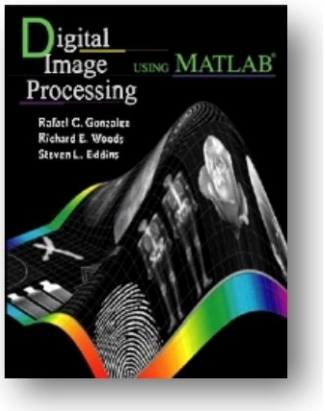

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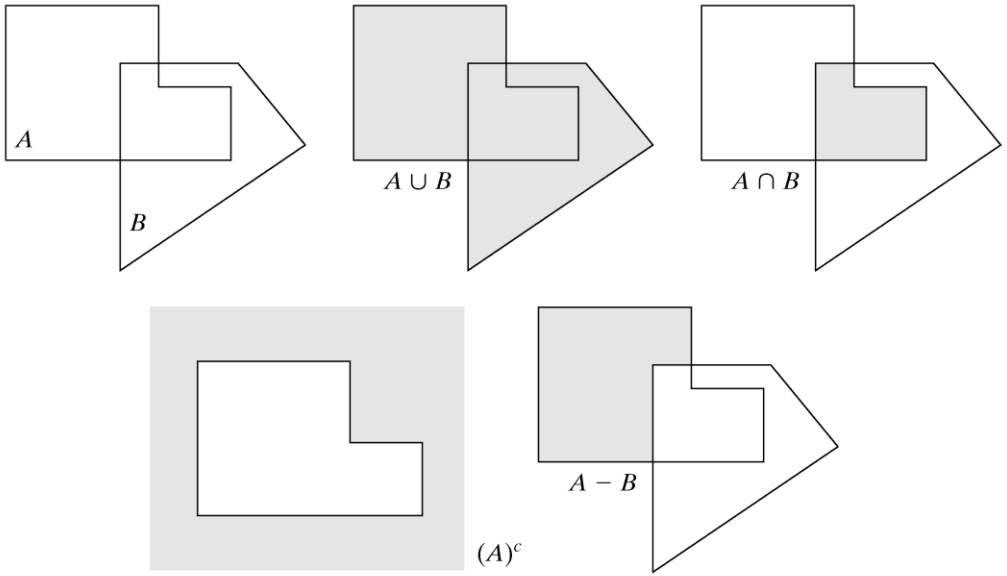
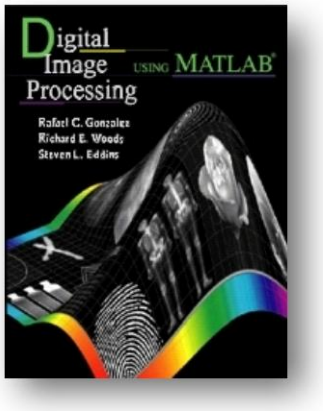


a b c
d e

FIGURE 9.1
(a) Two sets A and B. (b) The union of A and B. (c) The intersection of A and B. (d) The complement of A. (e) The difference between A and B.



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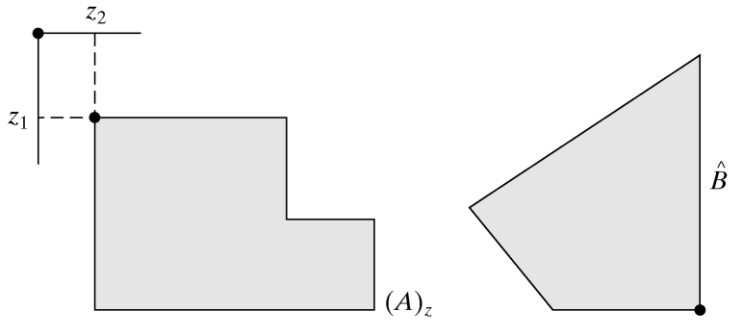
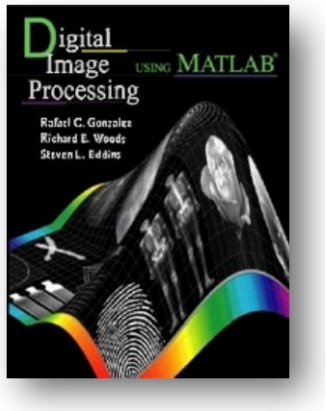


a b

FIGURE 9.2
(a) Translation of A by z.
(b) Reflection of B. The sets A and B are from Fig. 9.1.



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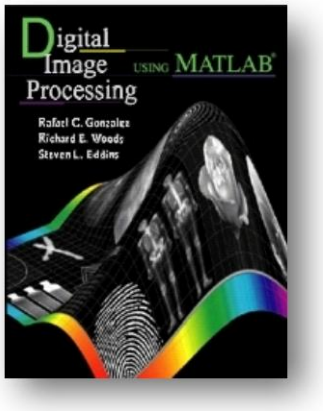
Set Operation	MATLAB Expression for Binary Images	Name
$A \cap B$	A & B	AND
$A \cup B$	A | B	OR
A^c	~A	NOT
$A - B$	A & ~B	DIFFERENCE

TABLE 9.1 Using logical expressions in MATLAB to perform set operations on binary images.



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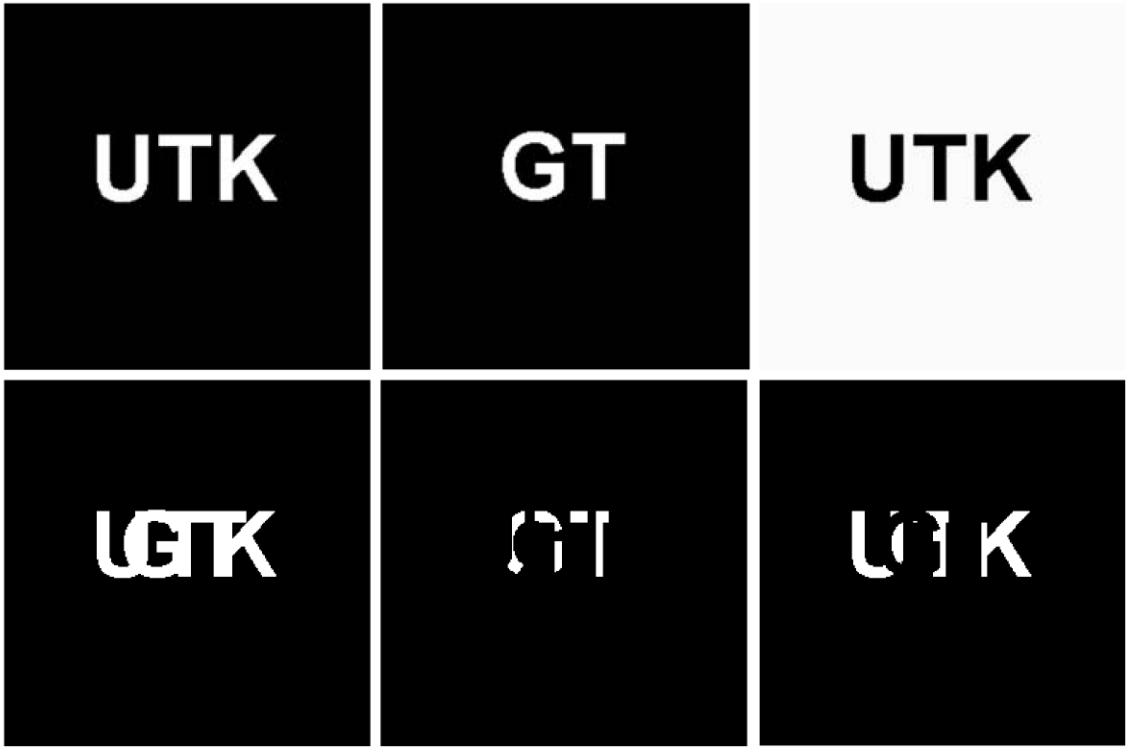
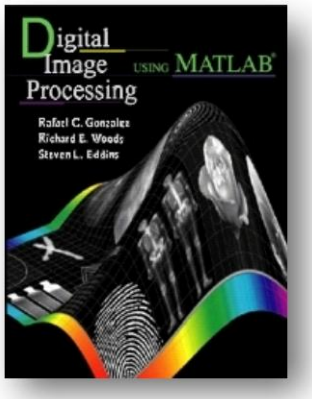
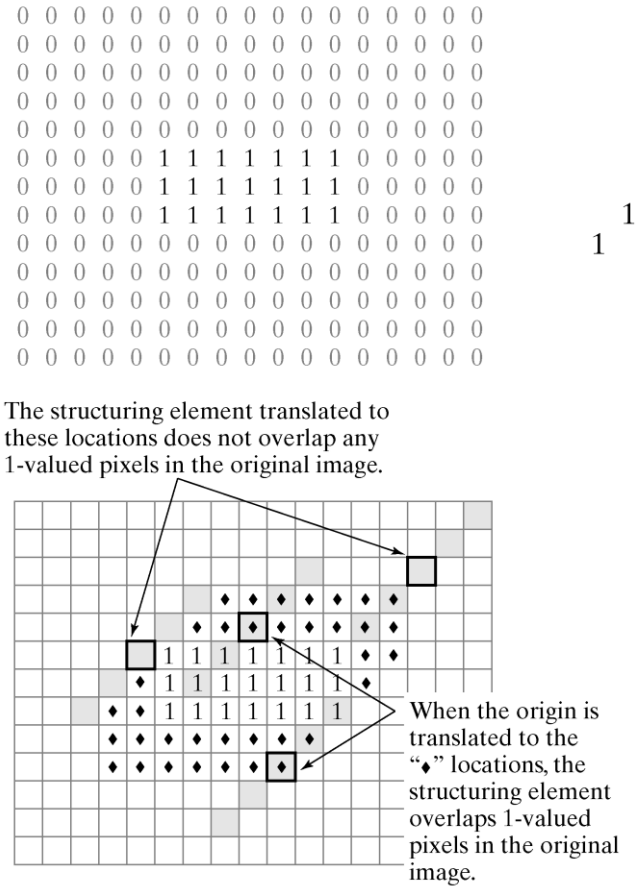


a b c
d e f

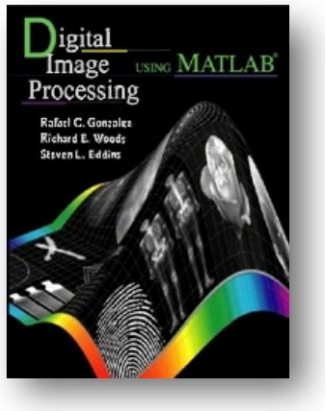
FIGURE 9.3 (a) Binary image A. (b) Binary image B. (c) Complement ~A. (d) Union A | B. (e) Intersection A & B. (f) Set difference A & ~B.





a b
c
d

FIGURE 9.4 Illustration of dilation. (a) Original image with rectangular object. (b) Structuring element with five pixels arranged in a diagonal line. The origin of the structuring element is shown with a dark border. (c) Structuring element translated to several locations on the image. (d) Output image.



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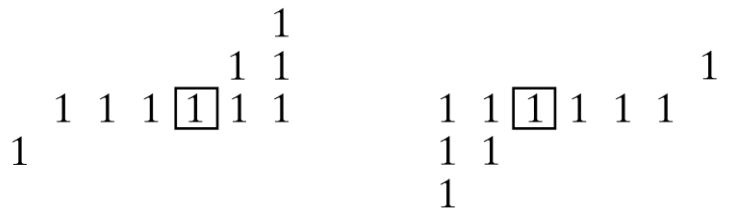
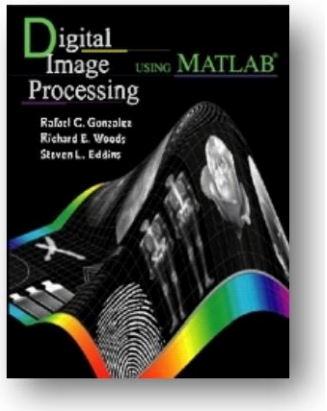


a b

FIGURE 9.5 Structuring element reflection. (a) Nonsymmetric structuring element. (b) Structuring element reflected about its origin.



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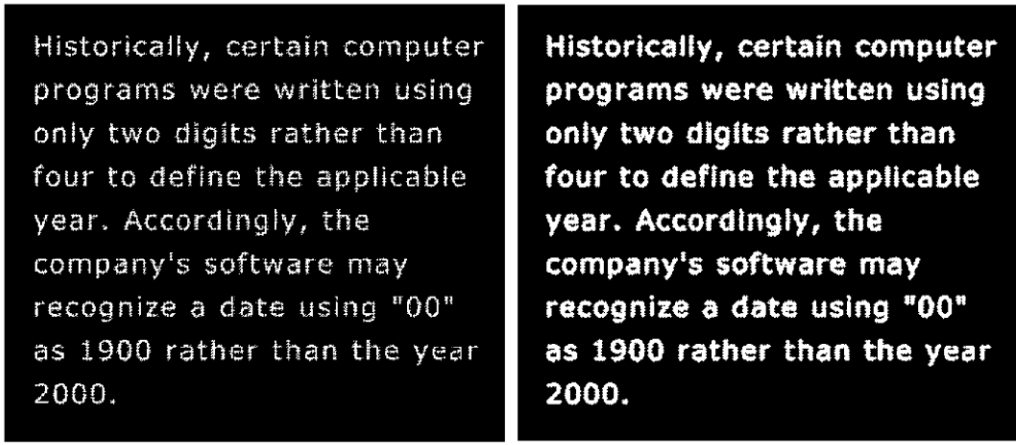
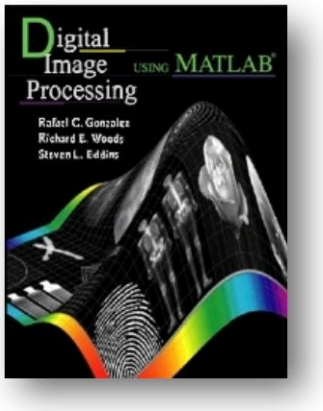


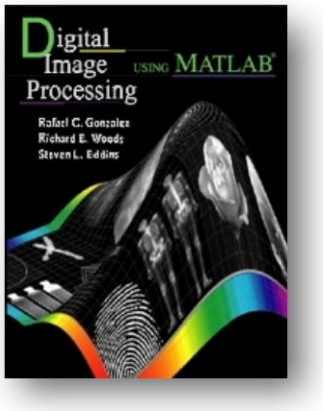
a b

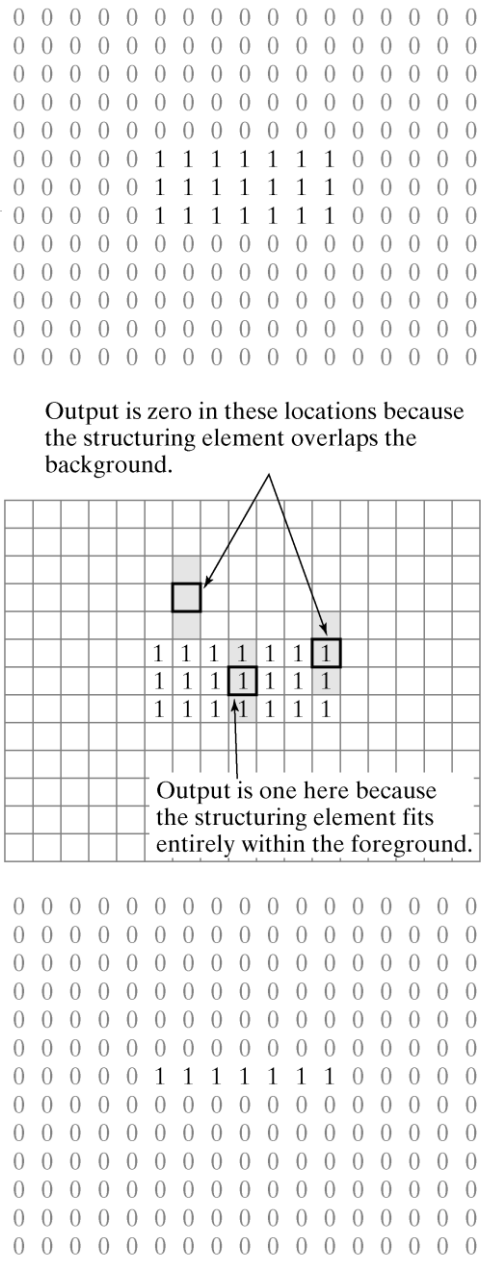
FIGURE 9.6
A simple example of dilation. (a) Input image containing broken text. (b) Dilated image.



Syntax Forms	Description
`se = strel('diamond', R)`	Creates a flat, diamond-shaped structuring element, where `R` specifies the distance from the structuring element origin to the extreme points of the diamond.
`se = strel('disk', R)`	Creates a flat, disk-shaped structuring element with radius `R`. (Additional parameters may be specified for the disk; see the `strel` help page for details.)
`se = strel('line', LEN, DEG)`	Creates a flat, linear structuring element, where `LEN` specifies the length, and `DEG` specifies the angle (in degrees) of the line, as measured in a counterclockwise direction from the horizontal axis.
`se = strel('octagon', R)`	Creates a flat, octagonal structuring element, where `R` specifies the distance from the structuring element origin to the sides of the octagon, as measured along the horizontal and vertical axes. `R` must be a nonnegative multiple of 3.
`se = strel('pair', OFFSET)`	Creates a flat structuring element containing two members. One member is located at the origin. The second member's location is specified by the vector `OFFSET`, which must be a two-element vector of integers.
`se = strel('periodicline', P, V)`	Creates a flat structuring element containing `2*P + 1` members. `V` is a two-element vector containing integer-valued row and column offsets. One structuring element member is located at the origin. The other members are located at `1*V`, `–1*V`, `2*V`, `–2*V`, `...`, `P*V`, and `–P*V`.
`se = strel('rectangle', MN)`	Creates a flat, rectangle-shaped structuring element, where `MN` specifies the size. `MN` must be a two-element vector of nonnegative integers. The first element of `MN` is the number rows in the structuring element; the second element is the number of columns.
`se = strel('square', W)`	Creates a square structuring element whose width is `W` pixels. `W` must be a nonnegative integer scalar.
`se = strel('arbitrary', NHOOD)` `se = strel(NHOOD)`	Creates a structuring element of arbitrary shape. NHOOD is a matrix of 0s and 1s that specifies the shape. The second, simpler syntax form shown performs the same operation.

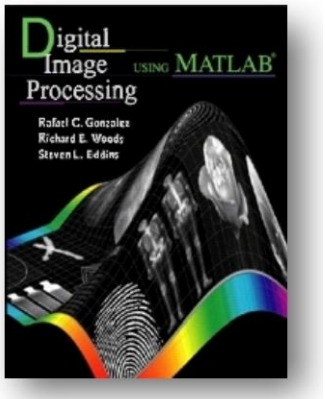
TABLE 9.2
The various syntax forms of function `strel`. (The word *flat* means that the structuring element has zero height. This is meaningful only for gray-scale dilation and erosion. See Section 9.6.1.)





a b
c
d

FIGURE 9.7 Illustration of erosion. (a) Original image with rectangular object. (b) Structuring element with three pixels arranged in a vertical line. The origin of the structuring element is shown with a dark border. (c) Structuring element translated to several locations on the image. (d) Output image.



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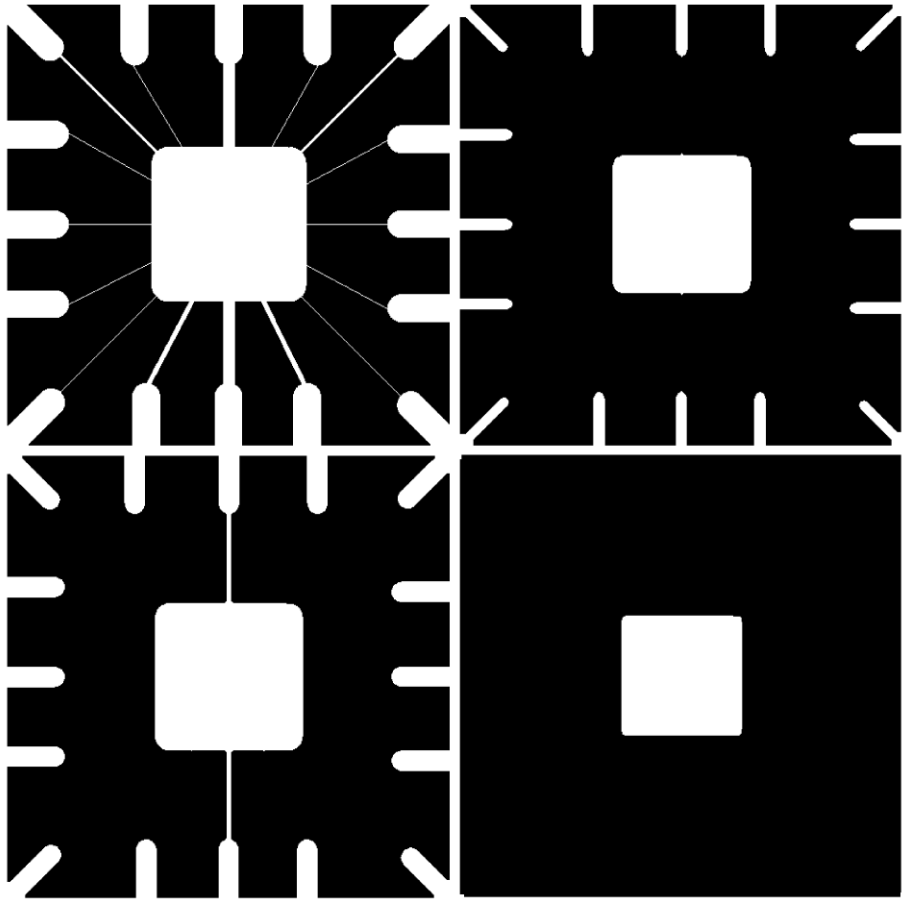
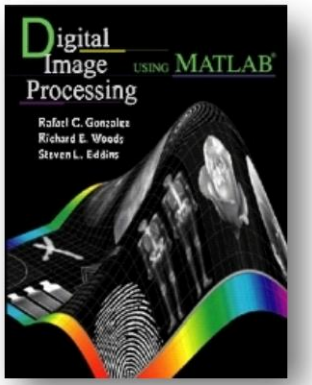


a b
c d

FIGURE 9.8 An illustration of erosion. (a) Original image. (b) Erosion with a disk of radius 10. (c) Erosion with a disk of radius 5. (d) Erosion with a disk of radius 20.



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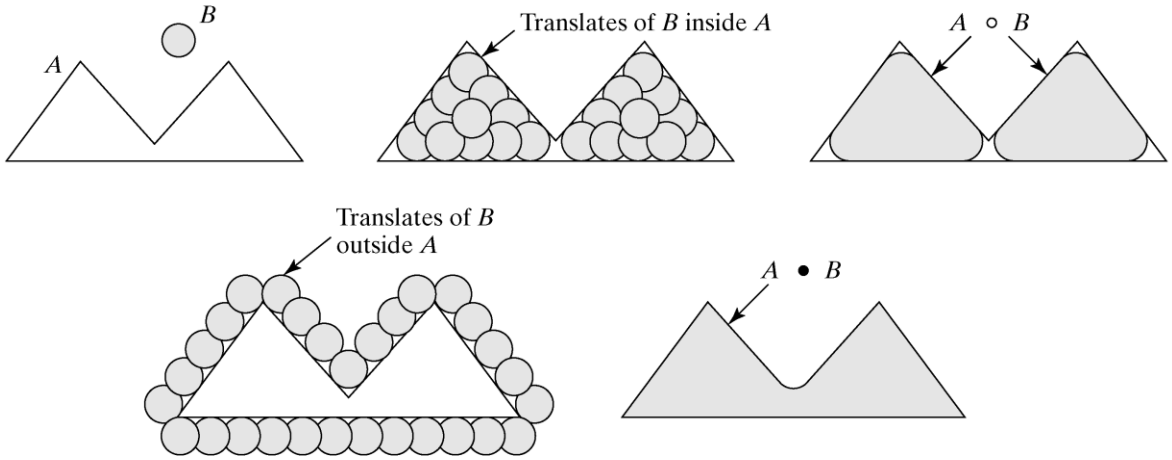
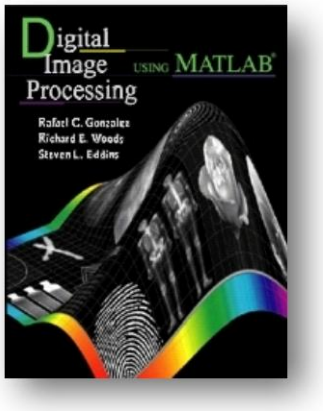


a b c
d e

FIGURE 9.9 Opening and closing as unions of translated structuring elements. (a) Set A and structuring element B. (b) Translations of B that fit entirely within set A. (c) The complete opening (shaded). (d) Translations of B outside the border of A. (e) The complete closing (shaded).



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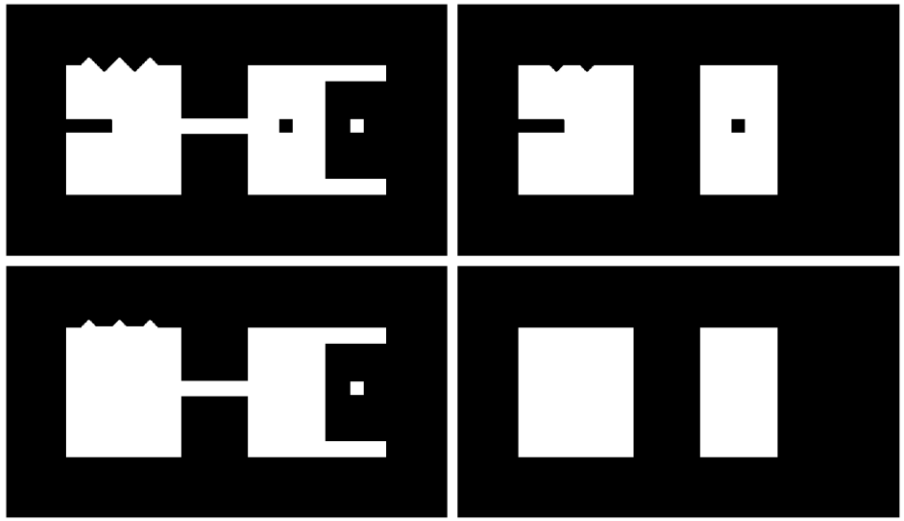
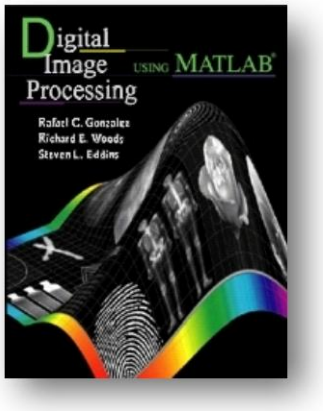


a b
c d

FIGURE 9.10 Illustration of opening and closing. (a) Original image. (b) Opening. (c) Closing. (d) Closing of (b).



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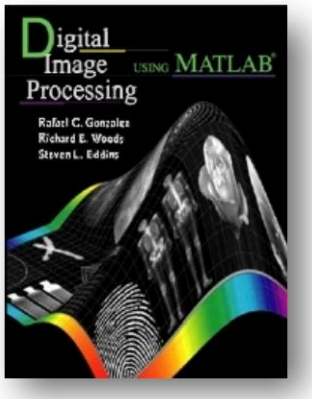
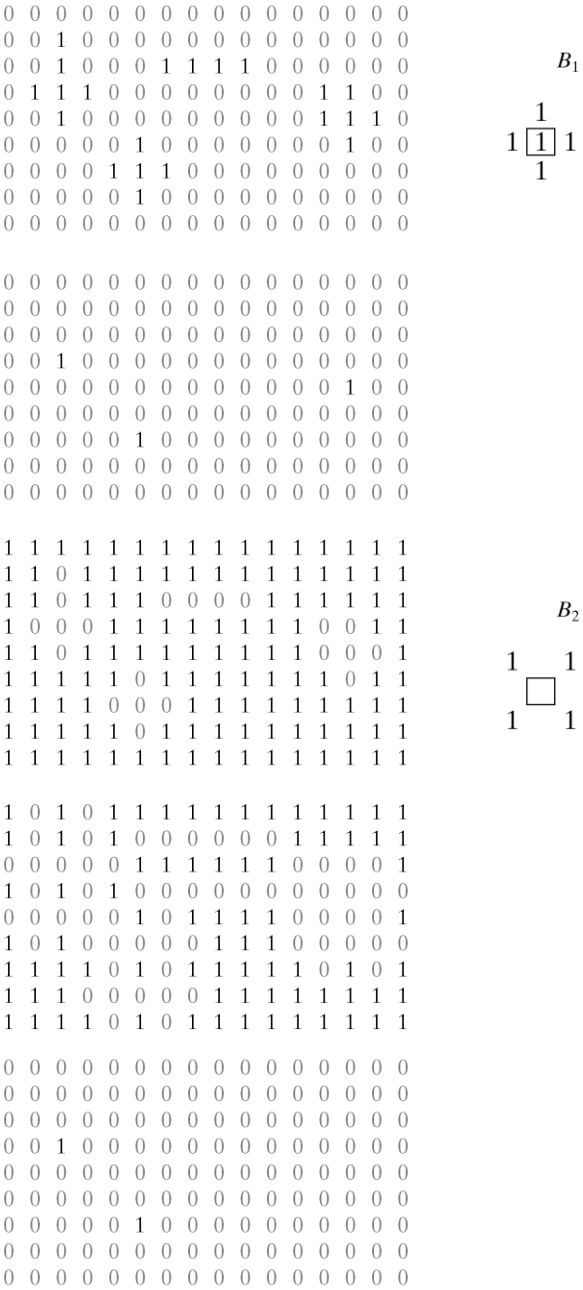
a b c

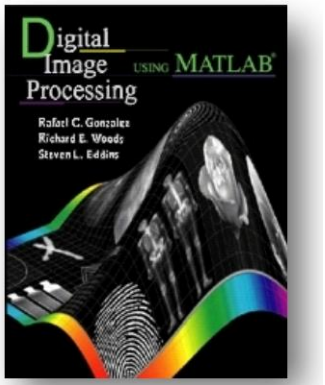
FIGURE 9.11 (a) Noisy fingerprint image. (b) Opening of image. (c) Opening followed by closing. (Original image courtesy of the National Institute of Standards and Technology.)





a b
c
d e
f
g

FIGURE 9.12
(a) Original image A. (b) Structuring element B_1. (c) Erosion of A by B_1. (d) Complement of the original image, A^c. (e) Structuring element B_2. (f) Erosion of A^c by B_2. (g) Output image.



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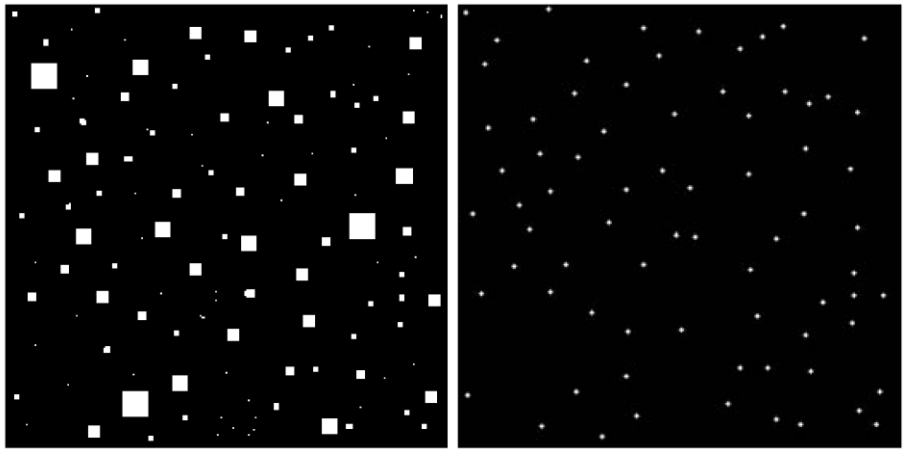
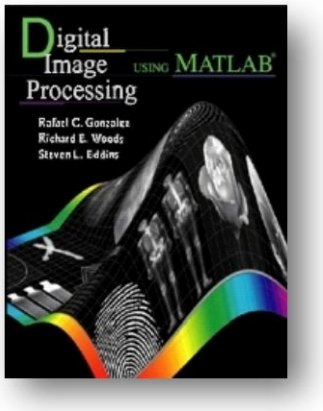


a b

FIGURE 9.13
(a) Original image. (b) Result of applying the hit-or-miss transformation (the dots shown were enlarged to facilitate viewing).



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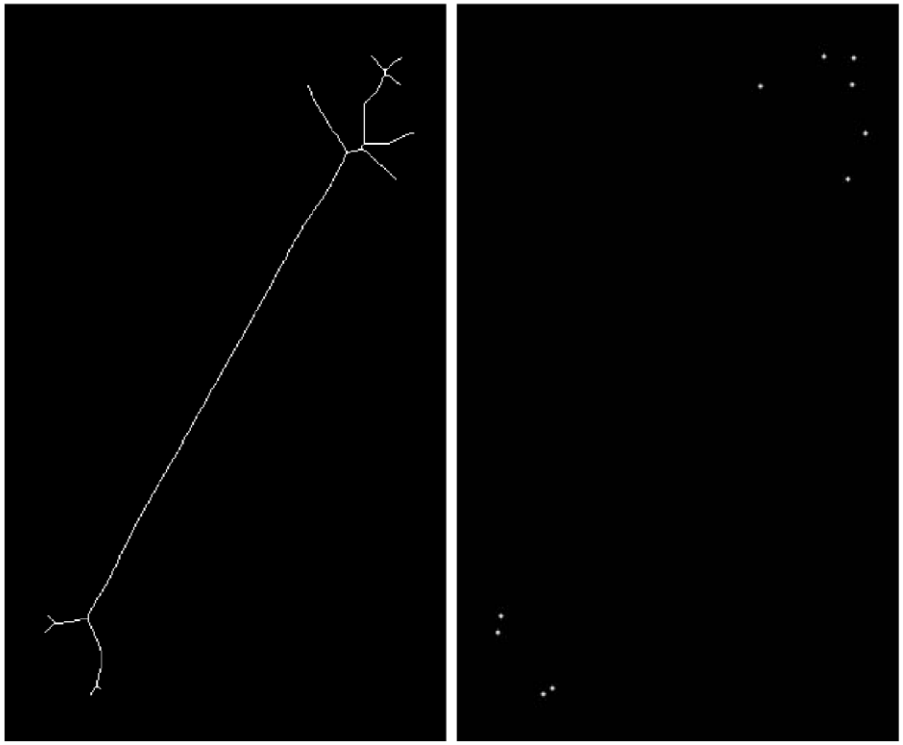
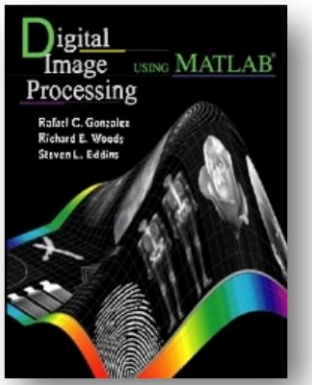


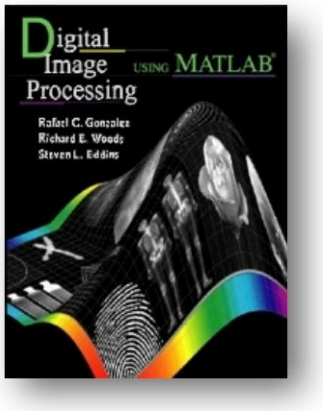
a b

FIGURE 9.14
(a) Image of a morphological skeleton.
(b) Output of function `endpoints`. The pixels in (b) were enlarged for clarity.



Operation	Description
`bothat`	"Bottom-hat" operation using a 3×3 structuring element; use `imbothat` (see Section 9.6.2) for other structuring elements.
`bridge`	Connect pixels separated by single-pixel gaps.
`clean`	Remove isolated foreground pixels.
`close`	Closing using a 3×3 structuring element; use `imclose` for other structuring elements.
`diag`	Fill in around diagonally connected foreground pixels.
`dilate`	Dilation using a 3×3 structuring element; use `imdilate` for other structuring elements.
`erode`	Erosion using a 3×3 structuring element; use `imerode` for other structuring elements.
`fill`	Fill in single-pixel "holes" (background pixels surrounded by foreground pixels); use `imfill` (see Section 11.1.2) to fill in larger holes.
`hbreak`	Remove H-connected foreground pixels.
`majority`	Make pixel p a foreground pixel if at least five pixels in $N_8(p)$ (see Section 9.4) are foreground pixels; otherwise make p a background pixel.
`open`	Opening using a 3×3 structuring element; use function `imopen` for other structuring elements.
`remove`	Remove "interior" pixels (foreground pixels that have no background neighbors).
`shrink`	Shrink objects with no holes to points; shrink objects with holes to rings.
`skel`	Skeletonize an image.
`spur`	Remove spur pixels.
`thicken`	Thicken objects without joining disconnected 1s.
`thin`	Thin objects without holes to minimally connected strokes; thin objects with holes to rings.
`tophat`	"Top-hat" operation using a 3×3 structuring element; use `imtophat` (see Section 9.6.2) for other structuring elements.

TABLE 9.3 Operations supported by function `bwmorph`.



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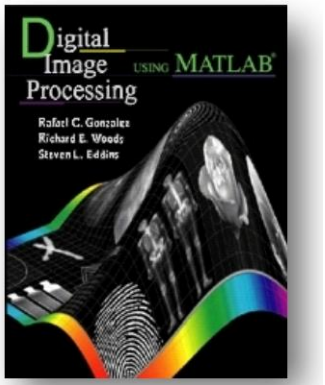
a b c

FIGURE 9.15 (a) Fingerprint image from Fig. 9.11(c) thinned once. (b) Image thinned twice. (c) Image thinned until stability.



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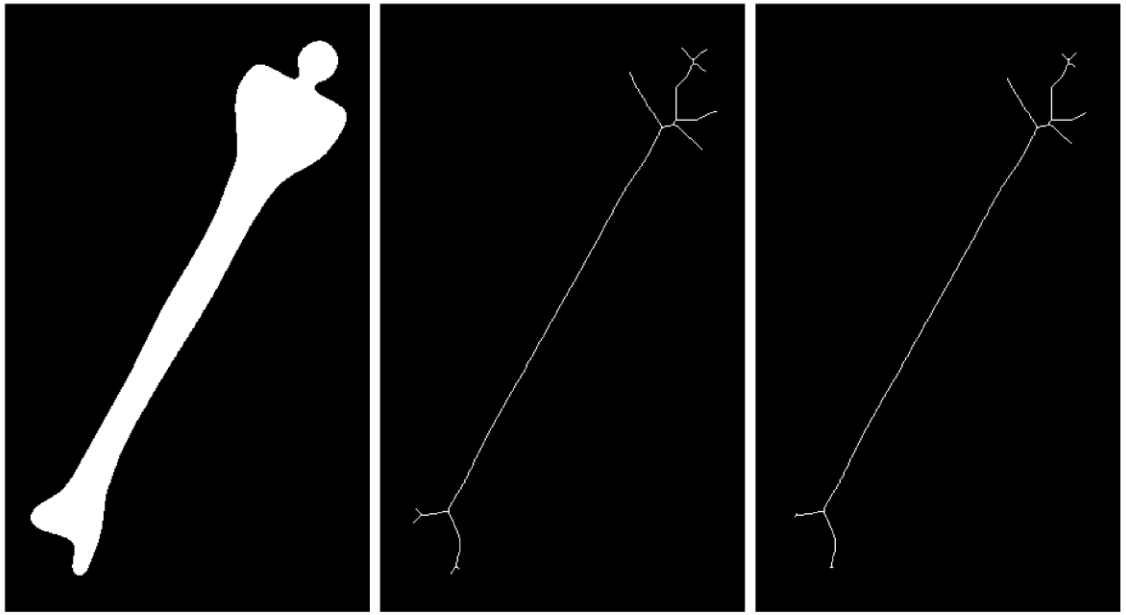
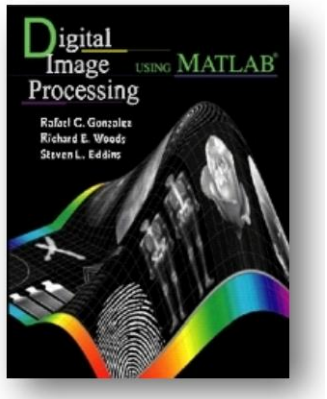


a b c

FIGURE 9.16 (a) Bone image. (b) Skeleton obtained using function `bwmorph`. (c) Resulting skeleton after pruning with function `endpoints`.



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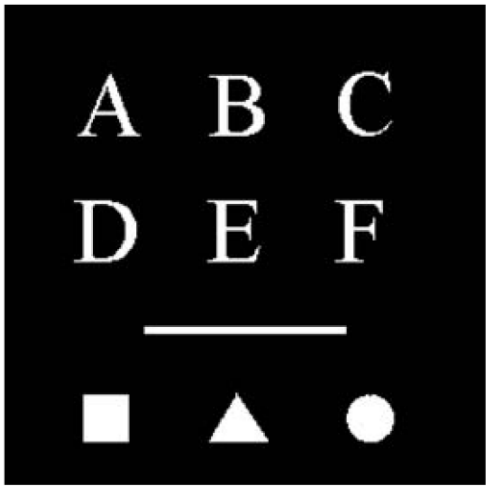
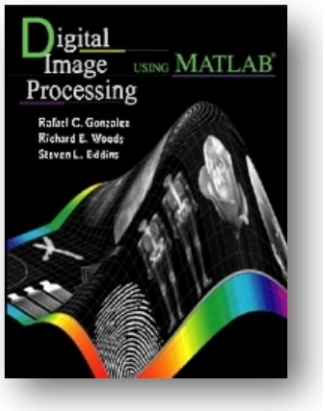


0	1	1	1	0	0	0	0	0	0
0	0	1	1	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	1	1	0	0
0	0	0	0	0	0	1	1	0	0
0	0	0	0	0	1	1	0	0	0

a b

FIGURE 9.17
(a) Image containing ten objects. (b) A subset of pixels from the image.



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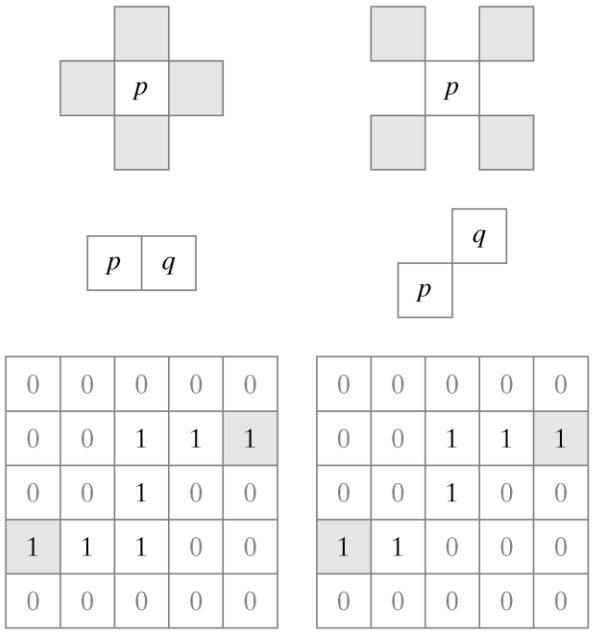
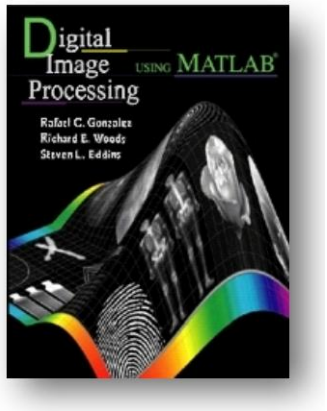


a b c
d e
f g

FIGURE 9.18 (a) Pixel p and its 4-neighbors, $N_4(p)$. (b) Pixel p and its diagonal neighbors, $N_D(p)$. (c) Pixel p and its 8-neighbors, $N_8(p)$. (d) Pixels p and q are 4-adjacent and 8-adjacent. (e) Pixels p and q are 8-adjacent but not 4-adjacent. (f) The shaded pixels are both 4-connected and 8-connected. (g) The shaded foreground pixels are 8-connected but not 4-connected.



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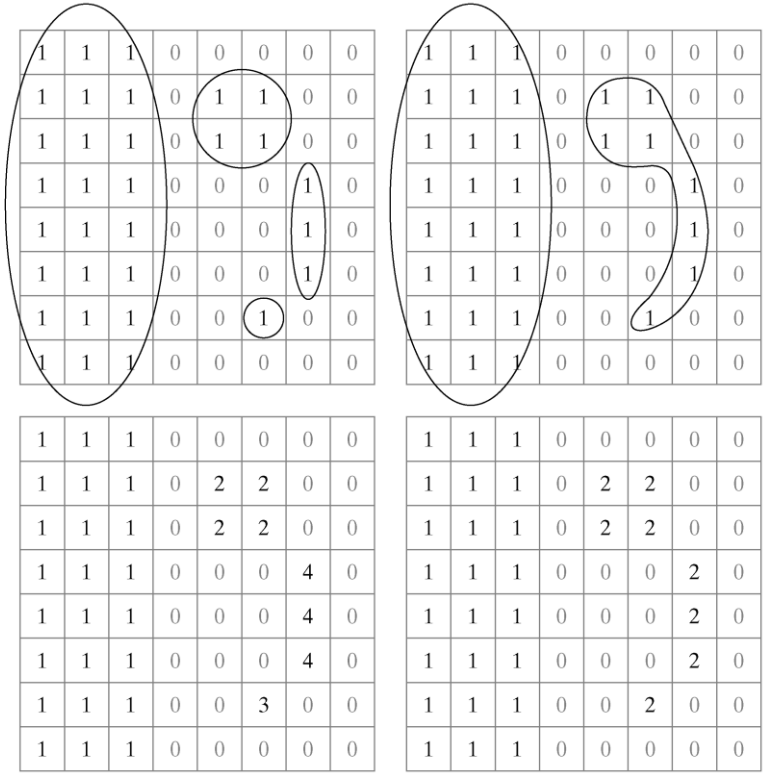
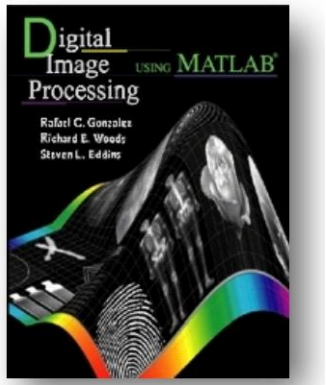


a b
c d

FIGURE 9.19 Connected components (a) Four 4-connected components. (b) Two 8-connected components. (c) Label matrix obtained using 4-connectivity (d) Label matrix obtained using 8-connectivity.



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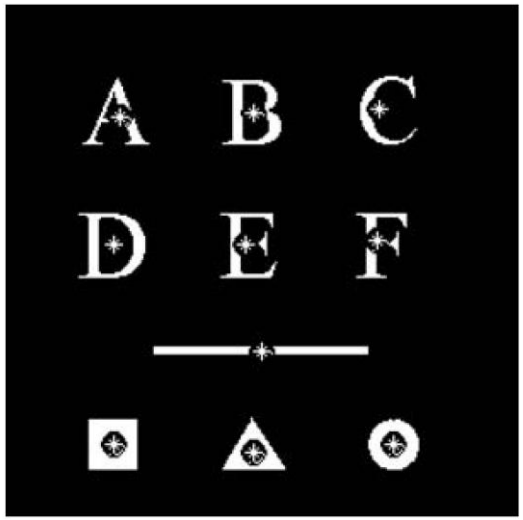
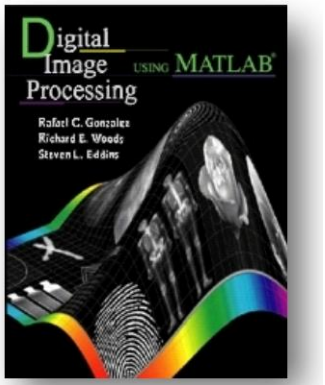


FIGURE 9.20 Centers of mass (white asterisks) shown superimposed on their corresponding connected components.



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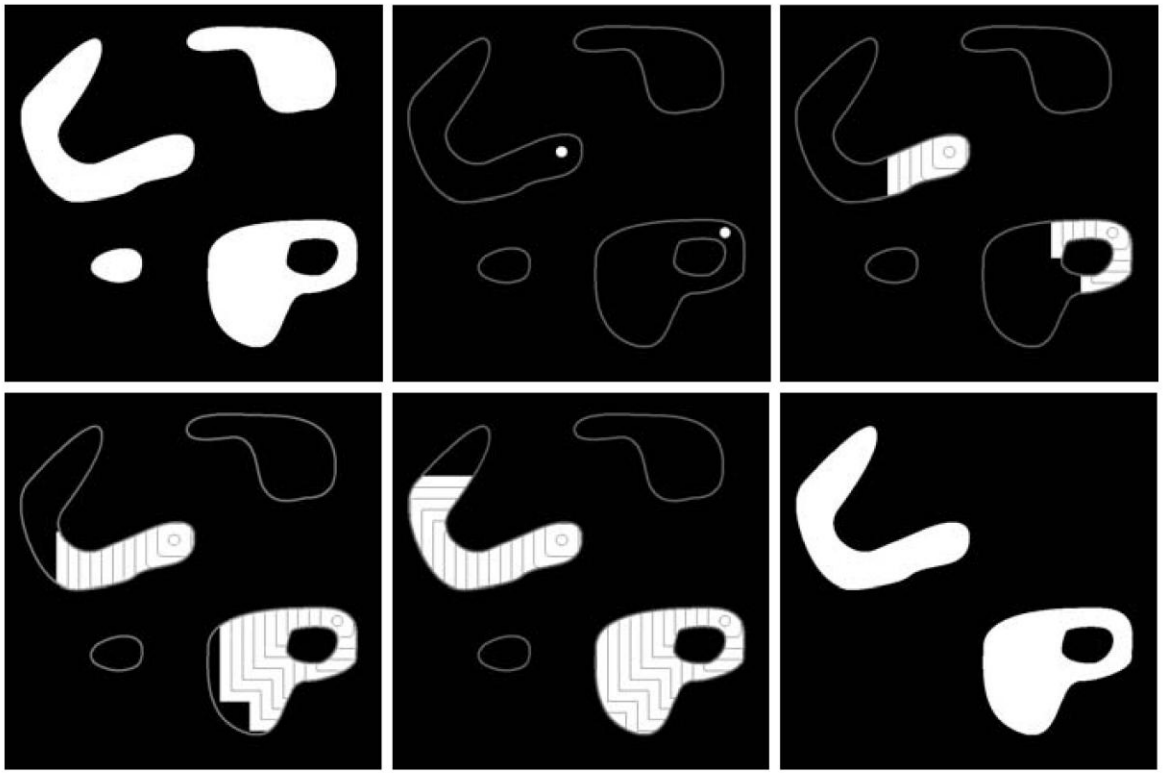
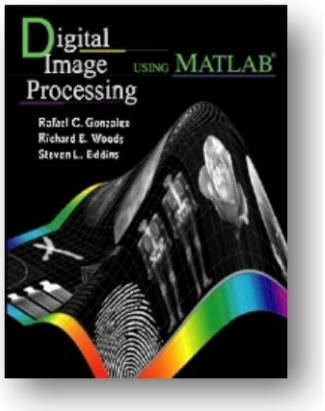


a b c
d e f

FIGURE 9.21 Morphological reconstruction. (a) Original image (the mask). (b) Marker image. (c)–(e) Intermediate result after 100, 200, and 300 iterations, respectively. (f) Final result. [The outlines of the objects in the mask image are superimposed on (b)–(e) as visual references.]



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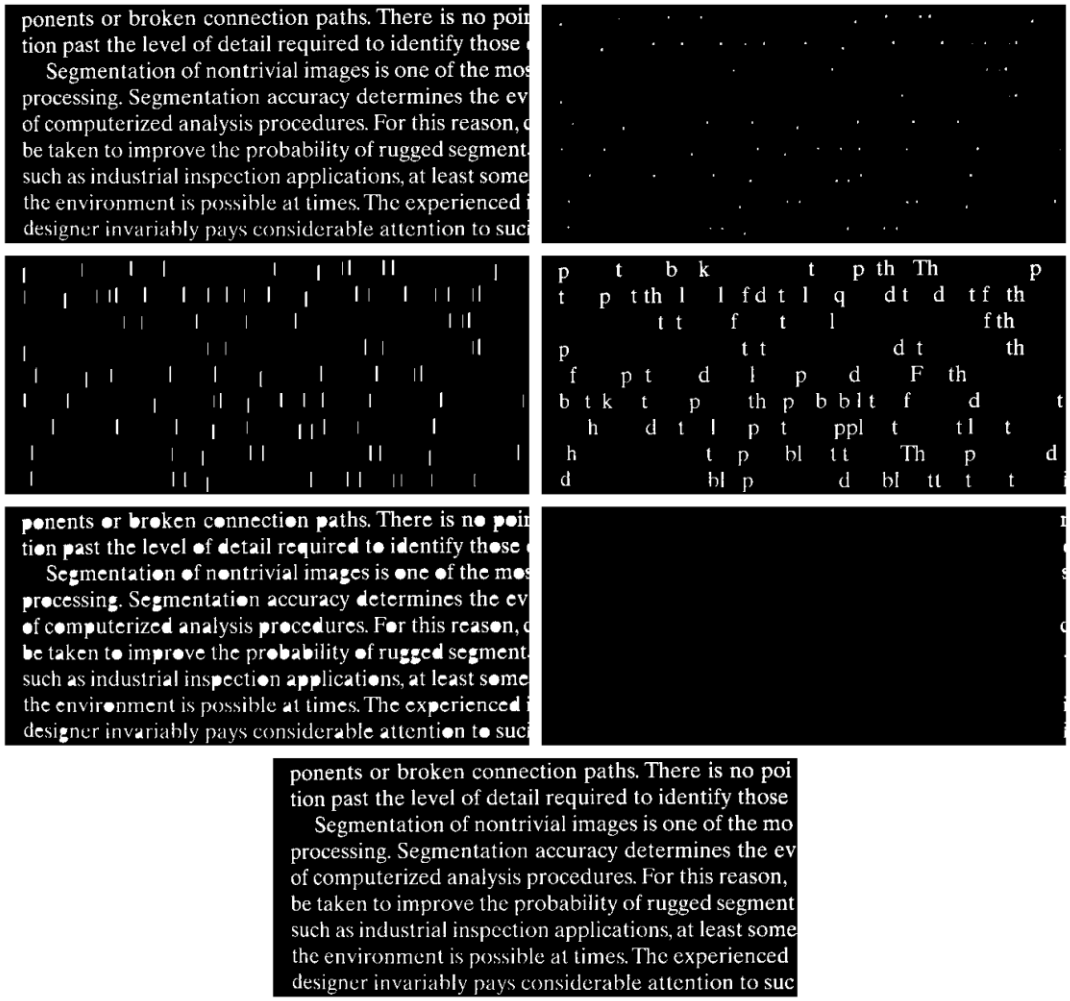
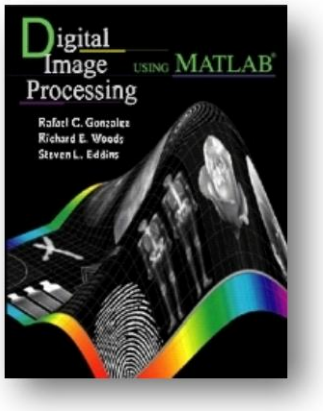


a b
c d
e f
g

FIGURE 9.22 Morphological reconstruction: (a) Original image. (b) Eroded with vertical line. (c) Opened with a vertical line. (d) Opened by reconstruction with a vertical line. (e) Holes filled. (f) Characters touching the border (see right border). (g) Border characters removed.



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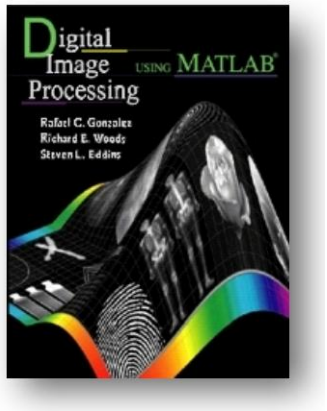
a b
c d

FIGURE 9.23 Dilation and erosion. (a) Original image. (b) Dilated image. (c) Eroded image. (d) Morphological gradient. (Original image courtesy of NASA.)



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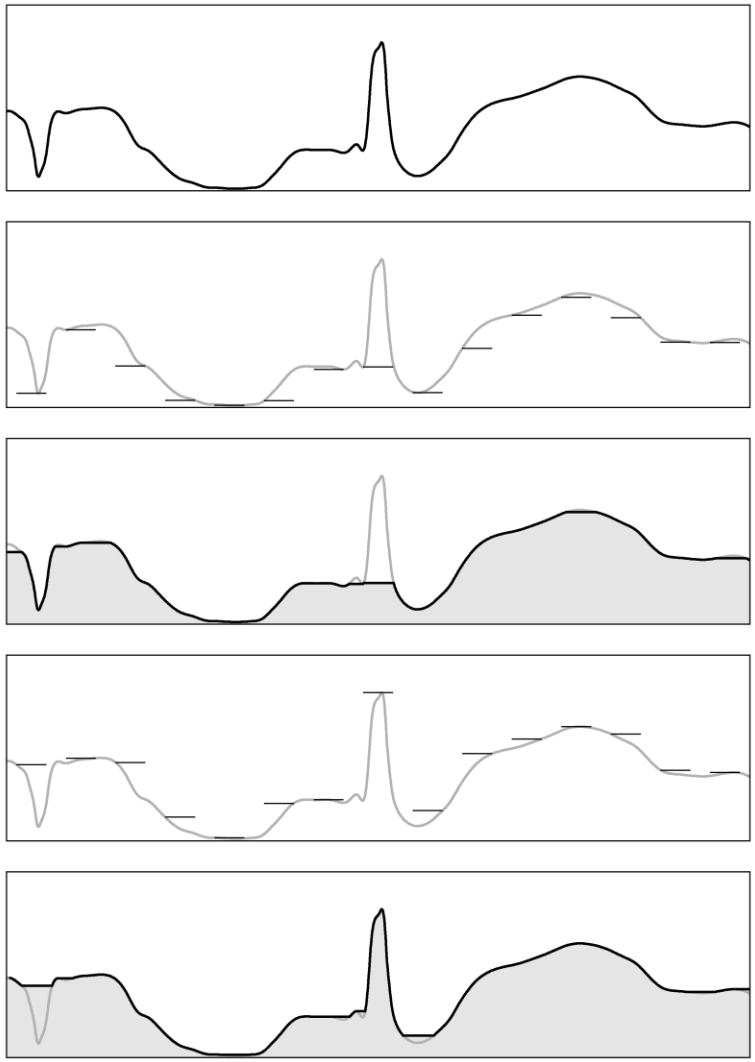
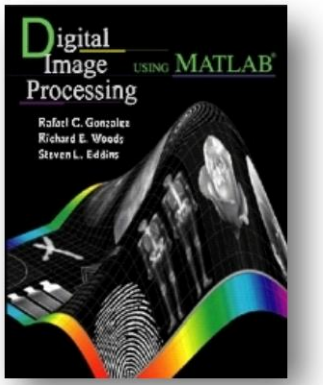


a
b
c
d
e

FIGURE 9.24 Opening and closing in one dimension. (a) Original 1-D signal. (b) Flat structuring element pushed up underneath the signal. (c) Opening. (d) Flat structuring element pushed down along the top of the signal. (e) Closing.



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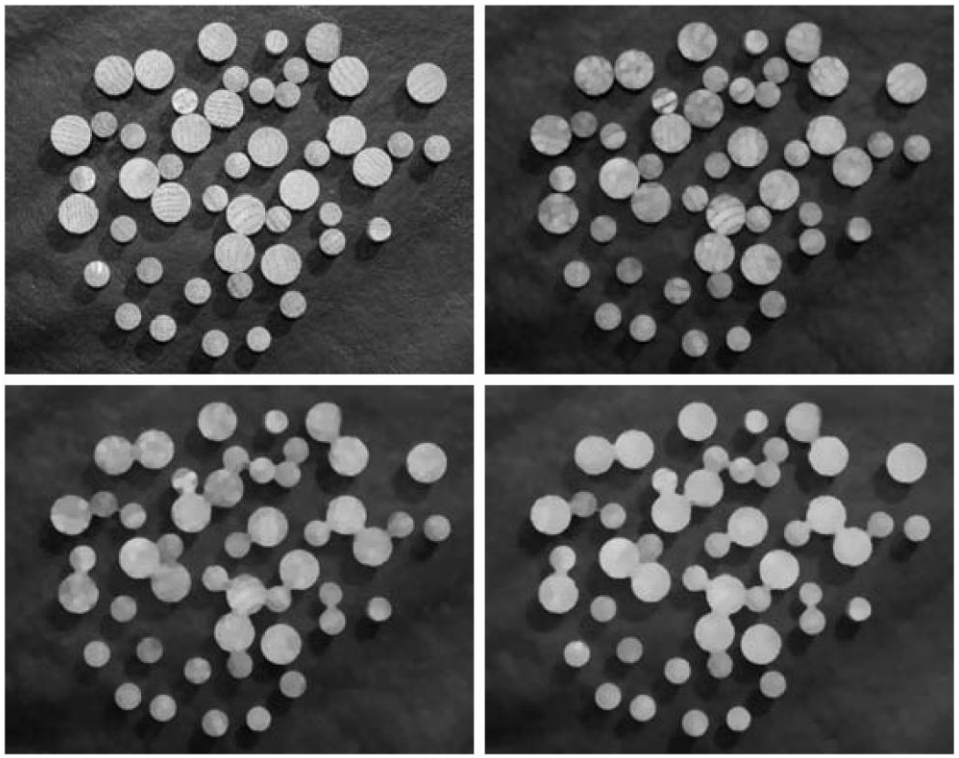
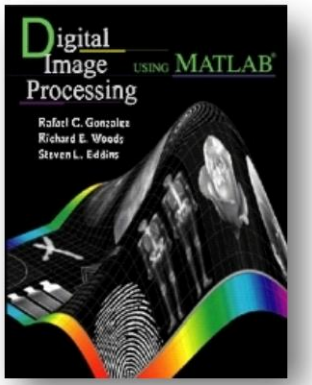


a b
c d

FIGURE 9.25
Smoothing using openings and closings. (a) Original image of wood dowel plugs. (b) Image opened using a disk of radius 5. (c) Closing of the opening. (d) Alternating sequential filter result.



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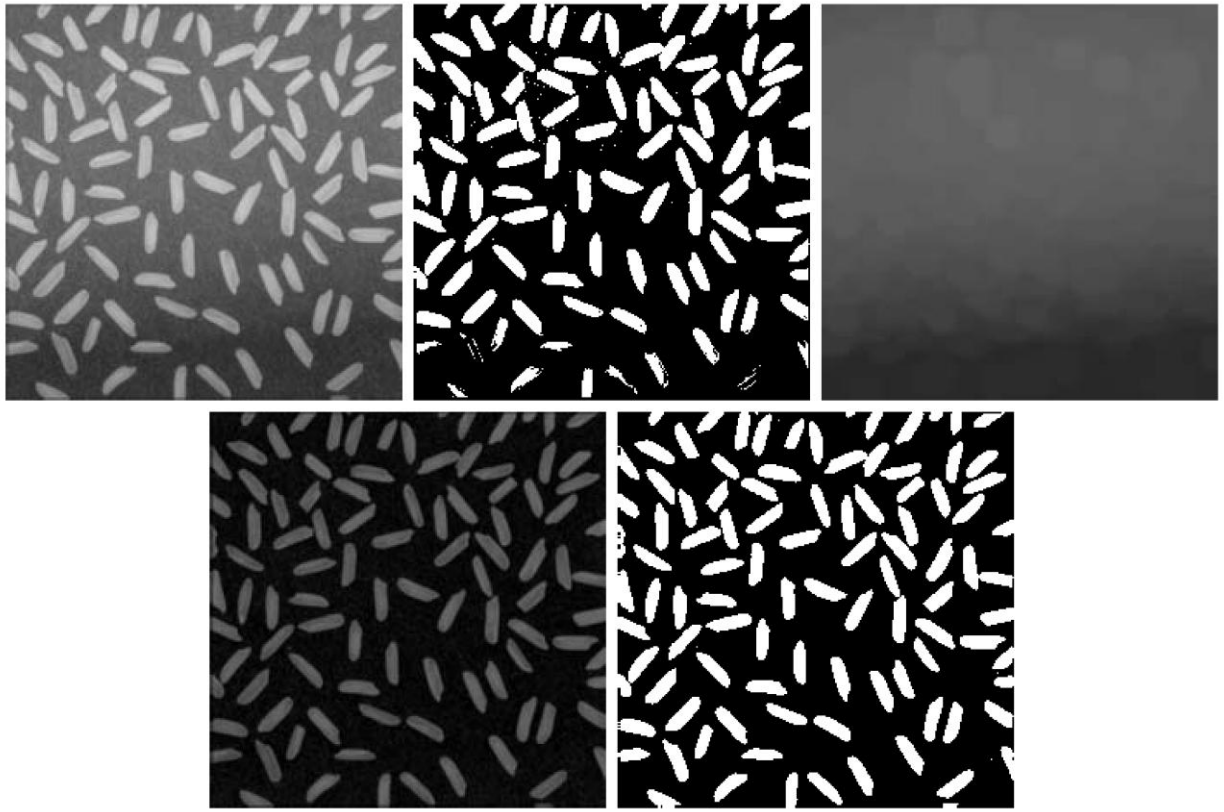
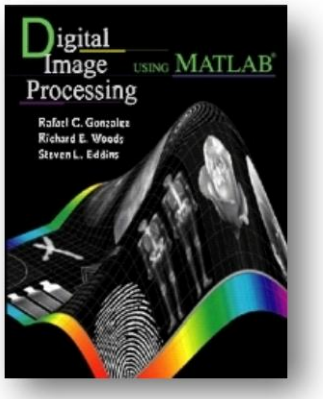


a b c
d e

FIGURE 9.26 Top-hat transformation. (a) Original image. (b) Thresholded image. (c) Opened image. (d) Top-hat transformation. (e) Thresholded top-hat image. (Original image courtesy of The MathWorks, Inc.)



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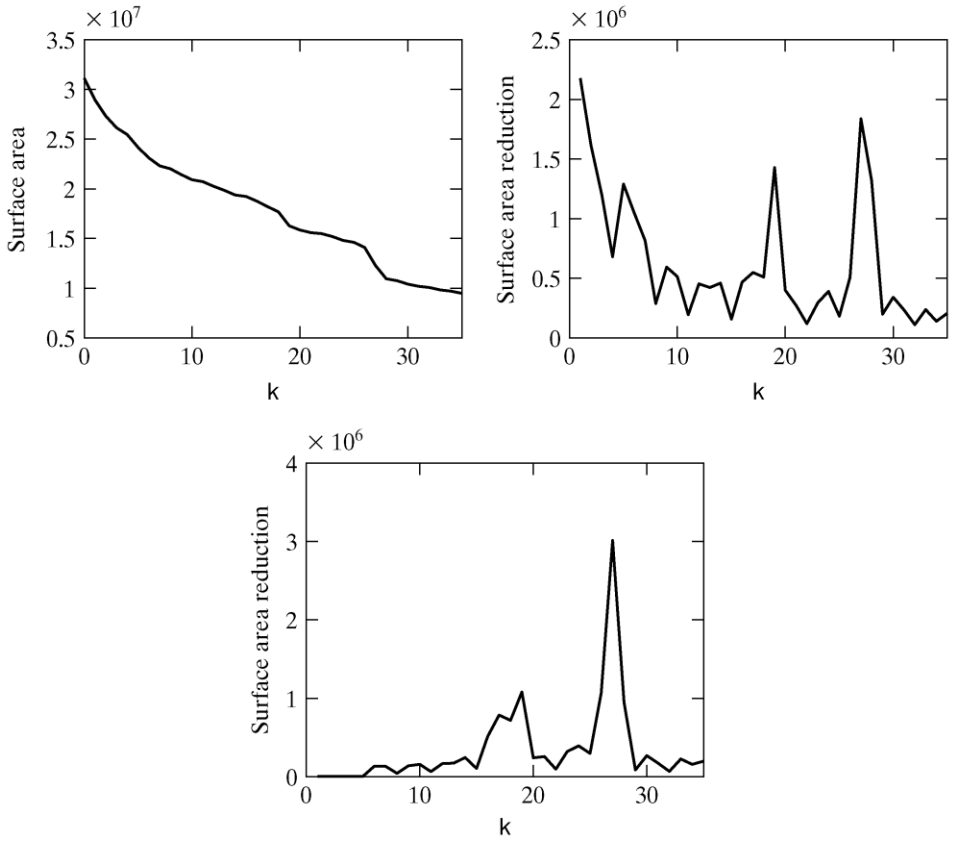
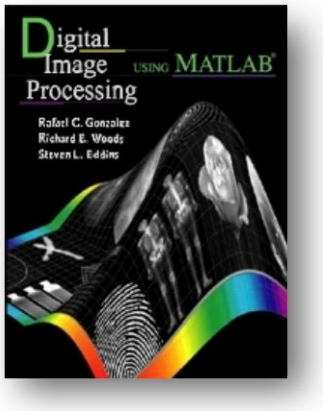


a b
c

FIGURE 9.27 Granulometry. (a) Surface area versus structuring element radius. (b) Reduction in surface area versus radius. (c) Reduction in surface area versus radius for a smoothed image.



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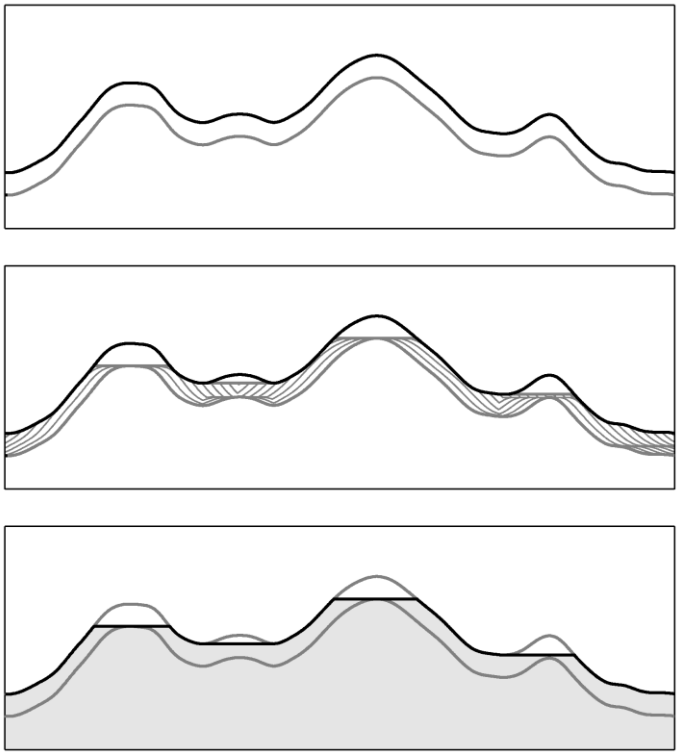
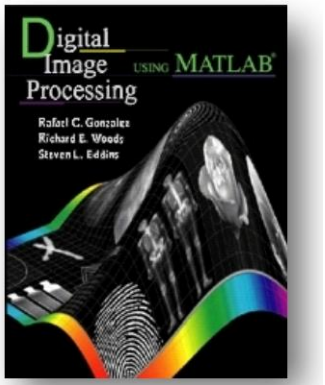


a
b
c

FIGURE 9.28 Gray-scale morphological reconstruction in one dimension. (a) Mask (top) and marker curves. (b) Iterative computation of the reconstruction. (c) Reconstruction result (black curve).



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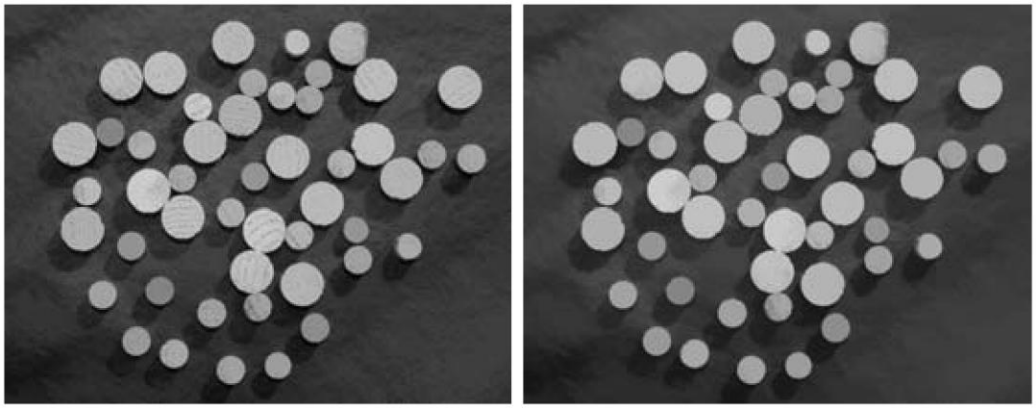
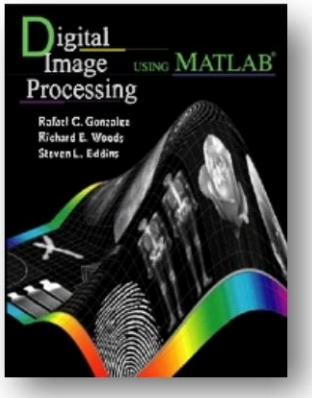
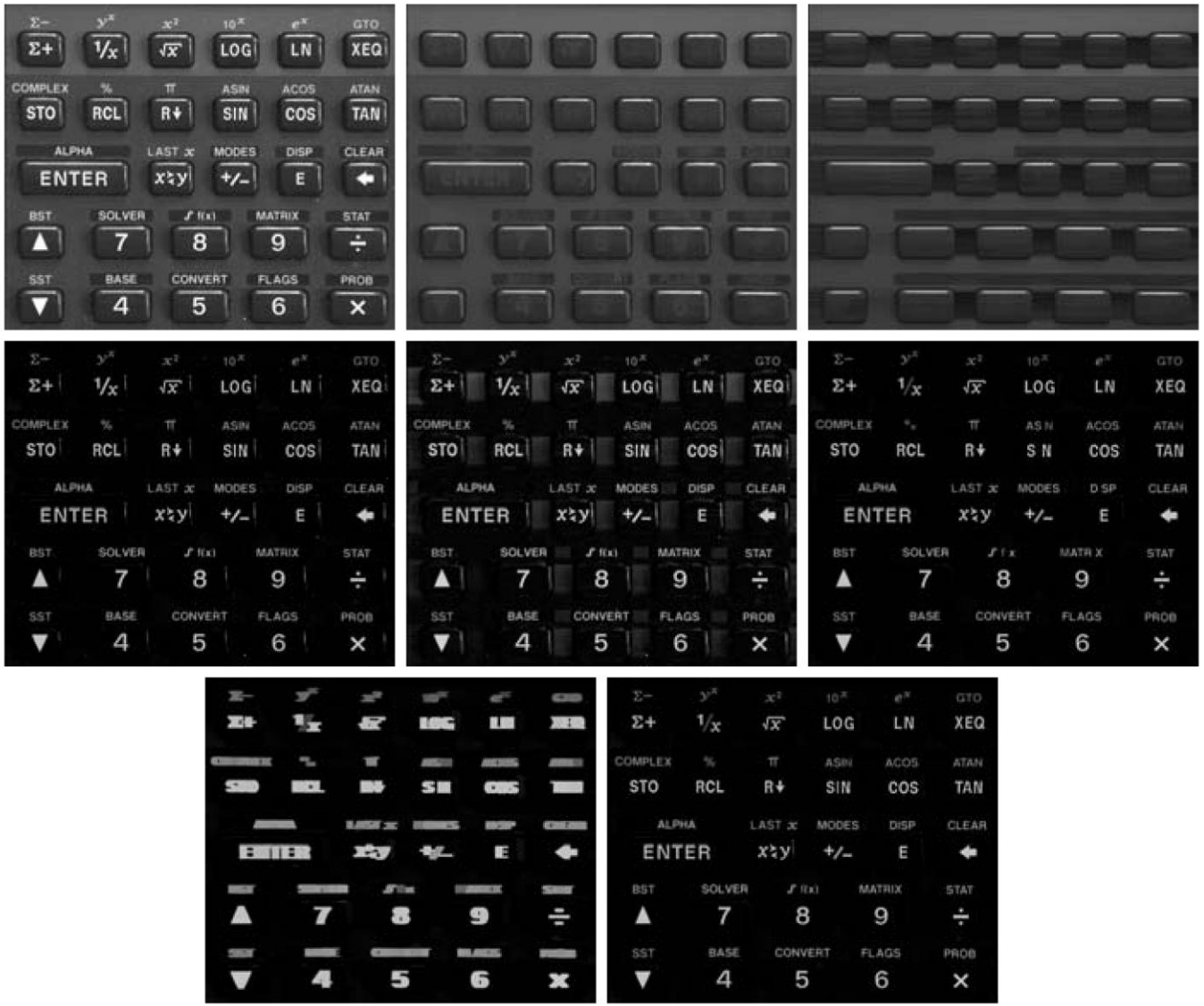


a b

FIGURE 9.29
(a) Opening-by-reconstruction. (b) Opening-by-reconstruction followed by closing-by-reconstruction.





a b c
d e f
g h

FIGURE 9.30 An application of gray-scale reconstruction. (a) Original image. (b) Opening-by-reconstruction. (c) Opening. (d) Tophat-by-reconstruction. (e) Tophat. (f) Opening-by-reconstruction of (d) using a horizontal line. (g) Dilation of (f) using a horizontal line. (h) Final reconstruction result.