Finger Print Analysis and Matching

Daniel Novák

16.10, 2012, Prague

Acknowledgments: Chris Miles,Tamer Uz, Andrzej Drygajlo

Handbook of Fingerprint Recognition,
Chapter III Sections 1-6

laboratory Gerstner

Department of Cybernetics, Czech Technical University

Outline

- Introduction
- Morphology imaging processing
- Post – processing
- Matching

Morphology Image Processing

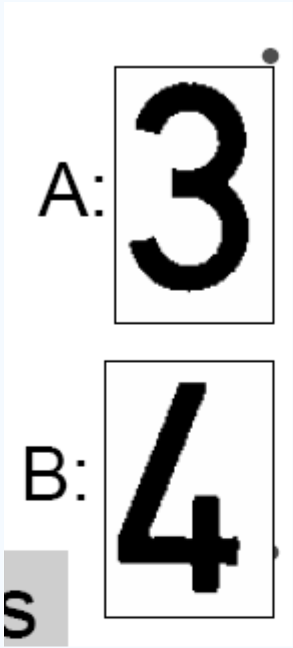
Daniel Novák

18.10. 2011, Prague

Acknowledgments: José Neira Parra

Morphology

- Morphology deals with form and structure
- Mathematical morphology is a tool for extracting image components useful in:
  - representation and description of region shape (e.g. boundaries)
  - pre- or post-processing (filtering, thinning, etc.)
- Based on set theory



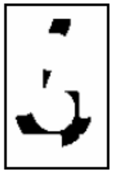
Definitions: Let **A** and **B** be binary images, **p** and **q** two pixels with indices `[i,j]` y `[k,l]` respectively, and Ω the universal binary image.

Union:

$$A \cup B = \{p | p \in A \vee p \in B\}$$

Intersection:

$$A \cap B = \{p | p \in A \wedge p \in B\}$$



Complement:

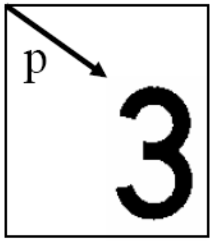
$$\overline{A} = \{p | p \in \Omega \wedge p \notin A\}$$

Difference:

$$A - B = A \cap \overline{B}$$

Translation:

$$A_p = \{a + p | a \in A\}$$



- **Vectorial sum:**

$$p + q = [i + k, j + l]$$

- **Vectorial difference:**

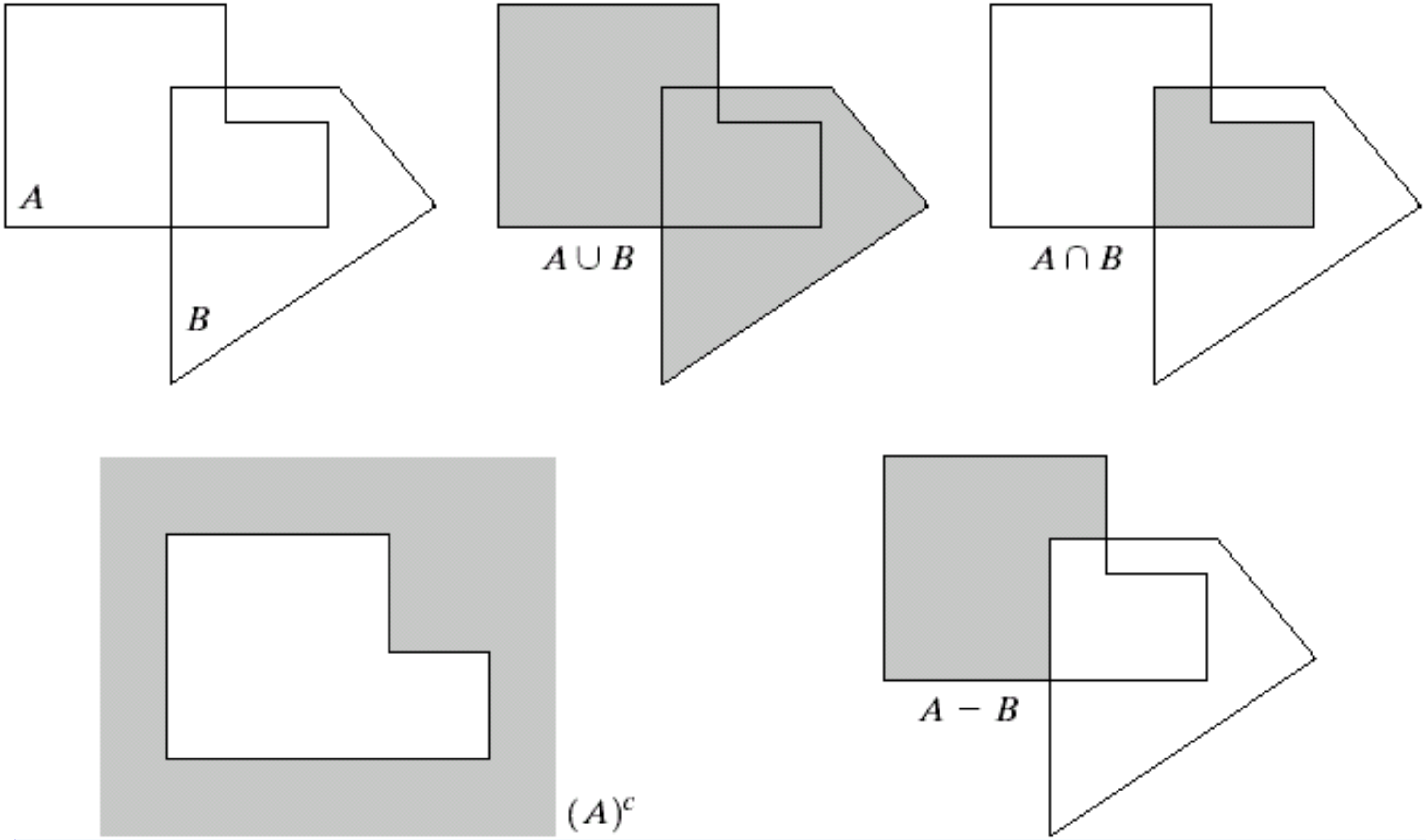
$$p - q = [i - k, j - l]$$

Reflex:

$$A' = \{-p | p \in A\}$$

Department of Cybernetics, Czech Technical University

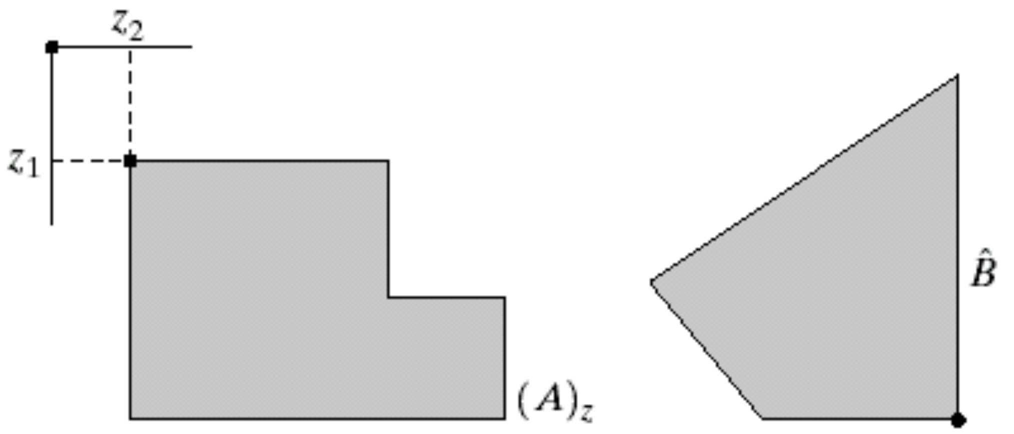
Morphological Image Processing



a b c
d e

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

Morphological Image Processing



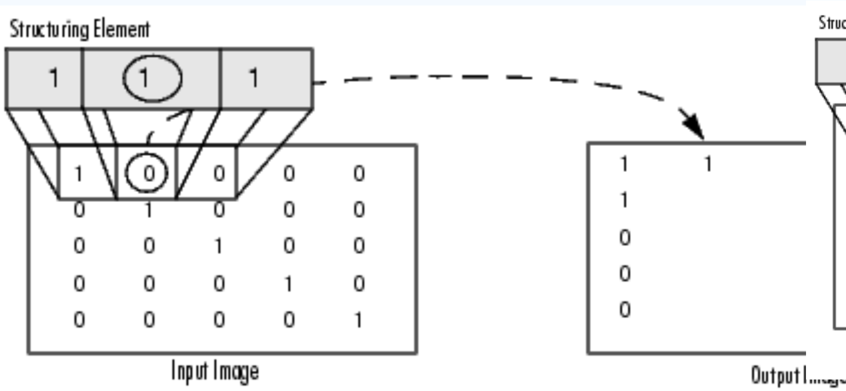
a b

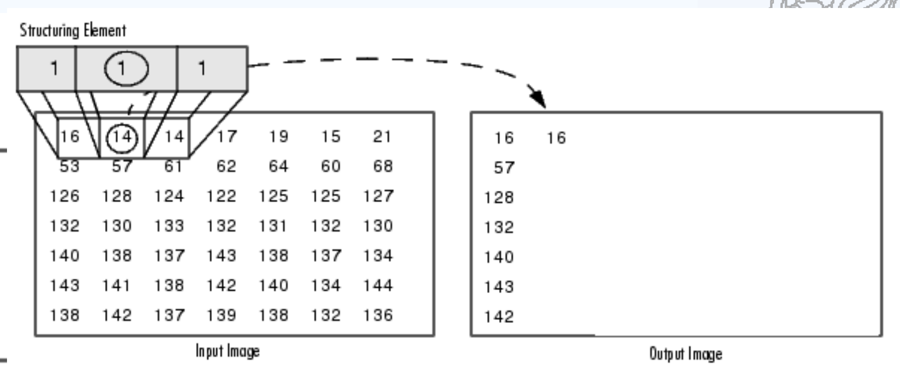
FIGURE 9.2
(a) Translation of A by z.
(b) Reflection of B. The sets A and B are from Fig. 9.1.

Dilation & Erosion

- The value of the output pixel is the *maximum* value of all the pixels in the input pixel's neighborhood.
- Dilation: $$A \oplus B = \{x \mid [(\hat{B})_x \cap A] \subseteq A\}$$
  - B is the structuring element in dilation.

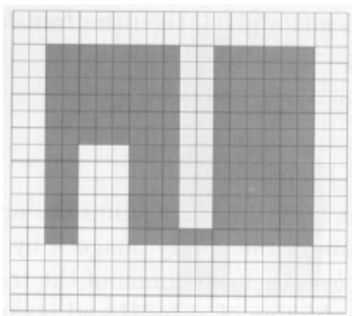
- The value of the output pixel is the *minimum* value of all the pixels in the input pixel's neighborhood.
- Erosion: $$A \quad B = \{x \mid (B)_x \subseteq A\}$$



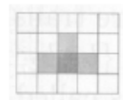


Dilation & Erosion

A

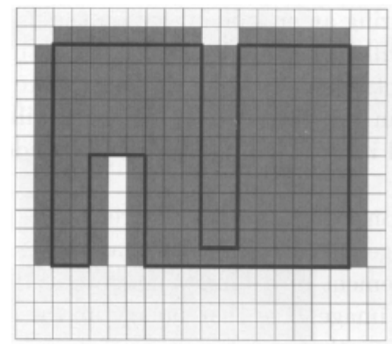


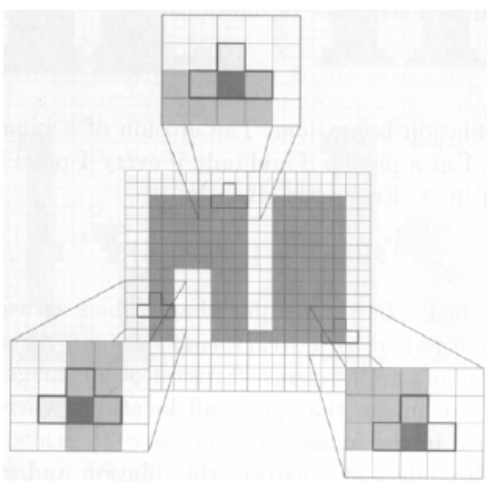
B



- **Dilation:** union of translations of an image ***A*** by each pixel of image ***B***, called ***structural element***:

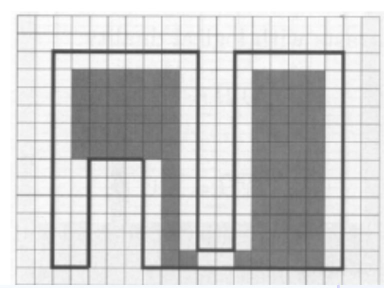
$$A \oplus B = \bigcup_{b_i \in B} A_{b_i}$$





- **Erosion** inverse operation

$$A \ominus B = \{p | B_p \subseteq A\}$$



Morphological Image Processing

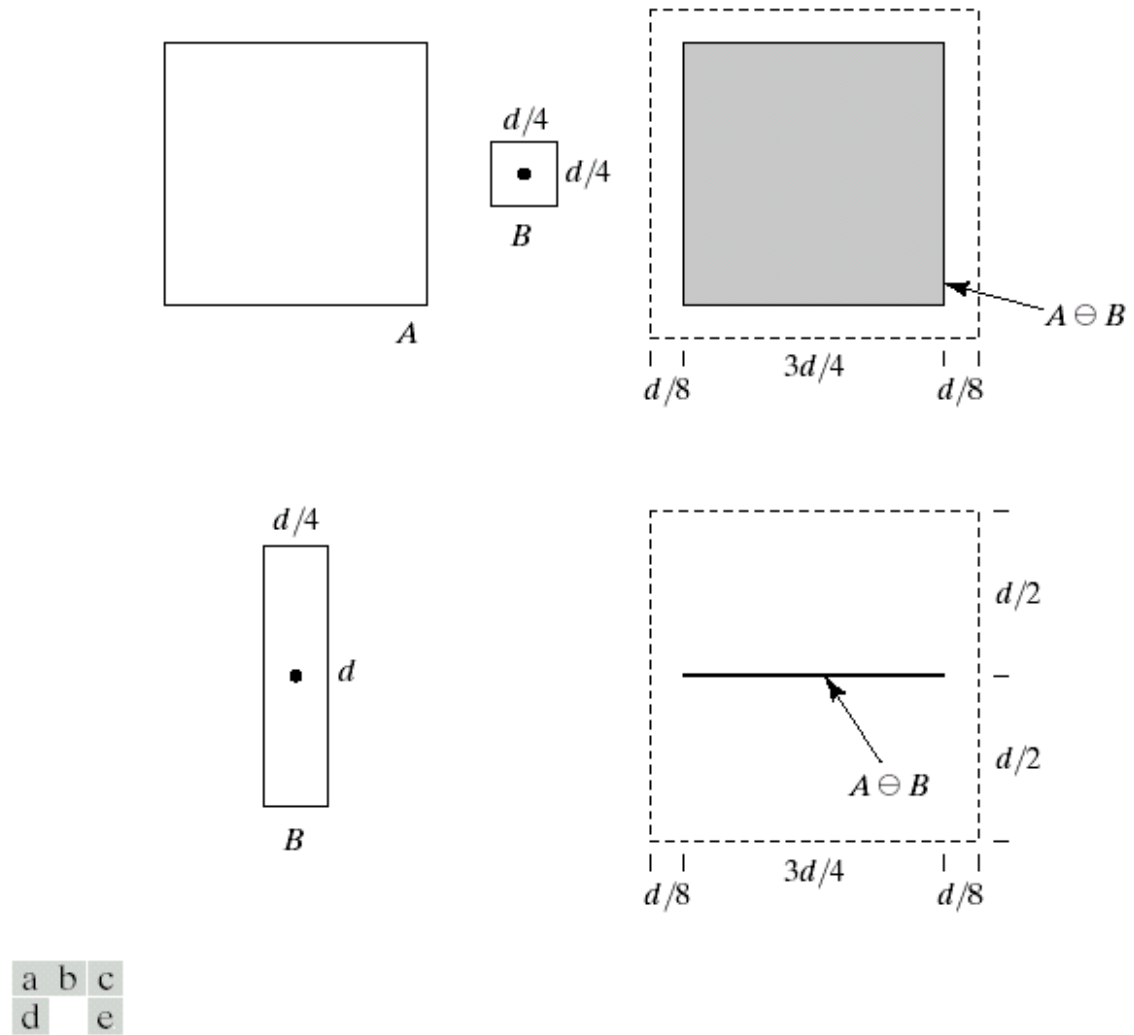
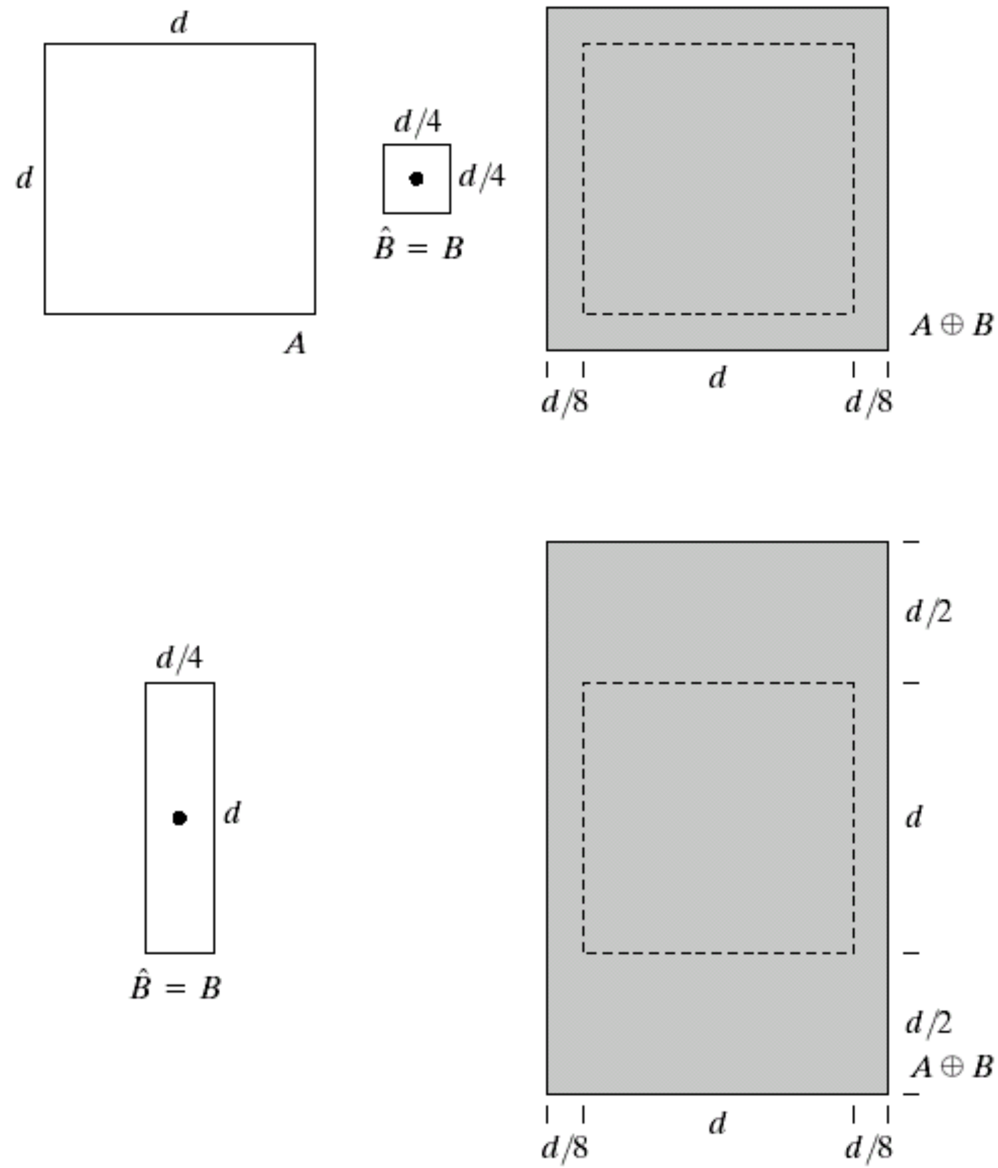


FIGURE 9.6 (a) Set A. (b) Square structuring element. (c) Erosion of A by B, shown shaded. (d) Elongated structuring element. (e) Erosion of A using this element.

Morphological Image Processing

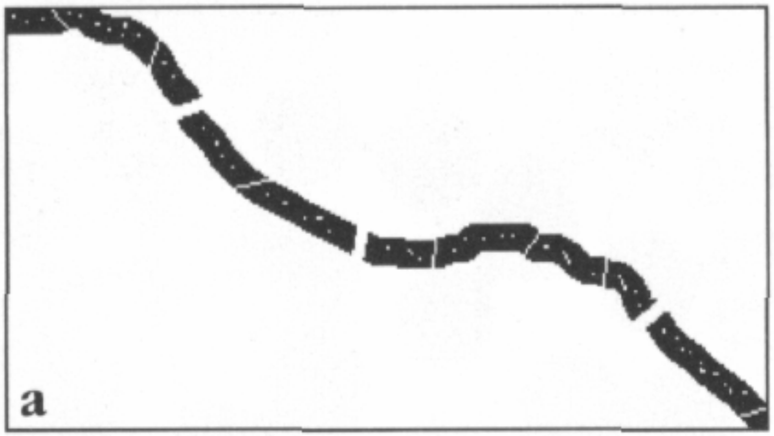
a b c
d e

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.

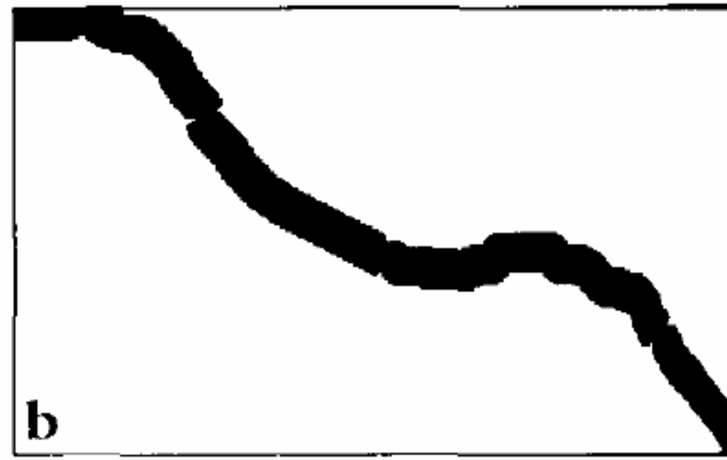


laboratory
erstner
iversity

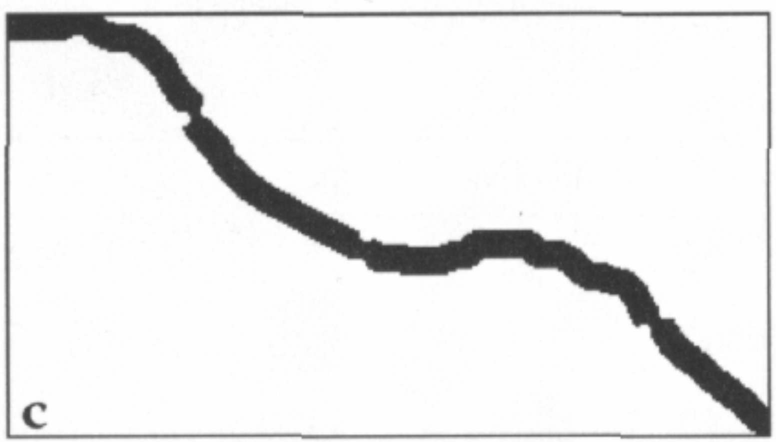
Object connection



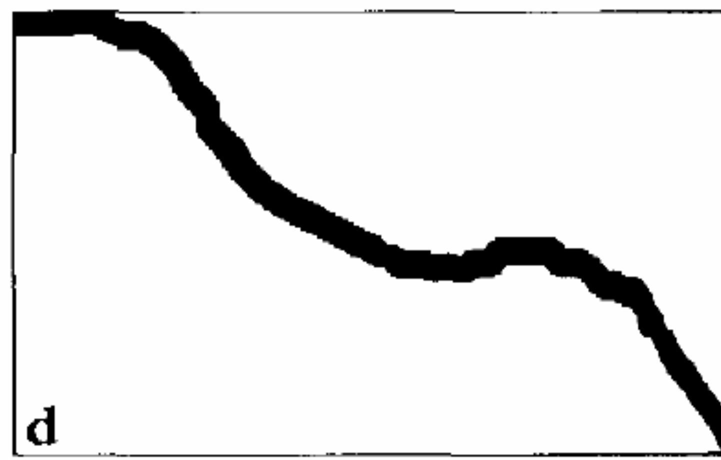
Original



Dilated twice



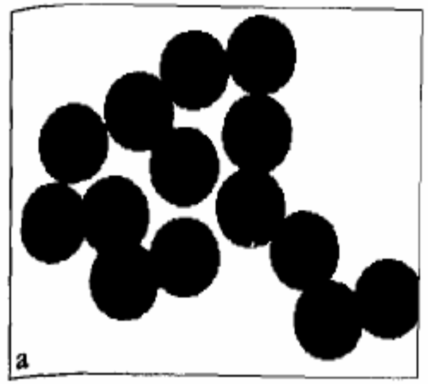
Eroded twice



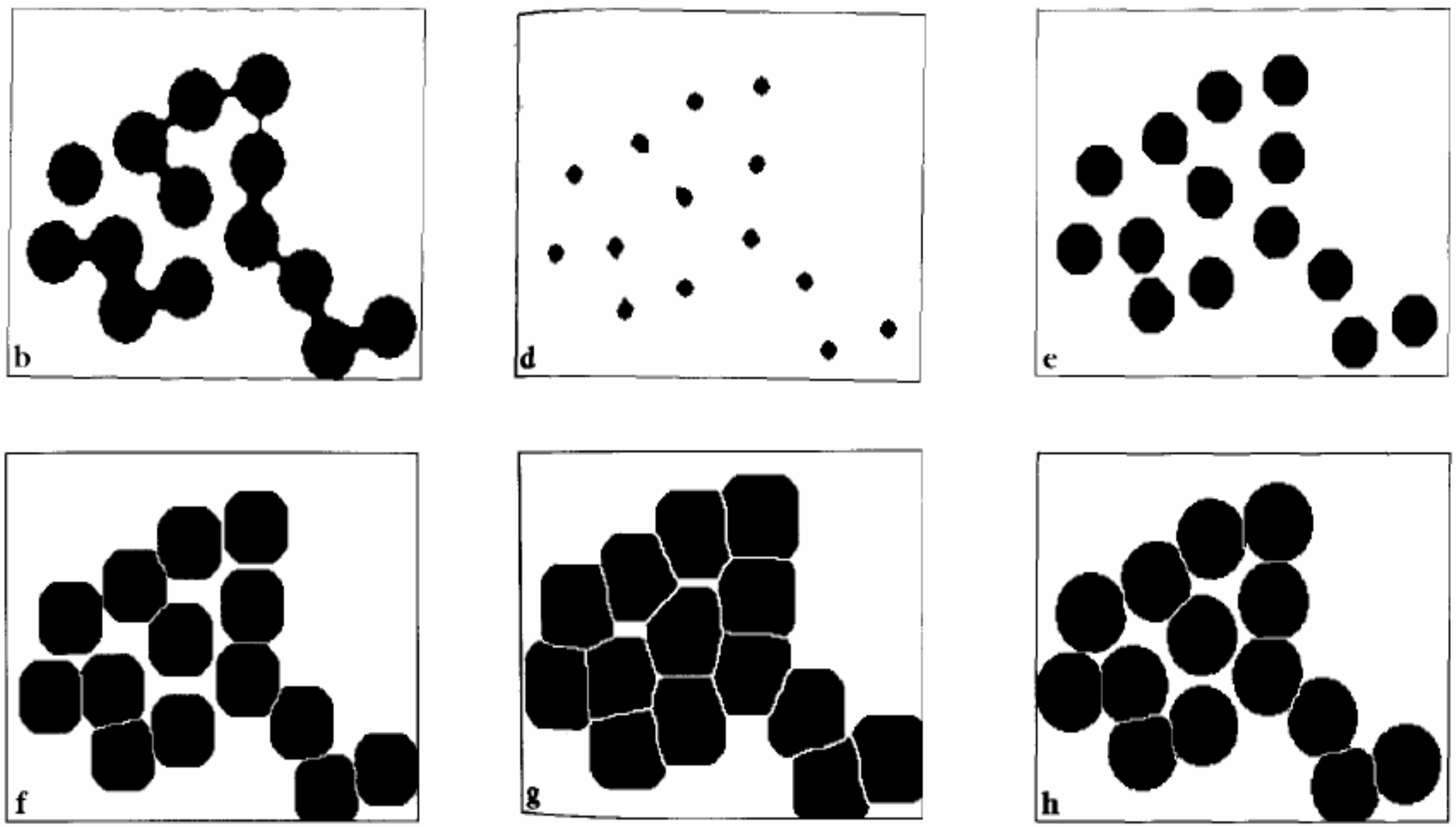
Dilated and eroded four times

Object separation

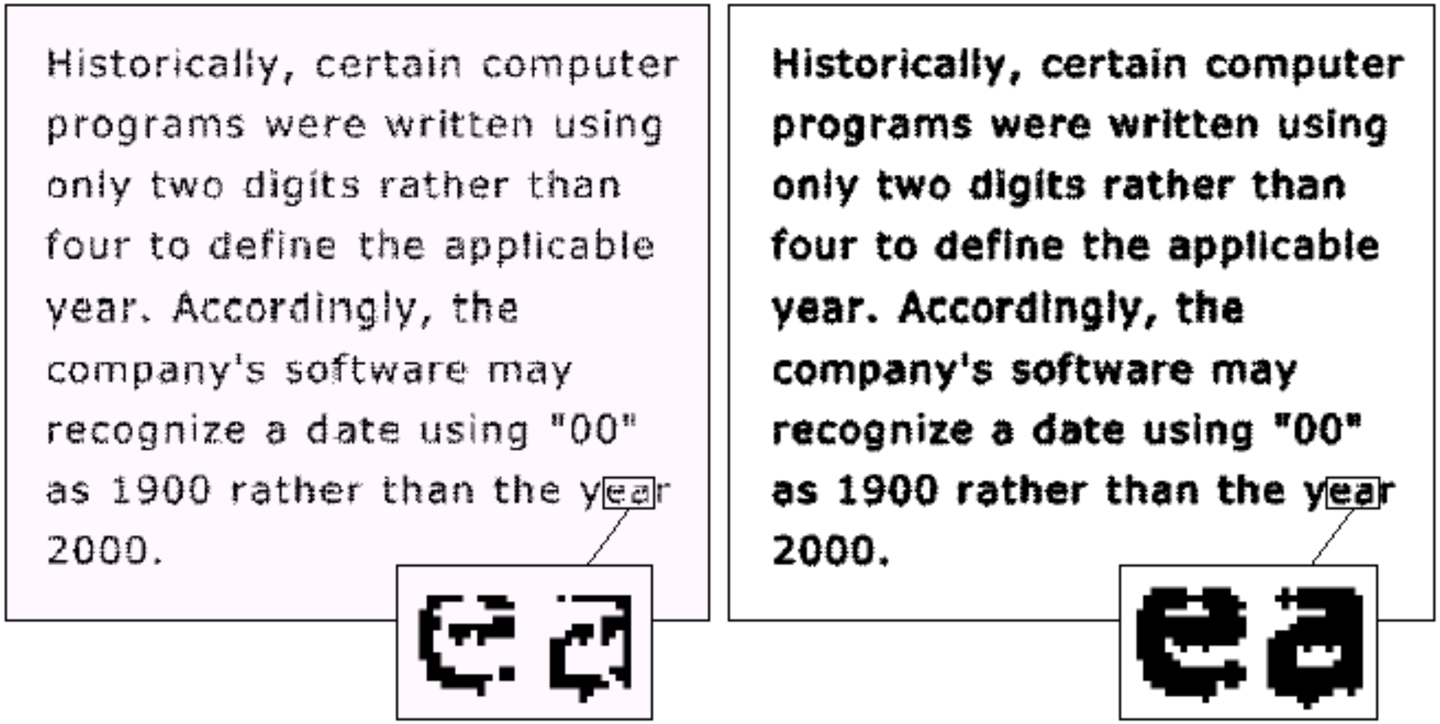
a. Original
b. Eroded twice
d. Eroded 7 times



e. Dilated four times with XOR
f. Dilated seven times with XOR
g. Dilated nine times with XOR
h. AND with original image



Morphological Image Processing

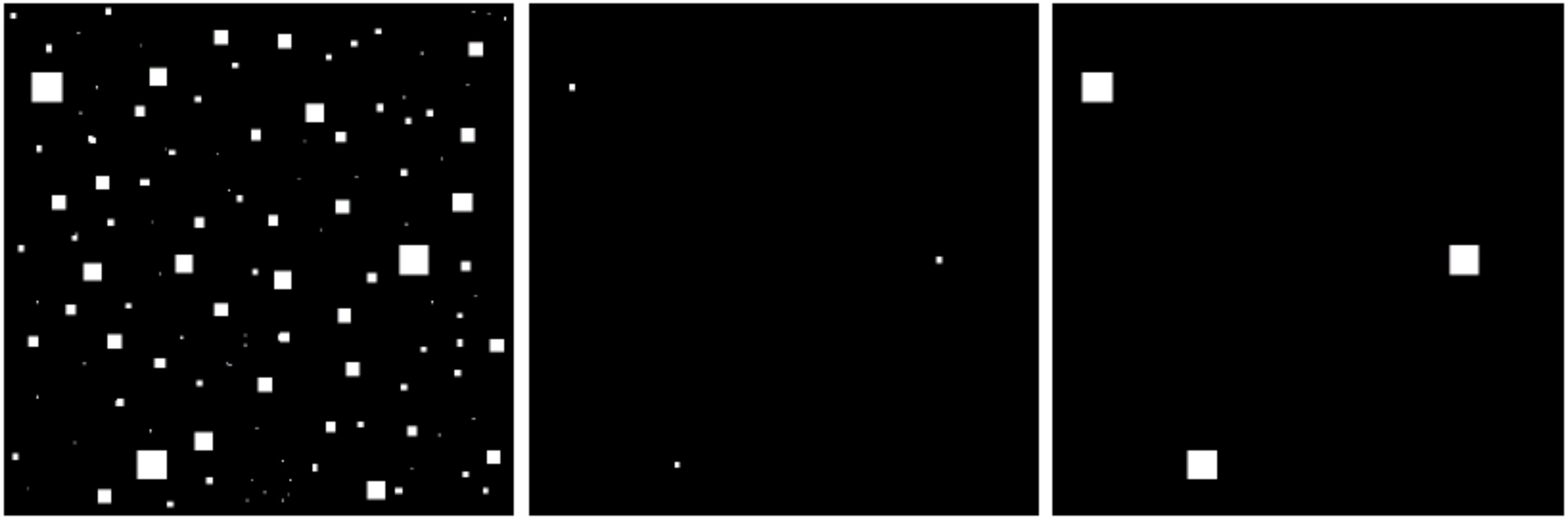


0	1	0
1	1	1
0	1	0

a c
b

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.

Morphological Image Processing

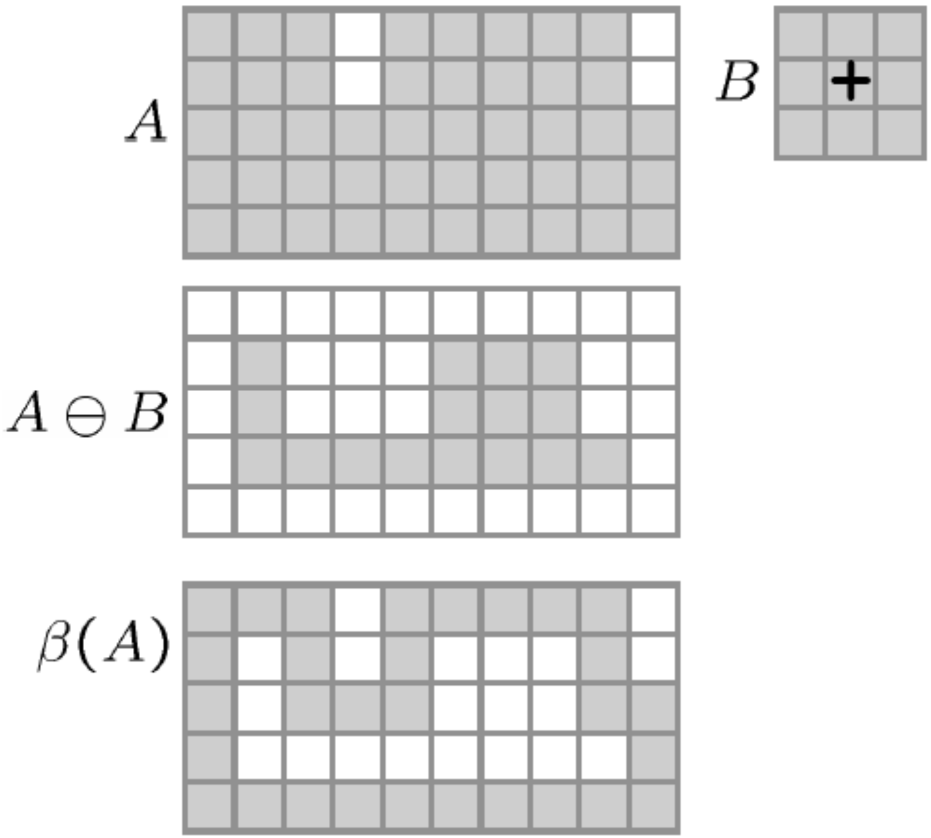


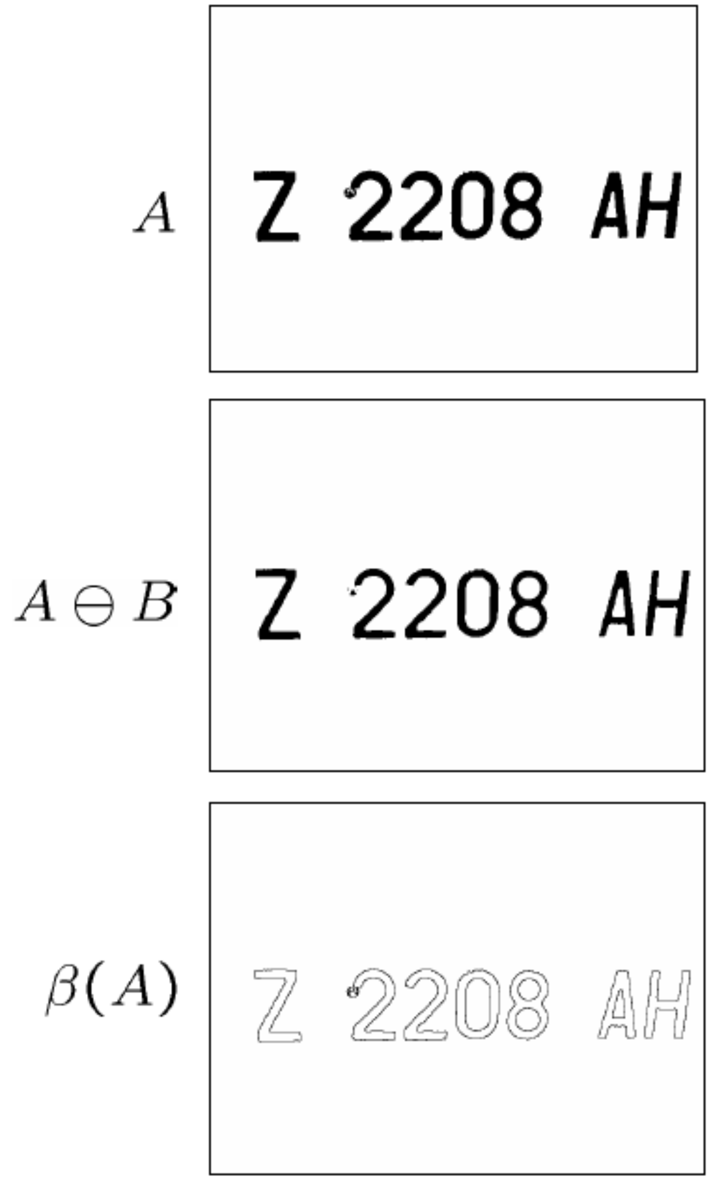
a b c

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.

Contour extraction

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





Opening & Closing

- In essence, dilation expands an image and erosion shrinks it.
- Opening:
  - generally smoothes the contour of an image, breaks isthmuses, eliminates protrusions.

- Closing:
  - smoothes sections of contours, but it generally fuses breaks, holes, gaps, etc.

– Opening of A by structuring element B:

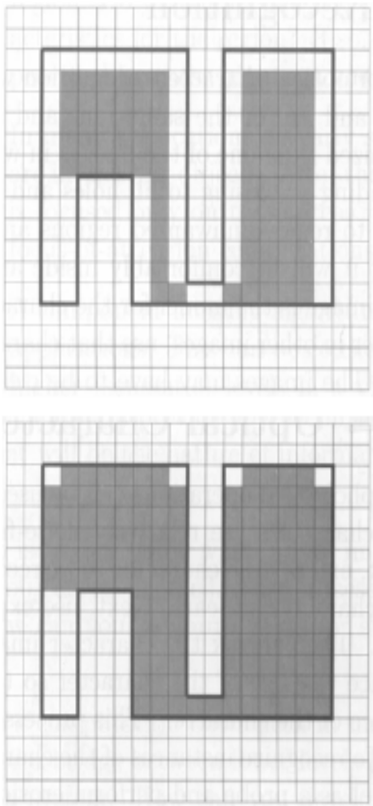
$$A \circ B = (A \ominus B) \oplus B$$

- Closing:

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

- **Opening:** erosion + dilation with the same element

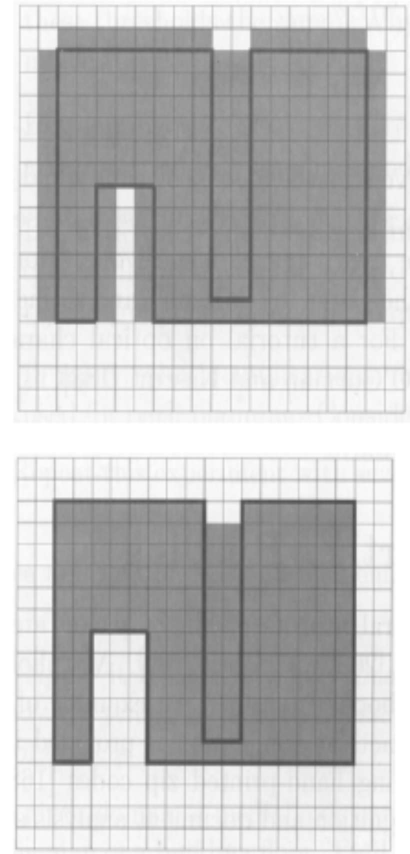
$$A \circ K = (A \ominus K) \oplus K$$



- Eliminates all regions too small to contain the structural element

- **Closing:** dilation + erosion with the same element

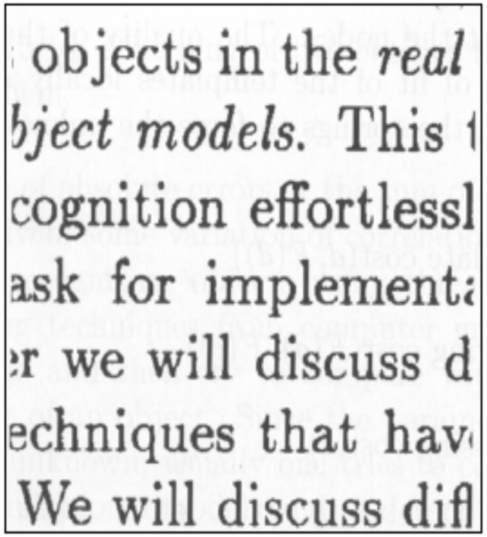
$$A \bullet K = (A \oplus K) \ominus K$$



- Fills all holes and cavities smaller than the structural element

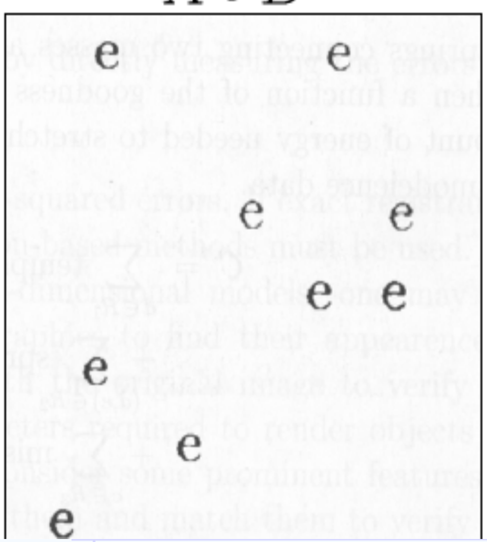
- **Template matching**

A

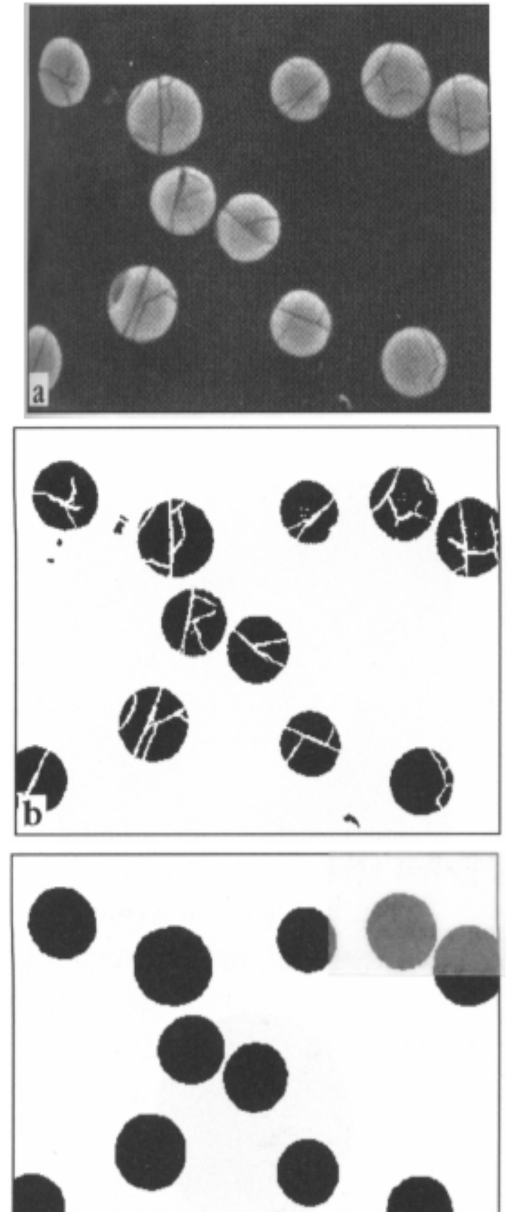


B

$A \circ B$



- **Reconstruction**

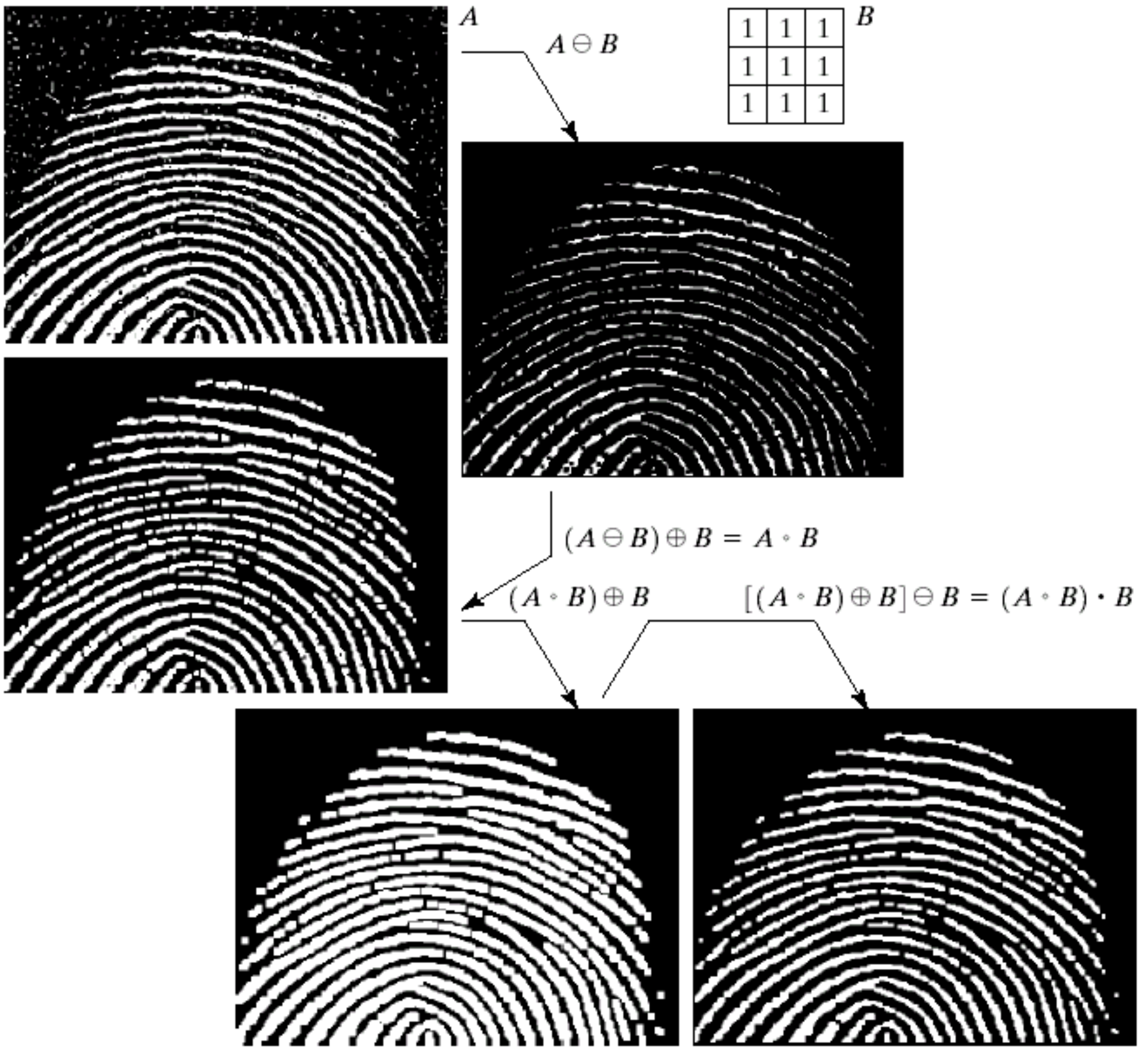


Original

Thresholded

Closing

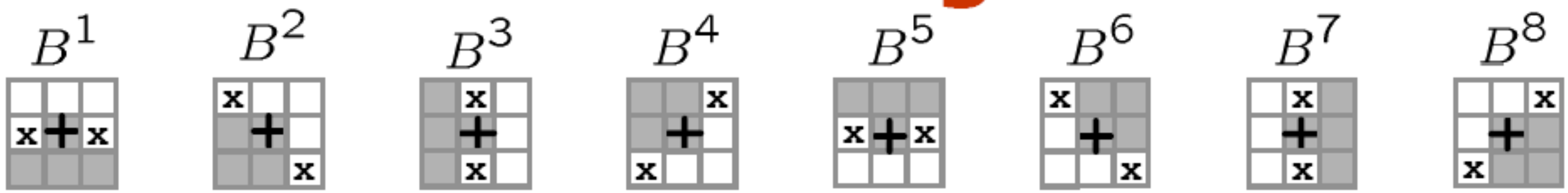
Morphological Image Processing



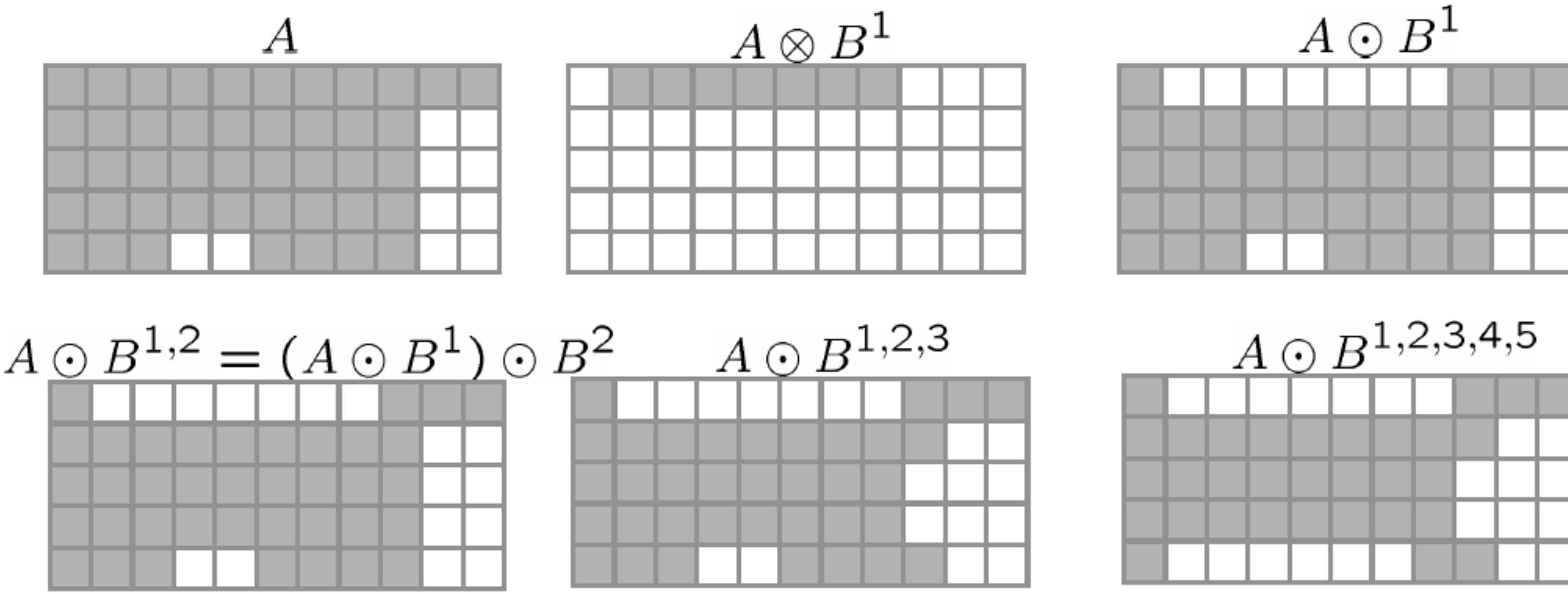
a b c d e f

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.)

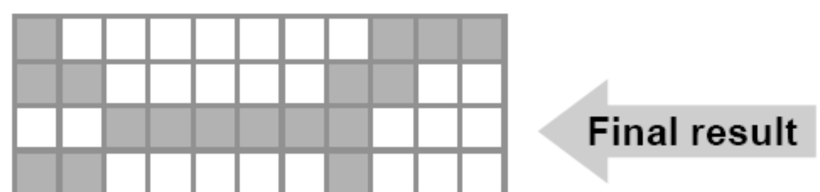
Thinning



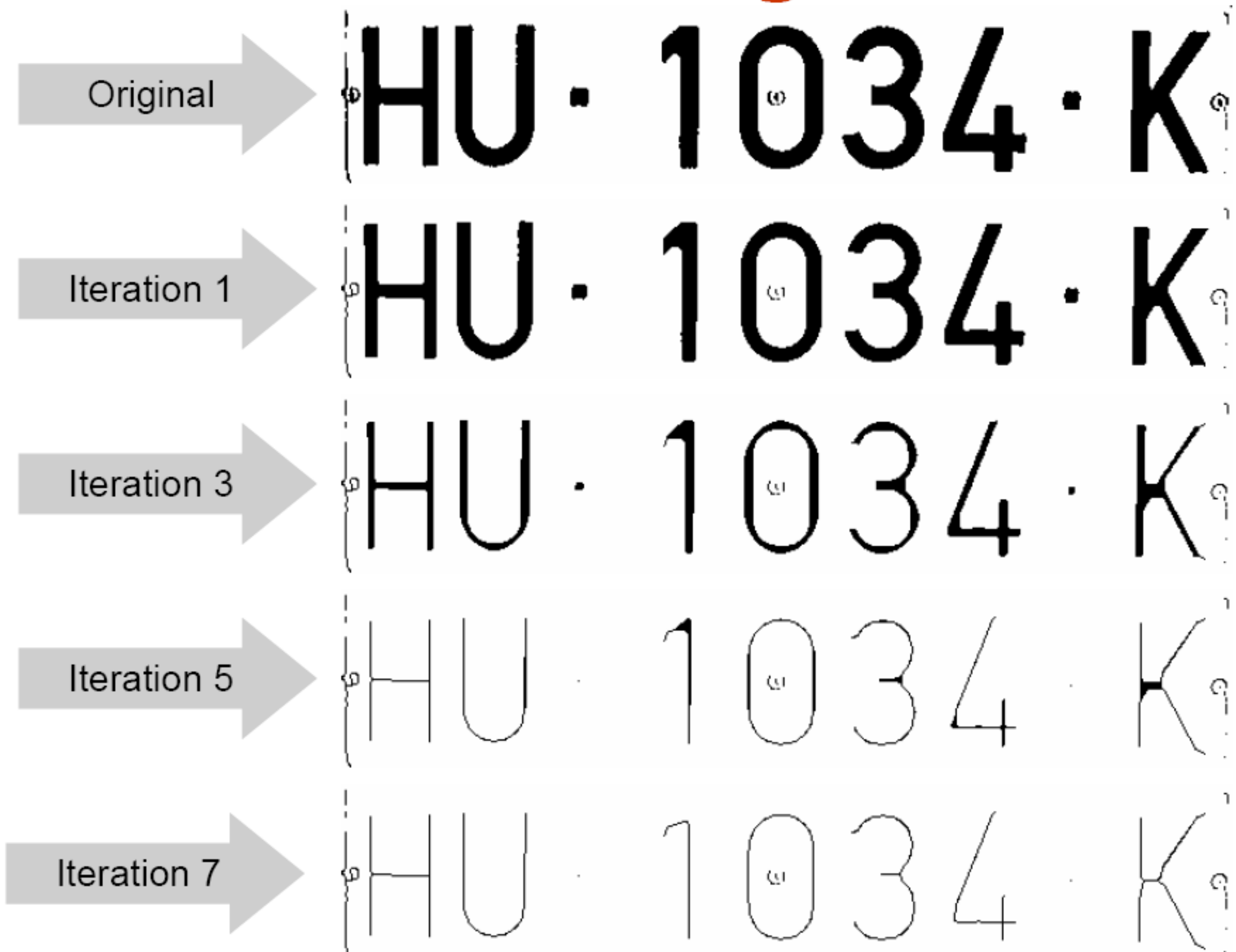
$$A \odot B^i = A - (A \otimes B^i)$$



$$X_0 = A$$
$$X_k = X_{k-1} \odot B^{\{1,\cdots,n\}}$$



Thinning


Original
HU·1034·K
Iteration 1
Iteration 3
Iteration 5
Iteration 7

Post-processing

- Reduces the width of the ridges to one pixel
- *Skeletons* , spikes
- Filling holes, removing small breaks, eliminating bridges between ridges etc.
- ***cleanskeleton:*** *removespur, linkbreak, removebridge*

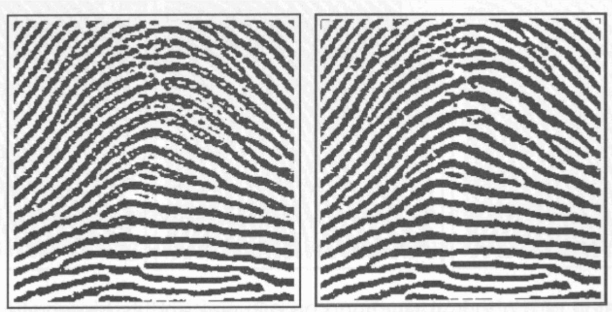
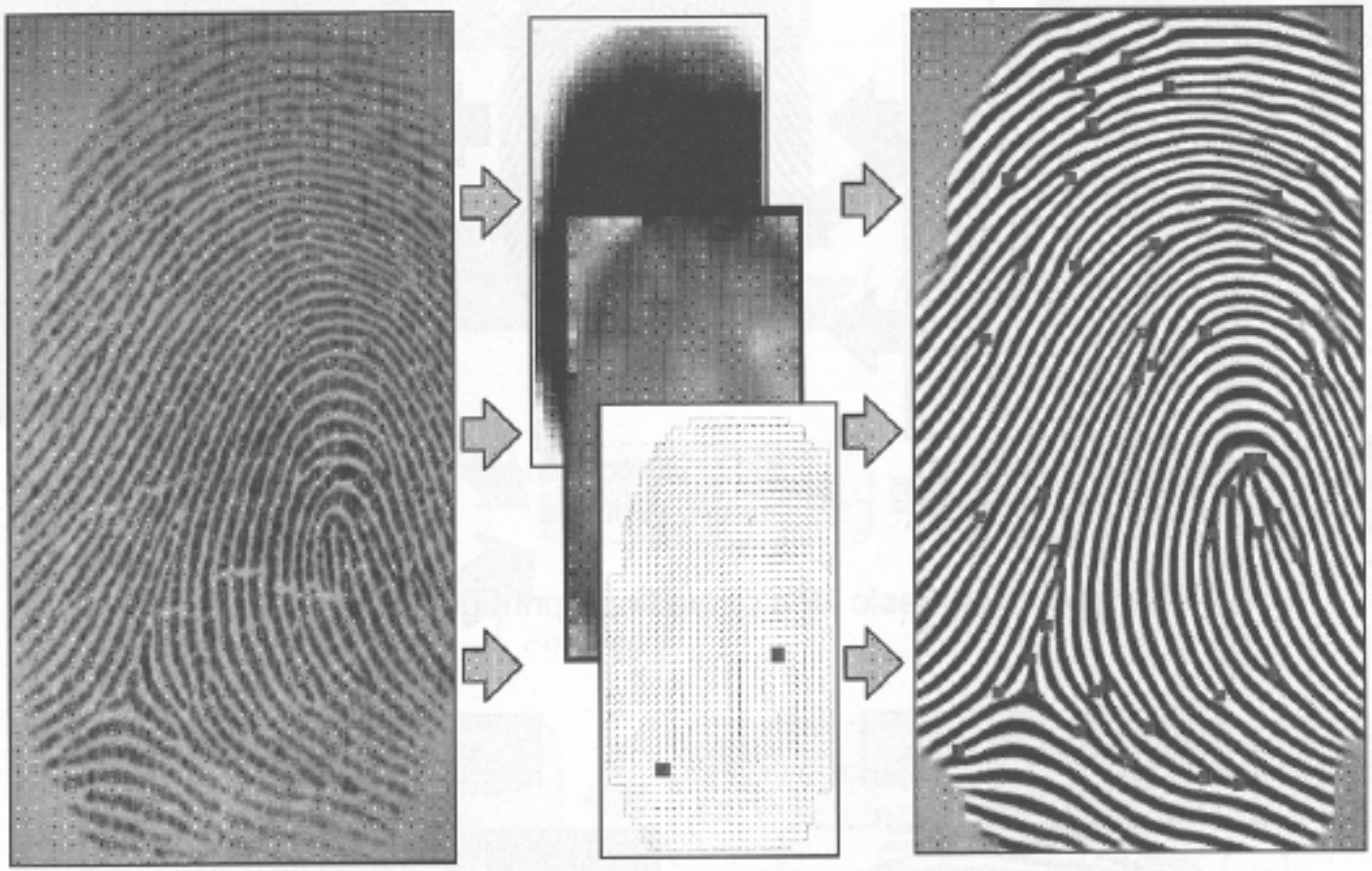


Figure 3.35. The result of eliminating small holes from both the ridges and valleys of the binary image; input image is shown on the left and the output is shown on the right. The filtering is performed by computing the connected components of the image and by removing the components whose area (number of pixels) is smaller than a given threshold.

Thinning

- enhance2ridgevalley.m
- imOutput = bwmorph(imcomplement(imReconstruct),'thin', 'Inf'); %thins the reconstructed image

Feature Extraction

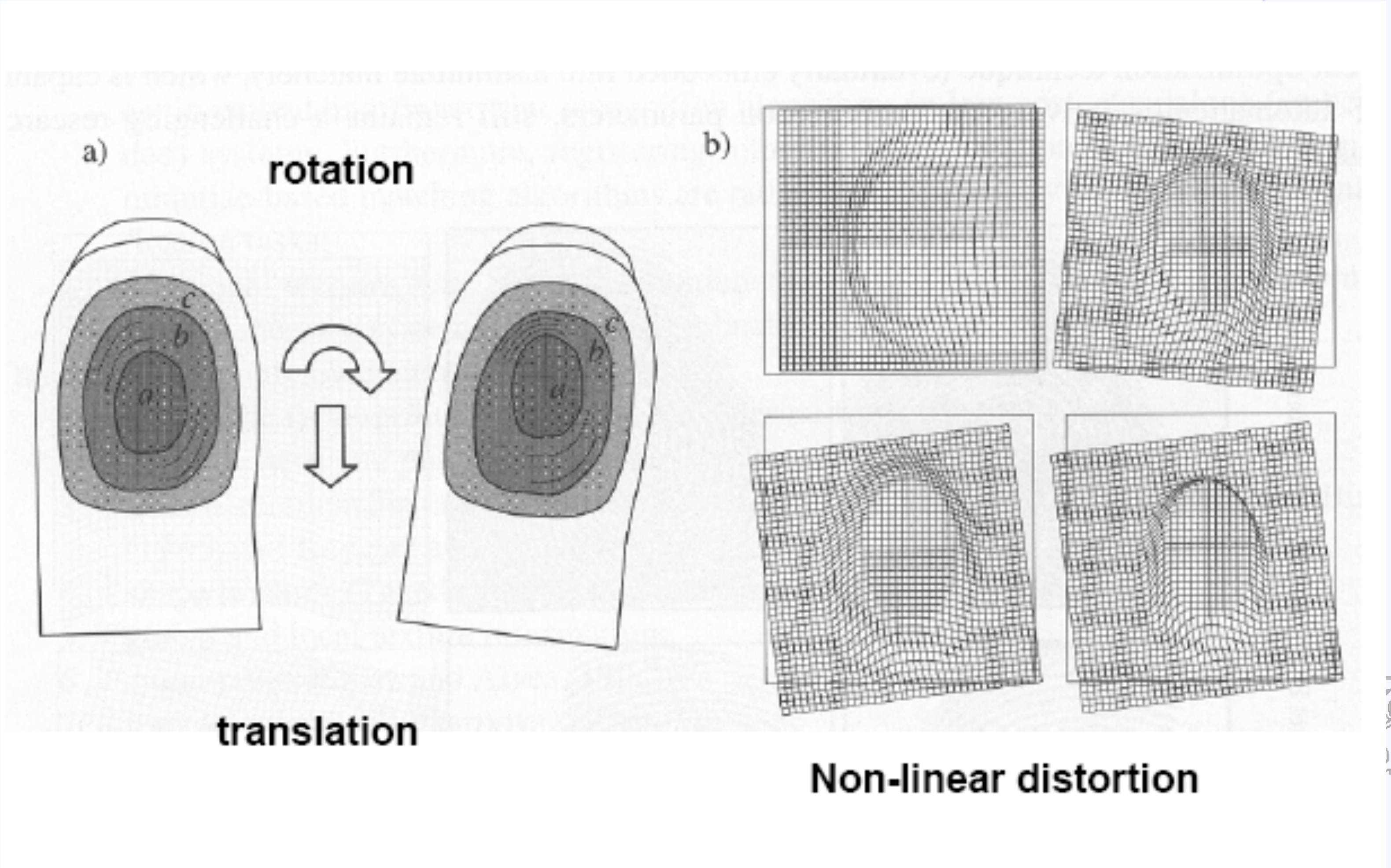


Fingerprint image | Fingerprint area, frequency image, and orientation image | Ridge pattern and minutiae points

Feature Extraction Errors

- The feature extraction algorithms are imperfect and often introduce measurement errors
- Errors may be made during any of the feature extraction stages, e.g., estimation of orientation and frequency images, detection of the number, type, and position of the singularities and minutiae, segmentation of the fingerprint area from bacground, etc.
- Aggressive enhancement algorithms may introduce inconsistent biases that perturb the location and orientation of the reported minutiae from their gray-scale counterparts
- In low-quality fingerprint images, the minutiae extraction process may introduce a large number of spurious minutiae and may not be able to detect all the true minutiae

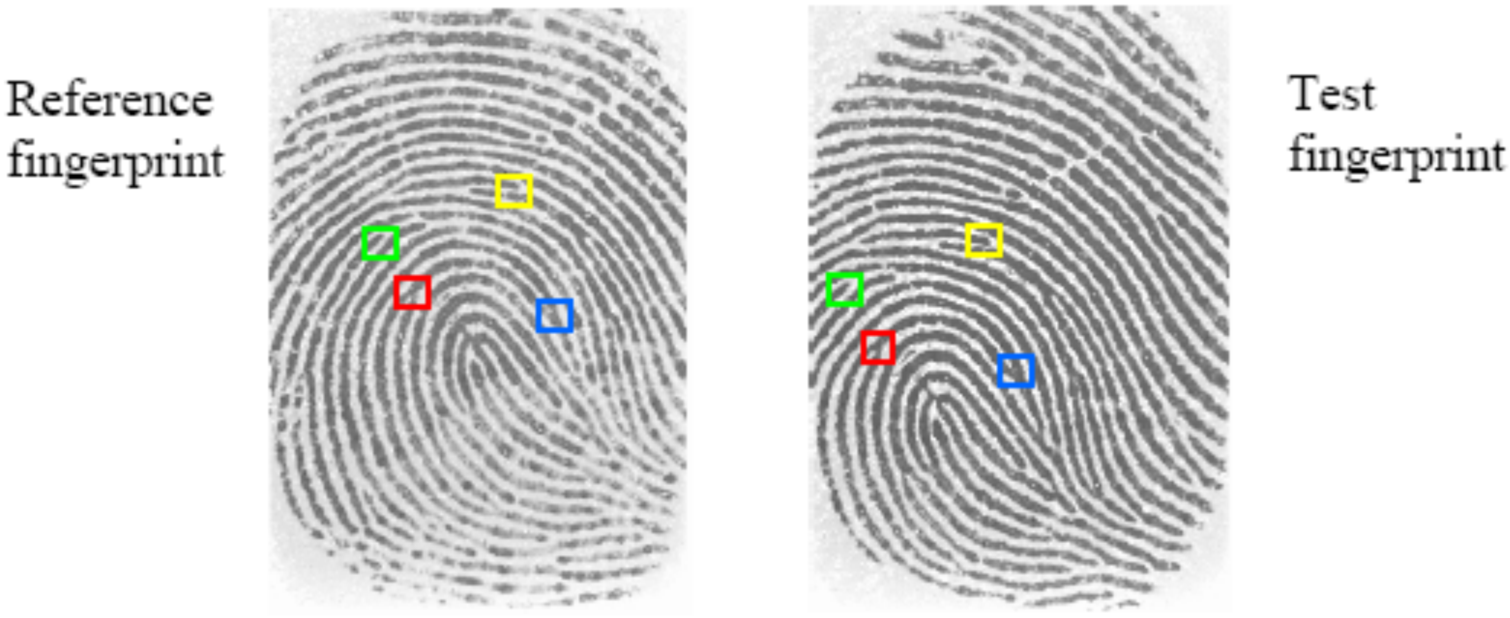
Non-linear distortion



Intra-variability

- Matching fingerprint images is an extremely difficult problem, mainly due to the large variability in different impressions of the same finger (intra-variability). The main factors are:
  - Displacement (global translation of the fingerprint area)
  - Rotation
  - Partial overlap
  - Non-linear distortion:
    - *the act of sensing maps the three-dimensional shape of a finger onto the two-dimensional surface of the sensor*
    - *skin elasticity*
  - Pressure and skin condition
  - Noise: introduced by the fingerprint sensing system
  - Feature extraction errors

Fingerprint matching



- Comes the test- and the reference fingerprint from the same finger?
  the two fingerprints can be *translated* and *rotated* relative to each other.
- Minutiae based matching: by *direct use of the local structure* of the fingerprints extract common minutiae points.

MATCHING: Approaches

- Correlation-based matching
  - Superimpose images – compare pixels
- Minutiae-based matching
  - Classical Technique – Most popular
  - Compare extracted minutiae
- Ridge Feature-based matching
  - Compare the structures of the ridges
  - Everything else

Fingerprint Matching

- Compare two given fingerprints *T,I*
  - Return degree of similarity *(0->1)*
  - Binary Yes/No
- *T* -> template, acquired during enrollment
- *I* -> Input
- Either input images, or feature vectors (minutiae) extracted from them

- Pressure and Skin condition
  - Pressure, dryness, disease, sweat, dirt, grease, humidity
- Noise
  - Dirt on the sensor
- Feature Extraction Errors

- Many algorithms match high quality images
- Challenge is in low-quality and partial matches
- **20% of the problems (low quality) at FVC2000 caused 80% of the false non-matches**
- Many were correctly identified at FVC2002 though

Correlation-based Techniques

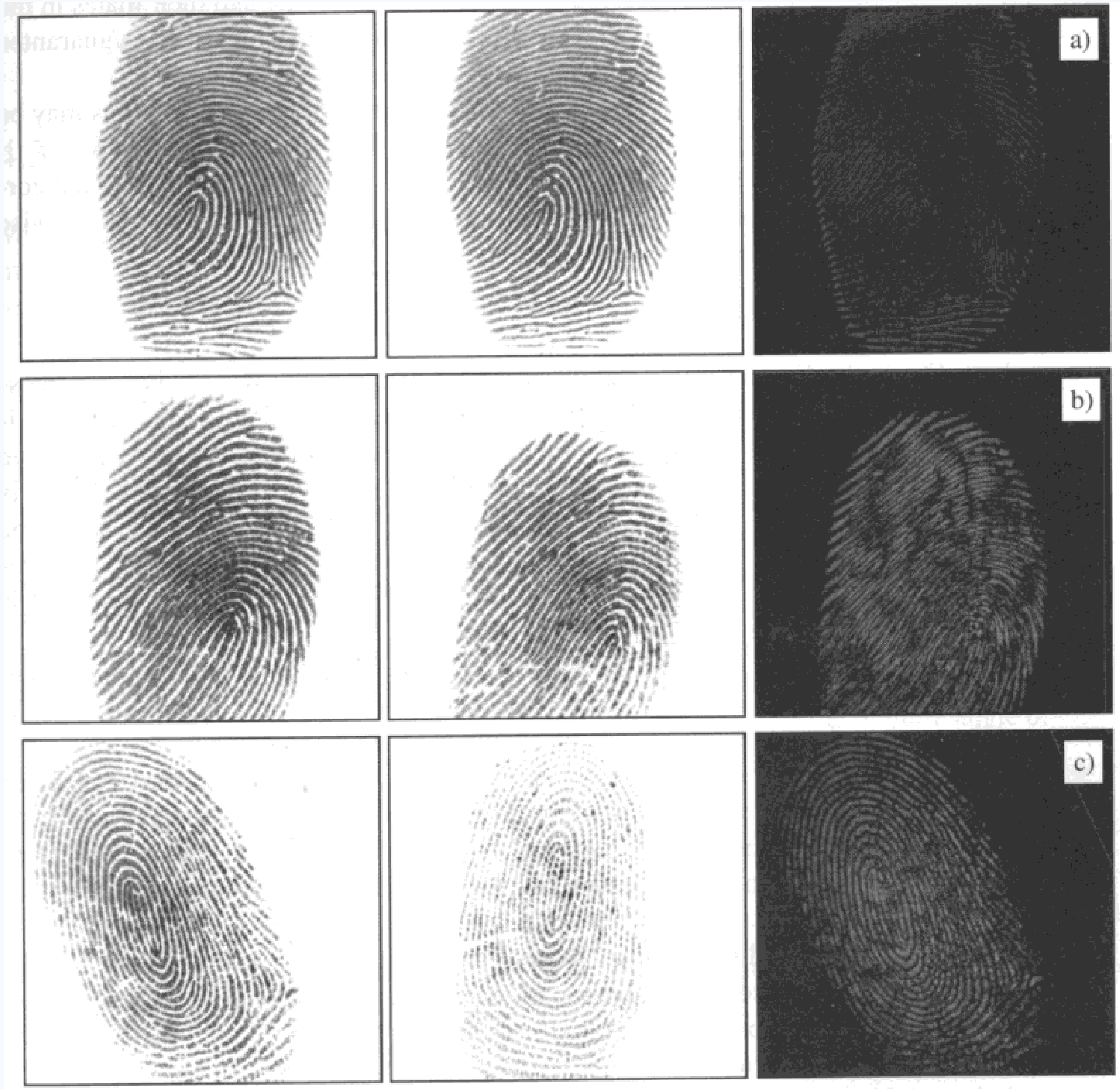
- T and I are images
- Sum of squared Differences
  - $SSD(T,I) = ||T-I||^2 = (T-I)^T(T-I) = ||T||^2 + ||I||^2 - 2T^TI$
  - Difference between pixels
- $||T||^2 + ||I||^2$ are constant under transformation
- Try to maximize correlation – Minimizes difference
  - $CC(T,I) = T^TI$
  - Can't be used because of displacement / rotation

Maximizing Correlation

- $I^{(\Delta x,\Delta y,\theta)}$
  - Transformation of I
  - Rotation around the origin by θ
  - Translation by x,y
- $S(T,I) = \max CC(T,I^{(\Delta x,\Delta y,\theta)})$
  - Try them all – take max

$$S(\mathbf{T},\mathbf{I}) = \max_{\Delta x,\Delta y,\theta} CC\left(\mathbf{T},\mathbf{I}^{(\Delta x,\Delta y,\theta)}\right)$$

Correlation Results



... impressions of the same finger and the absolute value of the

Minutiae-based Methods

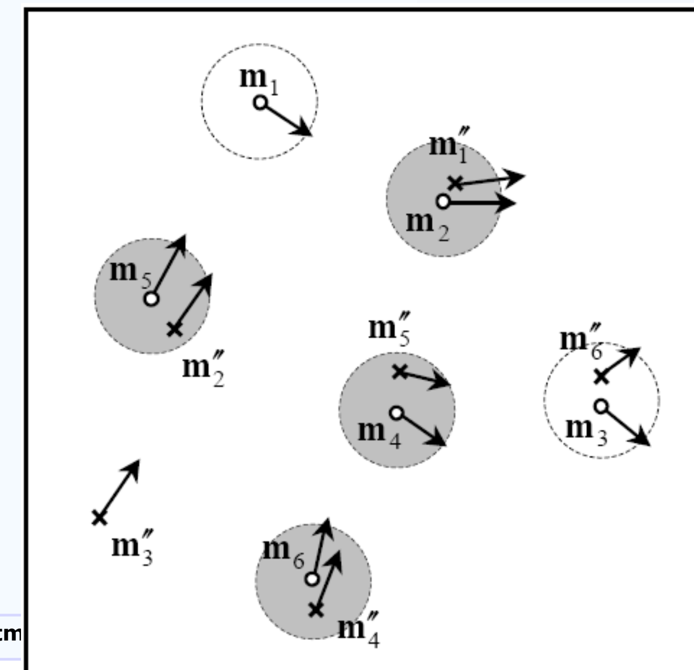
$$\mathbf{m} = \{x, y, \theta\}$$

$$\mathbf{T} = \{\mathbf{m}_1, \mathbf{m}_2, \ldots \mathbf{m}_m\}, \quad \mathbf{m}_i = \{x_i, y_i, \theta_i\}, \quad i = 1 \ldots m$$
$$\mathbf{I} = \{\mathbf{m}'_1, \mathbf{m}'_2, \ldots \mathbf{m}'_n\}, \quad \mathbf{m}'_j = \{x'_j, y'_j, \theta'_j\}, \quad j = 1 \ldots n,$$

- Classical Technique
- T, I are feature vectors of minutiae
- Minutiae = (x, y, θ)
- Two minutiae match if
  - Euclidean distance < r_0
  - Difference between angles < θ_0
  - Tolerance Boxes
    - r_0
    - θ_0

$$sd(\mathbf{m}'_j, \mathbf{m}_i) = \sqrt{(x'_j - x_i)^2 + (y'_j - y_i)^2} \leq r_0, \text{ and}$$

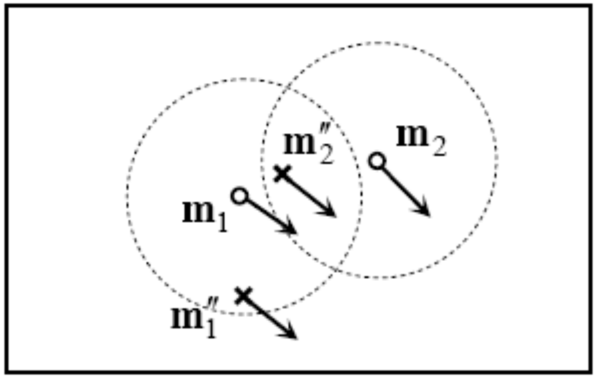
$$dd(\mathbf{m}'_j, \mathbf{m}_i) = \min\left(\left|\theta'_j - \theta_i\right|, 360^\circ - \left|\theta'_j - \theta_i\right|\right) \leq \theta_0 .$$



Formulation

- $M''_j = map(m'_j)$
  - Map applies a geometrical transformation
- $mm(m''_j, m_i)$ returns 1 if they match
- Matching can be formulated as

$$\underset{\Delta x, \Delta y, \theta, P}{\text{maximize}} \sum_{i=1}^{m} mm\left(map_{\Delta x, \Delta y, \theta}\left(\mathbf{m}'_{P(i)}\right), \mathbf{m}_i\right)$$



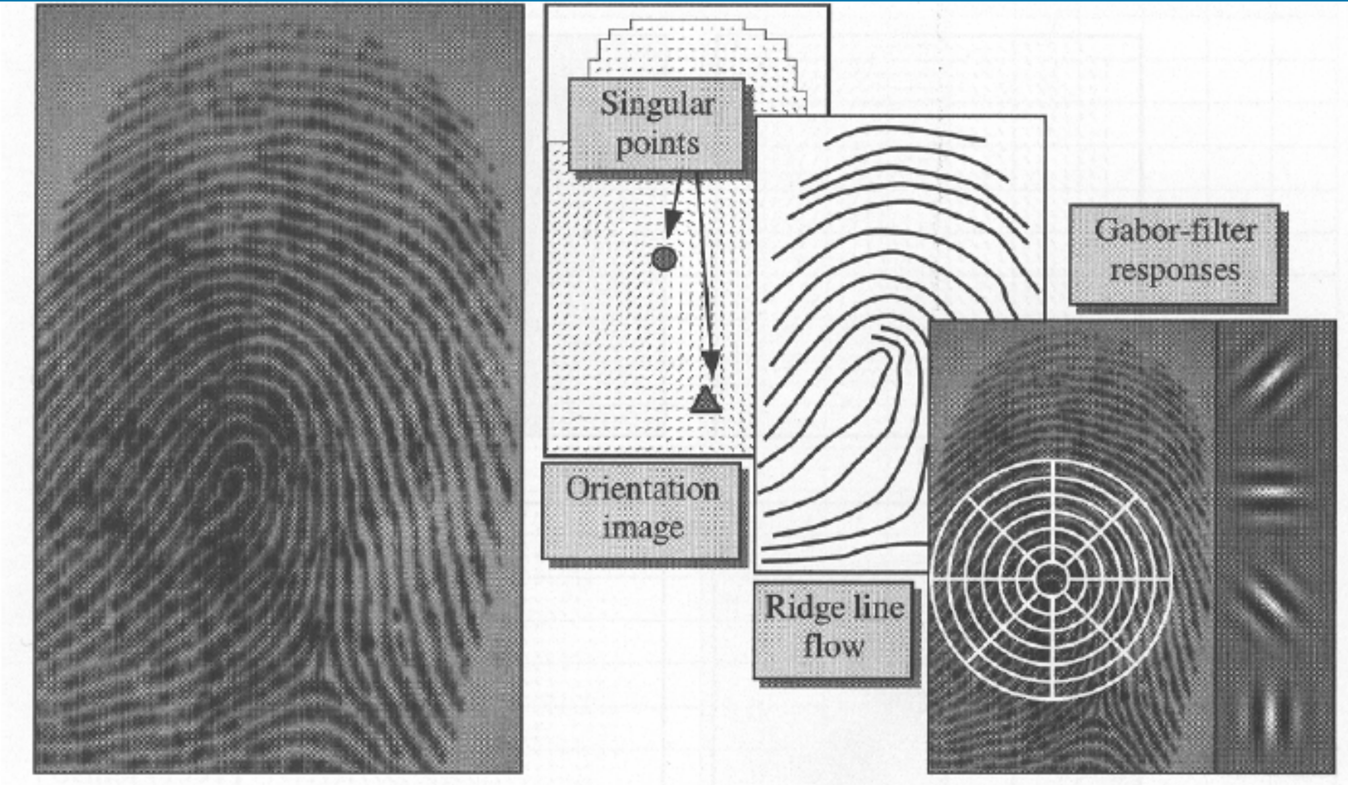
- **P is an unknown function which pairs the minutiae**
  - Which minutiae in I corresponds to which in T: ***allign2***

$$map_{\Delta x, \Delta y, \theta}\left(\mathbf{m}'_j = \{x'_j, y'_j, \theta'_j\}\right) = \mathbf{m}''_j = \{x''_j, y''_j, \theta'_j + \theta\}, \text{ where}$$

$$\begin{bmatrix} x''_j \\ y''_j \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x'_j \\ y'_j \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}.$$

$$mm\left(\mathbf{m}''_j, \mathbf{m}_i\right) = \begin{cases} 1 & sd\left(\mathbf{m}''_j, \mathbf{m}_i\right) \le r_0 \text{ and } dd\left(\mathbf{m}''_j, \mathbf{m}_i\right) \le \theta_0 \\ 0 & \text{otherwise.} \end{cases}$$

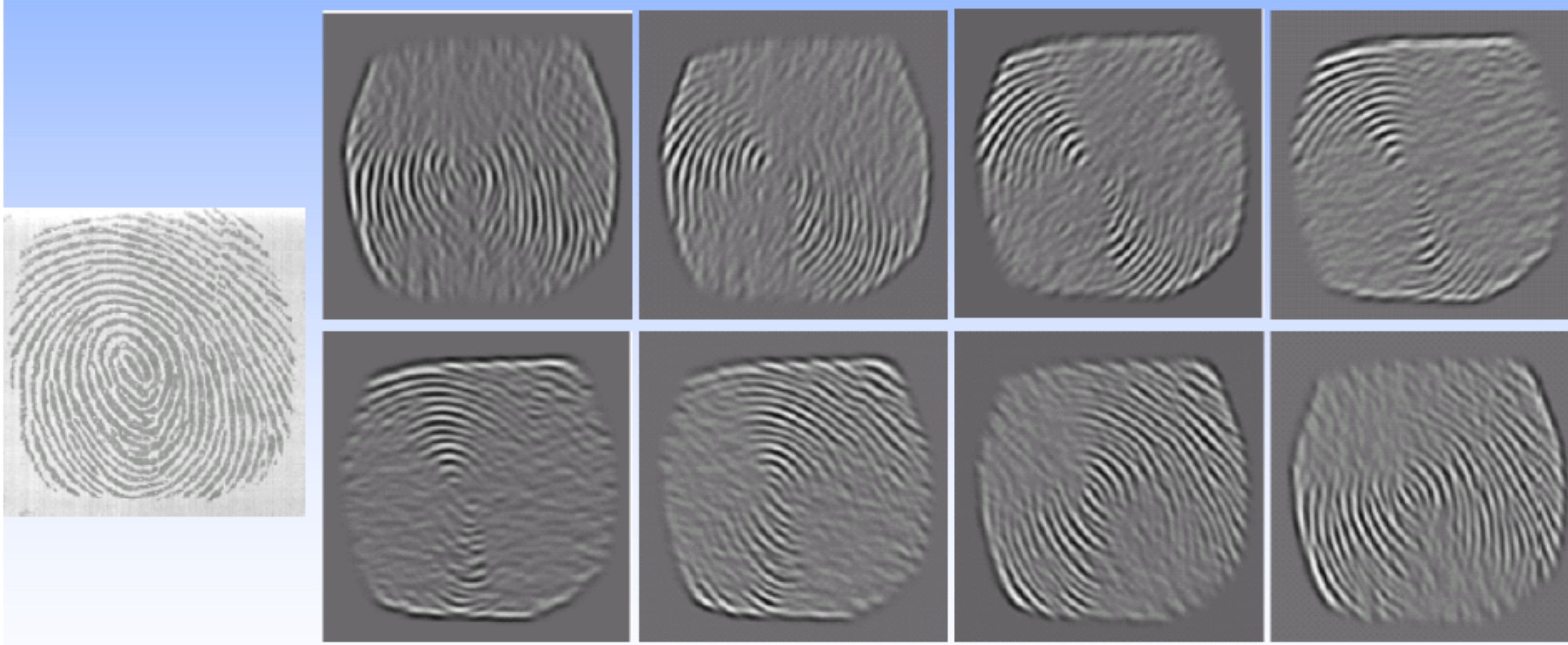
Ridge feature based matching



Most frequently used features for fingerprint matching:
-Orientation image
-Singular points (loop and delta)
-Ridge line flow
-**Gabor filter responses**

Gabor filters

- An input fingerprint image is filtered using 8 Gabor filters all having the same frequency but different orientations (0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, 157.5°)

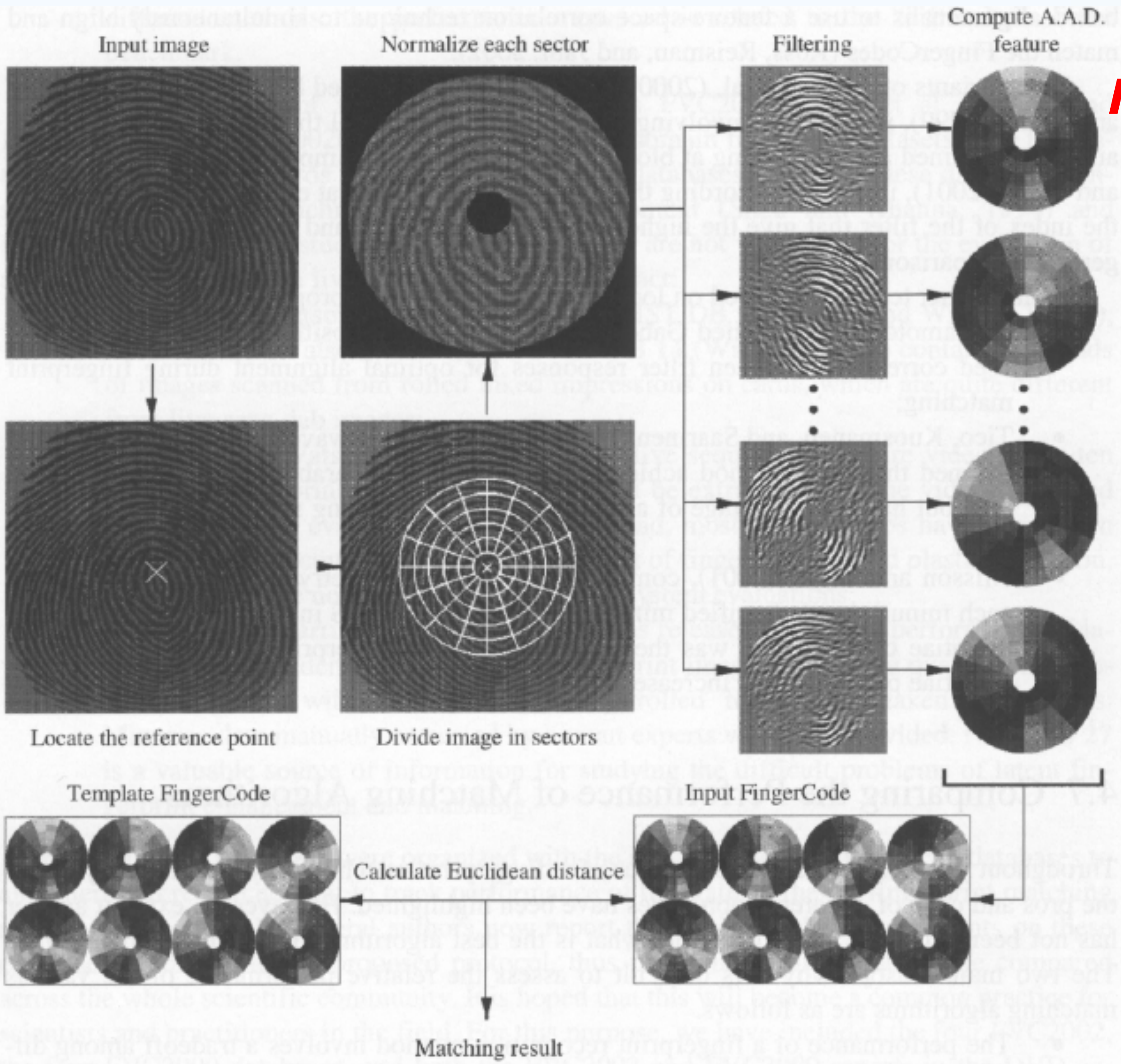


Local texture analysis

- The fingerprint area of interest is tesselated with respect to the core point
- The local texture information in each sector is decomposed into separate channels by using a Gabor filterbank
- Feature vector:
  - 80 cells (5 bands and 16 sectors)
  - Filterbank of 8 Gabor filters (8 orientations, 1 scale =1/10 for 500 dpi fingerprint images)
  - Each fingerprint is represented by a 80x8 = 640 fixed-size feature vector, called the FingerCode
- Computation of average absolute deviation (AAD)

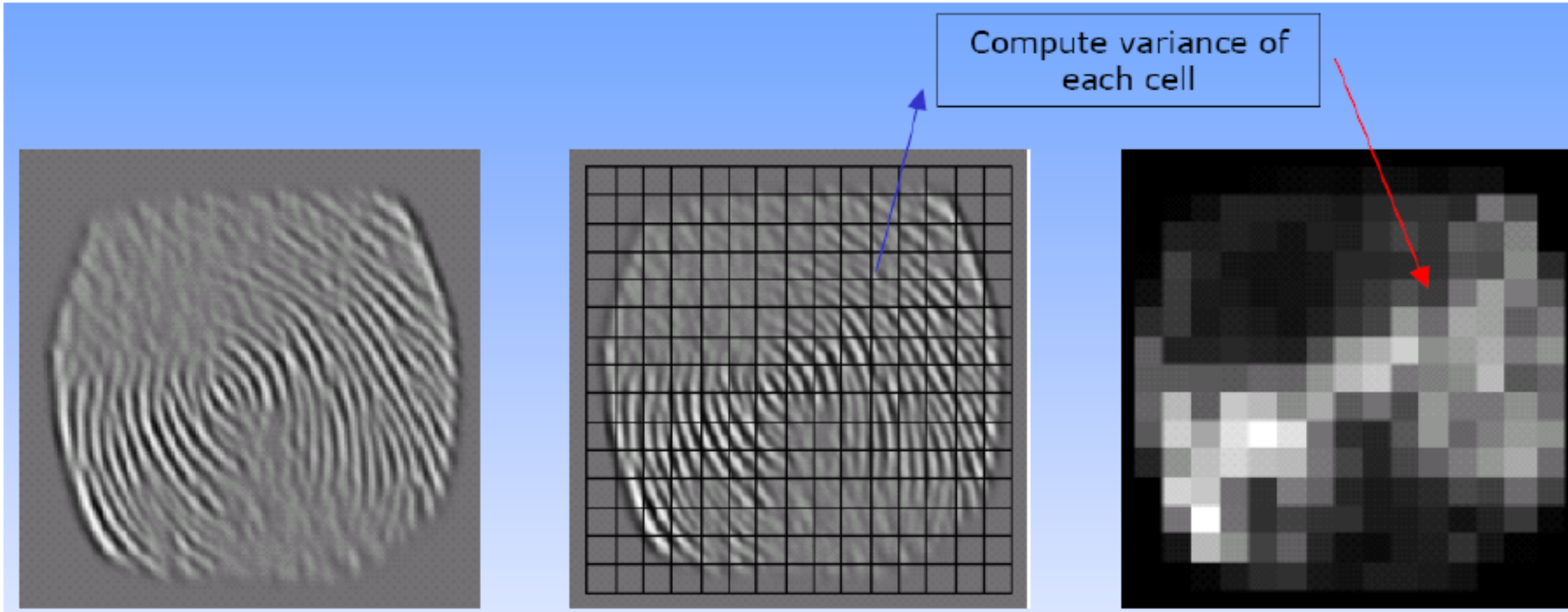
$$V_{ij} = \frac{1}{n_i}\left(\sum_{C_i}\left| g\left(x,y:\theta_j,1/10\right) - \overline{g_i} \right|\right),$$

Finger code approach



MatchGaborFeat

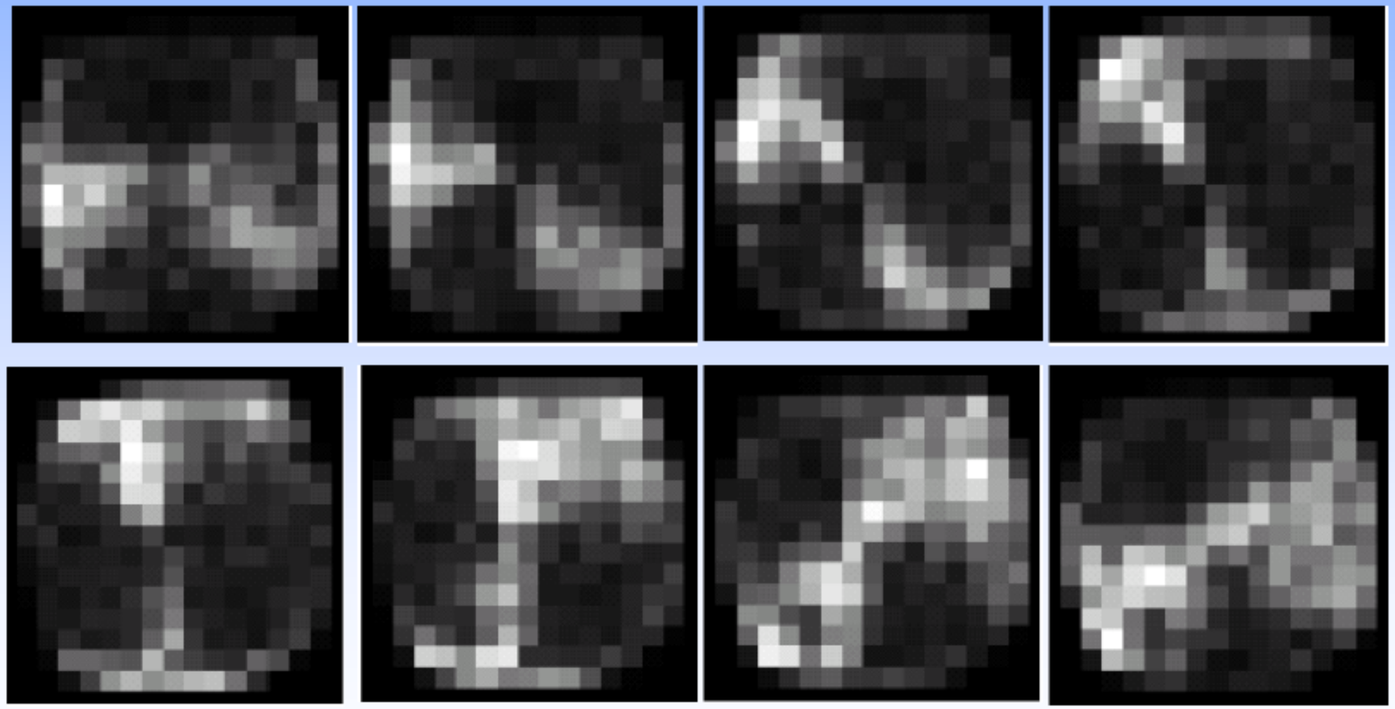
Texture based representation



(a) Filtered image (b) Square tessellation (c) Feature values

Ridge feature map

- The filtered images are examined using a square tessellation and the variance of pixel intensities in every cell is used as a feature value



The ridge feature map is a fixed-length feature vector

Ross, et al, “A Hybrid Fingerprint Matcher”, Pattern Recognition, Vol. 36, July 2003

Ridge feature based matching