

Morphological Image Processing

ICT4201: DIP
Part 1: Binary Image

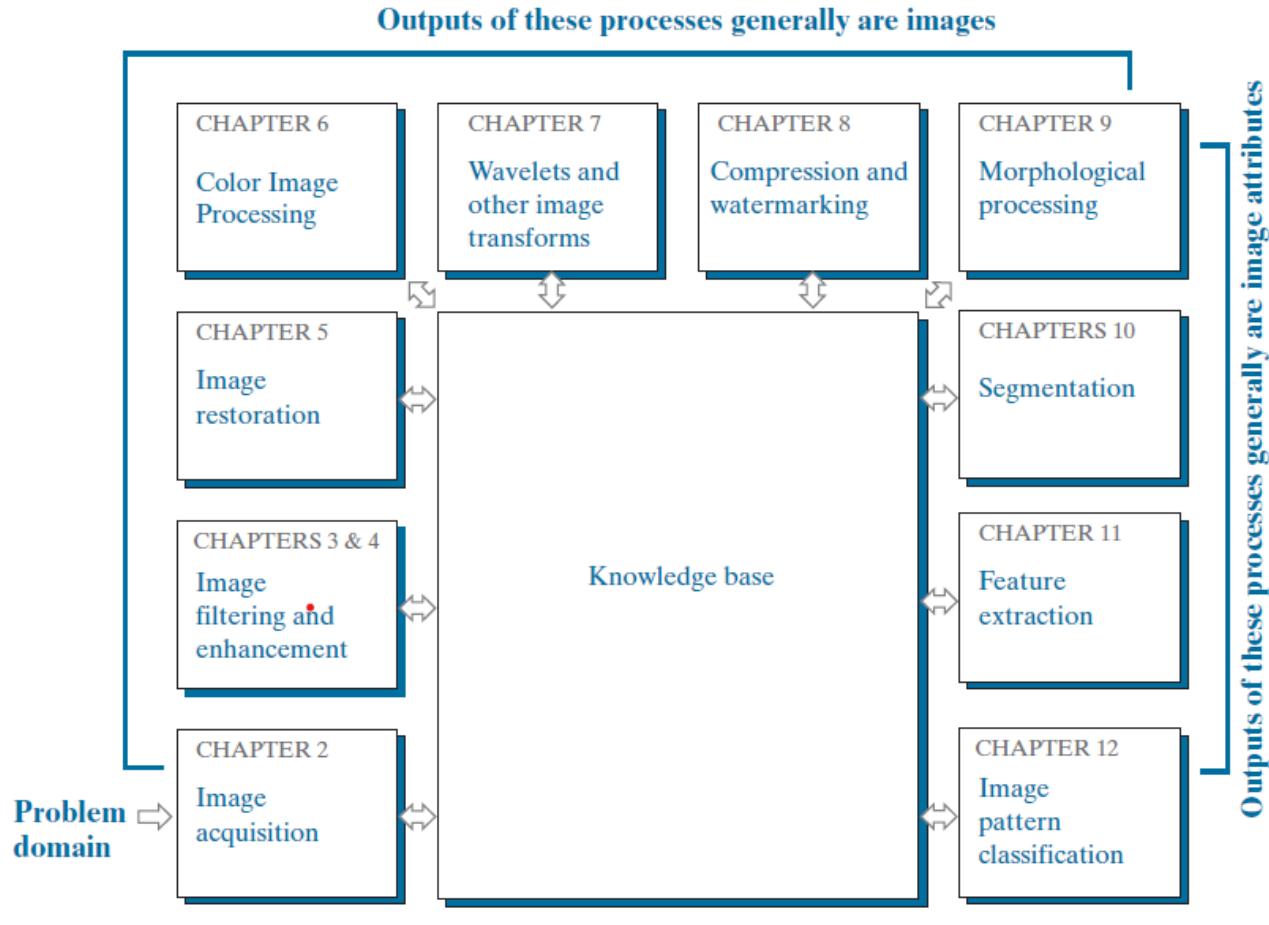
Introduction

- ▶ **Morphology:** a branch of biology that deals with the form and structure of animals and plants
- ▶ Morphological image processing or mathematical morphology is used to extract image components for representation and description of region shape, such as boundaries, skeletons, and the convex hull

Fundamental Steps of DIP

FIGURE 1.23

Fundamental steps in digital image processing. The chapter(s) indicated in the boxes is where the material described in the box is discussed.



Preliminaries (1)

► Reflection

The reflection of a set B , denoted \hat{B} , is defined as

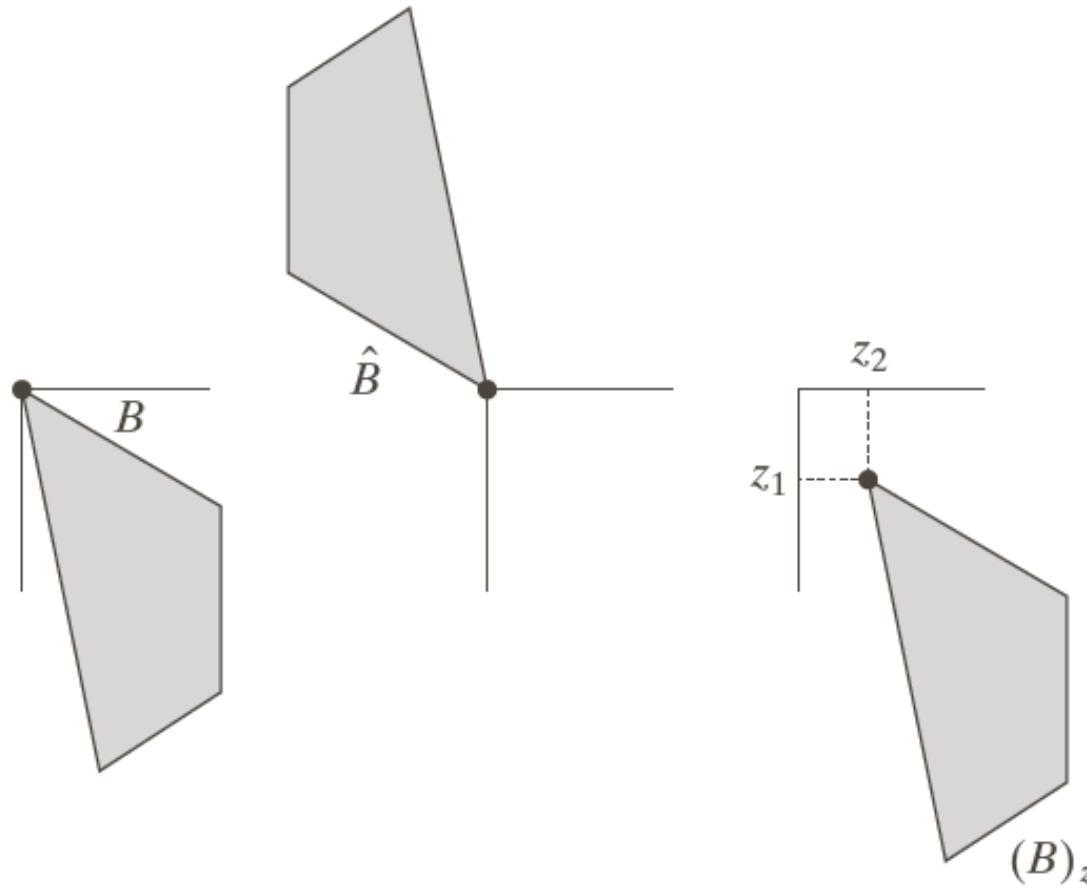
$$\hat{B} = \{w \mid w = -b, \text{for } b \in B\}$$

► Translation

The translation of a set B by point $z = (z_1, z_2)$, denoted $(B)_z$, is defined as

$$(B)_z = \{c \mid c = b + z, \text{for } b \in B\}$$

Example: Reflection and Translation



a | b | c

FIGURE 9.1

(a) A set, (b) its reflection, and (c) its translation by z .

Preliminaries (2)

► **Structure elements (SE)**

Small sets or sub-images used to probe an image under study for properties of interest

Examples: Structuring Elements (1)

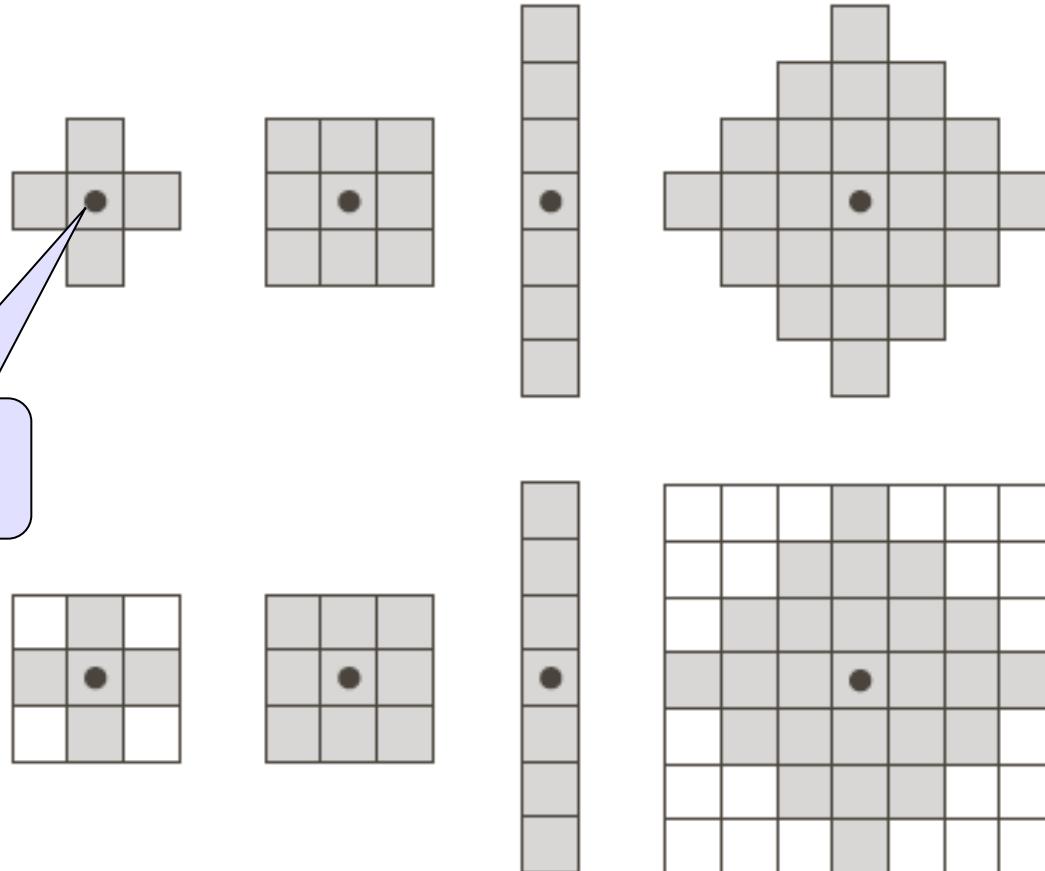
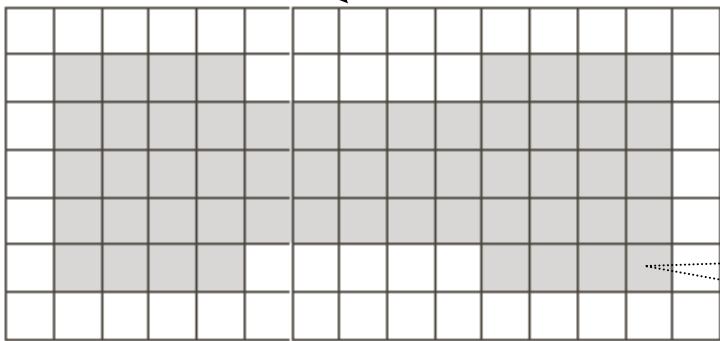
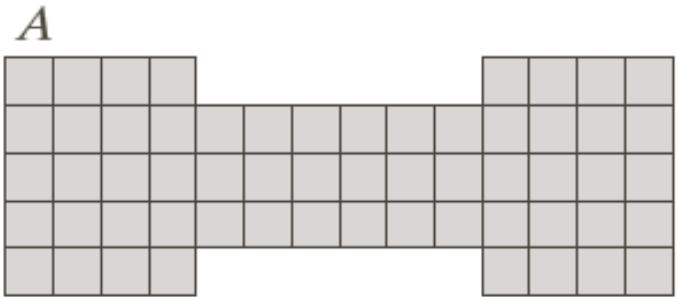


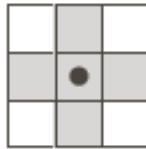
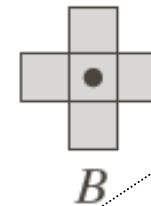
FIGURE 9.2 First row: Examples of structuring elements. Second row: Structuring elements converted to rectangular arrays. The dots denote the centers of the SEs.

Examples: Structuring Elements (2)

Accommodate the entire structuring elements when its origin is on the border of the original set A



a b
c d e



Origin of B visits every element of A

At each location of the origin of B, if B is completely contained in A, then the location is a member of the new set, otherwise it is not a member of the new set.

FIGURE 9.3 (a) A set (each shaded square is a member of the set). (b) A structuring element. (c) The set padded with background elements to form a rectangular array and provide a background border. (d) Structuring element as a rectangular array. (e) Set processed by the structuring element.

Erosion

With A and B as sets in \mathbb{Z}^2 , the erosion of A by B , denoted $A \ominus B$, defined

$$A \ominus B = \{z \mid (B)_z \subseteq A\}$$

The set of all points z such that B , translated by z , is contained by A .

$$A \ominus B = \{z \mid (B)_z \cap A^c = \emptyset\}$$

Example of Erosion (1)

a	b	c
d		e

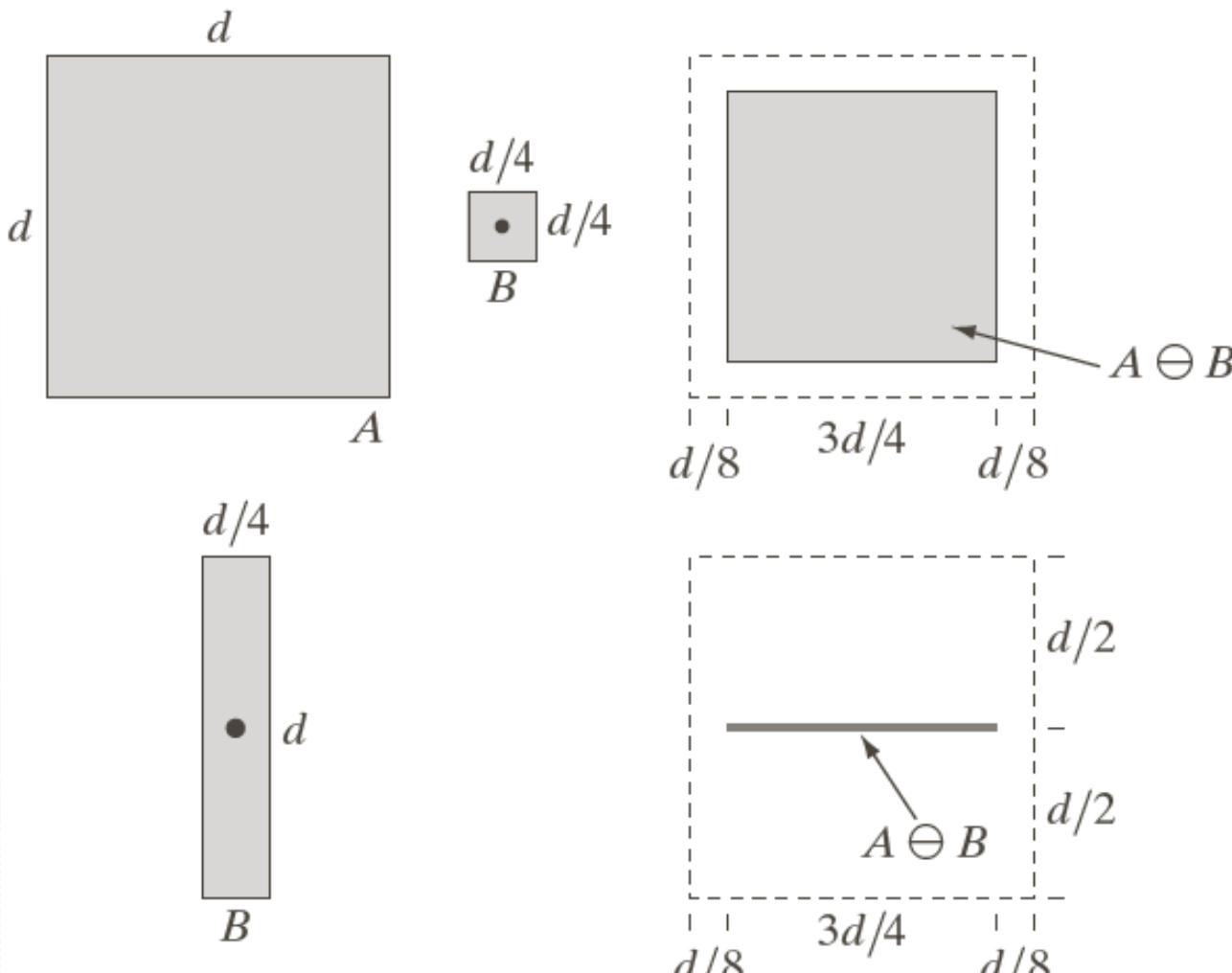
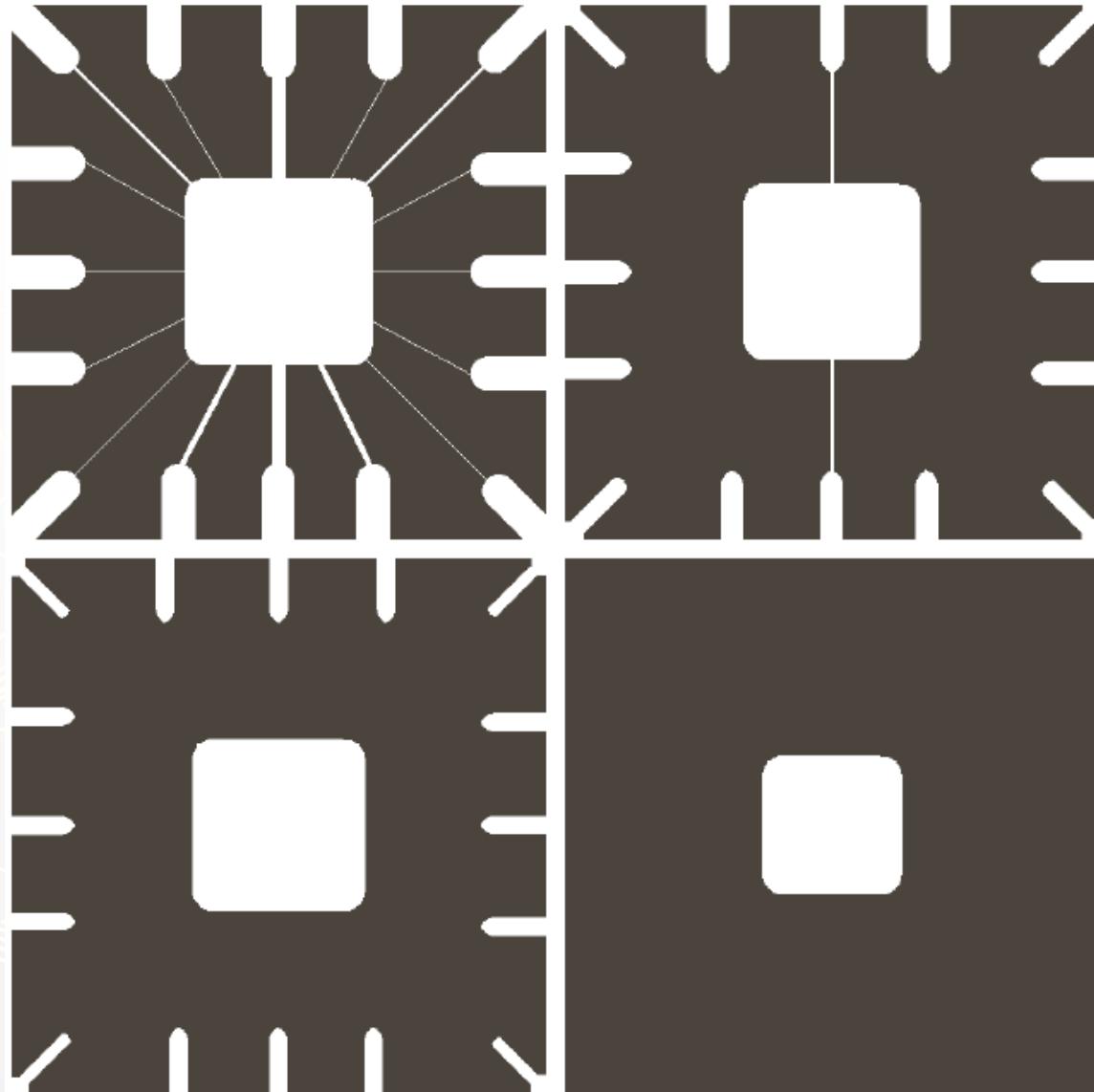


FIGURE 9.4 (a) Set A . (b) Square structuring element, B . (c) Erosion of A by B , shown shaded. (d) Elongated structuring element. (e) Erosion of A by B using this element. The dotted border in (c) and (e) is the boundary of set A , shown only for reference.

Example of Erosion (2)



a b
c d

FIGURE 9.5 Using erosion to remove image components. (a) A 486×486 binary image of a wire-bond mask. (b)–(d) Image eroded using square structuring elements of sizes 11×11 , 15×15 , and 45×45 , respectively. The elements of the SEs were all 1s.

Dilation

With A and B as sets in \mathbb{Z}^2 , the dilation of A by B , denoted $A \oplus B$, is defined as

$$A \oplus B = \left\{ z \mid (\hat{B})_z \cap A \neq \emptyset \right\}$$

The set of all displacements z , the translated B and A overlap by at least one element.

$$A \oplus B = \left\{ z \mid [(\hat{B})_z \cap A] \subseteq A \right\}$$

Examples of Dilation (1)

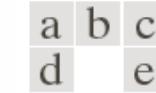
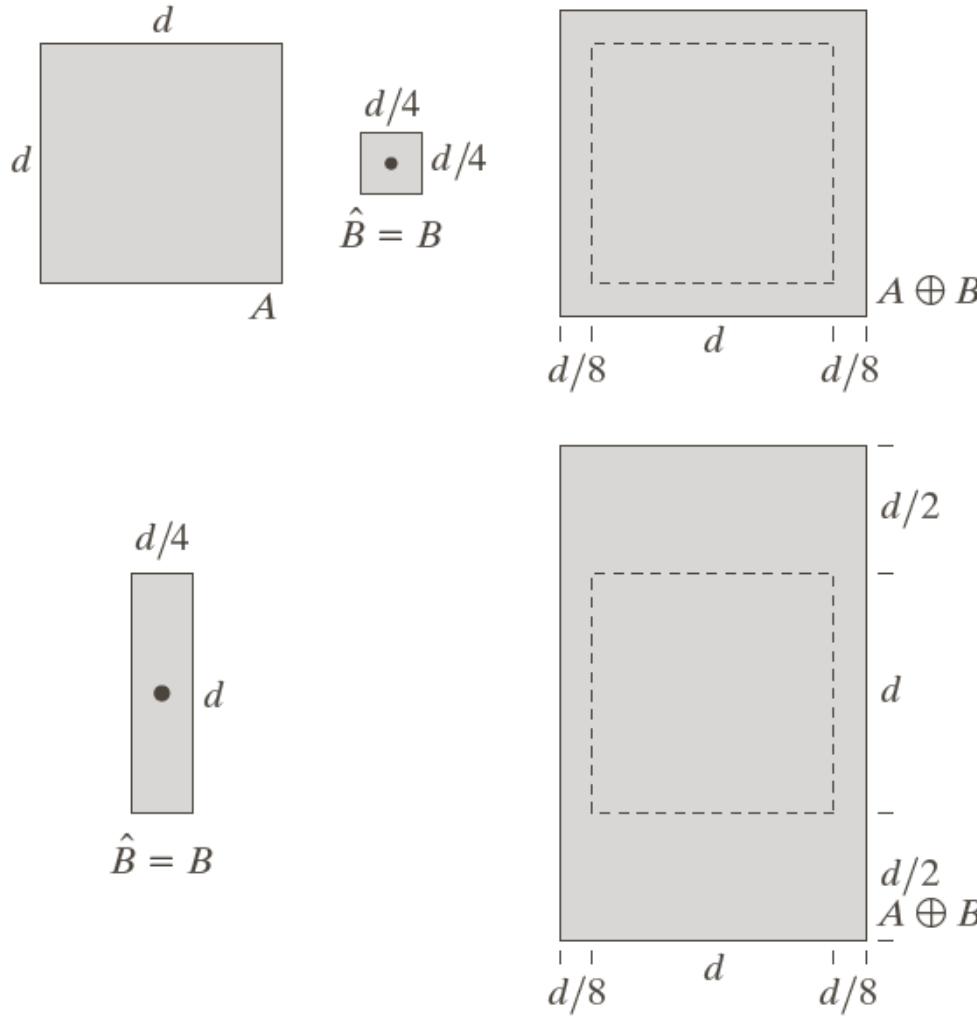


FIGURE 9.6

- (a) Set A .
- (b) Square structuring element (the dot denotes the origin).
- (c) Dilation of A by B , shown shaded.
- (d) Elongated structuring element.
- (e) Dilation of A using this element. The dotted border in (c) and (e) is the boundary of set A , shown only for reference

Examples of Dilation (2)

Historically, certain computer programs were written using only two digits rather than four to define the applicable year. Accordingly, the company's software may recognize a date using "00" as 1900 rather than the year 2000.



0	1	0
1	1	1
0	1	0

Historically, certain computer programs were written using only two digits rather than four to define the applicable year. Accordingly, the company's software may recognize a date using "00" as 1900 rather than the year 2000.



a
b
c

FIGURE 9.7
(a) Sample text of poor resolution with broken characters (see magnified view).
(b) Structuring element.
(c) Dilation of (a) by (b). Broken segments were joined.

Duality

- ▶ Erosion and dilation are duals of each other with respect to set complementation and reflection

$$(A \ominus B)^c = A^c \oplus \hat{B}$$

and

$$(A \oplus B)^c = A^c - \hat{B}$$

Duality

- ▶ Erosion and dilation are duals of each other with respect to set complementation and reflection

$$(A \ominus B)^c = \{z \mid (B)_z \subseteq A\}^c$$

Duality

- ▶ Erosion and dilation are duals of each other with respect to set complementation and reflection

$$\begin{aligned}(A \oplus B)^c &= \left\{ z \mid (\hat{B})_z \cap A \neq \emptyset \right\}^c \\&= \left\{ z \mid (\hat{B})_z \cap A^c = \emptyset \right\} \\&= A^c - \hat{B}\end{aligned}$$

Opening and Closing

- ▶ Opening generally smoothes the contour of an object, breaks narrow isthmuses, and eliminates thin protrusions
- ▶ Closing tends to smooth sections of contours but it generates fuses narrow breaks and long thin gulfs, eliminates small holes, and fills gaps in the contour

Opening and Closing

- ▶ The opening of set A by structuring element B , denoted $A \circ B$, is defined as

$$A \circ B = (A \ominus B) \oplus B$$

- ▶ The closing of set A by structuring element B , denoted $A \bullet B$, is defined as

$$A \bullet B = (A \oplus B) \ominus B$$

Opening and Closing

- ▶ The opening of set A by structuring element B , denoted $A \circ B$, is defined as

$$A \circ B = \cup \{(B)_z | (B)_z \subseteq A\}$$

The opening of A by B is the union of all the translations of B so that B fits entirely in A .

- ▶ Similarly, we can write the closing of A by B as

$$A \bullet B = \left[\cup \{(B)_z | (B)_z \cap A = \phi\} \right]^c$$

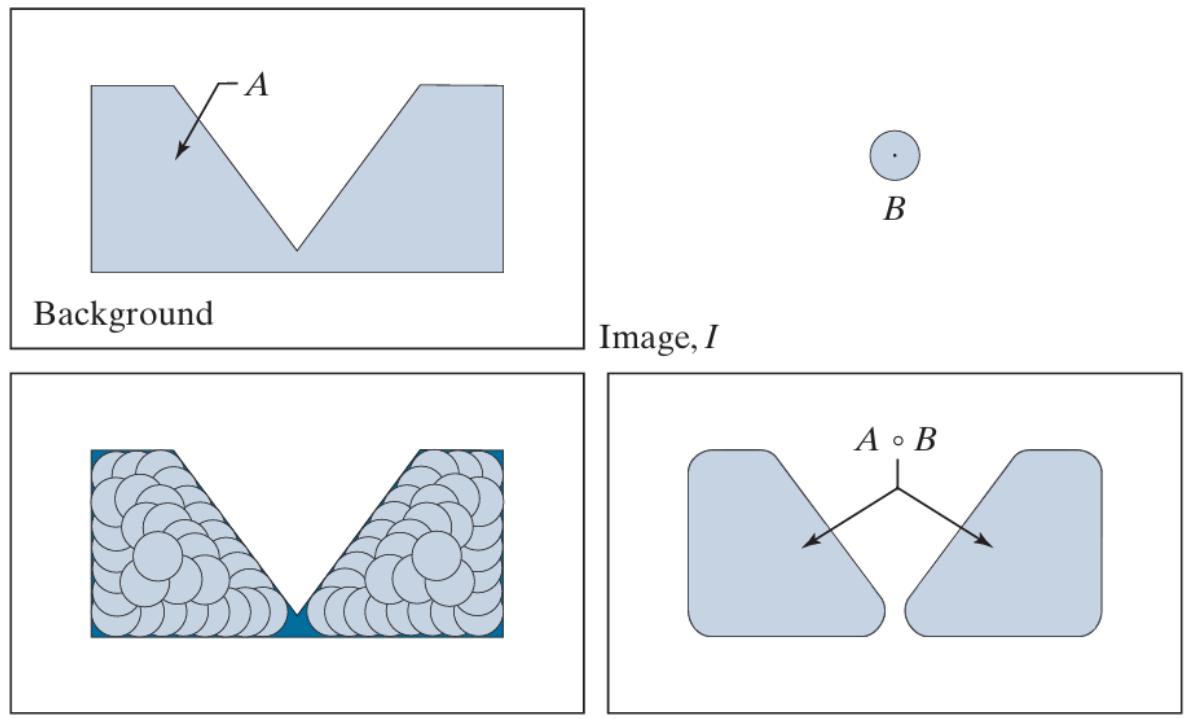
The closing is then the complement of the union of all translations of B that do not overlap A .

Example: Opening

a	b
c	d

FIGURE 9.8

- (a) Image I , composed of set (object) A and background.
- (b) Structuring element, B .
- (c) Translations of B while being contained in A . (A is shown dark for clarity.)
- (d) Opening of A by B .

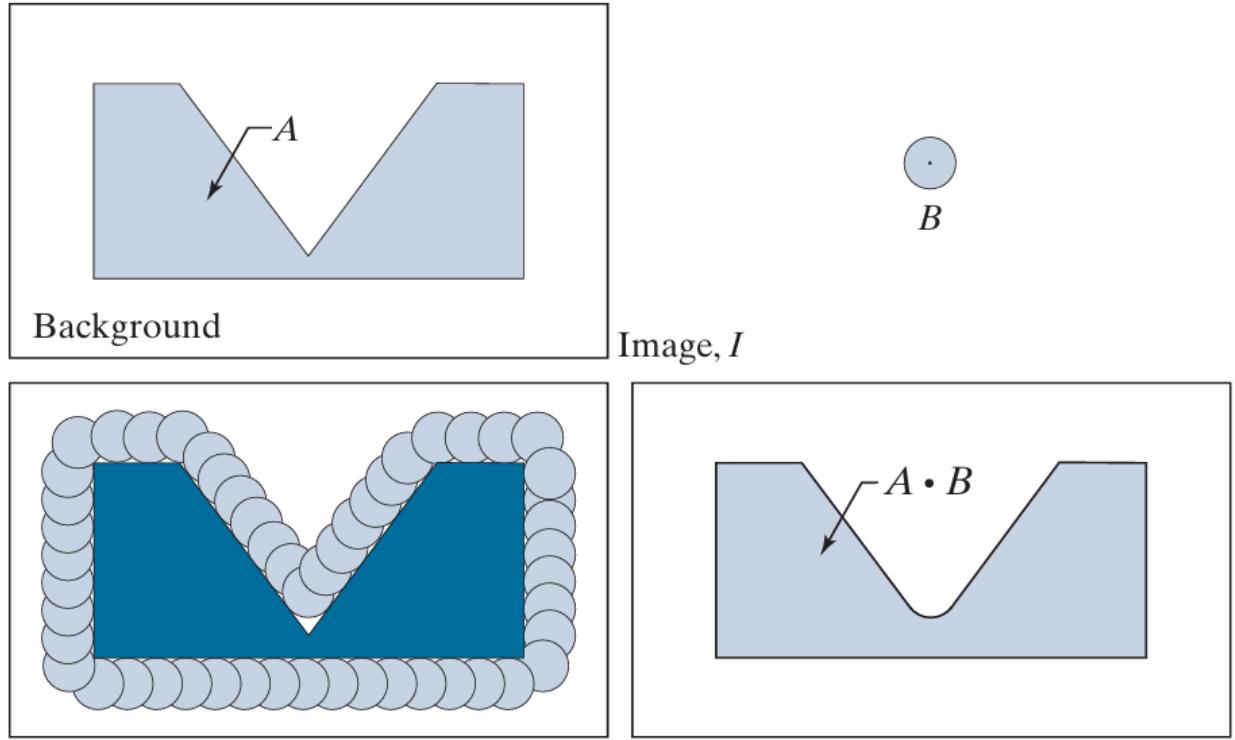


Example: Closing

a	b
c	d

FIGURE 9.9

- (a) Image I , composed of set (object) A , and background.
- (b) Structuring element B .
- (c) Translations of B such that B does not overlap any part of A . (A is shown dark for clarity.)
- (d) Closing of A by B .



Duality of Opening and Closing

- ▶ Opening and closing are duals of each other with respect to set complementation and reflection

$$(A \circ B)^c = (A^c \bullet \hat{B})$$

$$(A \bullet B)^c = (A^c \circ \hat{B})$$

The Properties of Opening and Closing

Morphological opening has the following properties:

- (a) $A \circ B$ is a subset of A .
- (b) If C is a subset of D , then $C \circ B$ is a subset of $D \circ B$.
- (c) $(A \circ B) \circ B = A \circ B$.

Similarly, closing satisfies the following properties:

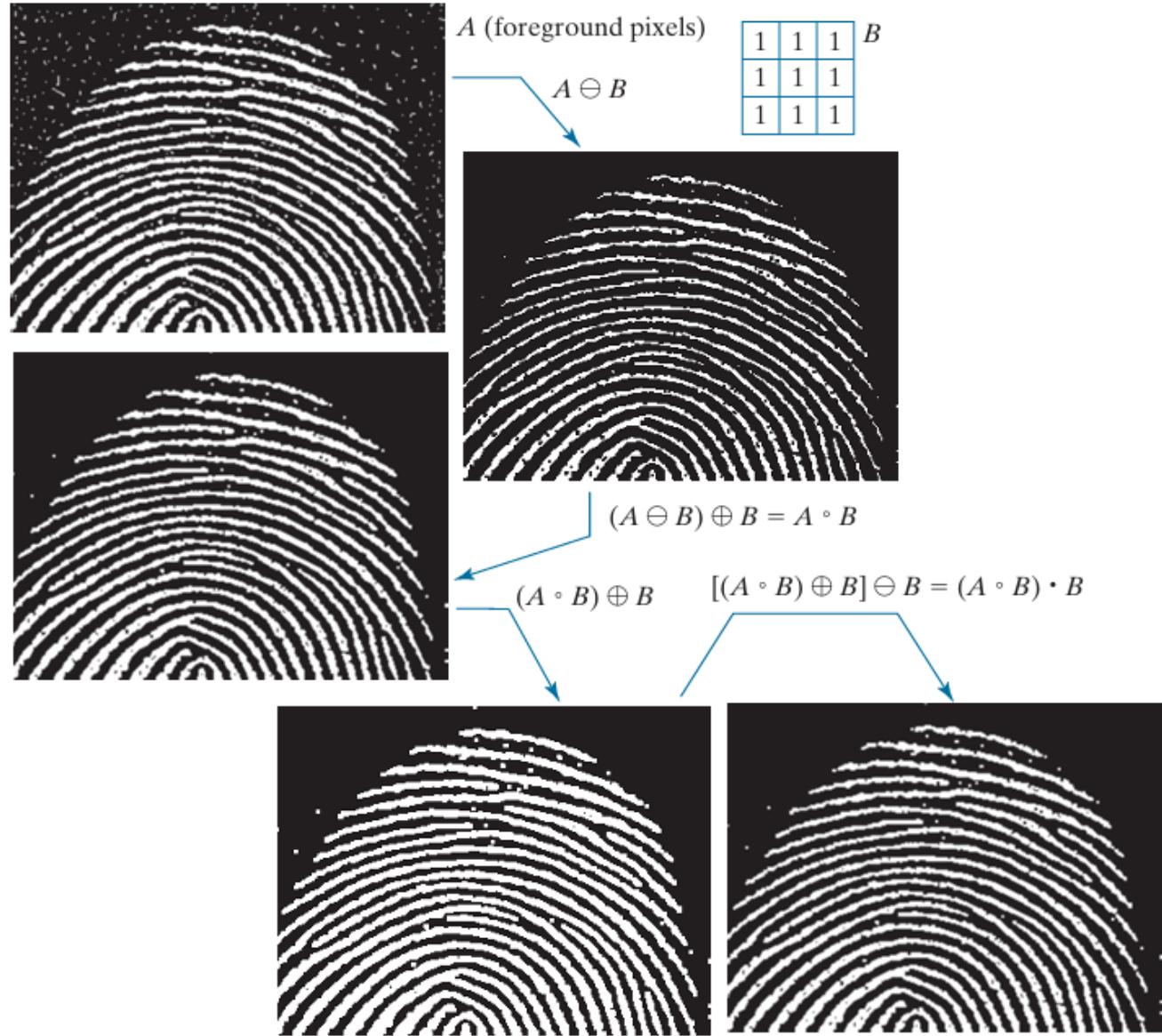
- (a) A is a subset of $A \bullet B$.
- (b) If C is a subset of D , then $C \bullet B$ is a subset of $D \bullet B$.
- (c) $(A \bullet B) \bullet B = A \bullet B$.

a	b
d	c
e	f

FIGURE 9.11

- (a) Noisy image.
- (b) Structuring element.
- (c) Eroded image.
- (d) Dilation of the erosion (opening of A).
- (e) Dilation of the opening.
- (f) Closing of the opening.

(Original image courtesy of the National Institute of Standards and Technology.)



The Hit-or-Miss Transformation

- ▶ The morphological hit-or-miss transform (HMT) is a basic tool for shape detection.
- ▶ Let I be a binary image composed of foreground (A) and background pixels, respectively. Unlike the morphological methods discussed thus far, the HMT utilizes two structuring elements: B_1 for detecting shapes in the foreground, and B_2 , for detecting shapes in the background.
- ▶ The HMT of image I is defined as

$$\begin{aligned} I \circledast B_{1,2} &= \left\{ z \mid (B_1)_z \subseteq A \text{ and } (B_2)_z \subseteq A^c \right\} \\ &= (A \ominus B_1) \cap (A^c \ominus B_2) \end{aligned}$$

- ▶ HMT is the set of translations, z , of structuring elements B_1 and B_2 such that, simultaneously, B_1 found a match in the fore ground (i.e., B_1 is contained in A) and B_2 found a match in the background (i.e., B_2 is contained in A^c). The word “simultaneous” implies that z is the same translation of both structuring elements.
- ▶ The word “miss” in the HMT arises from the fact that B_2 finding a match in A^c is the same as B_2 not finding (missing) a match in A .

a	b
c	d
e	f

FIGURE 9.12

(a) Image consisting of a foreground (1's) equal to the union, A , of set of objects, and a background of 0's.

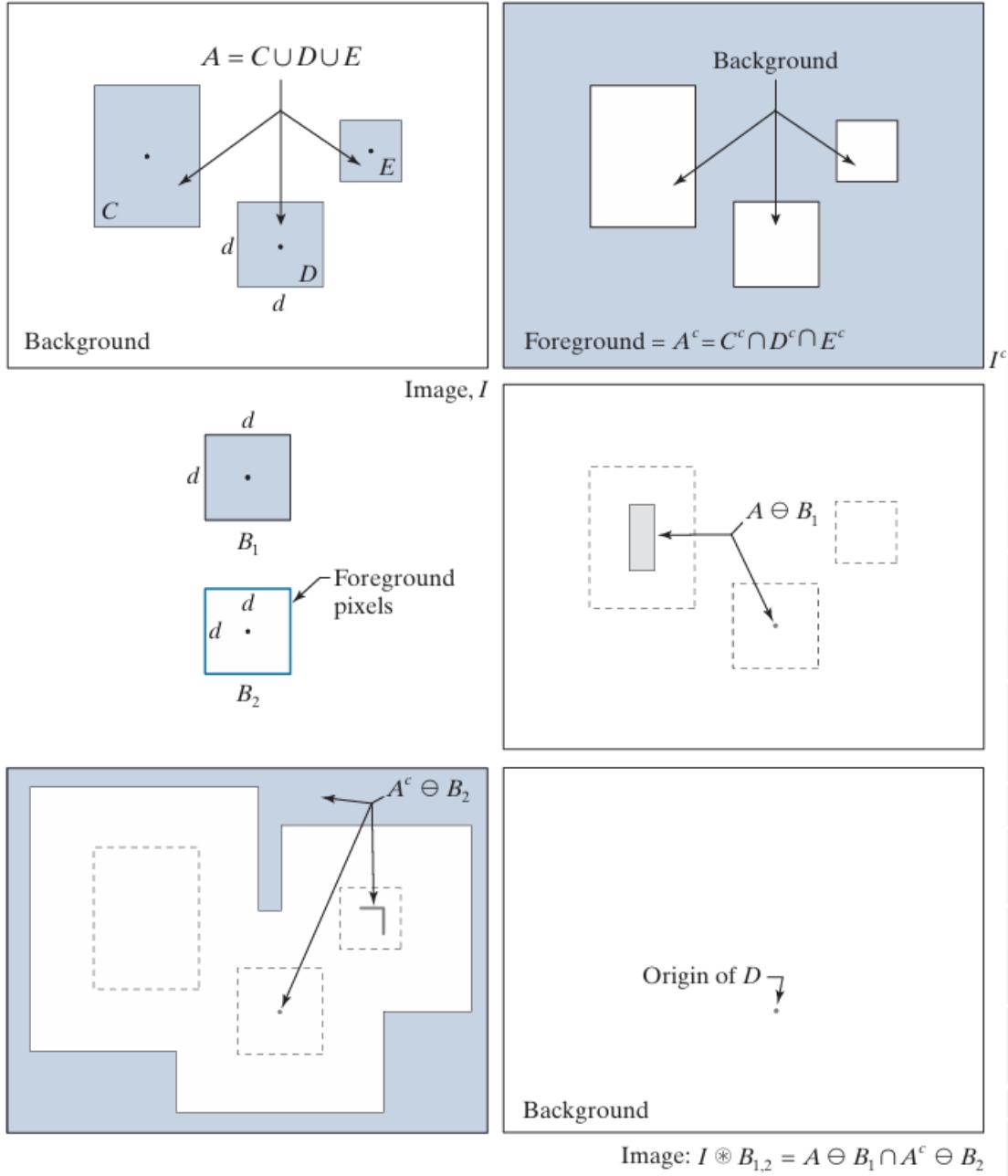
(b) Image with its foreground defined as A^c .

(c) Structuring elements designed to detect object D .

(d) Erosion of A by B_1 .

(e) Erosion of A^c by B_2 .

(f) Intersection of (d) and (e), showing the location of the origin of D , as desired. The dots indicate the origin of their respective components. Each dot is a single pixel.



Some Basic Morphological Algorithms (1)

► **Boundary Extraction**

The boundary of a set A, can be obtained by first eroding A by B and then performing the set difference between A and its erosion.

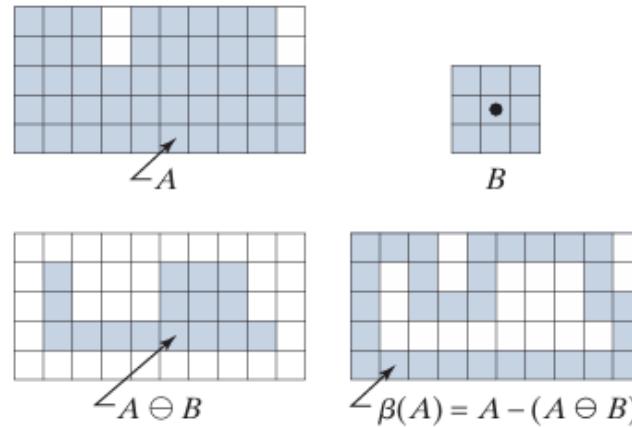
$$\beta(A) = A - (A \ominus B)$$

Example 1

a	b
c	d

FIGURE 9.15

- (a) Set, A , of foreground pixels.
- (b) Structuring element.
- (c) A eroded by B .
- (d) Boundary of A .



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

1	1	1
1	1	1
1	1	1

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

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

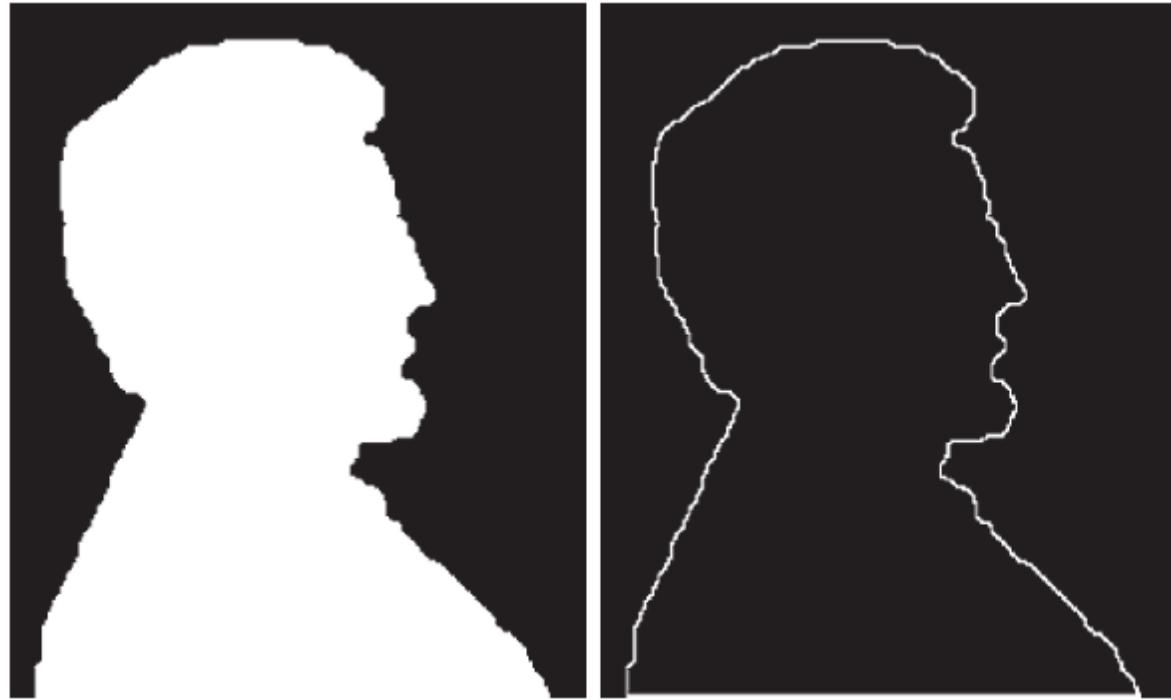
1	1	1	0	1	1	1	1	1	0
1	0	1	0	1	0	0	0	1	0
1	0	1	1	1	0	0	0	1	1
1	0	0	0	0	0	0	0	0	1
1	1	1	1	1	1	1	1	1	1

Example 2

a b

FIGURE 9.16

- (a) A binary image.
(b) Result of using Eq. (9-18) with the structuring element in Fig. 9.15(b).



Some Basic Morphological Algorithms (2)

► **Hole Filling**

A hole may be defined as a background region surrounded by a connected border of foreground pixels.

Let A denote a set whose elements are 8-connected boundaries, each boundary enclosing a background region (i.e., a hole). Given a point in each hole, the objective is to fill all the holes with 1s.

Some Basic Morphological Algorithms (2)

► Hole Filling

1. Forming an array X_0 of 0s (the same size as the array containing A), except the locations in X_0 corresponding to the given point in each hole, which we set to 1.

$$2. X_k = (X_{k-1} \oplus B) \cap A^c \quad k=1,2,3,\dots$$

Stop the iteration if $X_k = X_{k-1}$

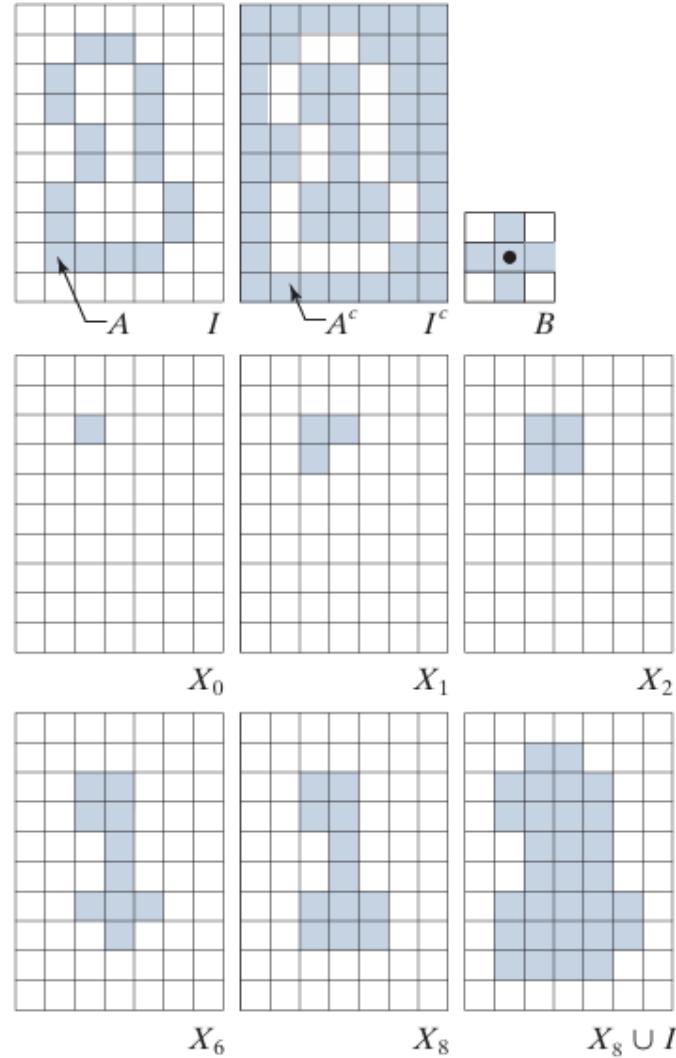
Example

a	b	c
d	e	f
g	h	i

FIGURE 9.17

Hole filling.

- (a) Set A (shown shaded) contained in image I .
- (b) Complement of I .
- (c) Structuring element B . Only the foreground elements are used in computations
- (d) Initial point inside hole, set to 1.
- (e)–(h) Various steps of Eq. (9-19).
- (i) Final result [union of (a) and (h)].



Some Basic Morphological Algorithms (3)

► **Extraction of Connected Components**

Central to many automated image analysis applications.

Let A be a set containing one or more connected components, and form an array X_0 (of the same size as the array containing A) whose elements are 0s, except at each location known to correspond to a point in each connected component in A, which is set to 1.

Some Basic Morphological Algorithms (3)

► Extraction of Connected Components

Central to many automated image analysis applications.

$$X_k = (X_{k-1} \oplus B) \cap A$$

B : structuring element

until $X_k = X_{k-1}$

Example

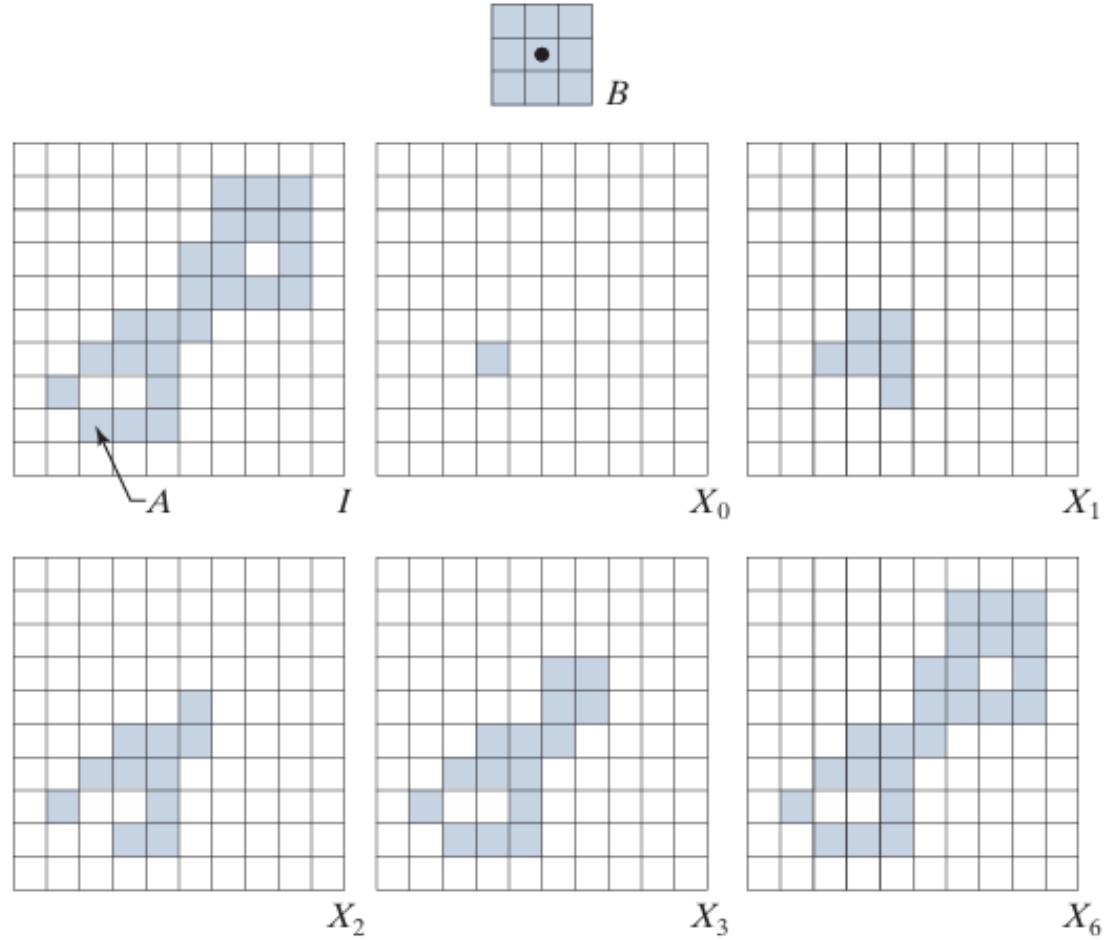
a
b
c

d
e
f

g

FIGURE 9.19

- (a) Structuring element.
- (b) Image containing a set with one connected component.
- (c) Initial array containing a 1 in the region of the connected component.
- (d)–(g) Various steps in the iteration of Eq. (9-20)



a
b
c d

FIGURE 9.20

- (a) X-ray image of a chicken filet with bone fragments.
(b) Thresholded image (shown as the negative for clarity).
(c) Image eroded with a 5×5 SE of 1's.
(d) Number of pixels in the connected components of (c). (Image (a) courtesy of NTB Elektronische Geraete GmbH, Diepholz, Germany, www.ntbxray.com.)



Connected component	No. of pixels in connected comp
01	11
02	9
03	9
04	39
05	133
06	1
07	1
08	743
09	7
10	11
11	11
12	9
13	9
14	674
15	85

Some Basic Morphological Algorithms (4)

► Convex Hull

A set A is said to be ***convex*** if the straight line segment joining any two points in A lies entirely within A .

The ***convex hull*** H or of an arbitrary set S is the smallest convex set containing S .

Some Basic Morphological Algorithms (4)

► Convex Hull

Let B^i , $i = 1, 2, 3, 4$, represent the four structuring elements.

The procedure consists of implementing the equation:

$$X_k^i = (X_{k-1} \circledast B^i) \cup A$$
$$i = 1, 2, 3, 4 \text{ and } k = 1, 2, 3, \dots$$

with $X_0^i = A$.

When the procedure converges, or $X_k^i = X_{k-1}^i$, let $D^i = X_k^i$,
the convex hull of A is

$$C(A) = \bigcup_{i=1}^4 D^i$$

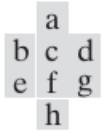
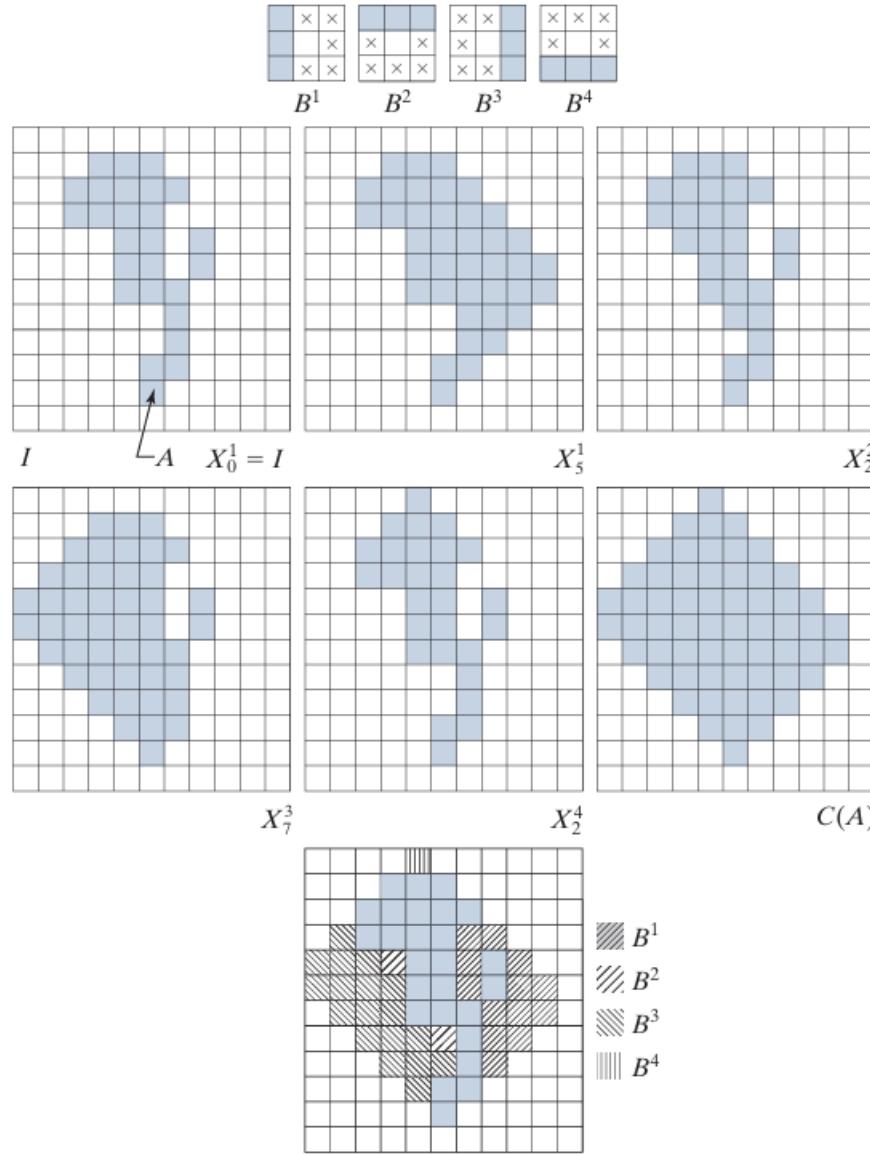


FIGURE 9.21

- (a) Structuring elements.
- (b) Set A .
- (c)–(f) Results of convergence with the structuring elements shown in (a).
- (g) Convex hull.
- (h) Convex hull showing the contribution of each structuring element.

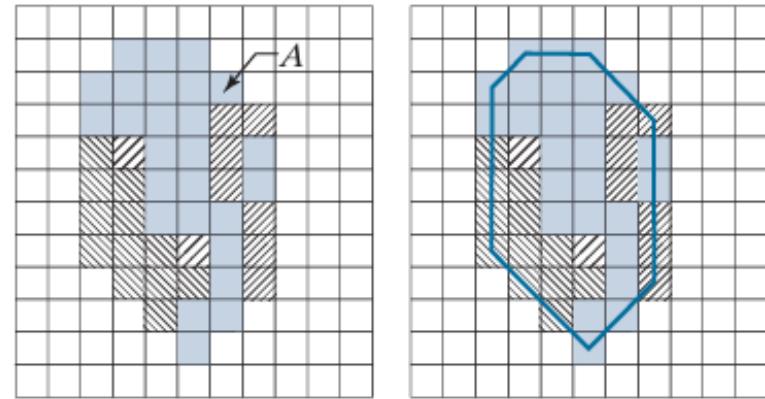


Example

a b

FIGURE 9.22

- (a) Result of limiting growth of the convex hull algorithm.
(b) Straight lines connecting the boundary points show that the new set is convex also.



Some Basic Morphological Algorithms (5)

► Thinning

The thinning of a set A by a structuring element B, defined

$$\begin{aligned}A \otimes B &= A - (A \circledast B) \\&= A \cap (A \circledast B)^c\end{aligned}$$

Some Basic Morphological Algorithms (5)

- ▶ A more useful expression for thinning A symmetrically is based on a sequence of structuring elements:

$$\{B\} = \{B^1, B^2, B^3, \dots, B^n\}$$

where B^i is a rotated version of B^{i-1}

The thinning of A by a sequence of structuring element $\{B\}$

$$A \otimes \{B\} = (((((A \otimes B^1) \otimes B^2) \dots) \otimes B^n))$$

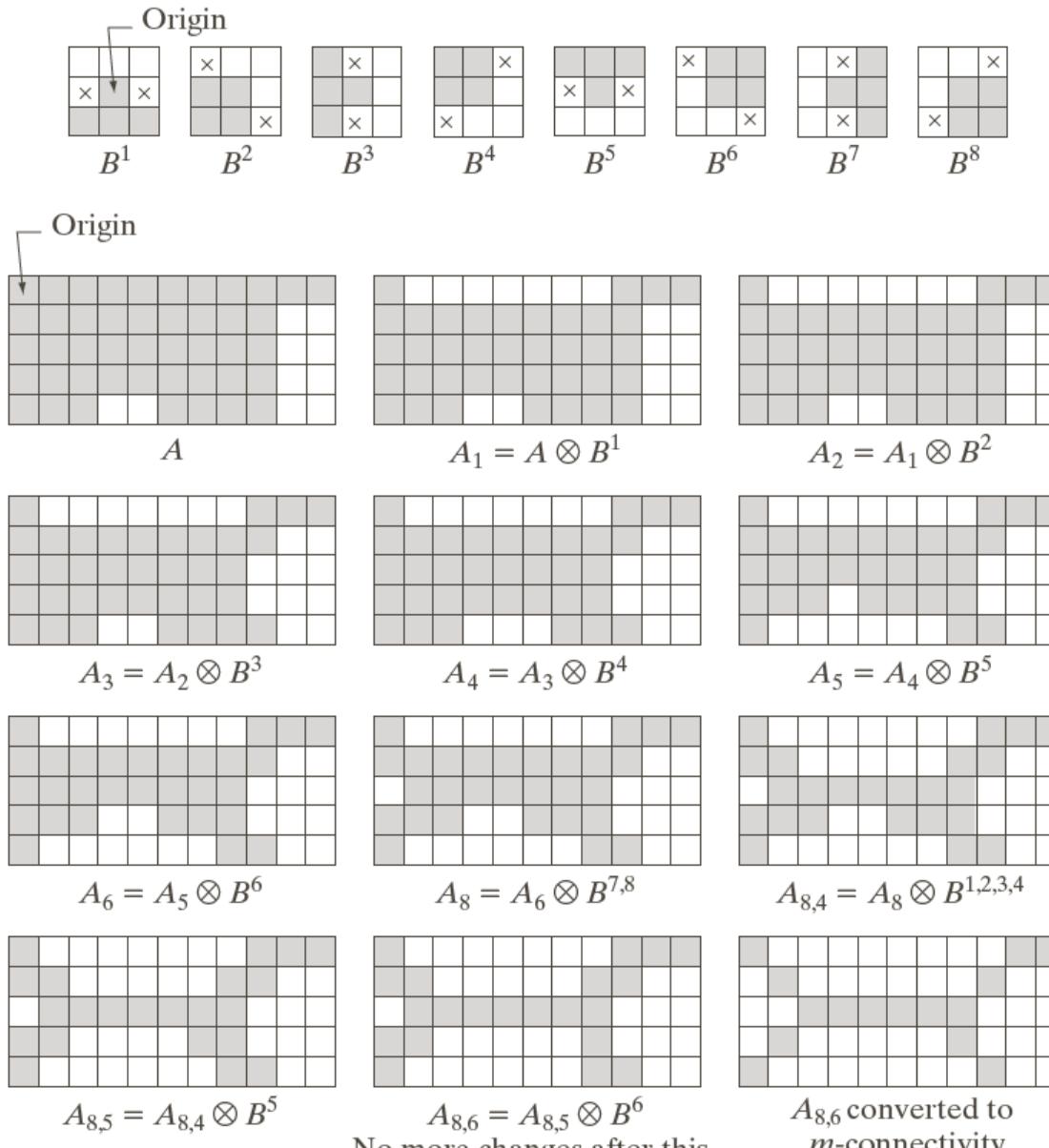


FIGURE 9.21 (a) Sequence of rotated structuring elements used for thinning. (b) Set A . (c) Result of thinning with the first element. (d)–(i) Results of thinning with the next seven elements (there was no change between the seventh and eighth elements). (j) Result of using the first four elements again. (l) Result after convergence. (m) Conversion to m -connectivity.

a
b
c
d
e
f
g
h
i
j
k
l
m

Some Basic Morphological Algorithms (6)

► Thickening:

The thickening is defined by the expression

$$A \odot B = A \cup (A * B)$$

The thickening of A by a sequence of structuring element $\{B\}$

$$A \odot \{B\} = ((\dots((A \odot B^1) \odot B^2)\dots) \odot B^n)$$

In practice, the usual procedure is to thin the background of the set and then complement the result.

Some Basic Morphological Algorithms (6)

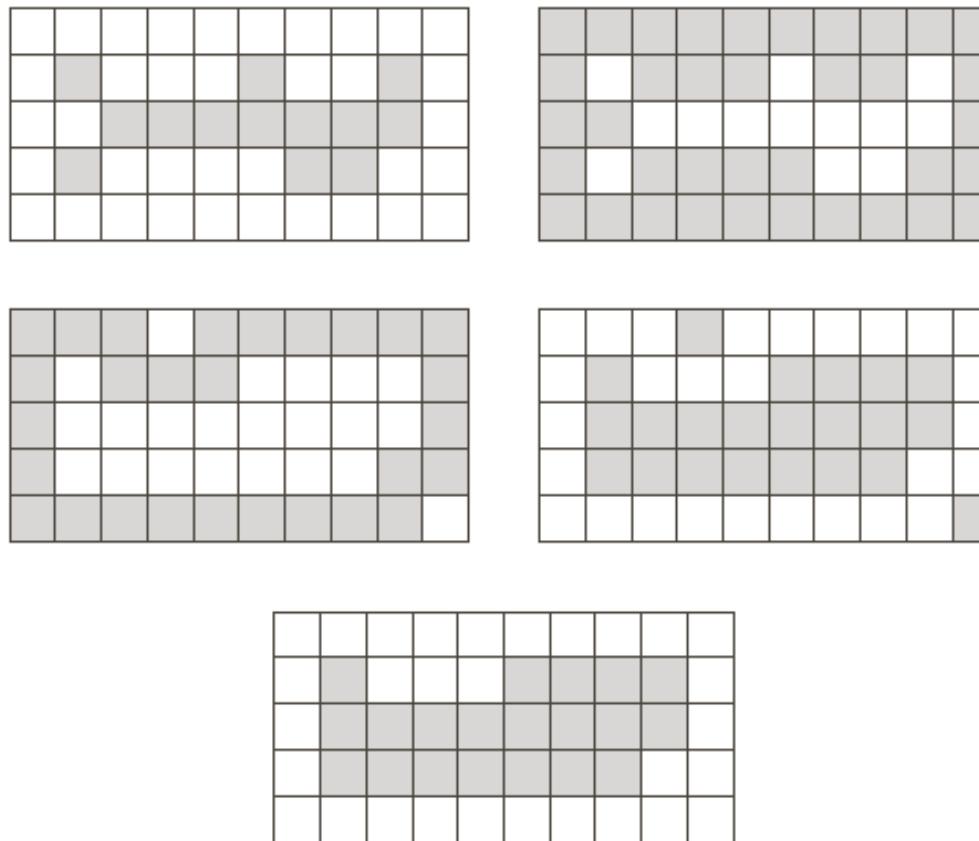


FIGURE 9.22 (a) Set A . (b) Complement of A . (c) Result of thinning the complement of A . (d) Thickened set obtained by complementing (c). (e) Final result, with no disconnected points.

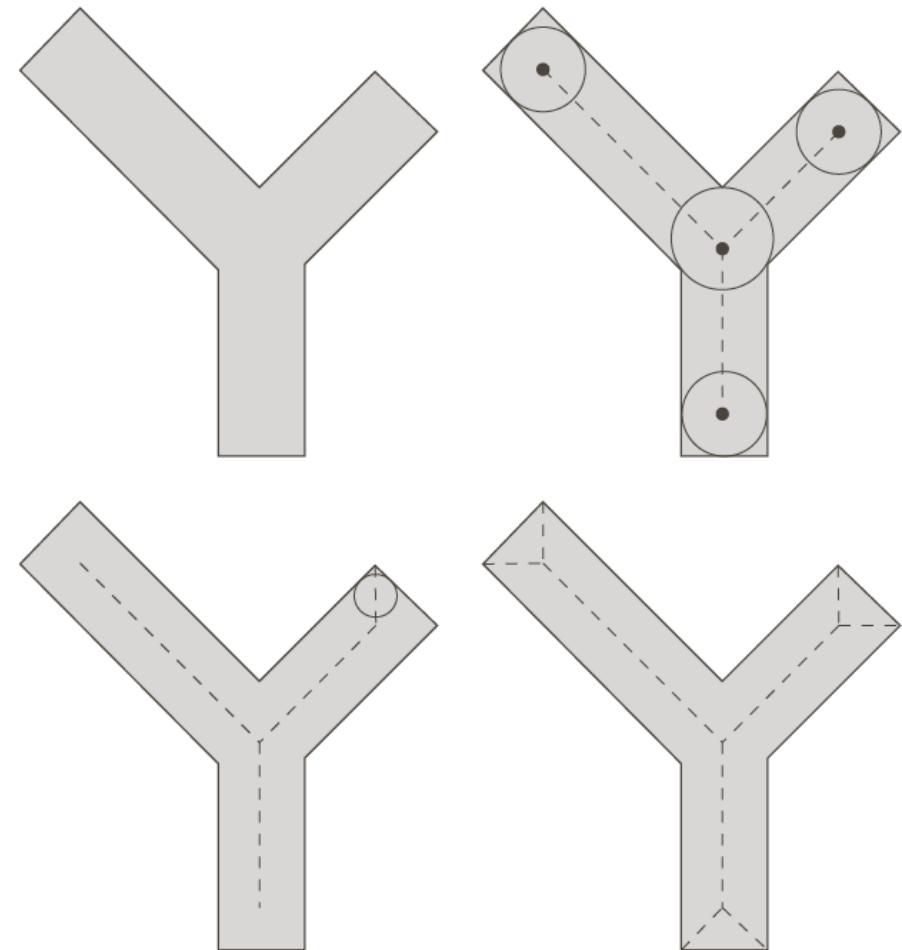
Some Basic Morphological Algorithms (7)

► Skeletons

A skeleton, $S(A)$ of a set A has the following properties

- a. if z is a point of $S(A)$ and $(D)_z$ is the largest disk centered at z and contained in A , one cannot find a larger disk containing $(D)_z$ and included in A .
The disk $(D)_z$ is called a maximum disk.
- b. The disk $(D)_z$ touches the boundary of A at two or more different places.

Some Basic Morphological Algorithms (7)



a	b
c	d

FIGURE 9.23

- (a) Set *A*.
- (b) Various positions of maximum disks with centers on the skeleton of *A*.
- (c) Another maximum disk on a different segment of the skeleton of *A*.
- (d) Complete skeleton.

Some Basic Morphological Algorithms (7)

The skeleton of A can be expressed in terms of erosion and openings.

$$S(A) = \bigcup_{k=0}^K S_k(A)$$

with $K = \max\{k \mid A \ominus kB \neq \emptyset\}$;

$$S_k(A) = (A \ominus kB) - (A \ominus kB) \circ B$$

where B is a structuring element, and

$$(A \ominus kB) = (((..((A \ominus B) \ominus B) \ominus ...)) \ominus B)$$

k successive erosions of A.

$k \setminus$	$A \ominus kB$	$(A \ominus kB) \circ B$	$S_k(A)$	$\bigcup_{k=0}^K S_k(A)$	$S_k(A) \oplus kB$	$\bigcup_{k=0}^K S_k(A) \oplus kB$
0						
1						
2						

FIGURE 9.24
 Implementation of Eqs. (9.5-11) through (9.5-15). The original set is at the top left, and its morphological skeleton is at the bottom of the fourth column. The reconstructed set is at the bottom of the sixth column.



Some Basic Morphological Algorithms (7)

A can be reconstructed from the subsets by using

$$A = \bigcup_{k=0}^K (S_k(A) \oplus kB)$$

where $S_k(A) \oplus kB$ denotes k successive dilations of A.

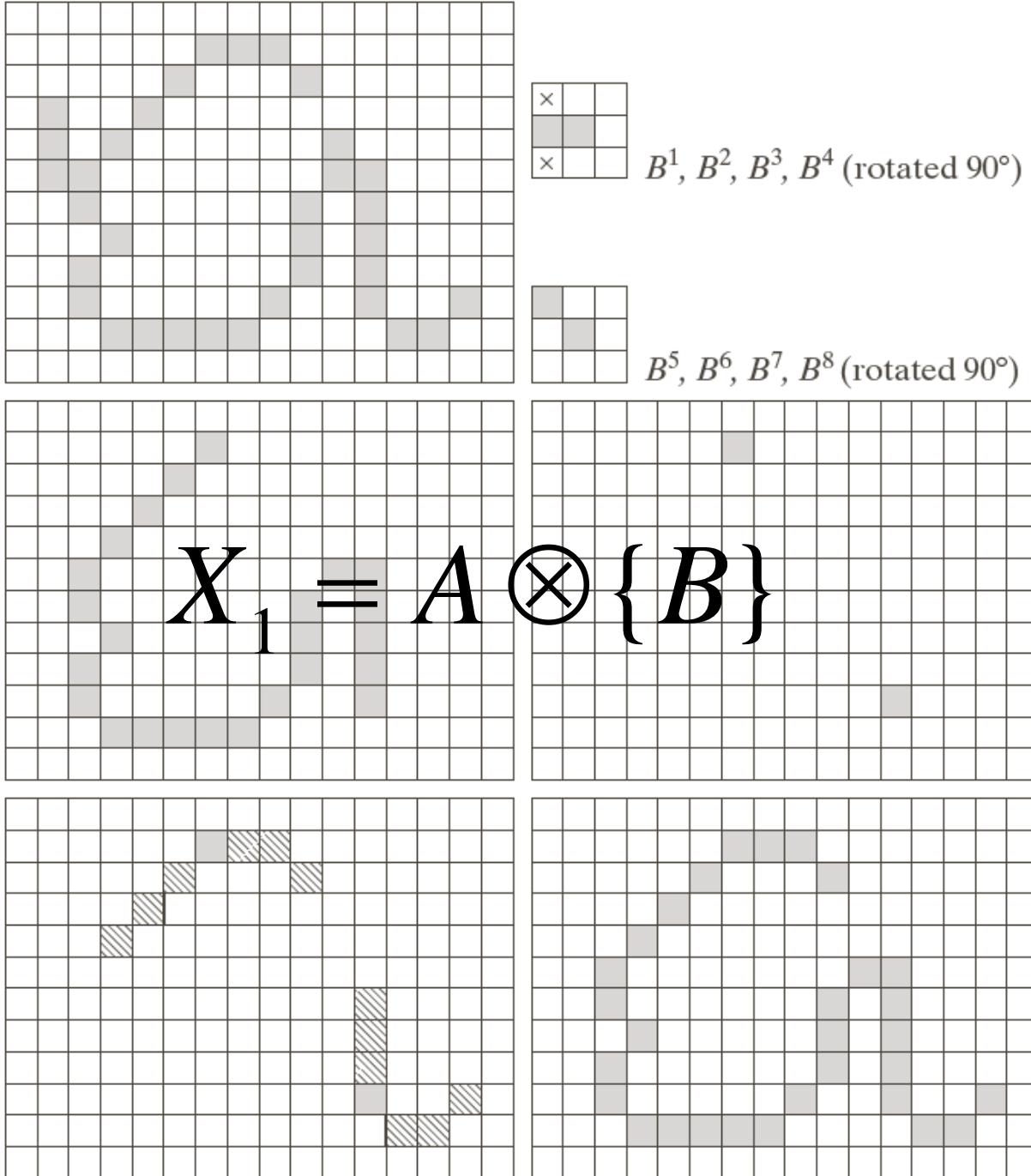
$$(S_k(A) \oplus kB) = (((\dots((S_k(A) \oplus B) \oplus B) \dots \oplus B))$$

Some Basic Morphological Algorithms (8)

► Pruning

- a. Thinning and skeletonizing tend to leave parasitic components
- b. Pruning methods are essential complement to thinning and skeletonizing procedures

Pruning: Example

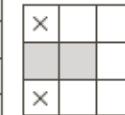
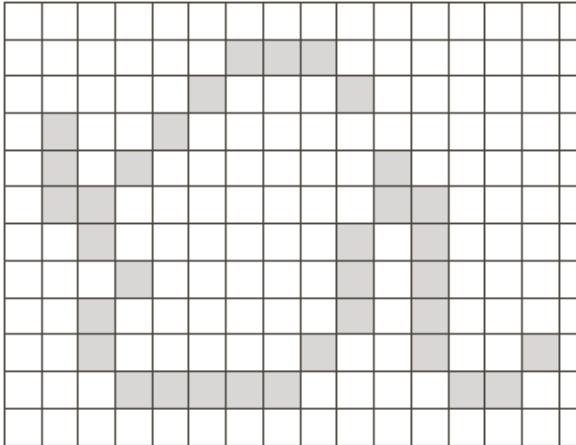


a	b
c	
d	e
f	g

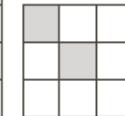
FIGURE 9.25

- (a) Original image.
- (b) and (c) Structuring elements used for deleting end points.
- (d) Result of three cycles of thinning.
- (e) End points of (d).
- (f) Dilation of end points conditioned on (a).
- (g) Pruned image.

Pruning: Example



B^1, B^2, B^3, B^4 (rotated 90°)



B^5, B^6, B^7, B^8 (rotated 90°)

$$X_2 = \bigcup_{k=1}^8 (X_1 \circledast B^k)$$

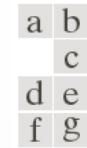
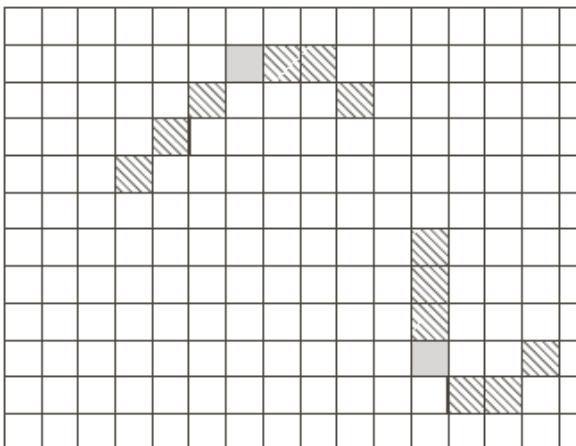
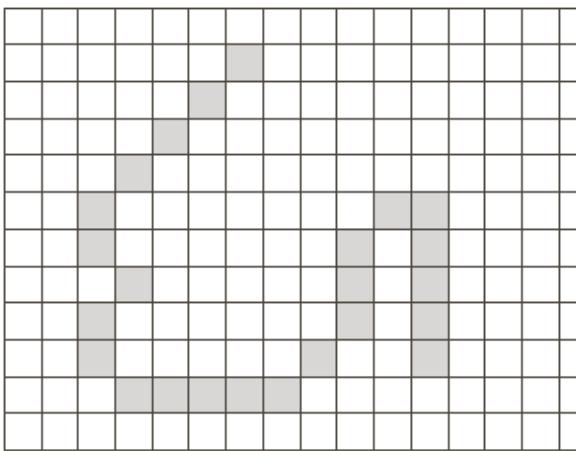
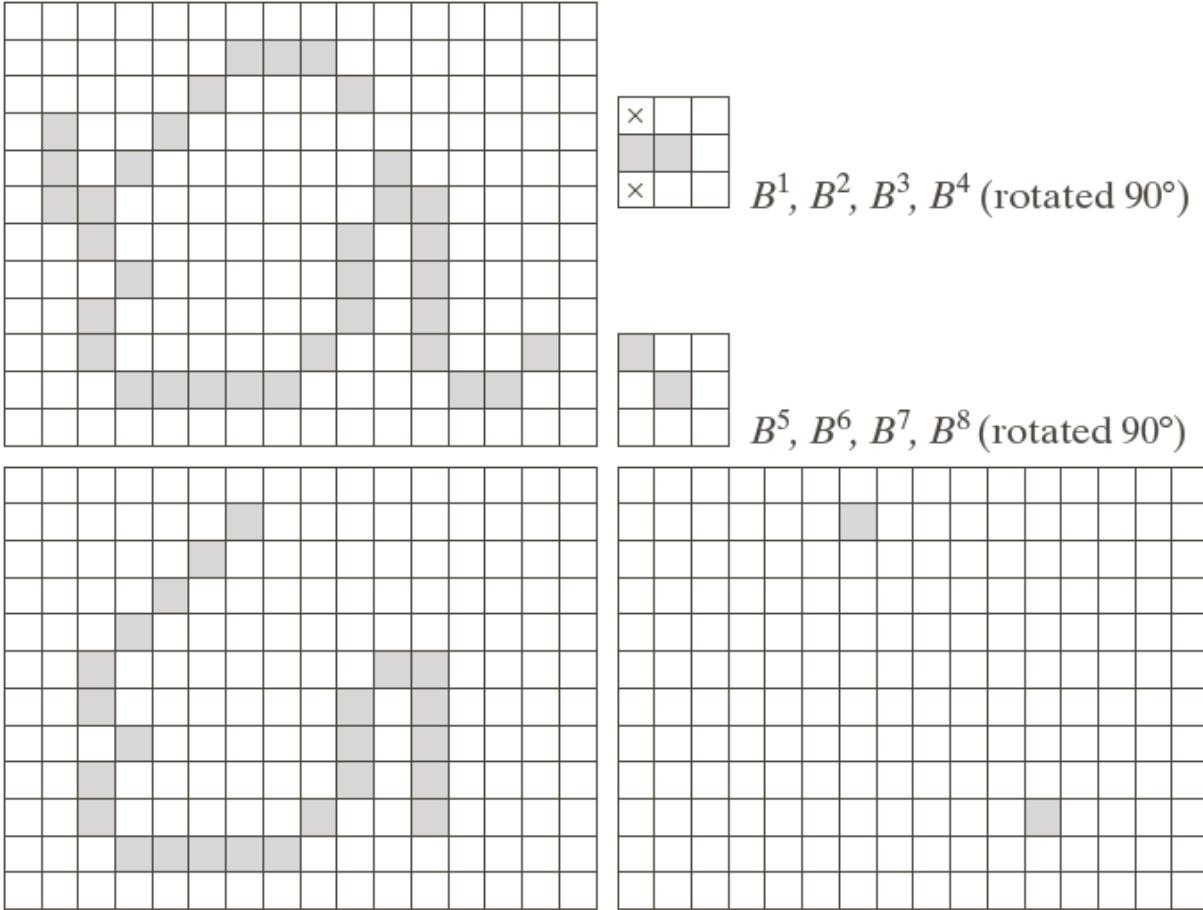


FIGURE 9.25

- (a) Original image.
- (b) and (c) Structuring elements used for deleting end points.
- (d) Result of three cycles of thinning.
- (e) End points of (d).
- (f) Dilation of end points conditioned on (a).
- (g) Pruned image.

Pruning: Example



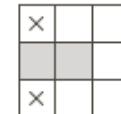
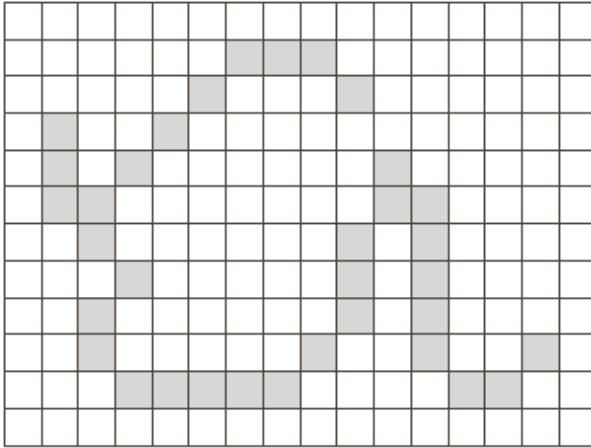
a	b
c	
d	e
f	g

FIGURE 9.25
 (a) Original image. (b) and (c) Structuring elements used for deleting end points. (d) Result of three cycles of thinning. (e) End points of (d). (f) Dilation of end points conditioned on (a). (g) Pruned image.

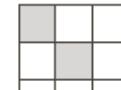
$$X_3 = (X_2 \oplus H) \cap A$$

$H : 3 \times 3$ structuring element

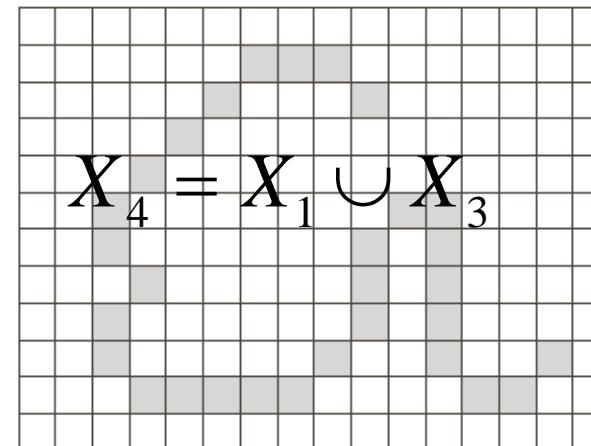
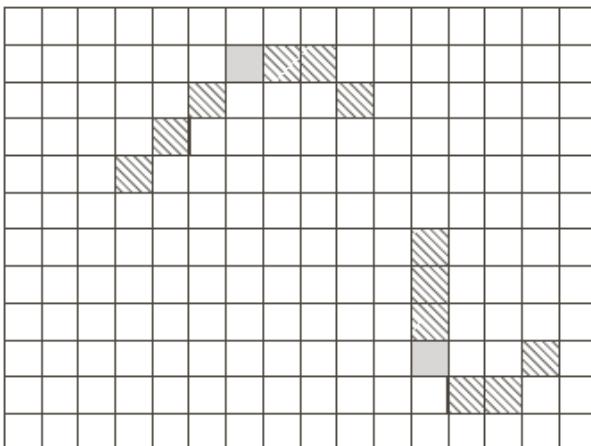
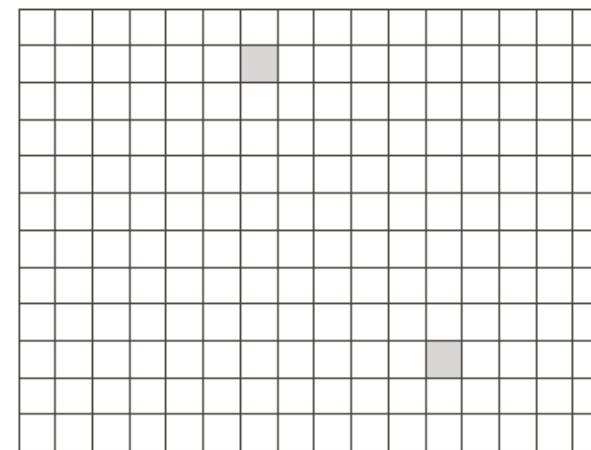
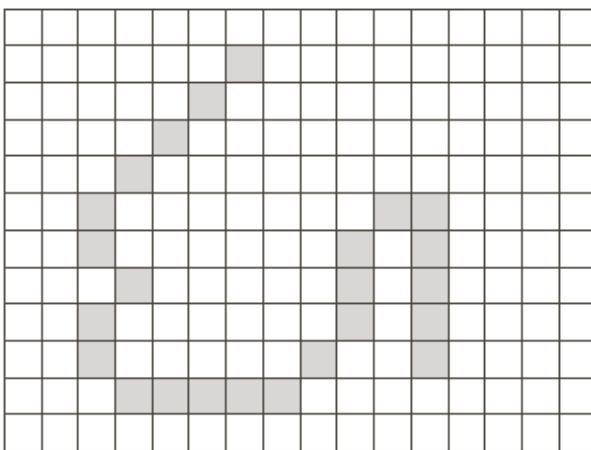
Pruning: Example



B^1, B^2, B^3, B^4 (rotated 90°)



B^5, B^6, B^7, B^8 (rotated 90°)



$$X_4 = X_1 \cup X_3$$

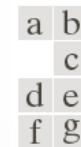
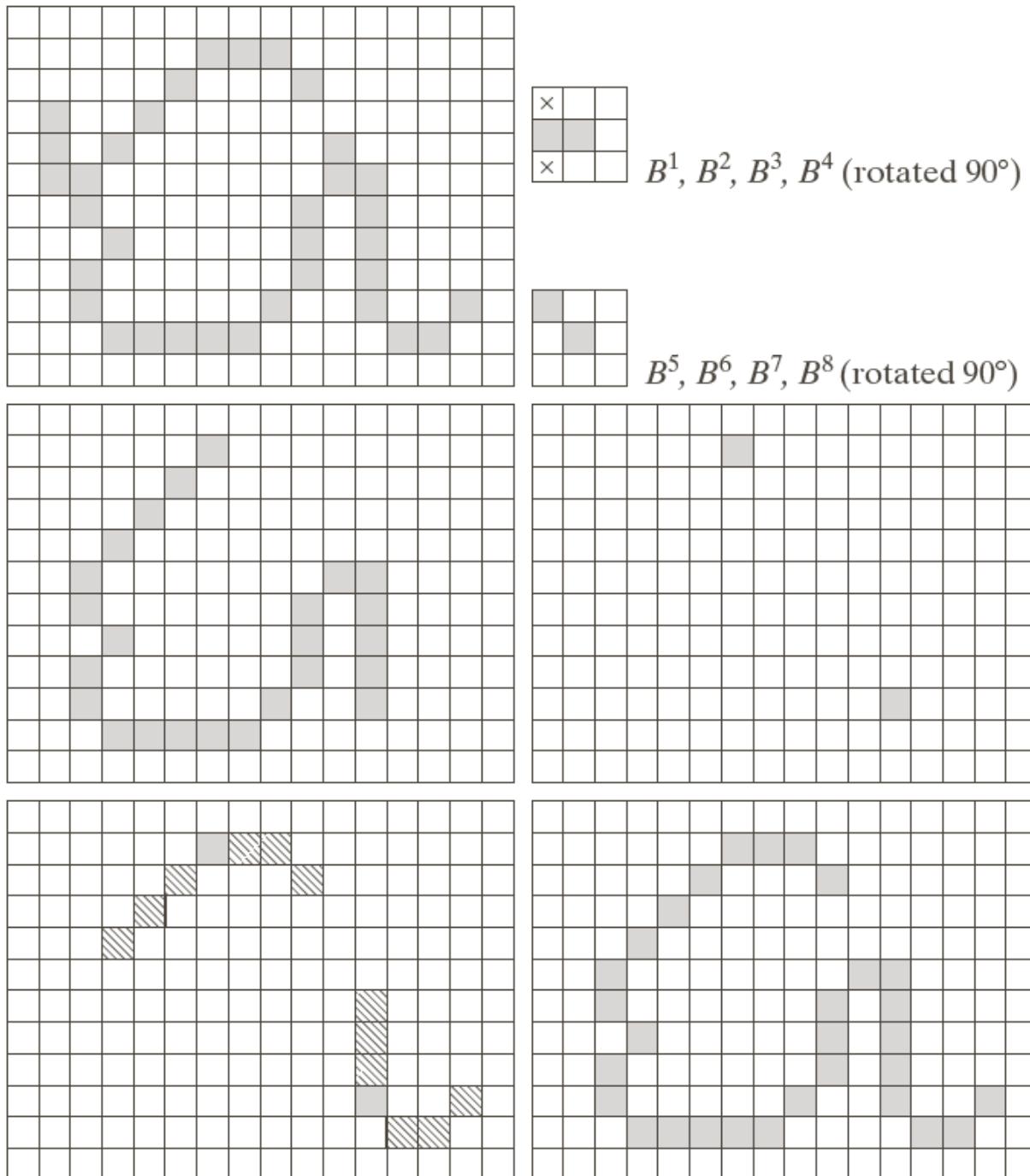


FIGURE 9.25

- (a) Original image.
- (b) and (c) Structuring elements used for deleting end points.
- (d) Result of three cycles of thinning.
- (e) End points of (d).
- (f) Dilation of end points conditioned on (a).
- (g) Pruned image.

Pruning: Example



a	b
c	
d	e
f	g

FIGURE 9.25

(a) Original image. (b) and (c) Structuring elements used for deleting end points. (d) Result of three cycles of thinning. (e) End points of (d). (f) Dilation of end points conditioned on (a). (g) Pruned image.

Some Basic Morphological Algorithms (9)

► Morphological Reconstruction

It involves two images and a structuring element

- a. One image contains the starting points for the transformation (The image is called marker)
- b. Another image (mask) constrains the transformation
- c. The structuring element is used to define connectivity

Morphological Reconstruction: Geodesic Dilation

Let F denote the marker image and G the mask image, $F \subseteq G$. The geodesic dilation of size 1 of the marker image with respect to the mask, denoted by $D_G^{(1)}(F)$, is defined as

$$D_G^{(1)}(F) = (F \oplus B) \cap G$$

The geodesic dilation of size n of the marker image F with respect to G , denoted by $D_G^{(n)}(F)$, is defined as

$$D_G^{(n)}(F) = D_G^{(1)}(F) [D_G^{(n-1)}(F)]$$

with $D_G^{(0)}(F) = F$.

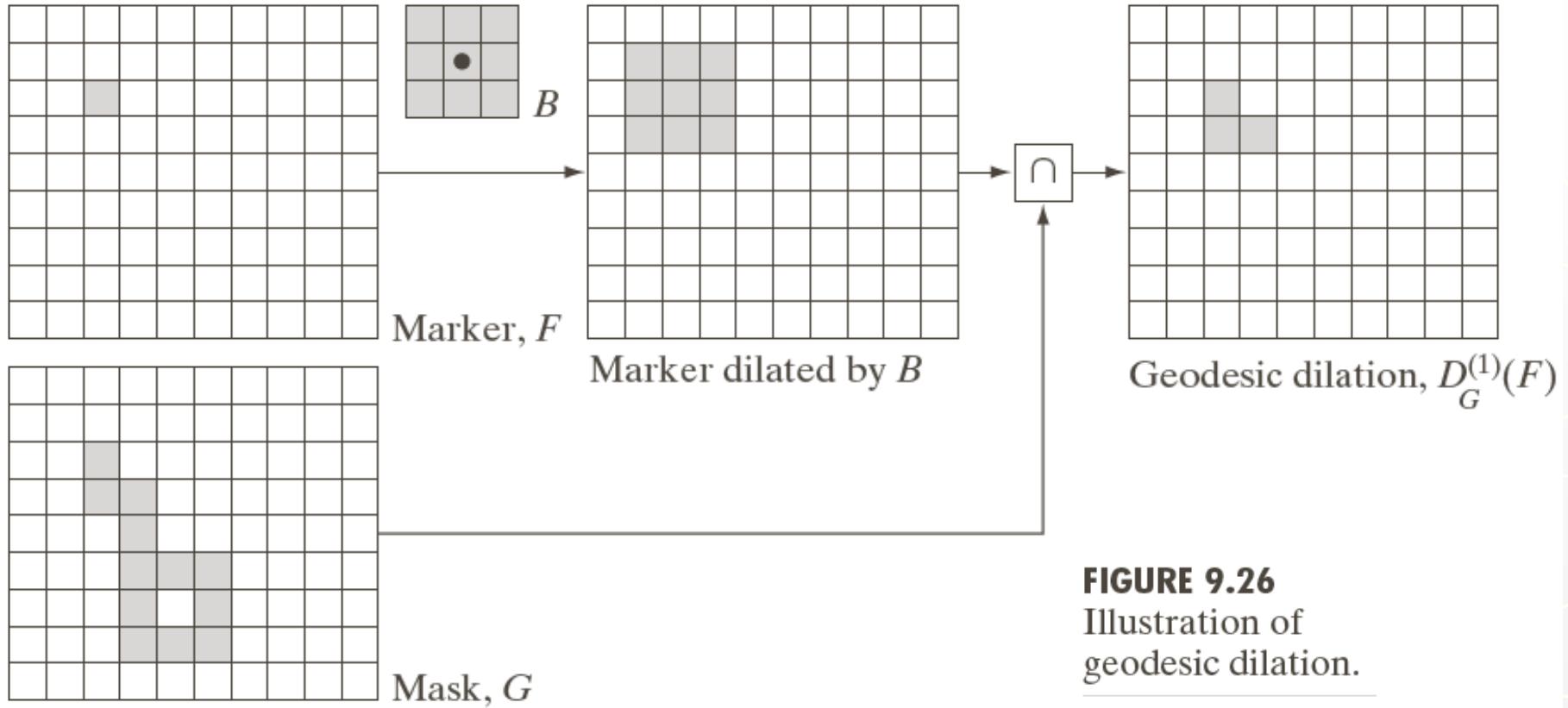


FIGURE 9.26
Illustration of
geodesic dilation.

Morphological Reconstruction: Geodesic Erosion

Let F denote the marker image and G the mask image. The geodesic erosion of size 1 of the marker image with respect to the mask, denoted by $E_G^{(1)}(F)$, is defined as

$$E_G^{(1)}(F) = (F \ominus B) \cup G$$

The geodesic erosion of size n of the marker image F with respect to G , denoted by $E_G^{(n)}(F)$, is defined as

$$E_G^{(n)}(F) = E_G^{(1)}(F) [E_G^{(n-1)}(F)]$$

with $E_G^{(0)}(F) = F$.

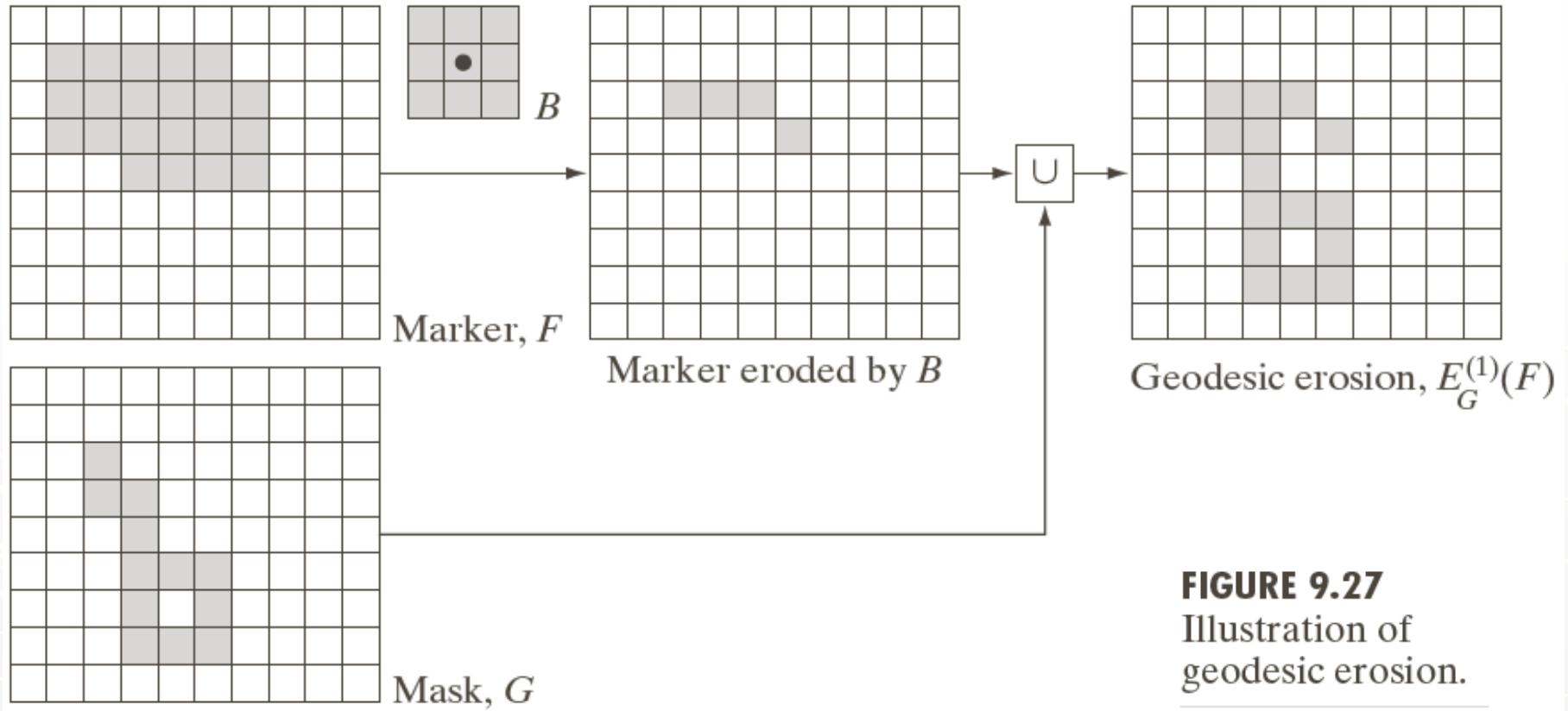


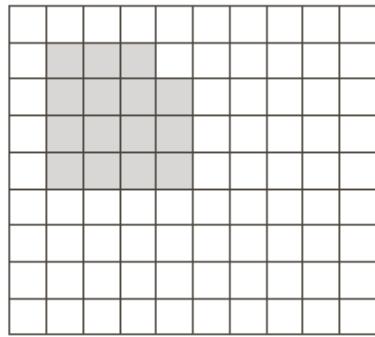
FIGURE 9.27
Illustration of
geodesic erosion.

Morphological Reconstruction by Dilation

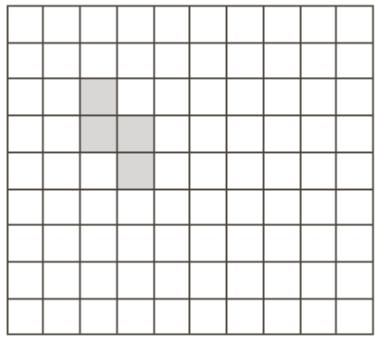
Morphological reconstruction by dilation of a mask image G from a marker image F , denoted $R_G^D(F)$, is defined as the geodesic dilation of F with respect to G , iterated until stability is achieved; that is,

$$R_G^D(F) = D_G^{(k)}(F)$$

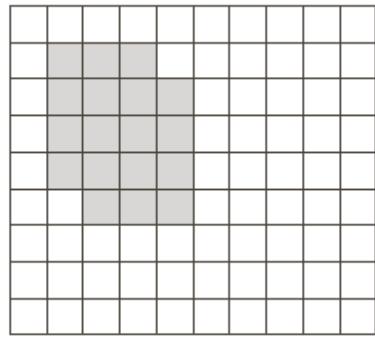
with k such that $D_G^{(k)}(F) = D_G^{(k-1)}(F)$.



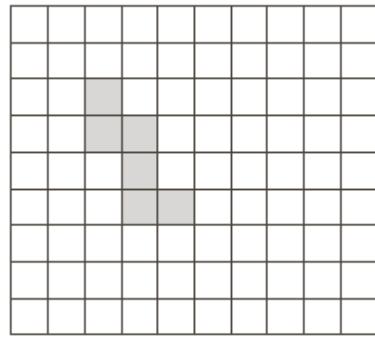
$D_G^{(1)}(F)$ dilated by B



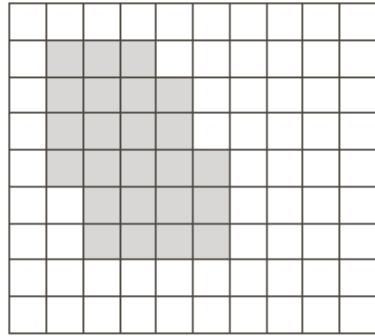
$D_G^{(2)}(F)$



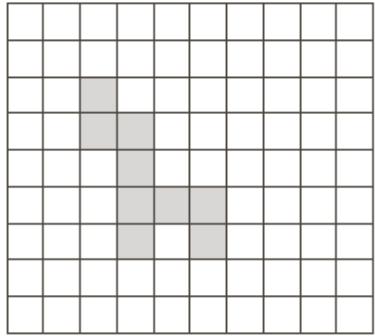
$D_G^{(2)}(F)$ dilated by B



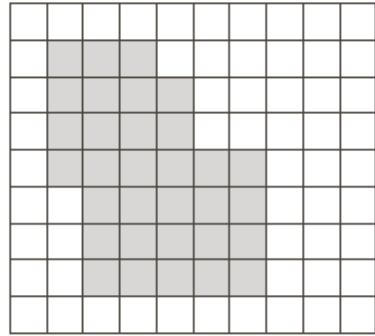
$D_G^{(3)}(F)$



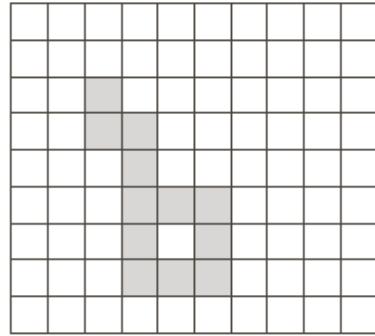
$D_G^{(3)}(F)$ dilated by B



$D_G^{(4)}(F)$



$D_G^{(4)}(F)$ dilated by B



$D_G^{(5)}(F) = R_G^D(F)$

a b c d
e f g h

FIGURE 9.28
Illustration of
morphological
reconstruction by
dilation. F, G, B
and $D_G^{(1)}(F)$ are
from Fig. 9.26.

Morphological Reconstruction by Erosion

Morphological reconstruction by erosion of a mask image G from a marker image F , denoted $R_G^E(F)$, is defined as the geodesic erosion of F with respect to G , iterated until stability is achieved; that is,

$$R_G^E(F) = E_G^{(k)}(F)$$

with k such that $E_G^{(k)}(F) = E_G^{(k-1)}(F)$.

Opening by Reconstruction

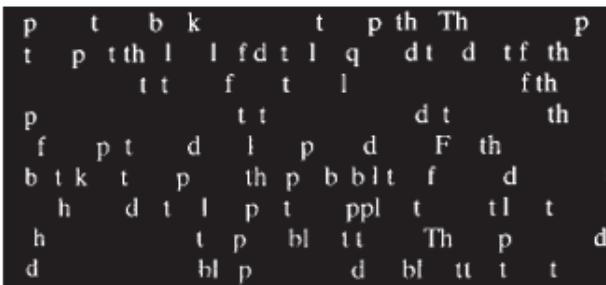
The opening by reconstruction of size n of an image F is defined as the reconstruction by dilation of F from the erosion of size n of F ; that is

$$O_R^{(n)}(F) = R_F^D \left[(F \ominus nB) \right]$$

where $(F \ominus nB)$ indicates n erosions of F by B .

ponents or broken connection paths. There is no point past the level of detail required to identify those.

Segmentation of nontrivial images is one of the most difficult tasks in computer vision and image processing. Segmentation accuracy determines the effectiveness of computerized analysis procedures. For this reason, considerable care must be taken to improve the probability of rugged segmentation. In some applications, such as industrial inspection applications, at least some tolerance for errors in the environment is possible at times. The experienced image processing designer invariably pays considerable attention to such



a b
c d

FIGURE 9.31 (a) Text image of size 918×2018 pixels. The approximate average height of the tall characters is 51 pixels. (b) Erosion of (a) with a structuring element of size 51×1 elements (all 1's). (c) Opening of (a) with the same structuring element, shown for comparison. (d) Result of opening by reconstruction.

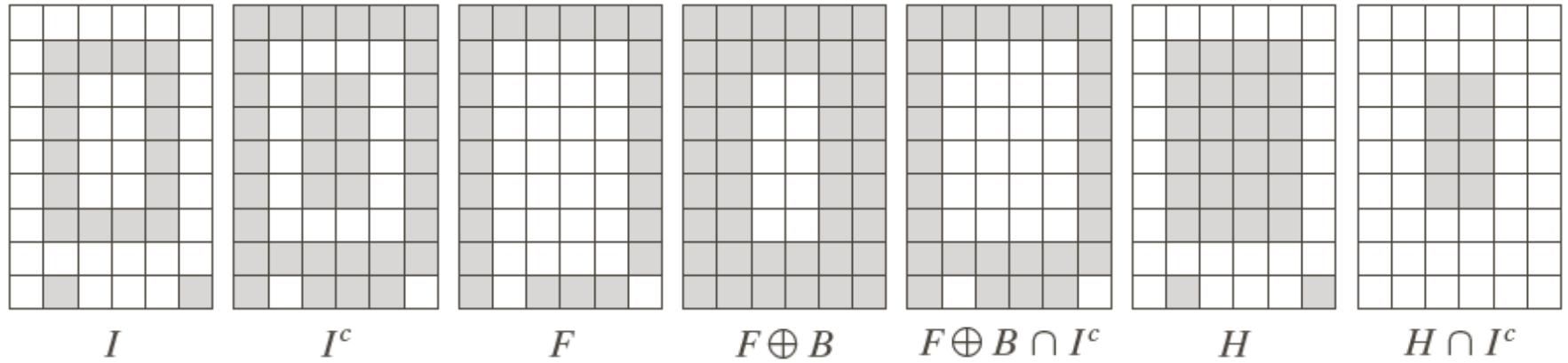
Filling Holes

Let $I(x, y)$ denote a binary image and suppose that we form a marker image F that is 0 everywhere, except at the image border, where it is set to $1 - I$; that is

$$F(x, y) = \begin{cases} 1 - I(x, y) & \text{if } (x, y) \text{ is on the border of } I \\ 0 & \text{otherwise} \end{cases}$$

then

$$H = [R_{I^c}^D(F)]^c$$



SE: 3×3 1s.

a b c d e f g

FIGURE 9.30
Illustration of
hole filling on a
simple image.

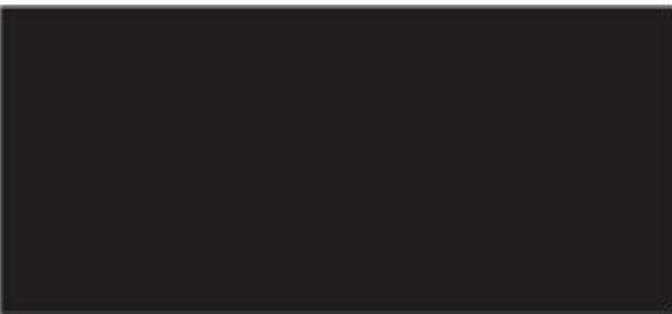
a b
c d

FIGURE 9.33

- (a) Text image of size 918×2018 pixels.
 - (b) Complement of (a) for use as a mask image.
 - (c) Marker image.
 - (d) Result of hole-filling using Eqs. (9-45) and (9-46).

ponents or broken connection paths. There is no point past the level of detail required to identify those.

Segmentation of nontrivial images is one of the most difficult tasks in computer vision processing. Segmentation accuracy determines the eventual success of computerized analysis procedures. For this reason, considerable care must be taken to improve the probability of rugged segmentation. In industrial inspection applications, at least some tolerance to variations in the environment is possible at times. The experienced computer vision designer invariably pays considerable attention to such factors.



ponents or broken connection paths. There is no point past the level of detail required to identify those.

Segmentation of nontrivial images is one of the most difficult problems in computer vision processing. Segmentation accuracy determines the eventual success or failure of computerized analysis procedures. For this reason, considerable care must be taken to improve the probability of rugged segmentation. In industrial inspection applications, at least some degree of tolerance to variations in the environment is possible at times. The experienced computer vision designer invariably pays considerable attention to such factors.

ponents or broken connection paths. There is no point in going past the level of detail required to identify those.

Segmentation of nontrivial images is one of the most difficult tasks in computer vision processing. Segmentation accuracy determines the effectiveness of computerized analysis procedures. For this reason, considerable attention has been taken to improve the probability of rugged segmentation. Such applications as industrial inspection are, at least sometimes, extremely difficult because the environment is possible at times. The experienced image processing designer invariably pays considerable attention to such problems.

$$H = \left[R_{I^c}^D(F) \right]^c$$

Border Clearing

It can be used to screen images so that only complete objects remain for further processing; it can be used as a signal that partial objects are present in the field of view.

The original image is used as the mask and the following marker image:

$$F(x, y) = \begin{cases} I(x, y) & \text{if } (x, y) \text{ is on the border of } I \\ 0 & \text{otherwise} \end{cases}$$

$$X = I - R_I^D(F)$$

ponents or broken connection paths. There is no point past the level of detail required to identify those

Segmentation of nontrivial images is one of the most processing. Segmentation accuracy determines the even of computerized analysis procedures. For this reason, care be taken to improve the probability of rugged segment such as industrial inspection applications, at least some the environment is possible at times. The experienced i designer invariably pays considerable attention to suc

ponents or broken connection paths. There is no point past the level of detail required to identify those

Segmentation of nontrivial images is one of the most processing. Segmentation accuracy determines the even of computerized analysis procedures. For this reason, care be taken to improve the probability of rugged segment such as industrial inspection applications, at least some the environment is possible at times. The experienced i designer invariably pays considerable attention to suc

a b

FIGURE 9.32
Border clearing.
(a) Marker image.
(b) Image with no
objects touching
the border. The
original image is
Fig. 9.29(a).

