Chapter 7 Image Segmentation

The principle goal of *image segmentation* is to partition an image into regions (also called classes or subimages) that are homogeneous with respect to one or more characteristics or features.

Image segmentation is a fundamental task in image processing providing the basis for any kind of further high-level image analysis.

Approaches to Segmentation

Image segmentation techniques may be classified into three types:

1) Thresholding

   Detection of a valley in the histogram

2) Edge-based approaches

   Detection of discontinuities in an image

3) Region-based approaches

   Selection of homogeneous regions in an image

1) Thresholding

Thresholding is an operation that involves tests against a function *T* of the form:

$$\boldsymbol{T = T[x, y, p(x, y), f(x, y)]}$$

where $f(x,y)$ is the gray level of point (x,y), and $p(x,y)$ denotes some local property of the point, e.g., the average gray level of a neighborhood centered on (x,y).

Types of Thresholding

- When *T* depends only on f(x,y) (that is, only on gray-level values), the threshold is called *global*.

- If *T* depends on both f(x,y) and p(x,y), the threshold is called *local*.

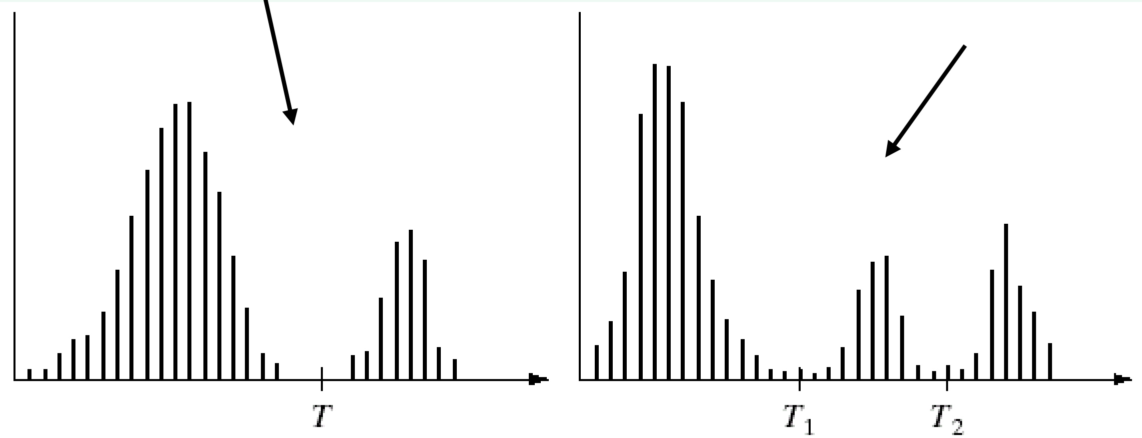
- If *T* depends on the spatial coordinates x and y, the threshold is called *dynamic* or *adaptive*.

Global Thresholding

Thresholding is a technique for separating data into groups. A thresholded image g(*x*,*y*) is defined as

$$g(x,y)=\begin{cases}1 & \text{if } f > T\\ 0 & \text{if } f \le T.\end{cases}$$

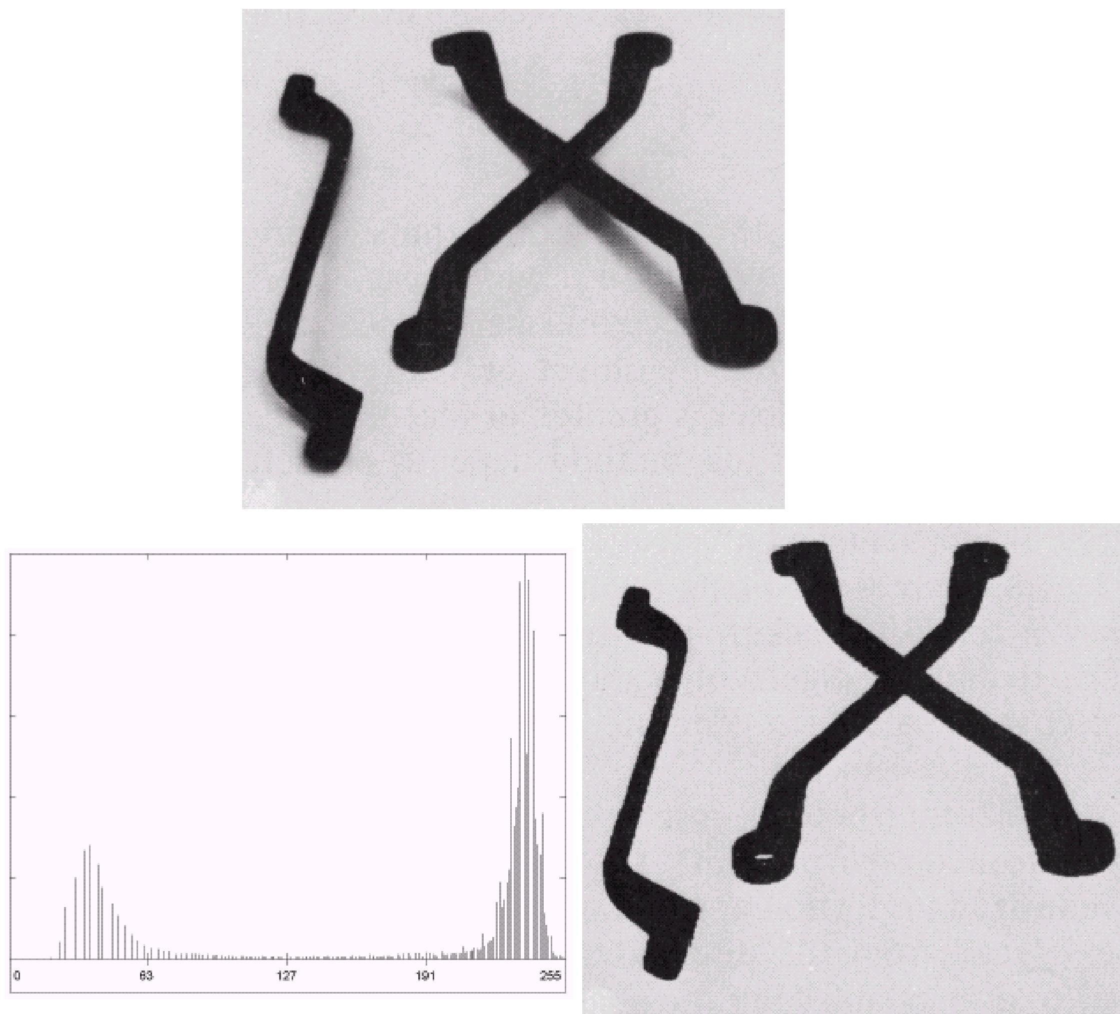
$$g(x,y)=\begin{cases}L_2 & \text{if } f > T_2\\ L_1 & \text{if } T_1 < f \le T_2\\ 0 & \text{if } f \le T_1\end{cases}$$



a b

FIGURE 10.26 (a) Gray-level histograms that can be partitioned by (a) a single threshold, and (b) multiple thresholds.

Global Thresholding (Example)



a
b c

FIGURE 10.28 (a) Original image. (b) Image histogram. (c) Result of global thresholding with *T* midway between the maximum and minimum gray levels.

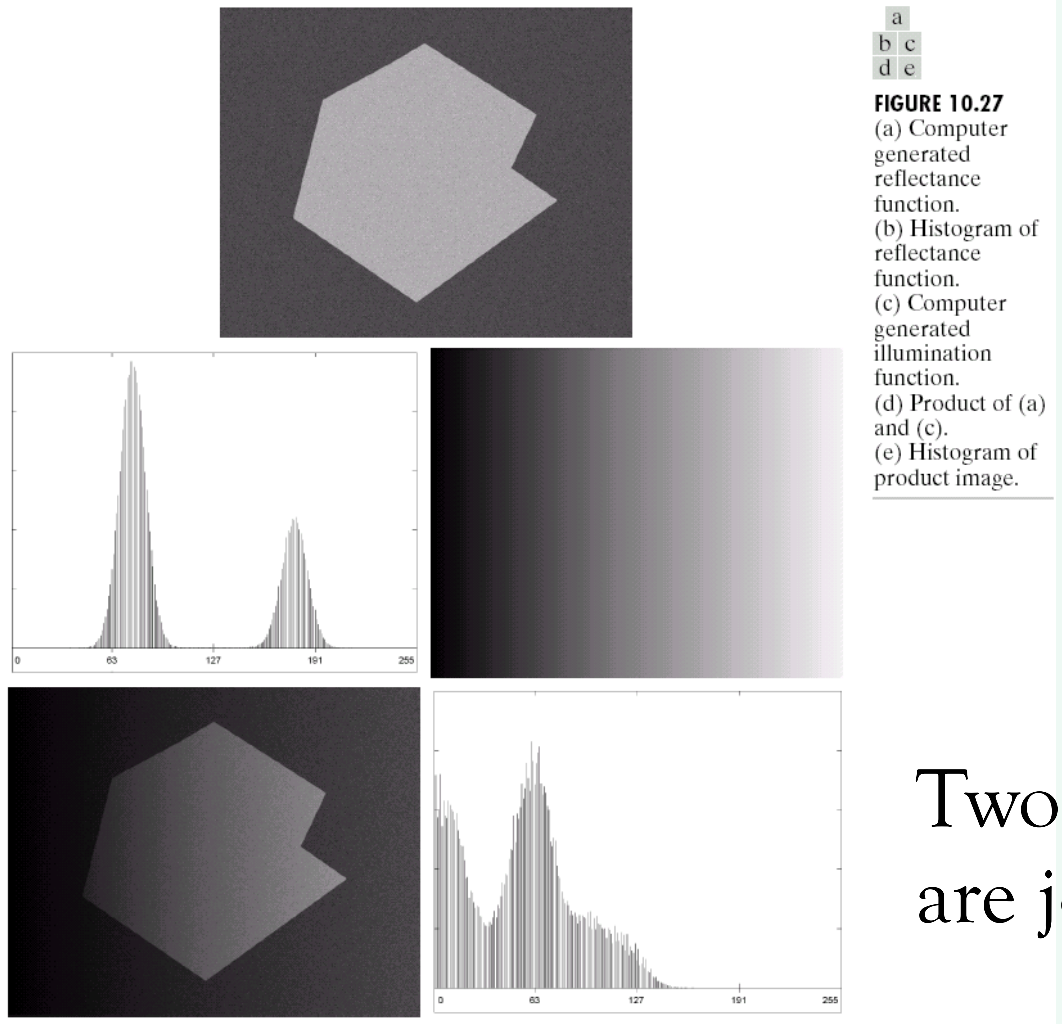
Global thresholding is successful in highly controlled environments, such as industrial inspection applications.

Difficulties in Thresholding

The following difficulties may arouse:

- Broad valley
- Numerous valleys
- Noise within the valley
- One peak is much larger than the other
- No clear valley (non-uniform illumination)

Effect of Non-uniform Illumination



Two peaks are well separated.

Two peaks are joined.

Non-uniform illumination makes segmentation by a single threshold difficult.

Automatic Methods for Selecting a Proper Threshold Value

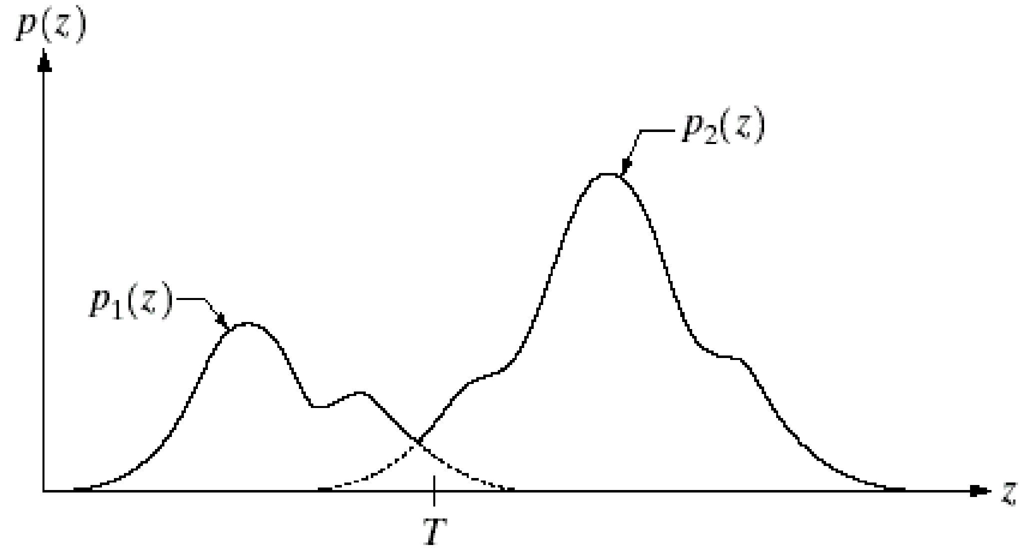
1. Optimal thresholding
   (See also Appendix 1)

2. Intermeans algorithm

3. Otsu's method

Optimal Thresholding Technique (Notation)

FIGURE 10.32 Gray-level probability density functions of two regions in an image.



z : Gray levels

T : Threshold level

$p_1(z)$, $p_2(z)$: Probability density functions

P_1, P_2 : Probabilities of occurrence of two classes

Summary of Optimal Thresholding Technique

If a histogram is modeled by

$$p(x) = P_1 p_1(x) + P_2 p_2(x)$$

the optimal threshold value T is equal to the solutions of $AT^2 + BT + C = 0$, where

$$A = \sigma_1^2 - \sigma_2^2$$

$$B = 2(m_1\sigma_2^2 - m_2\sigma_1^2)$$

$$C = \sigma_1^2 m_2^2 - \sigma_2^2 m_1^2 + 2\sigma_1^2\sigma_2^2 \ln\frac{\sigma_2 P_1}{\sigma_1 P_2}$$

Exercise 1 (Optimal Thresholding)

a) Derive Eqs. (10.3-12) and (10.3-13) from Eqs. (10.3-10) and (10.3-11).

b) Express the optimal threshold in the following four cases; (i) $A=0$, (ii) $B^2>4AC$, (iii) $B^2=4AC$ and (iv) $B^2<4AC$.

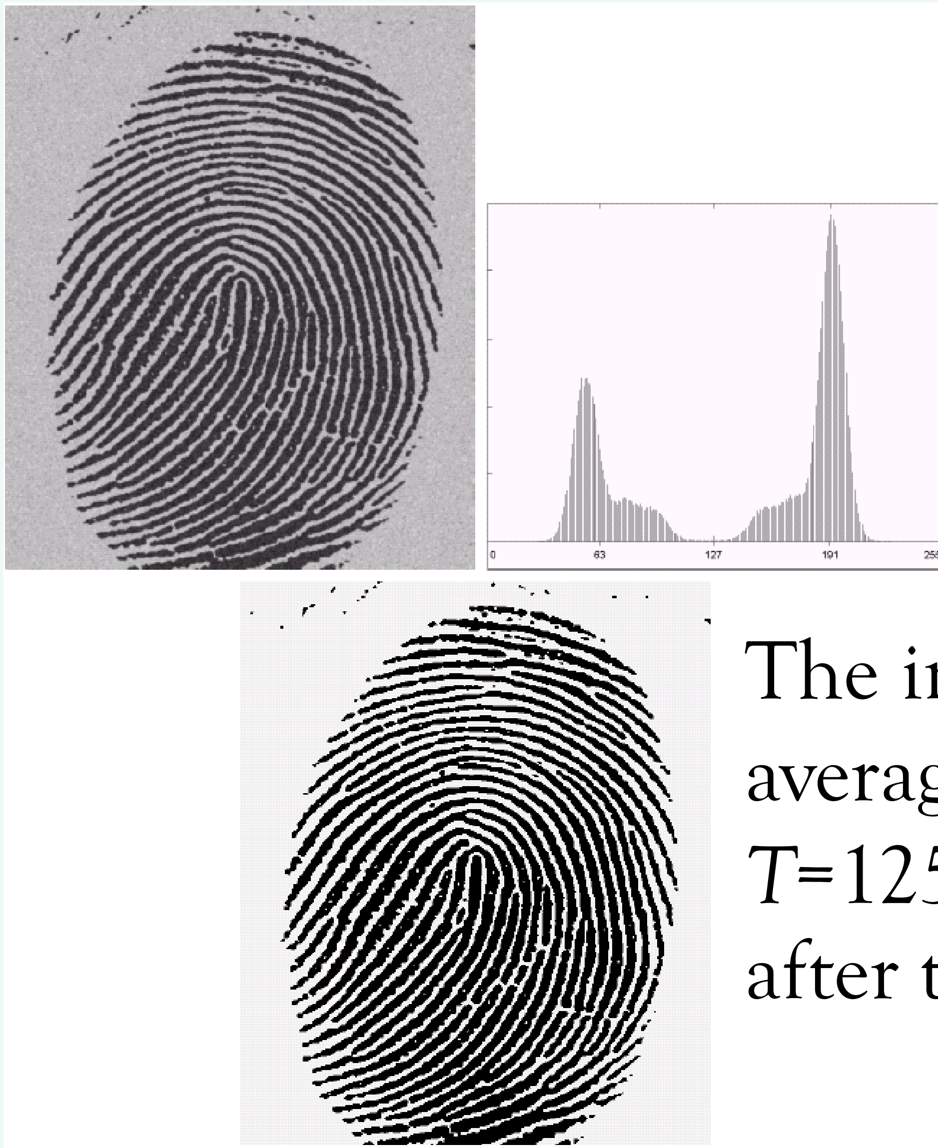
Intermeans Algorithm

1. Select an initial threshold value T, e.g. the average gray level of the image.
2. Segment an image into two groups using T.
3. Compute the average gray levels μ_1 and μ_2 of the two groups.
4. Set a new threshold value as

$$T = \frac{1}{2}(\mu_1 + \mu_2)$$

5. Repeat steps 2 to 4 until T becomes stable.

Intermeans Algorithm (Example)



a b
c

FIGURE 10.29 (a) Original image. (b) Image histogram. (c) Result of segmentation with the threshold estimated by iteration. (Original courtesy of the National Institute of Standards and Technology.)

The initial T is the average gray level, and T=125.4 was obtained after three iterations.

Otsu's Method

Otsu method selects the threshold value in order that the variance σ^2 between two groups separated becomes maximum:

$$\boldsymbol{\sigma^2(k) = P_0(m_0 - m) + P_1(m_1 - m) = P_0P_1(m_1 - m_0)^2}$$

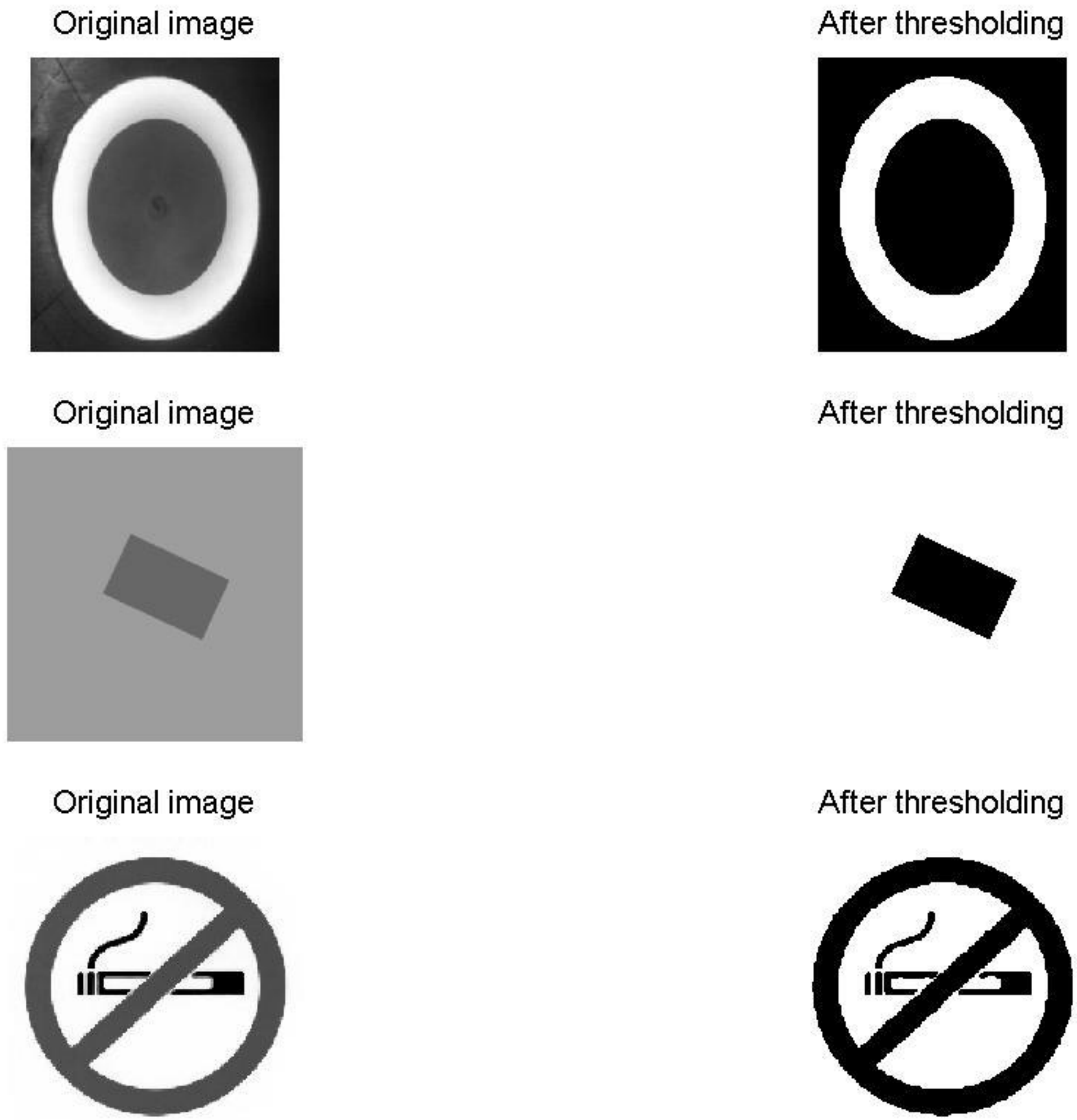
where P_0 and P_1 are the probabilities of occurrence of the two groups, and thus $P_0 + P_1 = 1$. m_0 and m_1 are the mean of each group, while m is the global mean, i.e., m= $P_0 m_0 + P_1 m_1$.

Otsu’s Method with MATLAB

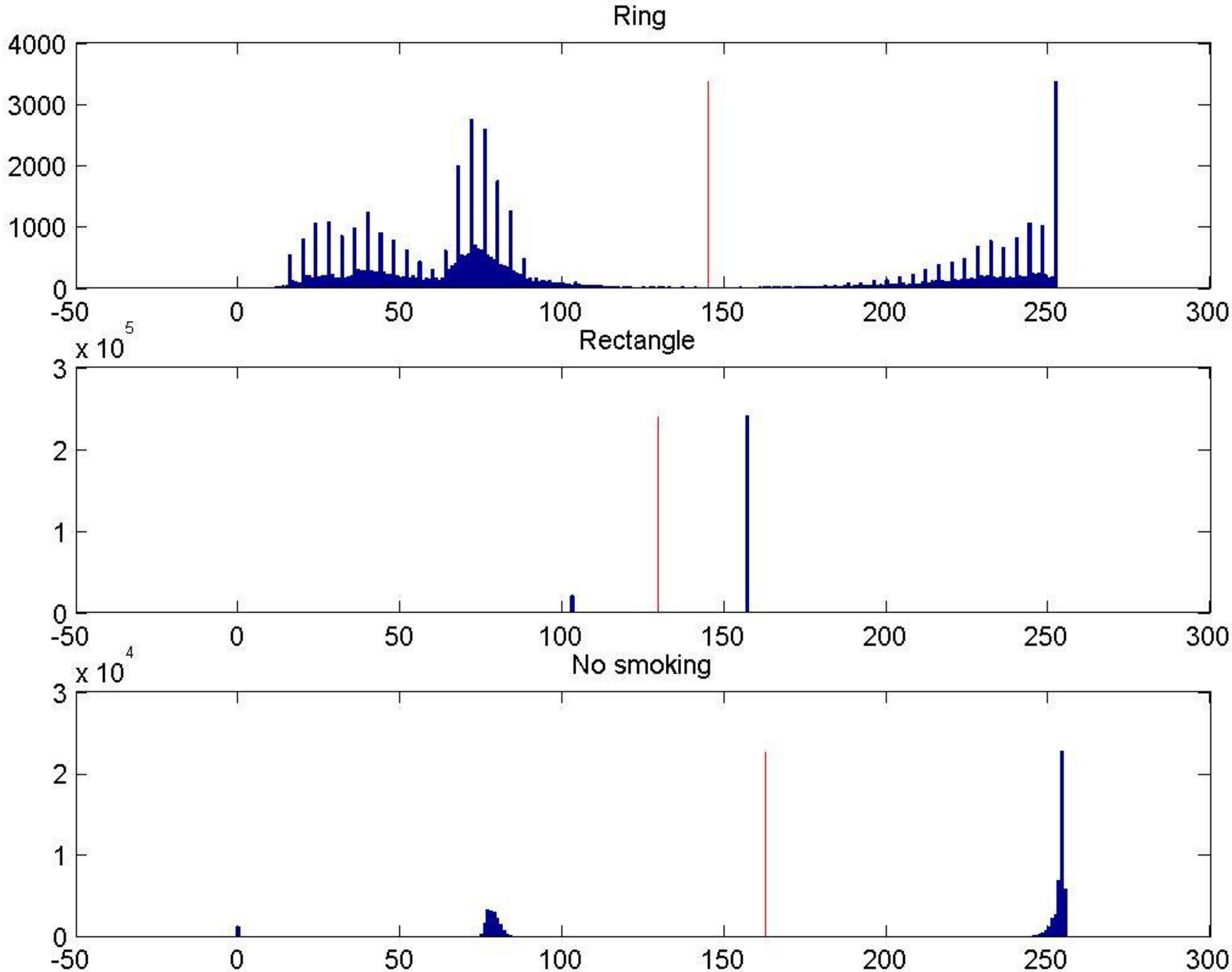
The MATLAB command ‘graythresh’ computes a value for global image thresholding using Otsu's method.

```
>> img=imread(‘Lena.gif');
>> thresh=graythresh(img);
>> imshow(img>thresh*255)
or
>> bw=im2bw(img,thresh); %Logical array.
>> imshow(bw)
>>
```

Otsu’s Method (Demo)



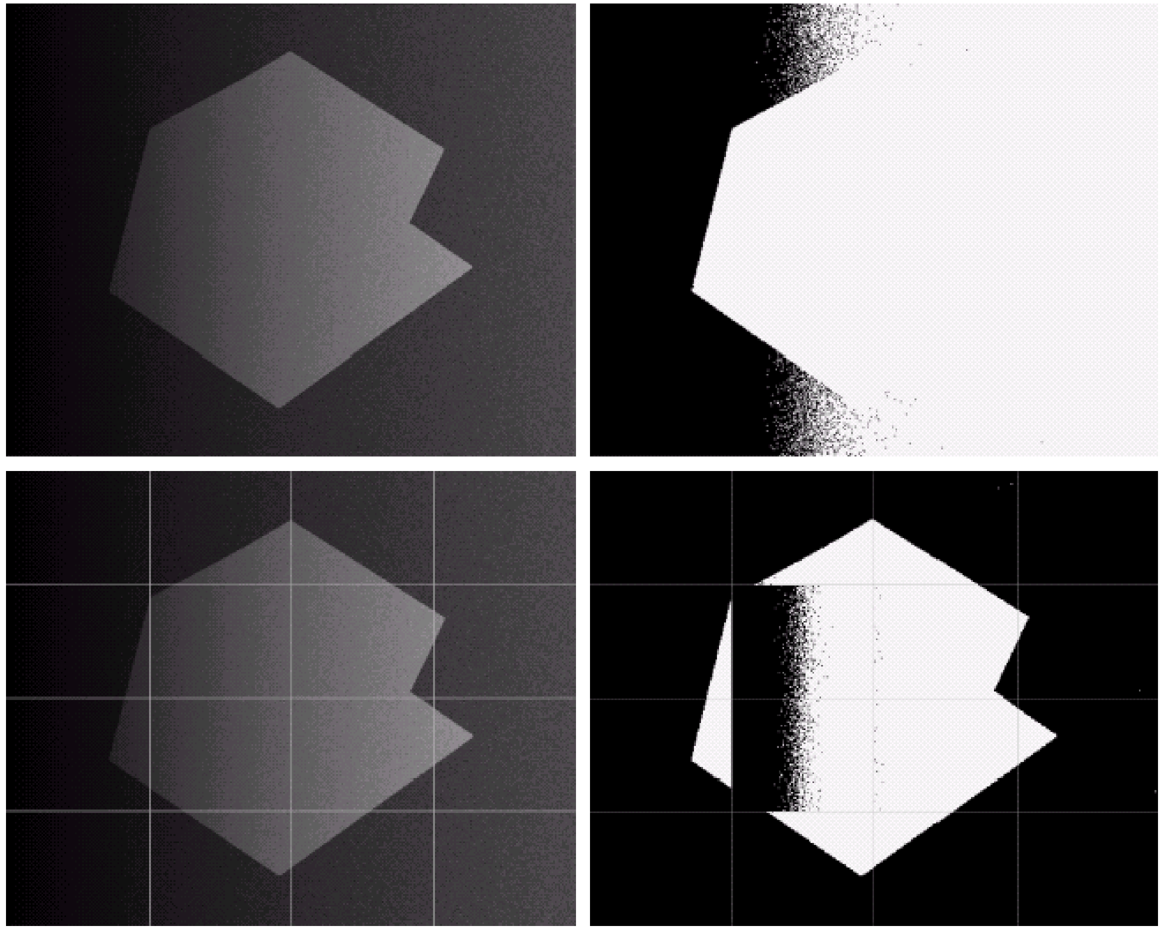
Thresholds by Otsu's Method



Adaptive Thresholding

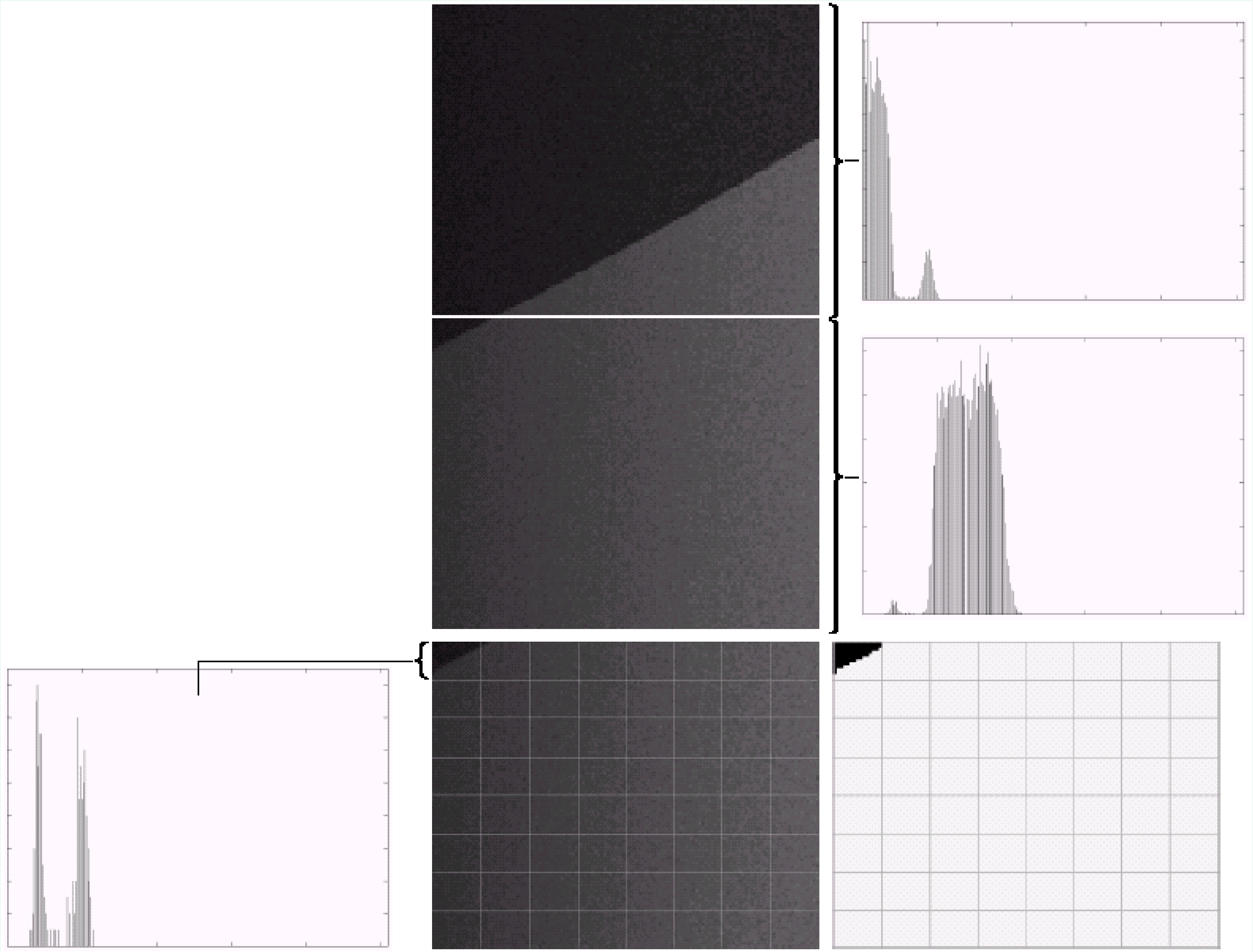
a b
c d

FIGURE 10.30 (a) Original image. (b) Result of global thresholding. (c) Image subdivided into individual subimages. (d) Result of adaptive thresholding.



One way to cope with non-uniform illumination is to partition the image into subimages and use a different threshold to each subimage.

Adaptive Thresholding (Further Partitioning)



Histogram of Edgy Pixels

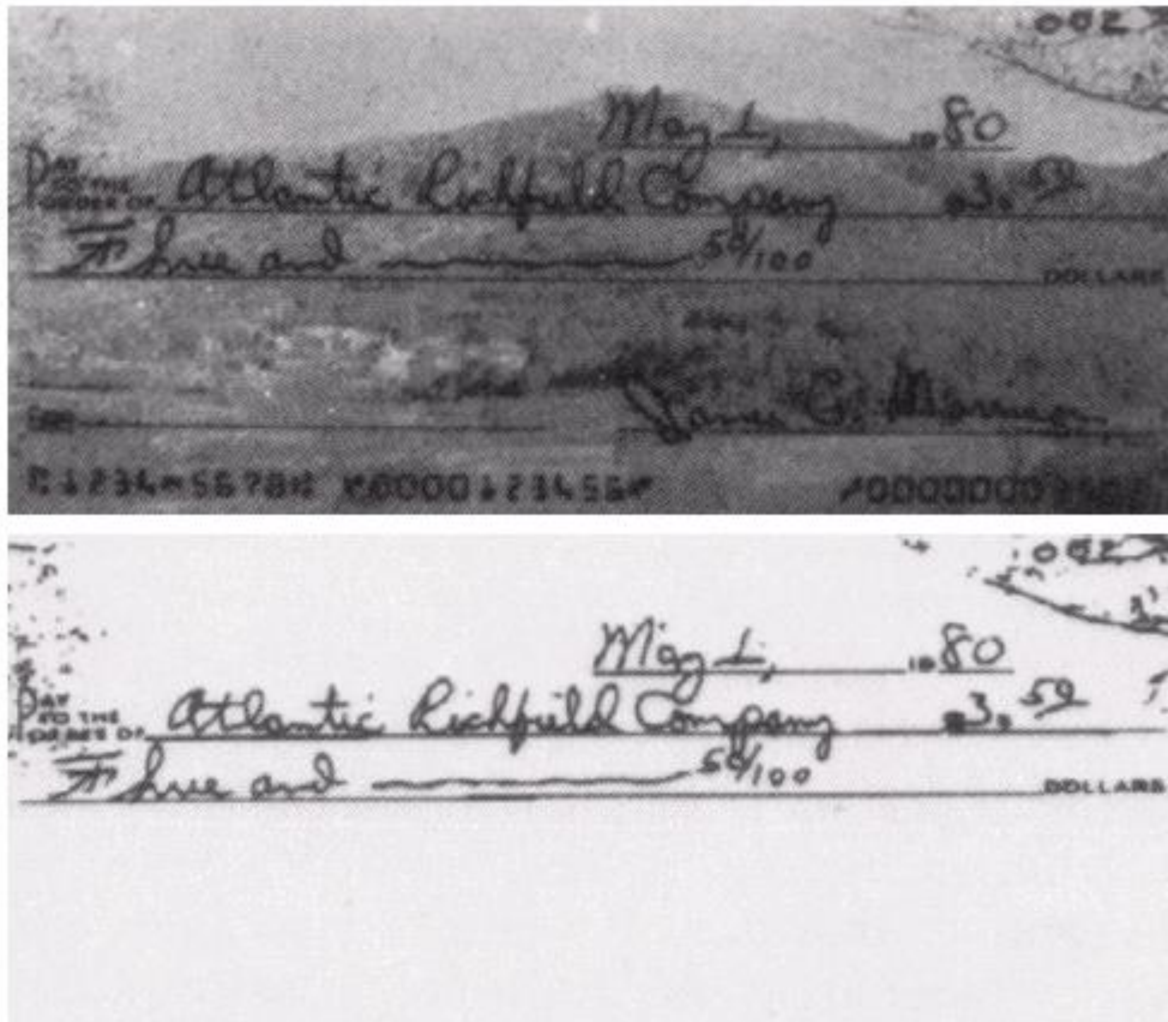
It is intuitively evident that gray levels in the vicinity of edges will provide an important clue for selecting a proper threshold value.

One approach for improving the shape of histograms is to consider only those pixels that lie on (∇) or near the edges (∇^2) between objects and the background.

Histogram of Edgy Pixels (Example)

a
b

FIGURE 10.37 (a) Original image. (b) Image segmented by local thresholding. (Courtesy of IBM Corporation.)



(a) An image of a scenic bank check and (b) its thresholding result.

2) Edge-based Segmentation

Three basic types of gray-level discontinuities in a digital image:

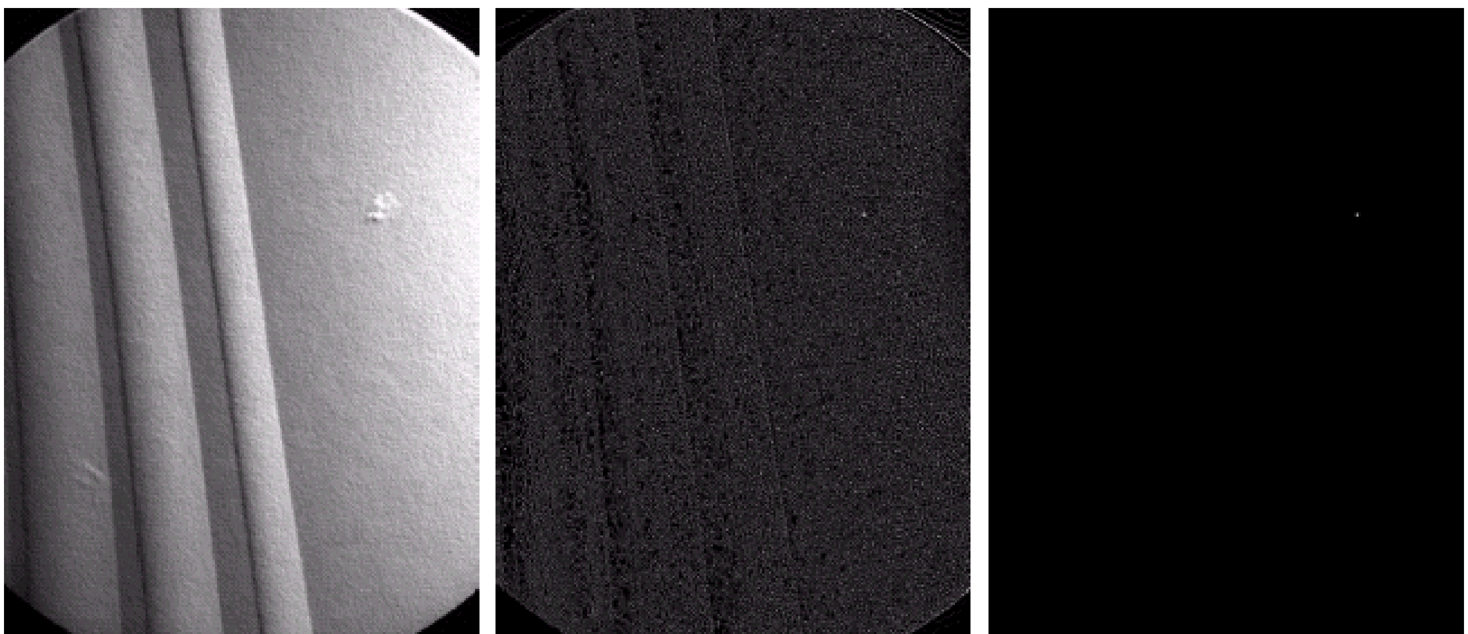
- Point detection
- Line detection
- Edge detection

The most common way to look for discontinuities is to run a mask through the image as we studied in Chapter 3.

Point Detection

Use the Laplacian!

–1	–1	–1
–1	8	–1
–1	–1	–1



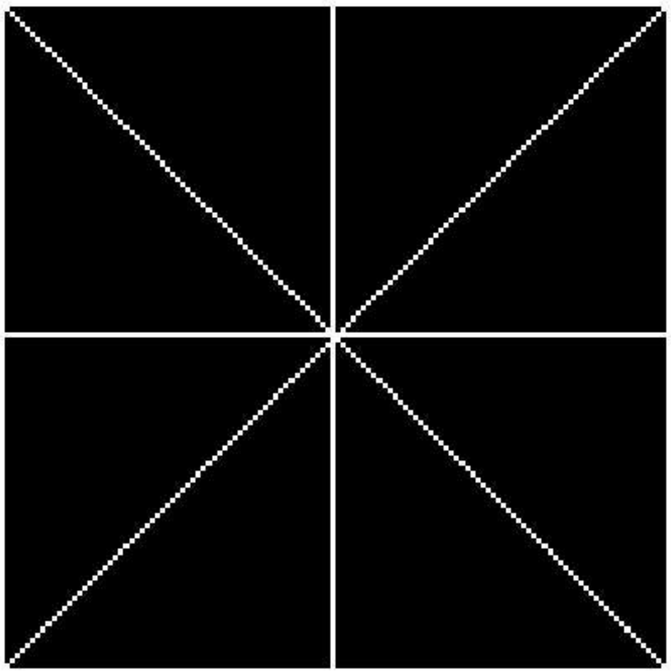
a
b c d

FIGURE 10.2
(a) Point detection mask.
(b) X-ray image of a turbine blade with a porosity.
(c) Result of point detection.
(d) Result of using Eq. (10.1-2).
(Original image courtesy of X-TEK Systems Ltd.)

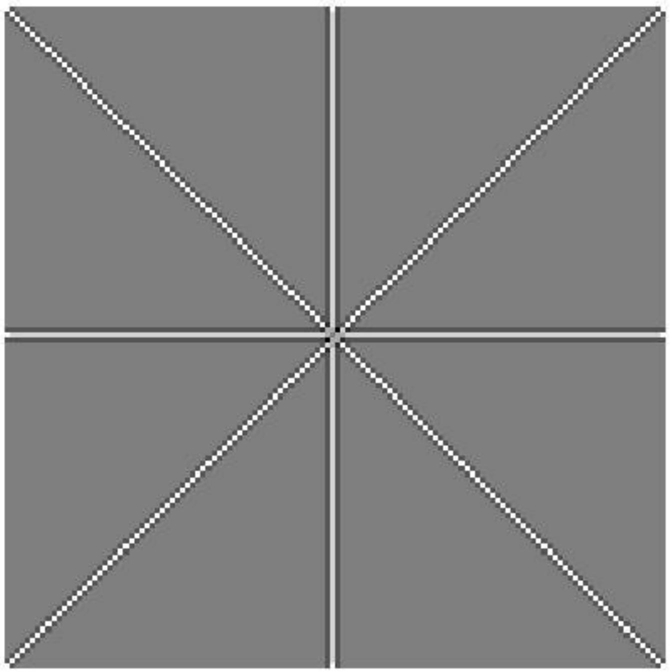
Line Detection by Laplacian

The Laplacian can also be used for detecting lines.

Original image



Lines by Laplacian



Line Detection by Multiple Masks

For detecting lines of various orientations, a set of convolution mask is used separately, and the maximum response among all can be used as the output.

FIGURE 10.3 Line masks.

−1	−1	−1
2	2	2
−1	−1	−1

Horizontal

−1	−1	2
−1	2	−1
2	−1	−1

+45°

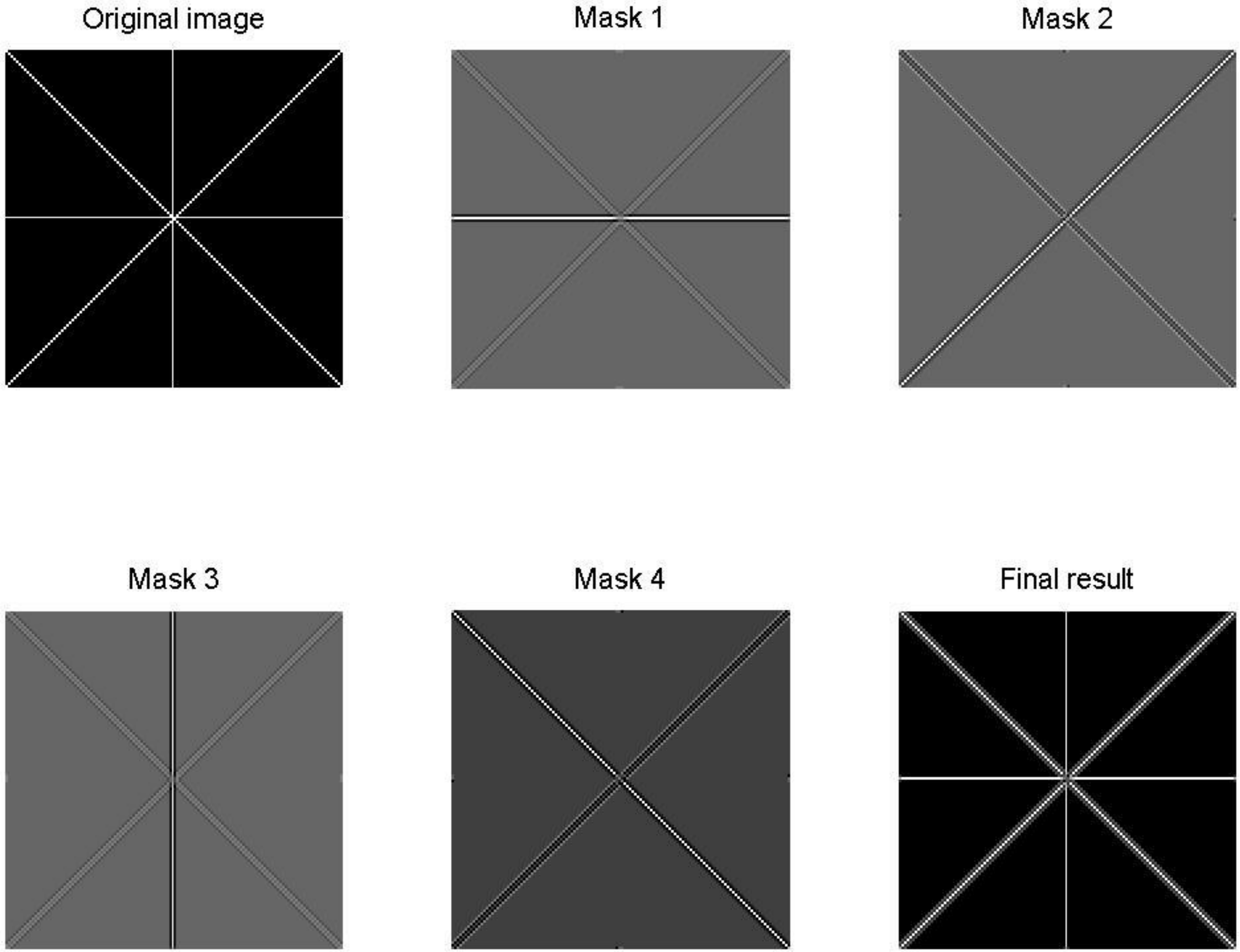
−1	2	−1
−1	2	−1
−1	2	−1

Vertical

2	−1	−1
−1	2	−1
−1	−1	2

−45°

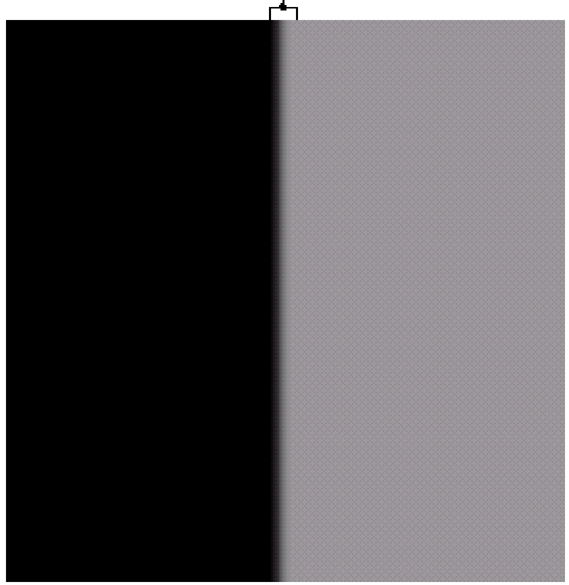
Line Detection (Demo)

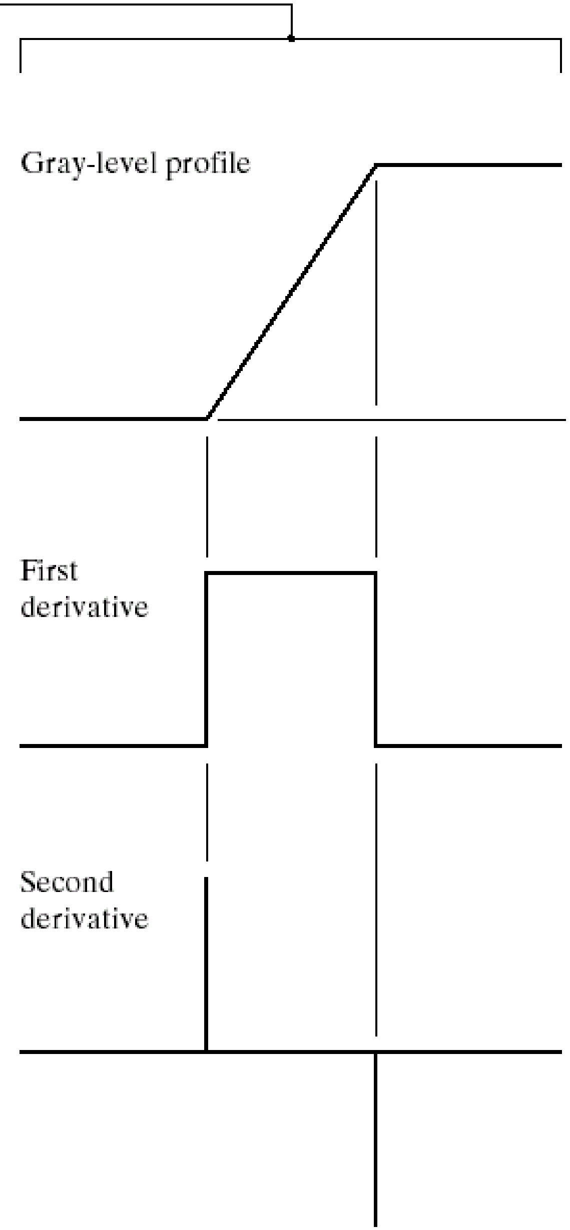


Edge Detection

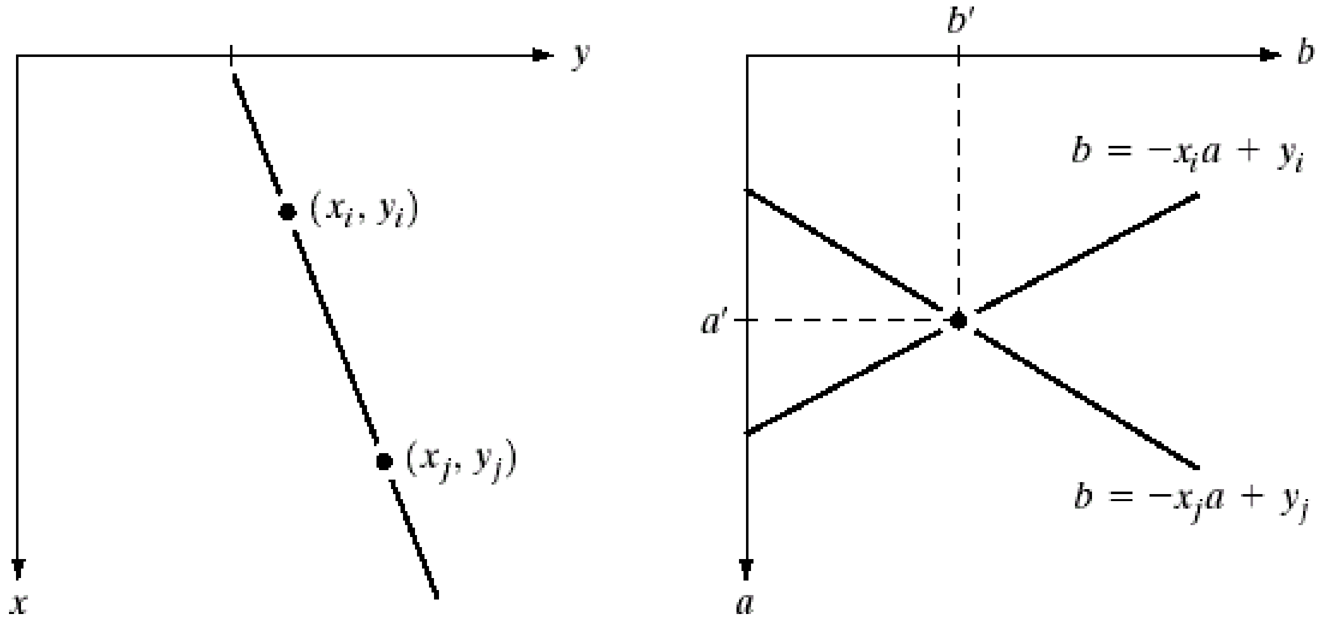
a b

FIGURE 10.6
(a) Two regions separated by a vertical edge.
(b) Detail near the edge, showing a gray-level profile, and the first and second derivatives of the profile.





Edge Linking (Hough Transform)



a b

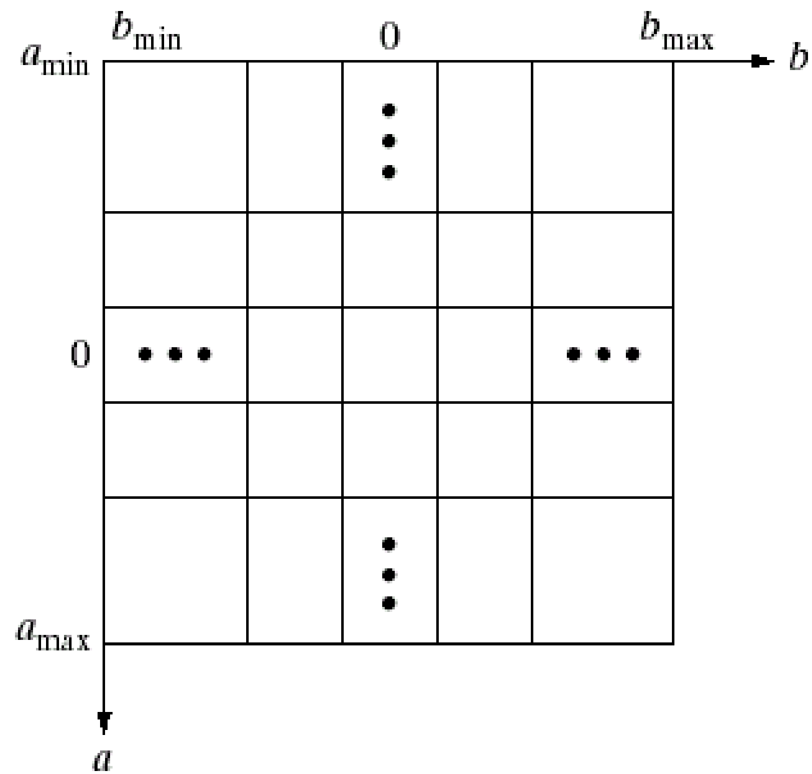
FIGURE 10.17 (a) xy-plane. (b) Parameter space.

$y=ax+b$ $\qquad$ $b=-xa+y$

- A point in xy-plane is transformed to a line in ab-plane, i.e., the parameter plane.
- A line in xy-plane is transformed to a point in ab-plane, i.e., the parameter plane.

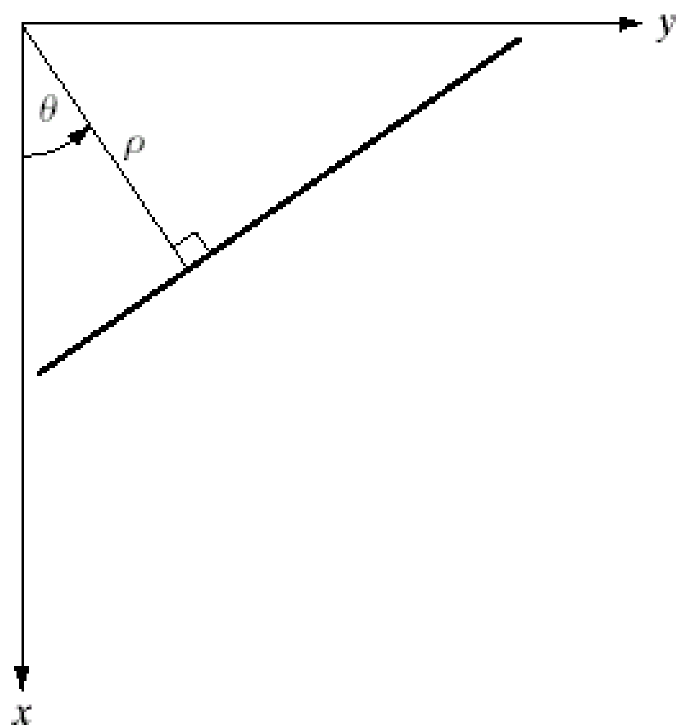
Parameter Plane (Hough Transform)

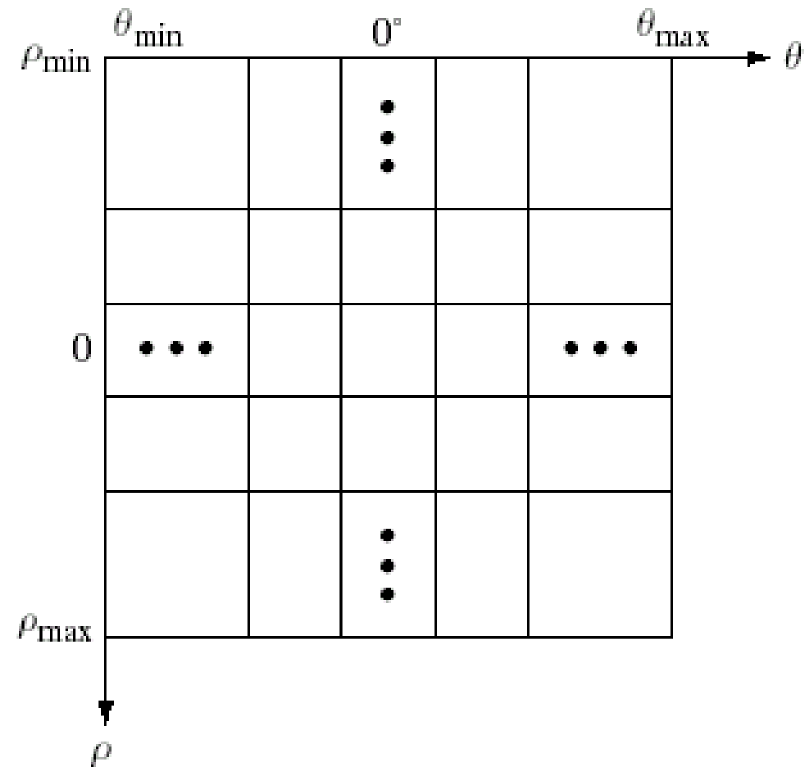
FIGURE 10.18 Subdivision of the parameter plane for use in the Hough transform.



The figure illustrates accumulator cells that are obtained by partitioning the parameter space.

Parameter Plane (Hough Transform)





In practice, a line is described in the normal representation: $x\cos\theta + y\sin\theta = \rho$

A point in xy-plane is then transformed to a sinusoidal curve in ab-plane.

Hough Transforms

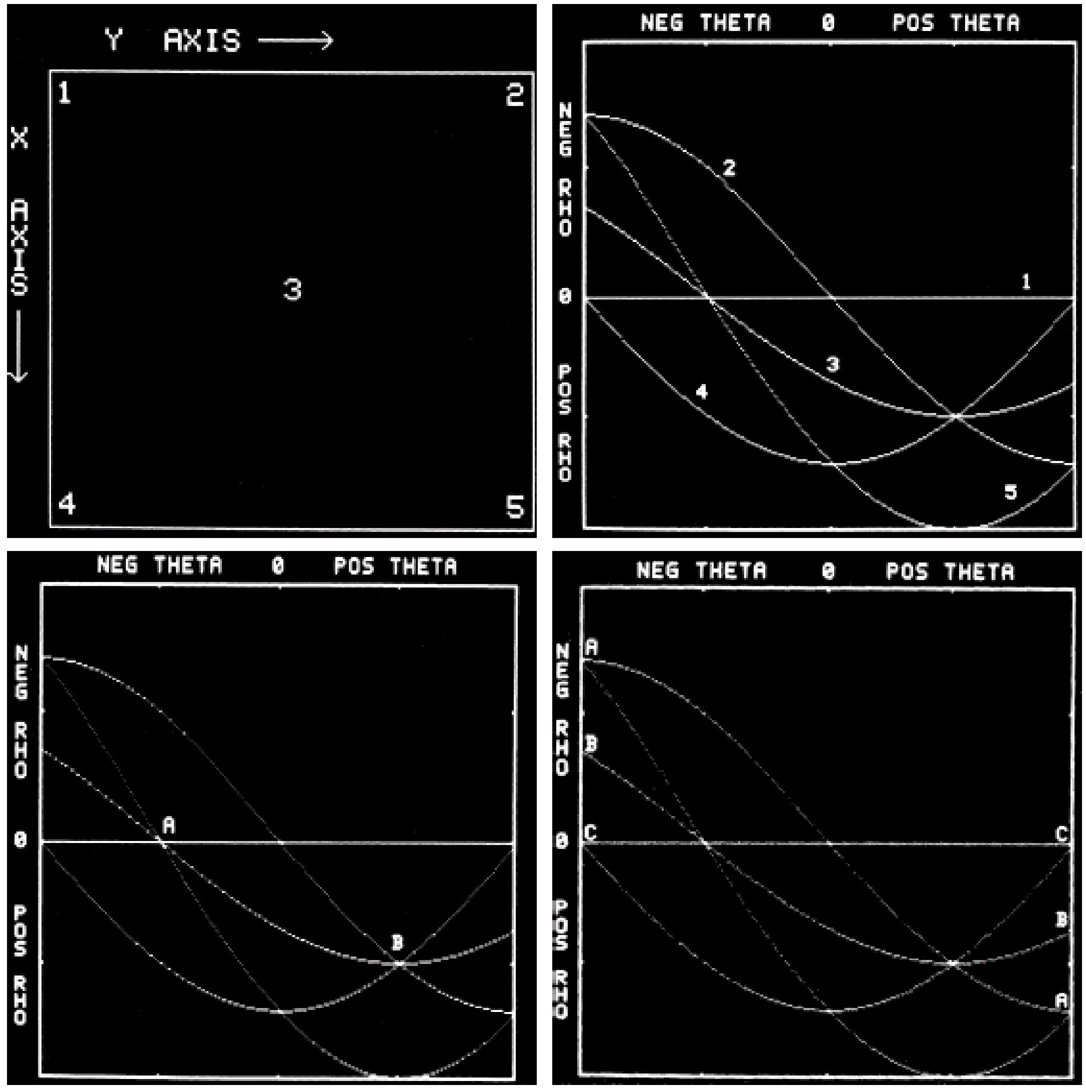
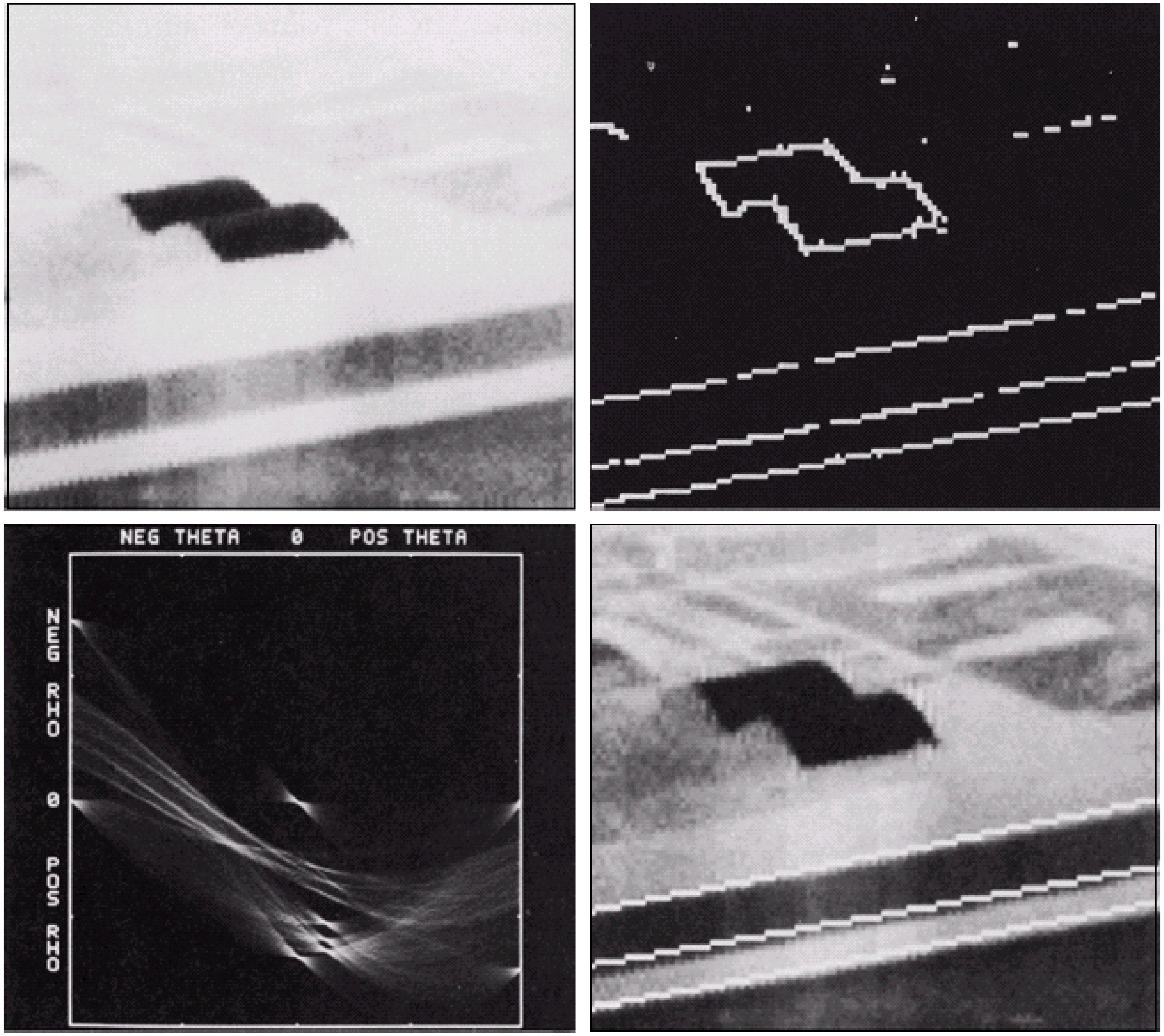


FIGURE 10.20 Illustration of the Hough transform. (Courtesy of Mr. D. R. Cate, Texas Instruments, Inc.)

A point in the parameter plane corresponds to a line in xy-plane.

Hough Transforms (Example)



a b
c d

FIGURE 10.21 (a) Infrared image. (b) Thresholded gradient image. (c) Hough transform. (d) Linked pixels. (Courtesy of Mr. D. R. Cate, Texas Instruments, Inc.)

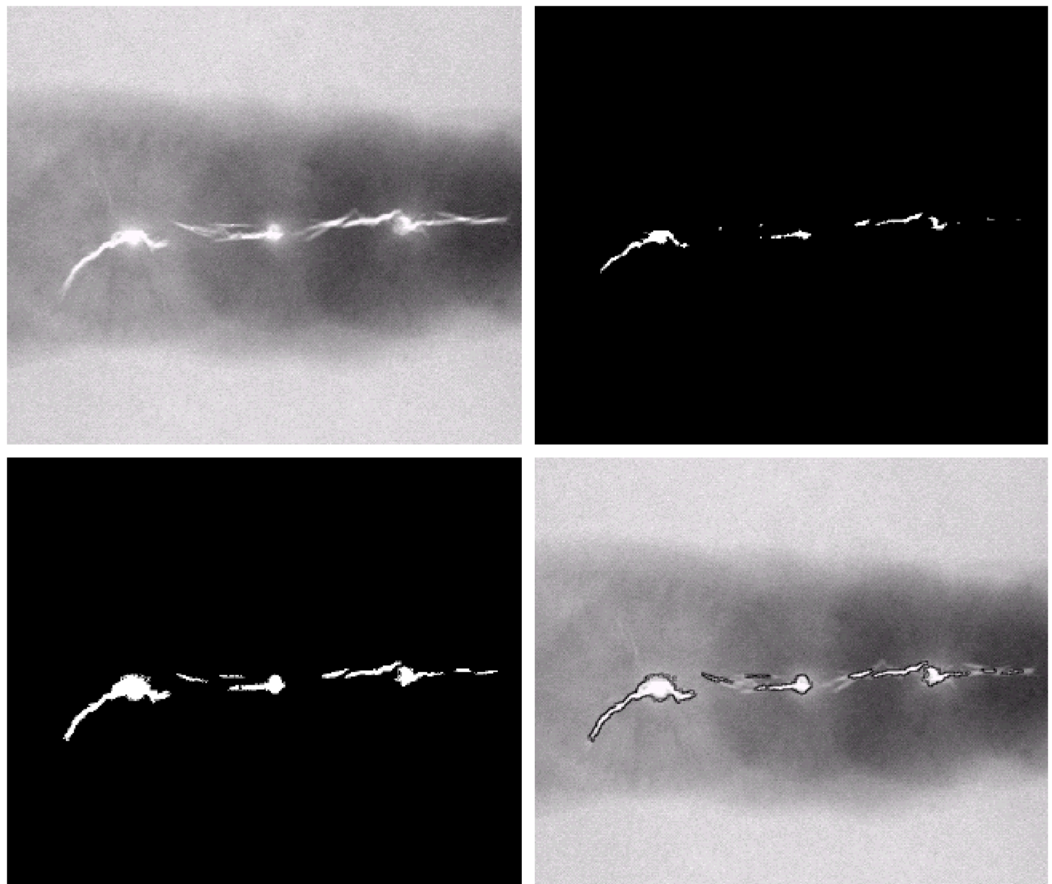
3) Region-based Segmentation

Region-based segmentation methods attempt to find homogeneous regions in an image.

Popular methods in this category are *region growing* and '*splitting and merge*' technique.

Region Growing

Region growing is a procedure that merges pixels or subregions into larger regions based on predefined criteria.



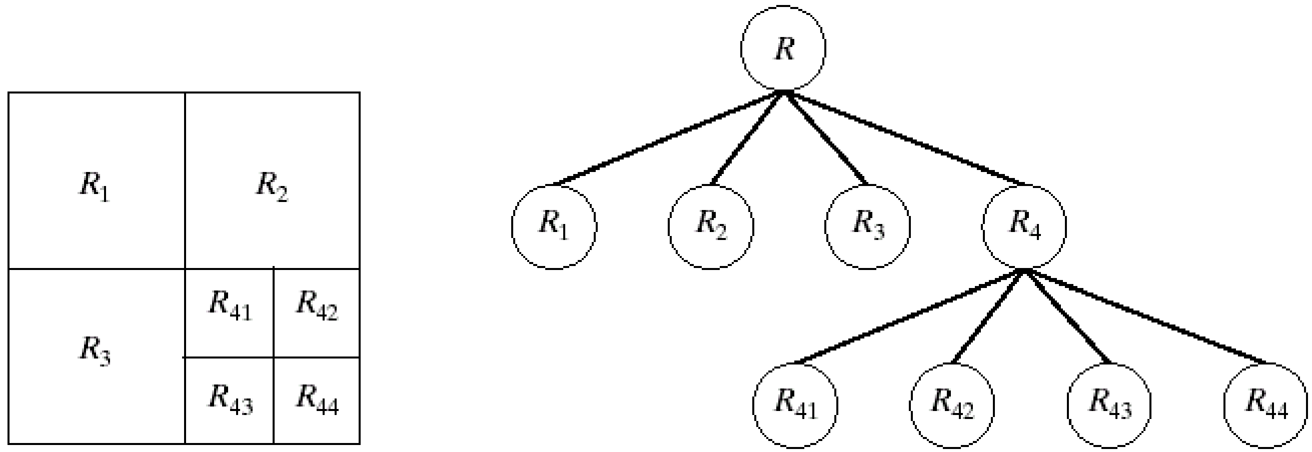
a b
c d

FIGURE 10.40 (a) Image showing defective welds. (b) Seed points. (c) Result of region growing. (d) Boundaries of segmented defective welds (in black). (Original image courtesy of X-TEK Systems, Ltd.).

Region Splitting and Merging

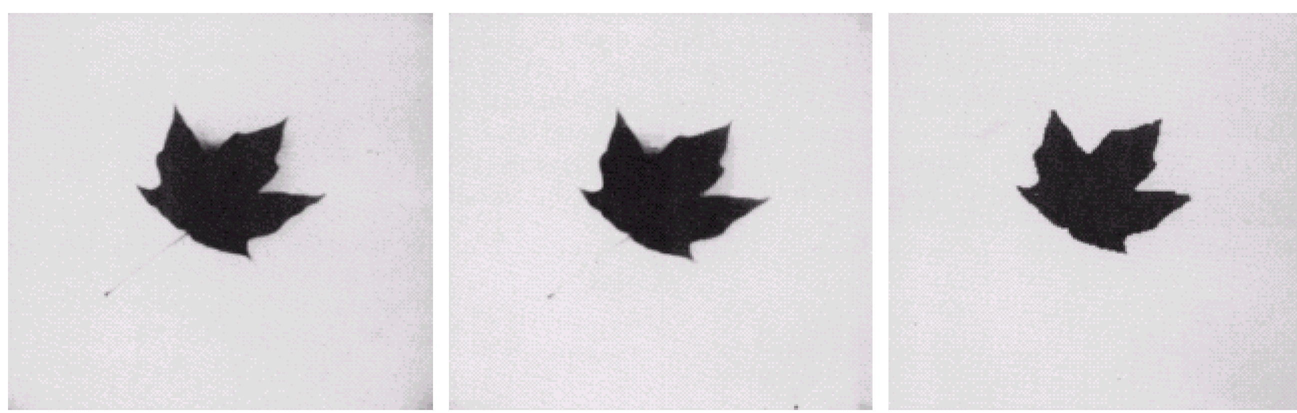
a b

FIGURE 10.42
(a) Partitioned image.
(b) Corresponding quadtree.



a b c

FIGURE 10.43
(a) Original image. (b) Result of split and merge procedure.
(c) Result of thresholding (a).



Assignment of Chapter 7

1. Obtain an image containing characters or/and numbers. Apply Otsu's method to it and comment on your results.
2. Using the same image, select an appropriate threshold value by using pixels in the vicinity of edges.