考試重點

Digital Image Processing

形態學的 Chapter 9

Morphological Image Processing

Fall 2018

吳俊霖
Jiunn-Lin Wu
jlwu@cs.nchu.edu.tw

*前/後處理都会用到

*跟其它chapter 無关 "独立"

國立中興大學

Morphological Image Processing

- We use mathematical morphology as a tool for extracting image component that are useful in the representation and description of region shape, such as boundaries, skeletons and the convex hull.
- We are interested also in morphological techniques for pre or postprocessing, such as morphological filtering, thinning, an pruning.
- The language of mathematical morphology is set theory. As such, morphology offers a unified and powerful approach to numerous image processing problems.
- Tools like morphology and related concepts are a cornerstone of the mathematical foundation that is utilized for extracting "meaning" from an image.

Some Basic Concepts from Set Theory

- Let *A* be a set in Z^2. If *a* is an element of *A*, then we write
  $a \in A$
- If *a* is not an element of *A*, we write $a \notin A$
- The set with no element s is called the *null* or *empty set* and denoted by the symbol ϕ.
- *A* is a *subset* of *B*, denoted as $A \subseteq B$
- The *union* of two sets *A* and *B*, denoted by $C = A \cup B$
- The *intersection* of two sets *A* and *B*, denoted by $D = A \cap B$

Some Basic Concepts from Set Theory

- Two sets *A* and *B* are said to be *disjoint* or *mutually exclusive* if they have no common elements. $A \cap B = \phi$
- The *complement* of a set *A* is the set of elements not contained in *A*: $A^c = \{w \mid w \notin A\}$
- The *difference* of two sets *A* and *B*, denoted *A-B*, is defined as
  $$A - B = \{w \mid w \in A, w \notin B\} = A \cap B^c$$

Some Basic Concepts from Set Theory

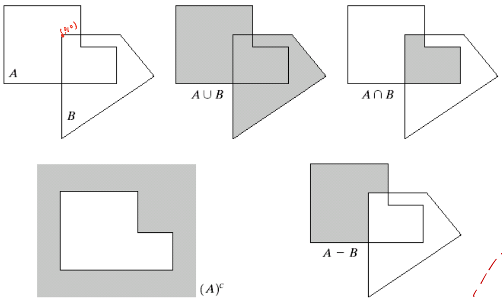


FIGURE 9.1 (a) Two sets A and B. (b) The union of A and B. (c) The intersection of A and B. (d) The complement of A. (e) The difference between A and B.

Some Basic Concepts from Set Theory

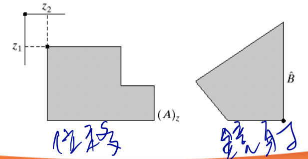
- The reflection (鏡射) of set B, denoted $\hat{B}$ (鏡射), is defined as

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

對稱原點做鏡射

- The translation (位移) of set A by point $z = (z_1, z_2)$, denoted $(A)_z$, is defined as

$$(A)_z = \{c \mid c = a + z, \quad for\ a \in A\}$$



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.

Some Basic Concepts from Set Theory

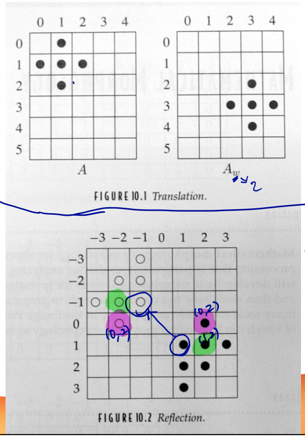


FIGURE 10.1 Translation.

FIGURE 10.2 Reflection.

def $\hat{B} = \{w \mid w = -b\}$

$b \in B$

$(1,1) \Rightarrow (-1,-1)$

Logic Operations Involving Binary Images

- Logic operations, although simple in nature, provide a powerful complement to implementation of image processing algorithms based on morphology.
- The principle logic operations used in image processing are AND, OR, and NOT(COMPLEMENT).
- They are functionally complete.

TABLE 9.1 The three basic logical operations.

p	q	p AND q (also $p \cdot q$)	p OR q (also $p + q$)	NOT (p) (also $\bar{p}$)
0	0	0	0	1
0	1	0	1	1
1	0	0	1	0
1	1	1	1	0

Logic Operations Involving Binary Images

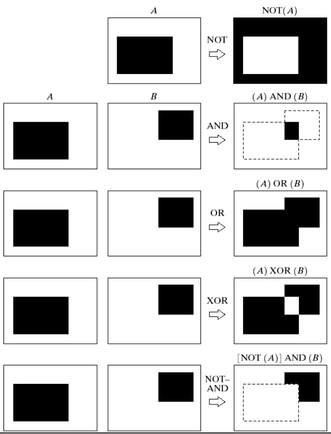


FIGURE 9.3 Some logic operations between binary images. Black represents binary 1s and white binary 0s in this example.

reflection 還是一樣

相對

white

Dilation and Erosion

處理 Binary 影像

- These operations are fundamental to morphological processing.

對於 Binary (黑白)

增胖 oriImg

- *Dilation*: With A and B as set in Z^2, the dilation of *A* by *B*, denoted $A \oplus B$, is defined as

預設是 binary Img

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

先鏡射(1) 再位移(2), 再跟 A 取交集, 結果不為 φ

- *Erosion*: For sets *A* and *B* in Z^2 the erosion of *A* by *B*, denoted $A \ominus B$, is defined as

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

先鏡射 再位移

Dilation 侵蝕

A ⊕ B

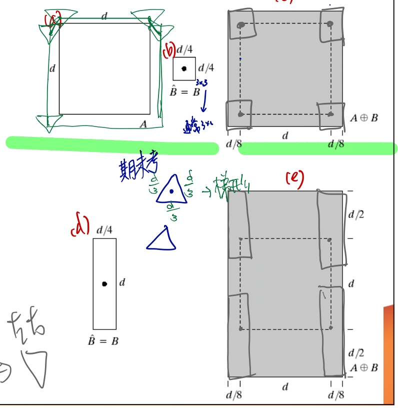


FIGURE 9.4 (a) Set *A*. (b) Square structuring element (dot is the center). (c) Dilation of *A* by *B*, shown shaded. (d) Elongated structuring element. (e) Dilation of *A* using this element.

左 右

Dilation 增胖 強化線條

- One of the simplest applications of dilation is for bridging gaps.
- One immediate advantage of the morphological approach over the lowpass filtering is it resulted directly in a binary image.

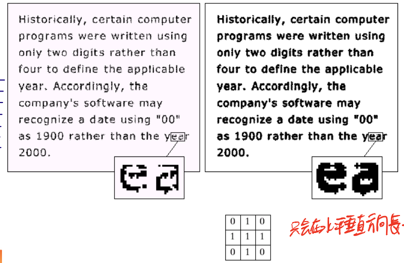
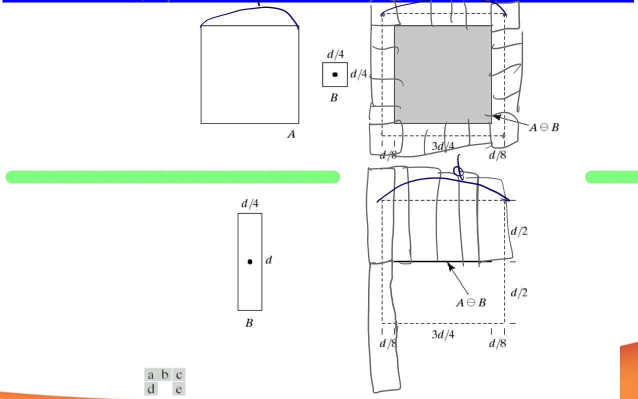


FIGURE 9.5 (a) Sample text of poor resolution with broken characters (magnified view). (b) Structuring element. (c) Dilation of (a) by (b). Broken segments were joined.

與Dilation相對 → 變瘦

Erosion

$A \ominus B$



a b c
d e

FIGURE 9.6 (a) Set A. (b) Square structuring element. (c) Erosion of A by B, shown shaded. (d) Elongated structuring element. (e) Erosion of A using this element.

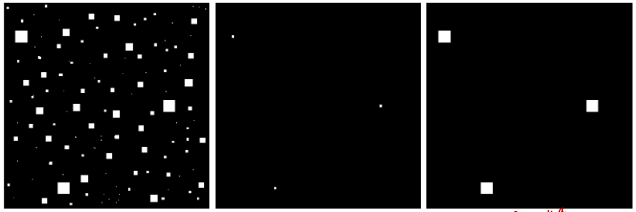
學習: Mask不只是3x3

極致是做 Erosion or Dilation

Erosion

- One of the simplest uses of erosion is for eliminating irrelevant detail (in terms of size) form a binary image.

15x15



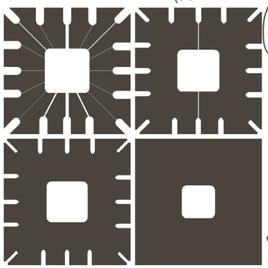
a b c

目的: 留下15x15

FIGURE 9.7 (a) Image of squares of size 1, 3, 5, 7, 9, and 15 pixels on the side. (b) Erosion of (a) with a square structuring element of 1's, 13 pixels on the side. (c) Dilation of (b) with the same structuring element.

若只有3x3的Mask, 也可以完成, 不斷做Erosion

Erosion



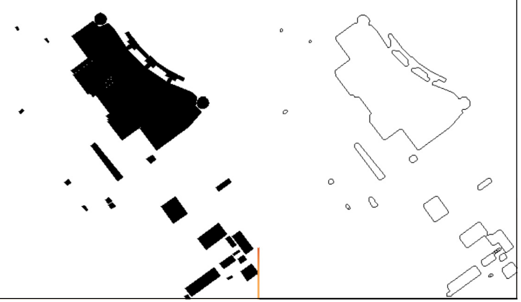
a b
c d

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.

變瘦 → 刪掉部份元素

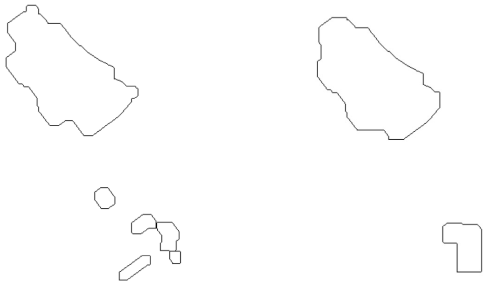
使用Morphology於CAD縮編的結果

- 測試地區:板橋車站
- Original image Mask size: 3X3



使用Morphology於CAD縮編的結果

- Mask size: 11x11 21x21



Opening

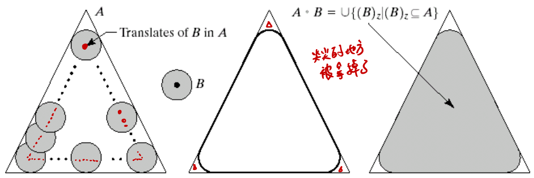
struct element 在裡面記 所構成的最大面積

- *Opening* generally smoothes the contour of an object, breaks narrow isthmuses, and eliminates thin protrusions

輪廓

先erison 再dilation 先縮小,再增胖

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



a b c d

FIGURE 9.8 (a) Structuring element B "rolling" along the inner boundary of A (the dot indicates the origin of B). (c) The heavy line is the outer boundary of the opening. (d) Complete opening (shaded).

close

open

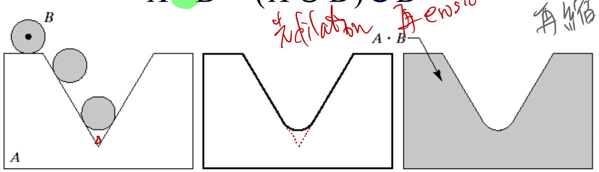
Closing

struct element 在外面記

- *Closing* also tend to smooth sections of contours but, as opposed to opening, it generally fuses narrow breaks and long thin gulfs, eliminates small holes, and fills gaps in the contour.

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

先dilation 再erosion 先變胖 再縮小



a b c

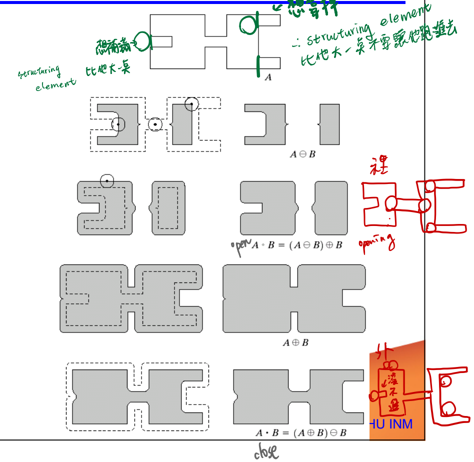
FIGURE 9.9 (a) Structuring element B "rolling" on the outer boundary of set A. (b) Heavy line is the outer boundary of the closing. (c) Complete closing (shaded).

Opening and Closing

ex:

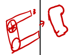
a
b c
d e
f g
h i

FIGURE 9.10 Morphological opening and closing. The structuring element is the small circle shown in various positions in (b). The dark dot is the center of the structuring element.



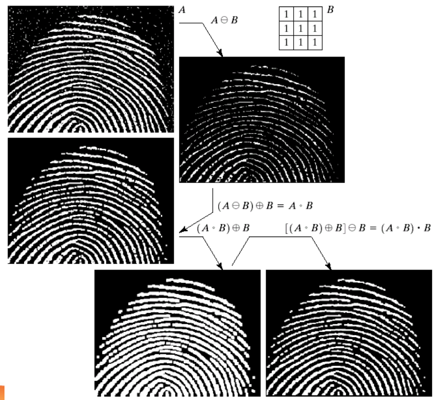
Opening and Closing

不是亂做
筆條：structure element 大一點的



- Morphological operations can be used to construct filters similar in concept to the spatial filters.
- The objective is to eliminate the noise and its effects on the print while distorting it as little as possible.
- A morphological filter consisting of opening followed by closing can be used to accomplish this objective.
- The final result is remarkably clean of noise specks, but it has the disadvantage that some of the print ridges were not fully repaired, and thus contain breaks.

Opening and Closing



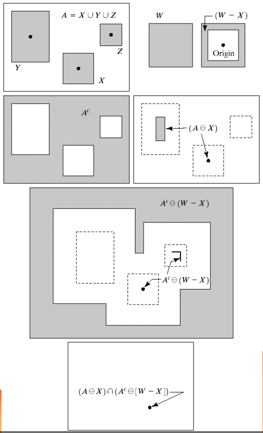
a b
d c
e f

FIGURE 9.11 (a) Noisy image. (c) Eroded image. (d) Opening of A. (d) Dilation of the opening. (e) Closing of the opening. (Original image for this example courtesy of the National Institute of Standards and Technology.)

The Hit-or-Miss Transformation

$$A \circledast B = (A \ominus X) \cap [A^c \ominus (W - X)]$$

*給一張影像把有X形狀的位置在哪裡並標出來
*想在一堆東西裡面找你要的某一個形狀（東西）在哪裡標出來



The Hit-or-Miss Transformation

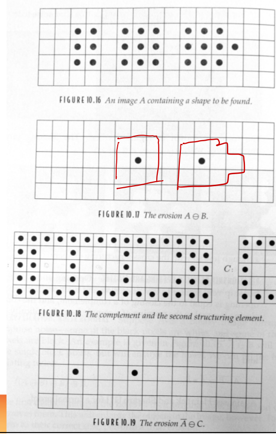


FIGURE 10.16 An image A containing a shape to be found.

FIGURE 10.17 The erosion $A \ominus B$.

FIGURE 10.18 The complement and the second structuring element.

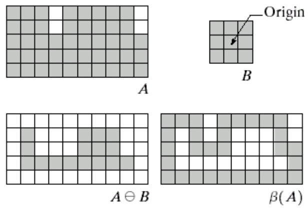
FIGURE 10.19 The erosion $\bar{A} \ominus C$.

Some Basic Morphological Algorithms

- When dealing with binary images, the principal application of morphology is extracting image components that are useful in the representation and description of shape.
- In particular, we consider morphological algorithms for extracting boundaries, connected components, the convex hull, and the skeleton of a region.
- We also develop several methods (for region filling, thinning, thickening, and pruning) that are used frequently in conjunction with these algorithms as pre- or post processing steps.

Boundary Extraction

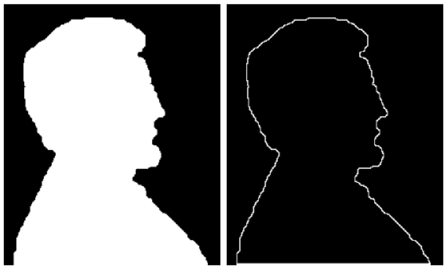
- $\beta(A) = A - (A \ominus B)$
- Although the structuring element shown in Fig. 9.13(b) is among the most frequently used, it is by no means unique.



a b
c d

FIGURE 9.13 (a) Set *A*. (b) Structuring element *B*. (c) *A* eroded by *B*. (d) Boundary, given by the set difference between *A* and its erosion.

Boundary Extraction



a b

FIGURE 9.14 (a) A simple binary image, with 1's represented in white. (b) Result of using Eq. (9.5-1) with the structuring element in Fig. 9.13(b).

Region Filling 補滿

- We develop a simple algorithm for region filling based on set dilations, complementation, and intersections.
- The following procedure fills the region with 1's:

補集合

$$X_k = (X_{k-1} \oplus \underbrace{B}_{\text{struct. elmt}}) \cap \underbrace{A^c}_{\text{Img}} \quad k = 1,2,3,\cdots$$

- The algorithm terminates at iteration step k if $X_k = X_{k-1}$

会考

Region Filling

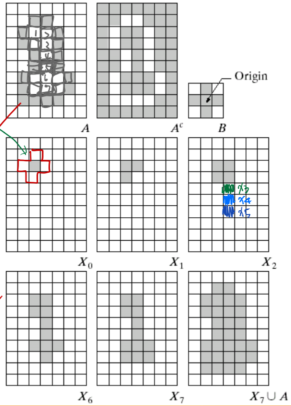
a b c
d e f
g h i

FIGURE 9.15 Region filling. (a) Set A. (b) Complement of A. (c) Structuring element B. (d) Initial point inside the boundary. (e)–(h) Various steps of Eq. (9.5-2). (i) Final result [union of (a) and (h)].

X_0 = 空洞裡的任一點

課本挑此点

考試會改 X_0 的位置 的時候



HW5

Region Filling

畫家 size 沒差 要封閉

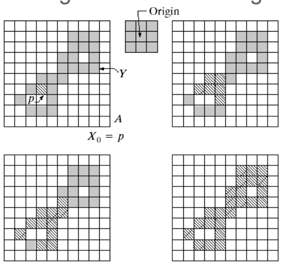
- The dark spots inside the spheres are the result of reflections. The objective is to eliminate the reflections by region filling.

a b c

FIGURE 9.16 (a) Binary image (the white dot inside one of the regions is the starting point for the region-filling algorithm). (b) Result of filling that region (c) Result of filling all regions.

Extraction of Connected Components

- $X_k = (X_{k-1} \oplus B) \cap A \quad k = 1,2,3,\cdots$
- If $X_k = X_{k-1}$, the algorithm has converged.



a b c
d e

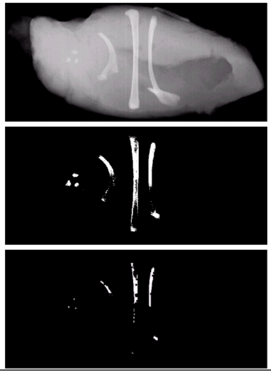
FIGURE 9.17 (a) Set A showing initial point p (all shaded points are valued 1, but are shown different from p to indicate that they have not yet been found by the algorithm). (b) Structuring element. (c) Result of first iterative step. (d) Result of second step. (e) Final result.

Extraction of Connected Components

- Connected components are used frequently for automated inspection.

a
b
c d

FIGURE 9.18 (a) X-ray image of chicken filet with bone fragments. (b) Thresholded image. (c) Image eroded with a 5 × 5 structuring element of 1's. (d) Number of pixels in the connected components of (c). (Image 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

Convex Hull 凸集合

- A set A is said to be convex if the straight line segment joining any two points in A lies entirely within A.
- The <u>*convex hull*</u> H of an arbitrary set S is the smallest convex set containing S.
- The set difference H-S is called the <u>*convex deficiency*</u> of S.
- $X_k^i = (X_{k-1} \circledast B^i) \cup A \quad i = 1, 2, 3, 4 \quad \text{and} \quad k = 1, 2, 3, \ldots$
- $X_0^i = A$
- $C(A) = \bigcup_{i=1}^{4} D^i$

Convex Hull 給一形狀 求最小凸集合

x: Don't care

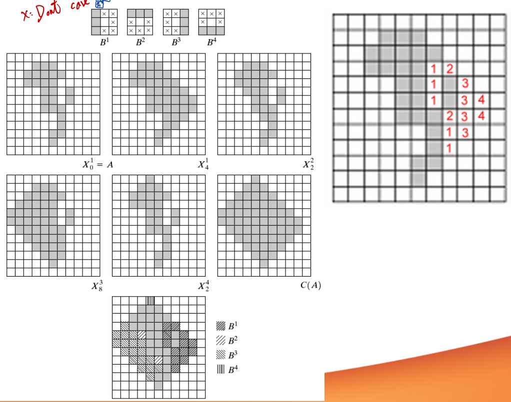


FIGURE 9.19 (a) Structuring elements. (b) Set A. (c)–(f) Results of convergence with the structuring elements shown in (a). (g) Convex hull. (h) Convex hull showing the contribution of each structuring element.

Convex Hull

- One obvious shortcoming of the above procedure is that the convex hull can grow beyond the minimum dimensions required to guarantee convexity.
- One simple approach to reduce this effect is to limit growth so that it does not extend past the vertical and horizontal dimensions of the original set of points.

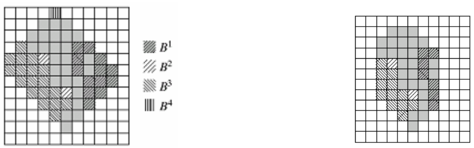
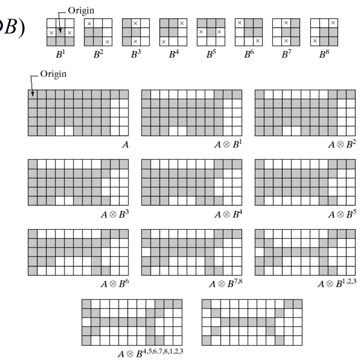


FIGURE 9.20 Result of limiting growth of convex hull algorithm to the maximum dimensions of the original set of points along the vertical and horizontal directions.

Thinning 細化 (→一個pixel寬)

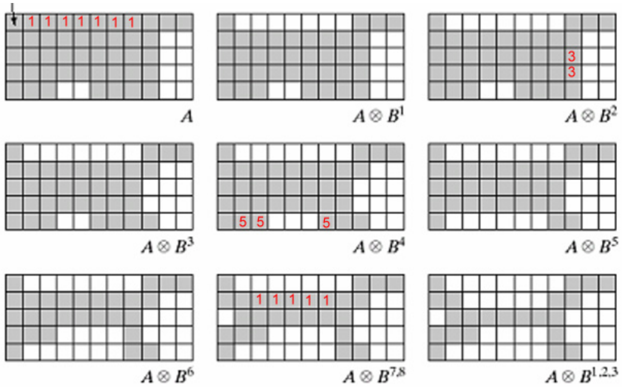
- $A \otimes B = A - (A \circledast B)$



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

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 element again (there were no changes for the next two elements). (k) Result after convergence. (l) Conversion to m-connectivity.

Thinning



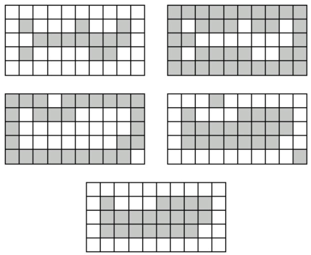
Thickening

- Thickening is the morphological dual of thinning and is defined by the expression

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

- Note that Fig. 9.22(c) that the thinned background forms a boundary for the thickening process.
- This useful feature is one of the reasons for using background thinning to accomplish thickening.

Thickening



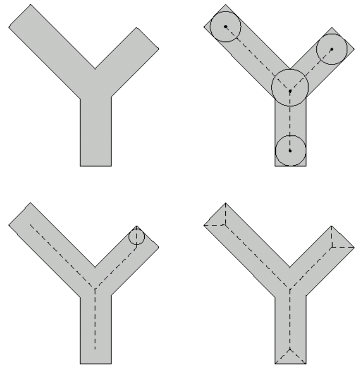
a b
c d
e

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.

Skeletons

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.



Skeletons

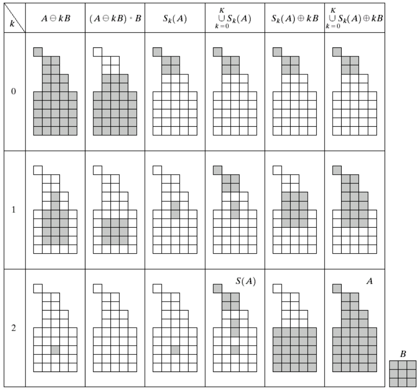


FIGURE 9.24 Implementation of Eqs. (9.5-11) through (9.5-15). The original set is at the top left, and its morphological skeleton is at the bottom of the fourth column. The reconstructed set is at the bottom of the sixth column.

Skeletons

TABLE 10.1 *Operations used to construct the skeleton.*

Erosions	Openings	Set differences
A	$A \circ B$	$A - (A \circ B)$
$A \ominus B$	$(A \ominus B) \circ B$	$(A \ominus B) - ((A \ominus B) \circ B)$
$A \ominus 2B$	$(A \ominus 2B) \circ B$	$(A \ominus 2B) - ((A \ominus 2B) \circ B)$
$A \ominus 3B$	$(A \ominus 3B) \circ B$	$(A \ominus 3B) - ((A \ominus 3B) \circ B)$
⋮	⋮	⋮
$A \ominus kB$	$(A \ominus kB) \circ B$	$(A \ominus kB) - ((A \ominus kB) \circ B)$

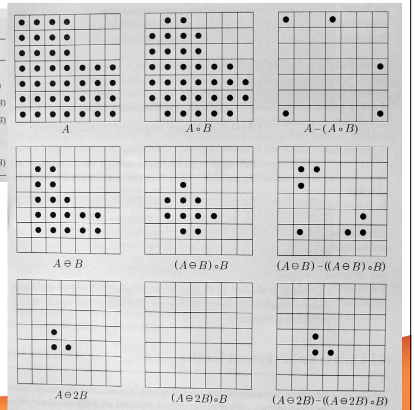
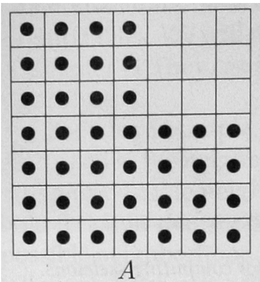


FIGURE 10.28 *Skeletonization.*

Skeletons



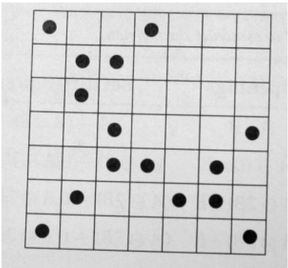


FIGURE 10.29 *The final skeleton.*

Skeletons

文字太粗不適合
做文字識別

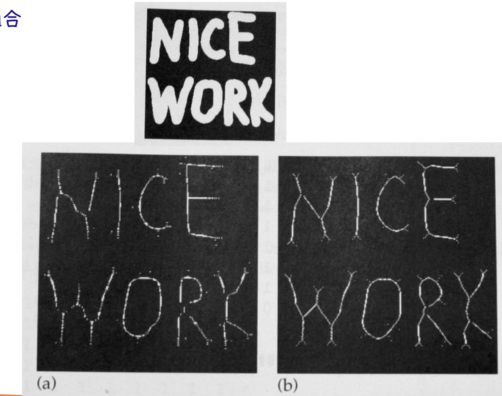


FIGURE 10.31 *Skeletonization of a binary image.*

Pruning 支幹修剪

- Pruning methods are an essential complement to thinning and skeletonizing algorithms because these procedures tend to leave parasitic components that need to be "cleaned up" by postprocessing.

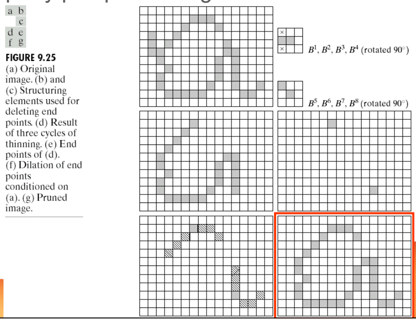


FIGURE 9.25 (a) Original image. (b) and (c) Structuring elements used for deleting end points. (d) Result of three cycles of thinning. (e) End points of (d). (f) Dilation of end points conditioned on (a). (g) Pruned image.

Summary of Morphological Operations on Binary Images

TABLE 9.2 Summary of morphological operations and their properties.

Operation	Equation	Comments (The Roman numerals refer to the structuring elements shown in Fig. 9.26).
Translation	$(A)_z = \{w \mid w = a + z, \text{ for } a \in A\}$	Translates the origin of A to point z.
Reflection	$\hat{B} = \{w \mid w = -b, \text{ for } b \in B\}$	Reflects all elements of B about the origin of this set.
Complement	$A^c = \{w \mid w \notin A\}$	Set of points not in A.
Difference	$A - B = \{w \mid w \in A, w \notin B\} = A \cap B^c$	Set of points that belong to A but not to B.
Dilation	$A \oplus B = \{z \mid (\hat{B})_z \cap A \neq \varnothing\}$	"Expands" the boundary of A. (I)
Erosion	$A \ominus B = \{z \mid (B)_z \subseteq A\}$	"Contracts" the boundary of A. (I)
Opening	$A \circ B = (A \ominus B) \oplus B$	Smoothes contours, breaks narrow isthmuses, and eliminates small islands and sharp peaks. (I)
Closing	$A \bullet B = (A \oplus B) \ominus B$	Smoothes contours, fuses narrow breaks and long thin gulfs, and eliminates small holes. (I)

課只有 dilation < erosion

可提示考
＊B (struct element) 通常用 Default 的 3x3, 可以 試試說 size

Summary of Morphological Operations on Binary Images

Hit-or-miss transform	$A \circledast B = (A \ominus B_1) \cap (A^c \ominus B_2) = (A \ominus B_1) - (A \oplus \hat{B}_2)$	The set of points (coordinates) at which, simultaneously, B_1 found a match ("hit") in A and B_2 found a match in A^c.
Boundary extraction	$\beta(A) = A - (A \ominus B)$	Set of points on the boundary of set A. (I)
Region filling 給一個封閉的框框可以把它填滿	$X_k = (X_{k-1} \oplus B) \cap A^c$; $X_0 = p$ and $k = 1, 2, 3, \ldots$	Fills a region in A, given a point p in the region. (II)
Connected components	$X_k = (X_{k-1} \oplus B) \cap A$; $X_0 = p$ and $k = 1, 2, 3, \ldots$	Finds a connected component Y in A, given a point p in Y. (I)
Convex hull	$X_k^i = (X_{k-1}^i \circledast B^i) \cup A$; $i = 1, 2, 3, 4$; $k = 1, 2, 3, \ldots$; $X_0^i = A$; and $D^i = X_{\text{conv}}^i$.	Finds the convex hull $C(A)$ of set A, where "conv" indicates convergence in the sense that $X_k^i = X_{k-1}^i$. (III)

Summary of Morphological Operations on Binary Images

TABLE 9.2 Summary of morphological results and their properties. *(continued)*

Operation	Equation	Comments (The Roman numerals refer to the structuring elements shown in Fig. 9.26).
Thinning 細化	$A \otimes B = A - (A \circledast B) = A \cap (A \circledast B)^c$ $A \otimes \{B\} = ((\ldots((A \otimes B^1) \otimes B^2) \ldots) \otimes B^n)$ $\{B\} = \{B^1, B^2, B^3, \ldots, B^n\}$	Thins set A. The first two equations give the basic definition of thinning. The last two equations denote thinning by a sequence of structuring elements. This method is normally used in practice. (IV)
Thickening	$A \odot B = A \cup (A \circledast B)$ $A \odot \{B\} = ((\ldots(A \odot B^1) \odot B^2 \ldots) \odot B^n)$	Thickens set A. (See preceding comments on sequences of structuring elements.) Uses IV with 0's and 1's reversed.

Summary of Morphological Operations on Binary Images

Skeletons 找骨幹	$S(A)=\bigcup_{k=0}^{K} S_k(A)$ $S_k(A)=\bigcup_{k=0}^{K}\{(A\ominus kB)-[(A\ominus kB)\circ B]\}$ Reconstruction of A: $A=\bigcup_{k=0}^{K}(S_k(A)\oplus kB)$	Finds the skeleton $S(A)$ of set A. The last equation indicates that A can be reconstructed from its skeleton subsets $S_k(A)$. In all three equations, K is the value of the iterative step after which the set A erodes to the empty set. The notation $(A\ominus kB)$ denotes the kth iteration of successive erosion of A by B. (I)
Pruning	$X_1 = A\otimes\{B\}$ $X_2=\bigcup_{k=1}^{8}(X_1\circledast B^k)$ $X_3=(X_2\oplus H)\cap A$ $X_4=X_1\cup X_3$	X_4 is the result of pruning set A. The number of times that the first equation is applied to obtain X_1 must be specified. Structuring elements V are used for the first two equations. In the third equation H denotes structuring element I.

Summary of Morphological Operations on Binary Images

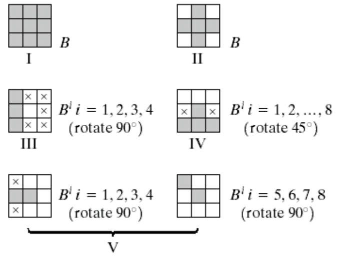


FIGURE 9.26 Five basic types of structuring elements used for binary morphology. The origin of each element is at its center and the ×'s indicate "don't care" values.

Gray-Scale Morphology

- We extend to gray-scale images the basic operations of dilation, erosion, opening and closing.
- We then use these operations to develop several basic gray-scale morphological algorithms. In particular, we develop algorithms for boundary extraction via a morphological gradient operations, and for region partitioning based on texture content.
- We also discuss algorithms for smoothing and sharpening, which often are useful as pre- or postprocessing steps.

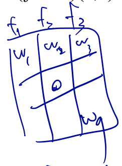
$A*B=\sum^{9} a_i \times W_i$

⊕ Max +

⊖ Min −

Dilation 局部亮點被拉寬

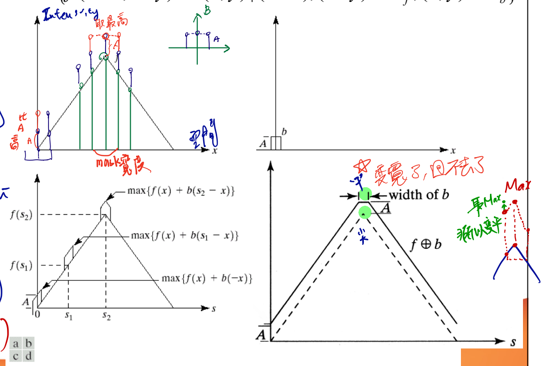
- $(f\oplus b)(s,t)=\max\{f(s-x,t-y)+b(x,y)\mid(s-x),(t-y)\in D_f,(x,y)\in D_b\}$



$g(x,y)=\sum_{i=1}^{9} w_i \cdot f_i$

$\mathrm{Max}(w_i+f_i)$

$\mathrm{Min}(w_i-f_i)$

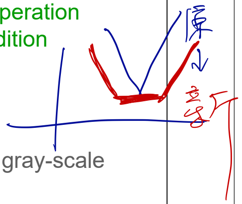


a b
c d

FIGURE 9.27 (a) A simple function. (b) Structuring element of height A. (c) Result of dilation for various positions of sliding b past f. (d) Complete result of dilation (shown solid).

Dilation

- It is similar to 2-D convolution, with the max operation replacing the sums of convolution and the addition replacing the products of convolution.

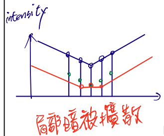


- The general effect of performing dilation on a gray-scale image is twofold:
  - If all the values of the structuring element are positive, the output image tends to be brighter than the input.
  - Dark details either are reduced or eliminated, depending on how their values and shapes relate to the structuring element used for dilation.

擴散多大？跟structure element一樣

Erosion 局部暗點被擴散

- $(f \ominus b)(s,t) = \min\{f(s+x,t+y) - b(x,y) \mid (s+x),(t+y) \in D_f, (x,y) \in D_b\}$
- It is similar in form of 2-D correlation, with the min operations replacing the sums of correlation and subtraction replacing the products of correlation.



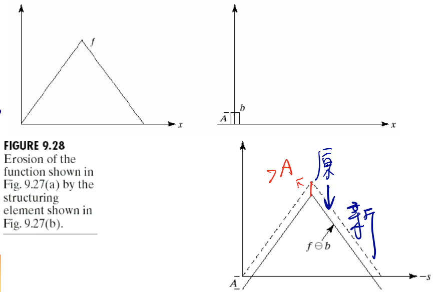


FIGURE 9.28 Erosion of the function shown in Fig. 9.27(a) by the structuring element shown in Fig. 9.27(b).

Dilation and Erosion

- Dilation is expected to produce an image that is brighter than the original and in which small, dark details have been reduced or eliminated.
- The eroded image is darker, and the sizes of small, bright features are reduced.

小的黑的拿掉

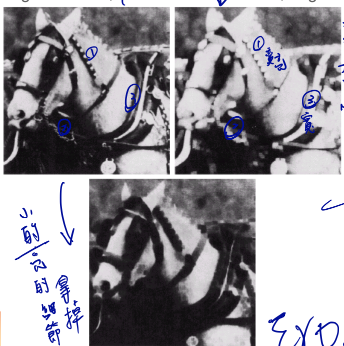


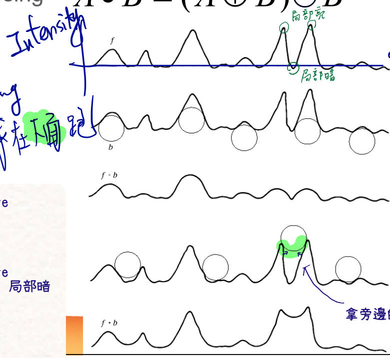
FIGURE 9.29 (a) Original image. (b) Result of dilation. (c) Result of erosion. (Courtesy of Mr. A. Morris, Leica Cambridge, Ltd.)

參考

Opening and Closing

- Opening $A \circ B = (A \ominus B) \oplus B$
- Closing $A \bullet B = (A \oplus B) \ominus B$

Dilation



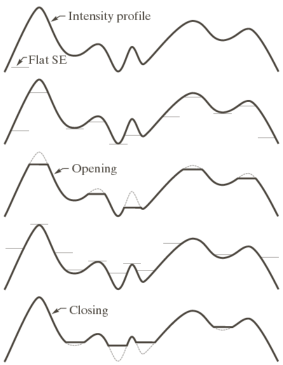
a b c d e

FIGURE 9.30 (a) A gray-scale scan line. (b) Positions of rolling ball for opening. (c) Result of opening. (d) Positions of rolling ball for closing. (e) Result of closing.

Opening:球在下面跑, structure element比亮的地方稍微大一點
拿掉小的亮的細節

Closing:球在上面跑, structure element比暗的地方稍微大一點, 局部暗點被補起來
拿掉小的暗的東西

Opening and Closing



a
b
c
d
e

FIGURE 9.36 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.

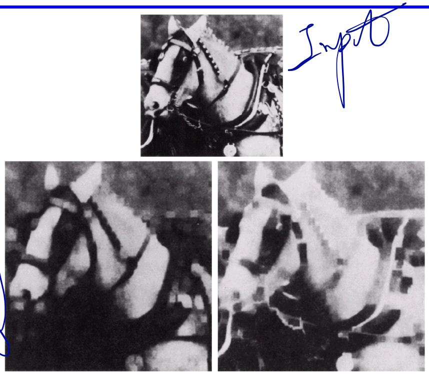
拿掉小的高的 Detail　拿掉小的暗的 Detail

Opening and Closing

↳相對於 structuring element 的 size

- In practical applications, opening operations usually are applied to remove small (with respect to the size of the structuring element) light details, while leaving the overall gray levels and larger bright features relatively undisturbed.
- In practice, closing is generally used to remove dark details from an image, while leaving bright features relatively undisturbed.

Opening and Closing



Input

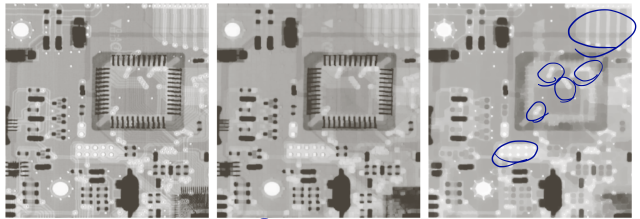
Opening 亮的消

Closing 暗的消

a b

FIGURE 9.31 (a) Opening and (b) closing of Fig. 9.29(a). (Courtesy of Mr. A. Morris, Leica Cambridge, Ltd.)

Opening and Closing



Opening　Closing

a b c

FIGURE 9.37 (a) A gray-scale X-ray image of size 448 × 425 pixels. (b) Opening using a disk SE with a radius of 3 pixels. (c) Closing using an SE of radius 5.

HW4

Morphological Smoothing
Morphological Gradient

Morphological Smoothing

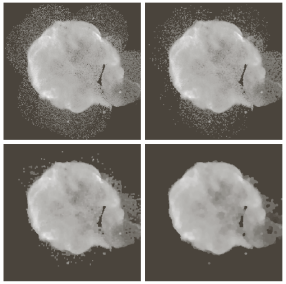
- One way to achieve smoothing is to perform a morphological opening followed by a closing.
- The net result of these two operations is to remove or attenuate both bright and dark artifacts or noise.

只要是小的細節就被拿掉
不管暗亮
(做closing opening)
(dilation->erosion
->erosion->dilation)

有點像
水彩畫

FIGURE 9.32 Morphological smoothing of the image in Fig. 9.29(a). (Courtesy of Mr. A. Morris, Leica Cambridge, Ltd.)

Morphological Smoothing



a b
c d

FIGURE 9.38 (a) 566 × 566 image of the Cygnus Loop supernova, taken in the X-ray band by NASA's Hubble Telescope. (b)–(d) Results of performing opening and closing sequences on the original image with disk structuring elements of radii, 1, 3, and 5, respectively. (Original image courtesy of NASA.)

Morphological Gradient

- Dilation and erosion often are sued to compute the *morphological gradient* of an image, denote *g*:

$$g = (f \oplus b) - (f \ominus b)$$

- The morphological gradient highlights sharp gray-level transitions in the input image.
- Morphological gradients obtained using symmetrical structuring elements tend to depend less on edge directionality.

Morphological Gradient

起到 sobel
以找 Edge
dilation - erosion

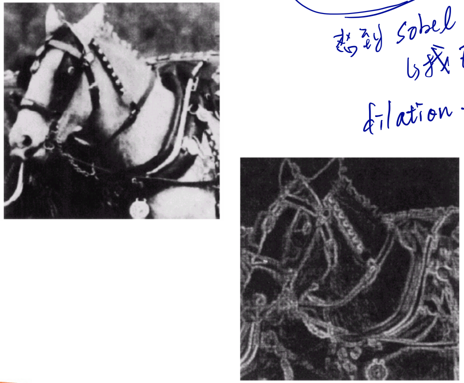
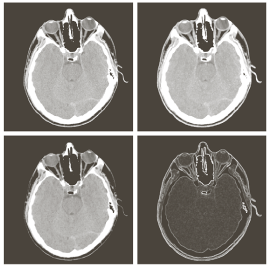


FIGURE 9.33 Morphological gradient of the image in Fig. 9.29(a). (Courtesy of Mr. A. Morris, Leica Cambridge, Ltd.)

Morphological Gradient



a b
c d

FIGURE 9.39 (a) 512 × 512 image of a head CT scan. (b) Dilation. (c) Erosion. (d) Morphological gradient, computed as the difference between (b) and (c). (Original image courtesy of Dr. David R. Pickens, Vanderbilt University.)

Morphological Gradient

把影像暗部細節抓出來 opening會把局部亮拿掉
拿原始影像減做opening結果，局部亮就被抓出來

名詞解釋

Top-hat Transformation

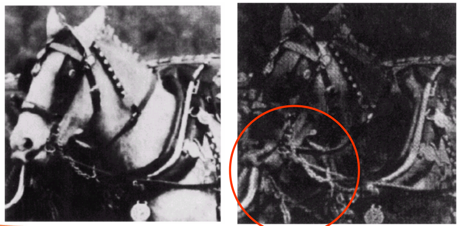
一種 Morphological 的運算

- The so-called morphological <u>*top-hat*</u> transformation of an image, denoted *h*, is defined as

$$h = f - (f \circ b)$$

原始 - opening
移掉小的亮的

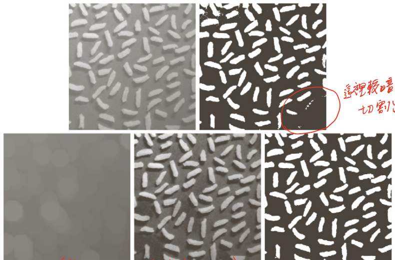
- It is useful for enhancing detail in the presence of shading.



暗處細節放大

FIGURE 9.34 Result of performing a top-hat transformation on the image of Fig. 9.29(a). (Courtesy of Mr. A. Morris, Leica Cambridge, Ltd.)

Top-hat Transformation



這裡較暗就無法被切割出來

a b
c d e

opening
亮的小的細節被拿掉

Top-hat (a-c)
得到小的亮的細節

FIGURE 9.40 Using the top-hat transformation for *shading correction*. (a) Original image of size 600 × 600 pixels. (b) Thresholded image. (c) Image opened using a disk SE of radius 40. (d) Top-hat transformation (the image minus its opening). (e) Thresholded top-hat image.

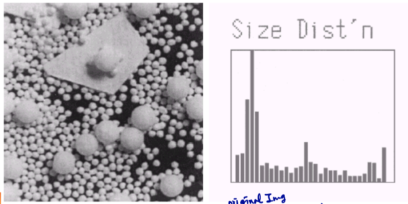
Granulometry

- Granulometry is a field that deals principally with determining the size distribution of particles in an image.
- The approach is based on the idea that opening operations of a particular size have the most effect on regions of the input image that contain particles of similar size.
- Thus , a measure of the relative number of such particles is obtained by computing the difference between the input and output images.

期末考擇一

Granulometry

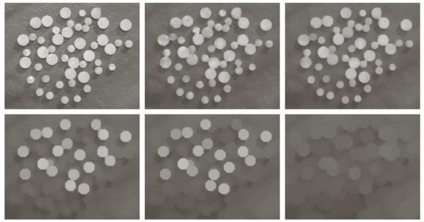
- Opening operations with structuring elements of increasing size are performed on the original image. The difference between the original image and its opening is computed after each pass when a different structuring element is completed. At the end of the process, these difference are normalized and then used to construct a histogram of particle-size distribution.



a b

FIGURE 9.36
(a) Original image consisting of overlapping particles; (b) size distribution. (Courtesy of Mr. A. Morris, Leica Cambridge, Ltd.)

Granulometry



a b c
d e f

FIGURE 9.41 (a) 531 × 675 image of wood dowels. (b) Smoothed image. (c)–(f) Openings of (b) with disks of radii equal to 10, 20, 25, and 30 pixels, respectively. (Original image courtesy of Dr. Steve Eddins, The MathWorks, Inc.)

Granulometry

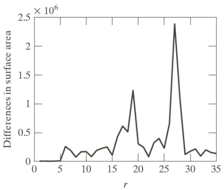


FIGURE 9.42 Differences in surface area as a function of SE disk radius, r. The two peaks are indicative of two dominant particle sizes in the image.

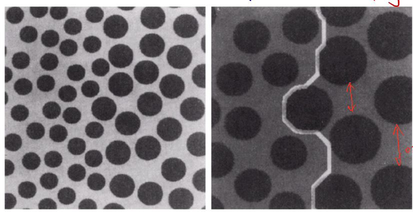
期末考擇一

Textural Segmentation

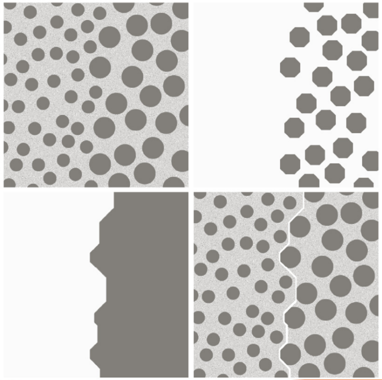
- Because closing tends to remove dark details from an image, the procedure in this particular case is to close the input image by using successively larger structuring elements.
- Next, a single opening is performed with a structuring element that is large in relation to the separation between the large blobs.

a b

FIGURE 9.35
(a) Original image. (b) Image showing boundary between regions of different texture. (Courtesy of Mr. A. Morris, Leica Cambridge, Ltd.)



Textural Segmentation



a b
c d

FIGURE 9.43 Textural segmentation. (a) A 600 × 600 image consisting of two types of blobs. (b) Image with small blobs removed by closing (a). (c) Image with light patches between large blobs removed by opening (b). (d) Original image with boundary between the two regions in (c) superimposed. The boundary was obtained using a morphological gradient operation.

Gray-Scale Morphological Reconstruction

a b c
d e f
g h i

FIGURE 9.44 (a) Original image of size 1134 × 1360 pixels. (b) Opening by reconstruction of (a) using a horizontal line 71 pixels long in the erosion. (c) Opening of (a) using the same line. (d) Top-hat by reconstruction. (e) Top-hat. (f) Opening by reconstruction of (d) using a horizontal line 11 pixels long. (g) Dilation of (f) using a horizontal line 21 pixels long. (h) Minimum of (d) and (g). (i) Final reconstruction result. (Images courtesy of Dr. Steve Eddins, The MathWorks, Inc.)