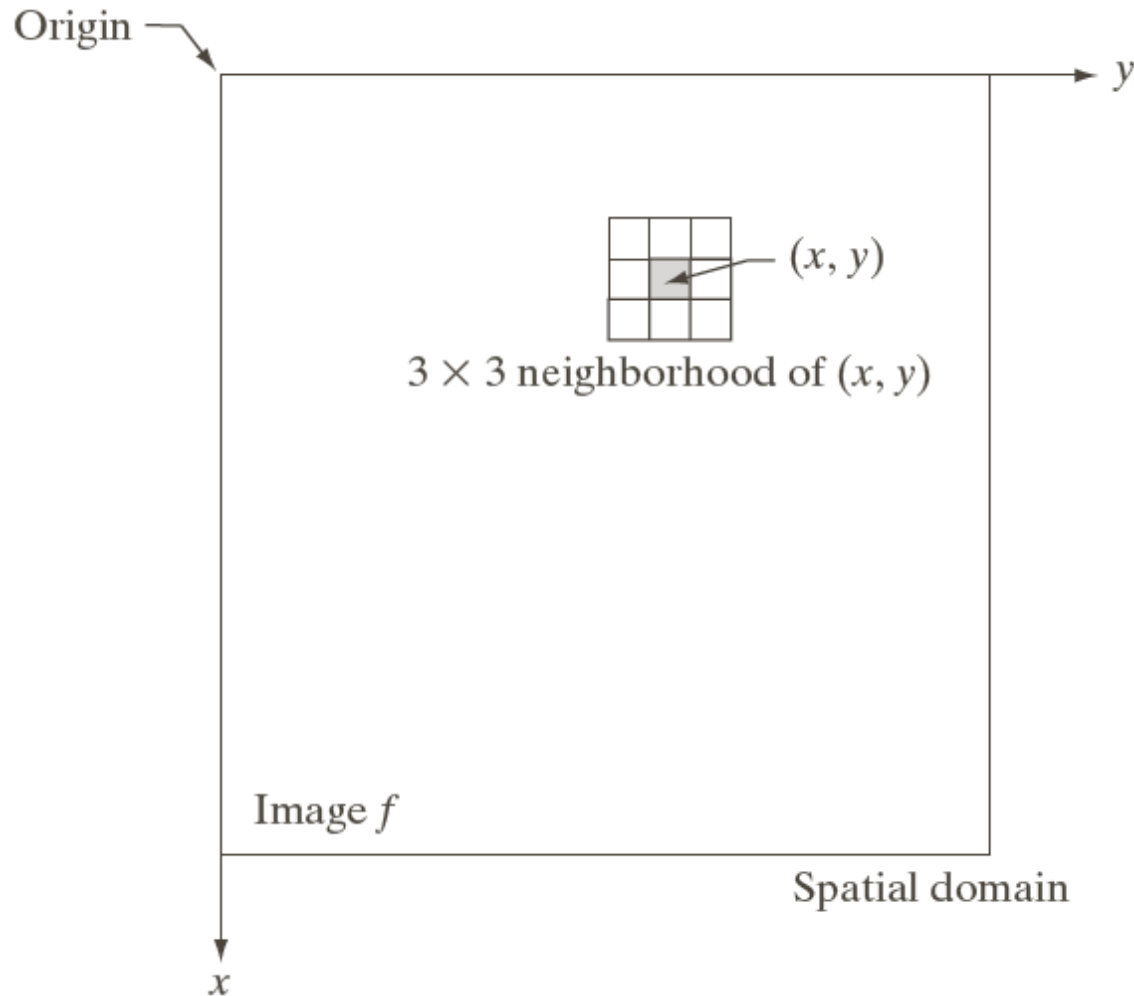


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**FIGURE 3.1**

A  $3 \times 3$  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.

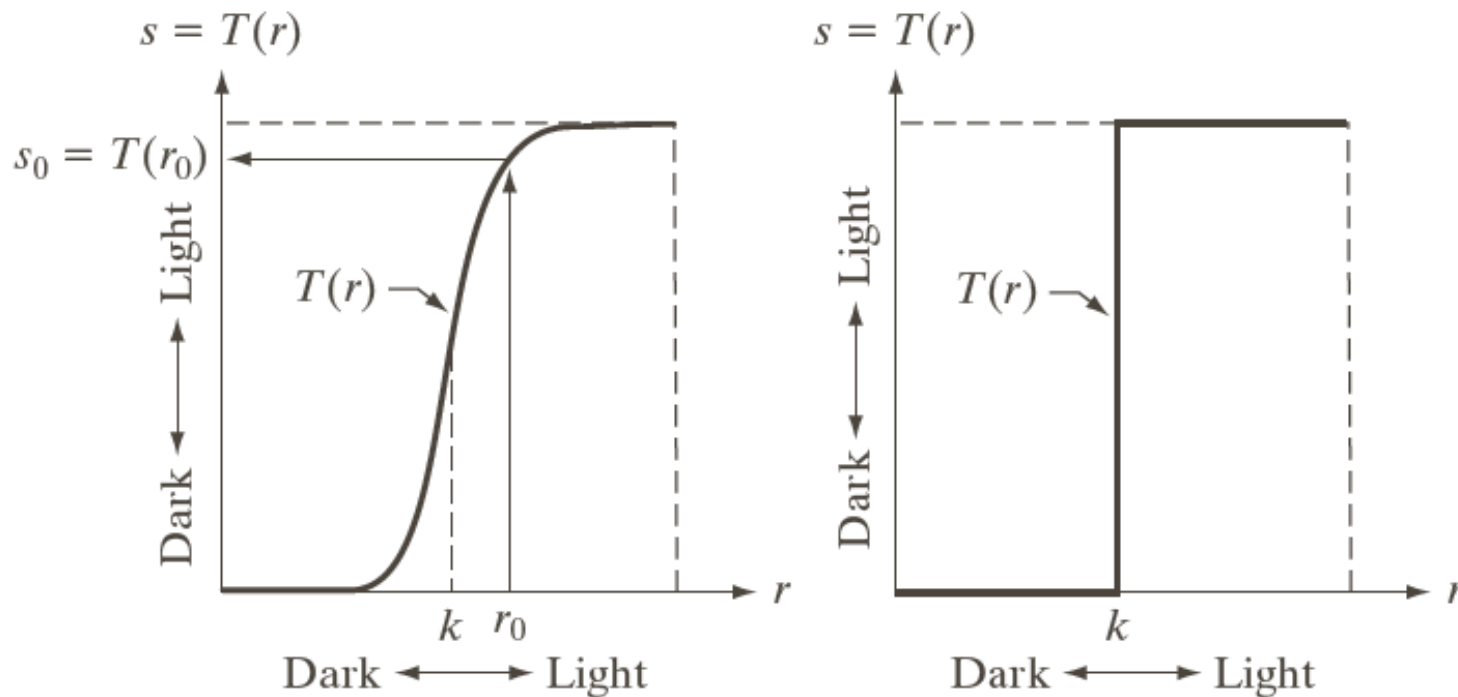


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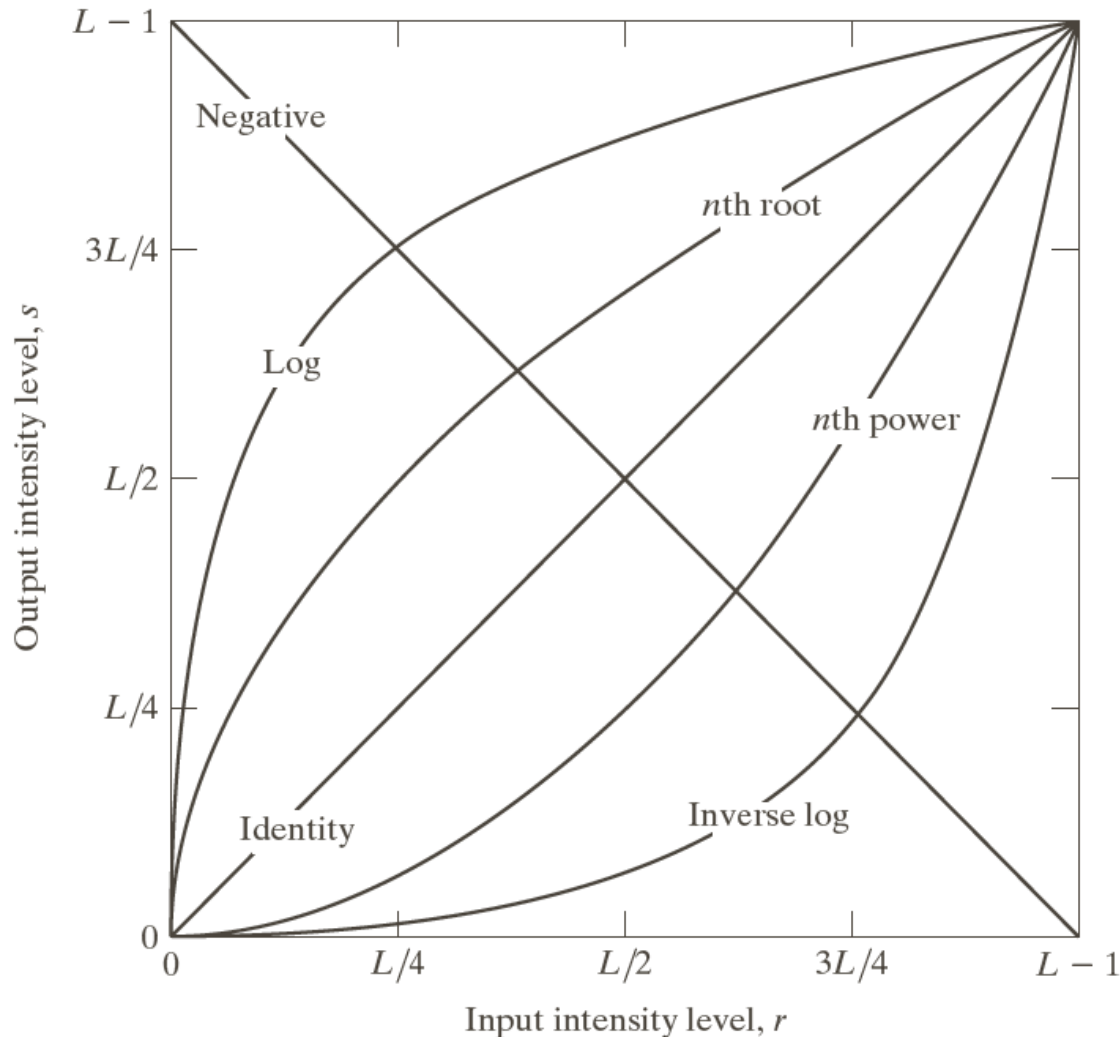


a b

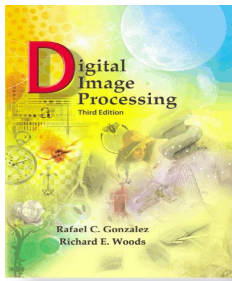
**FIGURE 3.2**  
Intensity transformation functions.  
(a) Contrast-stretching function.  
(b) Thresholding function.



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

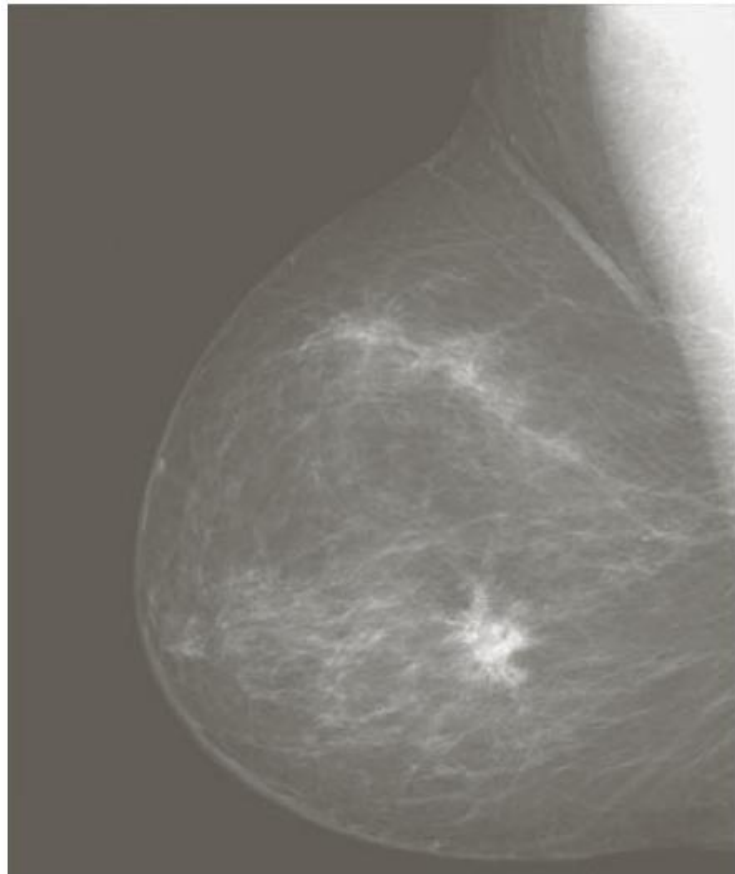


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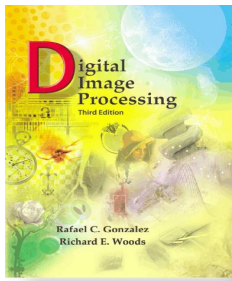
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a b

**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.)

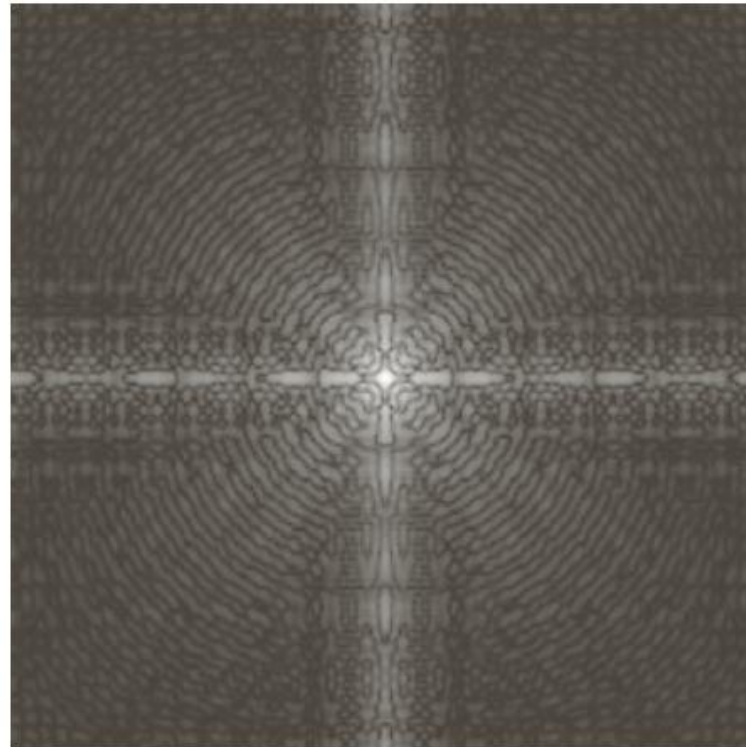
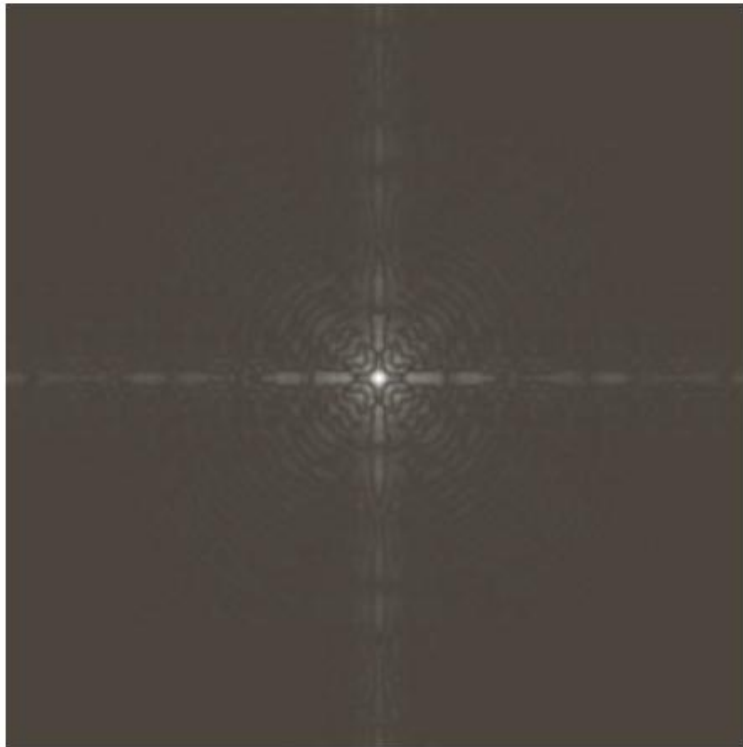


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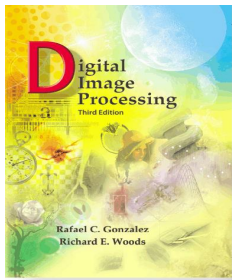


a b

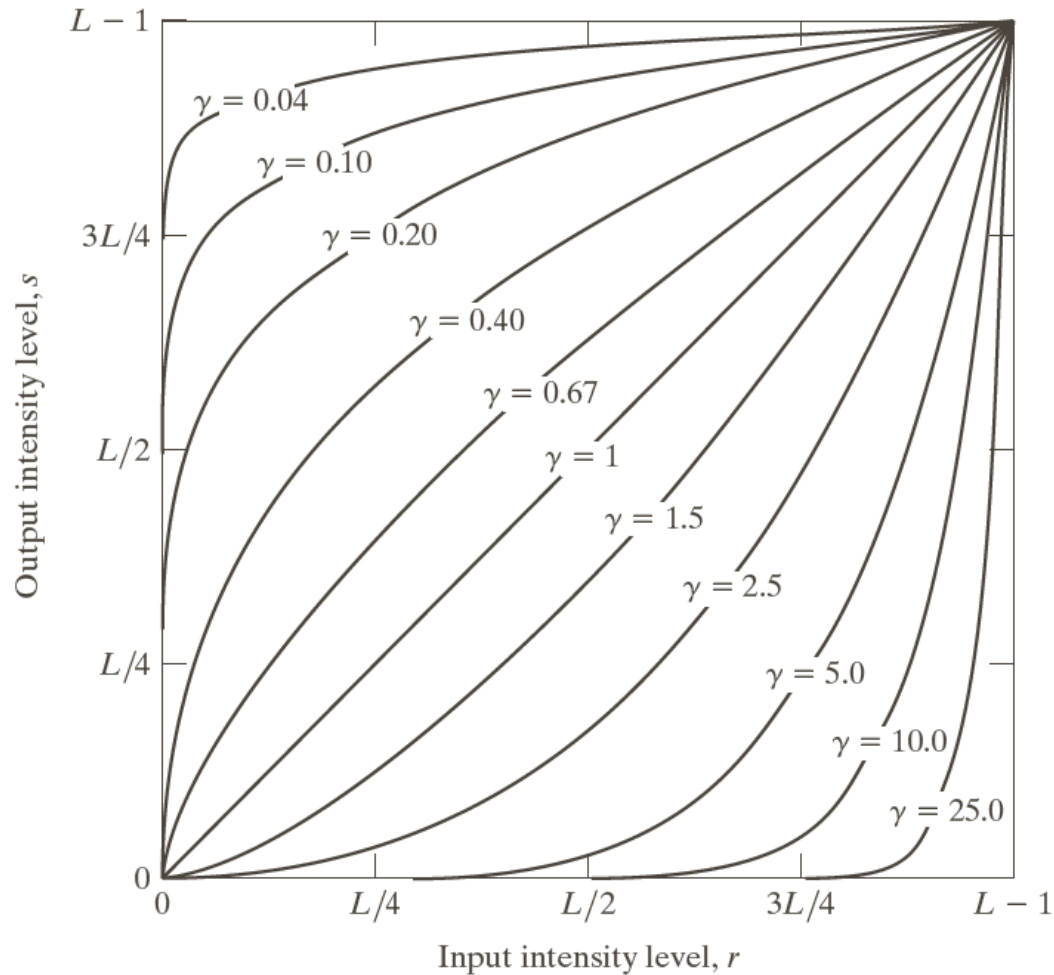
### **FIGURE 3.5**

(a) Fourier spectrum.

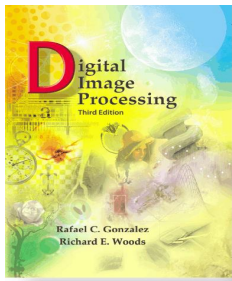
(b) Result of applying the log transformation in Eq. (3.2-2) with  $c = 1$ .



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

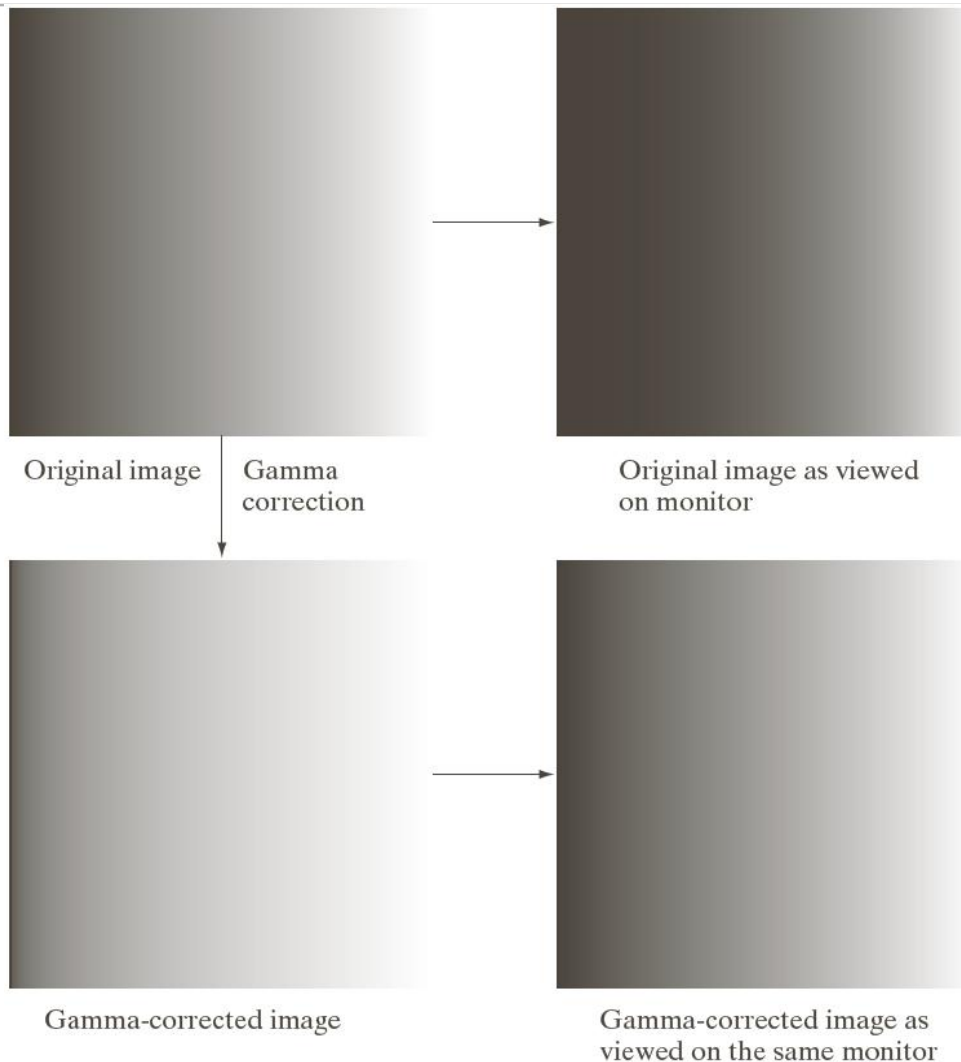


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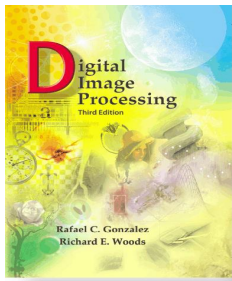


a	b
c	d

**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).



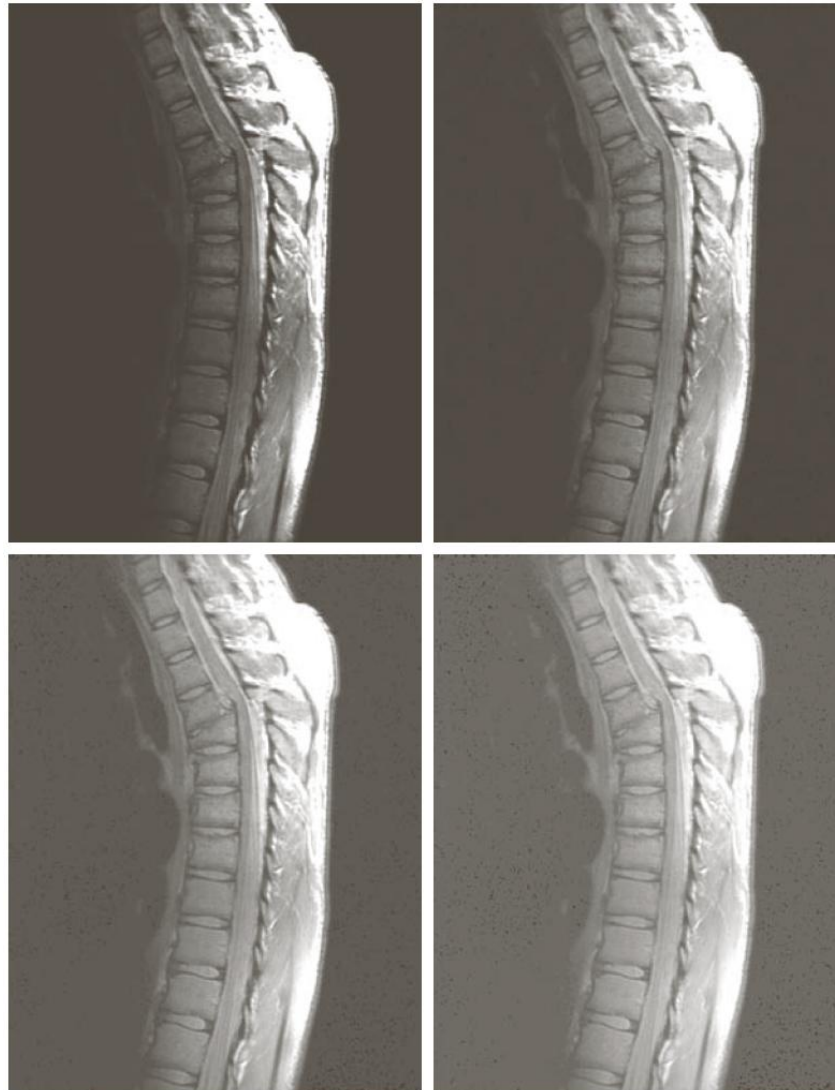


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a	b
c	d

**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.)





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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.)

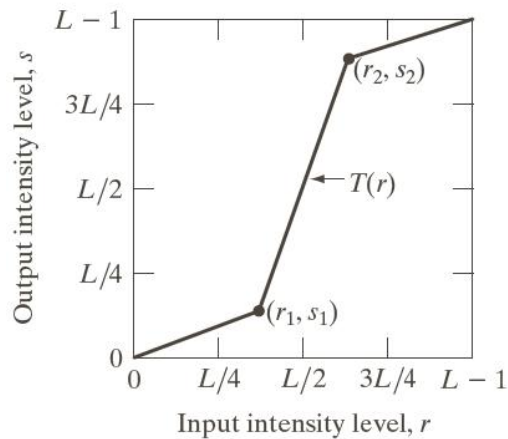


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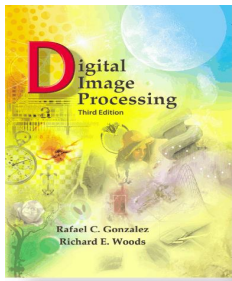
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a	b
c	d

**FIGURE 3.10**

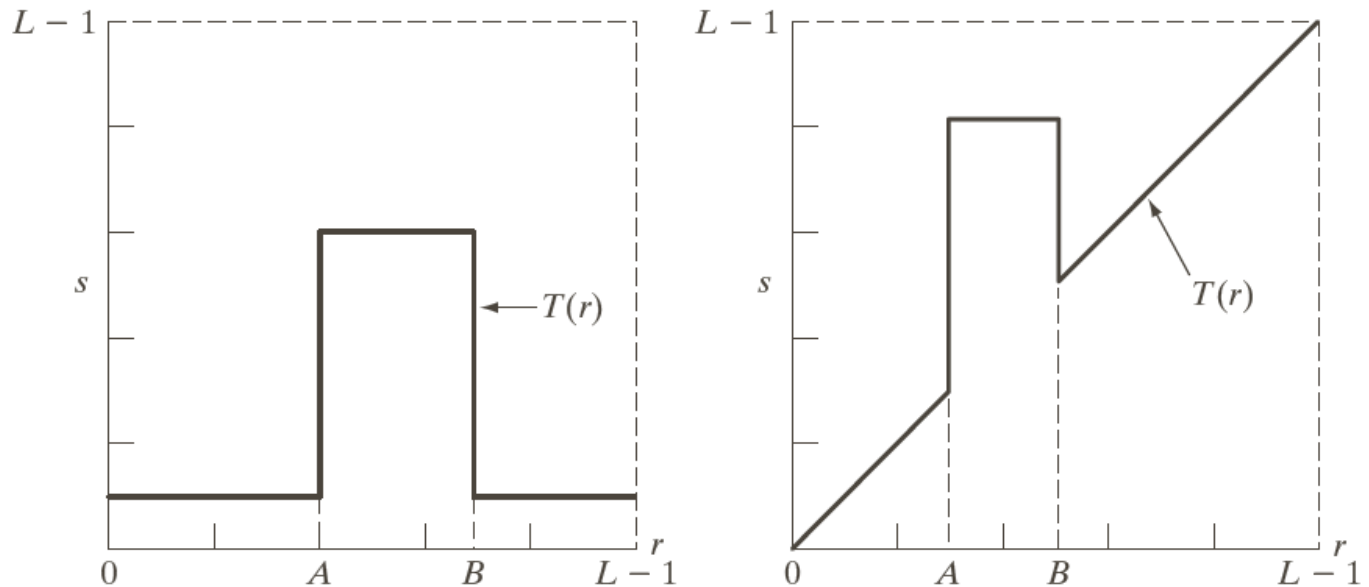
Contrast stretching.  
(a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)



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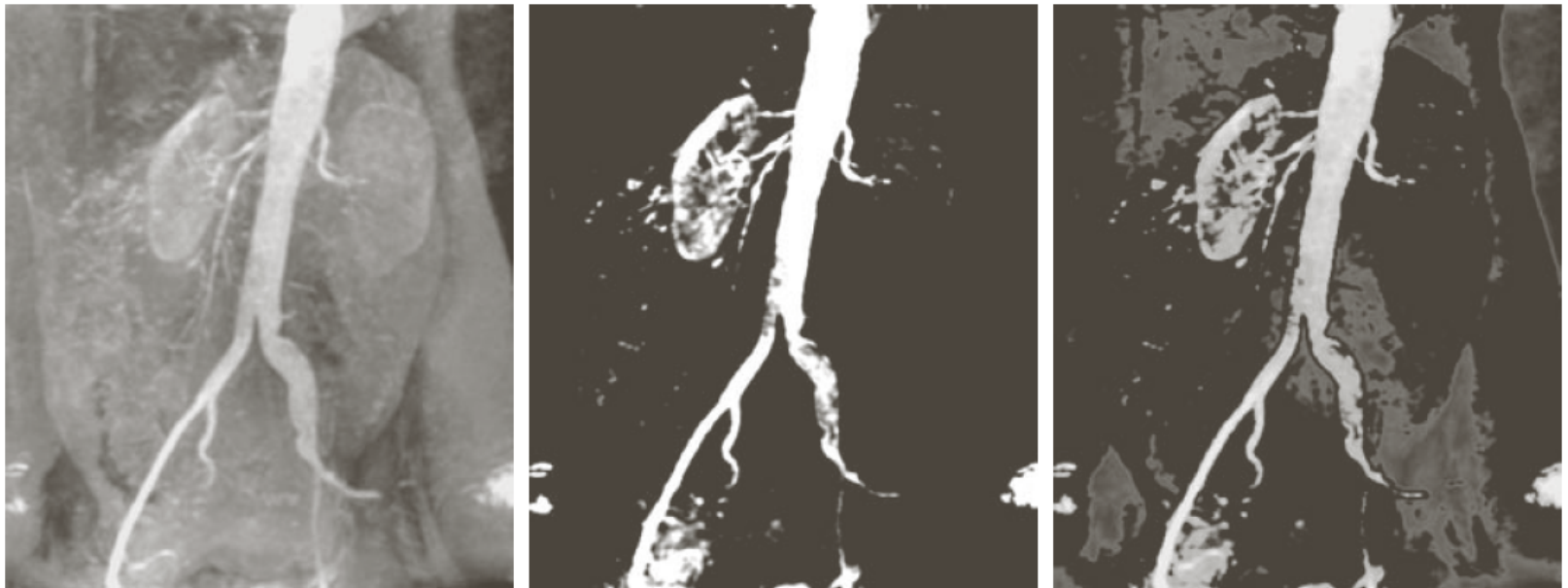
a b

**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.





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a b c

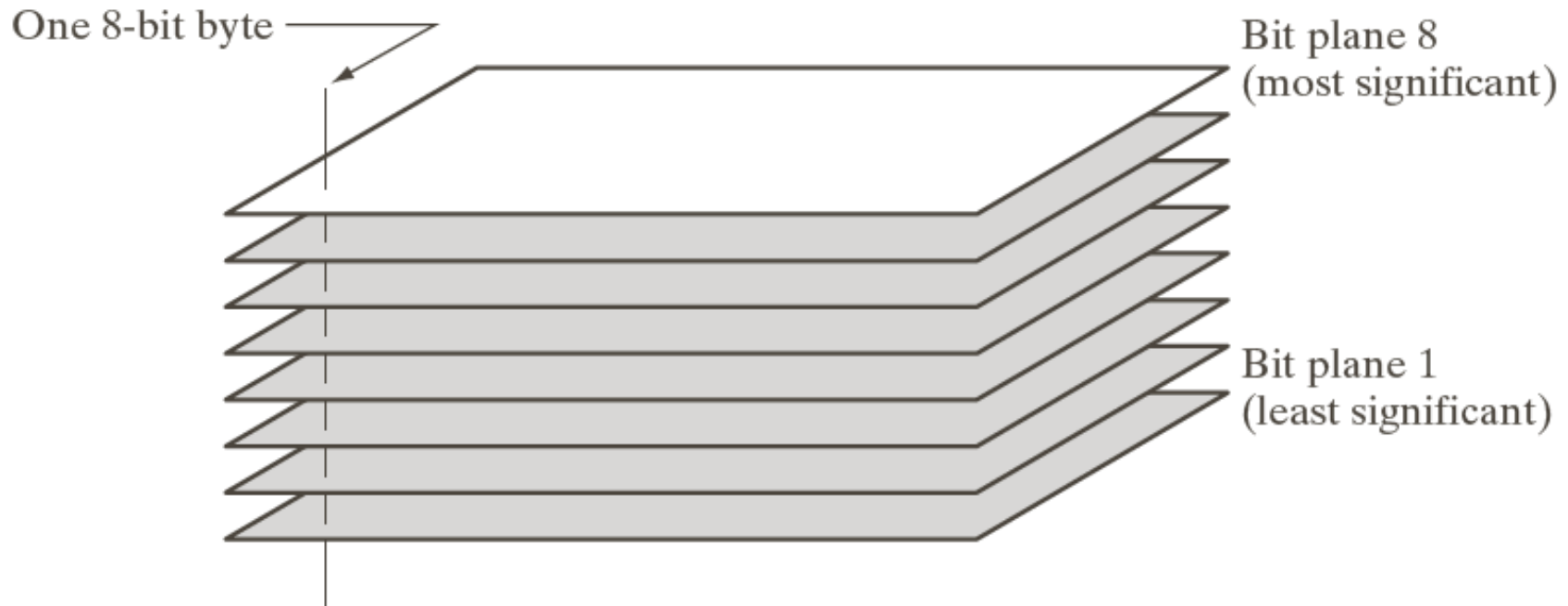
**FIGURE 3.12** (a) Aortic angiogram. (b) Result of using a slicing transformation of the type illustrated in Fig. 3.11(a), with the range of intensities of interest selected in the upper end of the gray scale. (c) Result of using the transformation in Fig. 3.11(b), with the selected area set to black, 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.)



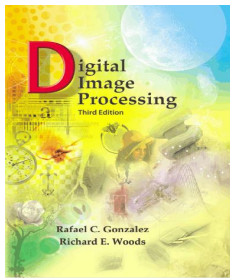


## Chapter 3

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**FIGURE 3.13**  
Bit-plane  
representation of  
an 8-bit image.



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a	b	c
d	e	f
g	h	i

**FIGURE 3.14** (a) An 8-bit gray-scale image of size  $500 \times 1192$  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.



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**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).



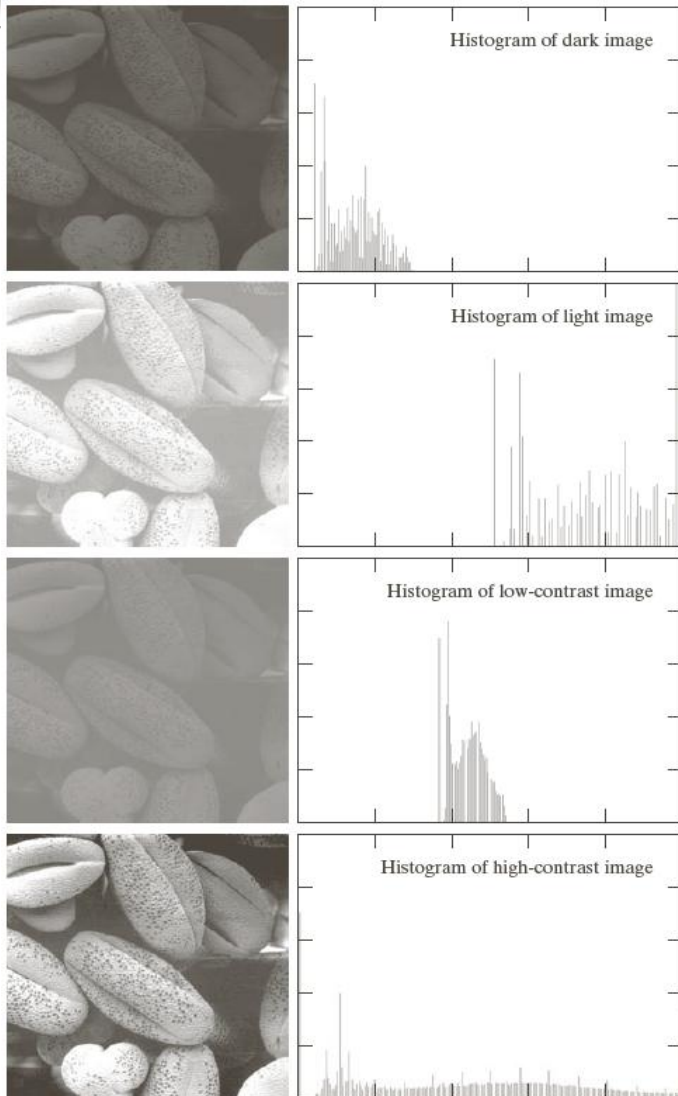


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**FIGURE 3.16** Four basic image types: dark, light, low contrast, high contrast, and their corresponding histograms.

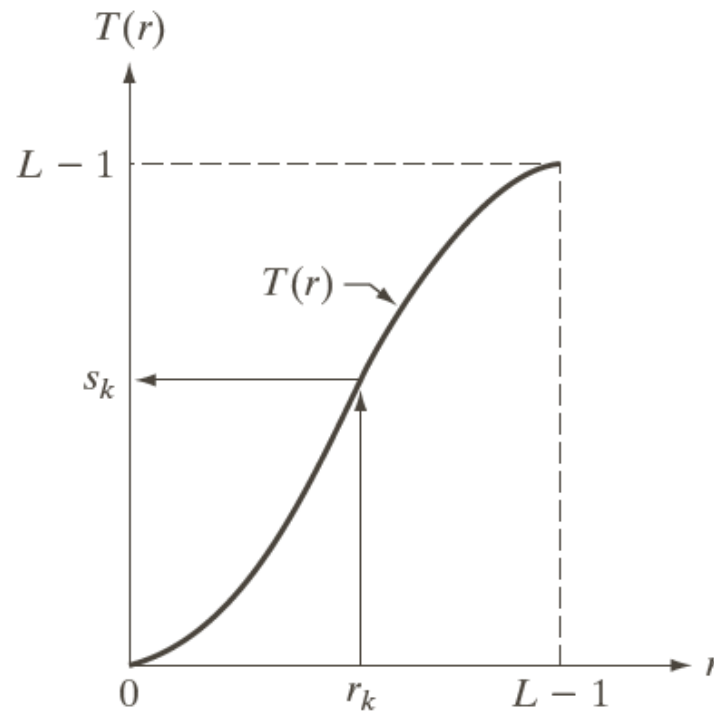
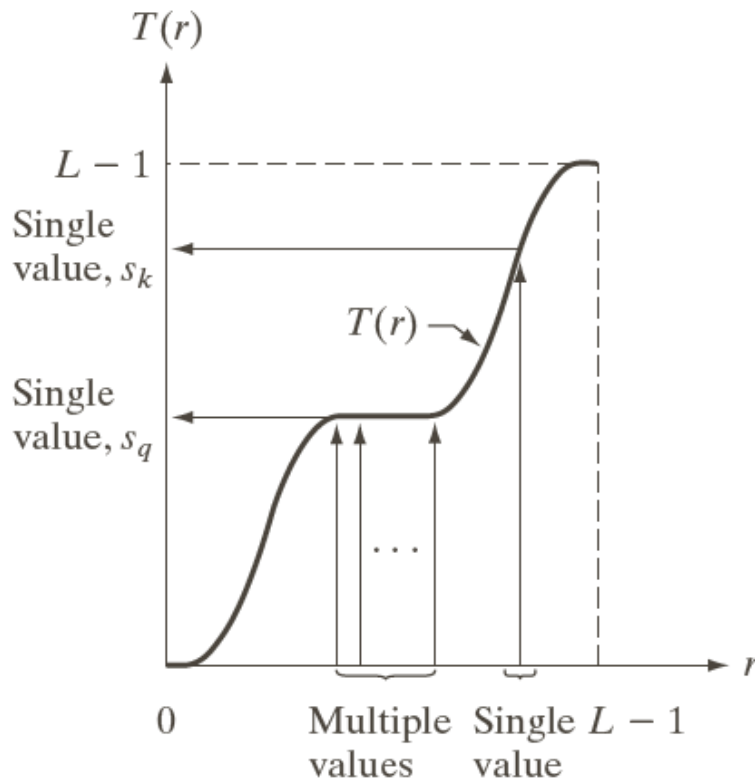


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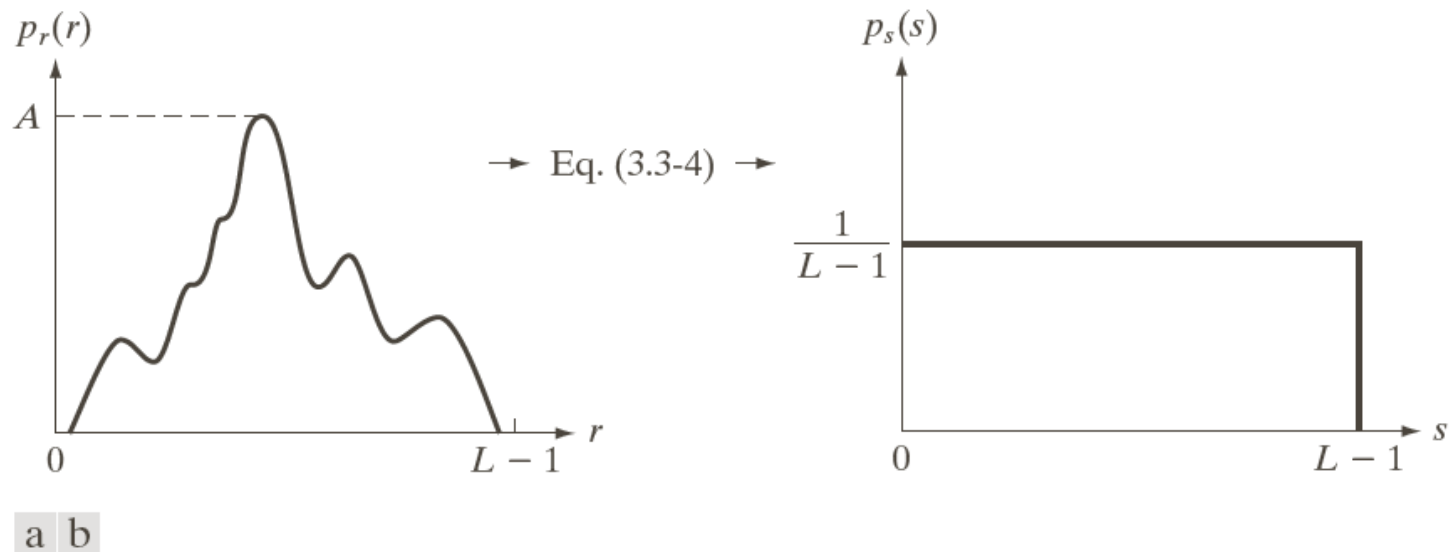


a b

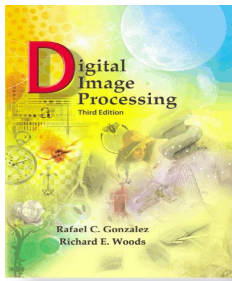
**FIGURE 3.17**  
(a) Monotonically increasing function, showing how multiple values can map to a single value.  
(b) Strictly monotonically increasing function. This is a one-to-one mapping, both ways.



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**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.



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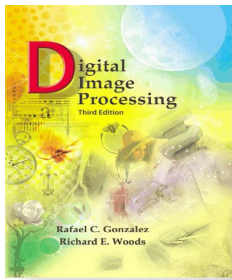
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$r_k$	$n_k$	$p_r(r_k) = n_k/MN$
$r_0 = 0$	790	0.19
$r_1 = 1$	1023	0.25
$r_2 = 2$	850	0.21
$r_3 = 3$	656	0.16
$r_4 = 4$	329	0.08
$r_5 = 5$	245	0.06
$r_6 = 6$	122	0.03
$r_7 = 7$	81	0.02

**TABLE 3.1**

Intensity distribution and histogram values for a 3-bit,  $64 \times 64$  digital image.

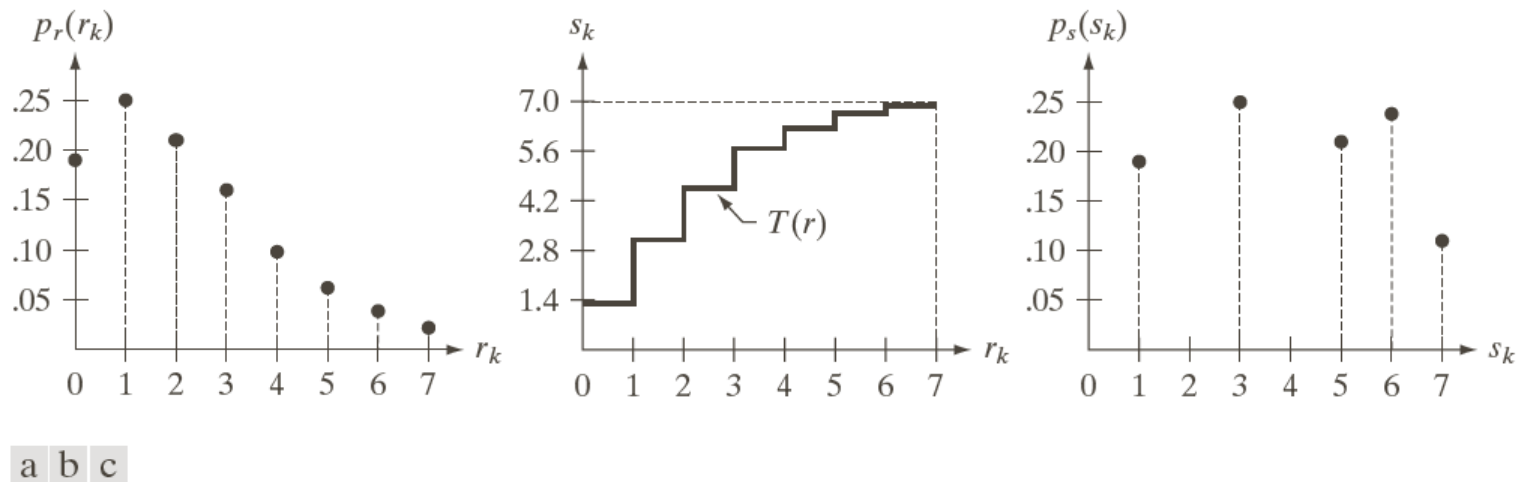


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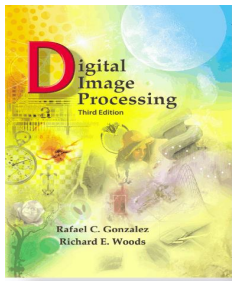
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**FIGURE 3.19** Illustration of histogram equalization of a 3-bit (8 intensity levels) image. (a) Original histogram. (b) Transformation function. (c) Equalized histogram.

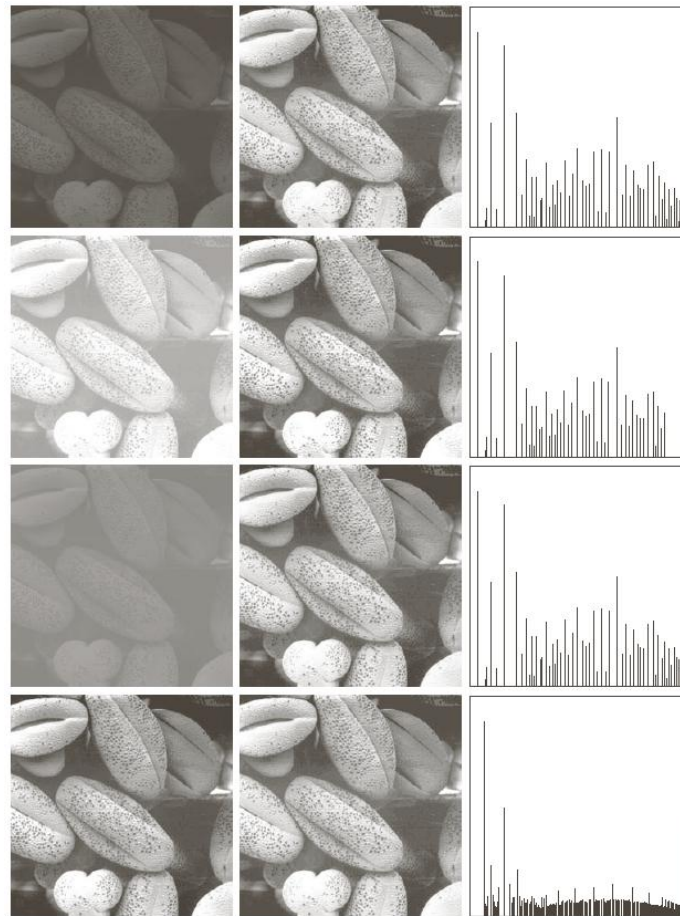


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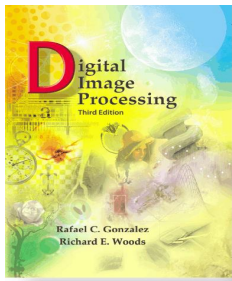
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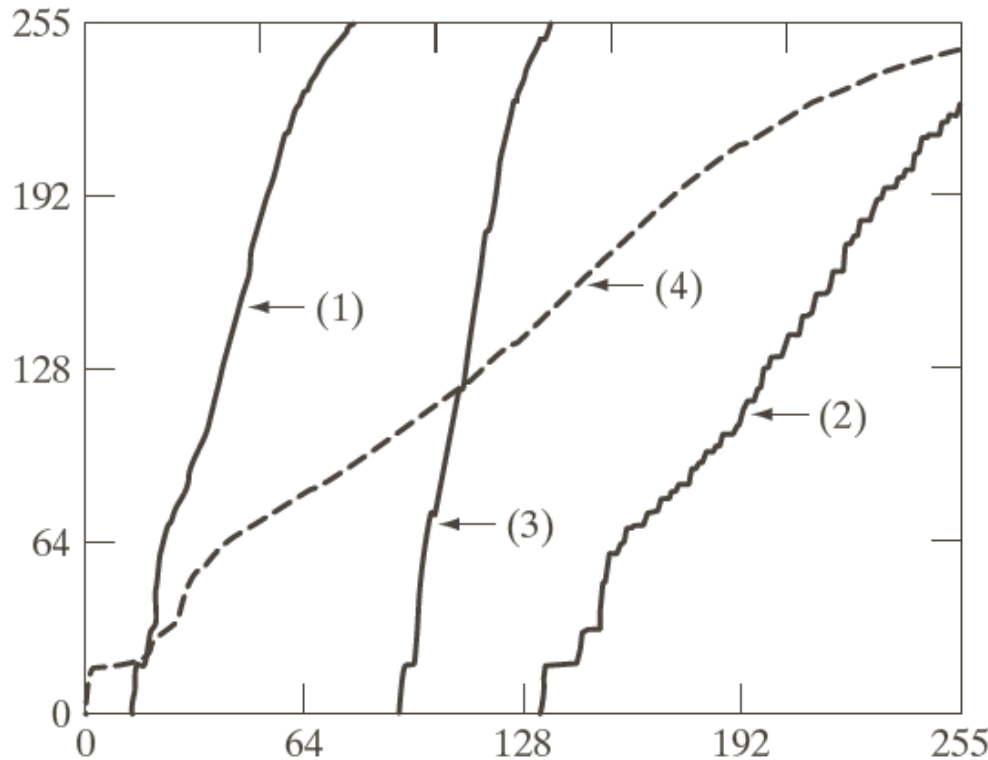
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**FIGURE 3.20** Left column: images from Fig. 3.16. Center column: corresponding histogram-equalized images. Right column: histograms of the images in the center column.

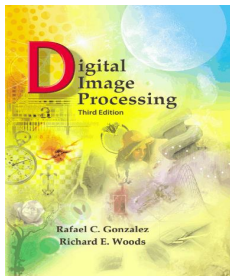


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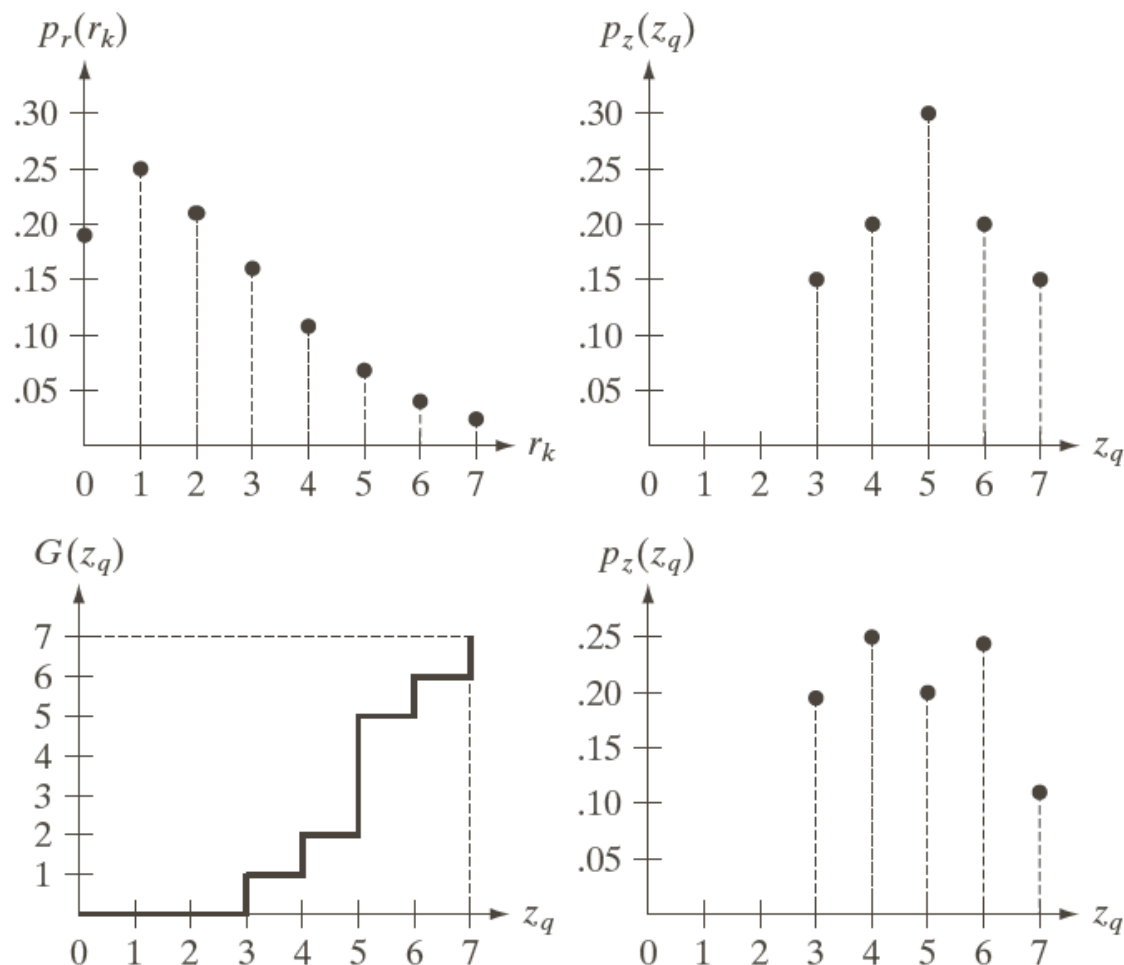


**FIGURE 3.21**  
Transformation functions for histogram equalization. Transformations (1) through (4) were obtained from the histograms of the images (from top to bottom) in the left column of Fig. 3.20 using Eq. (3.3-8).





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a	b
c	d

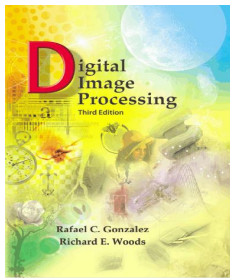
**FIGURE 3.22**

(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).



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$z_q$	Specified $p_z(z_q)$	Actual $p_z(z_k)$
$z_0 = 0$	0.00	0.00
$z_1 = 1$	0.00	0.00
$z_2 = 2$	0.00	0.00
$z_3 = 3$	0.15	0.19
$z_4 = 4$	0.20	0.25
$z_5 = 5$	0.30	0.21
$z_6 = 6$	0.20	0.24
$z_7 = 7$	0.15	0.11

**TABLE 3.2**

Specified and actual histograms (the values in the third column are from the computations performed in the body of Example 3.8).

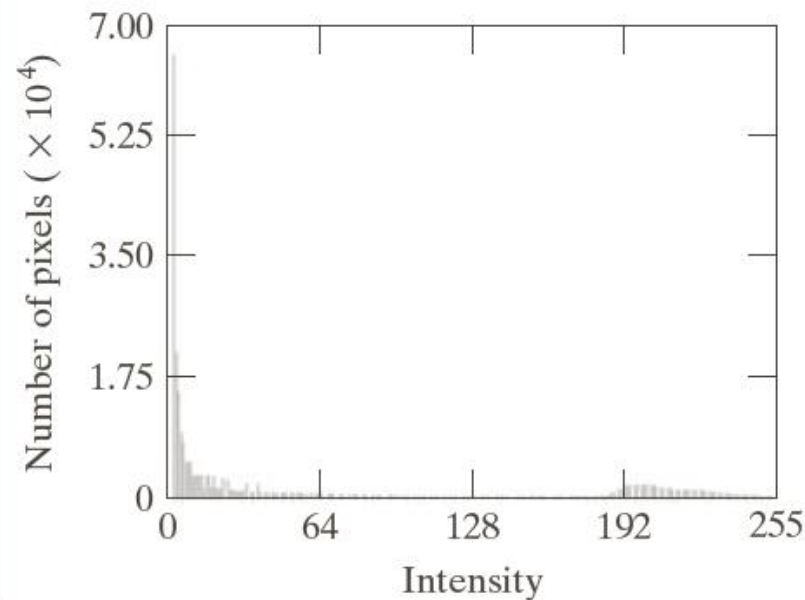
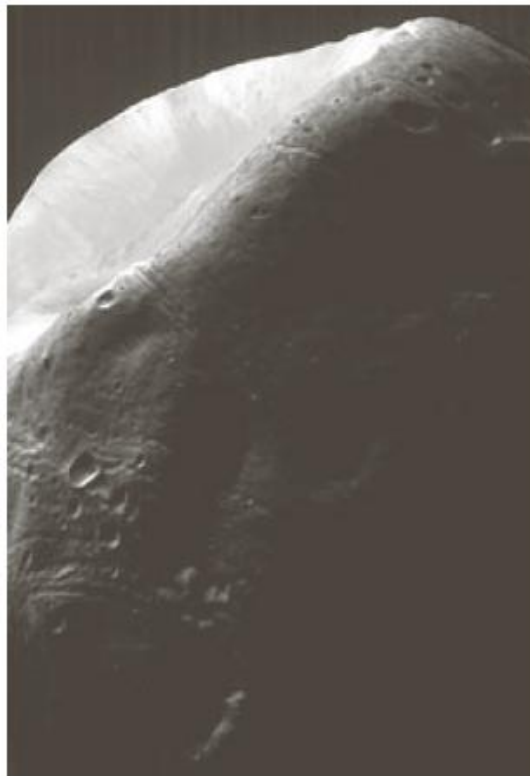


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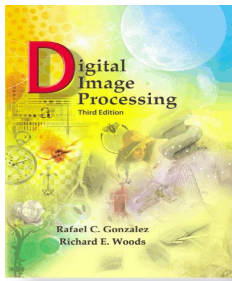
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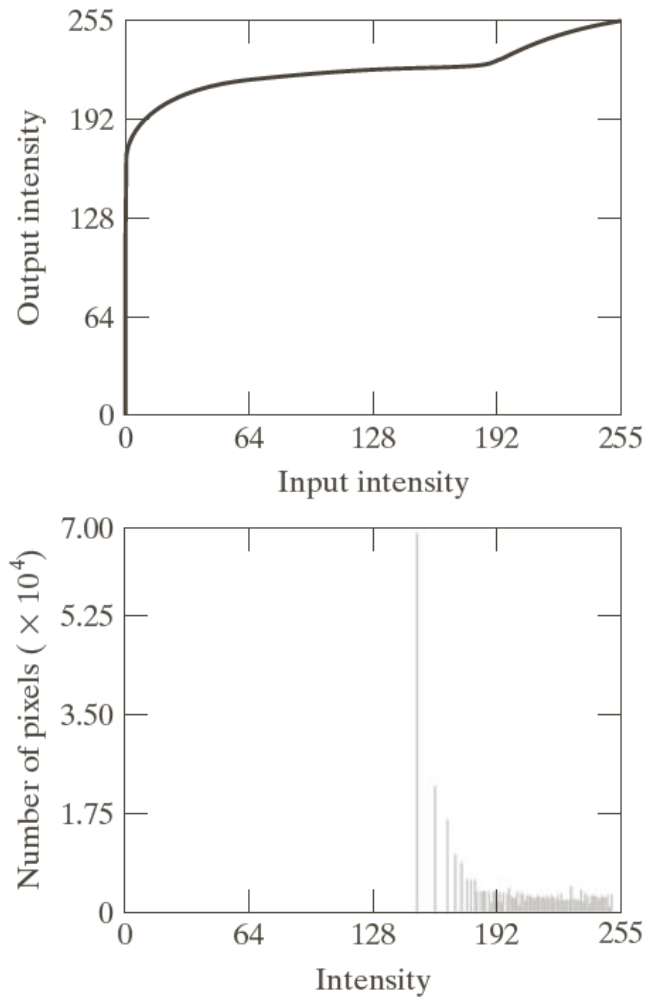


a b

**FIGURE 3.23**  
(a) Image of the Mars moon Phobos taken by NASA's *Mars Global Surveyor*.  
(b) Histogram. (Original image courtesy of NASA.)



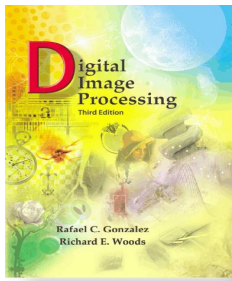
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a b  
c

**FIGURE 3.24**

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

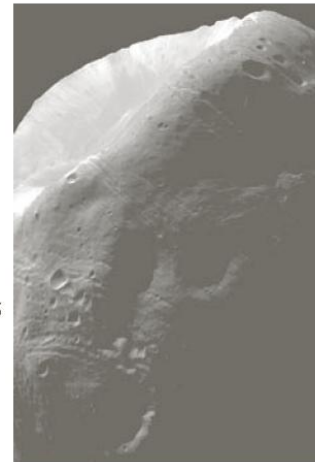
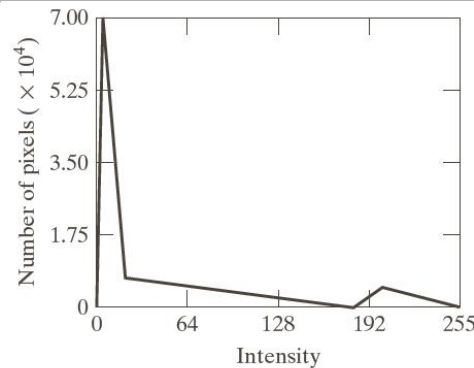


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a c  
b  
d

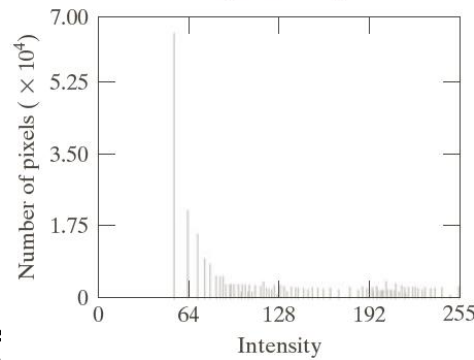
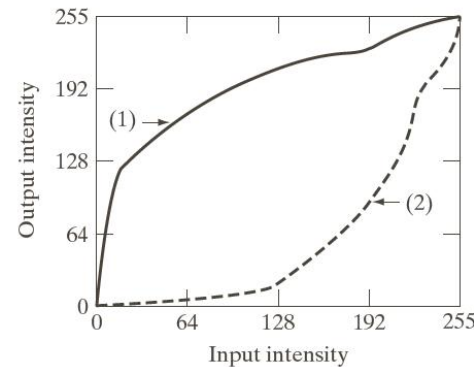
**FIGURE 3.25**

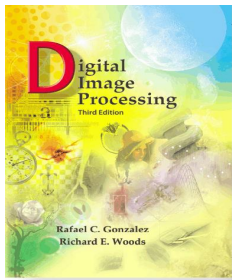
(a) Specified histogram.

(b) Transformations.

(c) Enhanced image using mappings from curve (2).

(d) Histogram of (c).



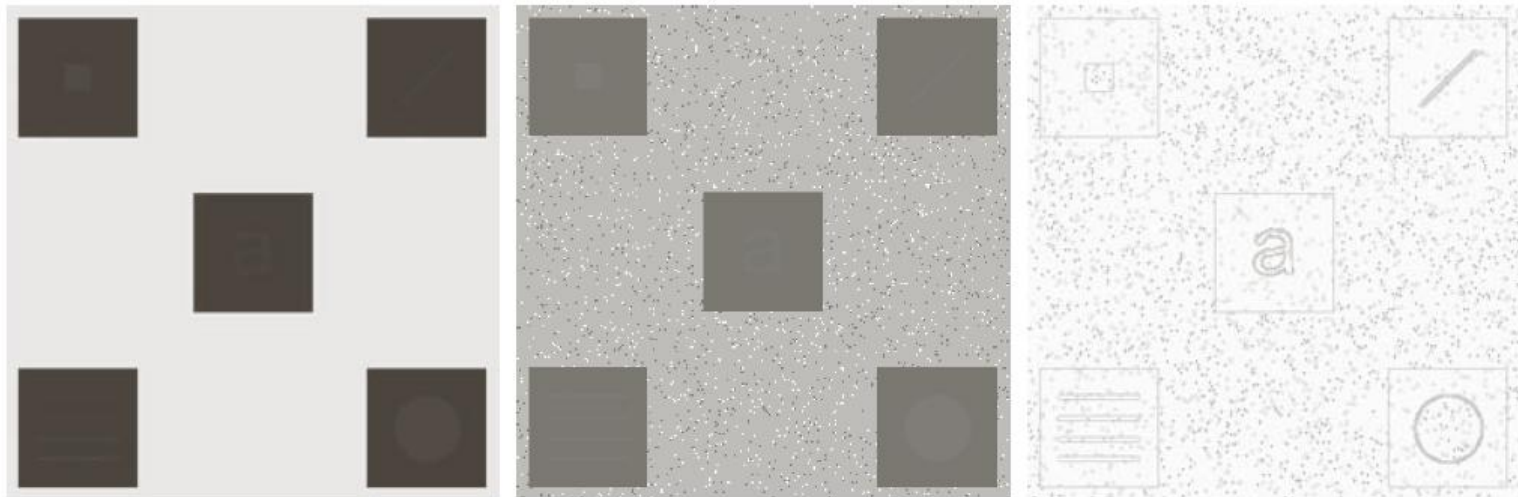


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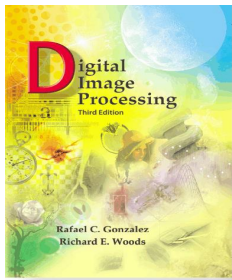
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a b c

**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  $3 \times 3$ .

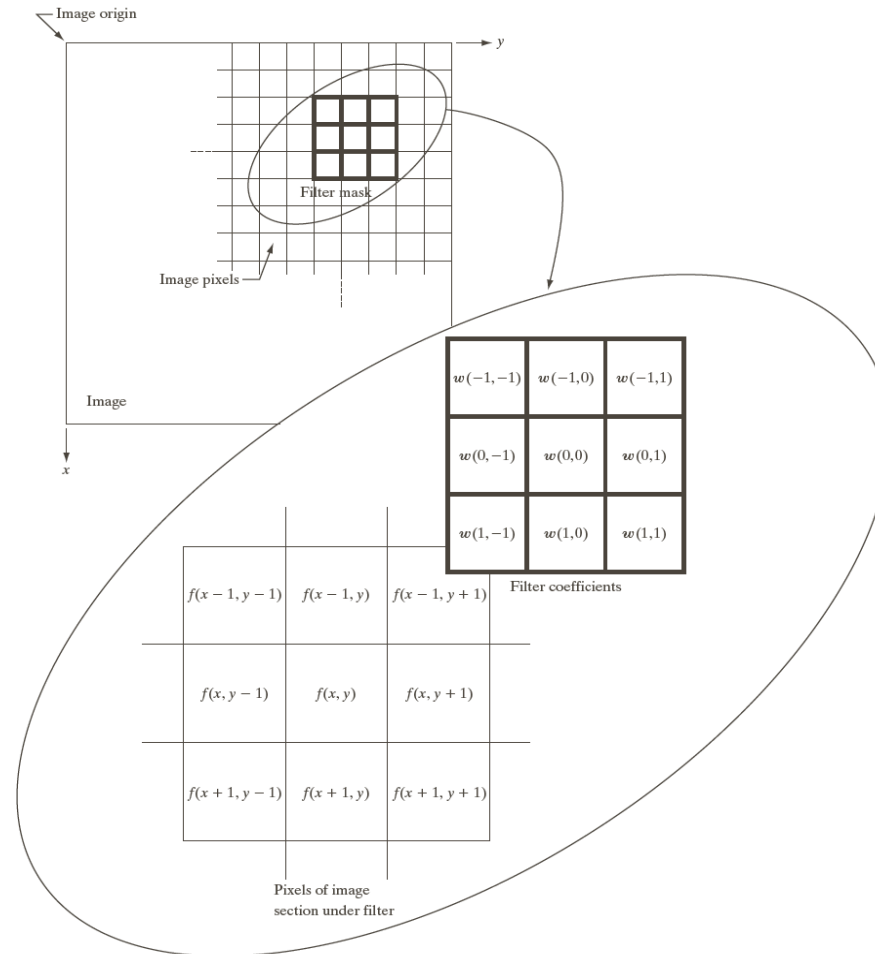


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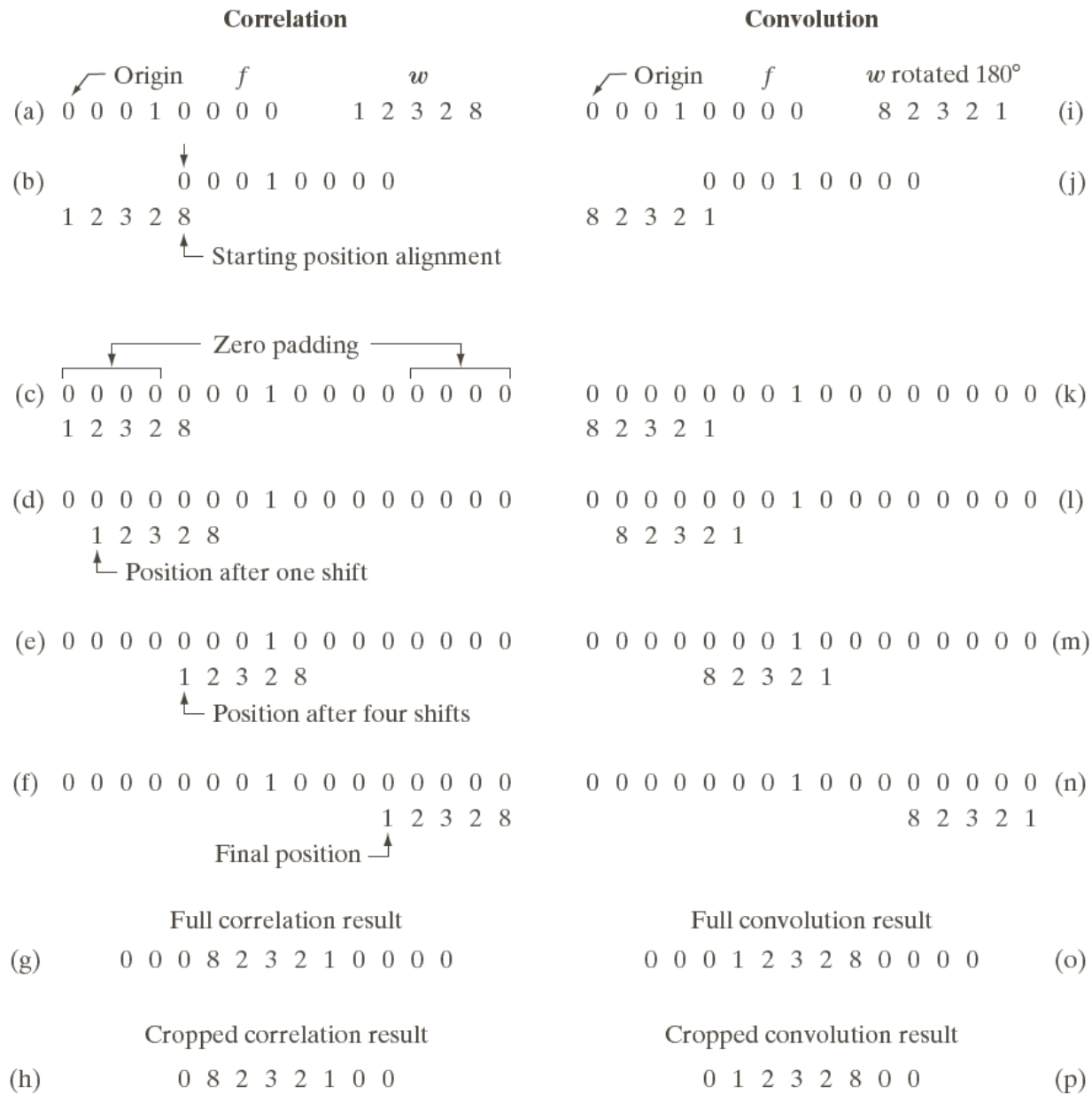
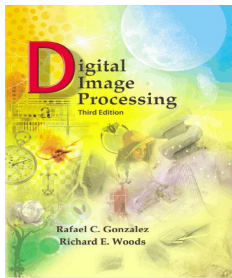
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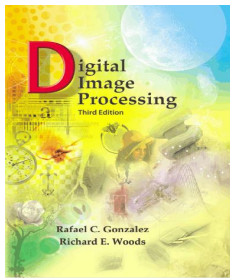


**FIGURE 3.28** The mechanics of linear spatial filtering using a  $3 \times 3$  filter mask. The form chosen to denote the coordinates of the filter mask coefficients simplifies writing expressions for linear filtering.





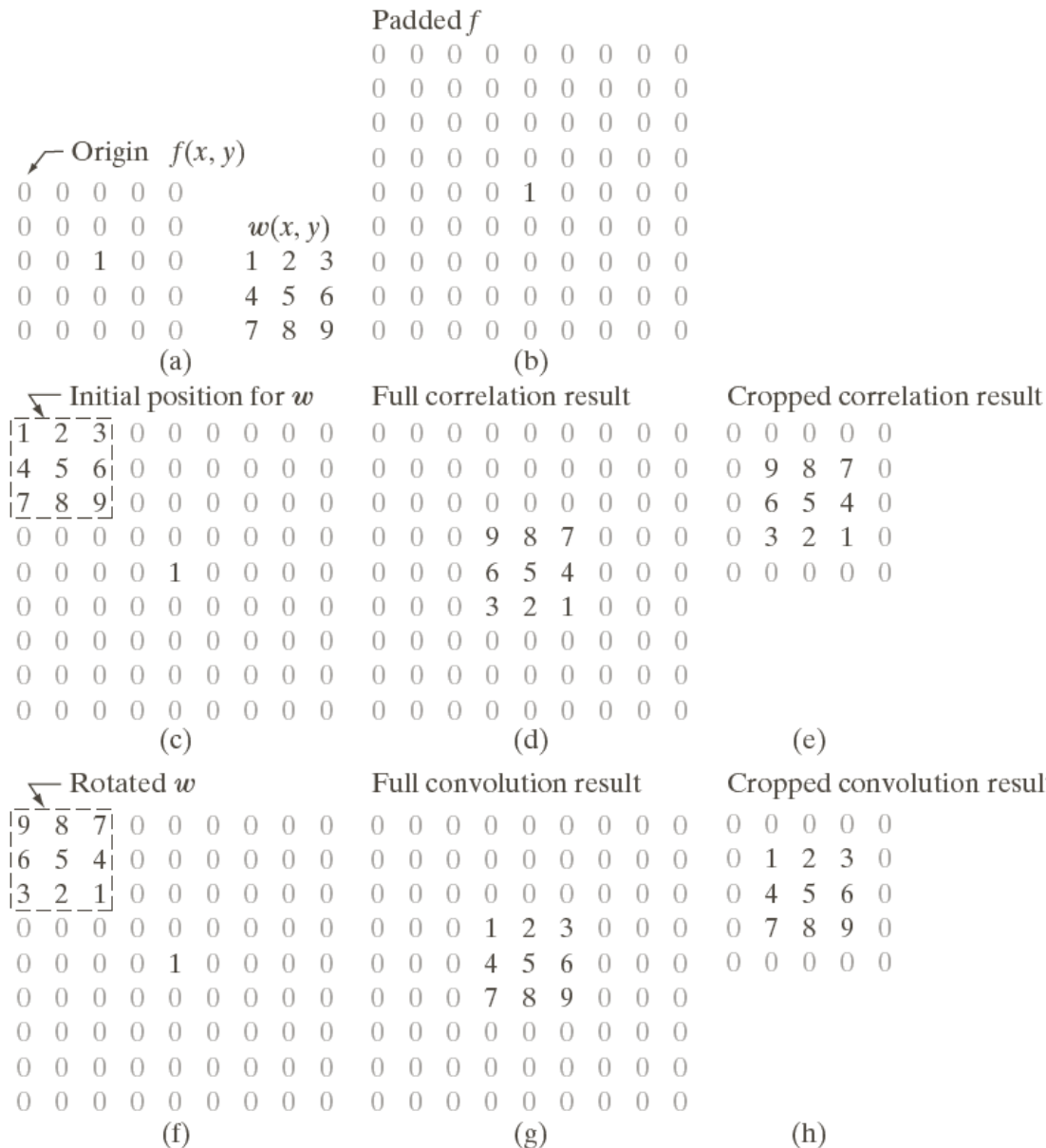
**FIGURE 3.29** Illustration of 1-D correlation and convolution of a filter with a discrete unit impulse. Note that correlation and convolution are functions of *displacement*.



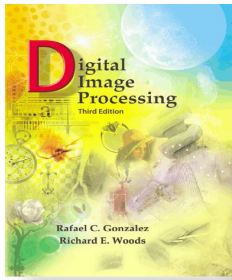
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**FIGURE 3.30** Correlation (middle row) and convolution (last row) of a 2-D discrete, unit impulse. The 0s are shown in gray to simplify visual analysis.



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$w_1$	$w_2$	$w_3$
$w_4$	$w_5$	$w_6$
$w_7$	$w_8$	$w_9$

**FIGURE 3.31**

Another representation of a general  $3 \times 3$  filter mask.



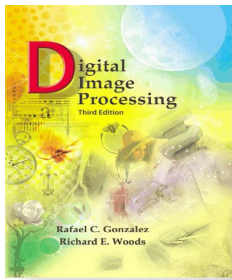
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$$\frac{1}{9} \times \begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

$$\frac{1}{16} \times \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline 2 & 4 & 2 \\ \hline 1 & 2 & 1 \\ \hline \end{array}$$

a b

**FIGURE 3.32** Two  $3 \times 3$  smoothing (averaging) filter masks. The constant multiplier in front of each mask is equal to 1 divided by the sum of the values of its coefficients, as is required to compute an average.

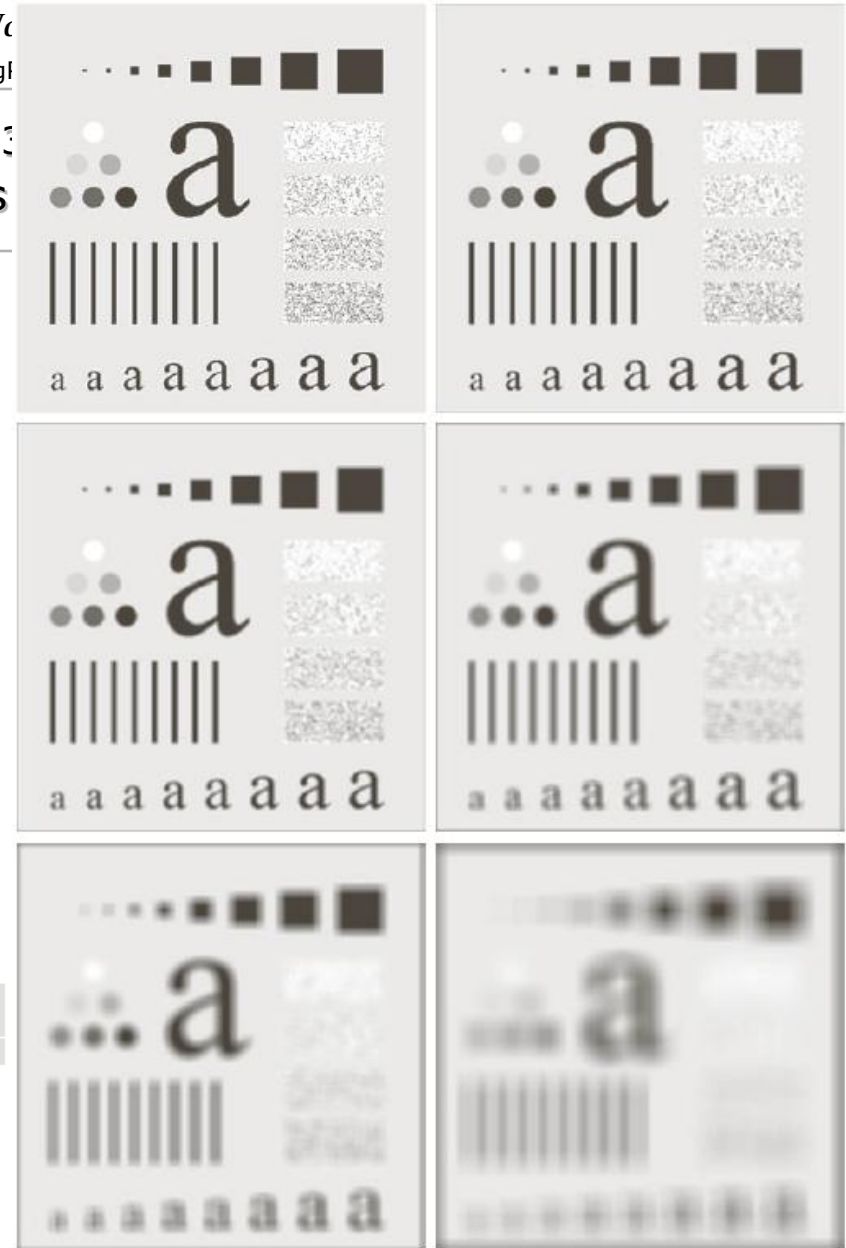


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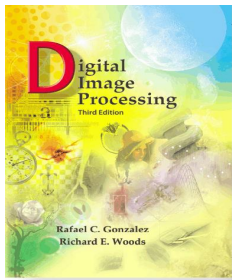
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## Chapter 3 Intensity Transformations



**FIGURE 3.33** (a) Original image, of size  $500 \times 500$  pixels. (b)–(f) Results of smoothing with square averaging filter masks of sizes  $m = 3, 5, 9, 15$ , and  $35$ , respectively. The black squares at the top are of sizes  $3, 5, 9, 15, 25, 35, 45$ , and  $55$  pixels, respectively; their borders are  $25$  pixels apart. The letters at the bottom range in size from  $10$  to  $24$  points, in increments of  $2$  points; the large letter at the top is  $60$  points. The vertical bars are  $5$  pixels wide and  $100$  pixels high; their separation is  $20$  pixels. The diameter of the circles is  $25$  pixels, and their borders are  $15$  pixels apart; their intensity levels range from  $0\%$  to  $100\%$  black in increments of  $20\%$ . The background of the image is  $10\%$  black. The noisy rectangles are of size  $50 \times 120$  pixels.

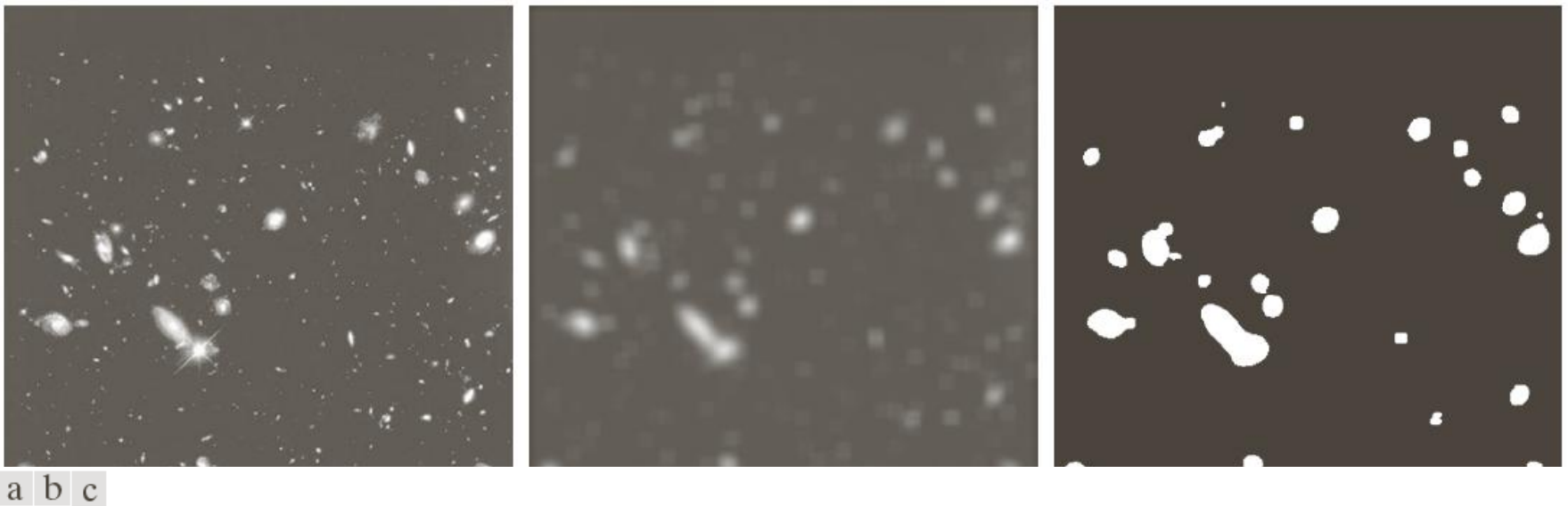


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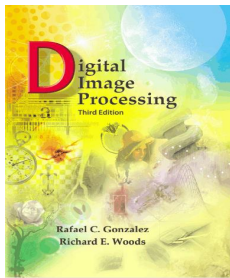
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## Chapter 3 Intensity Transformations & Spatial Filtering



**FIGURE 3.34** (a) Image of size  $528 \times 485$  pixels from the Hubble Space Telescope. (b) Image filtered with a  $15 \times 15$  averaging mask. (c) Result of thresholding (b). (Original image courtesy of NASA.)



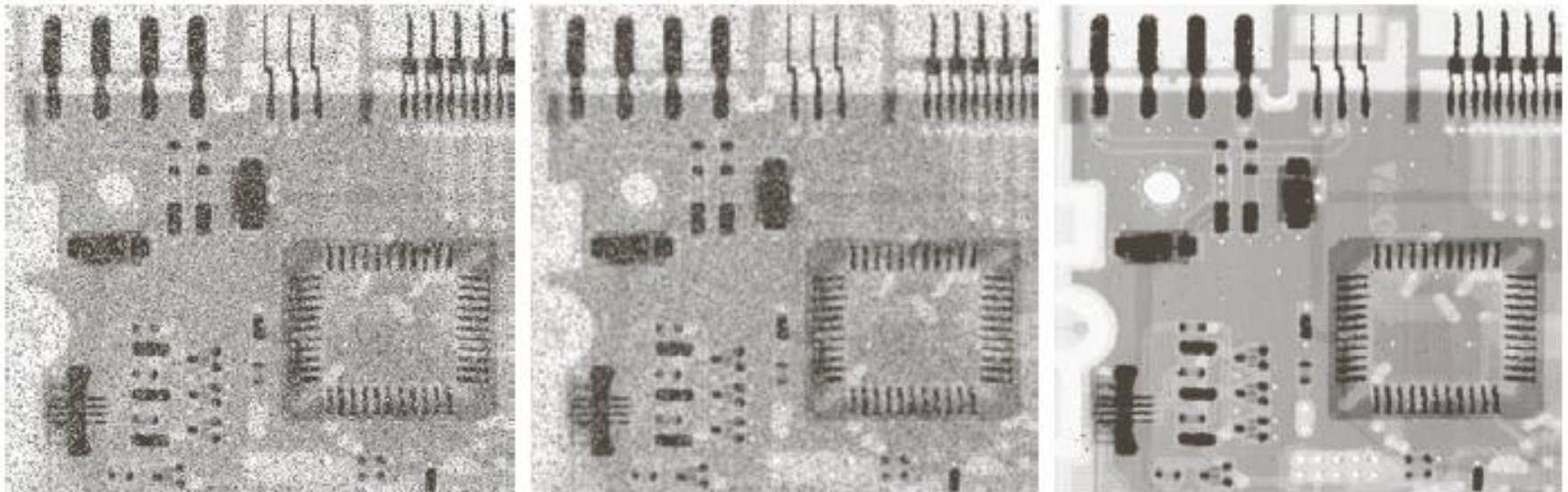


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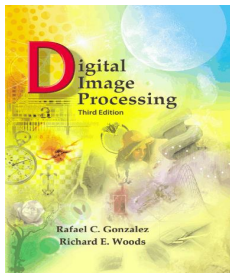
## Chapter 3 Intensity Transformations & Spatial Filtering



a b c

**FIGURE 3.35** (a) X-ray image of circuit board corrupted by salt-and-pepper noise. (b) Noise reduction with a  $3 \times 3$  averaging mask. (c) Noise reduction with a  $3 \times 3$  median filter. (Original image courtesy of Mr. Joseph E. Pascente, Lixi, Inc.)



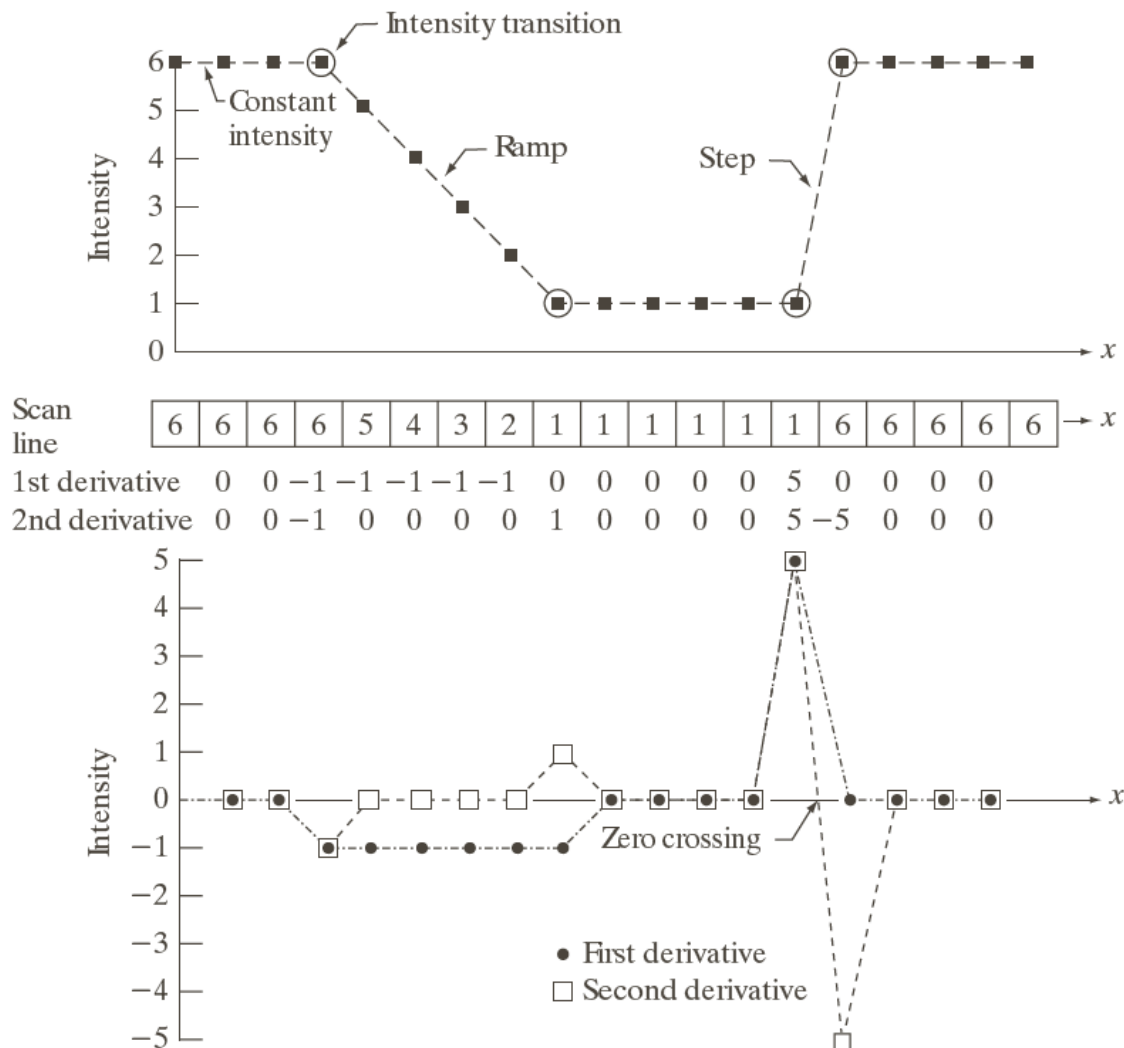


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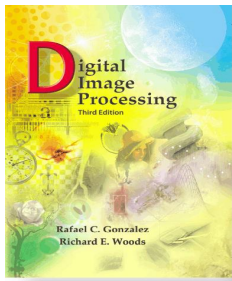
## Chapter 3 Intensity Transformations & Spatial Filtering



a  
b  
c

**FIGURE 3.36**

Illustration of the first and second derivatives of a 1-D digital function representing a section of a horizontal intensity profile from an image. In (a) and (c) data points are joined by dashed lines as a visualization aid.



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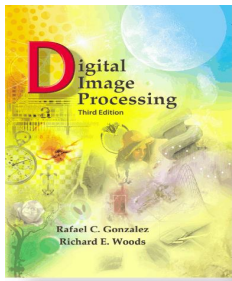
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0	1	0	1	1	1
1	-4	1	1	-8	1
0	1	0	1	1	1
0	-1	0	-1	-1	-1
-1	4	-1	-1	8	-1
0	-1	0	-1	-1	-1

a b  
c d

**FIGURE 3.37**

(a) Filter mask used to implement Eq. (3.6-6).  
(b) Mask used to implement an extension of this equation that includes the diagonal terms.  
(c) and (d) Two other implementations of the Laplacian found frequently in practice.

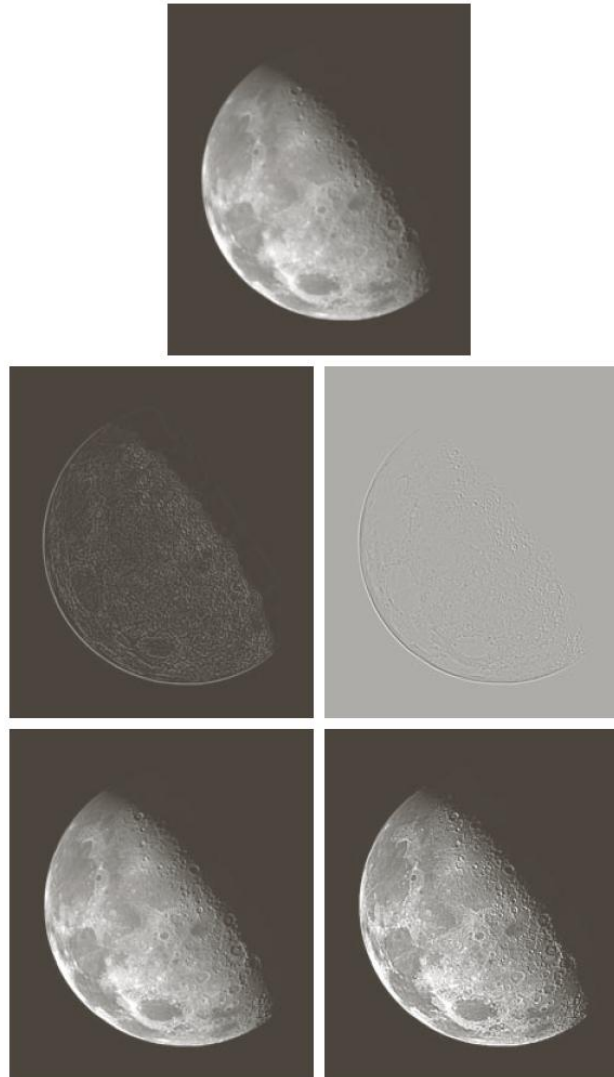


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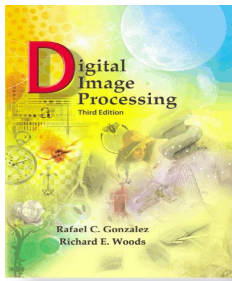
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**FIGURE 3.38**

(a) Blurred image of the North Pole of the moon.  
(b) Laplacian without scaling.  
(c) Laplacian with scaling.  
(d) Image sharpened using the mask in Fig. 3.37(a).  
(e) Result of using the mask in Fig. 3.37(b).  
(Original image courtesy of NASA.)

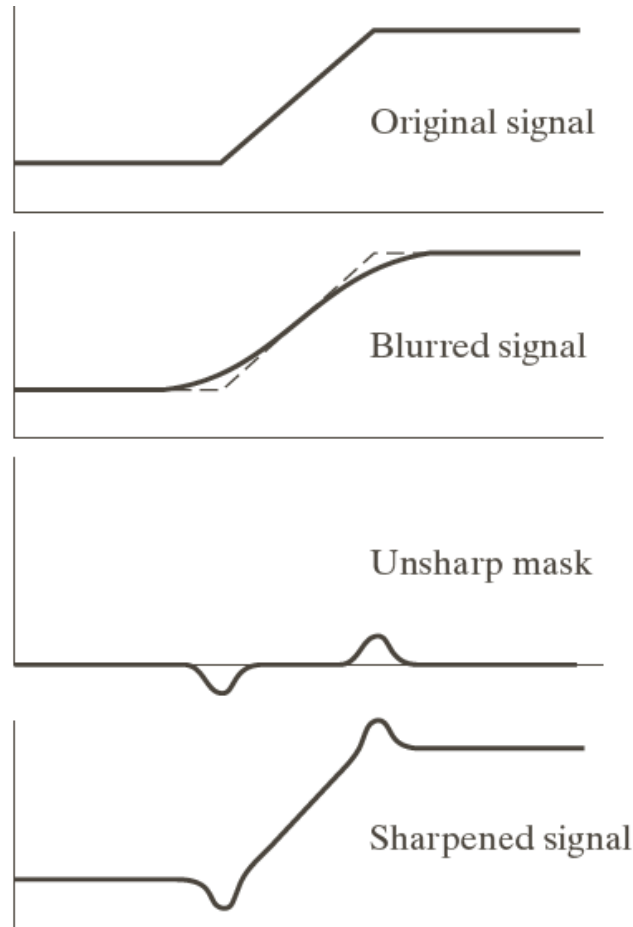


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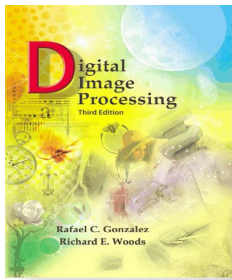
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## Chapter 3 Intensity Transformations & Spatial Filtering



a  
b  
c  
d

**FIGURE 3.39** 1-D illustration of the mechanics of unsharp masking. (a) Original signal. (b) Blurred signal with original shown dashed for reference. (c) Unsharp mask. (d) Sharpened signal, obtained by adding (c) to (a).



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a  
b  
c  
d  
e

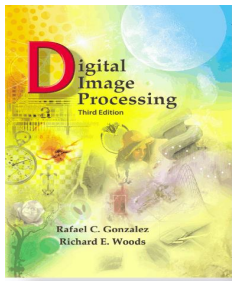
**FIGURE 3.40**

(a) Original image.

(b) Result of blurring with a Gaussian filter.

(c) Unsharp mask. (d) Result of using unsharp masking.

(e) Result of using highboost filtering.



## Chapter 3

# Intensity Transformations & Spatial Filtering

$z_1$	$z_2$	$z_3$
$z_4$	$z_5$	$z_6$
$z_7$	$z_8$	$z_9$

$-1$	$0$
$0$	$1$

$0$	$-1$
$1$	$0$

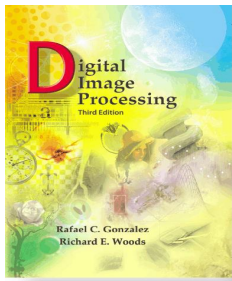
$-1$	$-2$	$-1$
$0$	$0$	$0$
$1$	$2$	$1$

$-1$	$0$	$1$
$-2$	$0$	$2$
$-1$	$0$	$1$

a	
b	c
d	e

**FIGURE 3.41**  
A  $3 \times 3$  region of an image (the  $z$ s are intensity values).  
(b)–(c) Roberts cross gradient operators.  
(d)–(e) Sobel operators. All the mask coefficients sum to zero, as expected of a derivative operator.



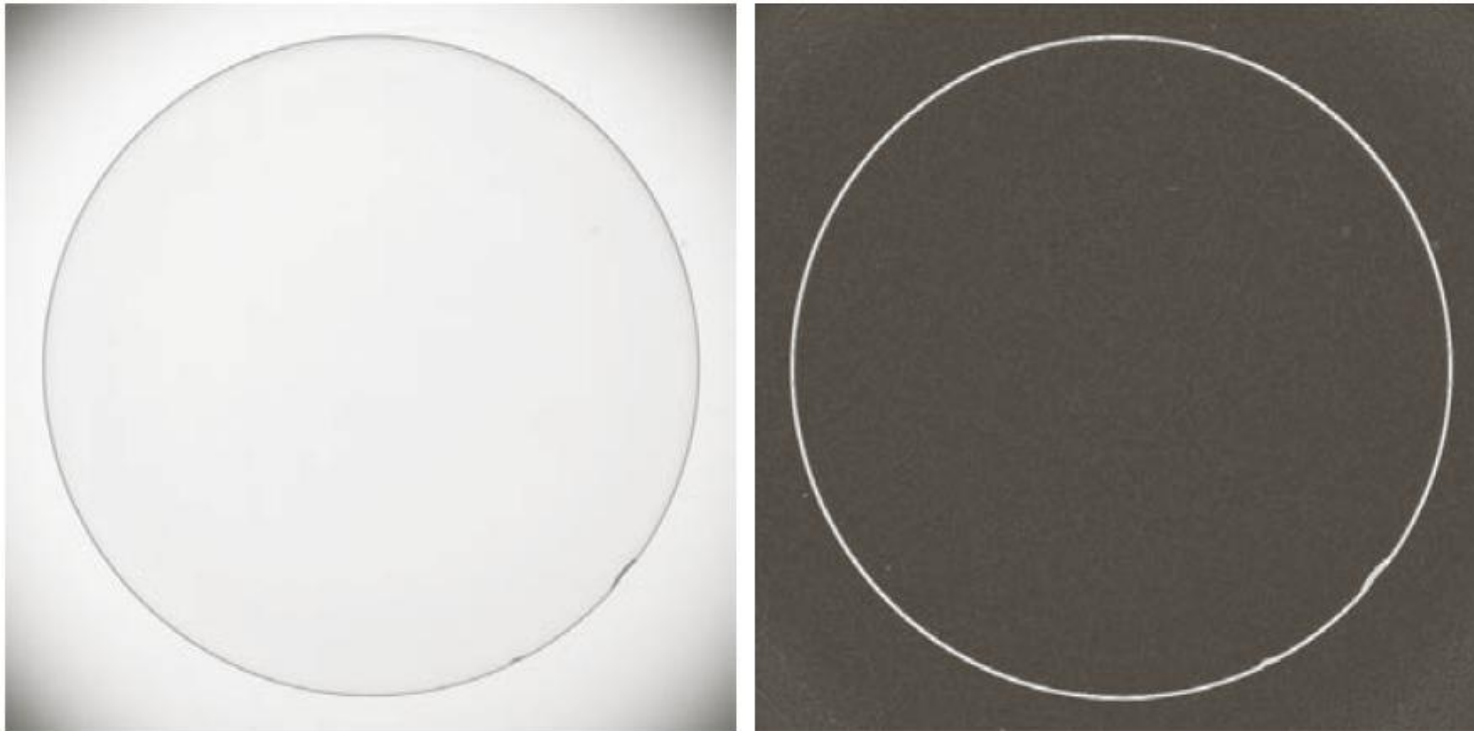


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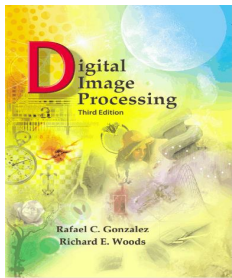
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a b

**FIGURE 3.42**  
(a) Optical image of contact lens (note defects on the boundary at 4 and 5 o'clock).  
(b) Sobel gradient.  
(Original image courtesy of Pete Sites, Perceptics Corporation.)

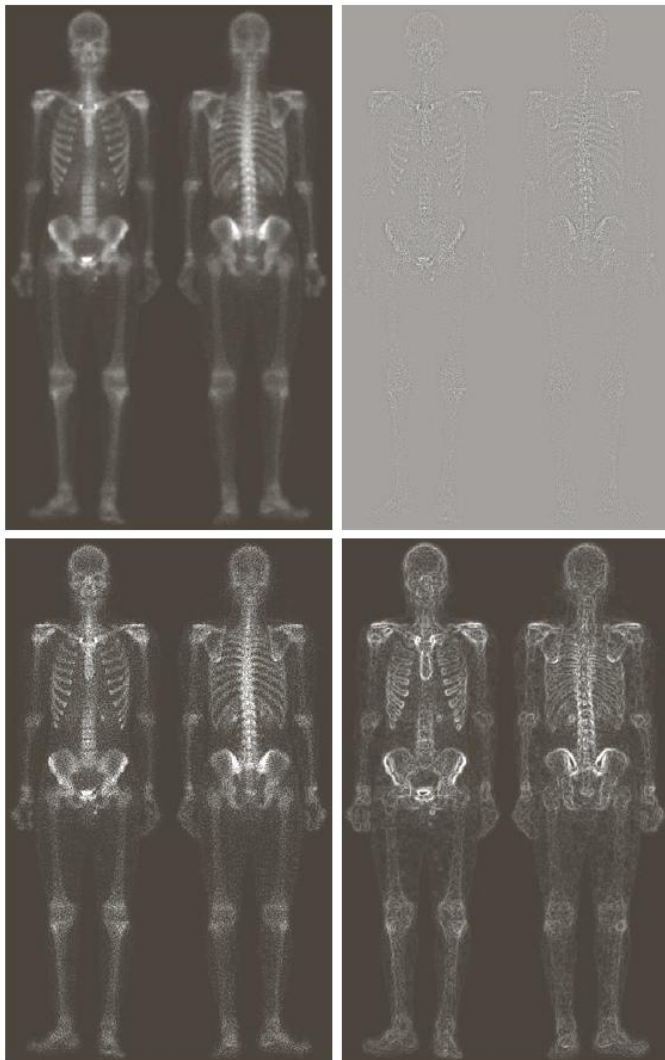


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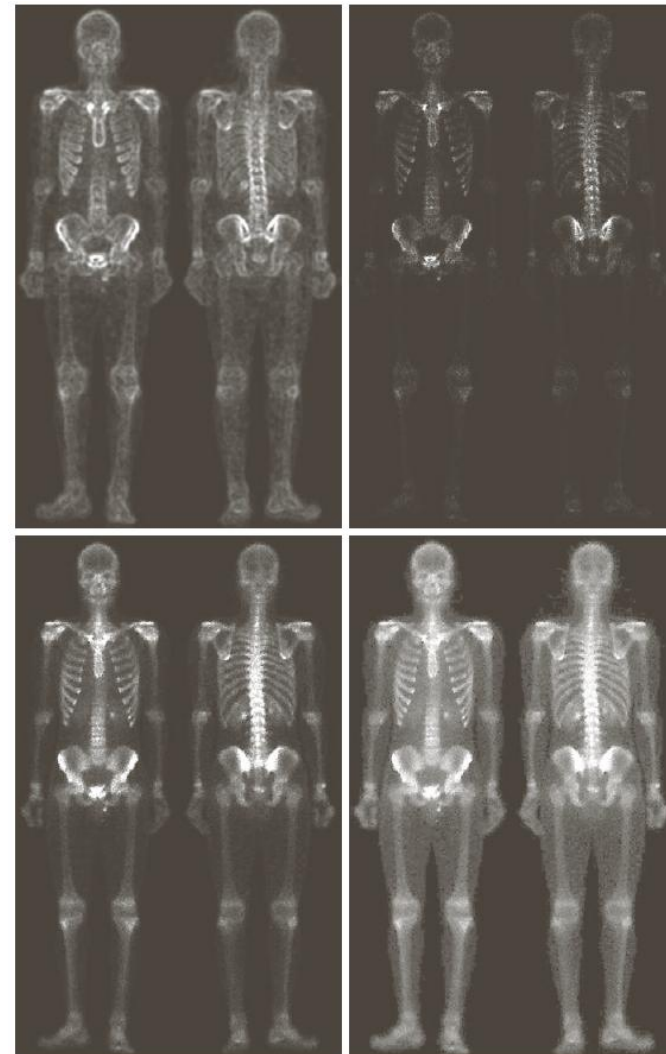
## Chapter 3 Intensity Transformations & Spatial Filtering



a b  
c d

**FIGURE 3.43**

(a) Image of whole body bone scan.  
(b) Laplacian of (a). (c) Sharpened image obtained by adding (a) and (b). (d) Sobel gradient of (a).



e f  
g h

**FIGURE 3.43**

(Continued)

(e) Sobel image smoothed with a  $5 \times 5$  averaging filter. (f) Mask image formed by the product of (c) and (e). (g) Sharpened image obtained by the sum of (a) and (f). (h) Final result obtained by applying a power-law transformation to (g). Compare (g) and (h) with (a). (Original image courtesy of G.E. Medical Systems.)