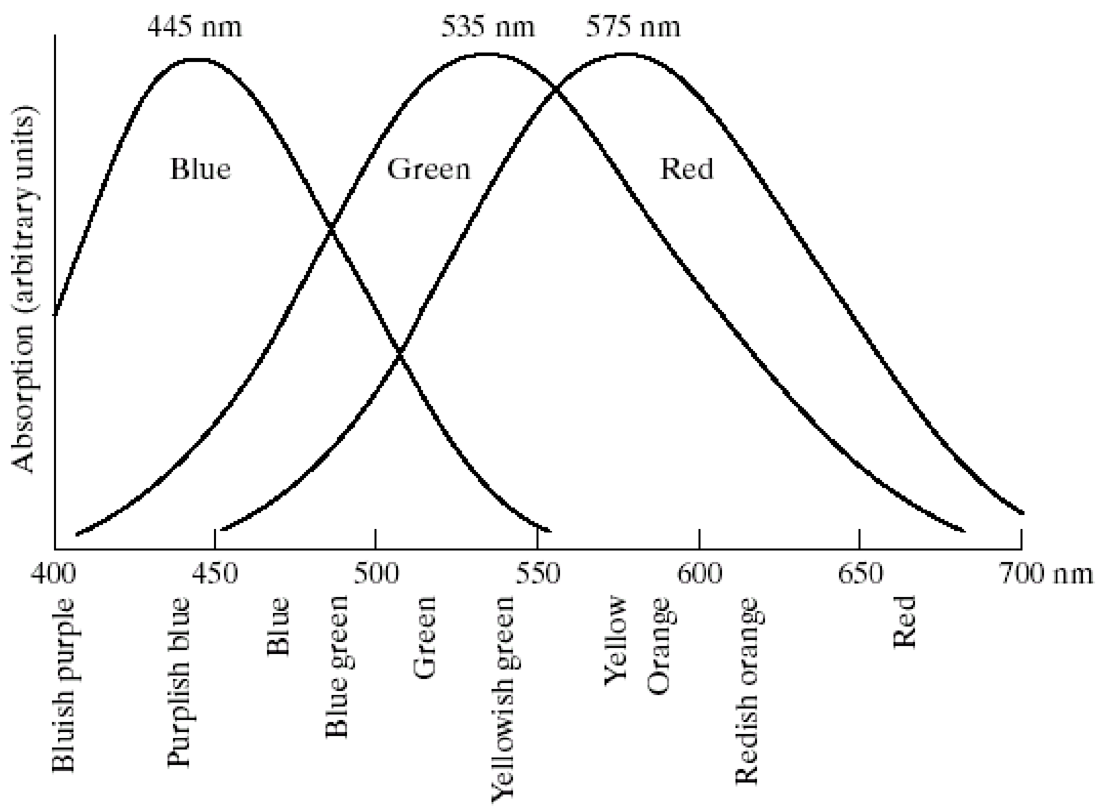
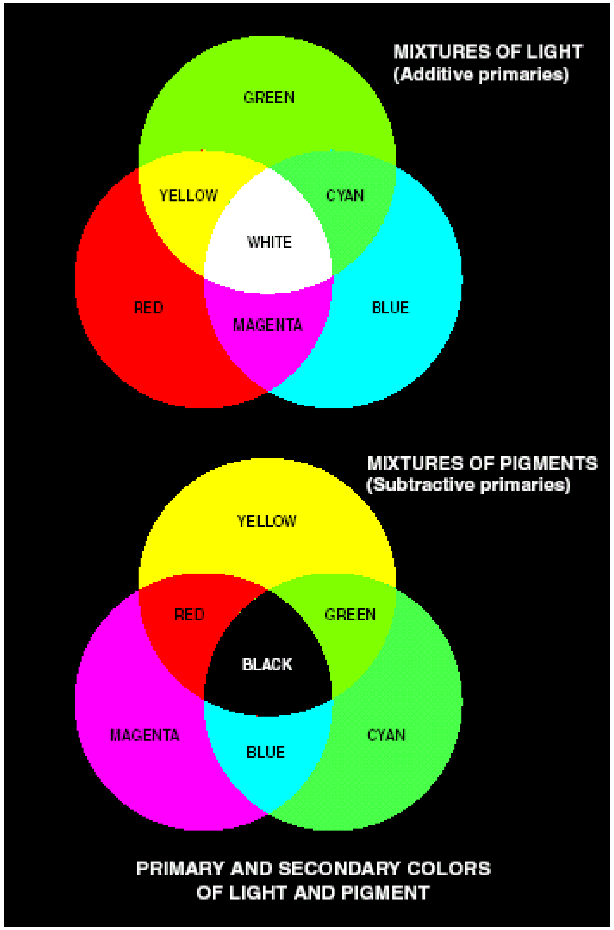


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Color Fundamentals



Yellow	R	G	
Magenta	R		B

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: Achromatic notion of intensity
  - Hue: Dominant color as perceived by an observer
  - Saturation: Relative purity or the amount of white light mixed with a hue

- **Hue and saturation taken together are called *Chromaticity*, and therefore, a color may be characterized by its Brightness and Chromaticity**

Color Fundamentals

- Tristimulus: The amounts of red, green, and blue needed to form any particular color

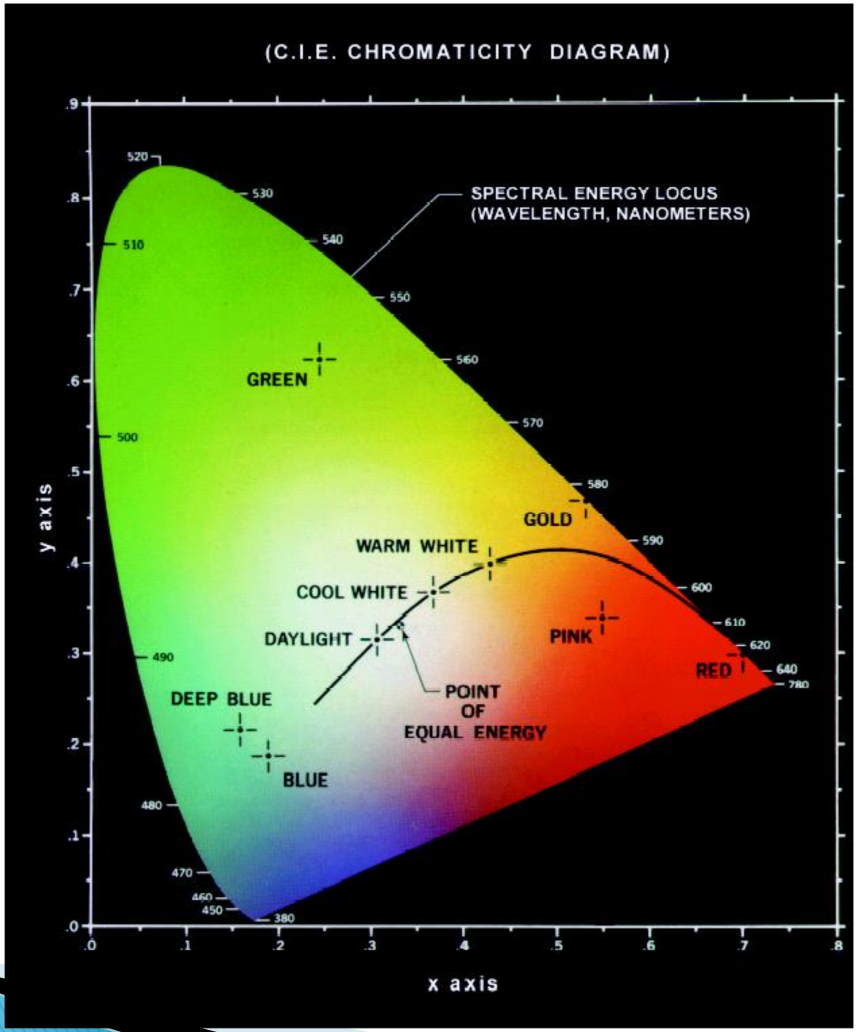
- Trichromatic coefficient

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

$$x + y + z = 1$$

Color Fundamentals

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



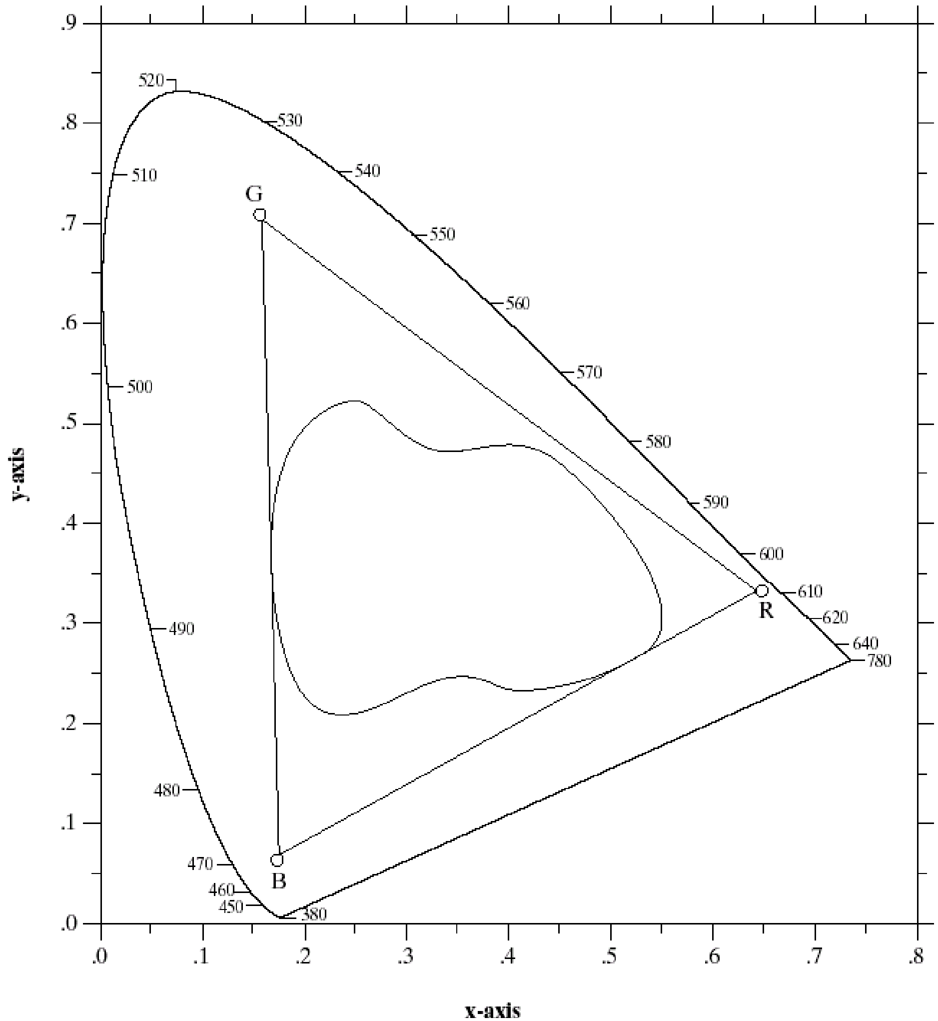
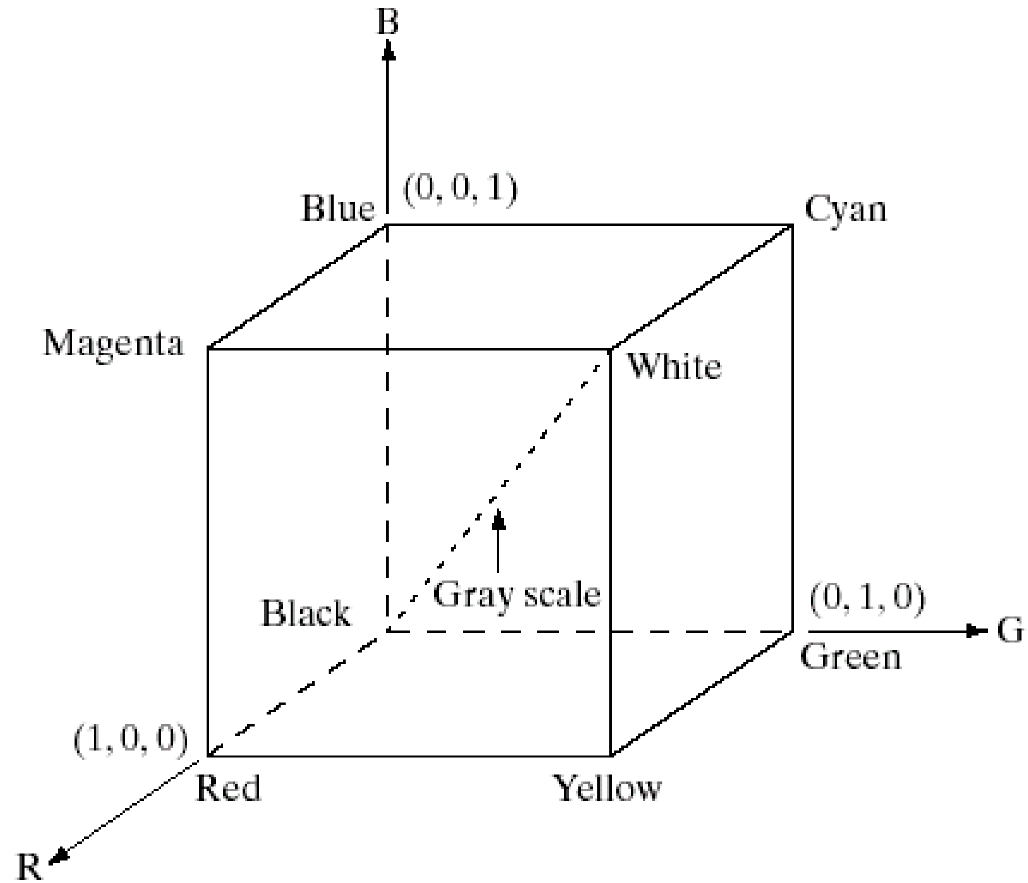


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

RGB Color Models

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).



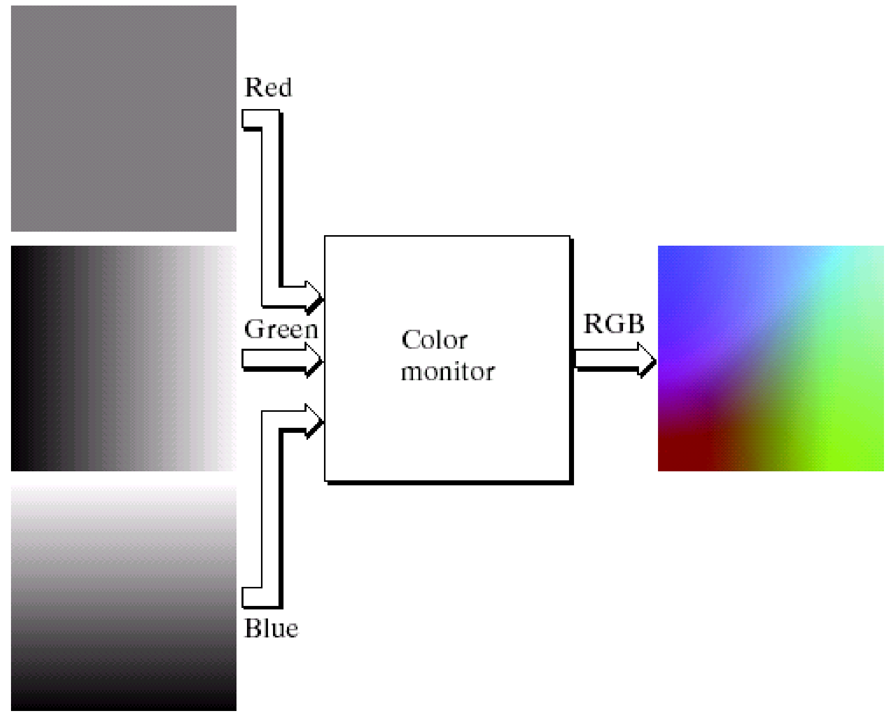
RGB Color Models

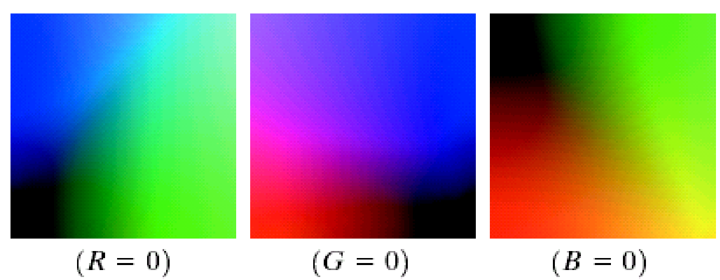
FIGURE 6.8 RGB 24-bit color cube.

RGB Color Models

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.

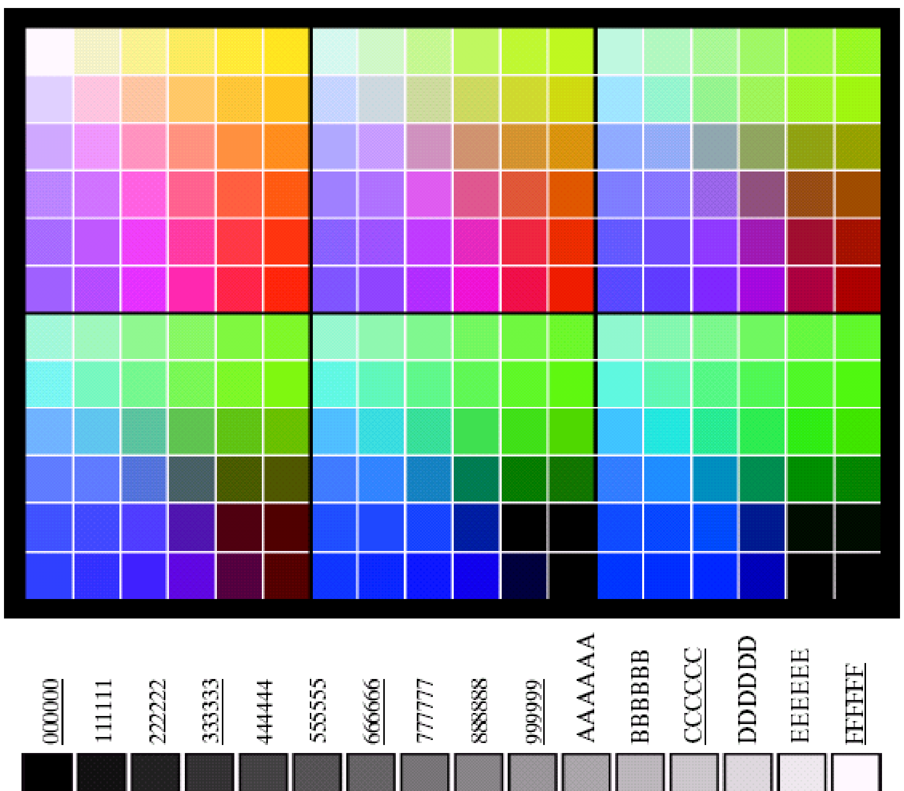




RGB Color Models

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).

RGB Color Models

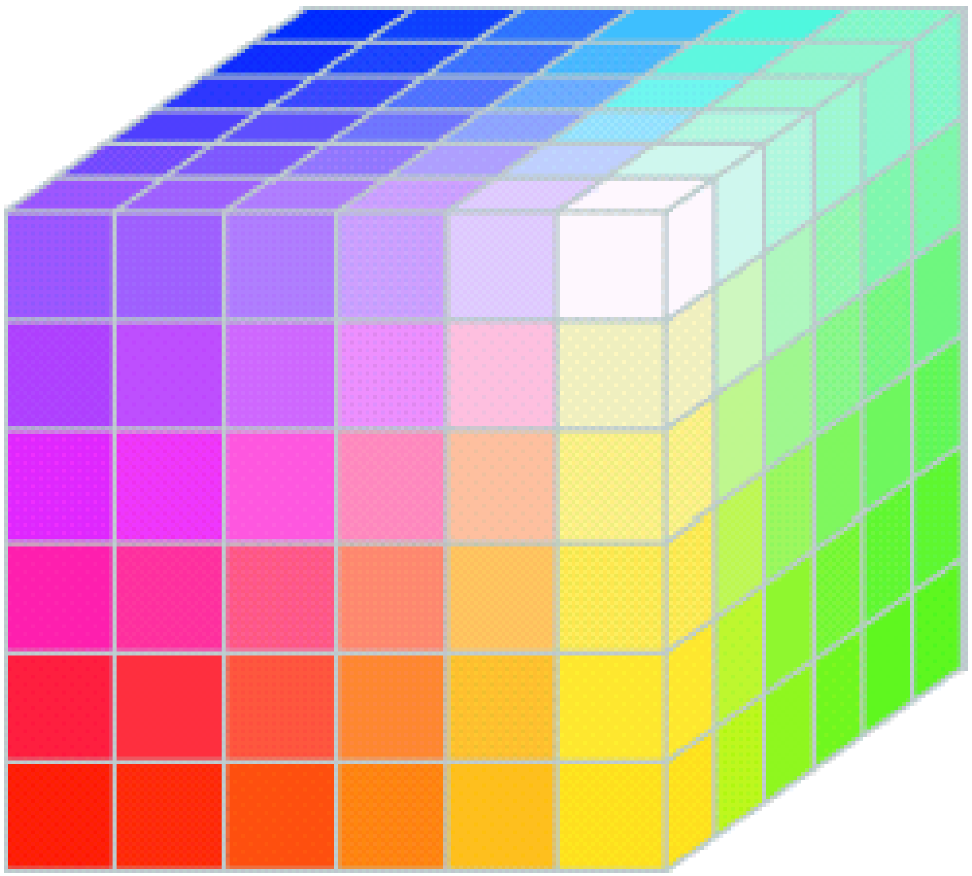


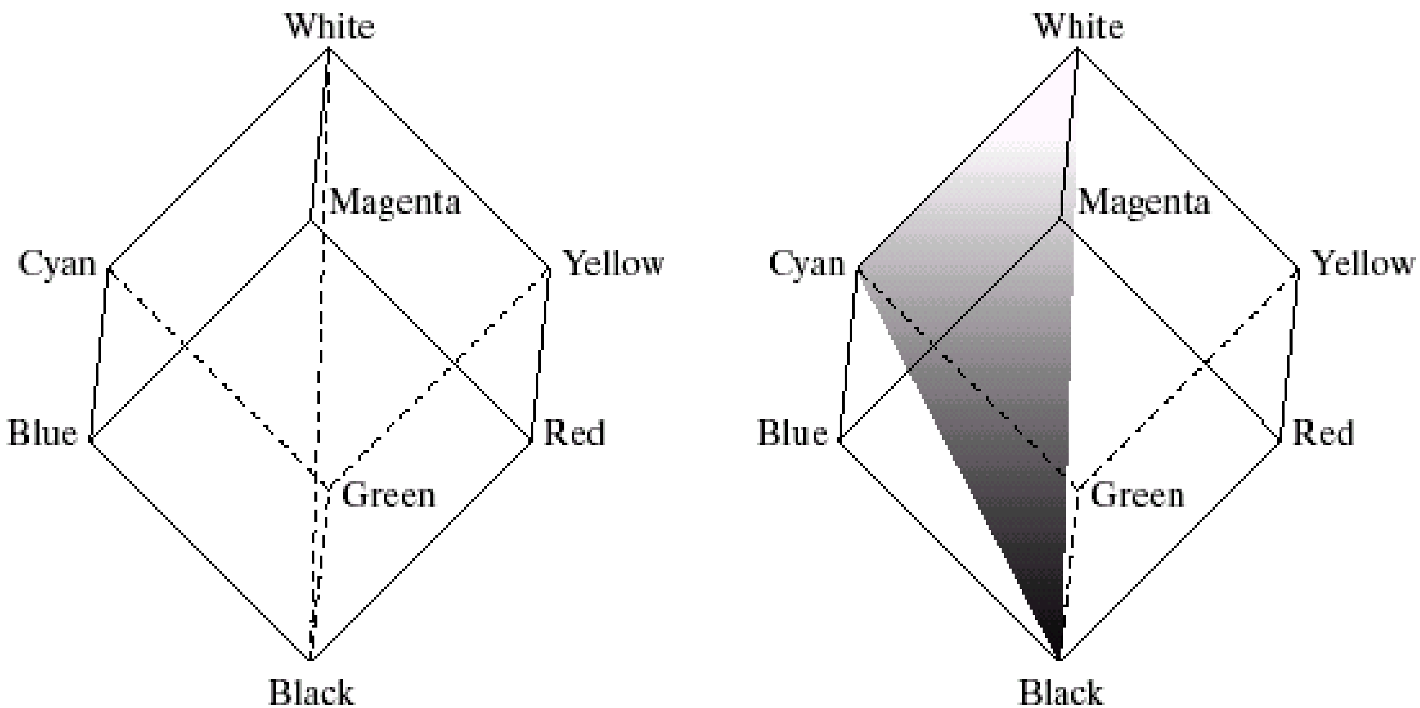
FIGURE 6.11 The RGB safe-color cube.

CMY and CMYK Color Models

- Cyan, Magenta and Yellow
  - The secondary colors of light

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

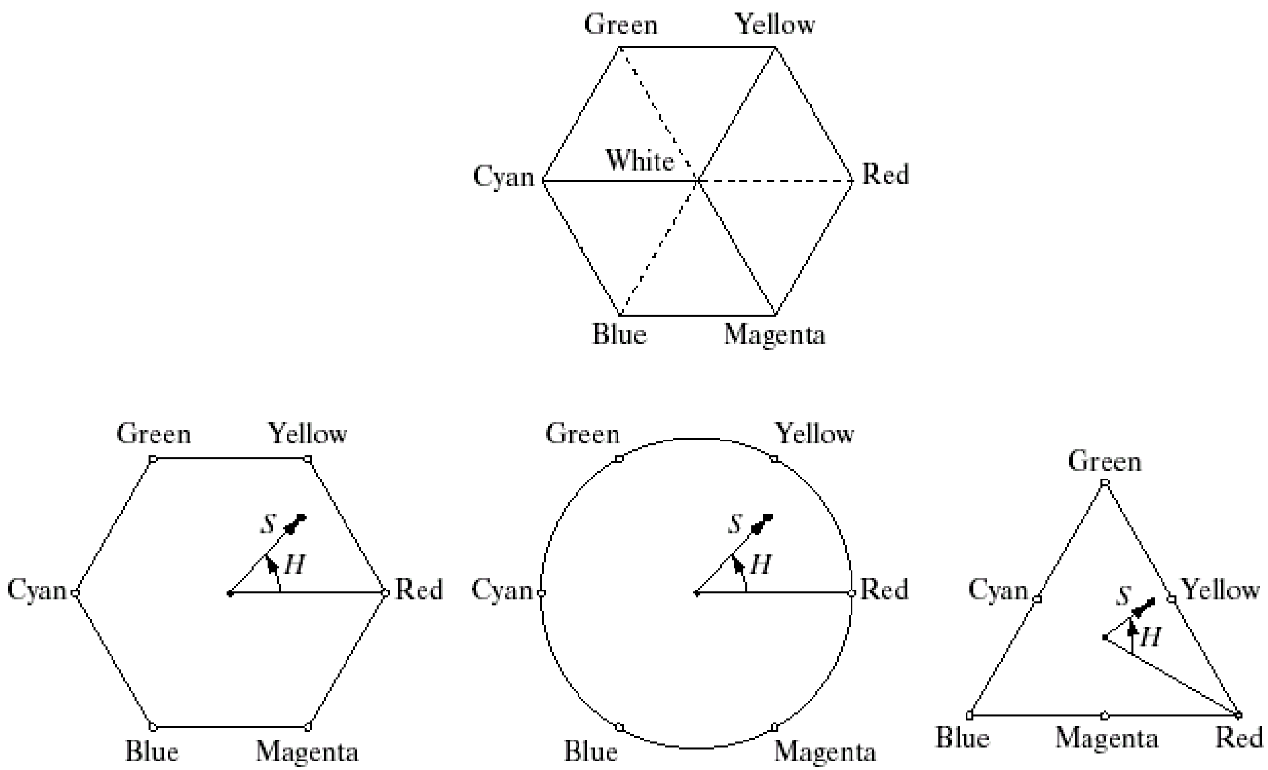
HSI Color Model



a b

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

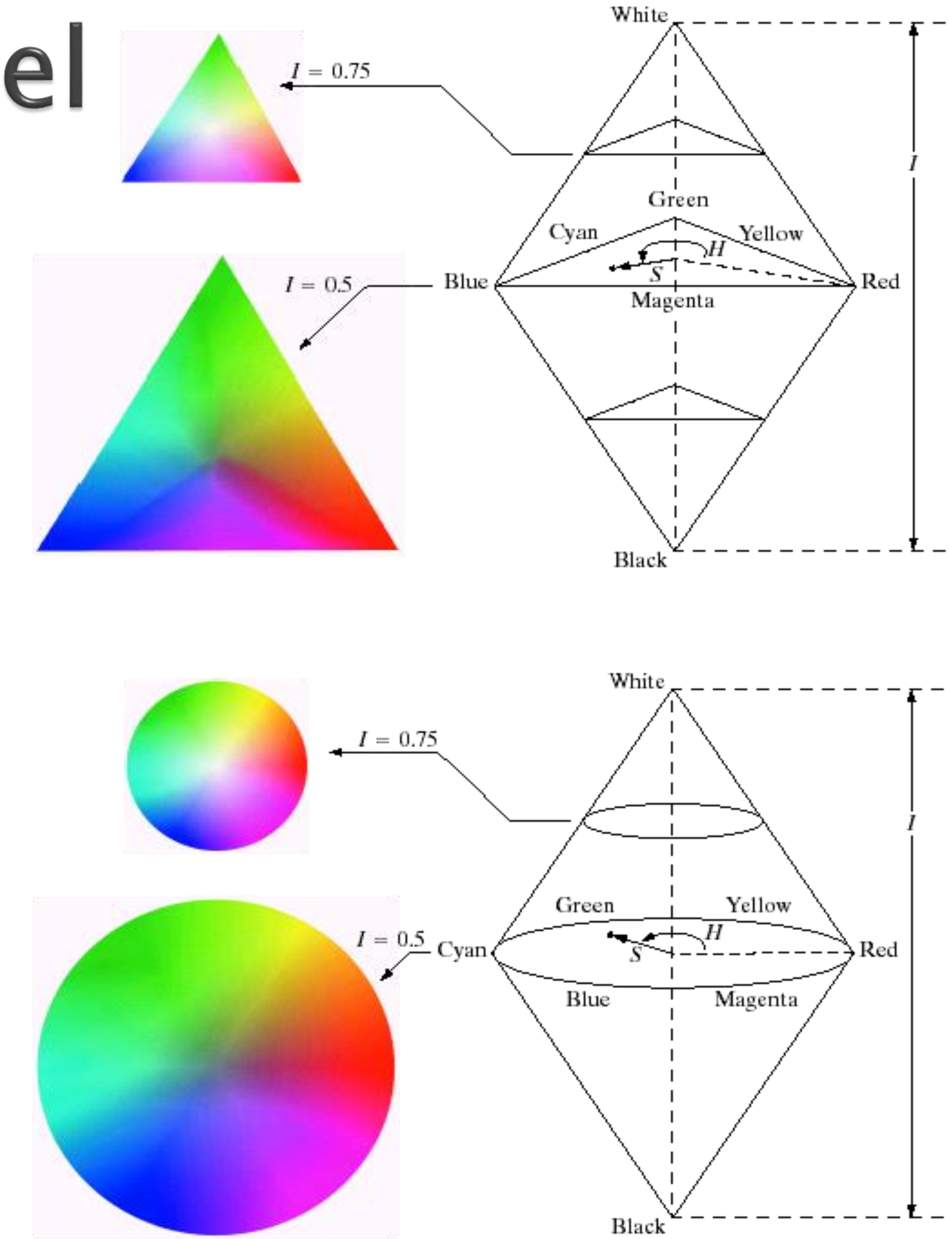
HSI Color Model



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.

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.

HSI Color Model

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

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

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

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

HSI Color Model

$$0^\circ \le H < 120^\circ$$

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

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

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

$$120^\circ \le H < 240^\circ$$

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

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

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

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

$$240^\circ \le H < 360^\circ$$

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

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

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

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

HSI Color Model

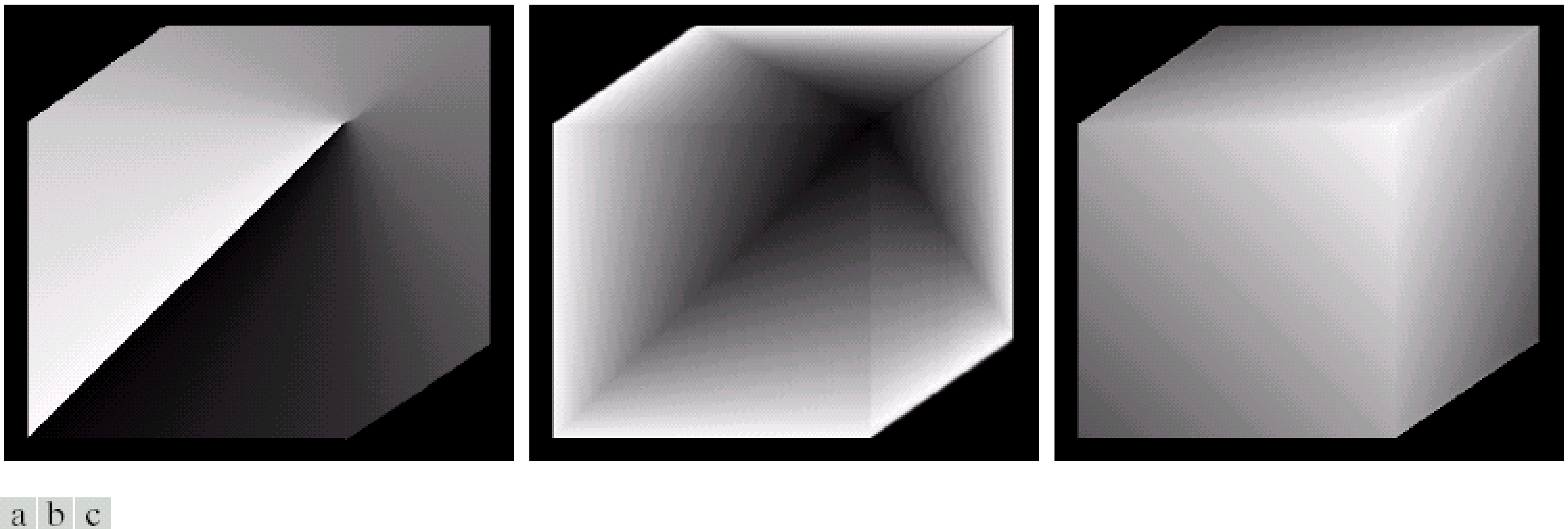
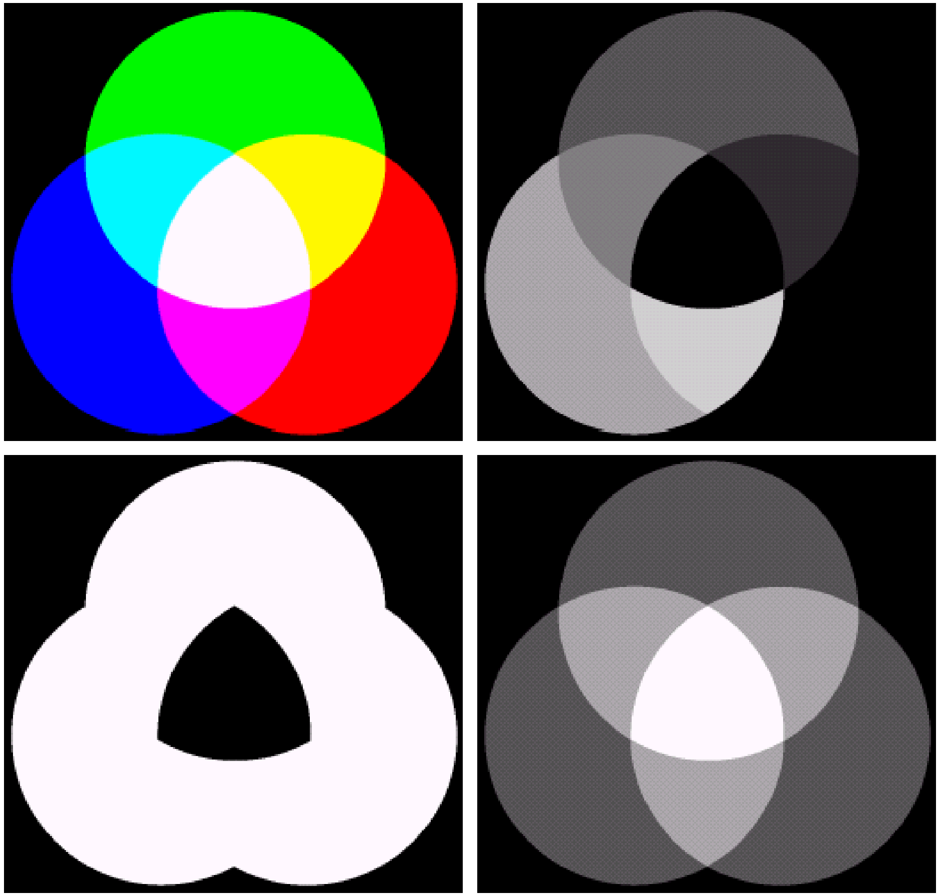


FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

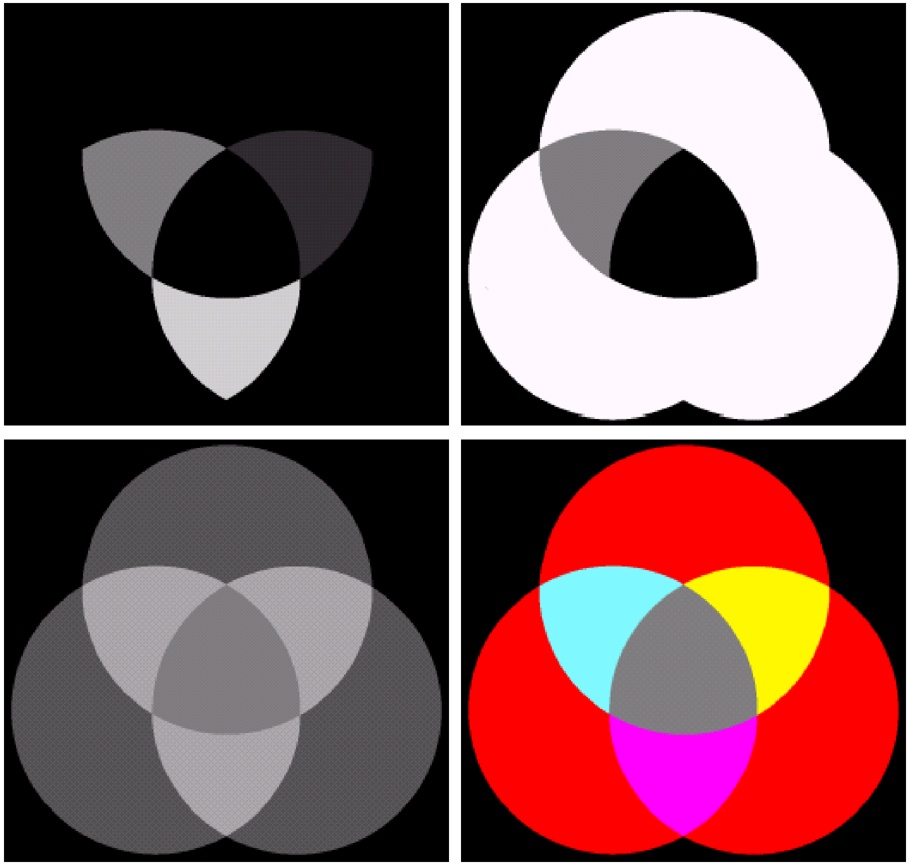
HSI Color Model



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.

HSI Color Model



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

- 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.

Intensity Slicing

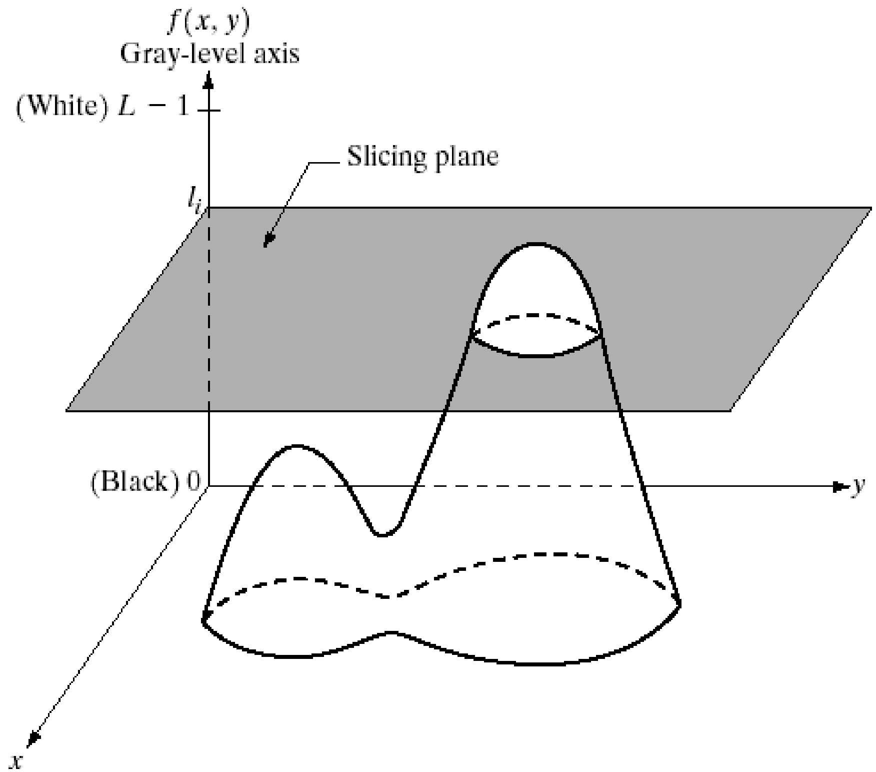


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

Intensity Slicing

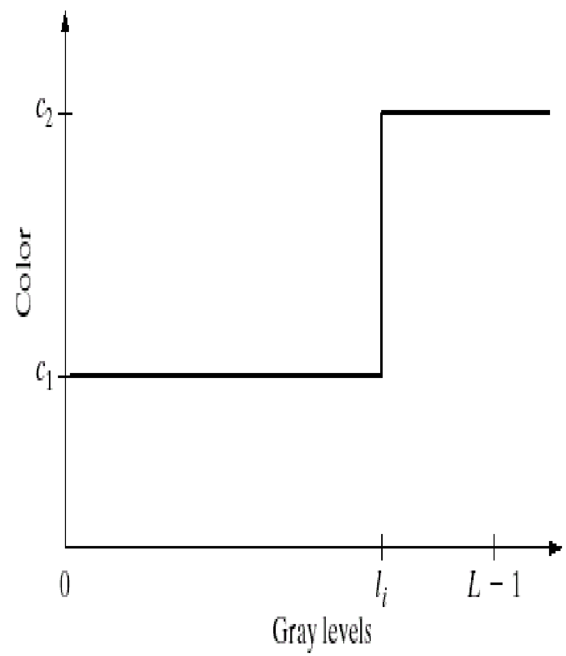
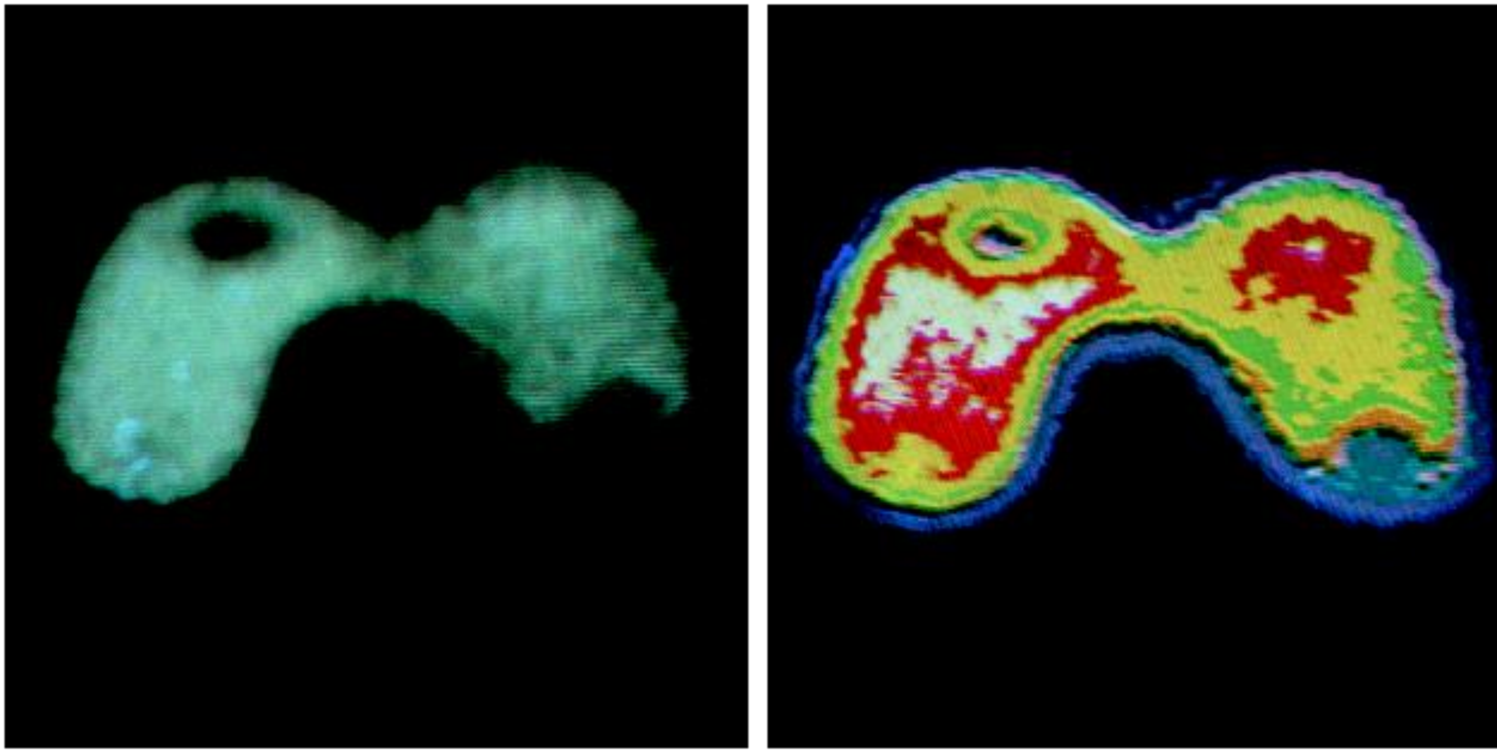


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

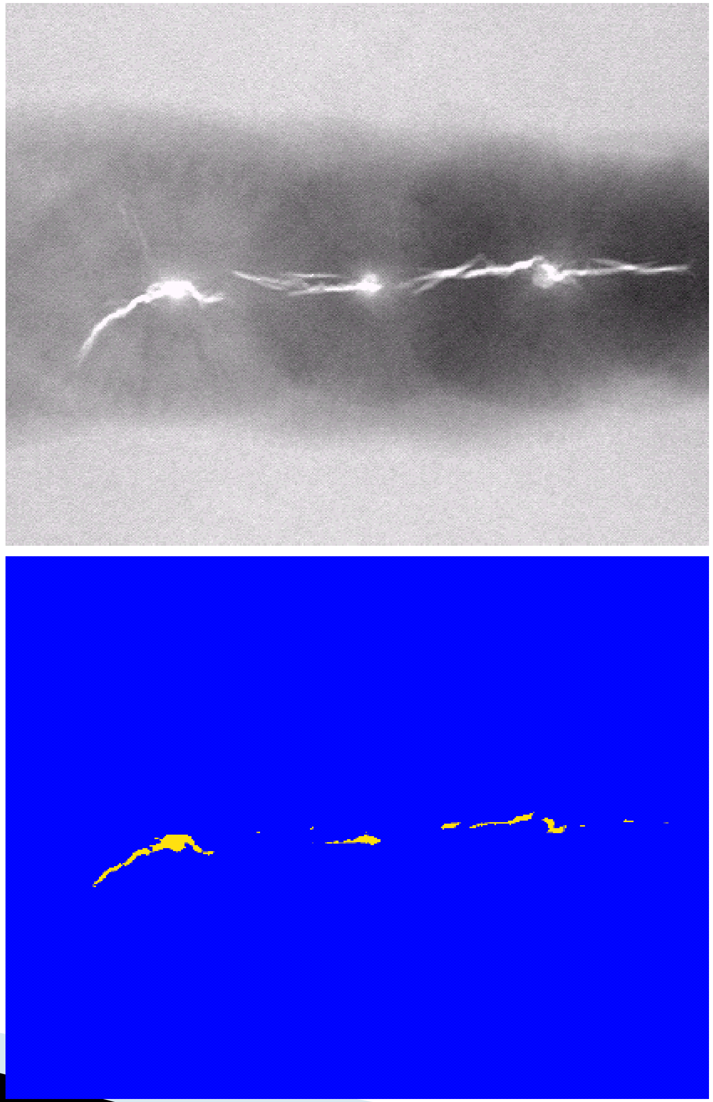
Intensity Slicing



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.)

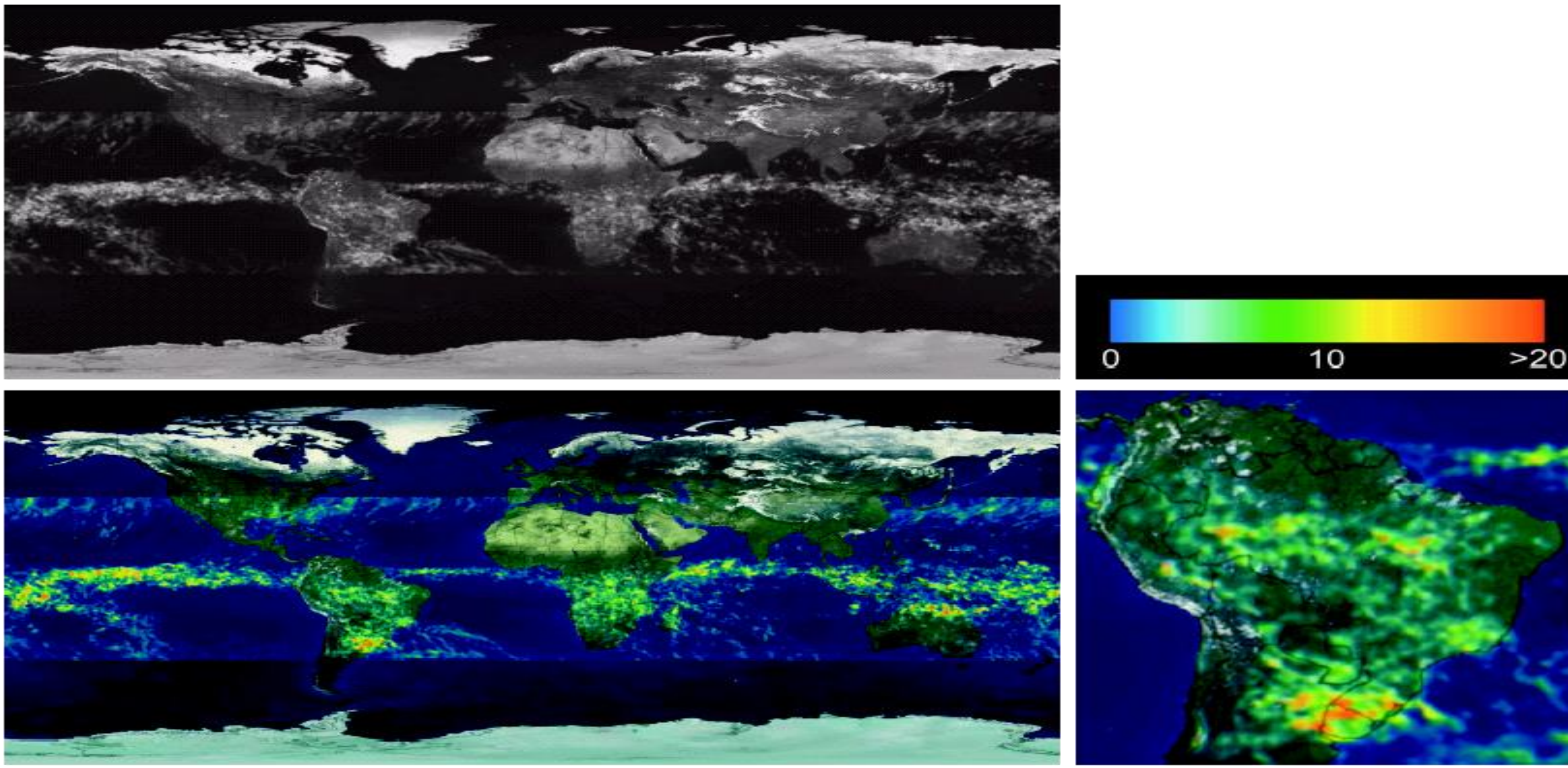
Intensity Slicing



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.)

Intensity Slicing



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 America region. (Courtesy of NASA.)

Intensity to Color Transformations

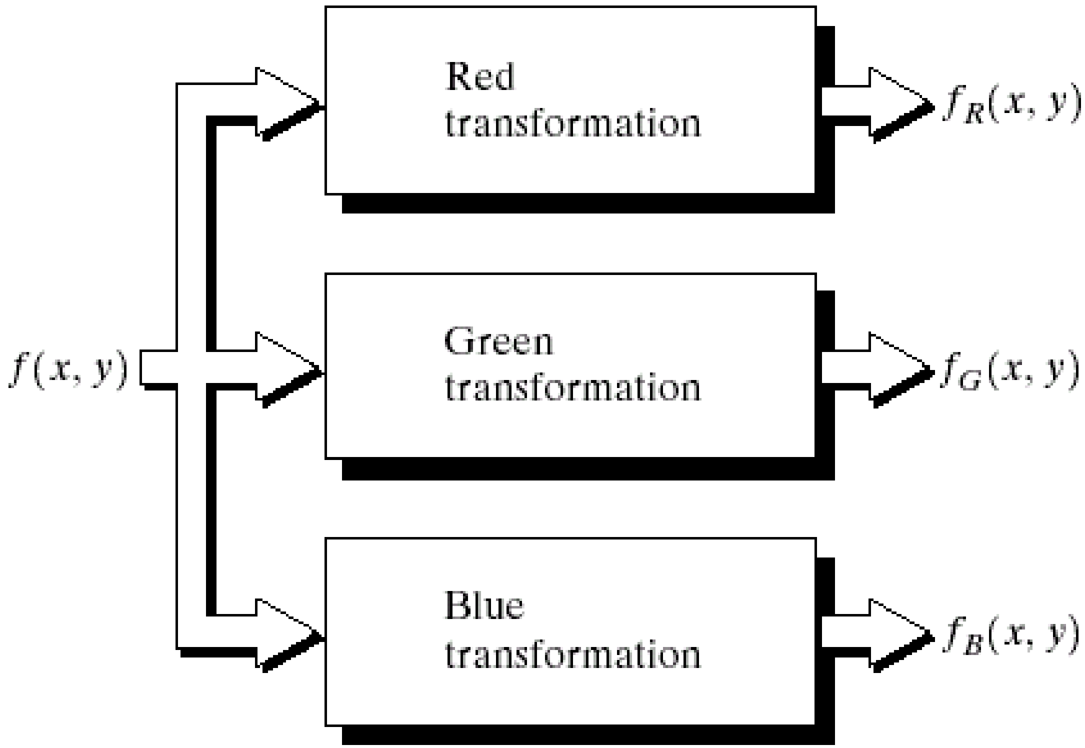


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

Intensity to Color Transformations

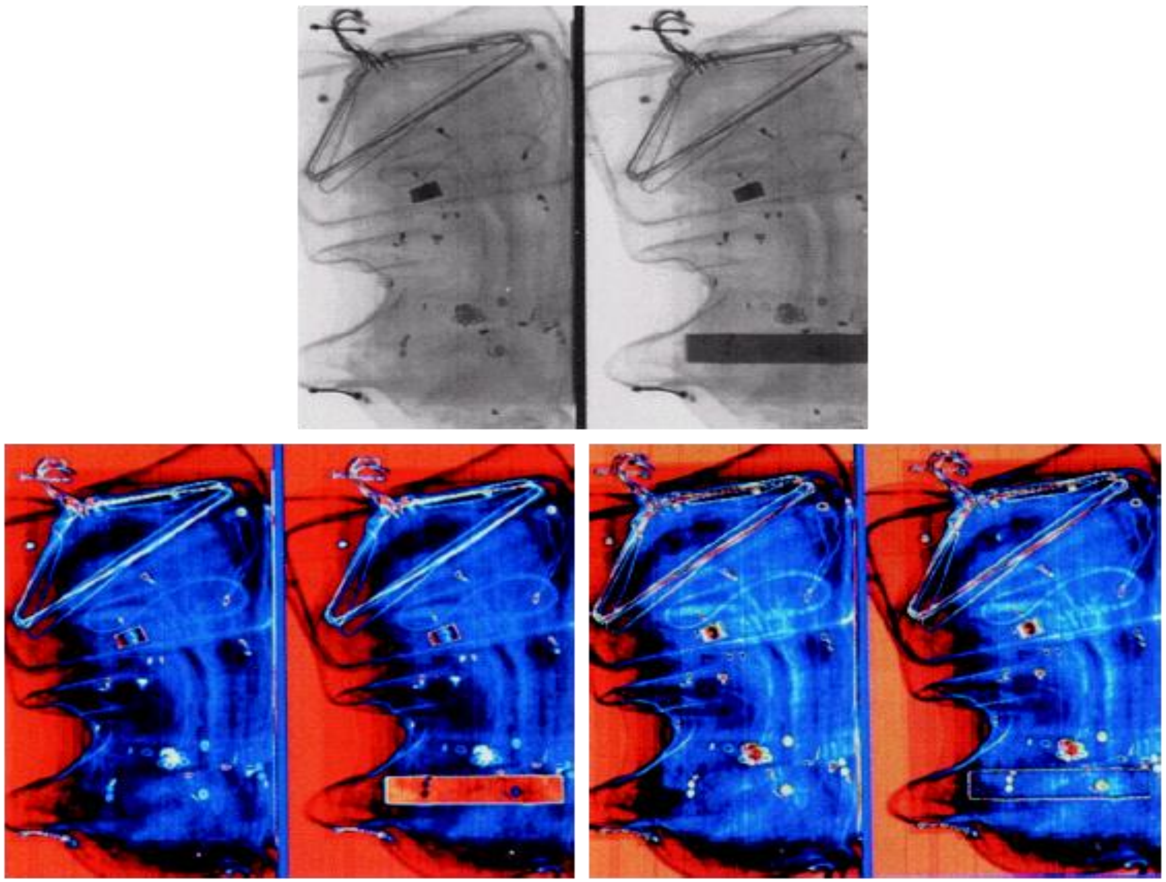
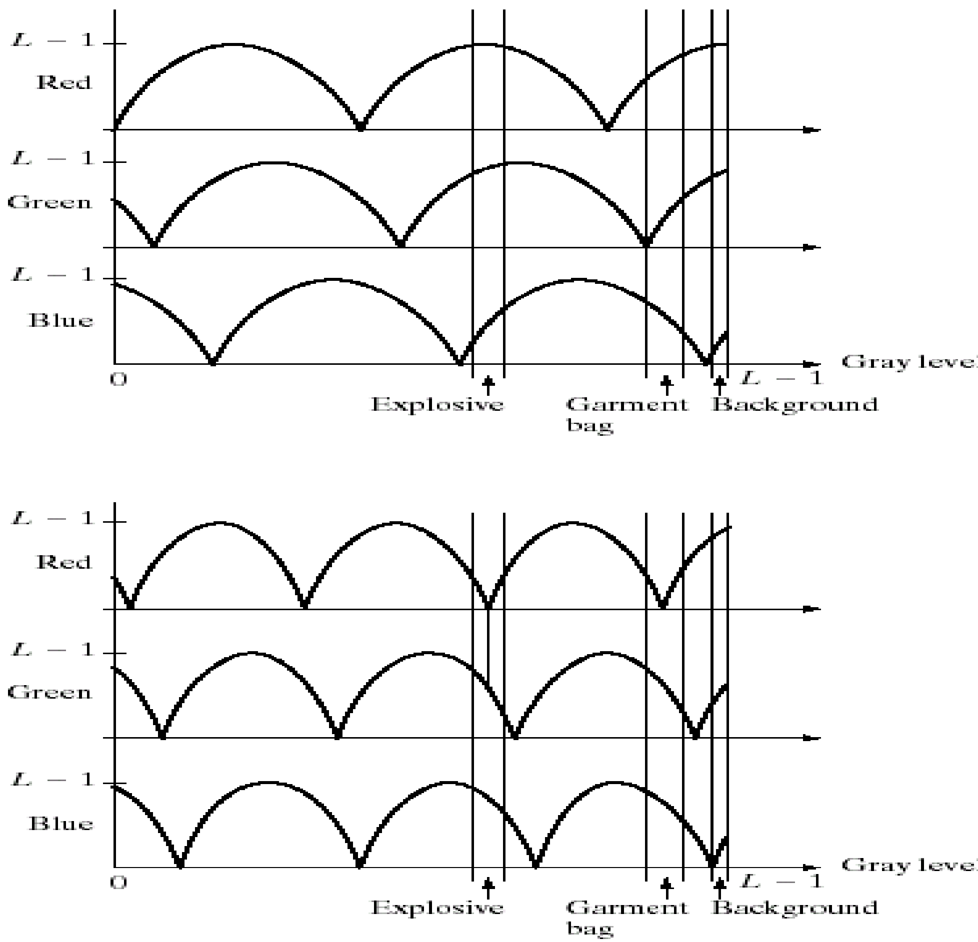


FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

Intensity to Color Transformations



a
b

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

Intensity to Color Transformations

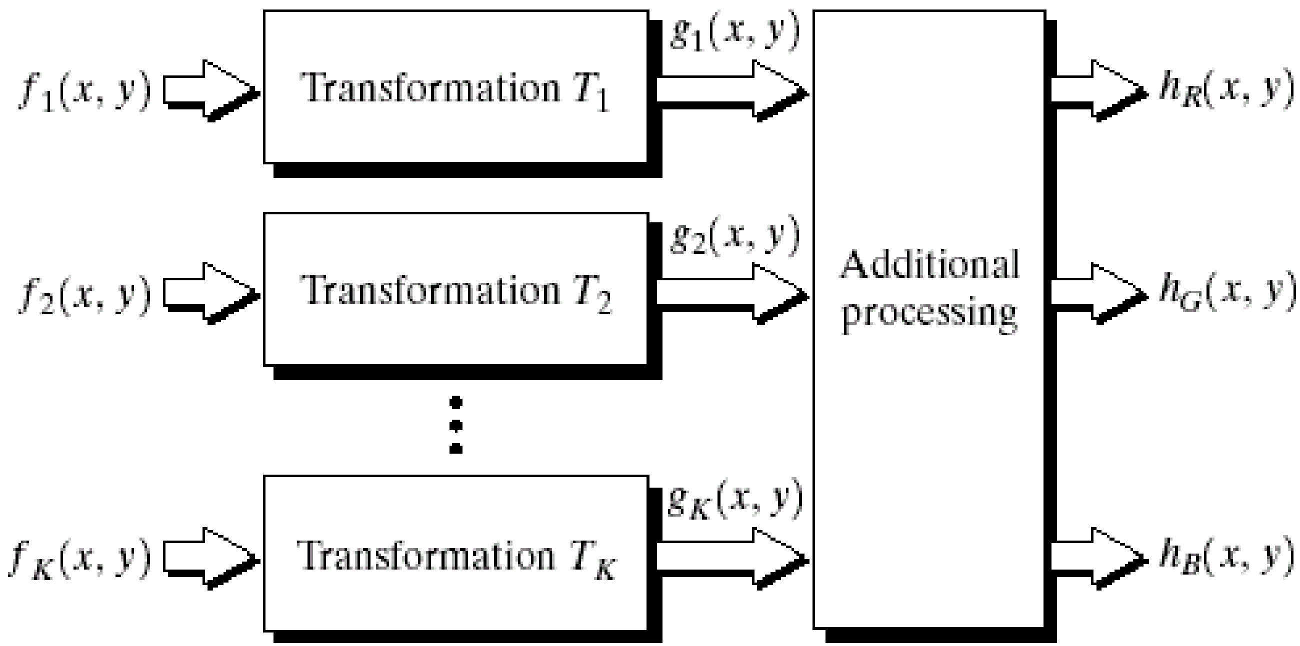
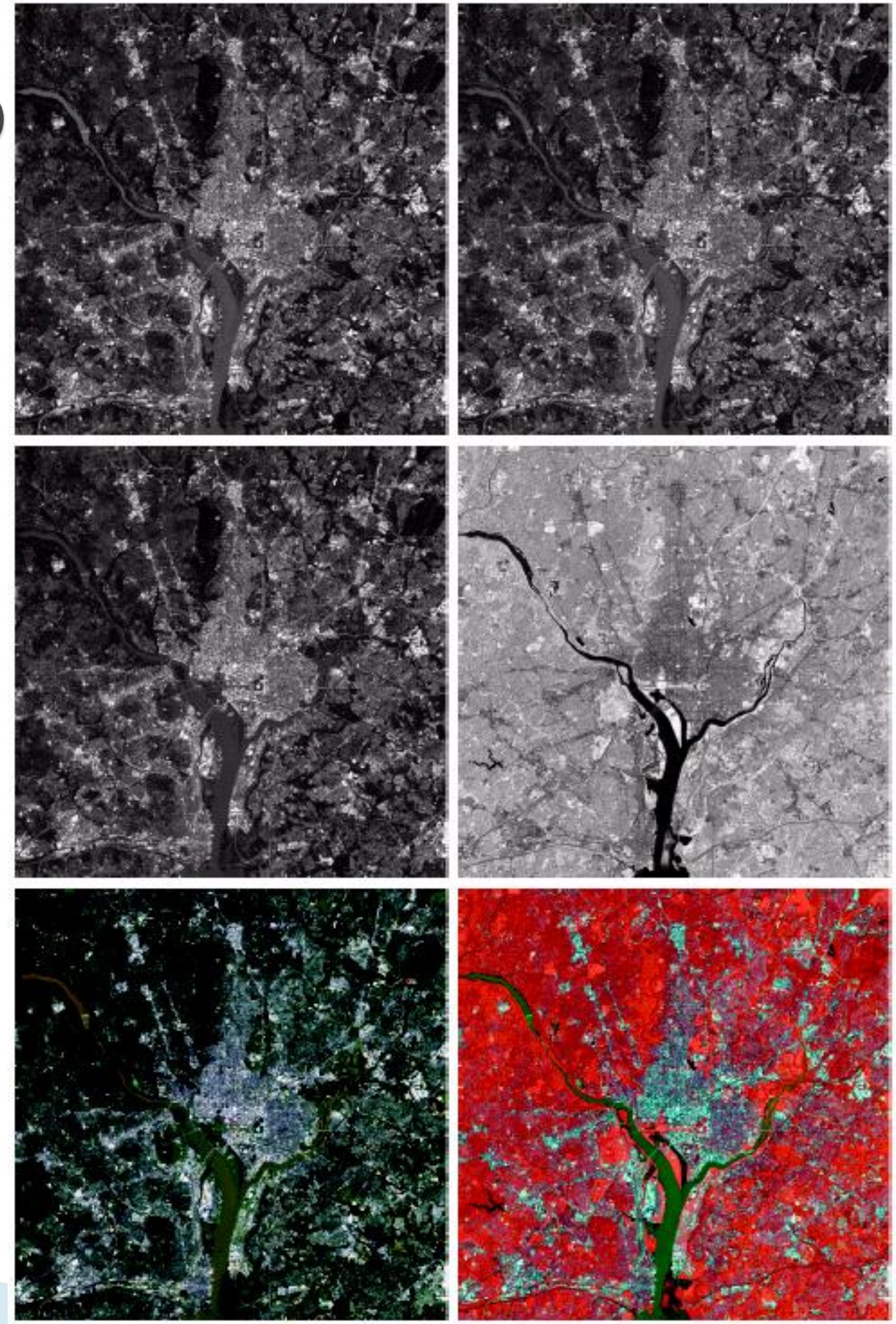
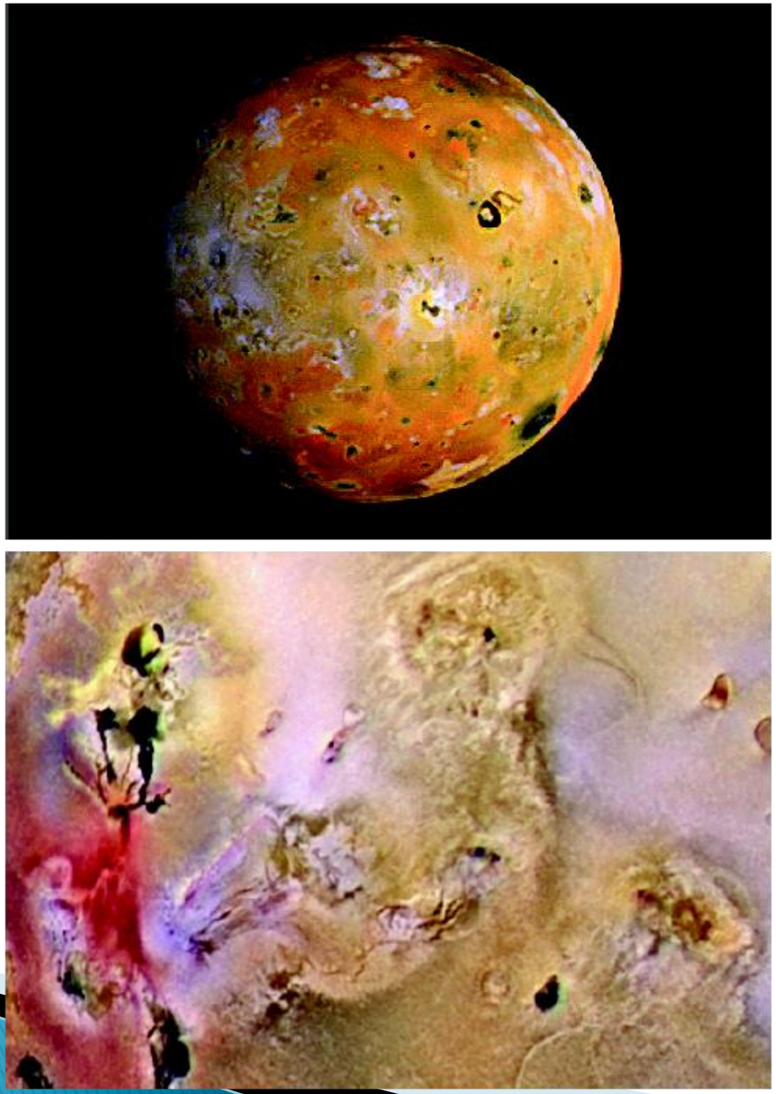


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

Intensity to Colo



Intensity to Color Transformations



a
b

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

Color Transformations

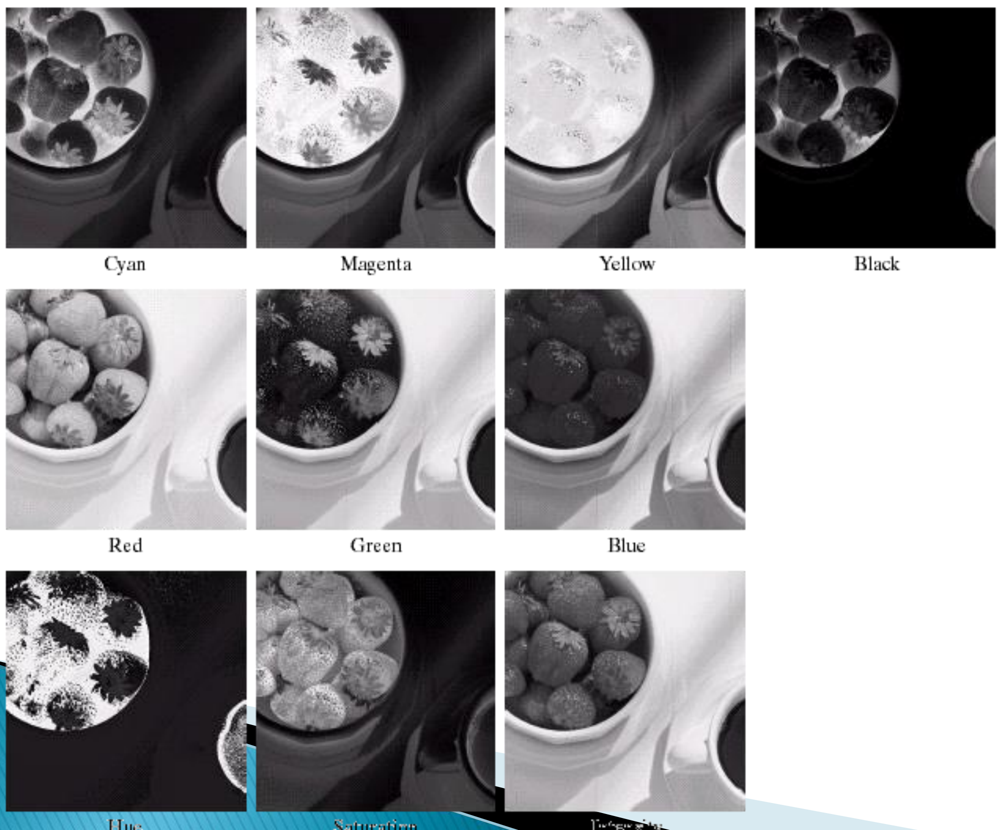
- Formulation

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

  - f(x,y): Color input image
  - g(x,y): Transformed or Processed color output image
  - T: Operator on f over a spatial neighborhood of (x,y)

Color Transformations

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



Color Transformations

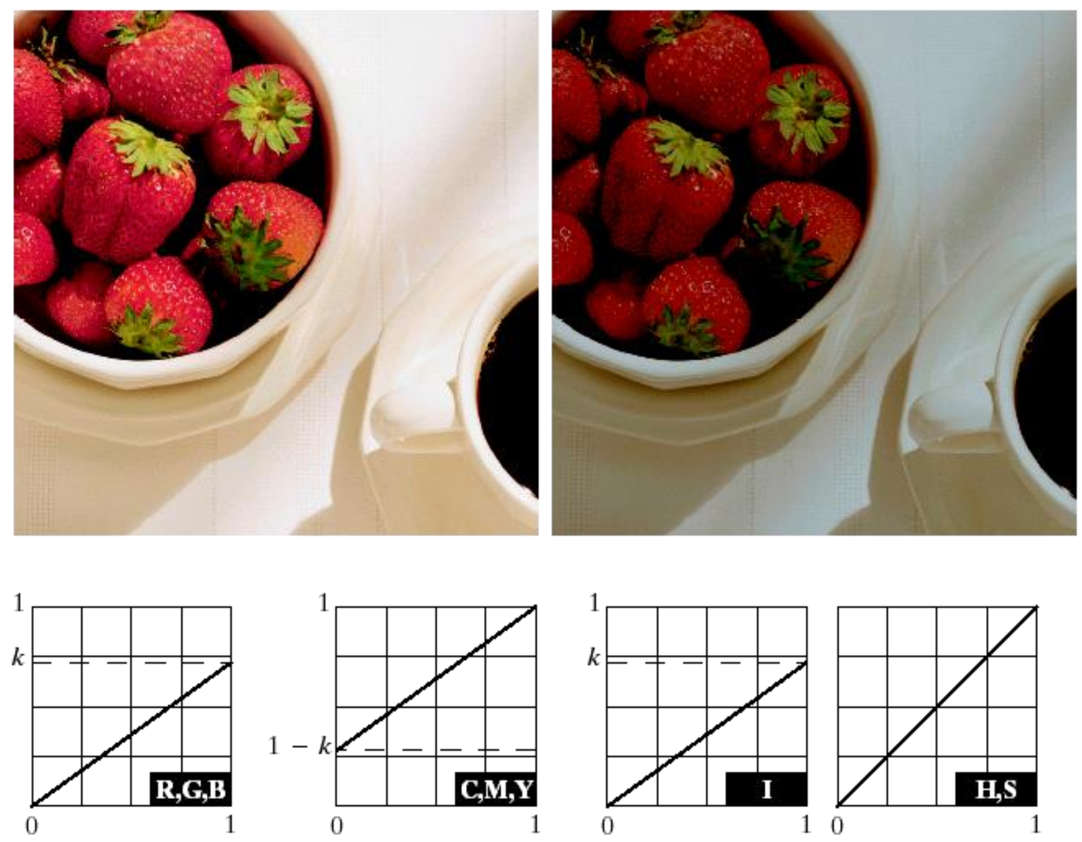


FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)

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

Check the number of operations.

Color Complements

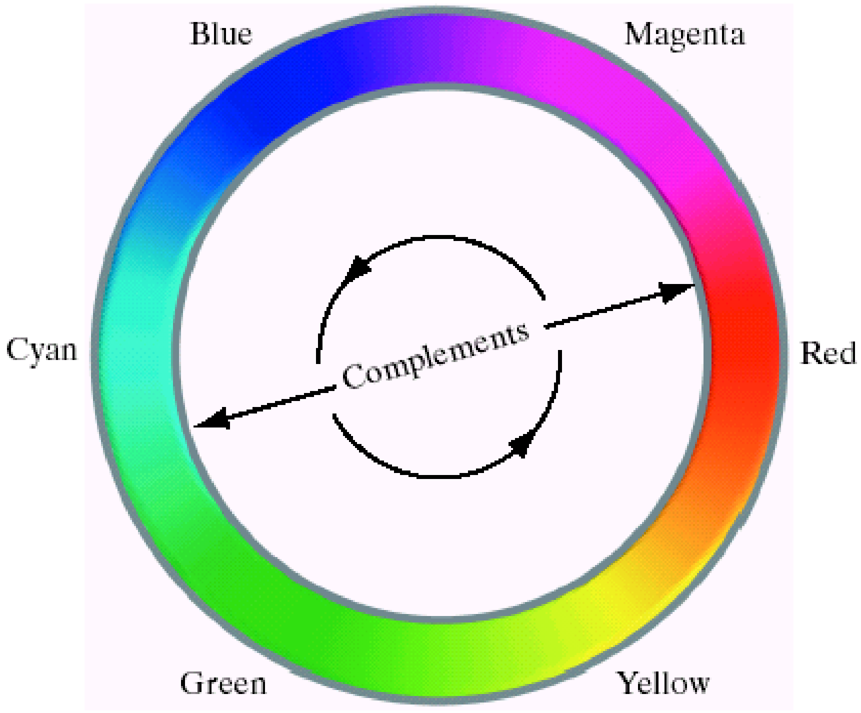


FIGURE 6.32 Complements on the color circle.

Color Complements

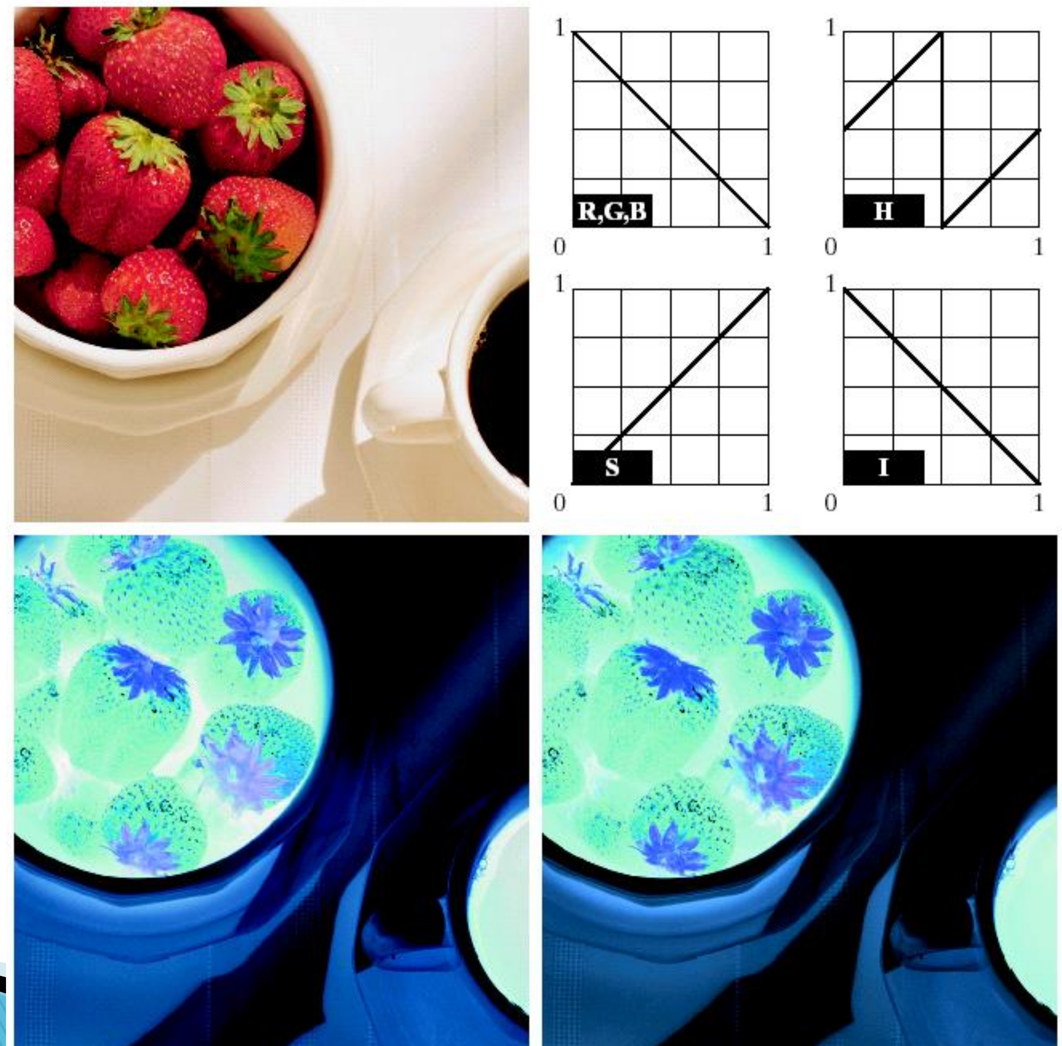


FIGURE 6.33 Color complement transformations. (a) Original image. (b) Complement transformation functions. (c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.

Color Slicing

- Highlighting a specific range of colors in an image is useful.

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

Color Slicing

- Colors of interest are enclosed by a cube (or hypercube for n>3) of with W
  - Center: $(a_1, a_2, \ldots\ldots, a_n)$

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

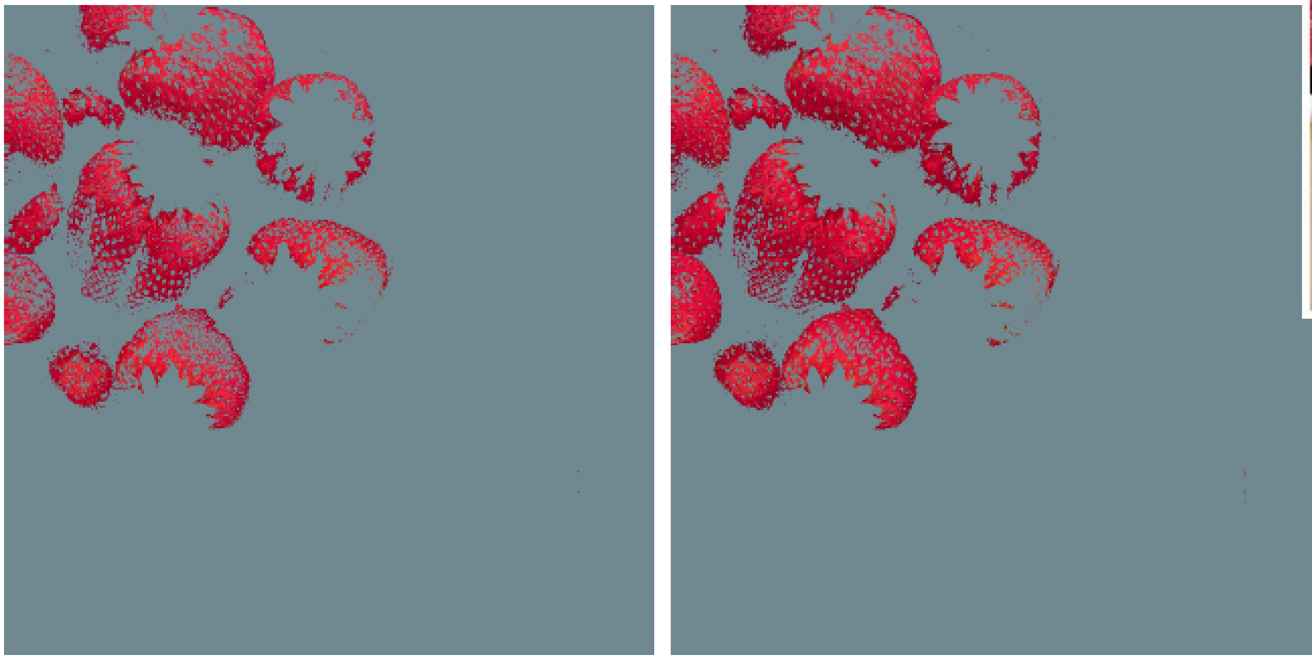
  - Neutral point: 0.5
    - It can be arbitrary chosen.

Color Slicing

- Colors of interest are enclosed by a sphere

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

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

- Transformations for modifying image tones normally are selected interactively.
- The idea is to adjust experimentally the image's brightness and contrast to provide maximum detail over a suitable range of intensities
- **The colors themselves are not changed.**

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 alter the image hues.

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

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

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

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 alter the image hues.

Tone and Color Corrections

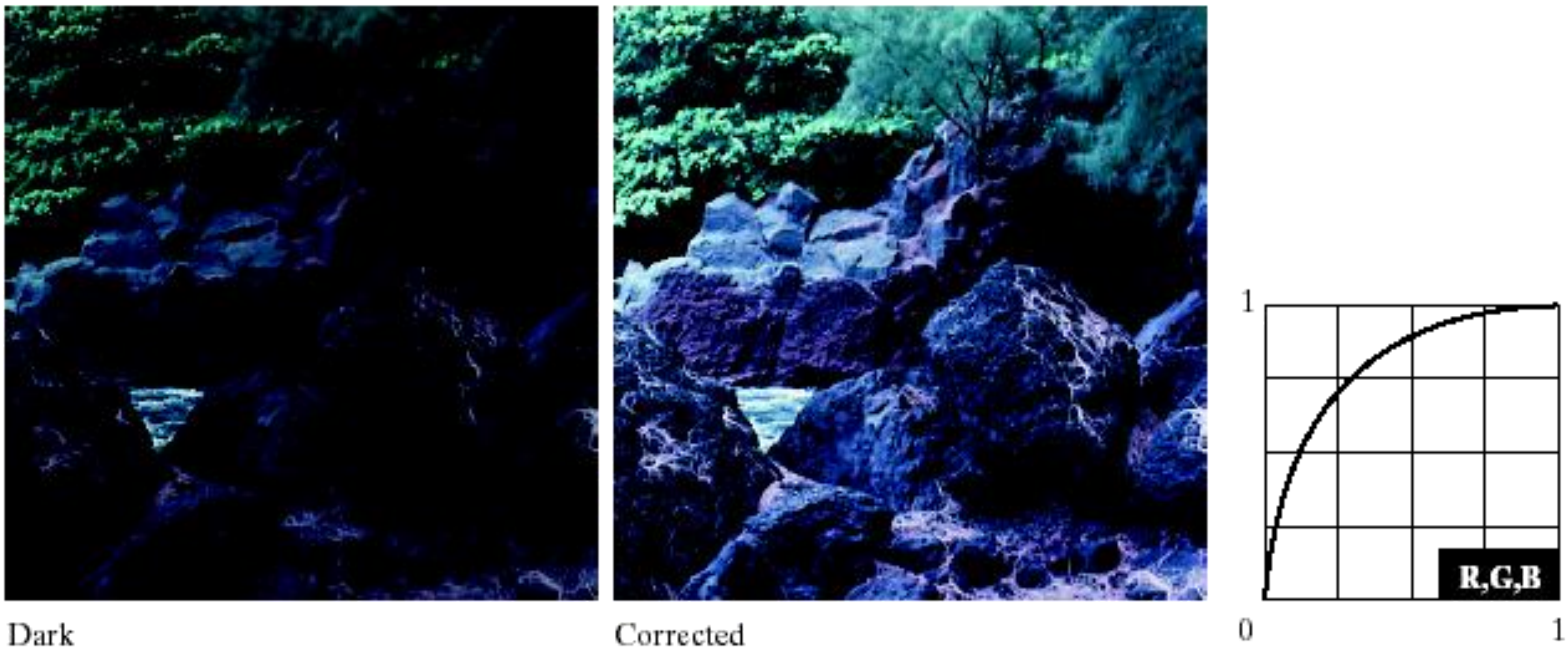


FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not alter the image hues.

Tone and Color Corrections

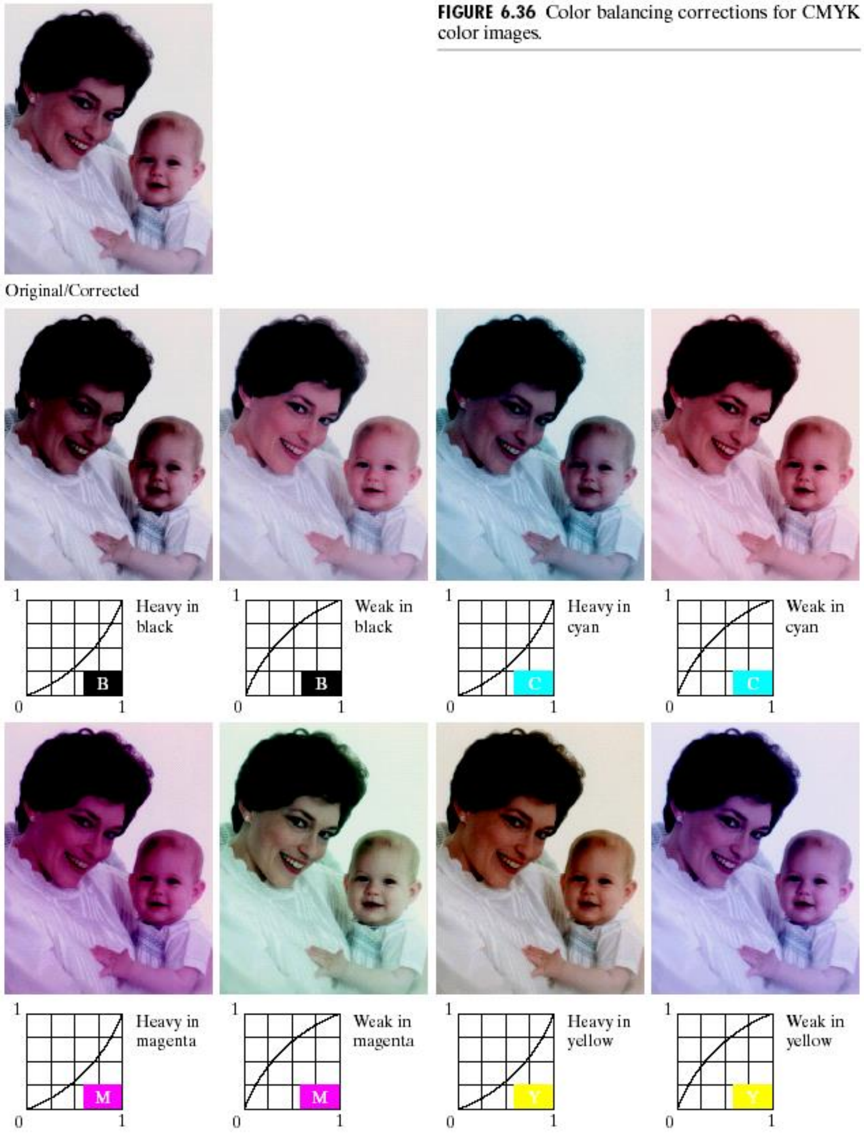


FIGURE 6.36 Color balancing corrections for CMYK color images.

Tone and Color Corrections

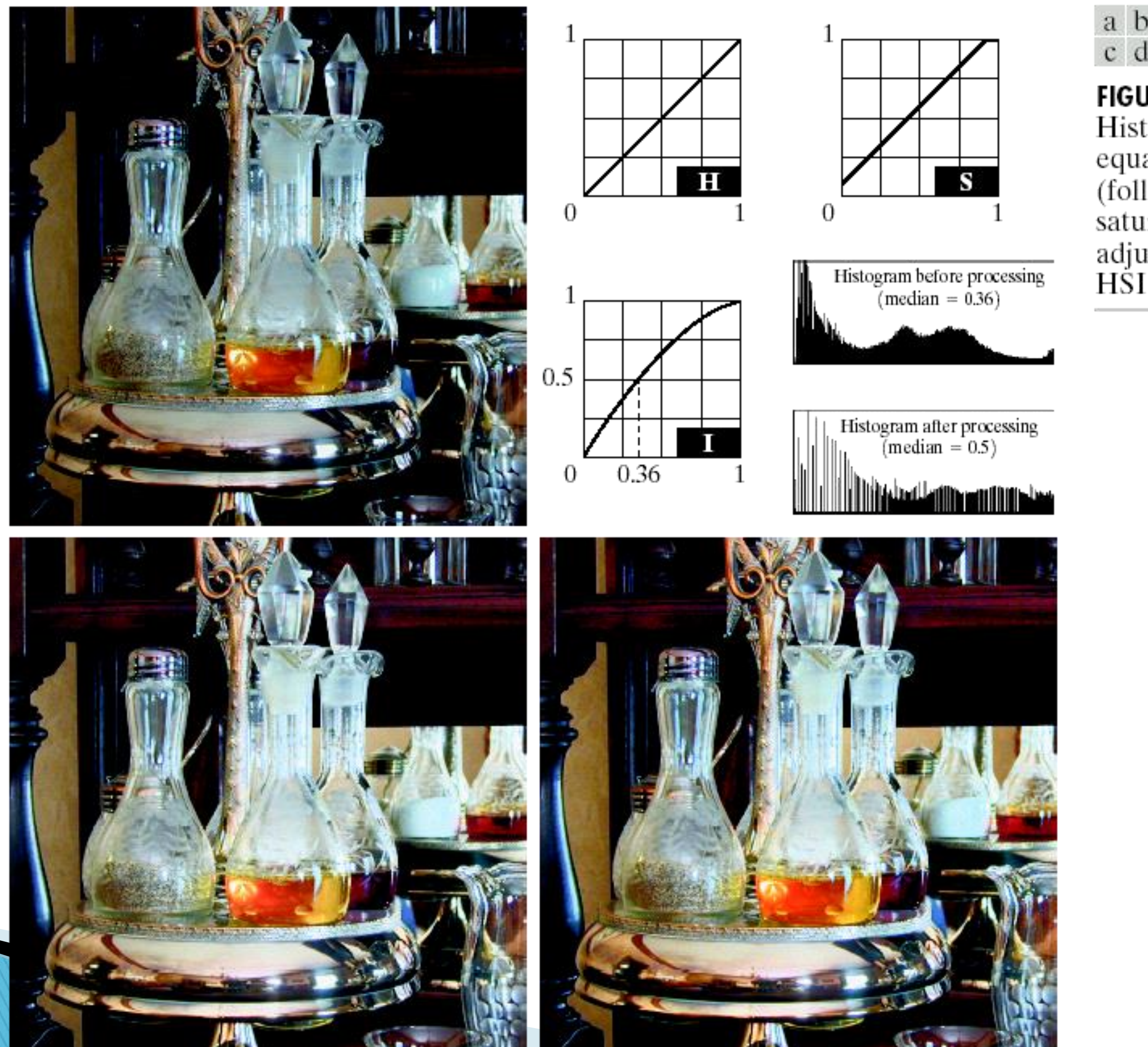


FIGURE 6.37 Histogram equalization (followed by saturation adjustment) in the HSI color space.

Color Image Smoothing

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

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

Color Image Smoothing

a b
c d

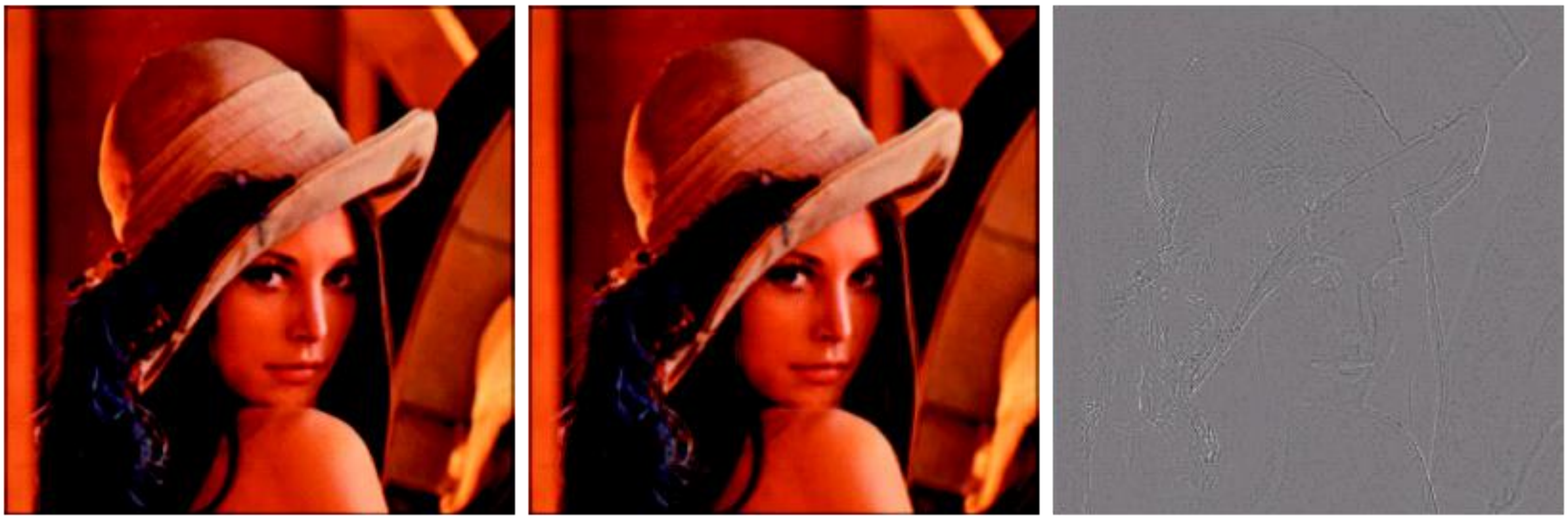
FIGURE 6.38
(a) RGB image.
(b) Red component image.
(c) Green component.
(d) Blue component.

Color Image Smoothing

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 Smoothing



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

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

a b c

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