Image Enhancement

- Spatial Domain (第三章)
- Frequency Domain (第四章)

Chapter 3
Image Enhancement in the Spatial Domain

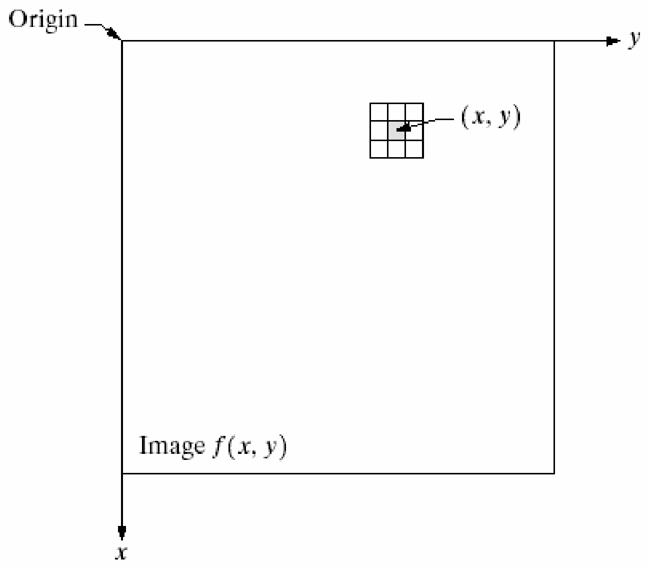

FIGURE 3.1 A 3 × 3 neighborhood about a point (x, y) in an image.

3.1 Transformation Function

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

f : original image

g : enhanced image

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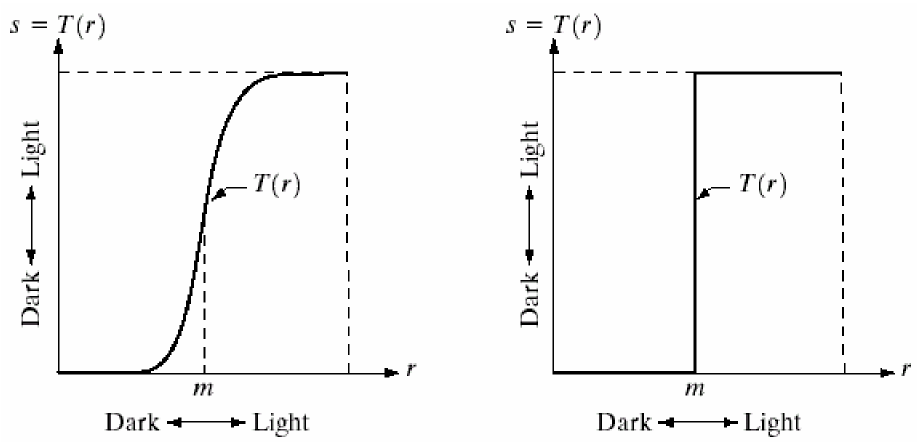
Image Enhancement in the Spatial Domain



a b

FIGURE 3.2 Gray-level transformation functions for contrast enhancement.

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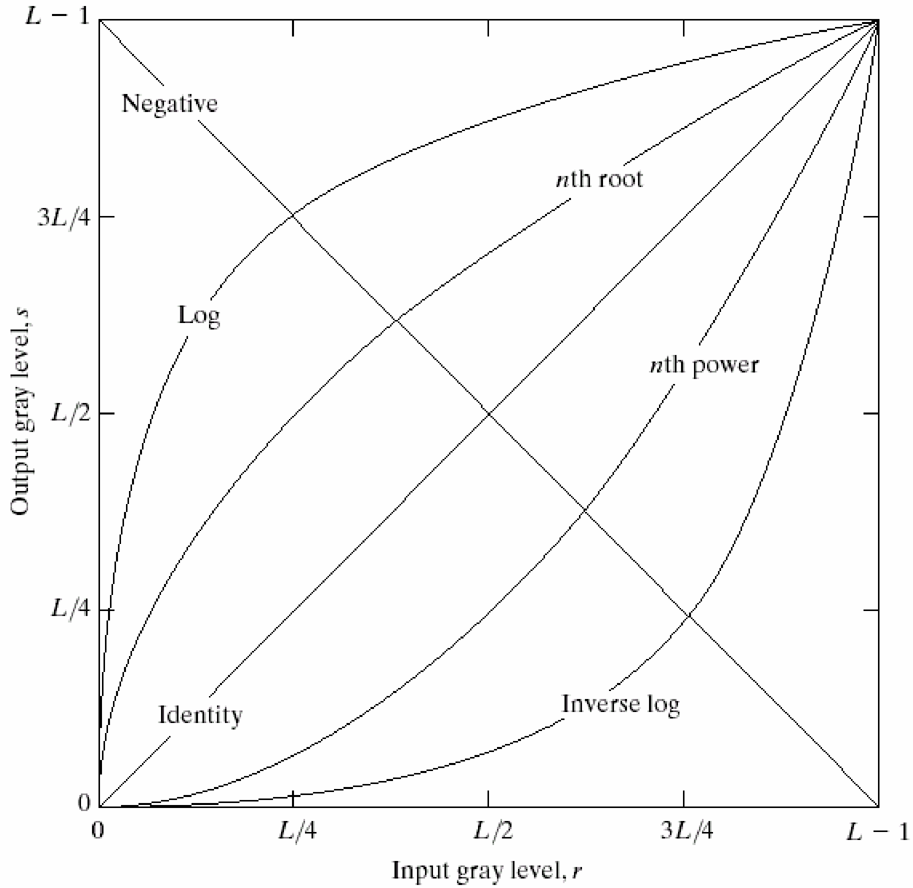
Image Enhancement in the Spatial Domain

FIGURE 3.3 Some basic gray-level transformation functions used for image enhancement.



Enchancement

- 1 . Negative :   slope = –1

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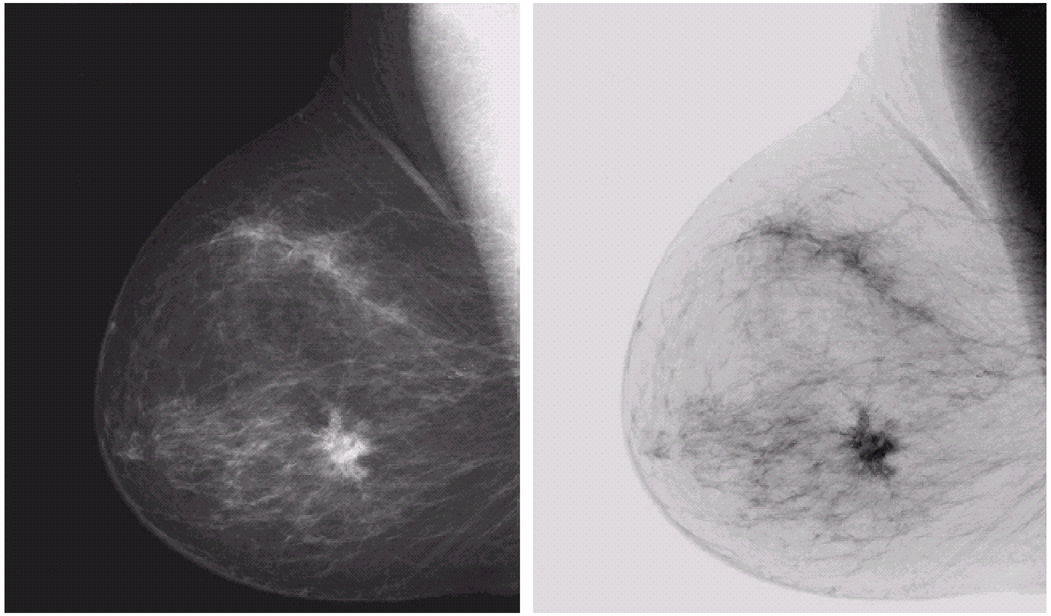

a b

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.)

Enchancement

- 2 . Log : $s = c * \log(1+r)$

T = log

c：常數

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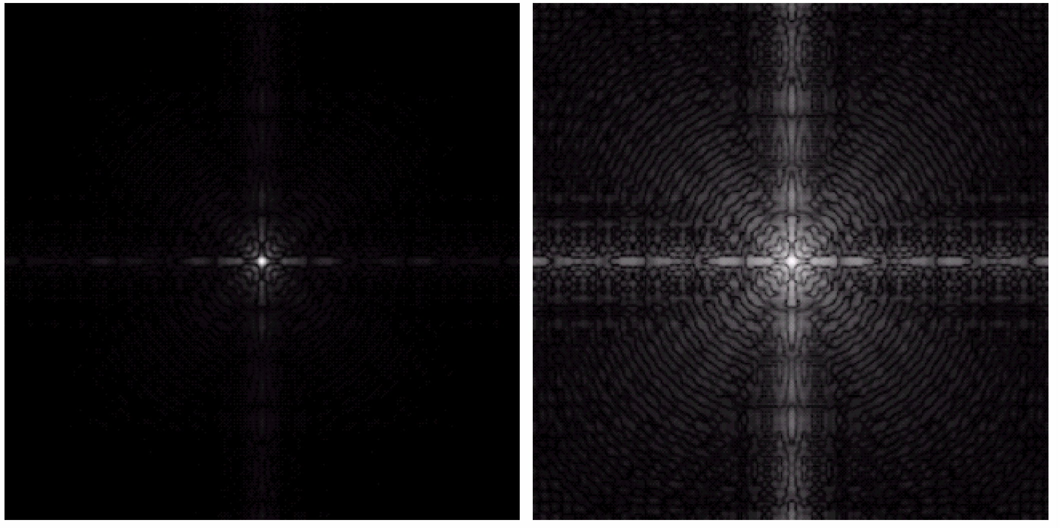
Image Enhancement in the Spatial Domain

a b

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



Enchancement

- 3 . $s = c\, r^{r}$

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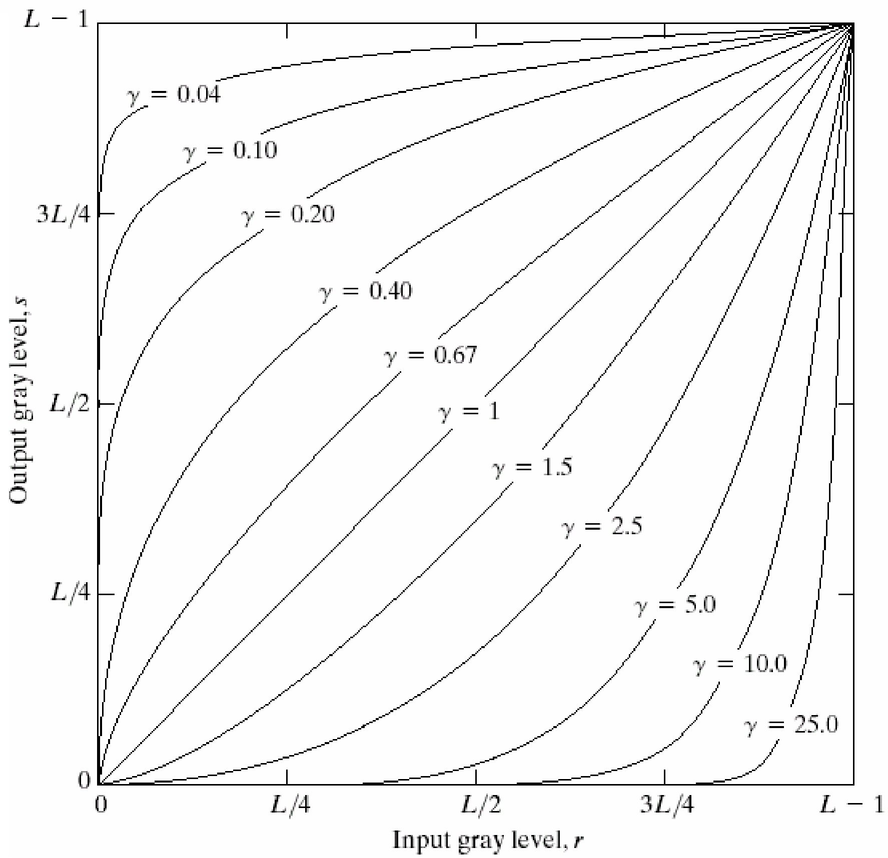

FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases).

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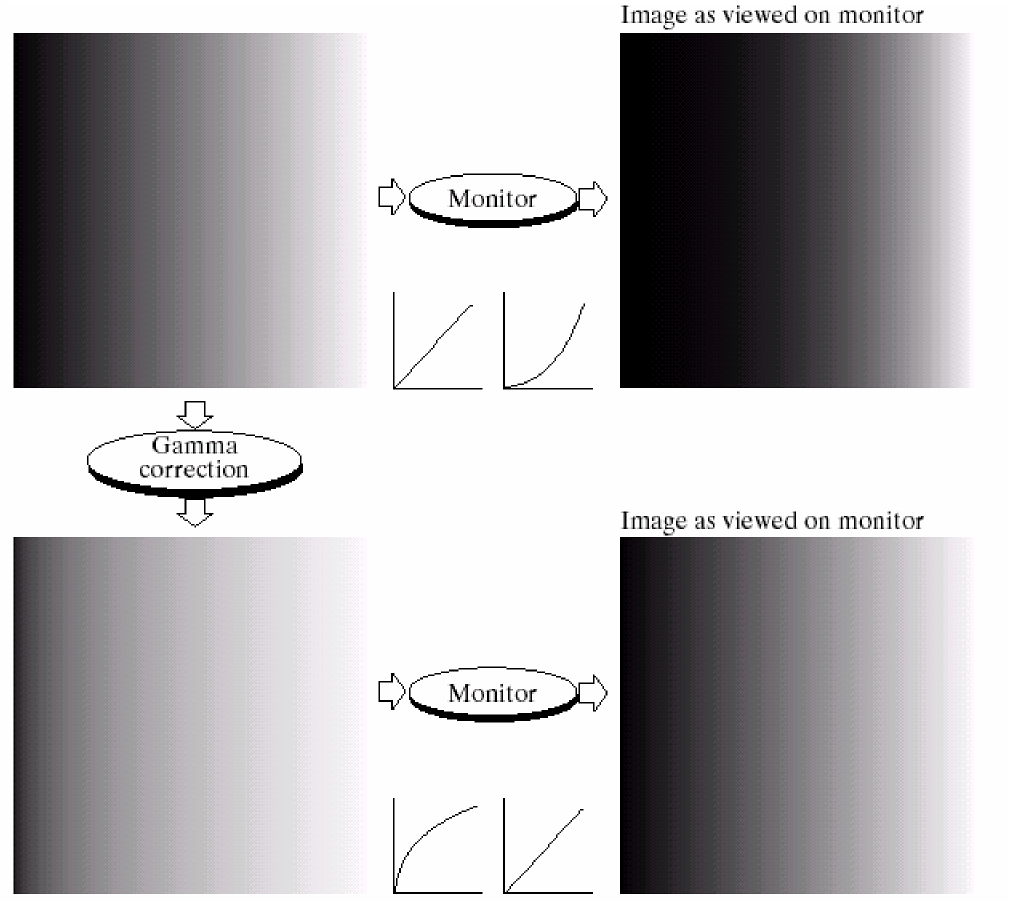

FIGURE 3.7 (a) Linear-wedge gray-scale image. (b) Response of monitor to linear wedge. (c) Gamma-corrected wedge. (d) Output of monitor.

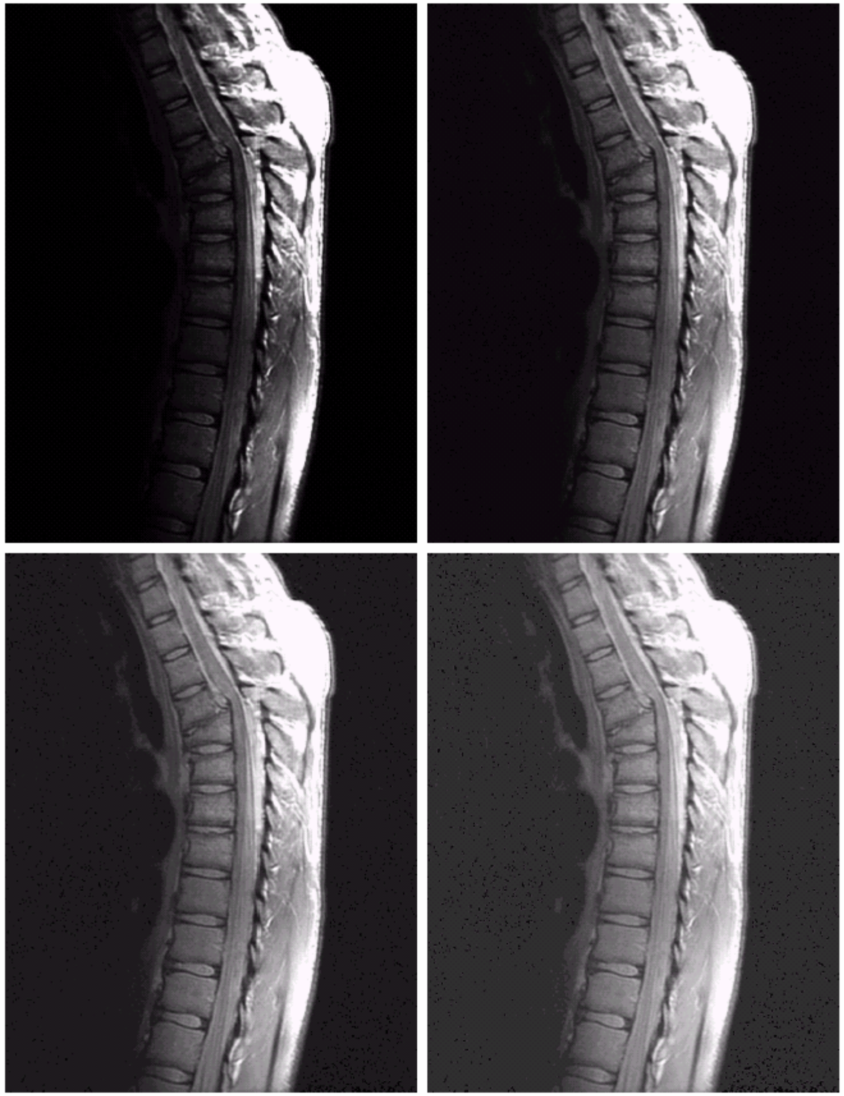

FIGURE 3.8 (a) Magnetic resonance (MR) image of a fractured human spine. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 0.6, 0.4,$ and 0.3, respectively. (Original image for this example courtesy of Dr. David R. Pickens, Department of Radiology and Radiological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

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a b
c d

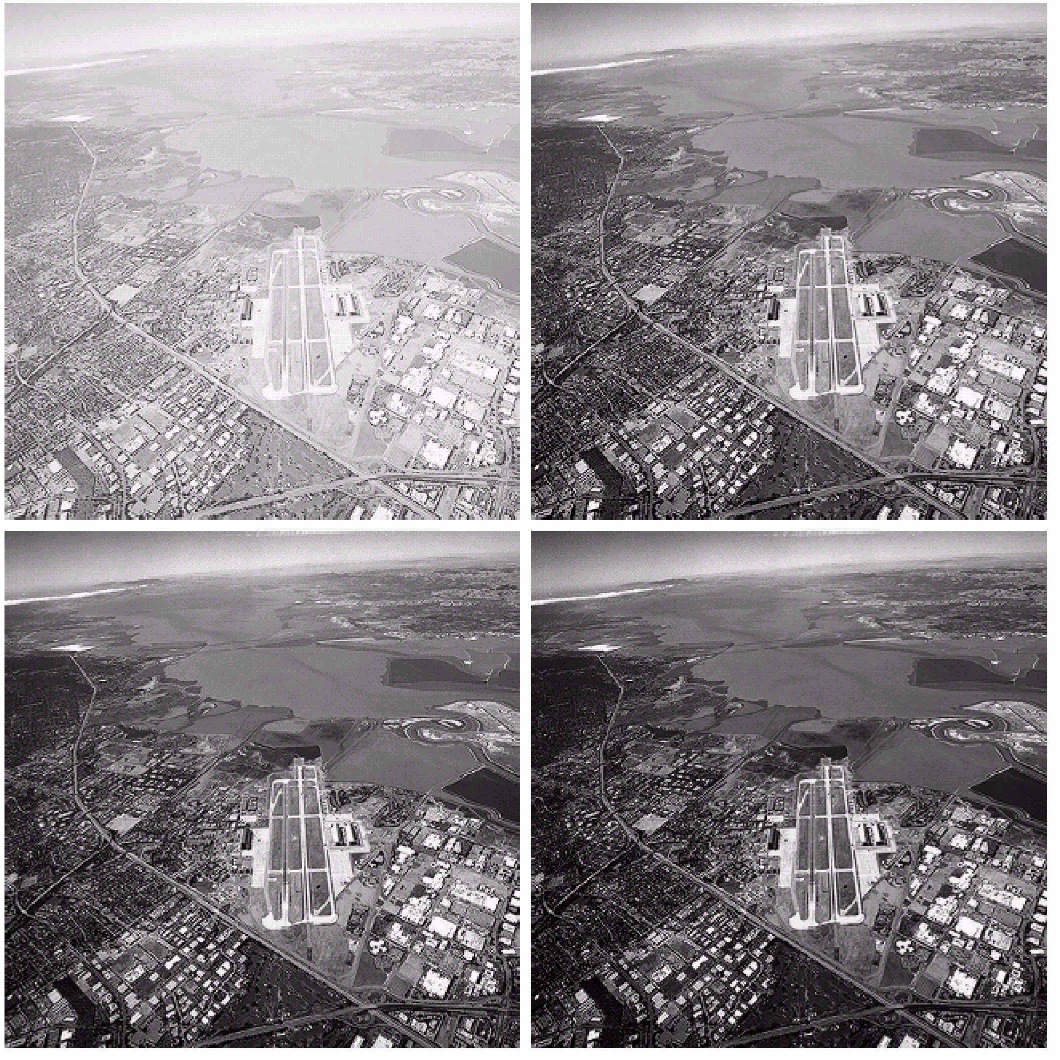
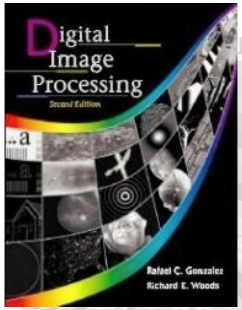


FIGURE 3.9 (a) Aerial image. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 3.0, 4.0,$ and 5.0, respectively. (Original image for this example courtesy of NASA.)

Enchancement

- 4 . Piecewise Linear Transformation

  -- Contrast stretching



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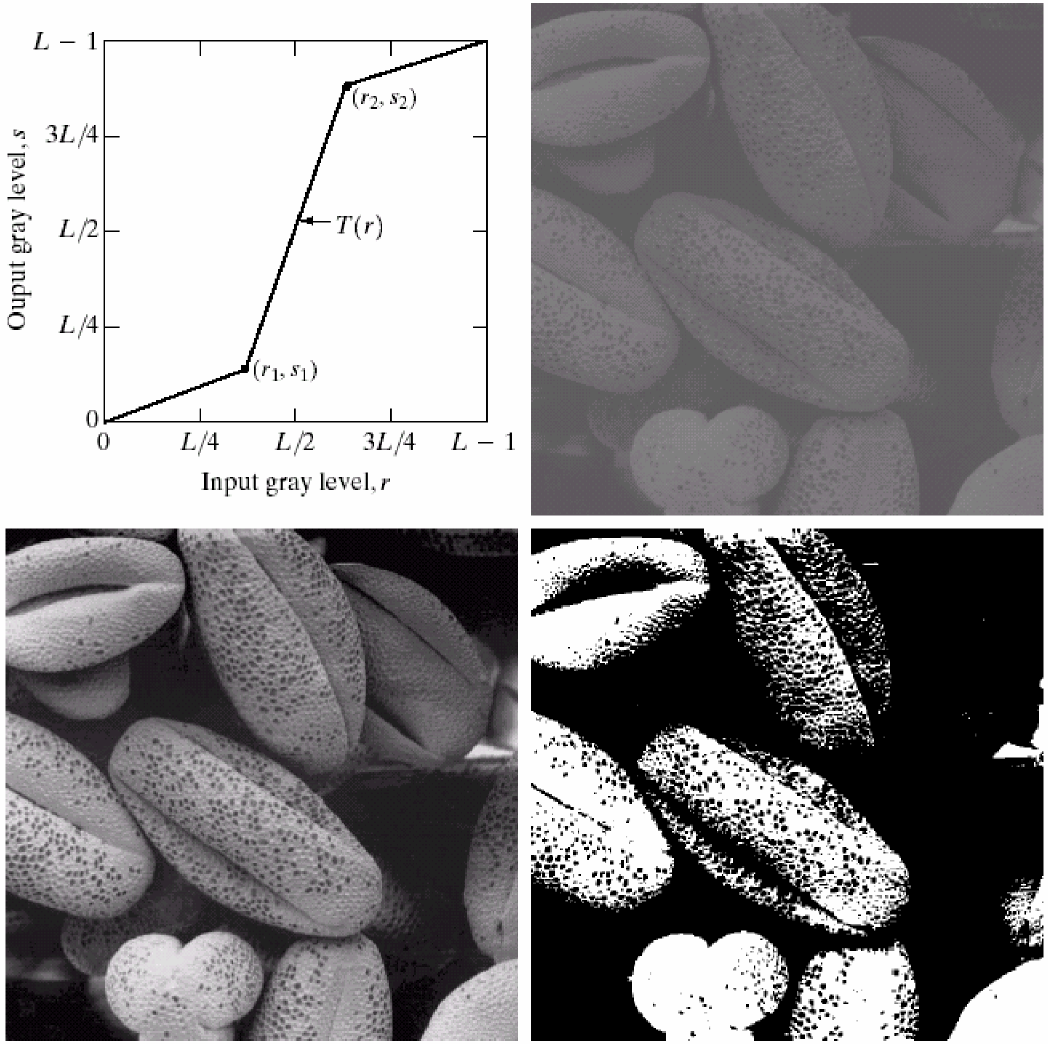

a b
c d

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.)

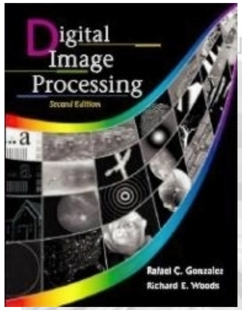

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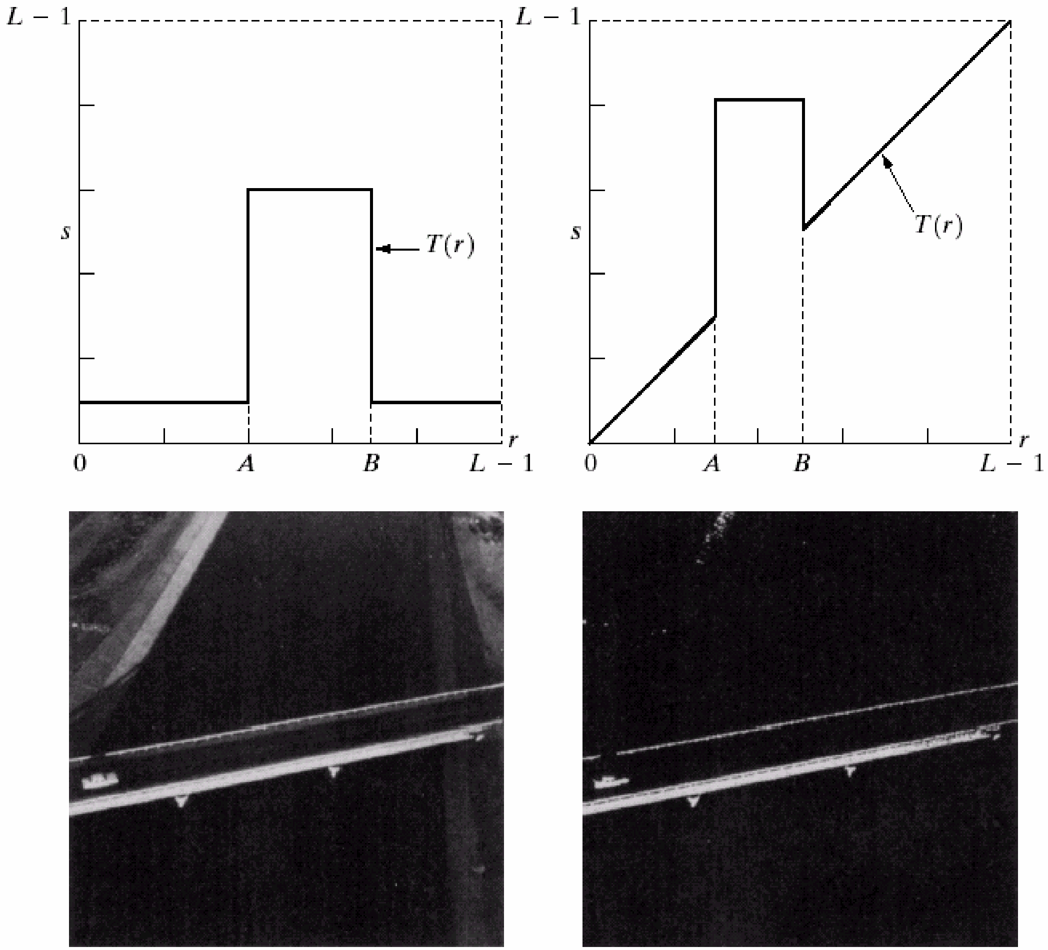
Image Enhancement in the Spatial Domain



a b
c d

FIGURE 3.11 (a) This transformation highlights range $[A, B]$ of gray levels and reduces all others to a constant level. (b) This transformation highlights range $[A, B]$ but preserves all other levels. (c) An image. (d) Result of using the transformation in (a).

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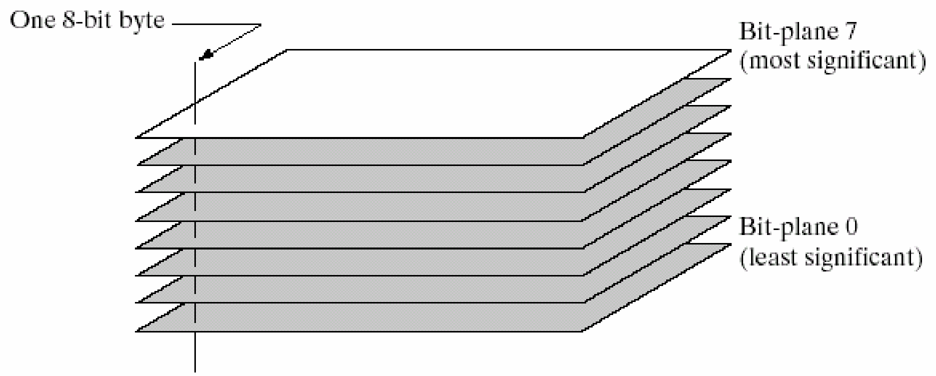

FIGURE 3.12 Bit-plane representation of an 8-bit image.

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Image Enhancement in the Spatial Domain

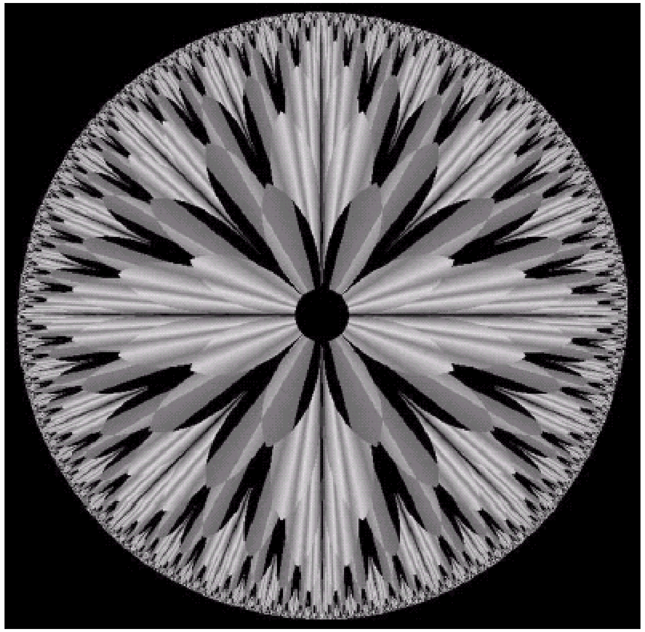

FIGURE 3.13 An 8-bit fractal image. (A fractal is an image generated from mathematical expressions). (Courtesy of Ms. Melissa D. Binde, Swarthmore College, Swarthmore, PA.)

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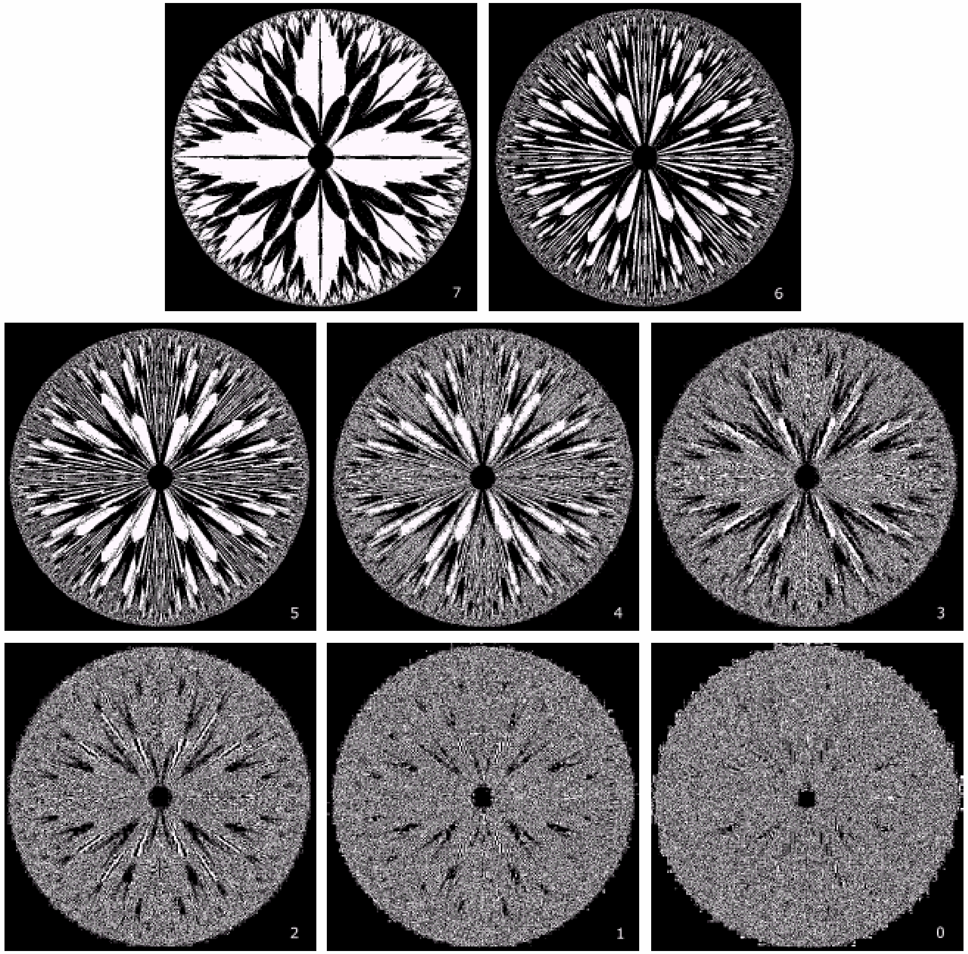
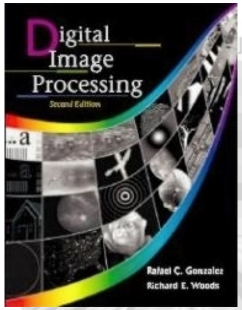


FIGURE 3.14 The eight bit planes of the image in Fig. 3.13. The number at the bottom, right of each image identifies the bit plane.



3.3 Histogram Processing

- Grey level: $0 \sim L-1$
- $P(r_k)=n_k/n$
- r_k: the kth grey level
- n_k: the # of pixel with grey level k
- n: the # of tatol pixel
- Histogram: $P(r_k)=n_k/n$

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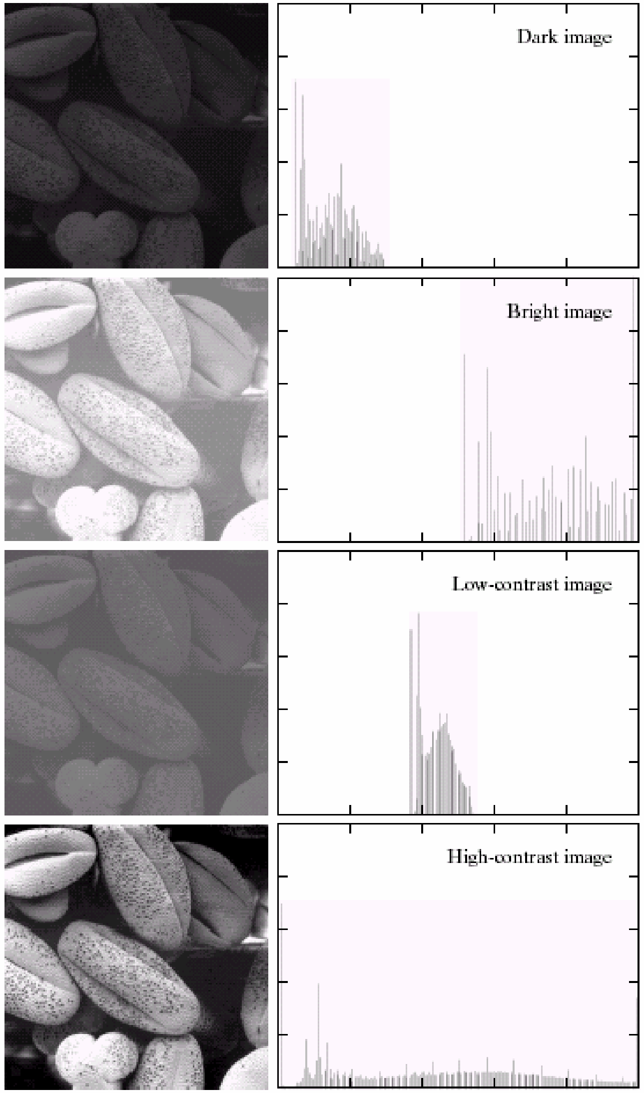
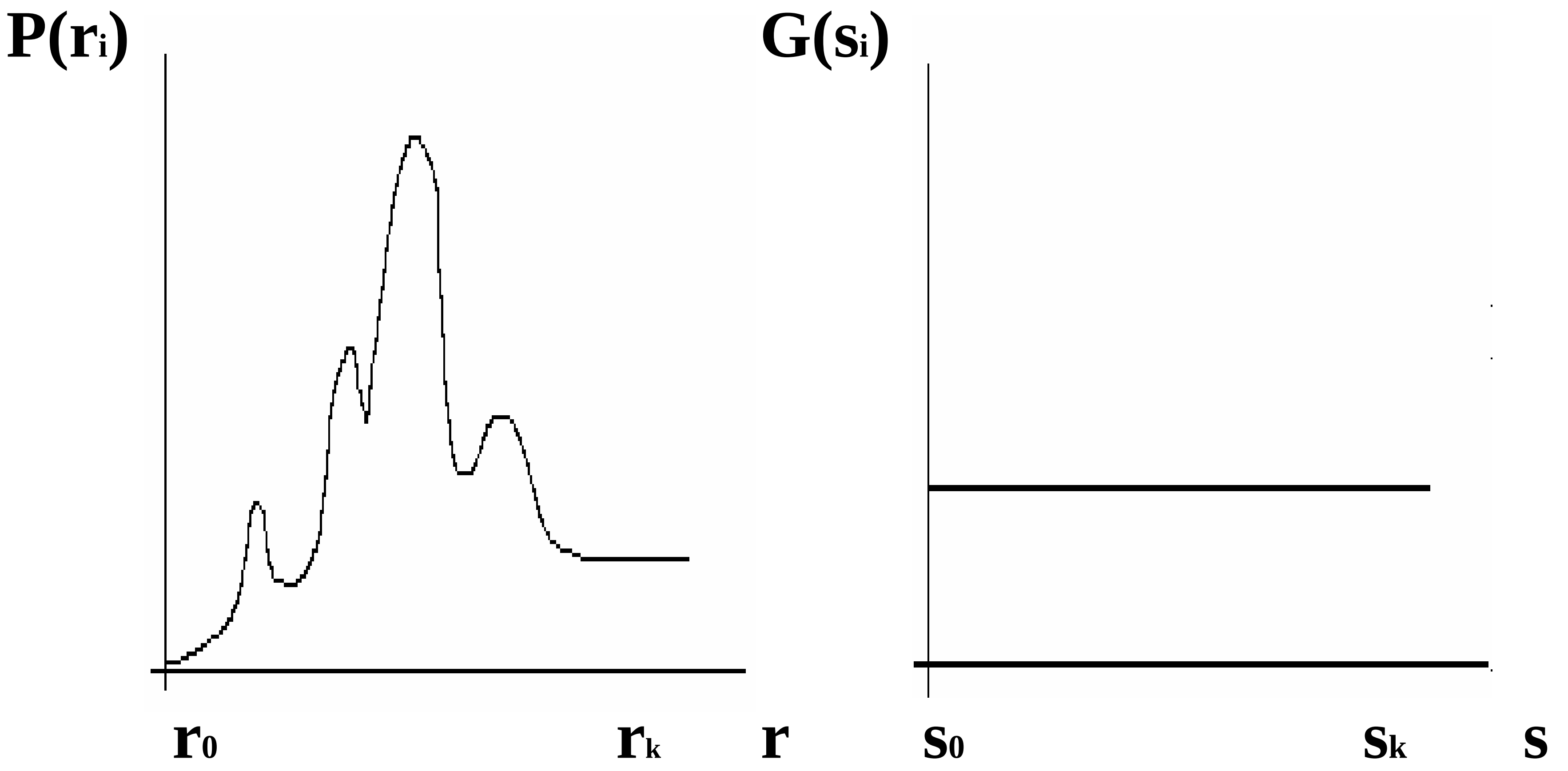


a b

FIGURE 3.15 Four basic image types: dark, light, low contrast, high contrast, and their corresponding histograms. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)

Histogram Equalization(1)

Image Size N*N



Histogram Equalization (2)

$$f(r) = S$$

Since

$$\sum_{i=0}^{k} P(r_i) = \sum_{i=0}^{k} G(s_i)$$

We know that G is equalized if

$$\forall \ i, \quad G(Si) = \frac{N^2}{S_K - S_0}$$

Histogram Equalization (3)

From probability CDF

$$\int_{S_0}^{S} \frac{N^2}{S_K - S_0}\, ds = \int_{r_0}^{r} P(s)\, ds$$

$$\frac{N^2 (S - S_0)}{S_K - S_0} = \int_{r_0}^{r} P(s)\, ds$$

Histogram Equalization (4)

$$S = \frac{S_K - S_0}{N^2} \int_{r_0}^{r} P(s)\, ds + S_0$$

From Discrete format

$$S = \frac{S_K - S_0}{N^2} \sum_{i = r_0}^{r} P(i) + S_0$$

Histogram Equalization (5)

$$S = f(r) = \frac{S_K - S_0}{N^2} \sum_{i=r_0}^{r} P(i) + S_0$$

EX:

$$S = f(100) = \frac{S_K - S_0}{N^2} \sum_{i=r_0}^{100} P(i) + S_0$$

- **Histogram Equalization**

$S=T(r)$

(a)$T(r)$=monotonic increasing

(b)$0<=T(r)<=1$

$r=T^{-1}(s)$

$Pdf=Pr(r)\cdot Ps(r)$

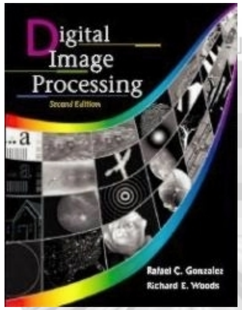
$Ps(s)=[Pr(r)dr/ds]r=T^{-1}(s)$

Controlling the pdf for transfer function

CDF $S=T(r)=\int_0^r Pr(w)dw \quad 0<=r<=1$

Note:

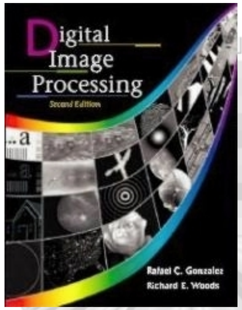
Using a transfer function equals to the CDF of r produce an image whose grey level has a uniform density and increase the dynamic range of the pixels



- **HistogramEqualization**
  - **Global**
  - **Local**

Pdf:Pr(r)

Ex.
Assume the pdf Pr(r) of a image is
$Pr(r)=-2r+2,\ 0<=r<=1$



$$S = T(r) = \int_0^r \Pr(w)\,dw$$

$$= \int_0^r (-2w + 2)\,dw$$

$$= -w^2 + 2w \Big|_0^r$$

$$= -r^2 + 2r$$

$$\therefore S = -r^2 + 2r$$

$$r = T^{-1}(s) = 1 \pm \sqrt{1 - s}$$

$$\therefore r = 1 - \sqrt{1 - s}$$

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Image Enhancement in the Spatial Domain

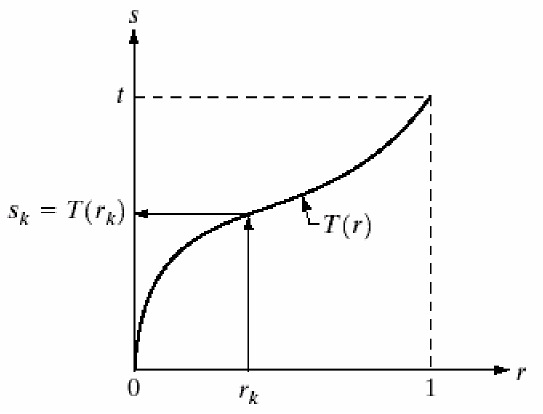

FIGURE 3.16 A gray-level transformation function that is both single valued and monotonically increasing.

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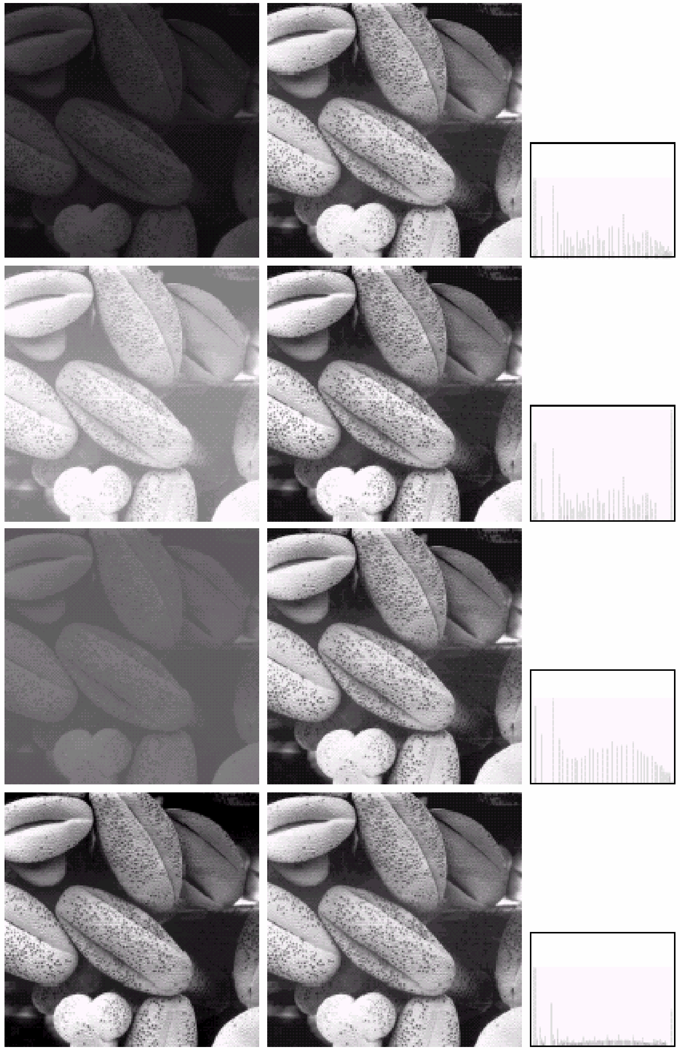
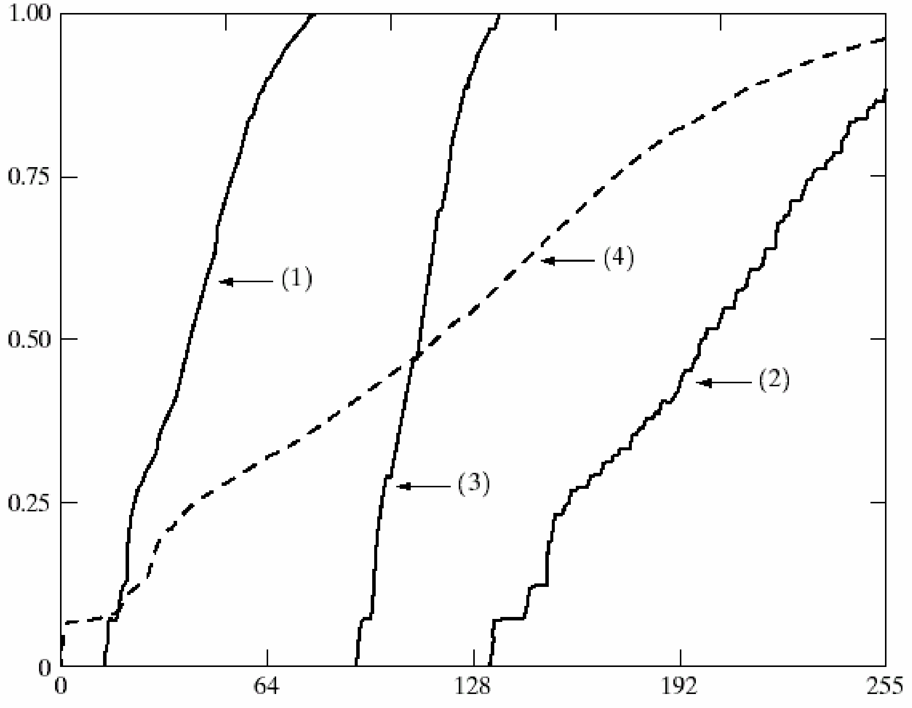


a b c

FIGURE 3.17 (a) Images from Fig. 3.15. (b) Results of histogram equalization. (c) Corresponding histograms.

FIGURE 3.18 Transformation functions (1) through (4) were obtained from the histograms of the images in Fig.3.17(a), using Eq. (3.3-8).



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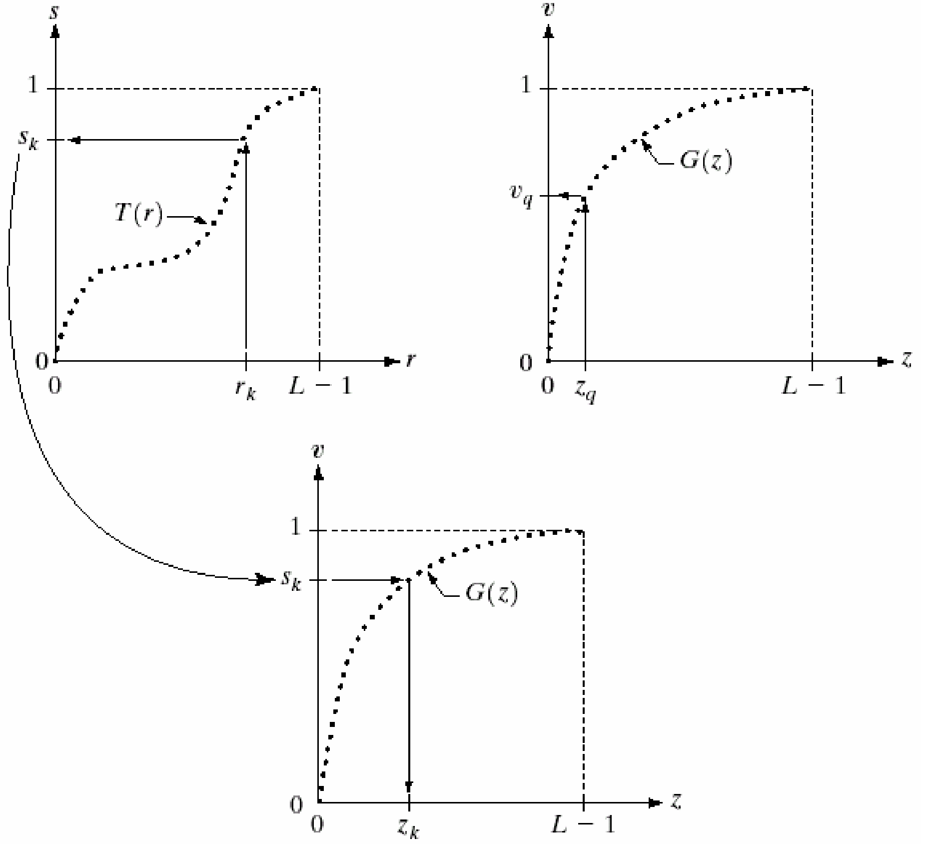
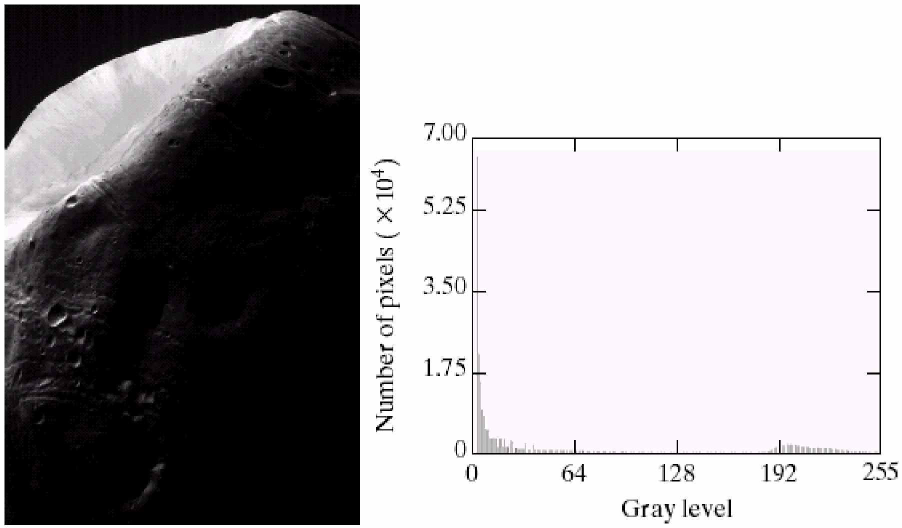


FIGURE 3.19 (a) Graphical interpretation of mapping from r_k to s_k via $T(r)$. (b) Mapping of z_q to its corresponding value v_q via $G(z)$. (c) Inverse mapping from s_k to its corresponding value of z_k.



a b

FIGURE 3.20 (a) Image of the Mars moon Photos taken by NASA's *Mars Global Surveyor*. (b) Histogram. (Original image courtesy of NASA.)

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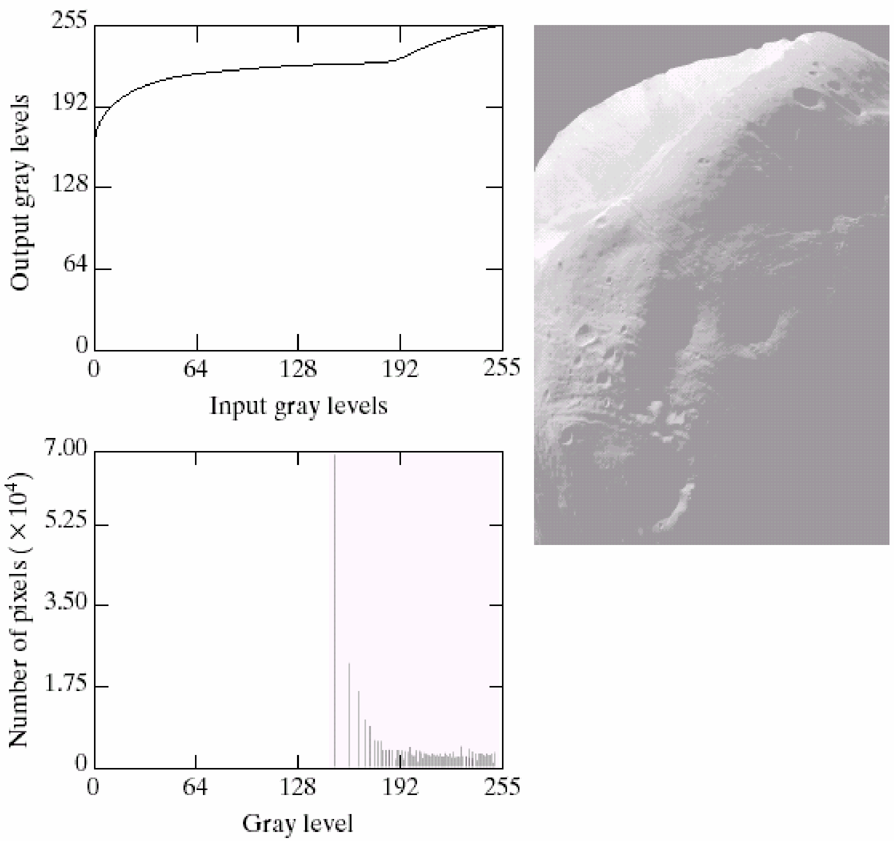

a b
c

FIGURE 3.21 (a) Transformation function for histogram equalization. (b) Histogram-equalized image (note the washed-out appearance). (c) Histogram of (b).

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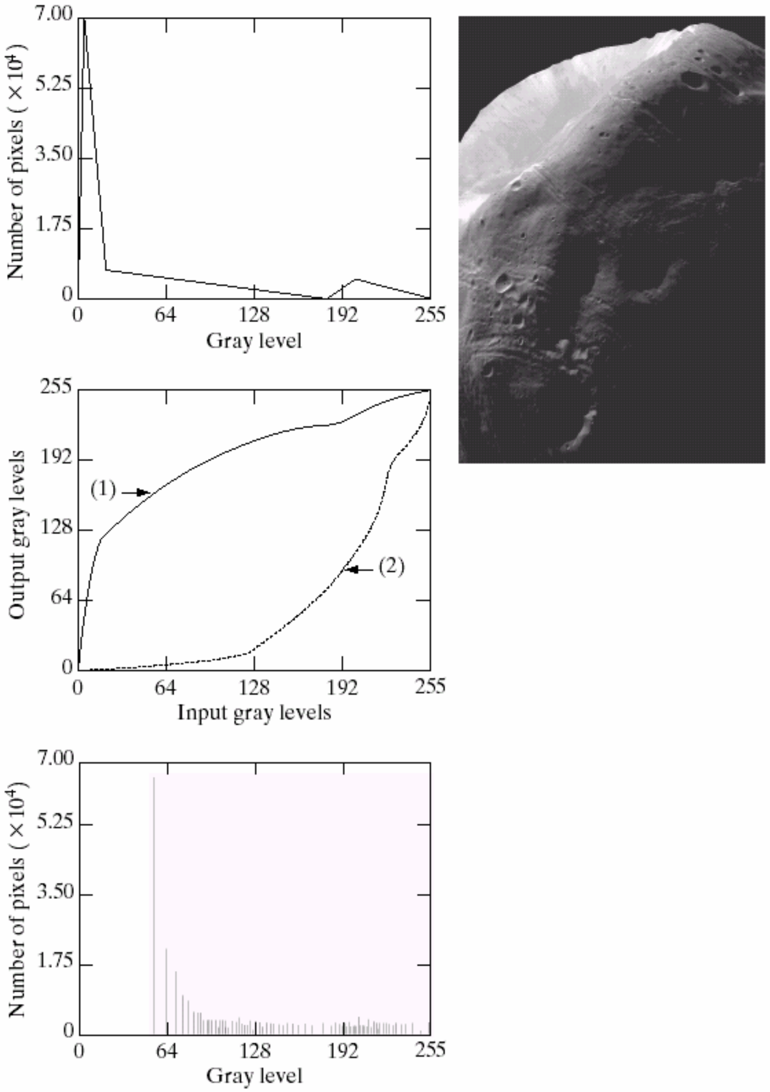

FIGURE 3.22 (a) Specified histogram. (b) Curve (1) is from Eq. (3.3-14), using the histogram in (a); curve (2) was obtained using the iterative procedure in Eq. (3.3-17). (c) Enhanced image using mappings from curve (2). (d) Histogram of (c).

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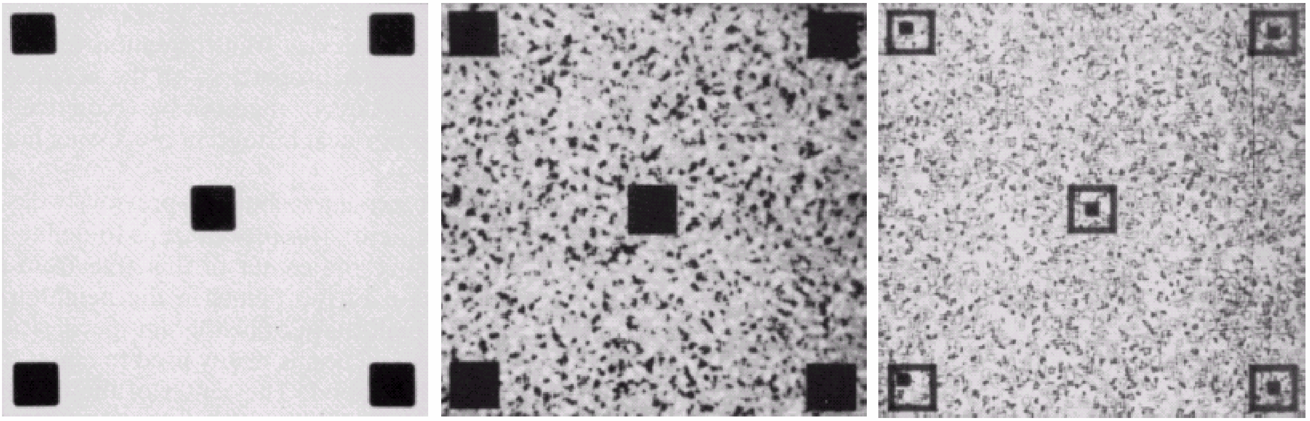

a b c

FIGURE 3.23 (a) Original image. (b) Result of global histogram equalization. (c) Result of local histogram equalization using a 7 × 7 neighborhood about each pixel.

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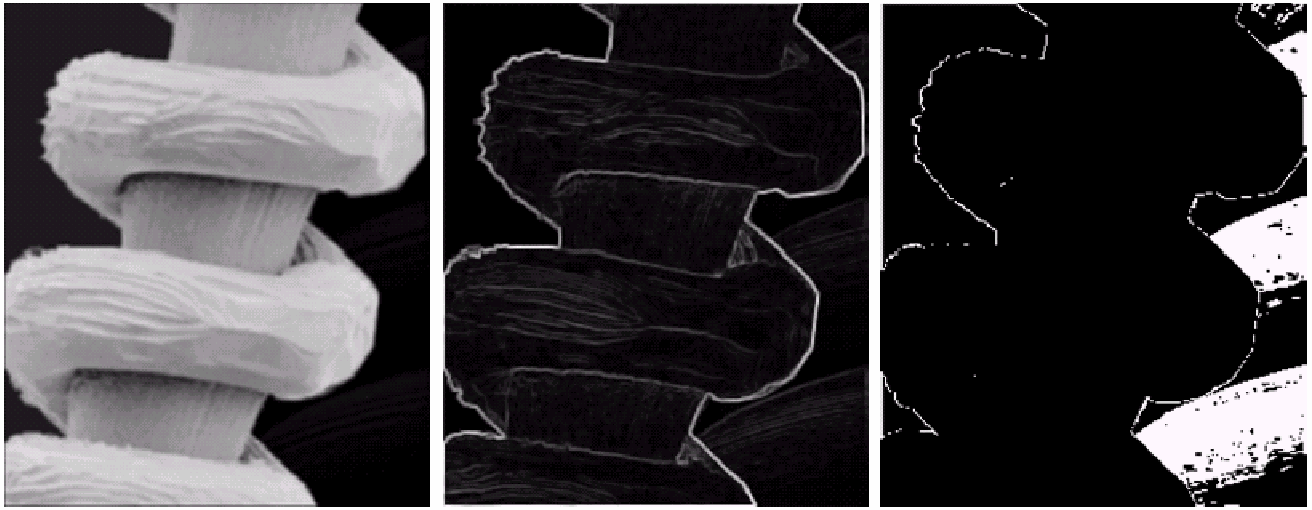
FIGURE 3.24 SEM image of a tungsten filament and support, magnified approximately 130×. (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene).



a b c

FIGURE 3.25 (a) Image formed from all local means obtained from Fig. 3.24 using Eq. (3.3-21). (b) Image formed from all local standard deviations obtained from Fig. 3.24 using Eq. (3.3-22). (c) Image formed from all multiplication constants used to produce the enhanced image shown in Fig. 3.26.

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FIGURE 3.26 Enhanced SEM image. Compare with Fig. 3.24. Note in particular the enhanced area on the right side of the image.

(1) *Substration*

$$g(x,y) = f(x,y) - h(x,y)$$

(2) *Averaging*

$$g(x,y) = f(x,y) + \eta(x,y)$$

$$\eta(x,y) \quad noise$$

$$\overline{g}(x,y) = \frac{1}{k}\sum_{i=1}^{k} g_i(x,y)$$

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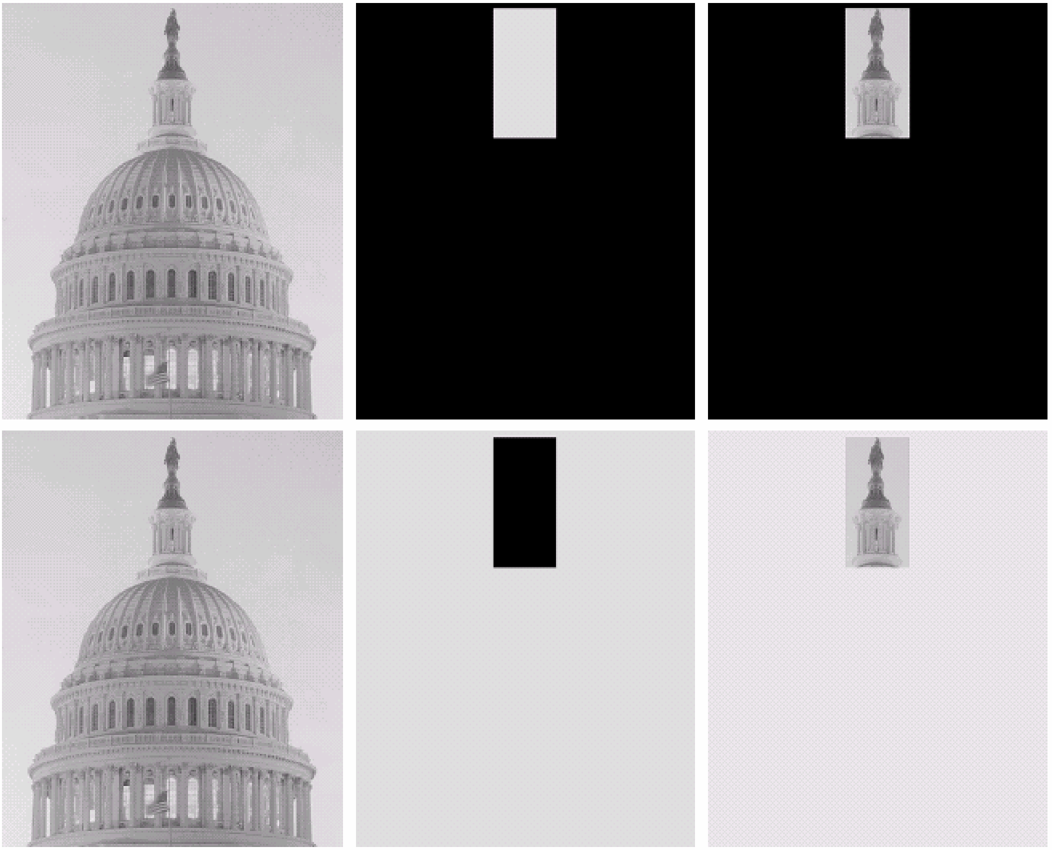

a b c
d e f

FIGURE 3.27 (a) Original image. (b) AND image mask. (c) Result of the AND operation on images (a) and (b). (d) Original image. (e) OR image mask. (f) Result of operation OR on images (d) and (e).

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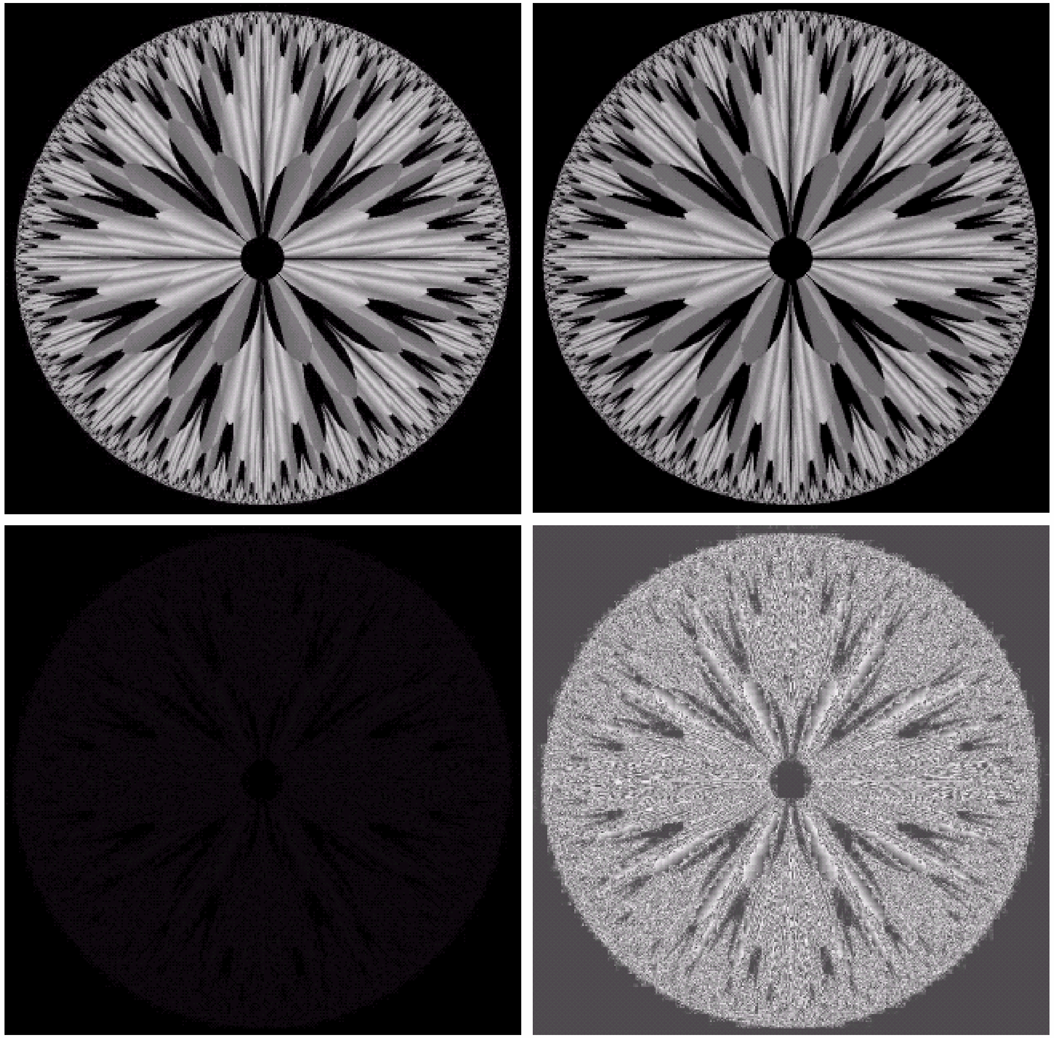
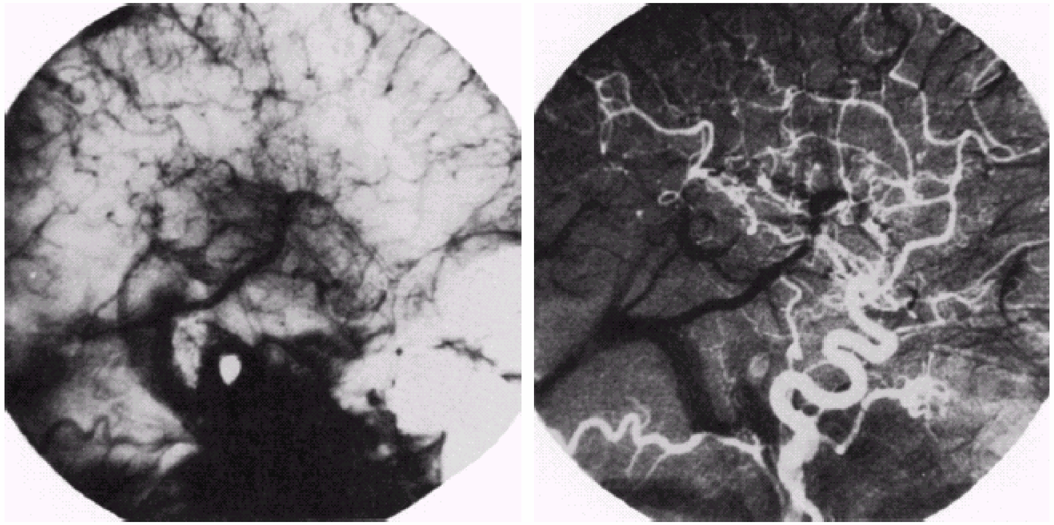


a b
c d

FIGURE 3.28 (a) Original fractal image. (b) Result of setting the four lower-order bit planes to zero. (c) Difference between (a) and (b). (d) Histogram-equalized difference image. (Original image courtesy of Ms. Melissa D. Binde, Swarthmore College, Swarthmore, PA).



a b

FIGURE 3.29 Enhancement by image subtraction. (a) Mask image. (b) An image (taken after injection of a contrast medium into the bloodstream) with mask subtracted out.

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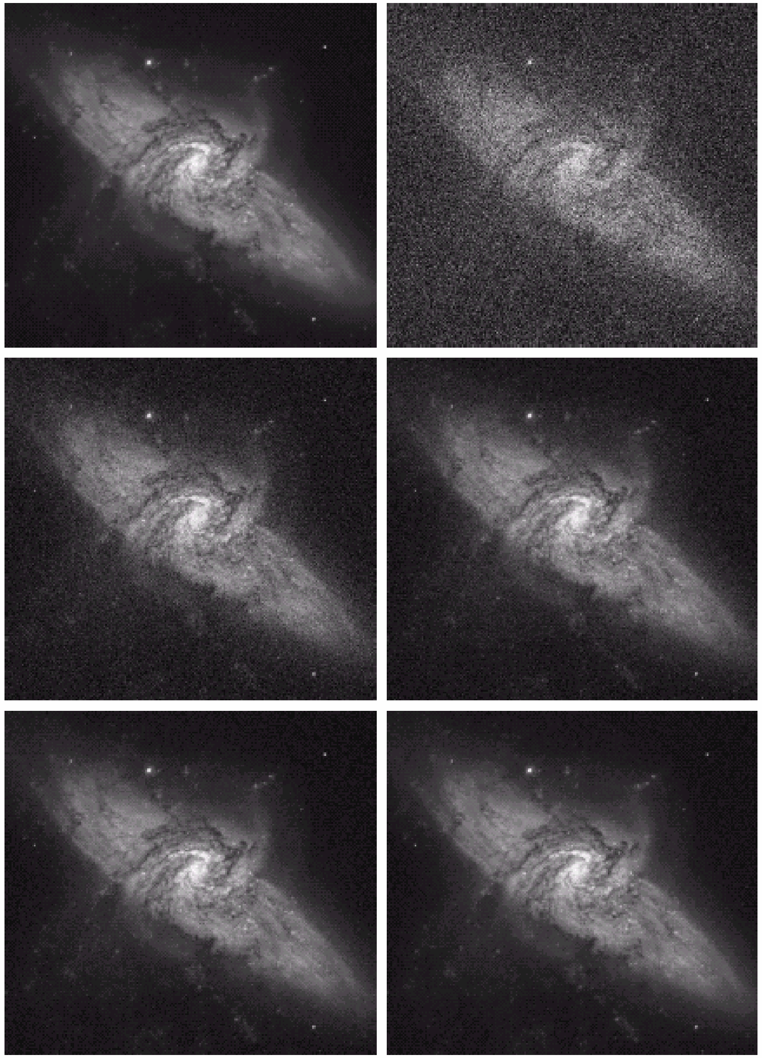
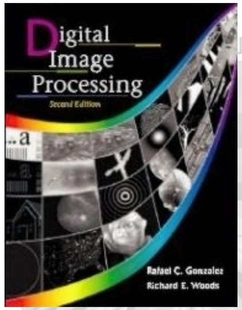


a b
c d
e f

FIGURE 3.30 (a) Image of Galaxy Pair NGC 3314. (b) Image corrupted by additive Gaussian noise with zero mean and a standard deviation of 64 gray levels. (c)–(f) Results of averaging $K = 8, 16, 64,$ and 128 noisy images. (Original image courtesy of NASA.)



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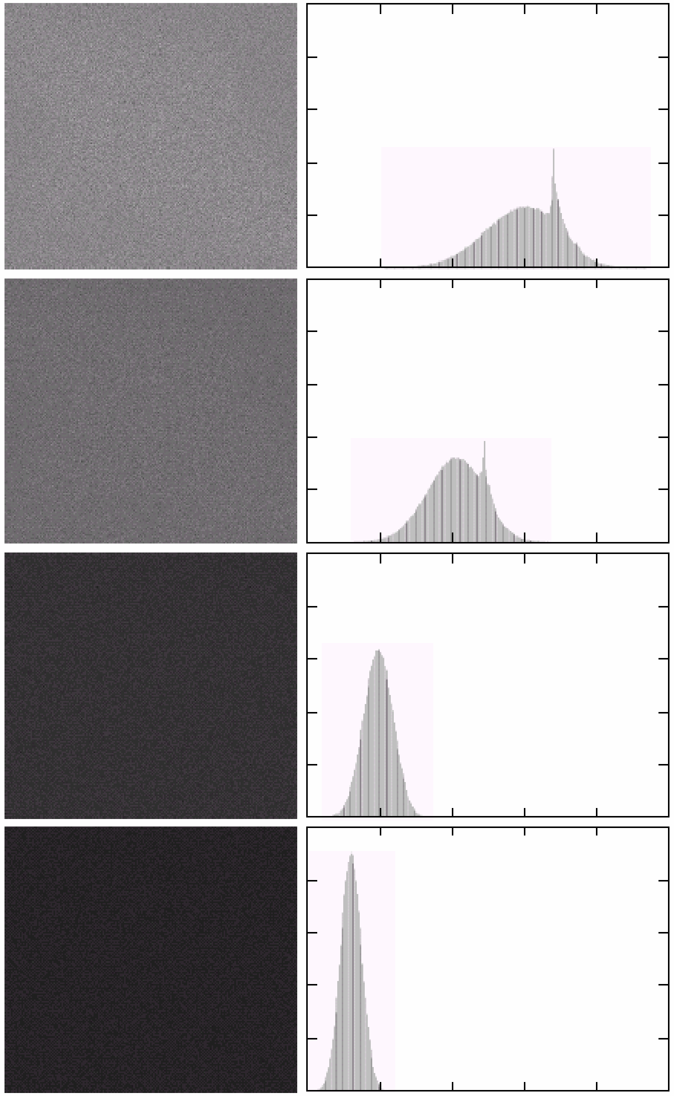


a b

FIGURE 3.31 (a) From top to bottom: Difference images between Fig. 3.30(a) and the four images in Figs. 3.30(c) through (f), respectively. (b) Corresponding histograms.

$$g(x,y)=\sum_{s=-a}^{a}\sum_{t=-b}^{b}w(x,y)f(x+s,y+t)$$

(1)Smooth Filtering (Low pass filter)

- noise redution, blurring

(2)Sharpening Filtering (high pass filter)

- highlight details

$$\text{eg.}\begin{matrix}-\frac{1}{9} & -\frac{1}{9} & -\frac{1}{9}\\ -\frac{1}{9} & \frac{8}{9} & -\frac{1}{9}\\ -\frac{1}{9} & -\frac{1}{9} & -\frac{1}{9}\end{matrix}$$

(3)Derivative Filter

- edge enchancement

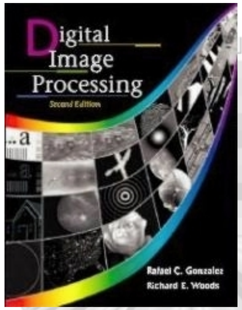
eg.Laplician

(4)Highboost Filtering

$$Hightboost = A \bullet orig\text{-}Lowpass = (A\text{-}1) \bullet orig + Hightpass$$

when $\text{A} = 1$, highpass

$\text{A} > 1$, party of the original image is added back to highpass



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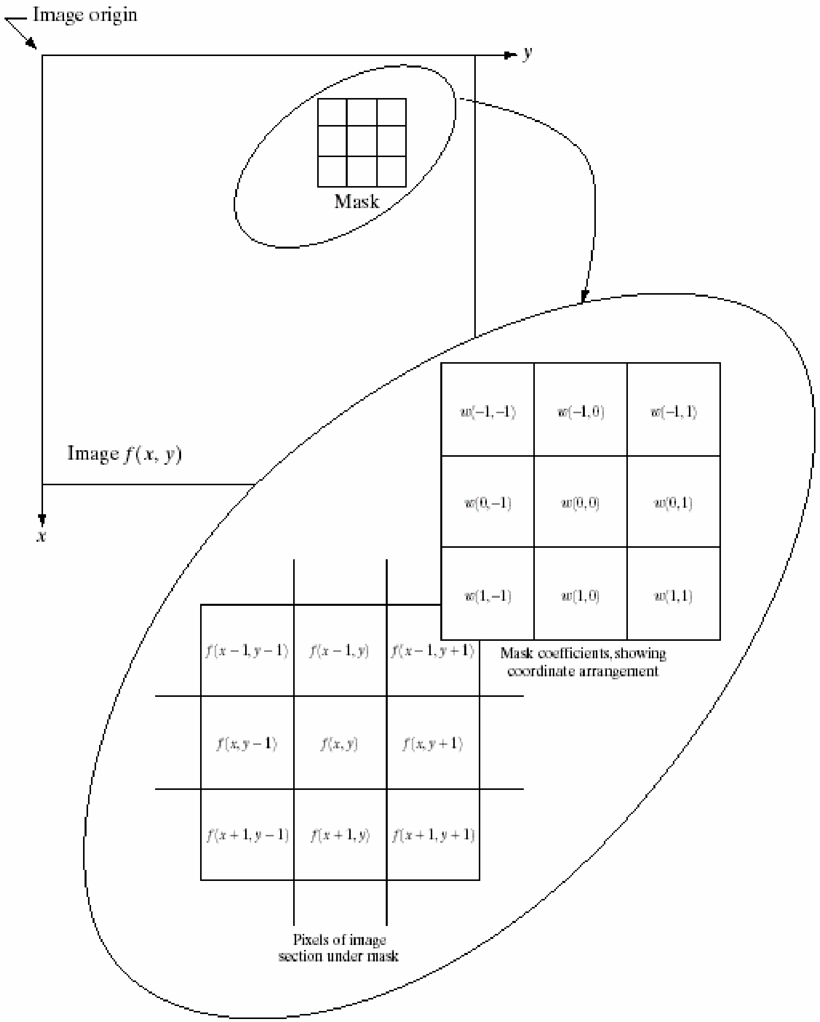

FIGURE 3.32 The mechanics of spatial filtering. The magnified drawing shows a 3 × 3 mask and the image section directly under it; the image section is shown displaced out from under the mask for ease of readability.

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FIGURE 3.33
Another representation of a general 3 × 3 spatial filter mask.

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

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$\frac{1}{9} \times$

1	1	1
1	1	1
1	1	1

$\frac{1}{16} \times$

1	2	1
2	4	2
1	2	1

a b

FIGURE 3.34 Two 3×3 smoothing (averaging) filter masks. The constant multipli er in front of each mask is equal to the sum of the values of its coefficients, as is required to compute an average.

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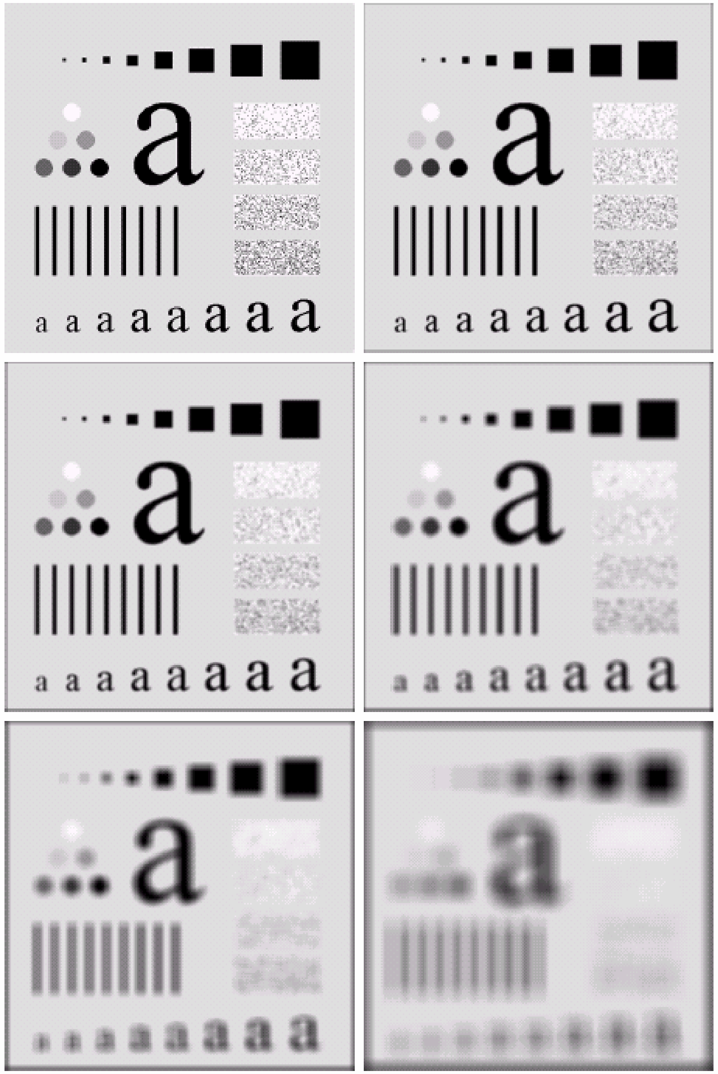

a b
c d
e f

FIGURE 3.35 (a) Original image, of size 500 × 500 pixels. (b)–(f) Results of smoothing with square averaging filter masks of sizes $n = 3, 5, 9, 15$, 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 gray 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 × 120 pixels.

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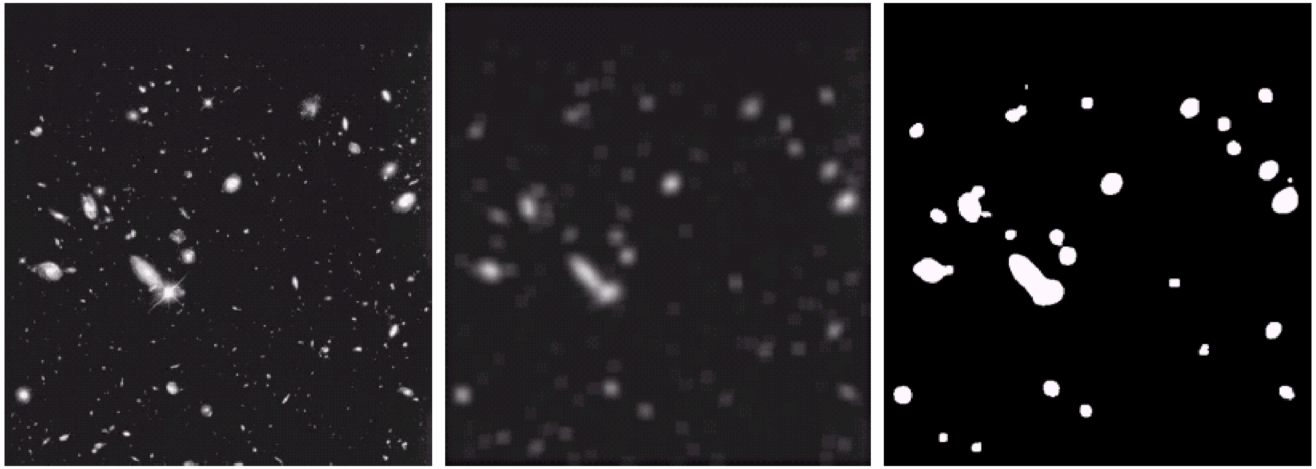
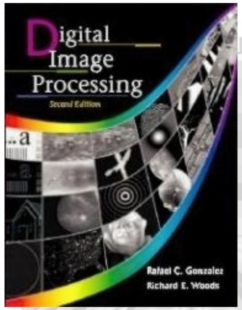


a b c

FIGURE 3.36 (a) Image from the Hubble Space Telescope. (b) Image processed by a 15 × 15 averaging mask. (c) Result of thresholding (b). (Original image courtesy of NASA.)



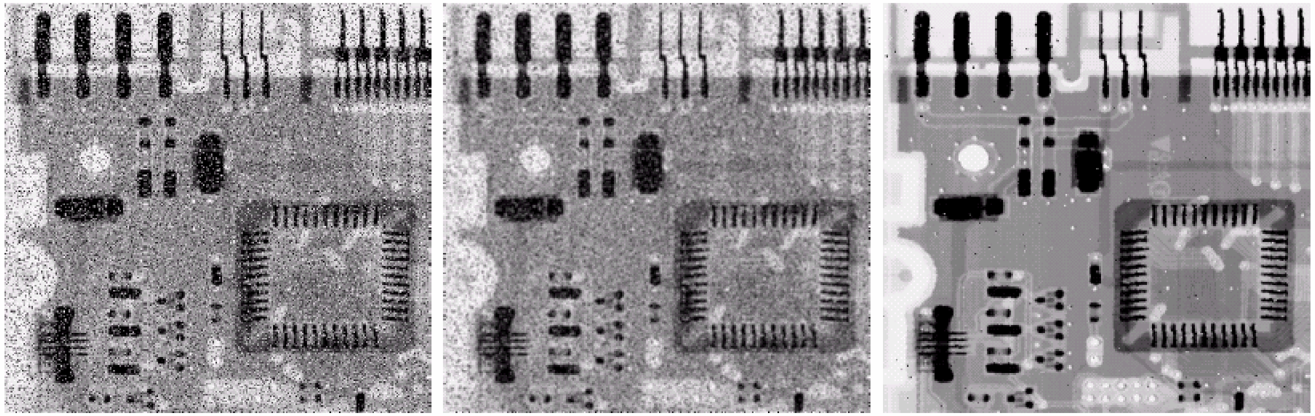
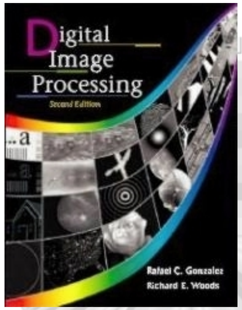


FIGURE 3.37 (a) X-ray image of circuit board corrupted by salt-and-pepper noise. (b) Noise reduction with a 3×3 averaging mask. (c) Noise reduction with a 3×3 median filter. (Original image courtesy of Mr. Joseph E. Pascente, Lixi, Inc.)



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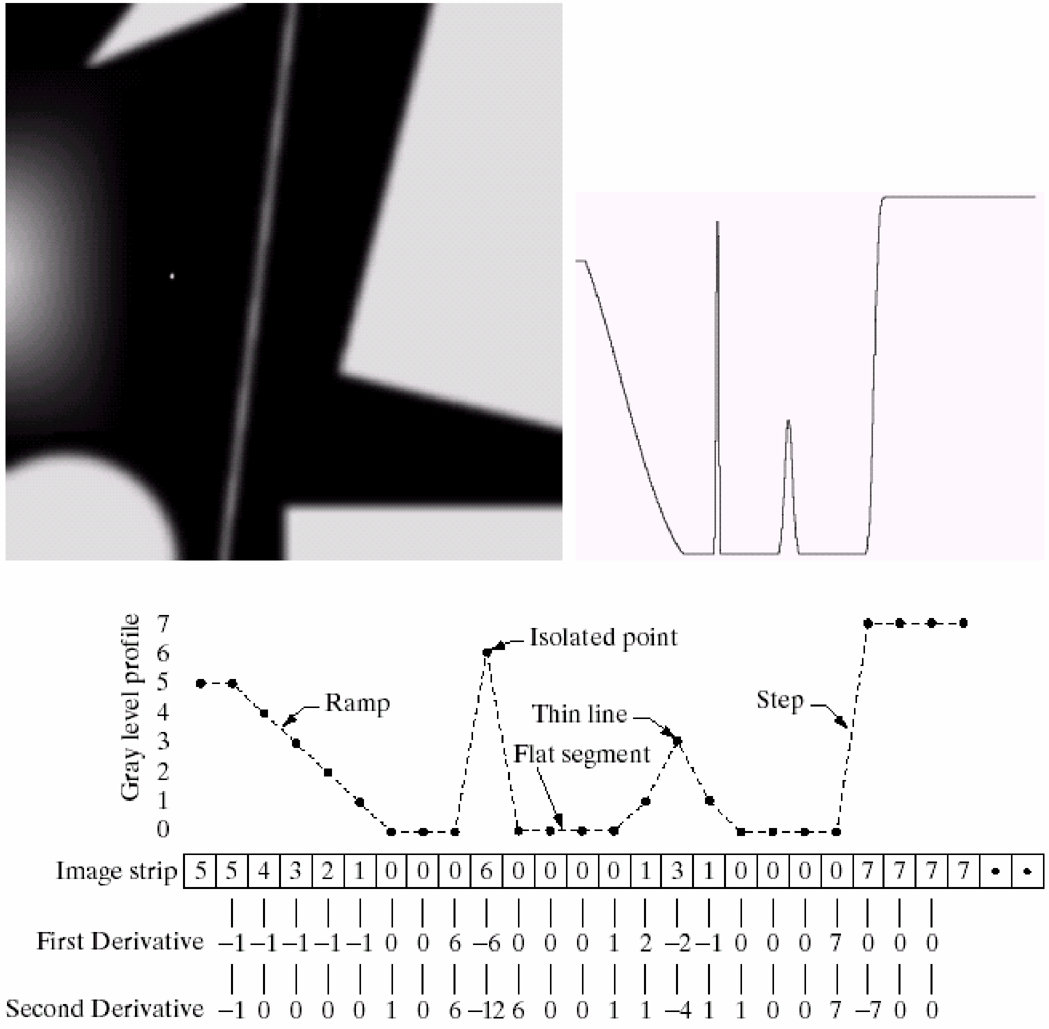
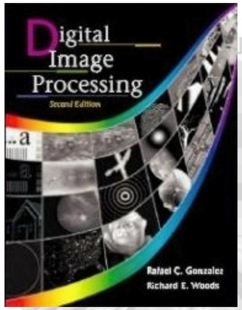


FIGURE 3.38 (a) A simple image. (b) 1-D horizontal gray-level profile along the center of the image and including the isolated noise point. (c) Simplified profile (the points are joined by dashed lines to simplify interpretation).



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0	1	0
1	−4	1
0	1	0

1	1	1
1	−8	1
1	1	1

0	−1	0
−1	4	−1
0	−1	0

−1	−1	−1
−1	8	−1
−1	−1	−1

a b
c d

FIGURE 3.39 (a) Filter mask used to implement the digital Laplacian, as defined in Eq. (3.7-4). (b) Mask used to implement an extension of this equation that includes the diagonal neighbors. (c) and (d) Two other implementations of the Laplacian.

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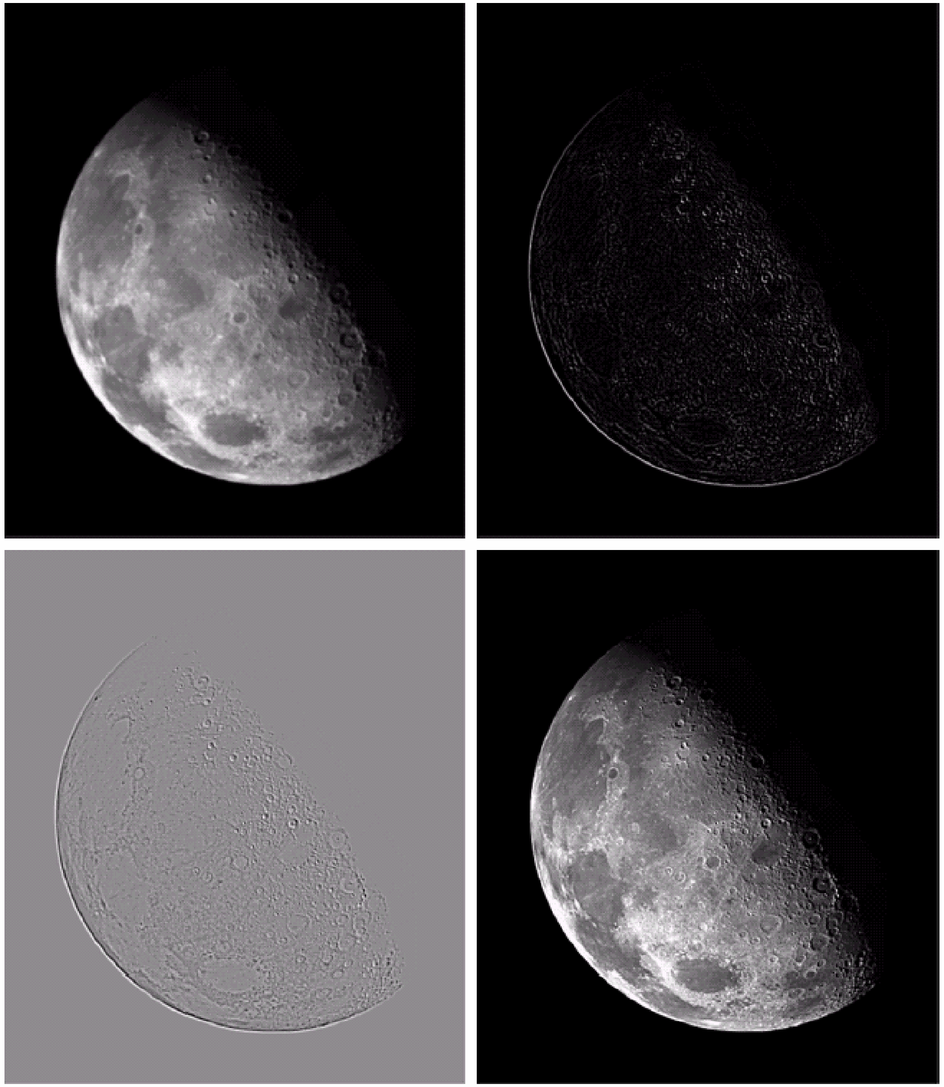
a b
c d

FIGURE 3.40 (a) Image of the North Pole of the moon. (b) Laplacian-filtered image. (c) Laplacian image scaled for display purposes. (d) Image enhanced by using Eq. (3.7-5). (Original image courtesy of NASA.)



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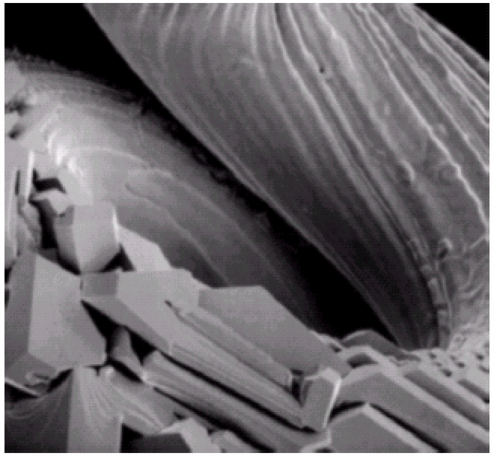
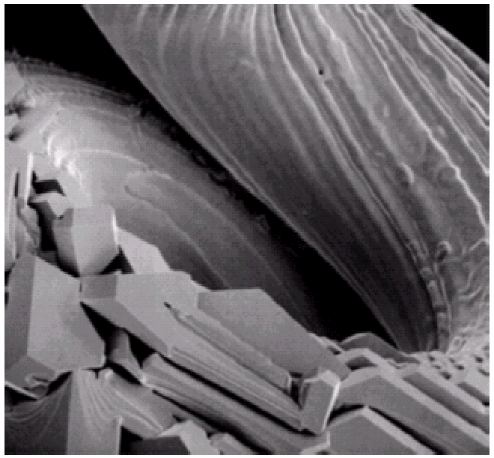
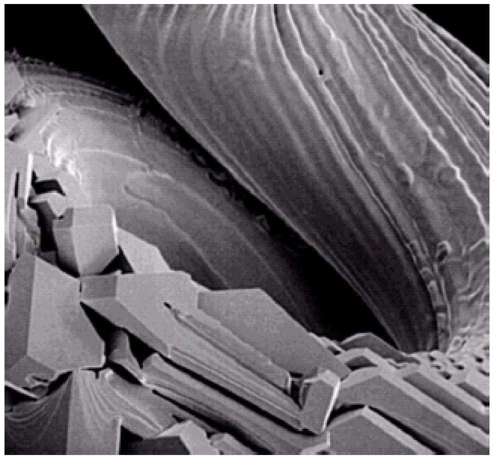
0	–1	0
–1	5	–1
0	–1	0

–1	–1	–1
–1	9	–1
–1	–1	–1







a b c
d e

FIGURE 3.41 (a) Composite Laplacian mask. (b) A second composite mask. (c) Scanning electron microscope image. (d) and (e) Results of filtering with the masks in (a) and (b), respectively. Note how much sharper (e) is than (d). (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene.)

0	−1	0		−1	−1	−1
−1	$A + 4$	−1		−1	$A + 8$	−1
0	−1	0		−1	−1	−1

a b

FIGURE 3.42 The high-boost filtering technique can be implemented with either one of these masks, with $A \geq 1$.

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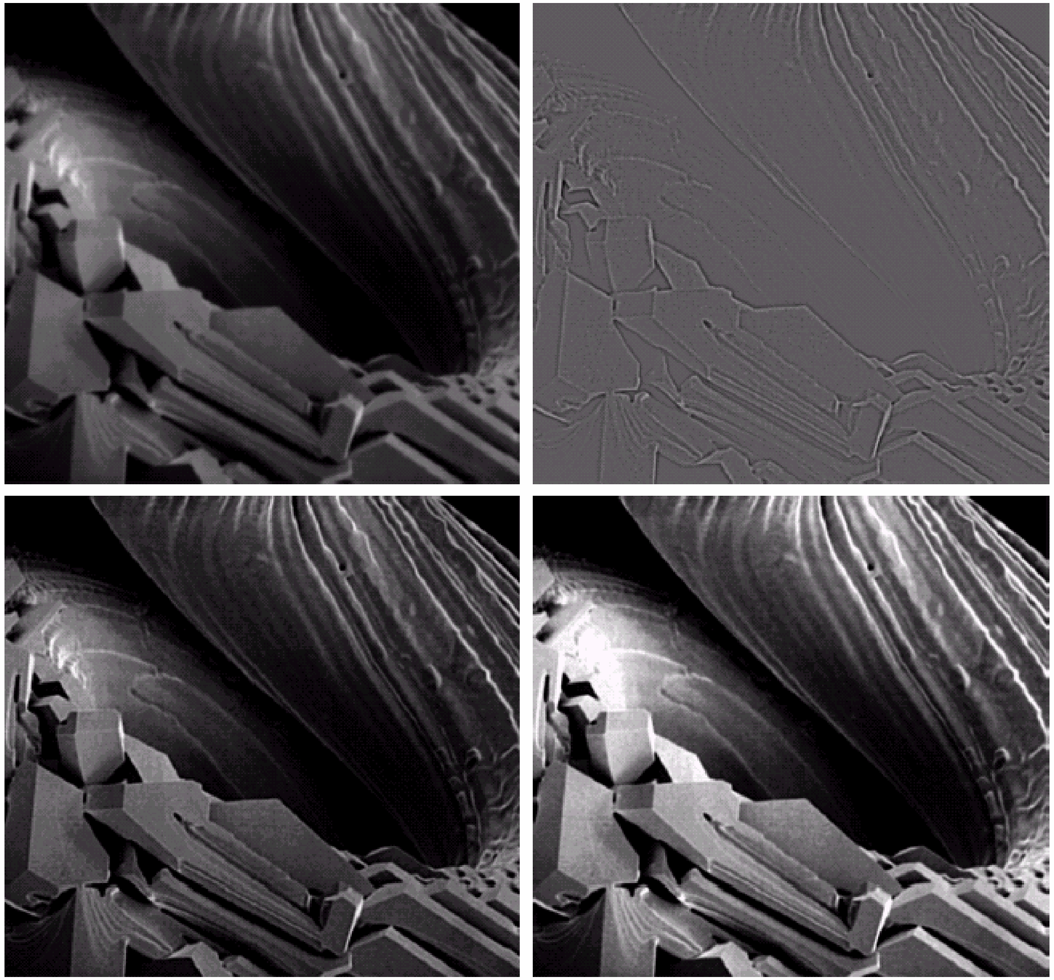

a b
c d

FIGURE 3.43 (a) Same as Fig. 3.41(c), but darker. (a) Laplacian of (a) computed with the mask in Fig. 3.42(b) using $A = 0$. (c) Laplacian enhanced image using the mask in Fig. 3.42(b) with $A = 1$. (d) Same as (c), but using $A = 1.7$.

a
b c
d e

FIGURE 3.44 A 3 × 3 region of an image (the z's are gray-level values) and masks used to compute the gradient at point labeled z_5. All masks coefficients sum to zero, as expected of a derivative operator.

(a)

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

(b)

−1	0
0	1

(c)

0	−1
1	0

(d)

−1	−2	−1
0	0	0
1	2	1

(e)

−1	0	1
−2	0	2
−1	0	1

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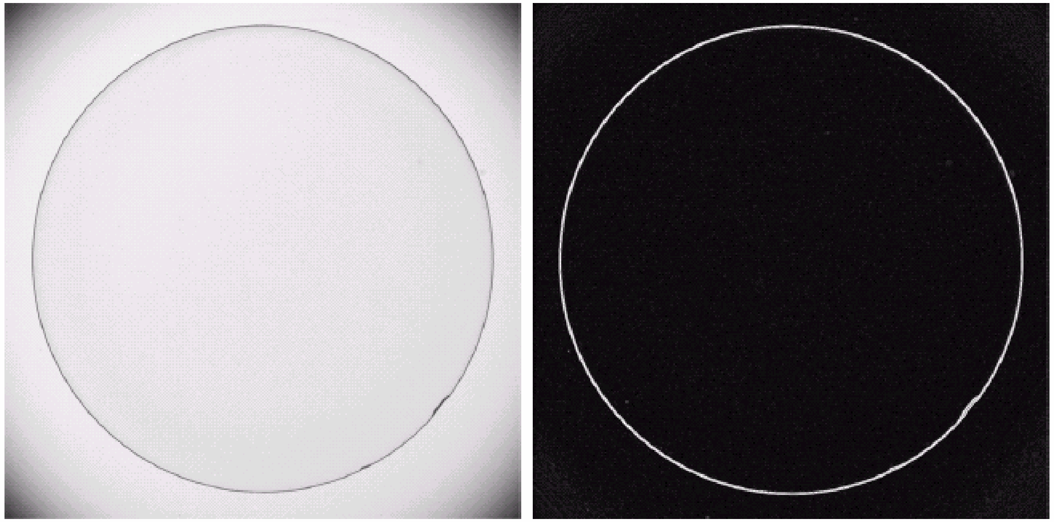

a b

FIGURE 3.45 Optical image of contact lens (note defects on the boundary at 4 and 5 o'clock). (b) Sobel gradient. (Original image courtesy of Mr. Pete Sites, Perceptics Corporation.)

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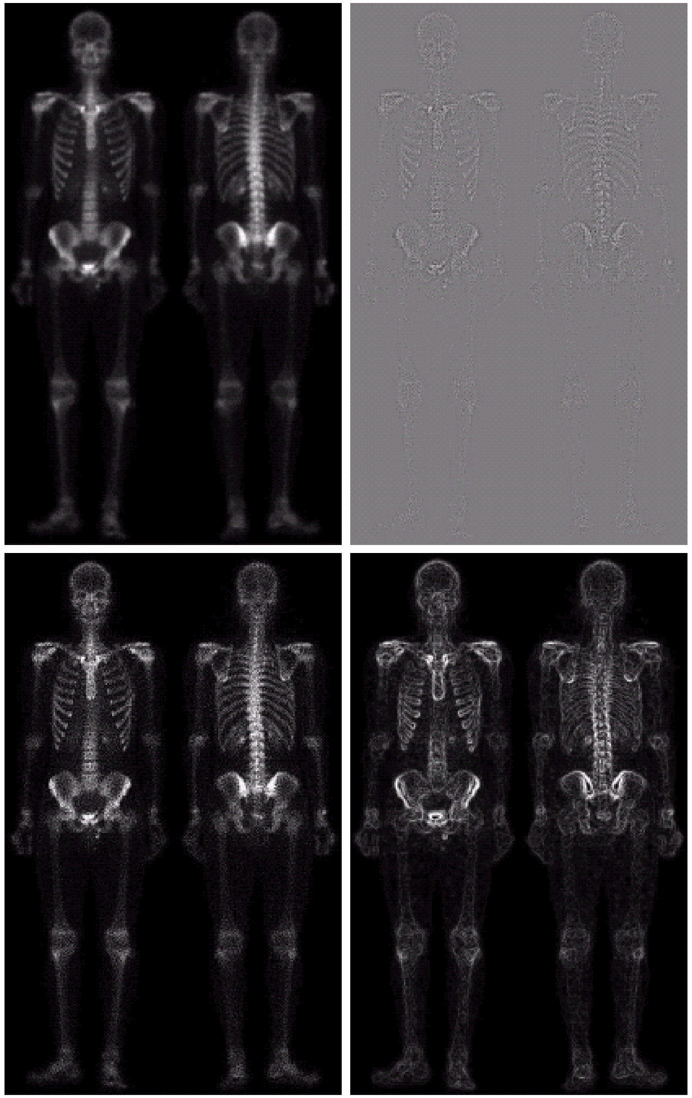
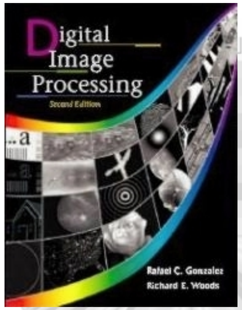


a b
c d

FIGURE 3.46
(a) Image of whole body bone scan.
(b) Laplacian of (a). (c) Sharpened image obtained by adding (a) and (b). (d) Sobel of (a).



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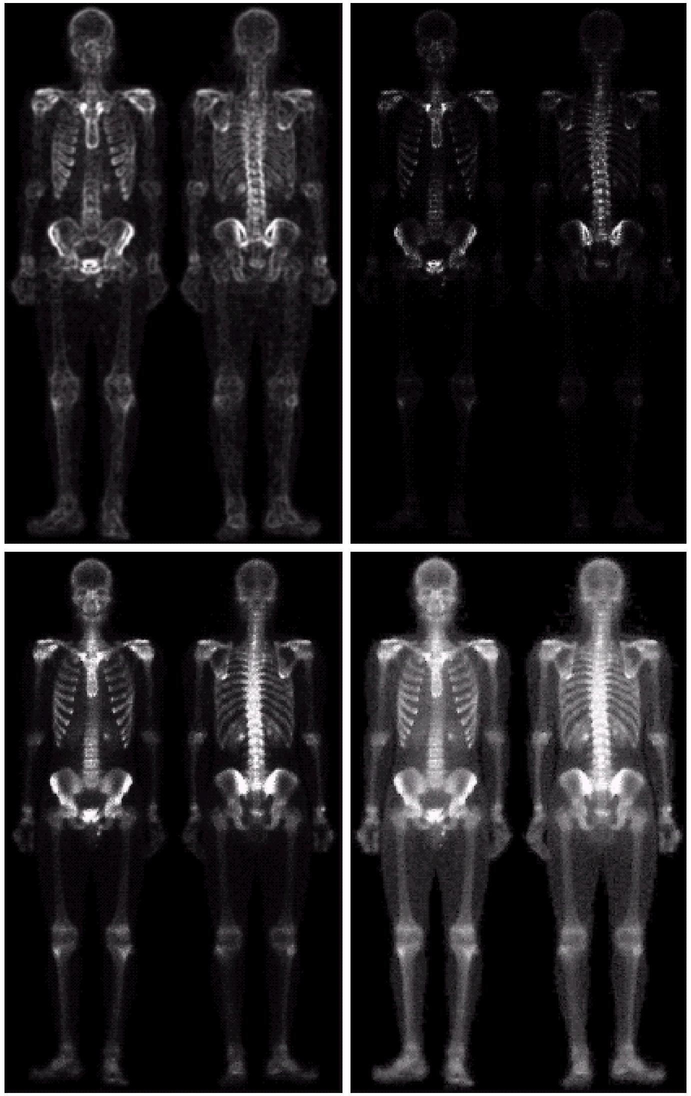

e f
g h

FIGURE 3.46 *(Continued)* (e) Sobel image smoothed with a 5 × 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.)