Unit 5
Image Segmentation

Image Segmentation

- Image segmentation divides an image into regions that are connected and have some similarity within the region and some difference between adjacent regions.
- The goal is usually to find individual objects in an image.
- For the most part there are fundamentally two kinds of approaches to segmentation: discontinuity and similarity.
  - Similarity may be due to pixel intensity, color or texture.
  - Differences are sudden changes (discontinuities) in any of these, but especially sudden changes in intensity along a boundary line, which is called an edge.

Detection of Discontinuities

- There are three kinds of discontinuities of intensity: points, lines and edges.
- The most common way to look for discontinuities is to scan a small mask over the image. The mask determines which kind of discontinuity to look for.

$$R = w_1 z_1 + w_2 z_2 + \ldots + w_9 z_9 = \sum_{i=1}^{9} w_i z_i$$

FIGURE 10.1 A general 3×3 mask.

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

Detection of Discontinuities

Types of Grey Level discontinuities are:

- **Point**
- **Line**
- **Edge**

* Isolated Point

* Horizontal
* vertical
* Slanted

* Object outline

Detection of Discontinuities

Point Detection

An isolated point is a point whose grey level is significantly different from its background in a homogeneous area

3x3

3x3

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

Mask

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

Image

Response of the mask:

$$R = \sum_{i=1}^{9} w_i z_i$$

✓ If,
$|R| \geq T$, a point is detected
where,
T is a non negative integer

−1	−1	−1
−1	8	−1
−1	−1	−1

✓

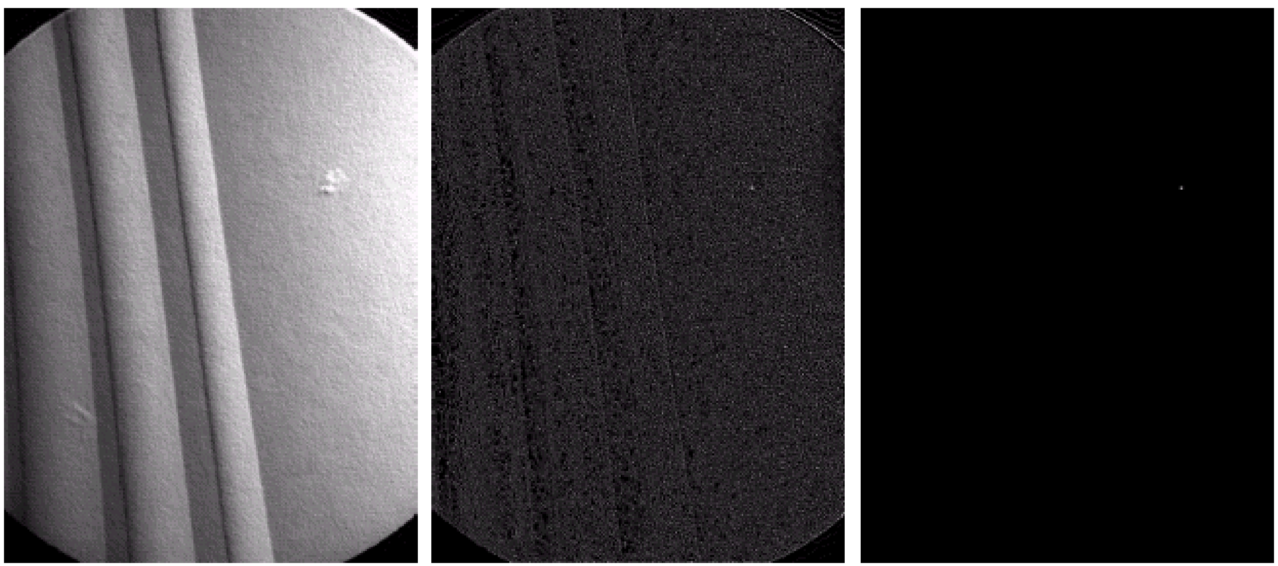
Sample Mask for Point Detection

Detection of Discontinuities
Point Detection

$$|R| \geq T$$

where T : a nonnegative threshold

−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.)

Detection of Discontinuities
Line Detection

- Only slightly more common than point detection is to find a one pixel wide line in an image.
- For digital images the only three point straight lines are only horizontal, vertical, or diagonal (+ or –45°).

FIGURE 10.3 Line masks.

Horizontal

−1	−1	−1
2	2	2
−1	−1	−1

+45°

−1	−1	2
−1	2	−1
2	−1	−1

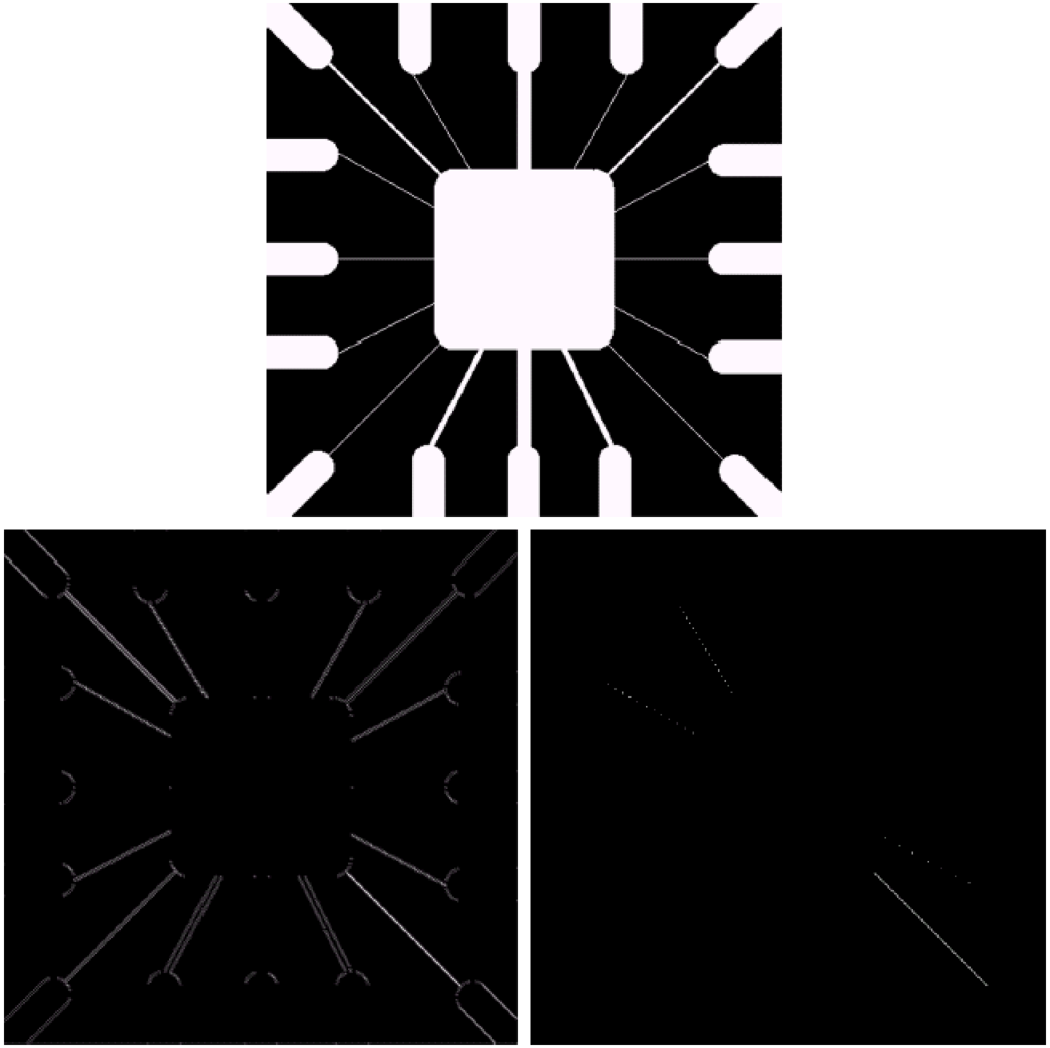
Vertical

−1	2	−1
−1	2	−1
−1	2	−1

−45°

2	−1	−1
−1	2	−1
−1	−1	2

Detection of Discontinuities
Line Detection



a
b c

FIGURE 10.4 Illustration of line detection. (a) Binary wire-bond mask. (b) Absolute value of result after processing with $-45°$ line detector. (c) Result of thresholding image (b).

Detection of Discontinuities

Edge Detection

- An edge is a set of connected pixels that lies on the boundary between two regions which differ in grey value. Pixels on edge is known as edge points
- **Edges provide an outline of the object**

In physical plane, **edge corresponds** to the **discontinuities in** depth, Surface orientation, change in material properties, light variations etc.

- It locates sharp changes in the intensity function
- Edges are pixels where brightness changes abruptly
- An edge can be extracted by computing the derivative of the image function
  - ✓ Magnitude of the derivative, indicates the strength or contrast of edge
  - ✓ Direction of the derivative vector, indicates the edge orientation

Detection of Discontinuities

Edge Detection

Some of the commonly encountered edges in image processing are:

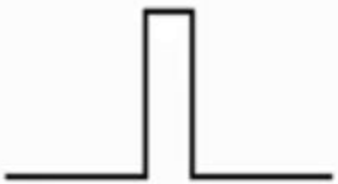
Step Edge

An abrupt change in intensity

Ramp Edge

A slow and gradual change in intensity

Spike Edge



Quick change or immediately returns to original intensity level

Roof Edge

It is not instantaneous over short distance

Detection of Discontinuities
Edge Detection

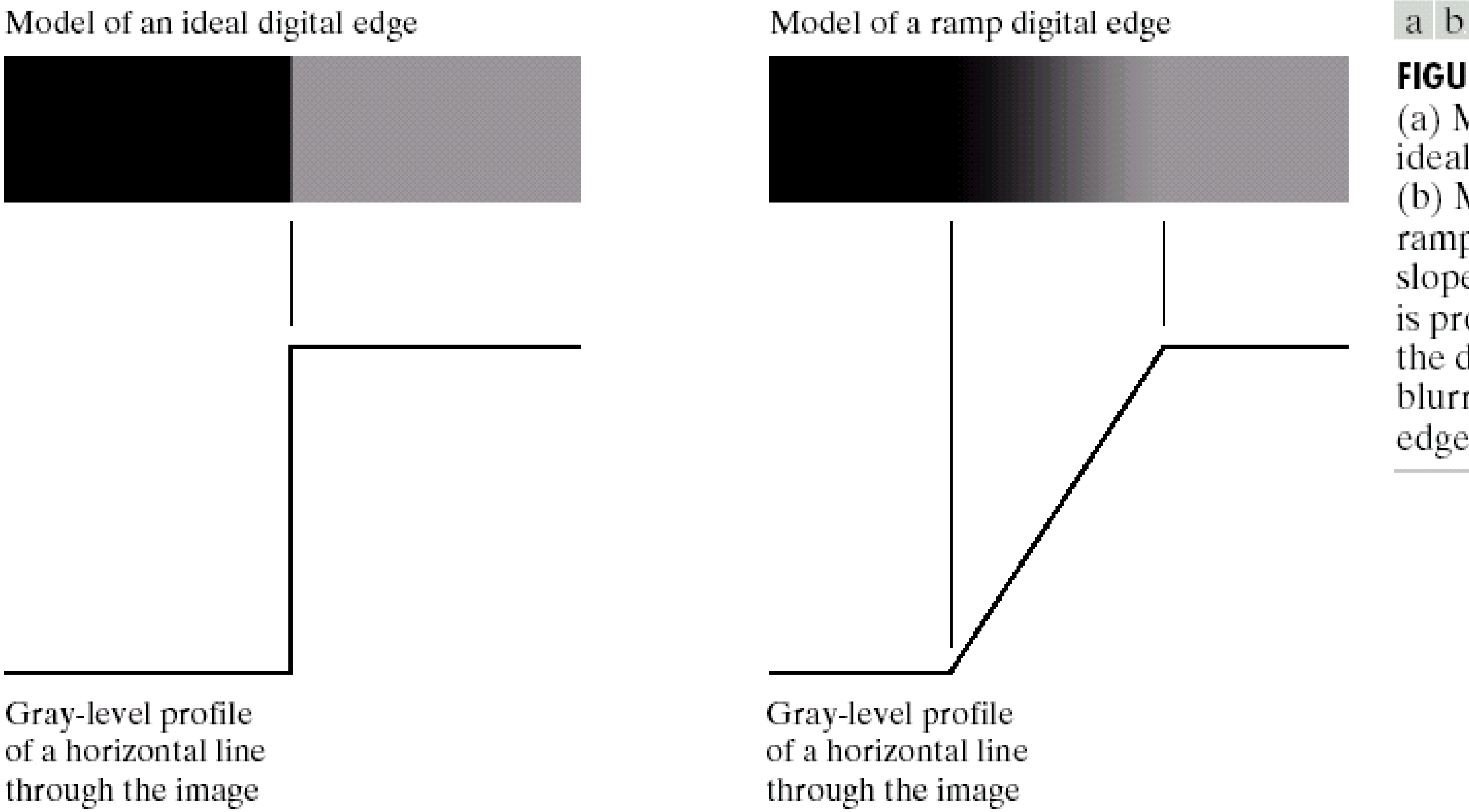


FIGURE 10.5 (a) Model of an ideal digital edge. (b) Model of a ramp edge. The slope of the ramp is proportional to the degree of blurring in the edge.

Detection of Discontinuities

Stages in Edge Detection

Start → Input Image → Filtering → Differn -tiation → Locali- zation → Display → End

Filtering: It involves smoothing. This stage may be performed explicitly or implicitly

Differntiation: It distinguishes the edge pixels from other pixels

$$\text{Vector:}\quad \nabla \mathbf{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \partial f / \partial x \\ \partial f / \partial y \end{bmatrix}$$

$$\text{Magnitude:}\quad \nabla f = \text{mag}(\nabla \mathbf{f}) = \left[G_x^2 + G_y^2 \right]^{1/2} \approx |G_x| + |G_y|$$

$$\text{Direction of gradient:}\quad \tan^{-1}\left(\frac{Gy}{Gx}\right)$$

Localization: It determine the exact location of edge

Detection of Discontinuities
Edge Detection

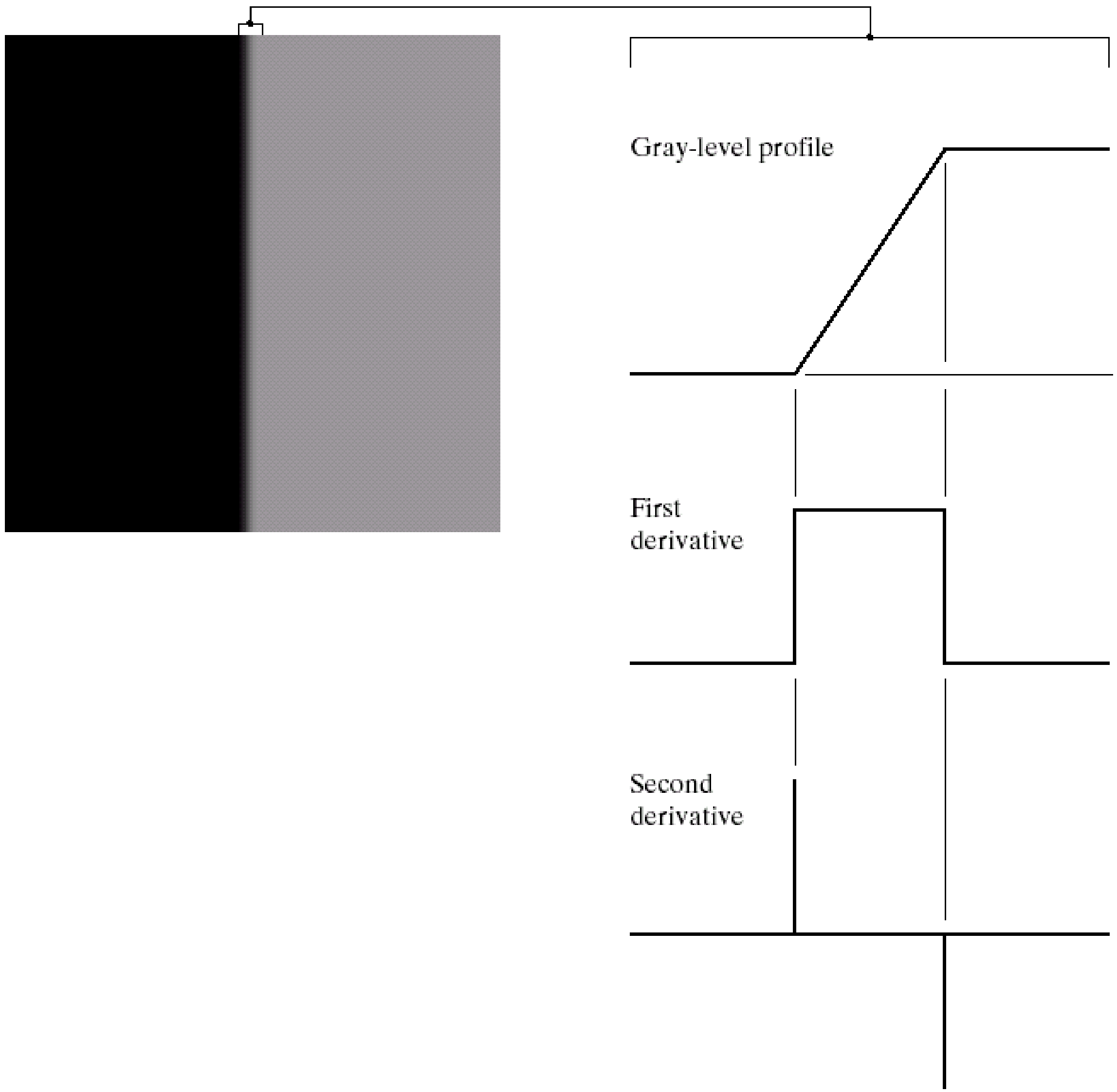


FIGURE 10.6 (a) Two regions separated by a vertical edge. (b) Detail near the edge, showing a gray-level profile, and the first and second derivatives of the profile.

Detection of Discontinuities
Edge Detection

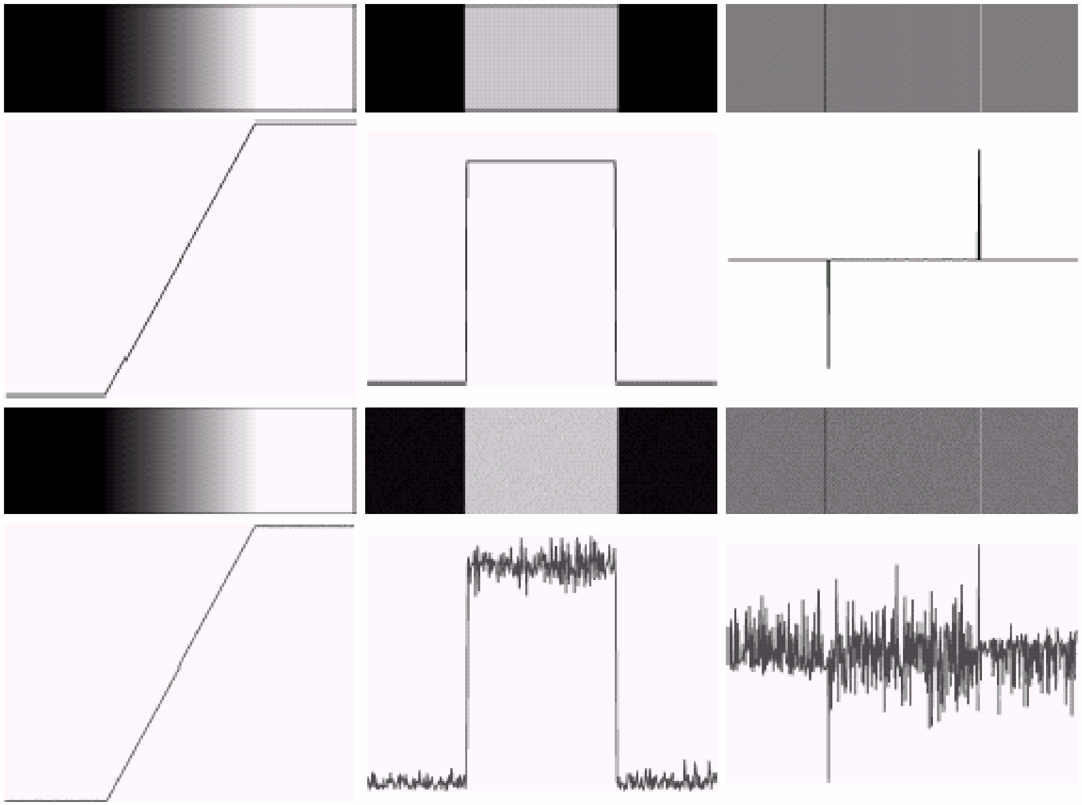


FIGURE 10.7 First column: images and gray-level profiles of a ramp edge corrupted by random Gaussian noise of mean 0 and $\sigma = 0.0, 0.1, 1.0$, and 10.0, respectively. Second column: first-derivative images and gray-level profiles. Third column: second-derivative images and gray-level profiles.

a
b
c
d

Detection of Discontinuities
Edge Detection

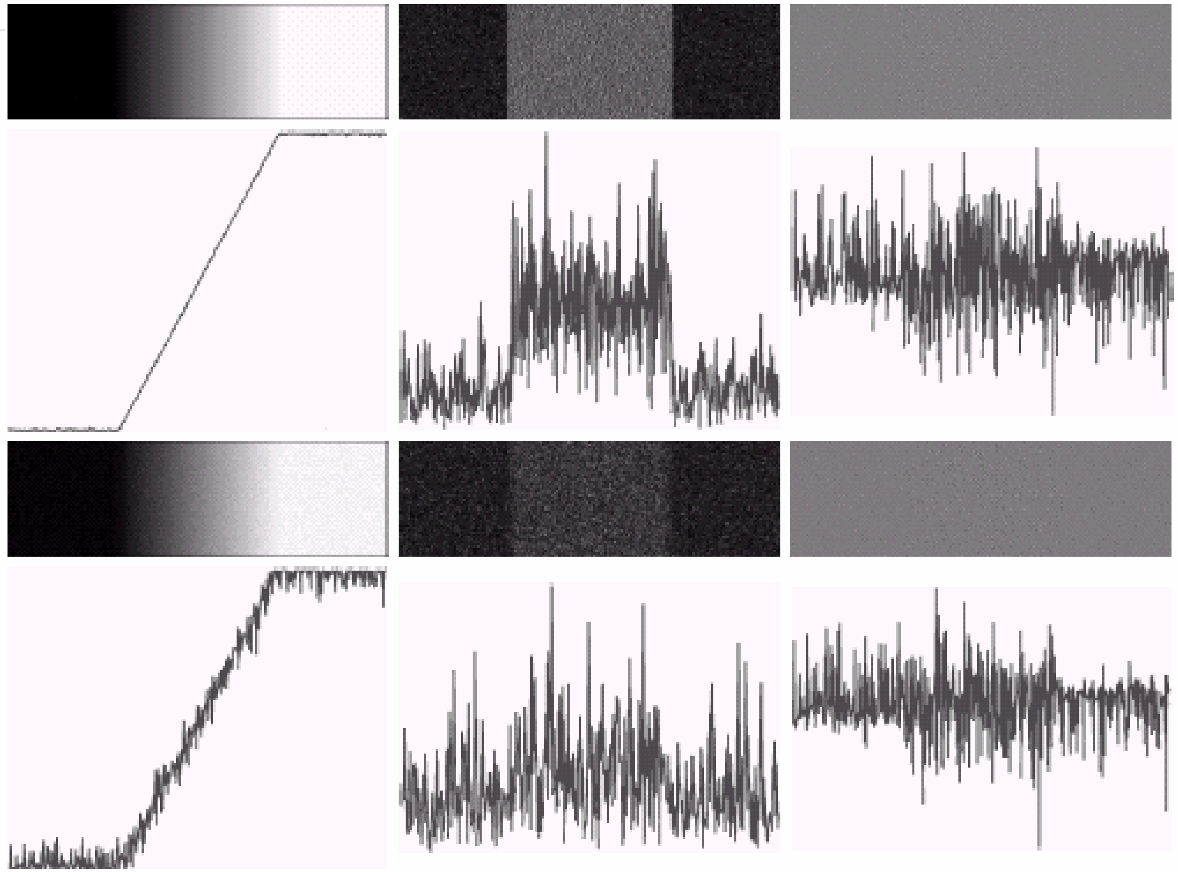


FIGURE 10.7 First column: images and gray-level profiles of a ramp edge corrupted by random Gaussian noise of mean 0 and $\sigma = 0.0, 0.1, 1.0$, and 10.0, respectively. Second column: first-derivative images and gray-level profiles. Third column: second-derivative images and gray-level profiles.

a
b
c
d

First Order Edge Detection Operators

- Local transitions among different image intensities constitute an edge
- Therefore the objective is to measure the **intensity gradient**
- Edge detectors can be viewed as **gradient calculators**

Gradient Operator is represented as:

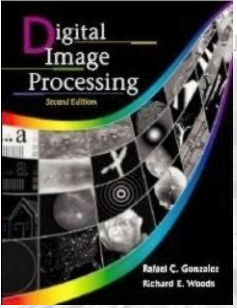
f(x,y)
2D

Vector: $\nabla \mathbf{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \partial f / \partial x \\ \partial f / \partial y \end{bmatrix}$

Magnitude: $\nabla f = \text{mag}(\nabla \mathbf{f}) = \left[G_x^2 + G_y^2\right]^{1/2} \approx |G_x| + |G_y|$

Direction of gradient: $\tan^{-1}\left(\frac{Gy}{Gx}\right)$

- An edge can be extracted by computing the derivative of the image function
  - ✓ **Magnitude of the derivative**, indicates the strength or contrast of edge
  - ✓ **Direction of the derivative vector**, indicates the edge orientation



Detection of Discontinuities
Gradient Operators

- First-order derivatives:
  - The gradient of an image $f(x,y)$ at location (x,y) is defined as the vector:

$$\nabla \mathbf{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

  - The magnitude of this vector: $\nabla f = \mathrm{mag}(\nabla \mathbf{f}) = \left[G_x^2 + G_y^2\right]^{1/2}$
  - The direction of this vector: $\alpha(x, y) = \tan^{-1}\left(\frac{G_x}{G_y}\right)$

Detection of Discontinuities
Gradient Operators

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

Roberts cross-gradient operators

−1	0
0	1

0	−1
1	0

Roberts

Prewitt operators

−1	−1	−1
0	0	0
1	1	1

−1	0	1
−1	0	1
−1	0	1

Prewitt

Sobel operators

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

Sobel

The way to implement first order derivative at point Z5 for Robert mask

$$G_x = (z_9 - z_5) \qquad (10.1\text{-}6)$$

$$G_y = (z_8 - z_6). \qquad (10.1\text{-}7)$$

An approach using masks of size 3×3 is given by

$$G_x = (z_7 + z_8 + z_9) - (z_1 + z_2 + z_3) \qquad (10.1\text{-}8)$$

and

$$G_y = (z_3 + z_6 + z_9) - (z_1 + z_4 + z_7). \qquad (10.1\text{-}9)$$

A slight variation of these two equations uses a weight of 2 in the center coefficient:

$$G_x = (z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3) \qquad (10.1\text{-}10)$$

and

$$G_y = (z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7). \qquad (10.1\text{-}11)$$

Detection of Discontinuities
Gradient Operators

Prewitt masks for detecting diagonal edges

0	1	1
−1	0	1
−1	−1	0

−1	−1	0
−1	0	1
0	1	1

Prewitt

Sobel masks for detecting diagonal edges

0	1	2
−1	0	1
−2	−1	0

−2	−1	0
−1	0	1
0	1	2

Sobel

a	b
c	d

FIGURE 10.9 Prewitt and Sobel masks for detecting diagonal edges.

Detection of Discontinuities
Gradient Operators: Example

a b
c d

FIGURE 10.10
(a) Original image. (b) $|G_x|$, component of the gradient in the x-direction. (c) $|G_y|$, component in the y-direction. (d) Gradient image, $|G_x| + |G_y|$.

$$\nabla f \approx |G_x| + |G_y|$$

Detection of Discontinuities Gradient Operators: Example

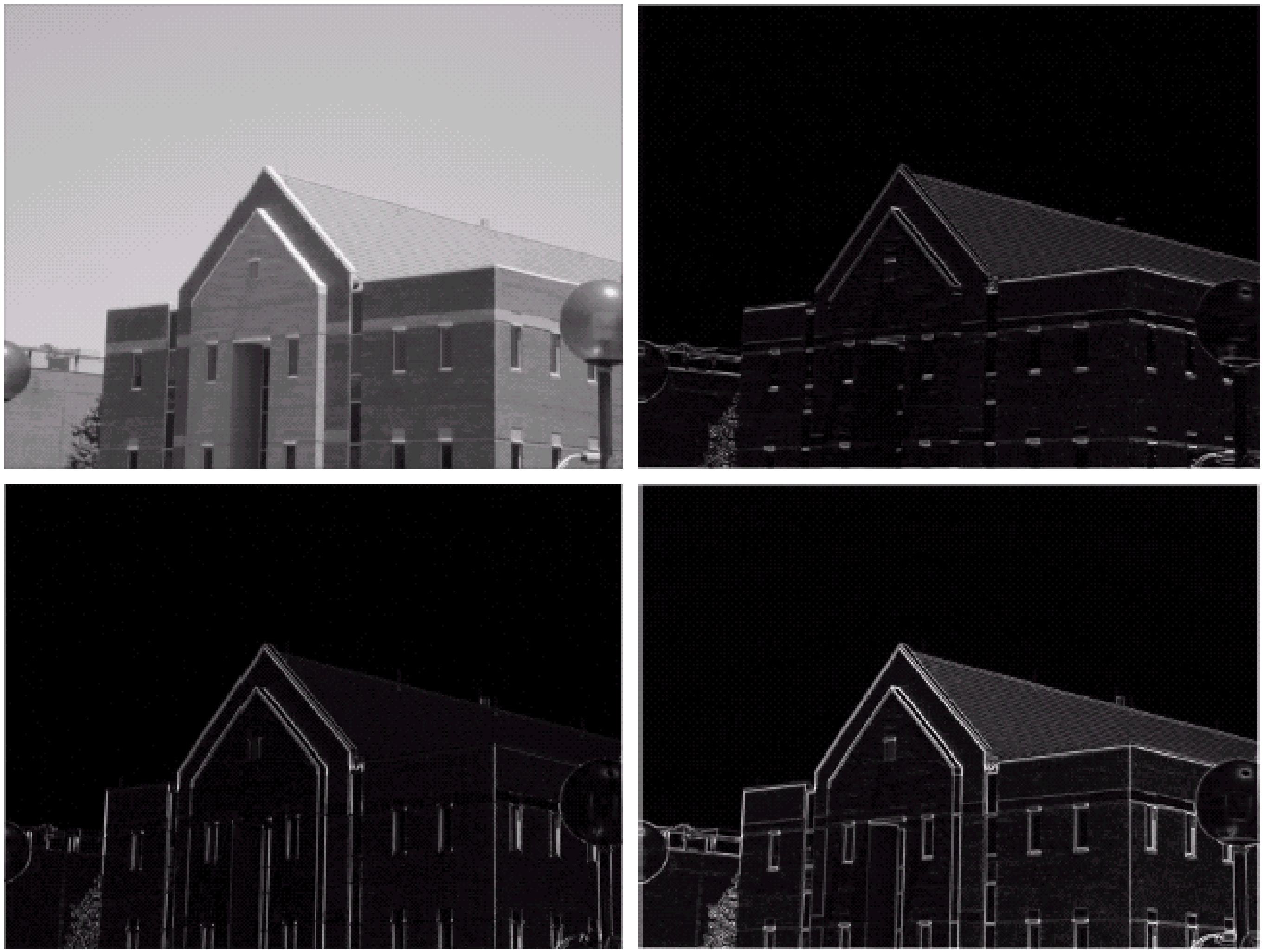
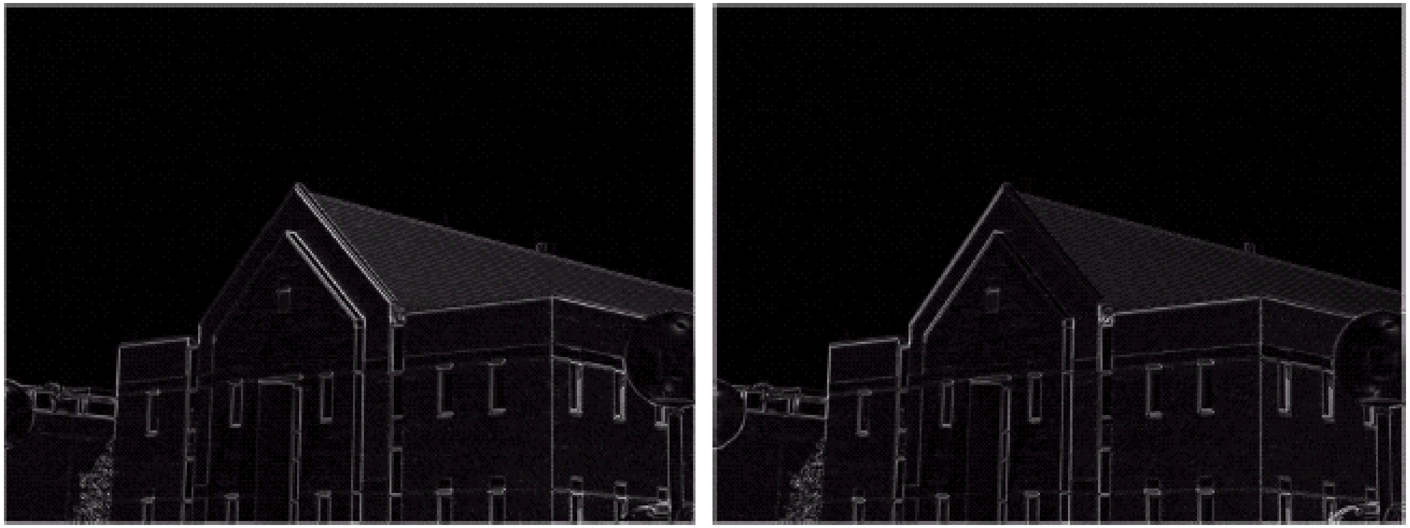


FIGURE 10.11 Same sequence as in Fig. 10.10, but with the original image smoothed with a 5 × 5 averaging filter.

Detection of Discontinuities
Gradient Operators: Example



a b

FIGURE 10.12 Diagonal edge detection. (a) Result of using the mask in Fig. 10.9(c). (b) Result of using the mask in Fig. 10.9(d). The input in both cases was Fig. 10.11(a).

0	1	2
−1	0	1
−2	−1	0

−2	−1	0
−1	0	1
0	1	2

Detection of Discontinuities
Gradient Operators

- Second-order derivatives: (The Laplacian)
  - The Laplacian of an 2D function $f(x,y)$ is defined as

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

  - Two forms in practice:

FIGURE 10.13 Laplacian masks used to implement Eqs. (10.1-14) and (10.1-15), respectively.

0	−1	0
−1	4	−1
0	−1	0

−1	−1	−1
−1	8	−1
−1	−1	−1

The Laplacian generally is not used in its original form for edge detection for many reasons:

1. Sensitive to noise
2. The magnitude of the Laplacian produces double edges
3. Laplacian is unable to detect edge direction.

Principle of Thresholding

Thresholding is an important technique for image segmentation

- It produces uniform regions based on the threshold criteria, T
- Key parameter of thresholding process is the choice of threshold value

- If thresholding operation depends upon only grey scale value, it is known as **Global Thresholding**
- In case neighborhood properties (or some local properties) is also taken into account, method is known as **Local Thresholding**
- If case T depends on pixel coordinates also, it is known as **Dynamic (or Adaptive) Thresholding**

Thresholding is a function of:

- Spatial Coordinates i.e (x,y)
- Grey level of the pixel i.e f(x,y)
- Some local property of the image i.e A(x,y)

Therefore, thresholding operation can be expressed as:

$$Th = T\,[x,y,\ f(x,y),\ A(x,y)]$$

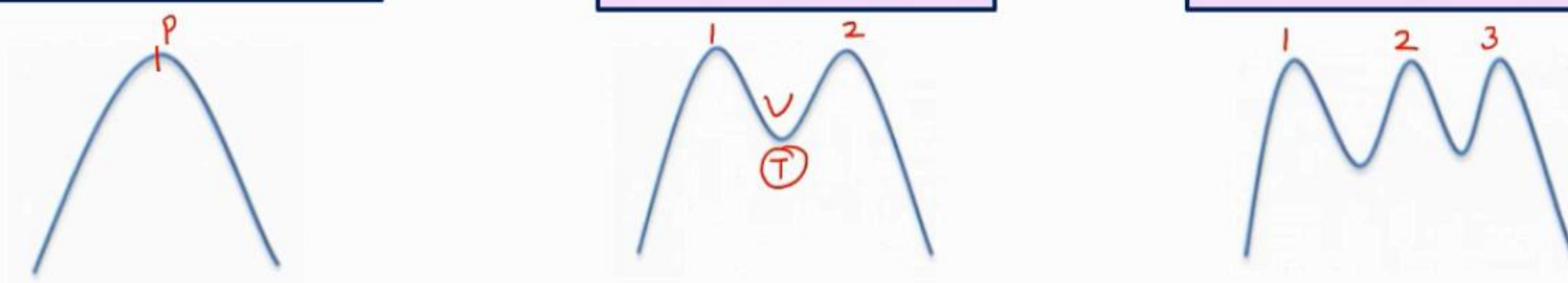
Principle of Thresholding

Histogram and Thresholding

1. The quality of thresholding algorithm depends on the selection of a suitable threshold
2. Tool that helps to find the threshold is histogram

Types of Histograms

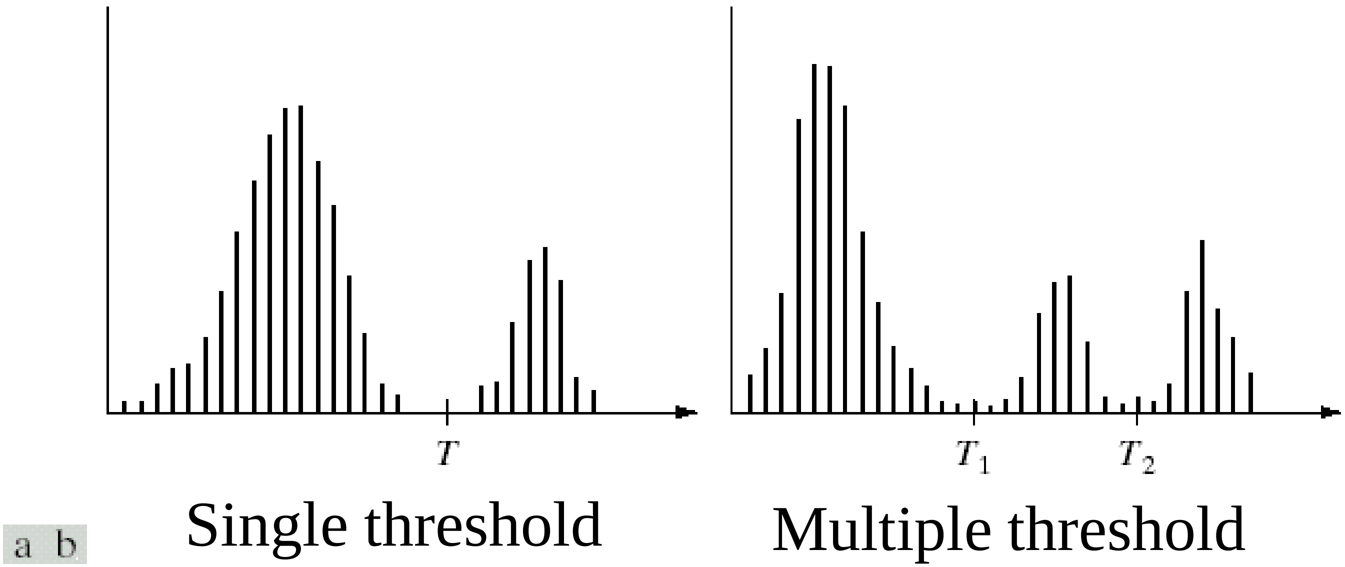
- Unimodal Histogram
- Bimodal Histogram
- Multimodal Histogram



Thresholding

- Assumption: the range of intensity levels covered by objects of interest is different from the background.

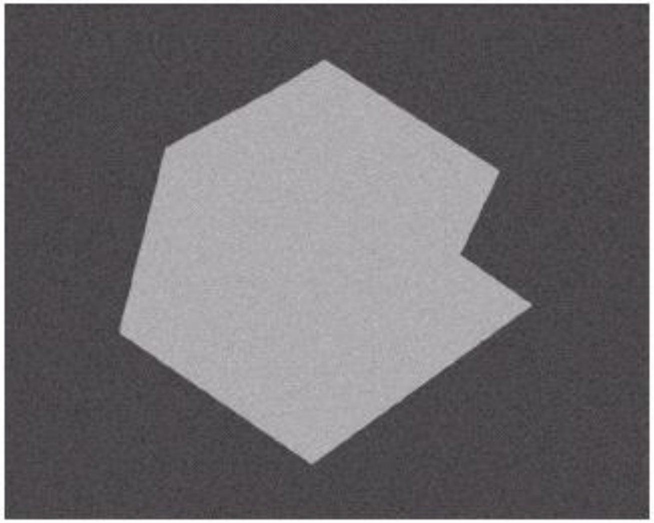
$$g(x,y)=\begin{cases}1 & \text{if } f(x,y)>T\\ 0 & \text{if } f(x,y)\le T\end{cases}$$



Single threshold   Multiple threshold

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

Thresholding
The Role of Illumination



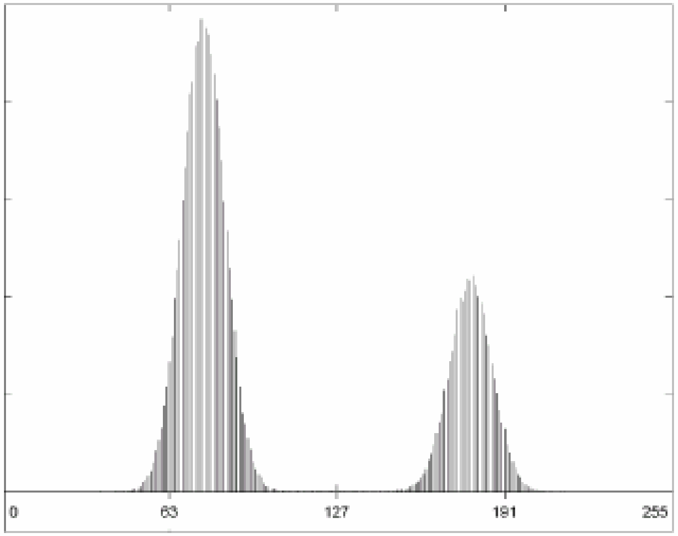
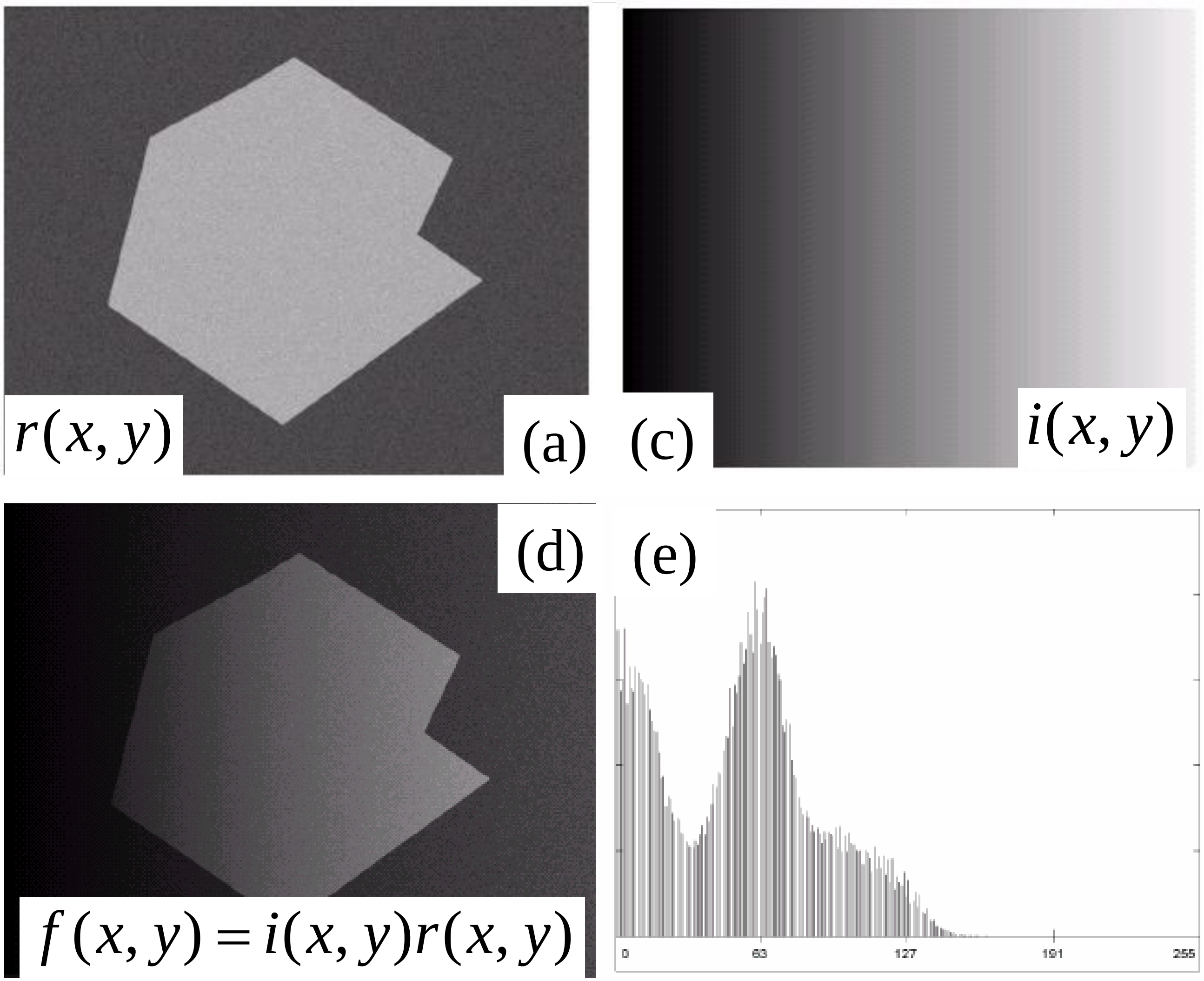


FIGURE 10.27 (a) Computer generated reflectance function. (b) Histogram of reflectance function.

Thresholding
The Role of Illumination



a
b c
d e

FIGURE 10.27 (a) Computer generated reflectance function. (b) Histogram of reflectance function. (c) Computer generated illumination function. (d) Product of (a) and (c). (e) Histogram of product image.

Principle of Thresholding

Global Thresholding

- In bimodal images, histogram have two distinct peaks separated by a valley between them
- Valley point is chosen as threshold (T)
- Then pixels of given image are compared with threshold

Threshold process is given as:

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

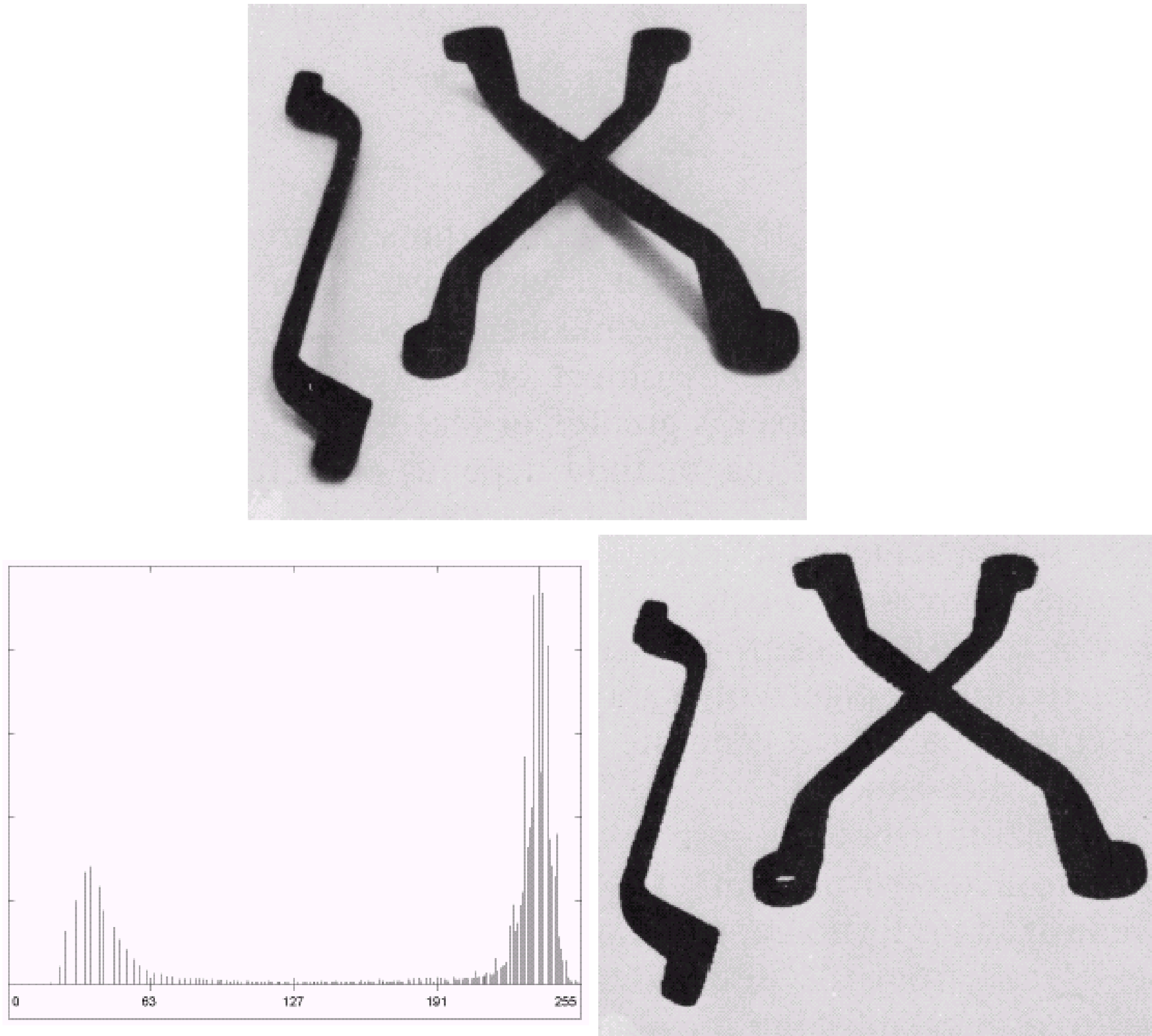
The basic global threshold (T) is calculated as:

1) Randomly select an initial threshold T
2) Segment the image using two group of pixels G_1 and G_2
3) Determine mean (m_1) of the pixels (in G_1 group) that lie below T in histogram
4) Determine mean (m_2) of the pixels (in G_2 group) that lie above T in histogram
5) New threshold is:

$$T_{new} = (m_1 + m_1)/2$$

6) Repeat the step no.2-5 until the difference in T in successive iterations is less than a predefined limit

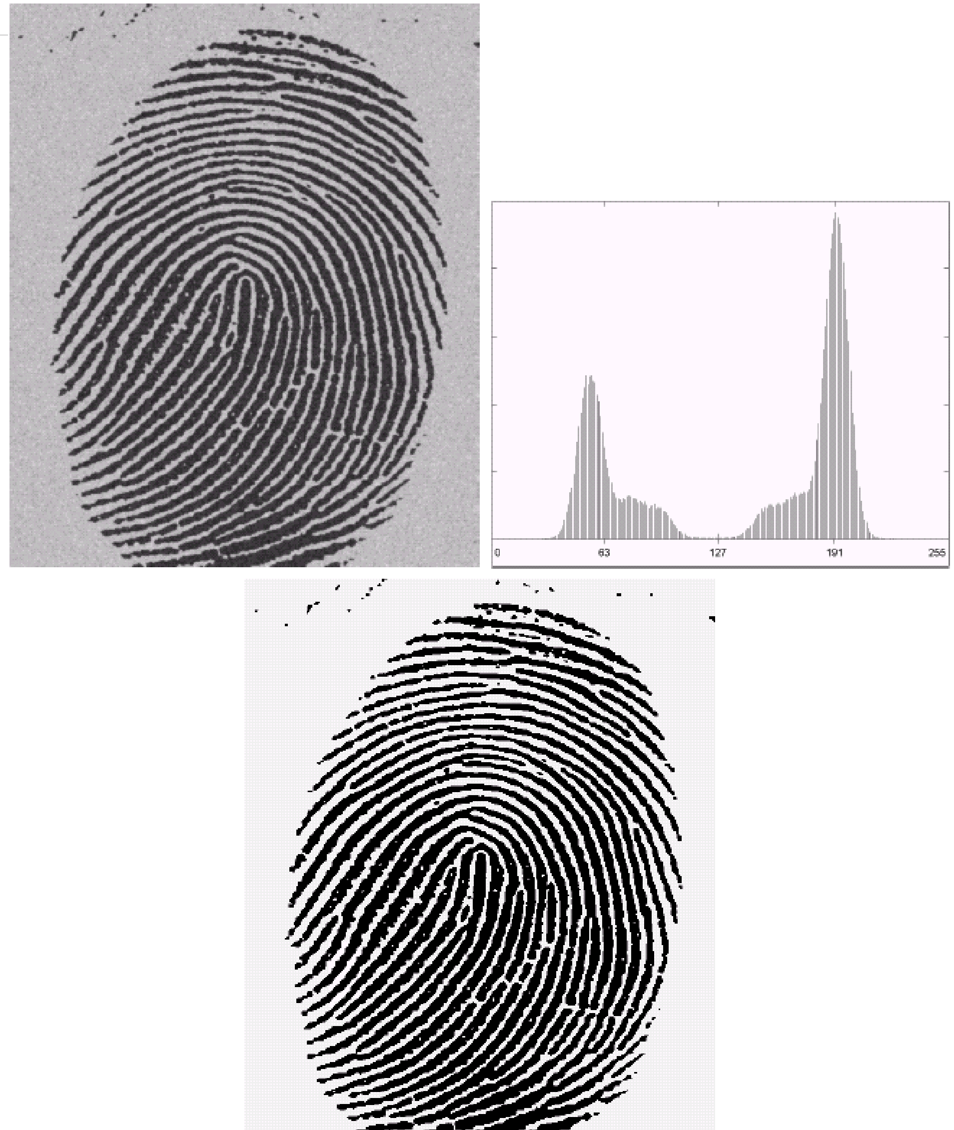
Thresholding
Basic Global Thresholding



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.

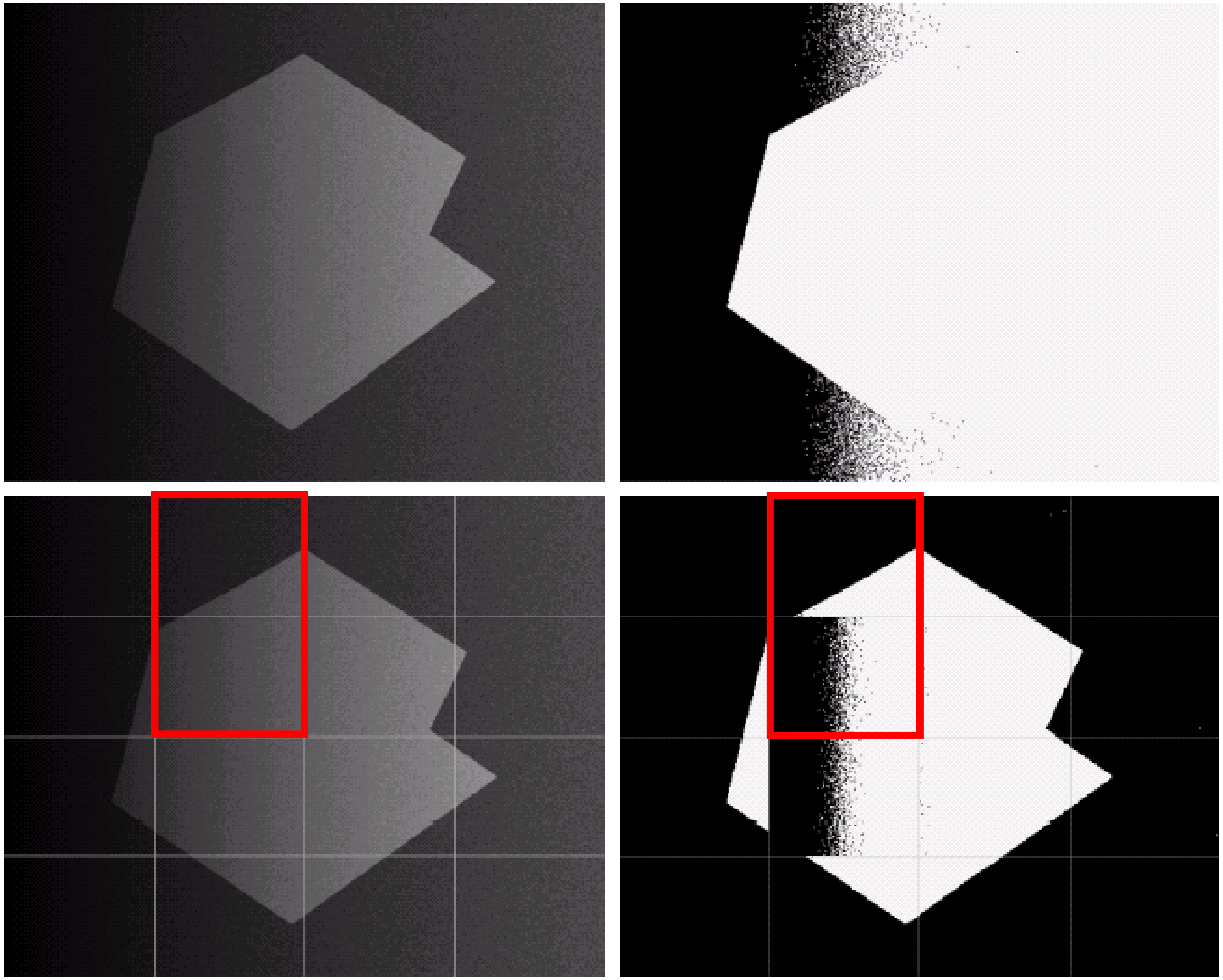
Thresholding
Basic Global Thresholding



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.)

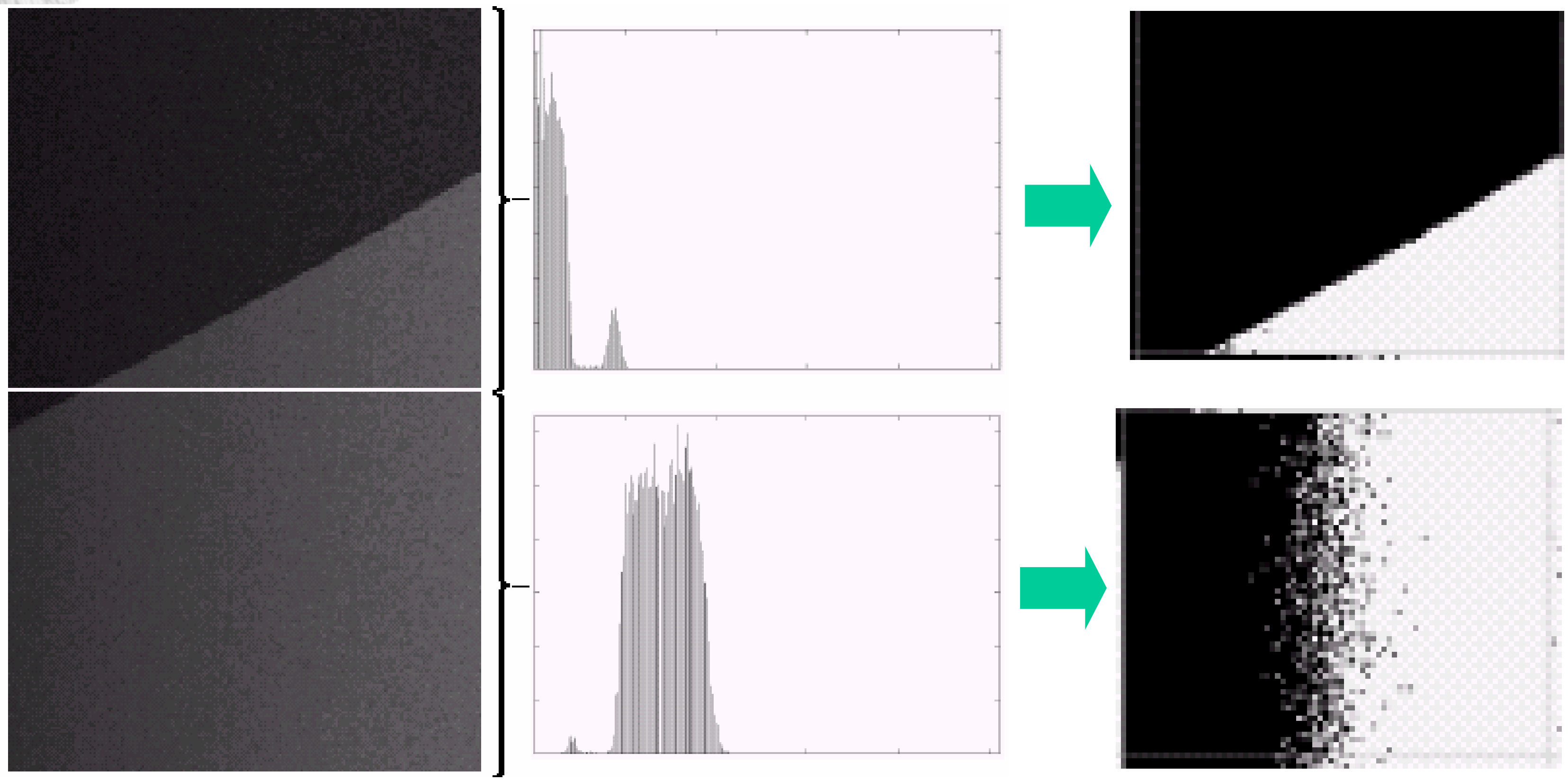
Thresholding
Basic Adaptive Thresholding



a	b
c	d

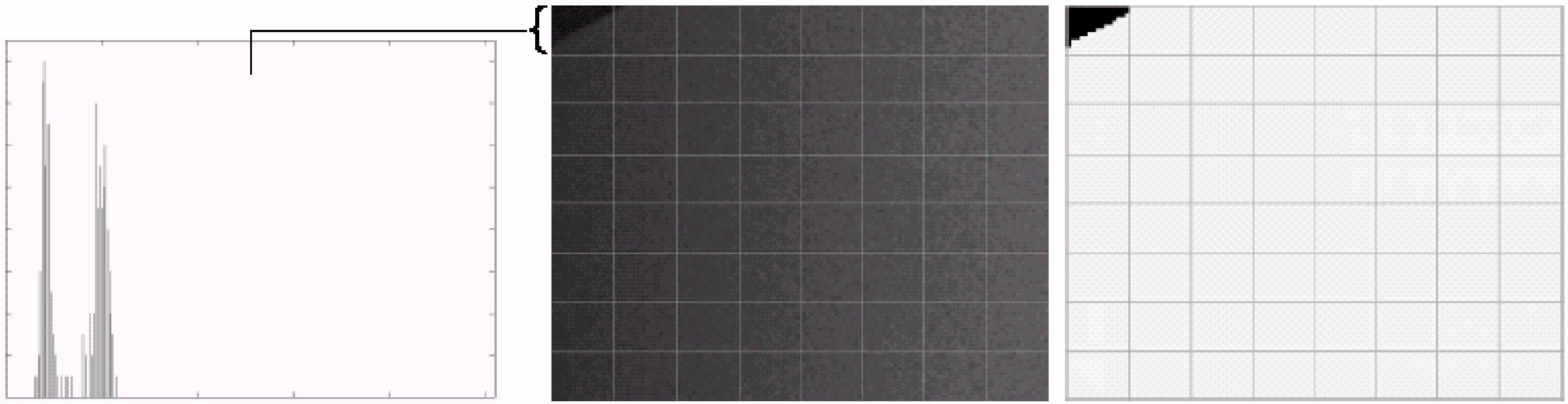
FIGURE 10.30 (a) Original image. (b) Result of global thresholding. (c) Image subdivided into individual subimages. (d) Result of adaptive thresholding.

Thresholding
Basic Adaptive Thresholding



How to solve this problem?

Thresholding
Basic Adaptive Thresholding



Answer: subdivision

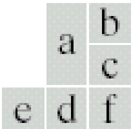
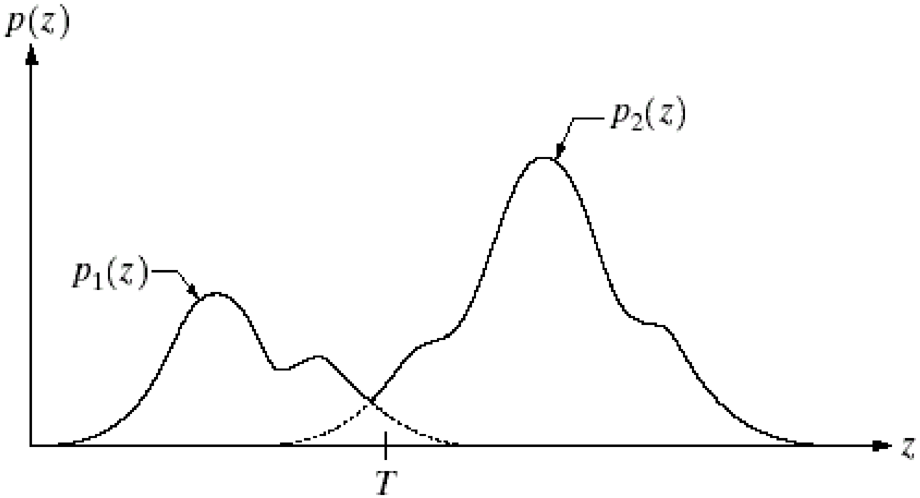


FIGURE 10.31 (a) Properly and improperly segmented subimages from Fig. 10.30. (b)–(c) Corresponding histograms. (d) Further subdivision of the improperly segmented subimage. (e) Histogram of small subimage at top, left. (f) Result of adaptively segmenting (d).

Thresholding
Optimal Global and Adaptive Thresholding

- This method treats pixel values as probability density functions.
- The goal of this method is to minimize the probability of misclassifying pixels as either object or background.
- There are two kinds of error:
  - mislabeling an object pixel as background, and
  - mislabeling a background pixel as object.

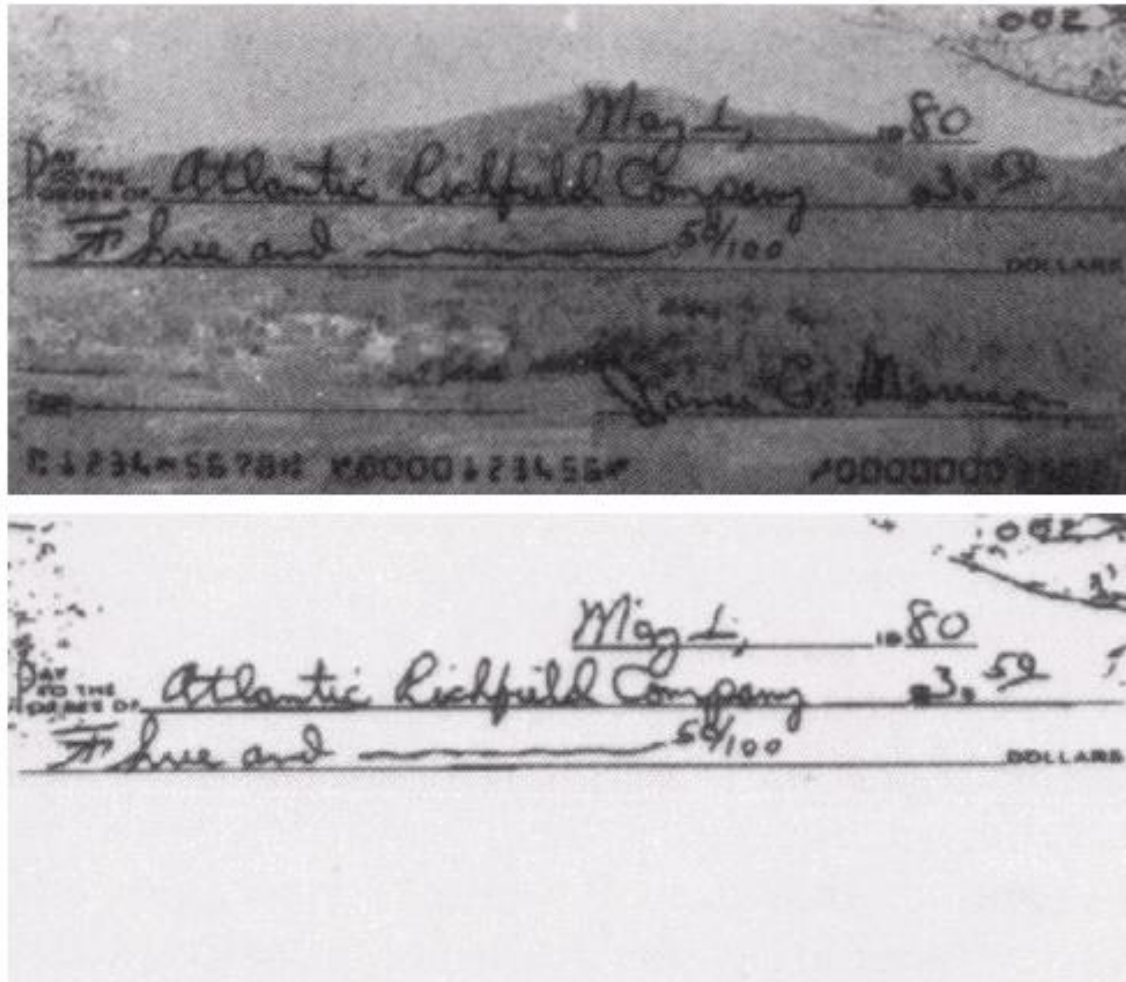
FIGURE 10.32 Gray-level probability density functions of two regions in an image.



Thresholding
Use of Boundary Characteristics

a
b

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



Thresholding
Thresholds Based on Several Variables

Color image

a b c

FIGURE 10.39 (a) Original color image shown as a monochrome picture. (b) Segmentation of pixels with colors close to facial tones. (c) Segmentation of red components.

Region-Based Segmentation

- Edges and thresholds sometimes do not give good results for segmentation.
- Region-based segmentation is based on the connectivity of similar pixels in a region.
  - Each region must be uniform.
  - Connectivity of the pixels within the region is very important.
- There are two main approaches to region-based segmentation: region growing and region splitting.

Region-Based Segmentation
Basic Formulation

- Let R represent the entire image region.
- Segmentation is a process that partitions R into subregions, $R_1, R_2, \ldots, R_n$, such that

(a) $\bigcup_{i=1}^{n} R_i = R$

(b) R_i is a connected region, $i = 1, 2, \ldots, n$

(c) $R_i \cap R_j = \phi$ for all i and $j, i \neq j$

(d) $P(R_i) = \text{TRUE}$ for $i = 1, 2, \ldots, n$

(e) $P(R_i \cup R_j) = \text{FALSE}$ for any adjacent regions R_i and R_j

where $P(R_k)$: a logical predicate defined over the points in set R_k

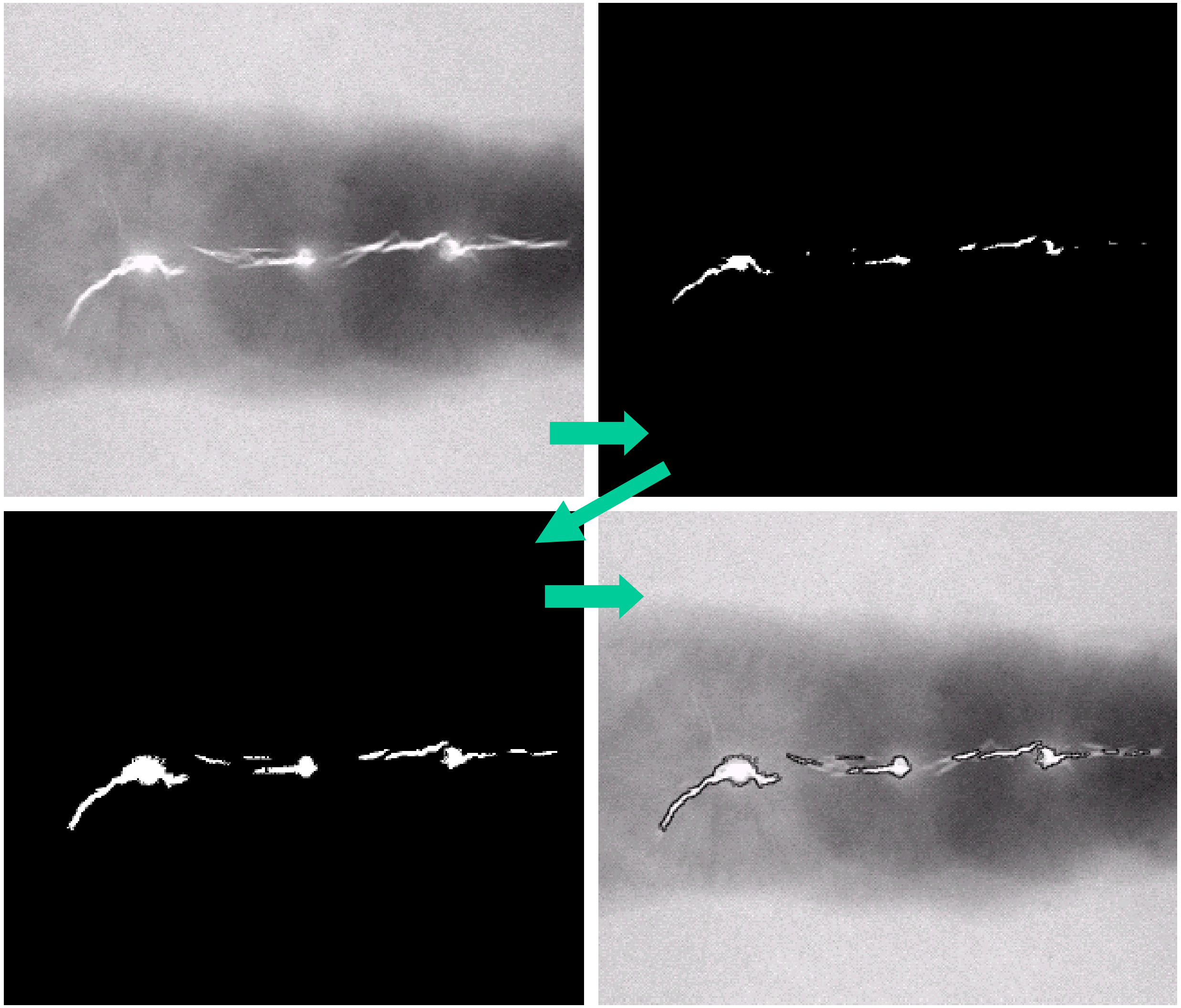
For example: $P(R_k)$=TRUE if all pixels in R_k have the same gray level.

Here, $P(R_i)$ is a logical predicate defined over the points in set R_i and $\varnothing$ is the null set.

Condition (a) indicates that the segmentation must be complete; that is, every pixel must be in a region. Condition (b) requires that points in a region must be connected in some predefined sense

Condition (c) indicates that the regions must be disjoint. Condition (d) deals with the properties that must be satisfied by the pixels in a segmented region—for example $P(R_i) =$ TRUE if all pixels in R_i have the same gray level. Finally, condition (e) indicates that regions R_i and R_j are different in the sense of predicate P.

Region-Based Segmentation
Region Growing



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-Based Segmentation
Region Growing

- Fig. 10.41 shows the histogram of Fig. 10.40 (a). It is difficult to segment the defects by thresholding methods. (Applying region growing methods are better in this case.)

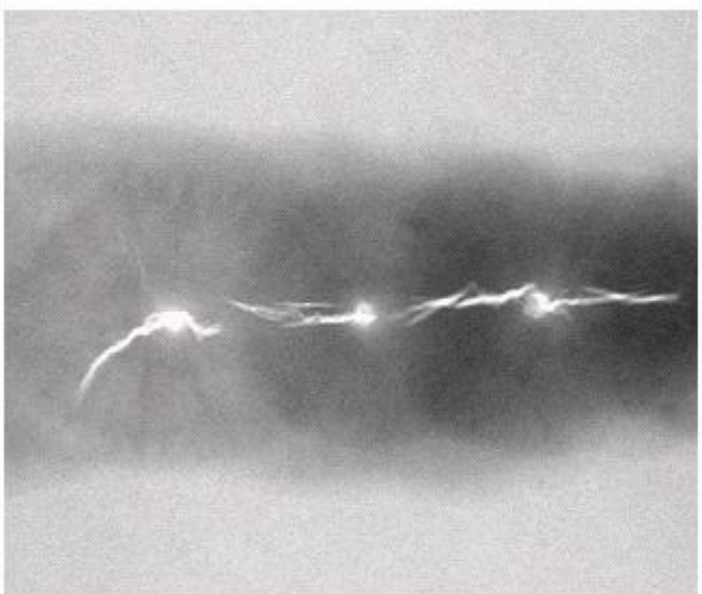


Figure 10.40(a)

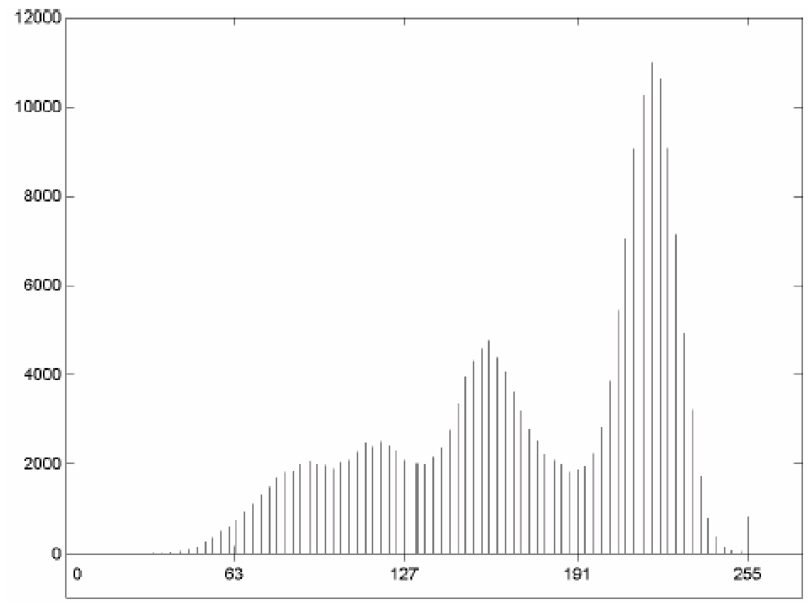


Figure 10.41

Region-Based Segmentation
Region Splitting and Merging

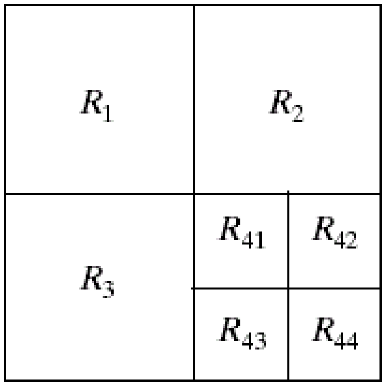
- Region splitting is the opposite of region growing.
  - First there is a large region (possible the entire image).
  - Then a predicate (measurement) is used to determine if the region is uniform.
  - If not, then the method requires that the region be split into two regions.
  - Then each of these two regions is independently tested by the predicate (measurement).
  - This procedure continues until all resulting regions are uniform.

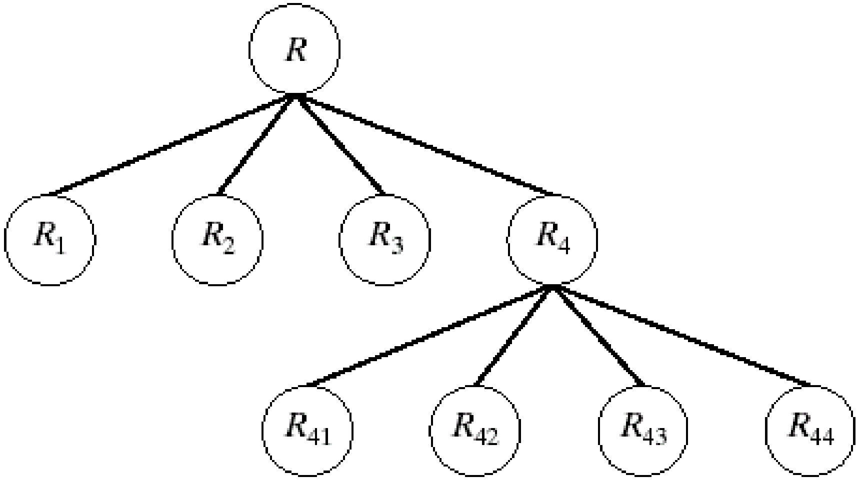
Region-Based Segmentation
Region Splitting

- The main problem with region splitting is determining where to split a region.
- One method to divide a region is to use a quadtree structure.
- Quadtree: a tree in which nodes have exactly four descendants.

a b

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



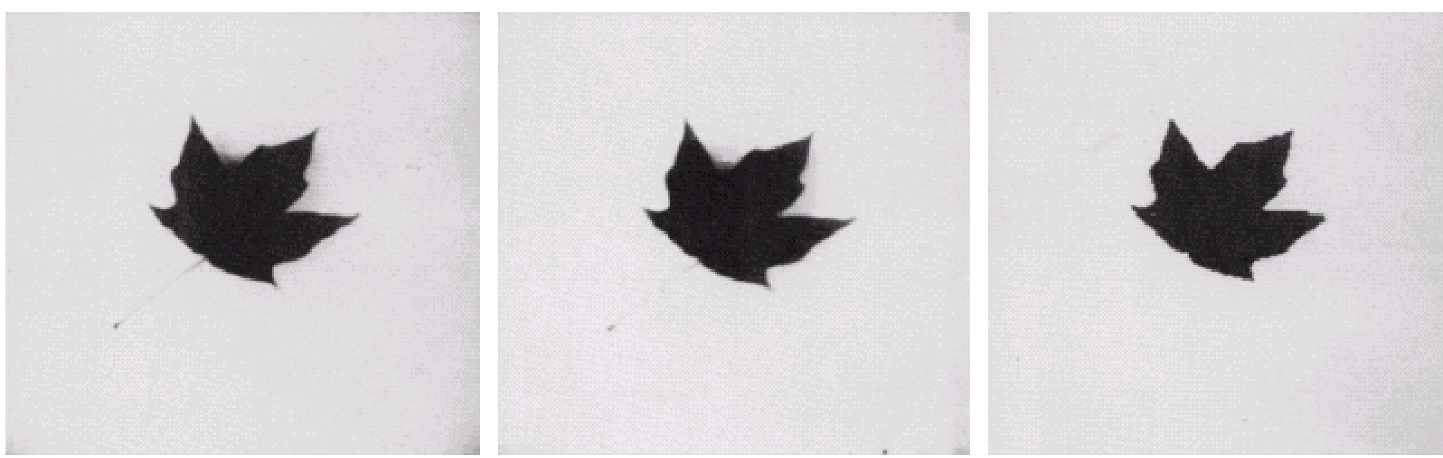


Region-Based Segmentation
Region Splitting and Merging

- The split and merge procedure:
  - Split into four disjoint quadrants any region R_i for which $P(R_i)$ = FALSE.
  - Merge any adjacent regions R_j and R_k for which $P(R_j \cup R_k)$ = TRUE. (the quadtree structure may not be preserved)
  - Stop when no further merging or splitting is possible.

a b c

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



Thank You