影像特徵之抽取與描述

壹、影像特徵表示方法

貳、邊界描述元

參、區域描述元

肆、特徵之形態描述

伍、特徵辨識

壹、影像特徵表示方法

一、鍊碼(Chain Codes)

１．四相連與八相連鍊碼：

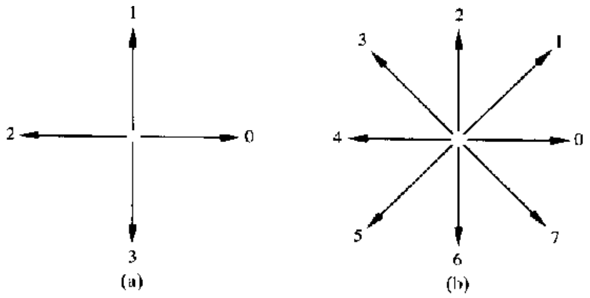

Figure 8.1 *Directions for (a) 4-directional chain code and (b) 8-directional chain code.*

２．再取樣(Resample)

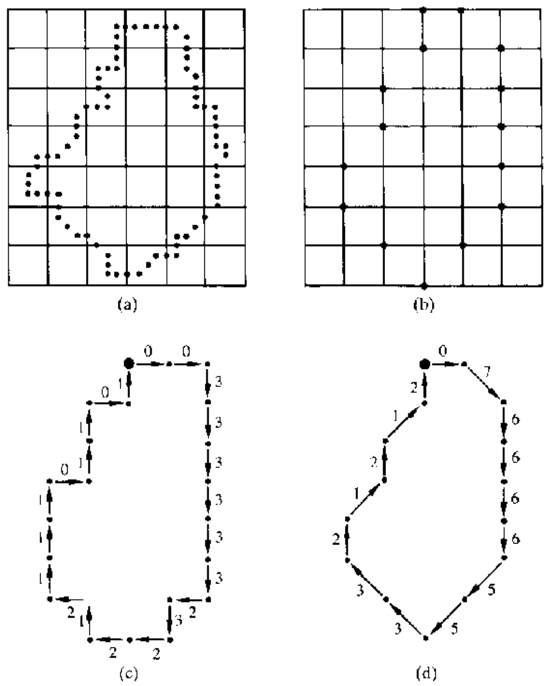

Figure 8.2 *(a) Digital boundary with resampling grid superimposed; (b) result of resampling; (c) 4-directional chain code; (d) 8-directional chain code.*

３．正規化(Normalization)

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二、多邊形近似法(Polygonal Approximation)

１．Sklansky-Chazin-Hanzen Method

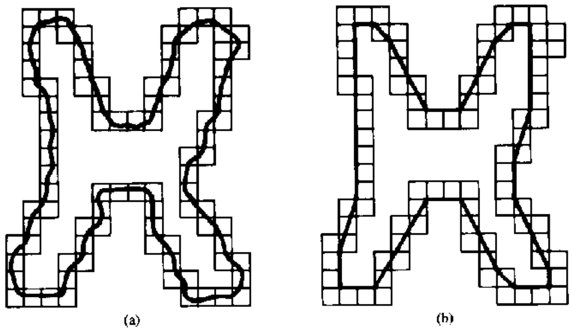
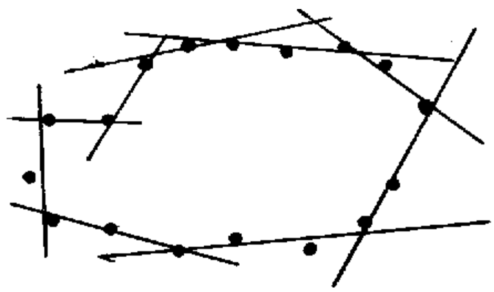


Figure 8.3 (a) Object boundary enclosed by cells; (b) minimum perimeter polygon.

２．Merging Techniques



３．Splitting Techniques

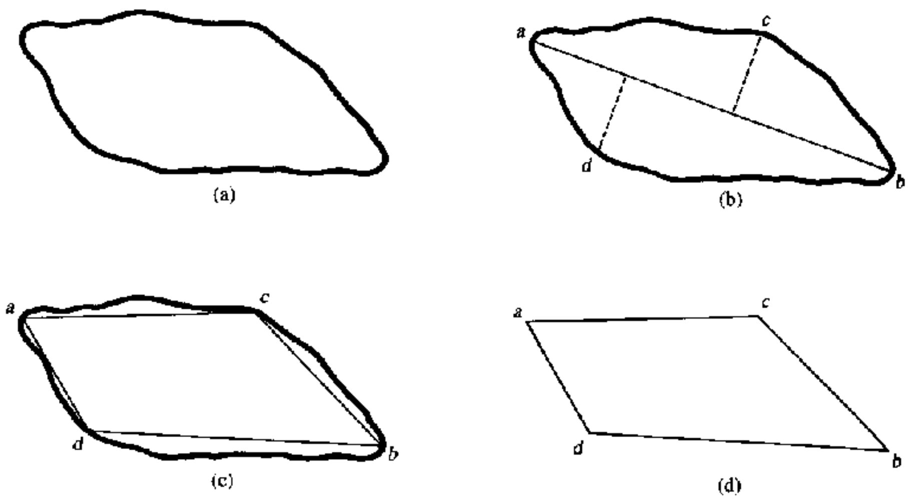


Figure 8.4 (a) Original boundary; (b) boundary divided into segments based on distance computations; (c) joining of vertices; (d) resulting polygon.

三、標記法(Signatures)

１．Distance-angle Method:

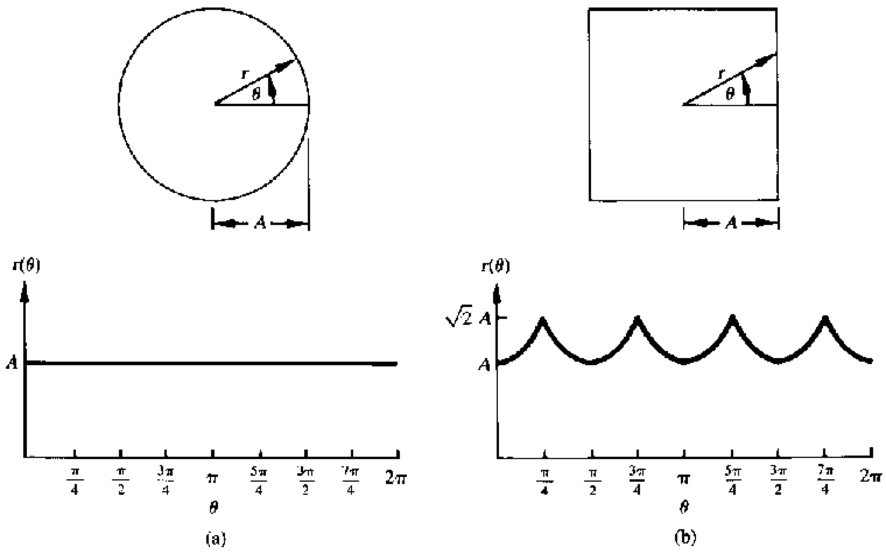


Figure 8.5 Two simple boundary shapes and their corresponding distance-versus-angle signatures. In (a) $r(\theta)$ is constant, while in (b) $r(\theta) = A \sec \theta$. (From Fu, Gonzalez, and Lee [1987].)

２．Slope Density Function:

四、邊界區段(Boundary Segments)

"分解複雜之邊界成爲較簡易之區段以利描述"

Convex hull H, Convex Deficiency D = H – S

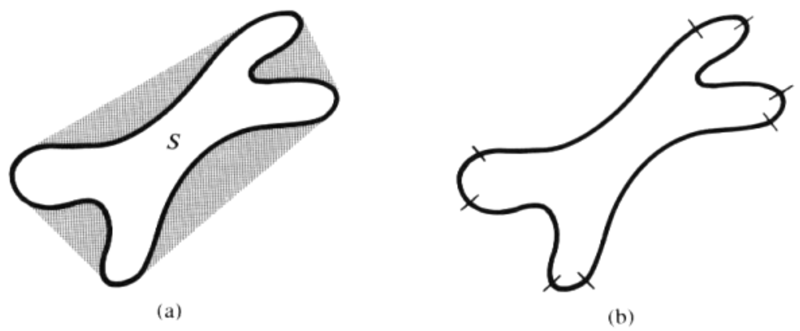


Figure 8.6 (a) A region (S) and its convex deficiency (shaded); (b) partitioned boundary.

五、區域之骨架(Skeleton)

１．MAT (Medial Axis Transformation)

邊界爲Ｂ的區域Ｒ其 MAT 之定義如下：對於Ｒ中的任意一點 p，我們從Ｂ中找出與 p 最接近之鄰近點，假如所找到之點不止一個，則我們稱 p 屬於Ｒ之中軸(Medial Axis)。

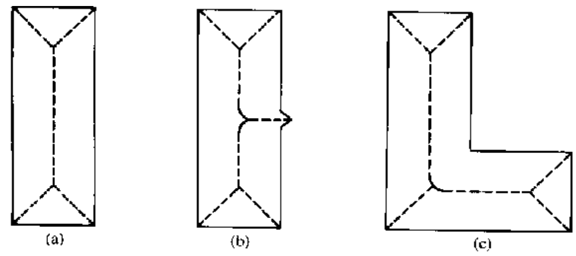


Figure 8.7 Medial axes of three simple regions.

２．細線化(Thinning)

p_9	p_2	p_3
p_8	p_1	p_4
p_7	p_6	p_5

步驟一：(a). $2 \leqq N(p_1) \leqq 6$,
(b). $S(p_1) = 1$,
(c). $p_2 \cdot p_4 \cdot p_6 = 0$,
(d). $p_4 \cdot p_6 \cdot p_8 = 0$,

步驟二：(a),(b)及(c’)(d’)
(c’). $p_2 \cdot p_4 \cdot p_8 = 0$,
(d’). $p_2 \cdot p_6 \cdot p_8 = 0$,

$N(p_1)$ 爲 p_1 周圍非零影像元素之個數。

$S(p_1)$ 爲依 $p_1, p_2, ..., p_8, p_9$ 順序灰度值由 0 轉至 1 之次數。

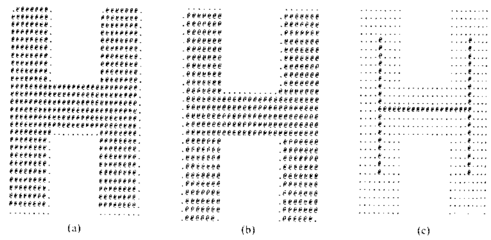
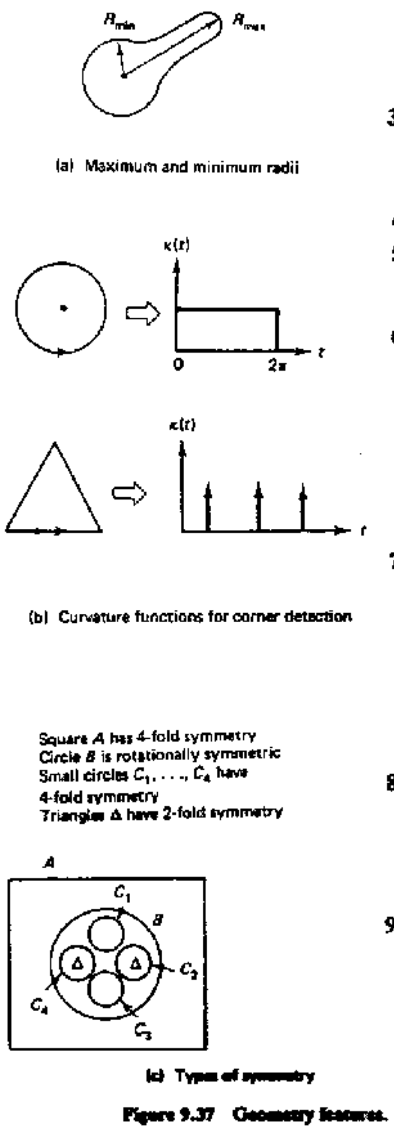


Figure 8.10 (a) Result of step 1 of the thinning algorithm during the first iteration through a region; (b) result of step 2; (c) final result. (From Zhang and Suen [1984].)

貳、邊界描述元

一、基本描述元(Some Simple Descriptors)



(a) Maximum and minimum radii

(b) Curvature functions for corner detection

(c) Types of symmetry

Figure 9.37 Geometry features.

1. ***Perimeter***

$$T = \int \sqrt{x^2(t) + y^2(t)}\,dt \tag{9.98}$$

where t is necessarily the boundary parameter but not necessarily its length.

2. ***Area***

$$A = \iint_{\mathscr{R}} dx\,dy = \int_{\partial\mathscr{R}} y(t)\frac{dx(t)}{dt}\,dt - \int_{\partial\mathscr{R}} x(t)\frac{dy(t)}{dt}\,dt \tag{9.99}$$

where $\mathscr{R}$ and $\partial\mathscr{R}$ denote the object region and its boundary, respectively.

3. ***Radii*** R_{min}, R_{max} are the minimum and maximum distances, respectively, to boundary from the center of mass (Fig. 9.37a). Sometimes the ratio R_{max}/R_{min} is used as a measure of eccentricity or elongation of the object.

4. ***Number of holes*** n_h

5. ***Euler number***

$$\mathscr{E} \triangleq \text{number of connected regions} - n_h \tag{9.100}$$

6. ***Corners*** These are locations on the boundary where the curvature $\kappa(t)$ becomes unbounded. When t represents distance along the boundary, then from (9.57) and (9.58), we can obtain

$$|\kappa(t)|^2 \triangleq \left(\frac{d^2y}{dt^2}\right)^2 + \left(\frac{d^2x}{dt^2}\right)^2 \tag{9.101}$$

In practice, a corner is declared whenever $|\kappa(t)|$ assumes a large value (Fig. 9.37b).

7. ***Bending energy*** This is another attribute associated with the curvature.

$$E = \frac{1}{T}\int_0^T |\kappa(t)|^2\,dt \tag{9.102}$$

In terms of $\{a(k)\}$, the FDs of $u(t)$, this is given by

$$E = \sum_{k=-\infty}^{\infty} |a(k)|^2 \left(\frac{2\pi k}{T}\right)^4 \tag{9.103}$$

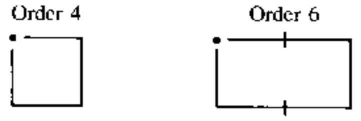
8. ***Roundness, or compactness***

$$\gamma = \frac{(\text{perimeter})^2}{4\pi(\text{area})} \tag{9.104}$$

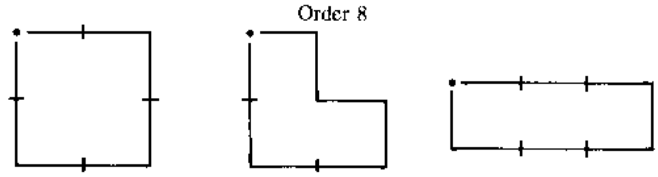
For a disc, γ is minimum and equals 1.

9. ***Symmetry*** There are two common types of symmetry of shapes, *rotational* and *mirror*. Other forms of symmetry are twofold, fourfold, eightfold, and so on (Fig. 9.37c). Distances from the center of mass to different points on the boundary can be used to analyze symmetry of shapes. Corner locations are also useful in determining object symmetry.

二、Shape Number

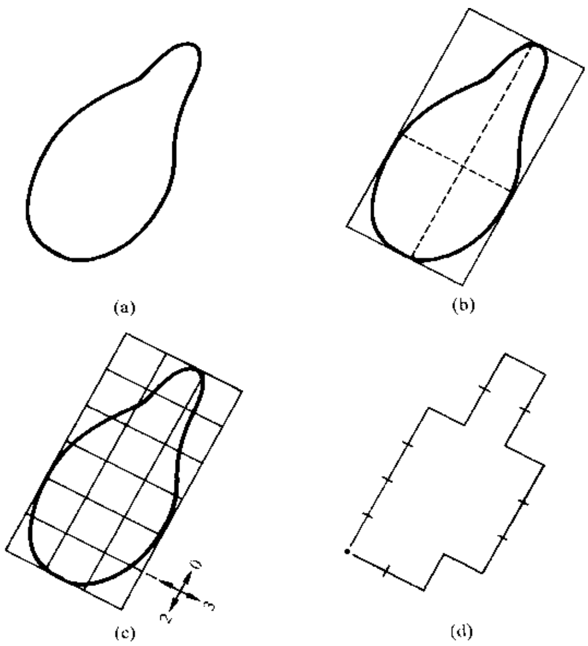


	Order 4	Order 6
Chain code:	0 3 2 1	0 0 3 2 2 1
Difference:	3 3 3 3	3 0 3 3 0 3
Shape no.:	3 3 3 3	0 3 3 0 3 3



Chain code:	0 0 3 3 2 2 1 1	0 3 0 3 2 2 1 1	0 0 0 3 2 2 2 1
Difference:	3 0 3 0 3 0 3 0	3 3 1 3 3 0 3 0	3 0 0 3 3 0 0 3
Shape no.:	0 3 0 3 0 3 0 3	0 3 0 3 3 1 3 3	0 0 3 3 0 0 3 3

Figure 8.12 *All shapes of order 4, 6, and 8. The directions are from Fig. 8.1(a), and the dot indicates the starting point.*



Chain code:	0 0 0 0 3 0 0 3 2 2 3 2 2 2 1 2 1 1
Difference:	3 0 0 0 3 1 0 3 3 0 1 3 0 0 3 1 3 0
Shape no.:	0 0 0 3 1 0 3 3 0 1 3 0 0 3 1 3 0 3

Figure 8.13 *Steps in the generation of a shape number.*

三、傅利葉描述元(Fourier Descriptor)

s(k) = x(k) + j y(k)

$$a(u) = \frac{1}{N}\sum_{k=0}^{N-1} s(k)\exp[-j2\pi uk/N]$$

$$s(k) = \sum_{k=0}^{N-1} a(u)\exp[j2\pi uk/N]$$

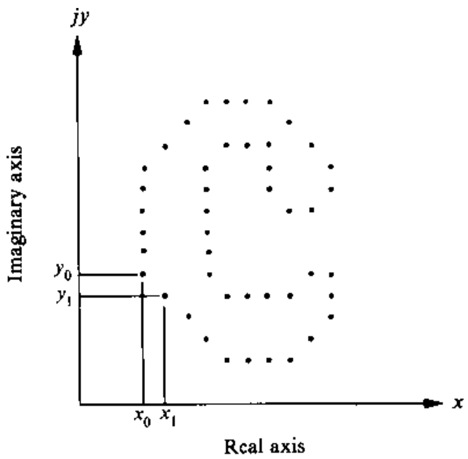


Figure 8.14 *A digital boundary and its representation as a complex sequence. The points (x_0, y_0) and (x_1, y_1) are (arbitrarily) the first two points in the sequence.*

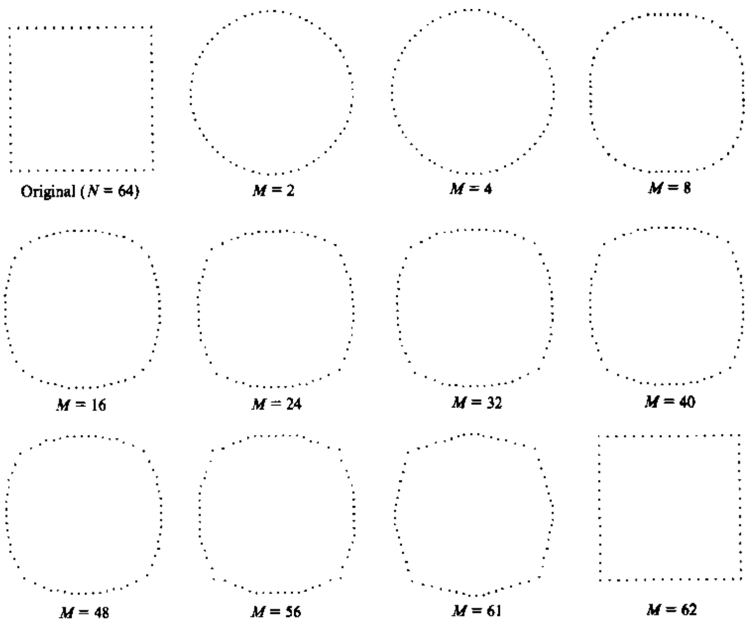


Figure 8.15 *Examples of reconstructions from Fourier descriptors for various values of M.*

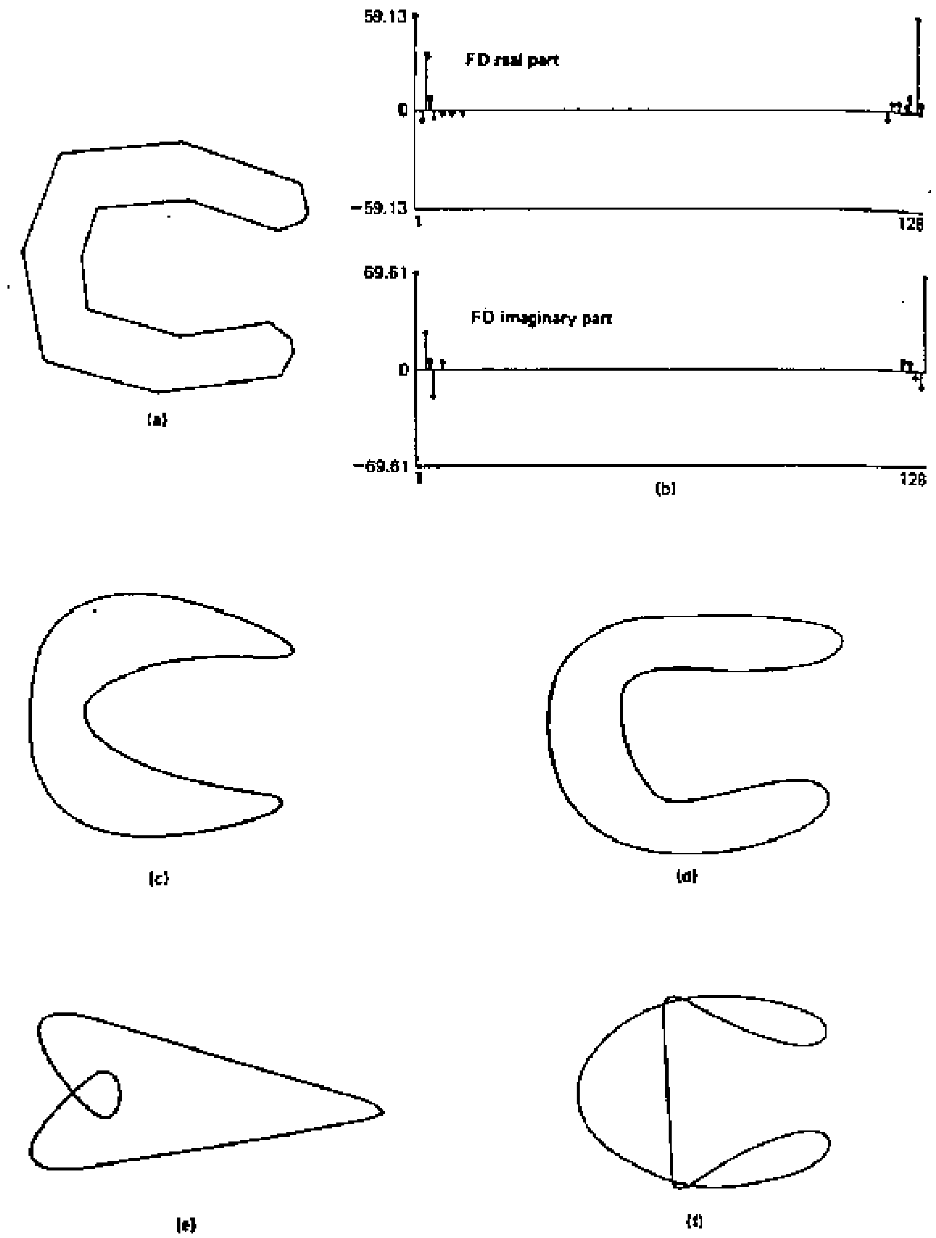


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Figure 9.27 Fourier descriptors. (a) Given shape; (b) FDs, real and imaginary components; (c) shape derived from largest five FDs; (d) derived from all FDs quantized to 17 levels each; (e) amplitude reconstruction; (f) phase reconstruction.

四、Moments

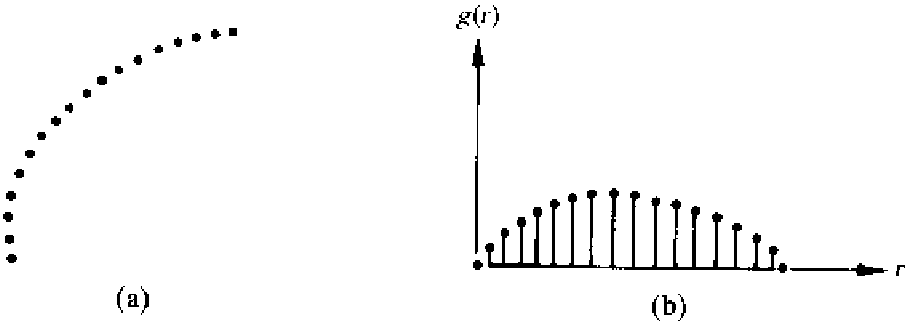


Figure 8.16 (a) Boundary segment; (b) representation as a 1-D function.

$$\mu_n(v) = \sum_{i=1}^{L} (v_i - m)^n \, p(v_i)$$

$$m = \sum_{i=1}^{L} v_i \, p(v_i)$$

以單一面積正規化(Normalization)後：

$$\mu_n(r) = \sum_{i=1}^{L} (r_i - m)^n \, g(r_i)$$

$$m = \sum_{i=1}^{K} r_i \, g(r_i)$$

參、區域描述元

一、拓璞描述元(Topological Descriptor)

Euler Number: $E = C - H$

Euler Formula: $W - Q + F = C - H$

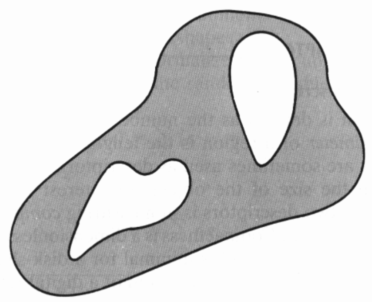


Figure 8.17 A region with two holes.

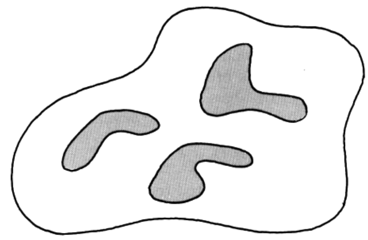


Figure 8.18 A region with three connected components.

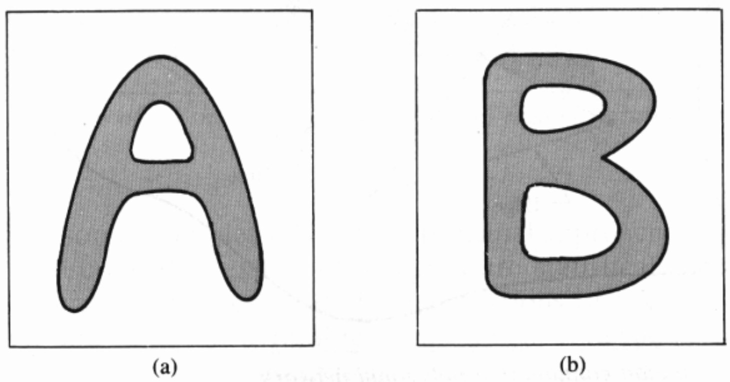


Figure 8.19 Regions with Euler number equal to 0 and −1, respectively.

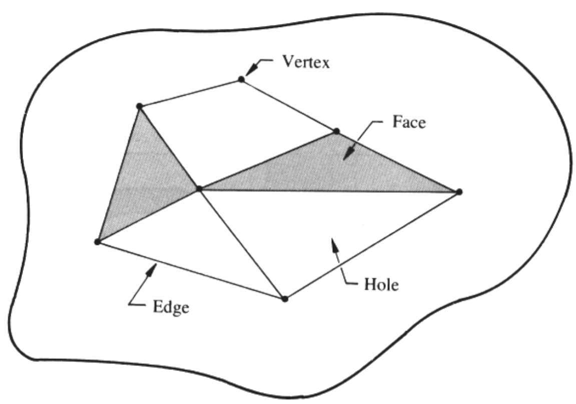


Figure 8.20 A region containing a polygonal network.

二、紋路(Texture)之描述

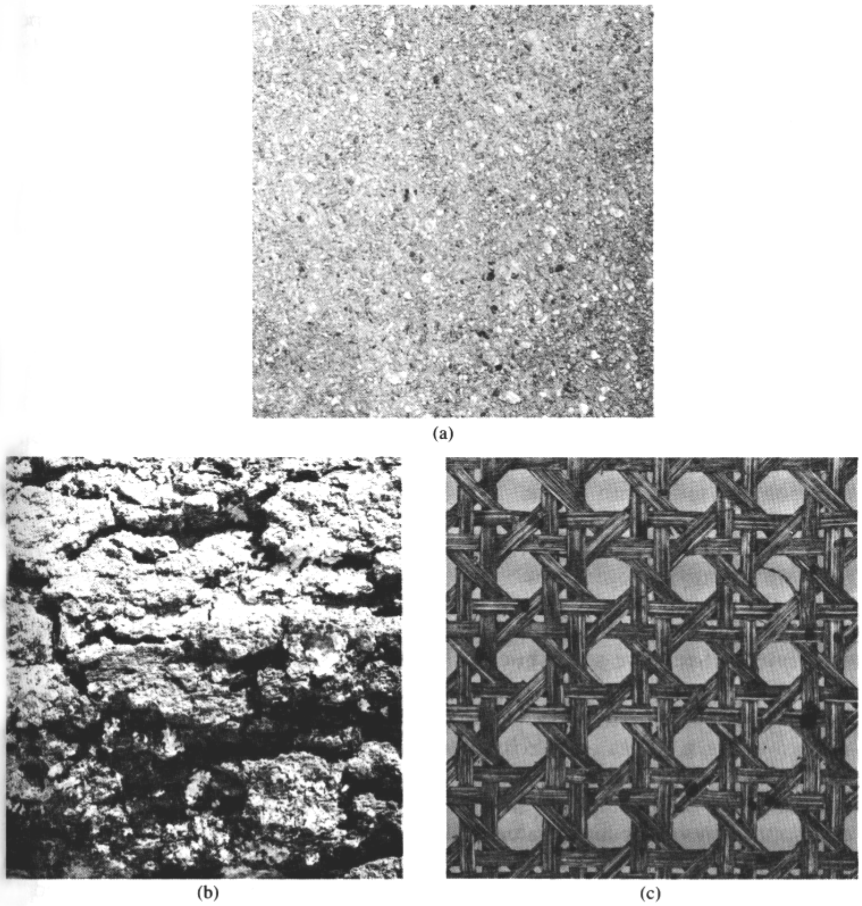


Figure 8.21 Examples of (a) smooth, (b) coarse, and (c) regular textures. (From Fu, Gonzalez, and Lee [1987].)

1 ．統計上之方法：

(1).應用 Moment 來描述：

$$\mu_n(z) = \sum_{i=1}^{L} (z_i - m)^n p(z_i)$$

$$m = \sum_{i=1}^{L} z_i p(z_i)$$

$$R = 1 - \frac{1}{1+\sigma^2(z)}$$

$\mu_0(z) = 1$, $\mu_1(z) = 0$, $\mu_2(z)$ 爲 Variance

$\mu_3(z)$ 表 Skewness, $\mu_4(z)$ 表 Flatness

(2).應用位置運算子來描述(Position Operator)

0 0 0 1 2
1 1 0 1 1
2 2 1 0 0 ←—— Image
1 1 0 2 0
0 0 1 0 1

P as "one pixel to the right and one pixel below," ← Operator

$$A = \begin{bmatrix} 4 & 2 & 1 \\ 2 & 3 & 2 \\ 0 & 2 & 0 \end{bmatrix}$$ ← Matrix

對 Matrix A 而言之其他描述元

(a).最大機率(Maximum Probability)

$$\max_{ij}(c_{ij})$$

(b).k 階基本差異 moment

$$\sum_i \sum_j (i-j)^k c_{ij}$$

(c).k 階反基本差異 moment

$$\sum_i \sum_j c_{ij} / (i-j)^k \quad \mathrm{i} \neq \mathrm{j}$$

(d).Entropy

$$-\sum_i \sum_j c_{ij} \log c_{ij}$$

(e).一致性(Uniformity)

$$\sum_i \sum_j c_{ij}^2$$

２．結構上之方法(Structural Approaches)

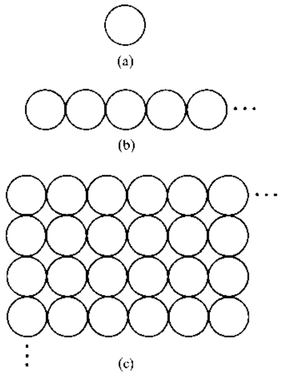


Figure 8.22 (a) Texture primitive; (b) pattern generated by the rule $S \rightarrow aS$; (c) 2-D texture pattern generated by this and other rules.

３．頻譜上之方法(Spectral Approaches)

$$S(r) = \sum_{\theta=0}^{\pi} S_{\theta}(r) \qquad S(\theta) = \sum_{r=1}^{R} S_{r}(\theta)$$

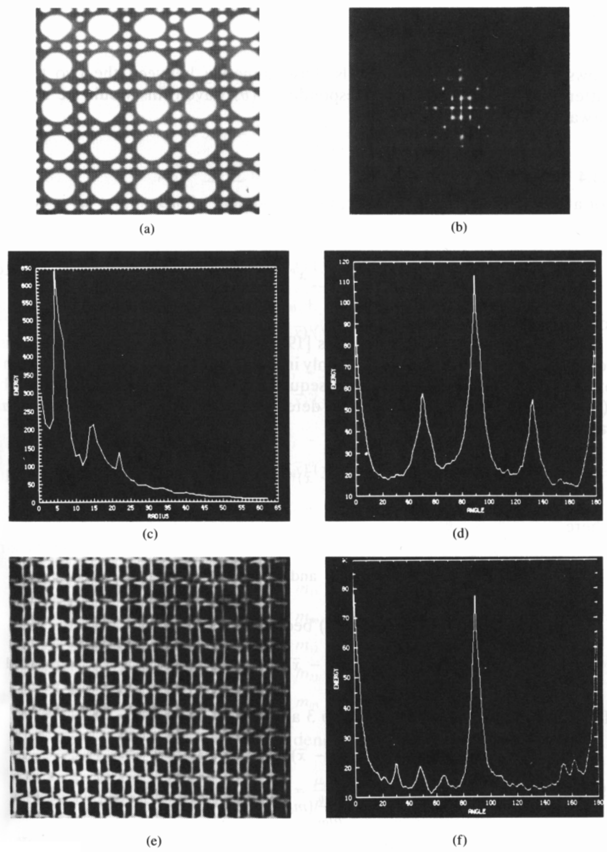


Figure 8.23 (a) Image showing periodic texture; (b) spectrum; (c) plot of $S(r)$; (d) plot of $S(\theta)$; (e) another image with a different type of periodic texture; (f) plot of $S(\theta)$. (Courtesy of D. Brzakovic, University of Tennessee.)

三、應用 Moment

$$m_{pq} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x^p y^q f(x, y)\, dxdy$$

$$\mu_{pq} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (x - \bar{x})^p (y - \bar{y})^q f(x, y)\, dxdy,$$

其中 $\bar{x} = \dfrac{m_{10}}{m_{00}}, \quad \bar{y} = \dfrac{m_{01}}{m_{00}}.$

$$\mu_{pq} = \sum_x \sum_y (x - \bar{x})^p (y - \bar{y})^q f(x, y).$$

$$\begin{aligned}
\mu_{00} &= m_{00}, & \mu_{11} &= m_{11} - \bar{y}m_{10} \\
\mu_{10} &= 0, & \mu_{30} &= m_{30} - 3\bar{x}m_{20} + 2m_{10}\bar{x}^2 \\
\mu_{01} &= 0, & \mu_{12} &= m_{12} - 2\bar{y}m_{11} - \bar{x}m_{02} + 2\bar{y}^2 m_{10} \\
\mu_{20} &= m_{20} - \bar{x}m_{10}, & \mu_{21} &= m_{21} - 2\bar{x}m_{11} - \bar{y}m_{20} + 2\bar{x}^2 m_{01} \\
\mu_{02} &= m_{02} - \bar{y}m_{01}, & \mu_{03} &= m_{03} - 3\bar{y}m_{02} + 2\bar{y}^2 m_{01}
\end{aligned}$$

The *normalized central moments*, denoted by η_{pq}, are defined as

$$\eta_{pq} = \frac{\mu_{pq}}{\mu_{00}^{\gamma}},$$

$$\gamma = \frac{p + q}{2} + 1$$

$$\begin{aligned}
\phi_1 &= \eta_{20} + \eta_{02} \\
\phi_2 &= (\eta_{20} - \eta_{02})^2 + 4\eta_{11}^2 \\
\phi_3 &= (\eta_{30} - 3\eta_{12})^2 + (3\eta_{21} - \eta_{03})^2 \\
\phi_4 &= (\eta_{30} + \eta_{12})^2 + (\eta_{21} + \eta_{03})^2 \\
\phi_5 &= (\eta_{30} - 3\eta_{12})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] \\
&\quad + (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] \\
\phi_6 &= (\eta_{20} - \eta_{02})[(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] \\
&\quad + 4\eta_{11}(\eta_{30} + \eta_{12})(\eta_{21} + \eta_{03}) \\
\phi_7 &= (3\eta_{21} - \eta_{30})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] \\
&\quad + (3\eta_{12} - \eta_{30})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2]
\end{aligned}$$

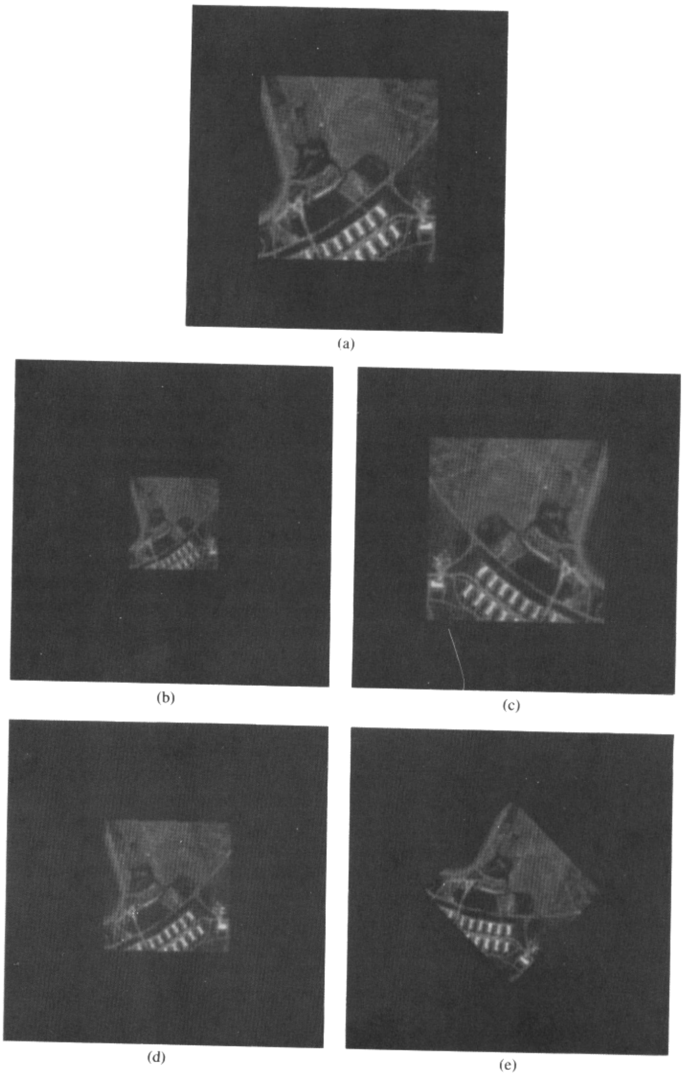


Figure 8.24 *Images used to demonstrate properties of moment invariants.*

Table 8.2 Moment Invariants for the Images in Figs. 8.24(a)–(e)

Invariant (Log)	*Original*	*Half Size*	*Mirrored*	*Rotated 2°*	*Rotated 45°*
ϕ_1	6.249	6.226	6.919	6.253	6.318
ϕ_2	17.180	16.954	19.955	17.270	16.803
ϕ_3	22.655	23.531	26.689	22.836	19.724
ϕ_4	22.919	24.236	26.901	23.130	20.437
ϕ_5	45.749	48.349	53.724	46.136	40.525
ϕ_6	31.830	32.916	37.134	32.068	29.315
ϕ_7	45.589	48.343	53.590	46.017	40.470

† Derivation of these results involves concepts that are beyond the scope of this discussion. The book by Bell [1965] and the paper by Hu [1962] contain detailed discussions of these concepts.

肆、特徵之形態描述

一、膨脹與侵蝕(Dilation and Erosion)

１．膨脹之定義：

$$A \oplus B = \{x | (\hat{B})_x \cap A \neq \phi\}$$

２．侵蝕之定義：$\ominus$

$$A \Theta B = \{x | (B)_x \subseteq A\}$$

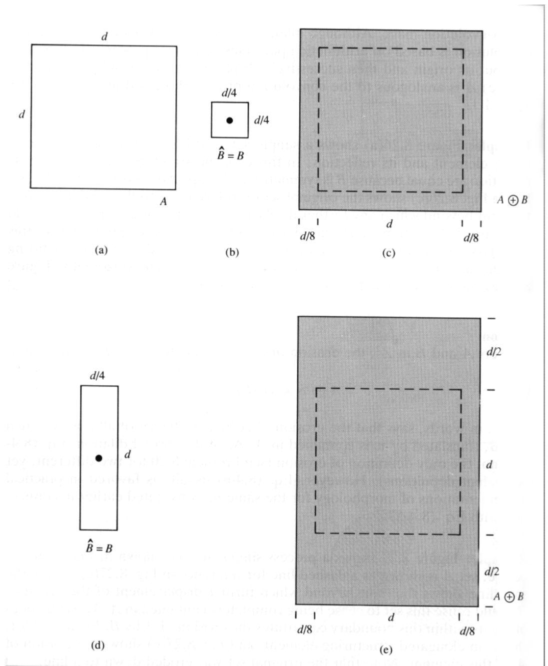


Figure 8.26 (a) Original set A; (b) square structuring element and its reflection; (c) dilation of A by B, shown shaded; (d) elongated structuring element; (e) dilation of A using this element.

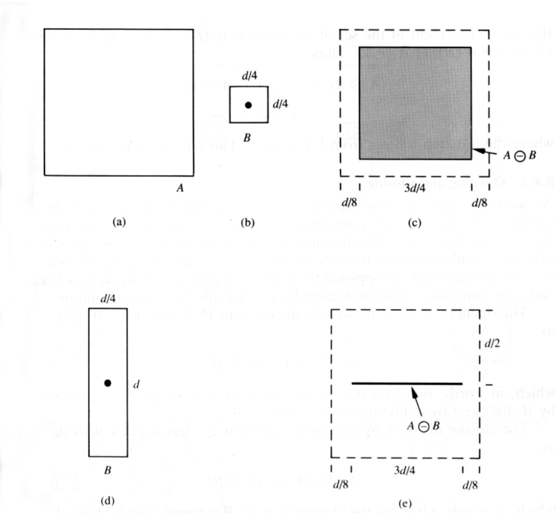


Figure 8.27 (a) Original set A; (b) structuring element B; (c) erosion of A by B, shown shaded; (d) elongated structuring element; (e) erosion of A by this element.

二、開啟與閉合(Openning and Closing)

１．開啟之定義：

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

２．閉合之定義：

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

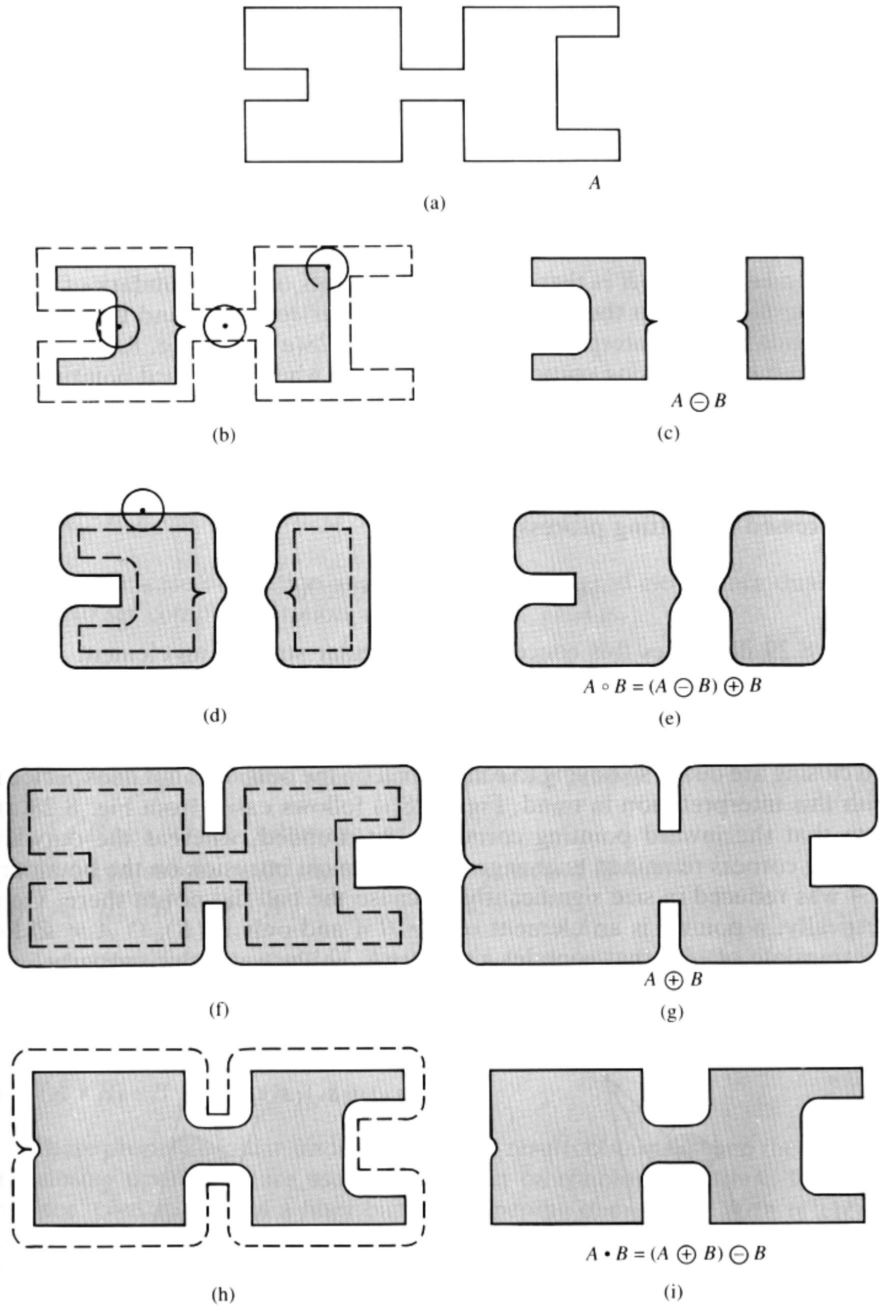


Figure 8.28 *Illustrations of opening and closing operations.*

Table 8.3 Summary of Morphological Results and Their Properties

Operation	*Equation*	*Comments*[a]
Translation	$(A)_x = \{c \mid c = a + x, \quad \text{for } a \in A\}$	Translates the origin of A to point x.
Reflection	$\hat{B} = \{x \mid x = -b, \quad \text{for } b \in B\}$	Reflects all elements of B about the origin of this set.
Complement	$A^c = \{x \mid x \notin A\}$	Set of points not in A.
Difference	$A - B = \{x \mid x \in A, x \notin B\} = A \cap B^c$	Set of points that belong to A but not to B.
Dilation	$A \oplus B = \{x \mid (\hat{B})_x \cap A \neq \varnothing\}$	"Expands" the boundary of A. (I)
Erosion	$A \ominus B = \{x \mid (B)_x \subseteq A\}$	"Contracts" the boundary of A. (I)
Opening	$A \circ B = (A \ominus B) \oplus B$	Smooths contours, breaks narrow isthmuses, and eliminates small islands and sharp peaks. (I)
Closing	$A \bullet B = (A \oplus B) \ominus B$	Smooths contours, fuses narrow breaks and long thin gulfs, and eliminates small holes. (I)
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	$X_k = (X_{k-1} \oplus B) \cap A^c; \quad X_0 = p$ and $k = 1, 2, 3, \ldots$	Fills a region in A, given a point p in the region. (II)
Connected components	$X_k = (X_{k-1} \oplus B) \cap A; \quad X_0 = p$ and $k = 1, 2, 3, \ldots$	Finds a connected component Y in A, given a point p in Y. (I)

Table 8.3 (Continued)

Operation	Equation	Comments[a]
Convex hull	$X_k^i = (X_{k-1}^i \circledast B^i) \cup A; \quad i = 1, 2, 3, 4,$ $k = 1, 2, 3, \ldots, X_0^i = A$, and $D^i = X_{\text{conv}}^i$ $C(A) = \bigcup_{i=1}^{4} D^i$	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)
Thinning	$A \otimes B = A - (A \circledast B)$ $= A \cap (A \circledast B)^c$ $A \circledast \{B\} = ((\ldots((A \otimes B^1) \otimes B^2) \ldots) \otimes B^n)$ $\{B\} = \{B^1, B^2, B^3, \ldots, B^n\}$	Thins set A. The first two equations give the basic definition of thinning. The last two equations shown 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.
Skeletons	$S(A) = \bigcup_{k=0}^{K} S_k(A)$ $S_k(A) = \bigcup_{k=0}^{K} \{(A \ominus kB) - [(A \ominus kB) \circ B]\}$ $A = \bigcup_{k=0}^{K} (S_k(A) \oplus kB)$	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. (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. The third equation uses structuring element (I).

[a] The Roman numerals in parentheses refer to the structuring element(s) used in the morphological process (see Fig. 8.41).

伍、特徵辨識

一、影像分析之層次

１．低階處理(Low-level Processing)
２．中階處理(Intermidiate-level Processing)
３．高階處理(High-level Processing)

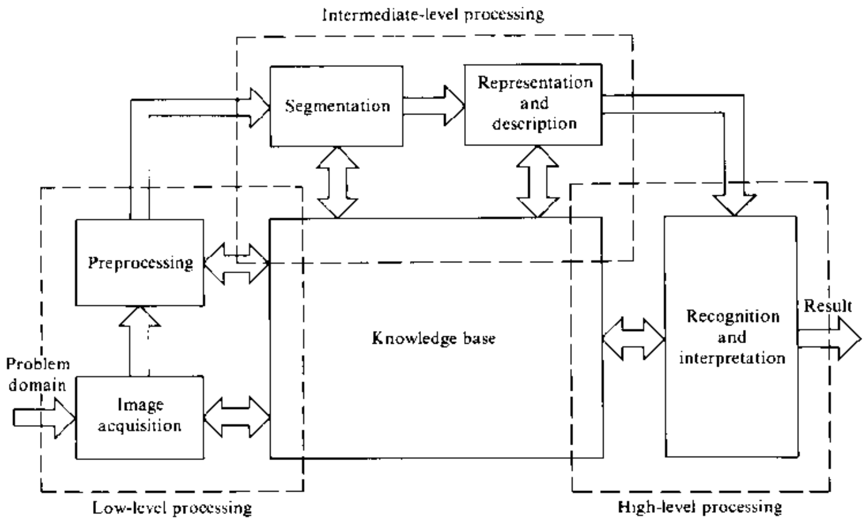


Figure 9.1 *Elements of image analysis.*

二、特徵與特徵分類(Pattern and Pattern Classes)

１．向量(Vector) —— Quantitative Description
２．符號串(String) — Structural Description
３．樹(Tree) ———— Structural Description

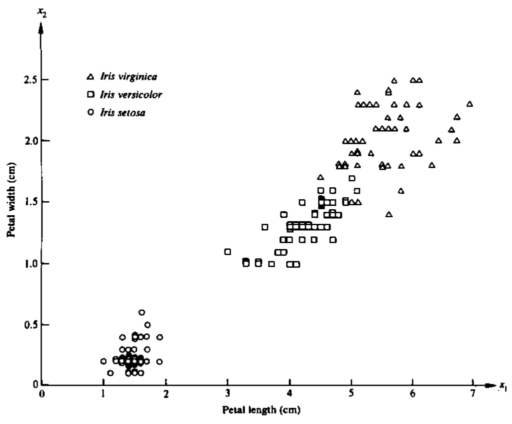


Figure 9.2 *Two measurements performed on three types of iris. (Adapted from Duda and Hart [1973].)*

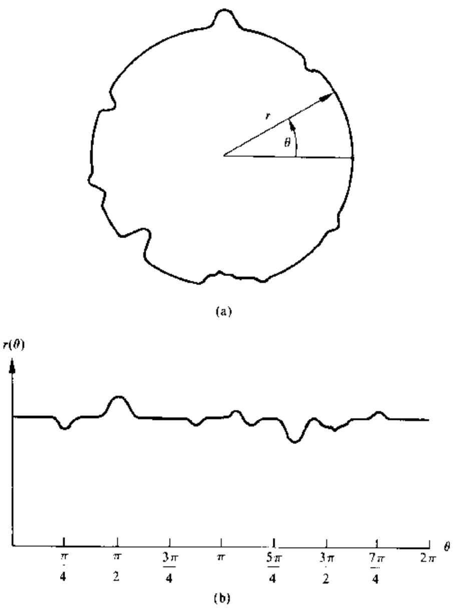


Figure 9.3 A noisy object and its corresponding signature.

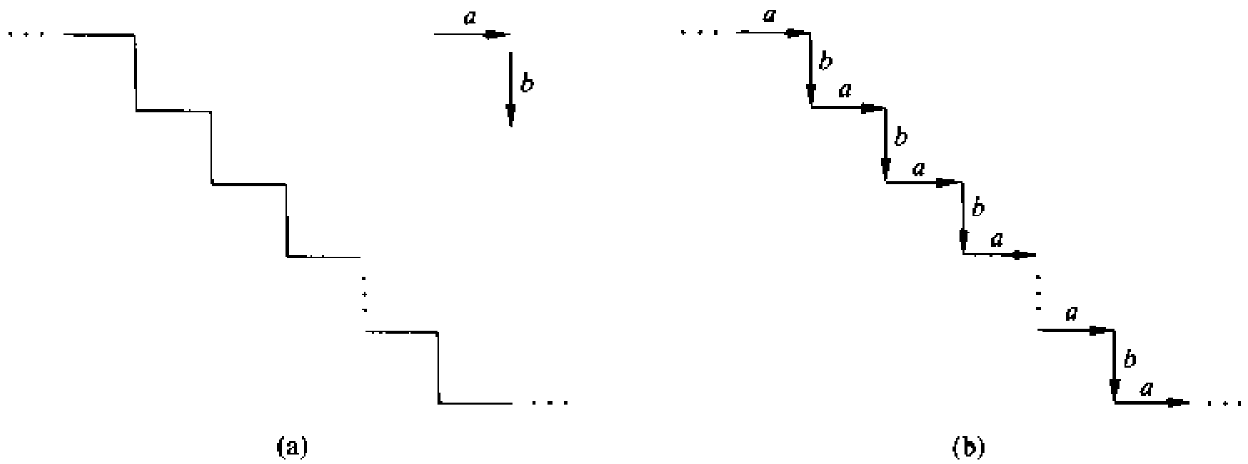
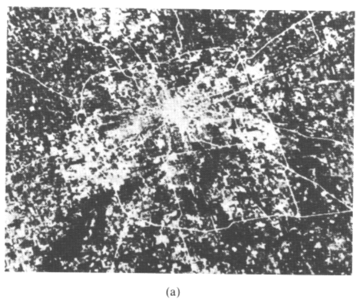
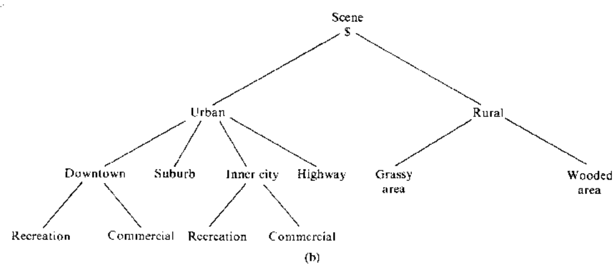


Figure 9.4 *(a) Staircase structure; (b) structure coded in terms of the primitives a and b to yield the string representation . . . ababab. . . .*



(a)

Figure 9.5 *(a) Aerial photograph of urban and rural land areas; (b) tree representation. (From Brayer, Swain, and Fu [1977].)*



(b)

Figure 9.5 *con't.*

三、比對(Matching)

1．最小距離分類法(Minimum Distance Classifier)

$$m_j = \frac{1}{N_j}\sum x \qquad \mathrm{i} = 1,2,\ldots,\mathrm{M}$$

$$D_j(x) = \left\| x - m_j \right\| \qquad \mathrm{j} = 1,2,\ldots,\mathrm{M}$$

$$\mathrm{d}_{\mathrm{j}}(x) = x^T m_j - 1/2 m_j^T m_j \qquad \mathrm{j} = 1,2,\ldots,\mathrm{M}$$

分類界限(Decision Boundary)

$d_{ij}(\times) = d_i(\times) - d_j(\times) = 0$

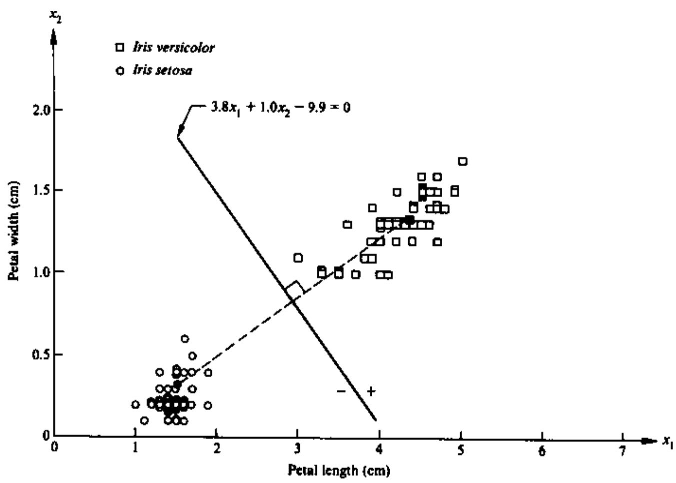


Figure 9.6 Decision boundary of minimum distance classifier for the classes of Iris versicolor and Iris setosa.

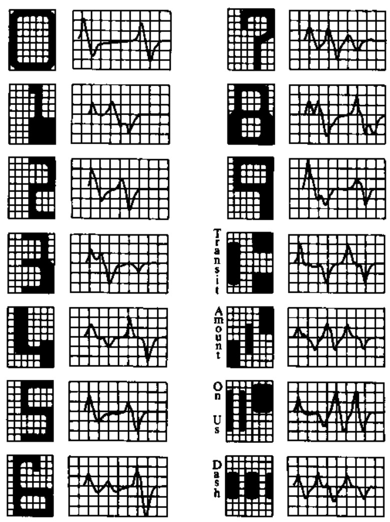


Figure 9.7 American Bankers Association E-13B font character set and corresponding waveforms.

２．利用相關比對(Matching by Correlation)

$$c(s,t) = \sum_x \sum_y f(x,y) w(x-s, y-t)$$

$$\gamma(s,t) = \frac{\sum_x \sum_y [f(x,y) - \bar{f}(x,y)][w(x-s,y-t) - \overline{w}]}{\{\sum_x \sum_y [f(x,y) - \bar{f}(x,y)]^2 \sum_x \sum_y [w(x-s,y-t) - \overline{w}]^2\}^{1/2}}$$

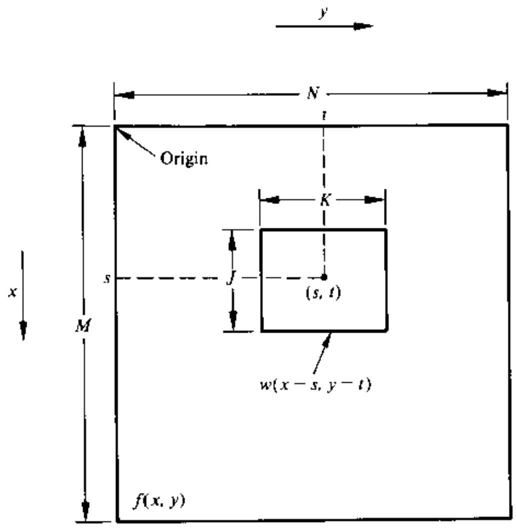


Figure 9.8 *Arrangement for obtaining the correlation of f(x, y) and w(x, y) at point (s, t).*

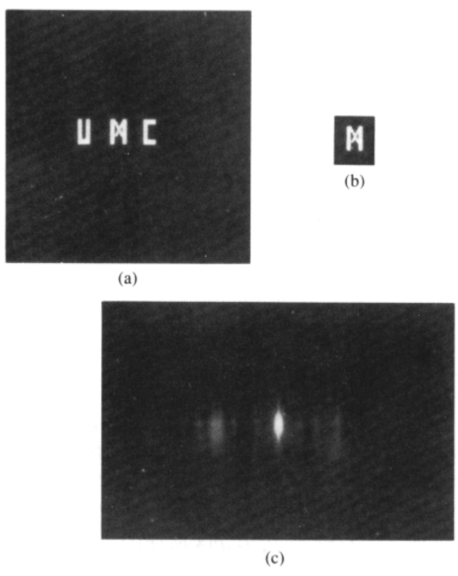


Figure 9.9 *Example of correlation. Note the brightness of γ(s, t) at the position where the two letters match. (Adapted from Hall et al. [1971].)*

３．符號串比對(String Matching)

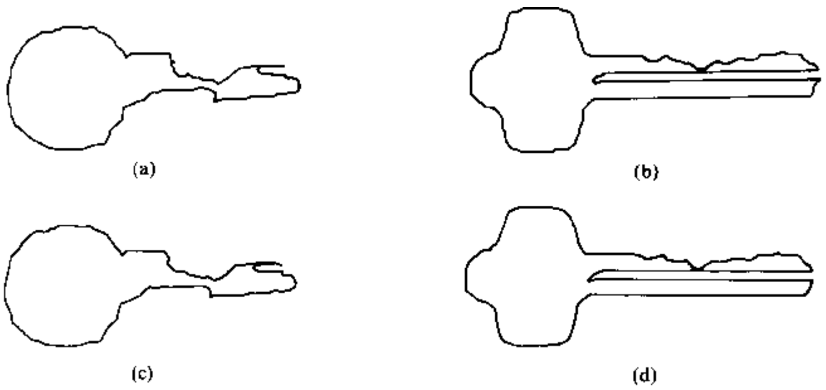
令Ａ與Ｂ分別為 $a_1a_2...a_n$ 與 $b_1b_2...b_m$ 之符號串。

M 為兩符號串中比對相同之符號個數 $(a_k=b_k)$。

Q 為兩符號串中比對不符之符號個數。

$$Q = \max(|A|, |B|) - M$$

$$R = \frac{M}{Q} = \frac{\mathrm{M}}{\max(|\mathrm{A}|,|\mathrm{B}|) - \mathrm{M}}$$



R	1.a	1.b	1.c	1.d	1.e
1.b	16.0				
1.c	9.6	26.3			
1.d	5.07	8.1	10.3		
1.e	4.67	7.2	10.3	14.2	
1.f	4.67	7.2	10.3	8.5	23.7

(e)

R	2.a	2.b	2.c	2.d	2.e
2.b	33.5				
2.c	4.75	5.8			
2.d	3.6	4.23	19.3		
2.e	2.83	3.25	9.17	18.3	
2.f	2.63	3.0	7.71	13.5	27.0

(f)

R	1.a	1.b	1.c	1.d	1.e	1.f
2.a	1.24	1.50	1.32	1.47	1.55	1.48
2.b	1.18	1.43	1.32	1.47	1.55	1.48
2.c	1.02	1.18	1.19	1.32	1.39	1.48
2.d	1.02	1.18	1.19	1.32	1.39	1.40
2.e	0.93	1.07	1.08	1.19	1.24	1.25
2.f	0.89	1.02	1.02	1.14	1.11	1.18

(g)

Figure 9.25 *(a) and (b) Sample boundaries of two different object classes; (c) and (d) their corresponding polygonal approximations; (e)–(g) tabulations of R. (Adapted from Sze and Yang [1981].)*