The National University of Computer and Emerging Sciences

Local Histogram & Connected Components

Digital Image Processing

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国家计算机与新兴科学大学

局部直方图 & 连通组件

数字图像处理

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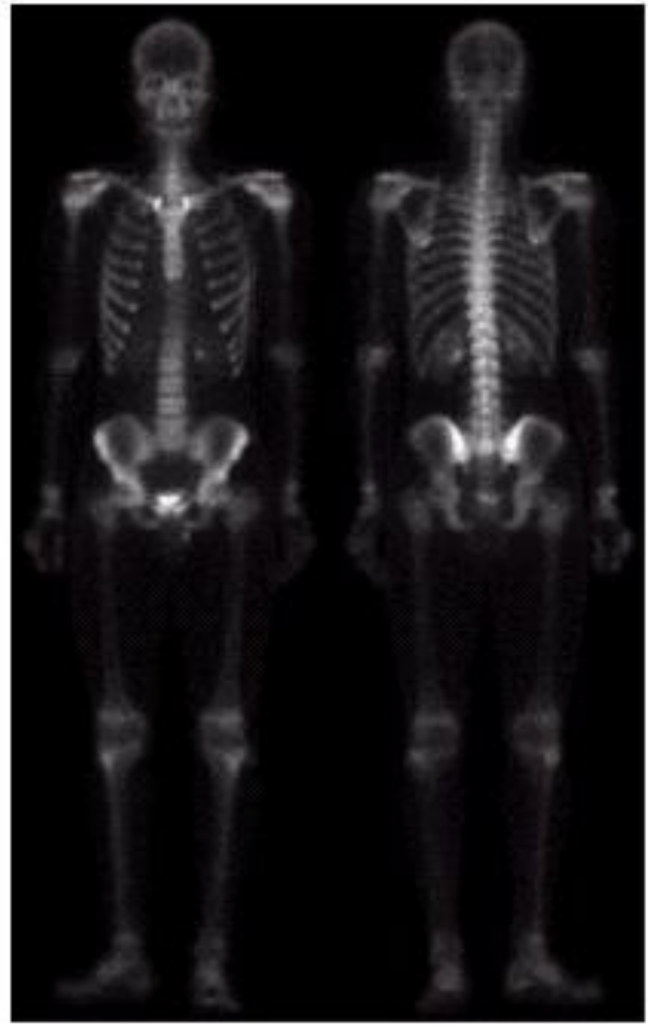
Combining Spatial Enhancement Methods

Successful image enhancement is typically not achieved using a single operation

Rather we combine a range of techniques in order to achieve a final result

This example will focus on enhancing the bone scan to the right

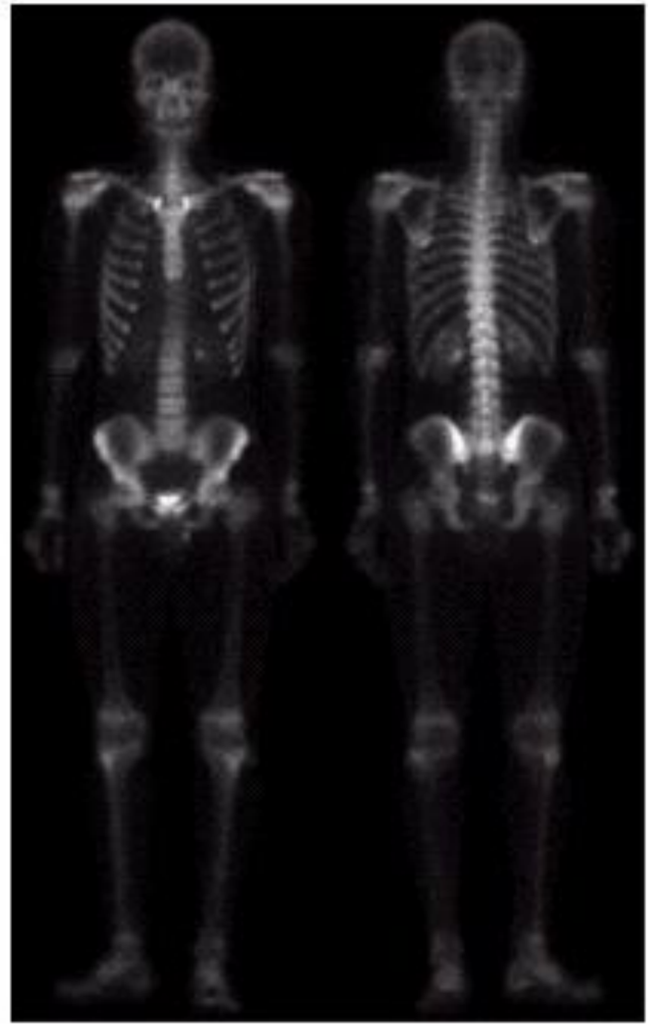


结合空间增强方法

成功的图像增强
通常无法通过单一操作实现

相反，我们结合一系列
技术以实现最终结果

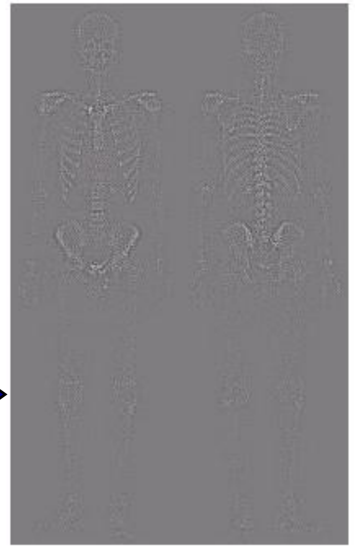
本例将重点关注
增强右侧的骨扫描



Combining Spatial Enhancement Methods (cont…)

(a)

Laplacian filter of bone scan (a)



(b)

Sharpened version of bone scan achieved by subtracting (a) and (b)

(c)

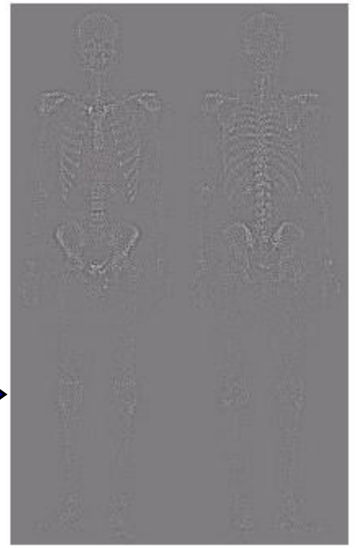
Sobel filter of bone scan (a)

(d)

结合空间增强方法（续...）

(a)

拉普拉斯 滤波器 of 骨扫描（a）



(b)

锐化版本的
骨扫描实现的
by 减去 (a)
和 (b)

(c)

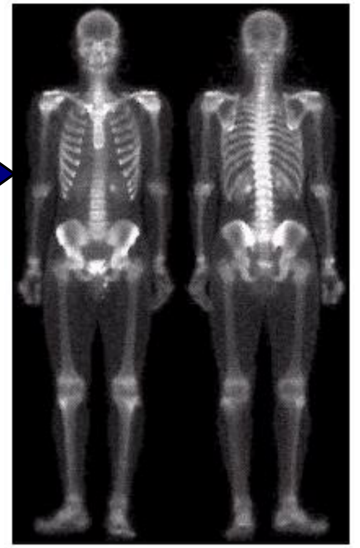
骨的索贝尔滤波器
扫描 (a)

(d)

Combining Spatial Enhancement Methods (cont…)

Result of applying a power-law trans. to (g)

(h)

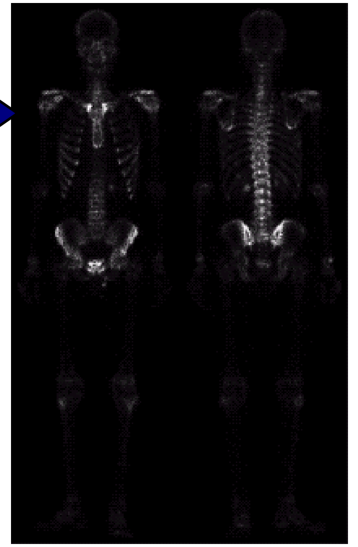


Sharpened image which is sum of (a) and (f)

(g)

The product of (c) and (e) which will be used as a mask

(f)



(e)

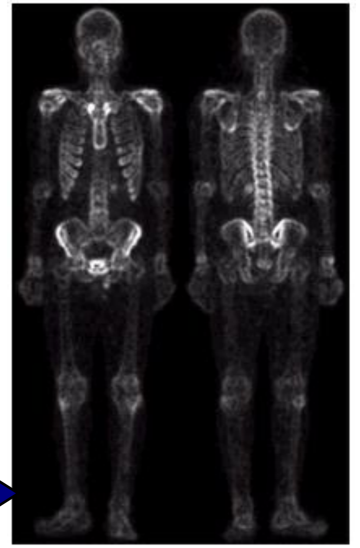
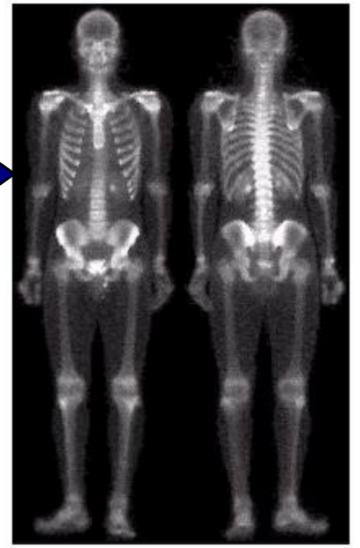


Image (d) smoothed with a 5*5 averaging filter

结合空间增强方法（续...）

应用 a 的结果
幂律变换到
(g)

(h)

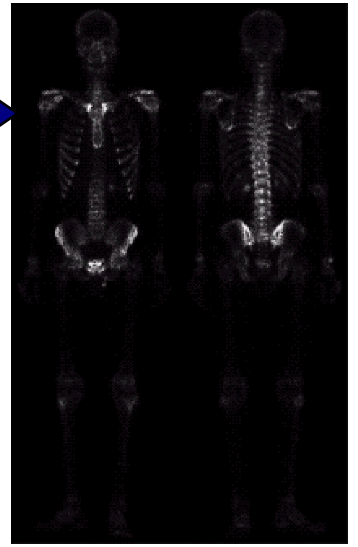


锐化 图像
这是 (a) 的总和
和 (f)

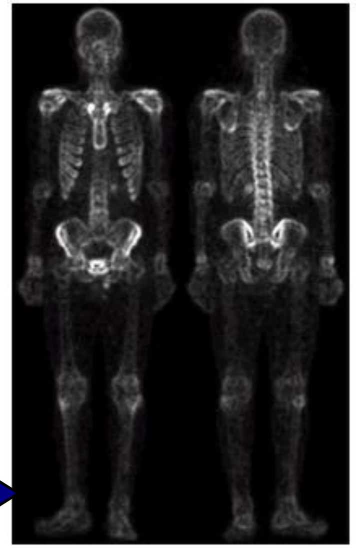
(g)

（c）的乘积
和（e），将会是
用作掩模

(f)



(e)



图像 (d) 使用
一个 5*5 平均滤波器

Combining Spatial Enhancement Methods (cont…)

Compare the original and final images

结合空间增强方法（续...）

比较原始图像和最终图像

Goals

- Today's Lecture
  – Point, Line and Edge Detection
  – Contours

目标

- 今天的讲座– 点、线和边缘检测–
轮廓

Point, Line and Edge Detection

- *Edge pixels* are pixels at which the intensity of an image changes abruptly, and *edges* (or *edge segments*) are sets of connected edge pixels
- *Edge detectors* are local image filters that detect edge pixels.
- A *line* may be viewed as a (typically) thin edge segment in which the intensity of the background on either side of the line is either much higher or much lower than the intensity of the line pixels.
- An *isolated point* may be viewed as a foreground (background) pixel surrounded by background (foreground) pixels.

点、线和边缘检测

- 边缘像素 是图像强度突然变化的像素，边缘 (或 边缘段) 是一组连接的边缘像素
- 边缘检测器 是检测边缘像素的局部图像滤波器。
- 一条 线 可以被视为一个（通常）较薄的边缘段，其中线两侧的背景强度要么高得多，要么低得多于线像素的强度。
- 一个孤立点可以被视为一个被背景（前景）像素包围的前景（背景）像素。

Edge Detection with Derivatives

- First-order derivatives generally produce thicker edges in image
- Second-order derivatives have a stronger response to fine detail, such as thin lines, isolated points, and noise
- Second-order derivatives produce a double-edge response at ramp and step transition in intensity
- The sign of the second derivative can be used to determine whether a transition into an edge is from light to dark or dark to light

边缘检测与导数

- 一阶导数通常会在图像中产生更厚的边缘
- 二阶导数对细节的响应更强，例如细线、孤立点和噪声
- 二阶导数在强度的斜坡和阶跃过渡产生双边缘响应。
- 该 二阶导数的符号 可以用来确定一个过渡到 边缘是从亮到暗还是从暗到亮

Background

- First-order derivative

$$\frac{\partial f}{\partial x} = f\,'(x) = f(x+1) - f(x)$$

- Second-order derivative

$$\frac{\partial^2 f}{\partial x^2} = f(x+1) + f(x-1) - 2f(x)$$

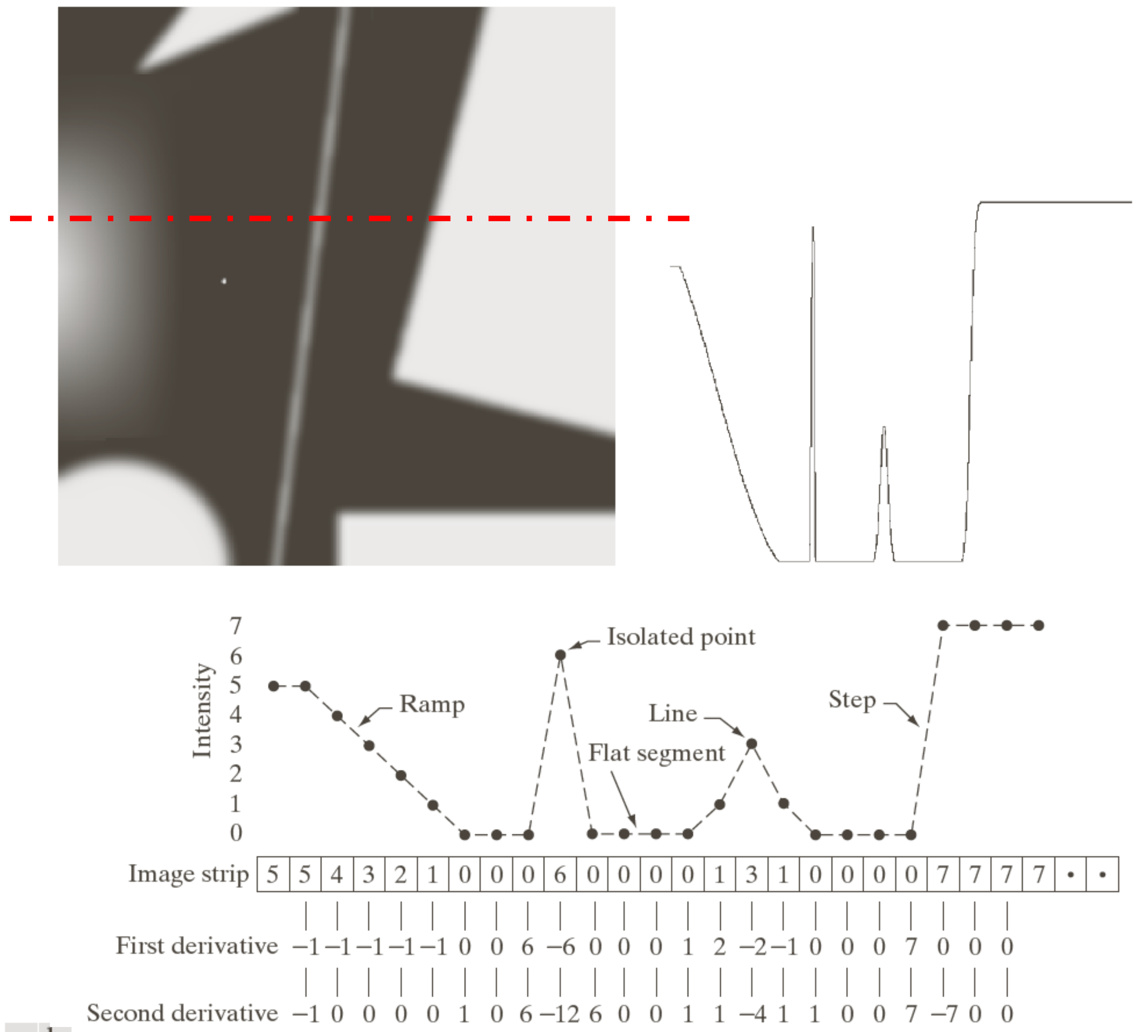
背景

- 一阶导数

$$\frac{\partial f}{\partial x} = f\,'(x) = f(x+1) - f(x)$$

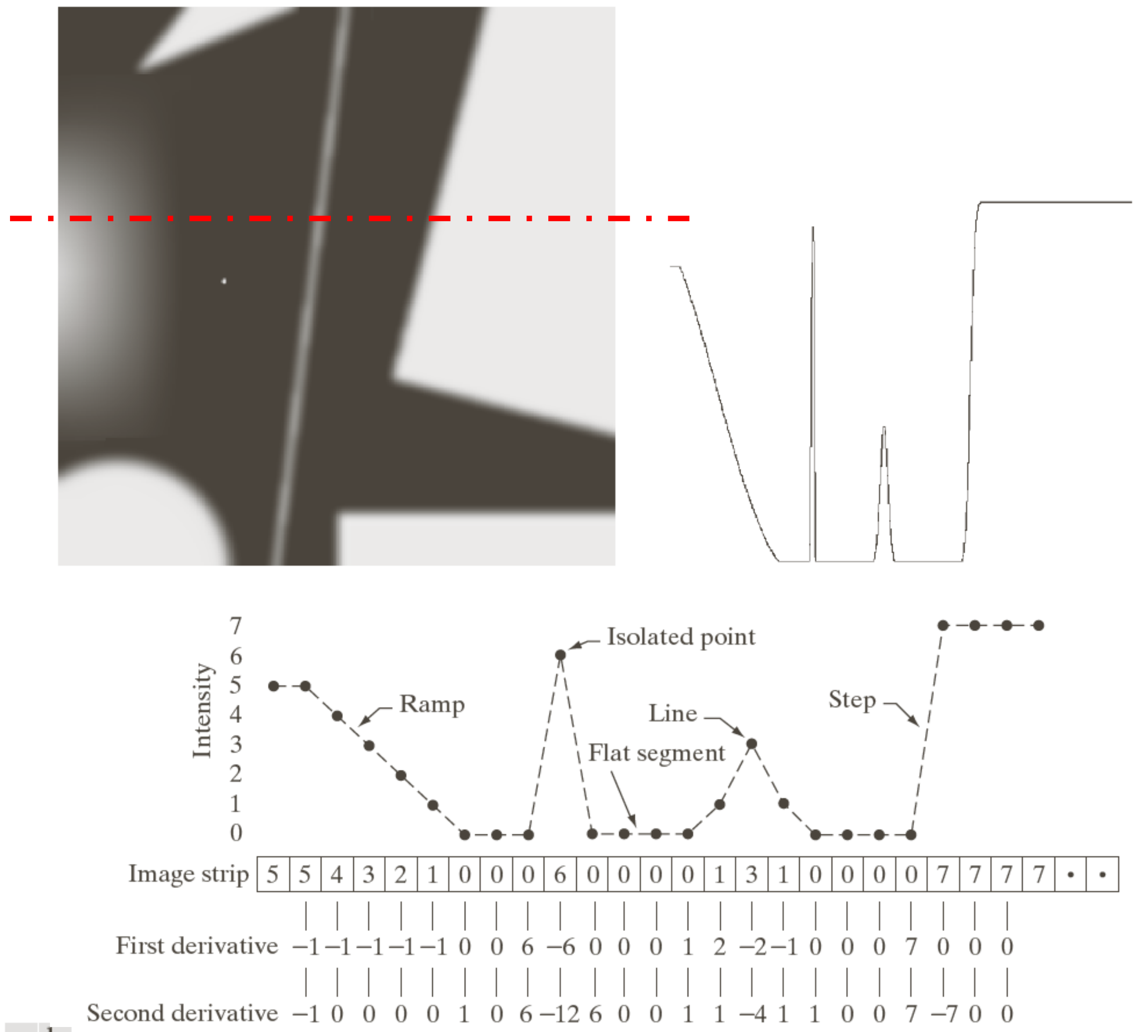
- 二阶导数

$$\frac{\partial^2 f}{\partial x^2} = f(x+1) + f(x-1) - 2f(x)$$



a b
c

FIGURE 10.2 (a) Image. (b) Horizontal intensity profile through the center of the image, including the isolated noise point. (c) Simplified profile (the points are joined by dashes for clarity). The image strip corresponds to the intensity profile, and the numbers in the boxes are the intensity values of the dots shown in the profile. The derivatives were obtained using Eqs. (10.2-1) and (10.2-2).



a b
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Characteristics of First and Second Order Derivatives

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- Second-order derivatives produce a double-edge response at ramp and step transition in intensity
- The sign of the second derivative can be used to determine whether a transition into an edge is from light to dark or dark to light

一阶和二阶导数的特性

- 一阶导数通常在图像中产生更厚的边缘
- 二阶导数对细节（如细线、孤立点和噪声）有更强的响应
- 二阶导数在强度的斜坡和阶跃过渡处产生双边缘响应
- 二阶导数的符号可以用来确定边缘的过渡是从亮到暗还是从暗到亮

Detection of Isolated Points

- The Laplacian

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

$$= f(x+1,y) + f(x-1,y) + f(x,y+1) + f(x,y-1)$$

$$-4f(x,y)$$

$$g(x,y) = \begin{cases} 1 & \text{if } |R(x,y)| \geq T \\ 0 & \text{otherwise} \end{cases} \qquad R = \sum_{k=1}^{9} w_k z_k$$

孤立点的检测

- 拉普拉斯

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

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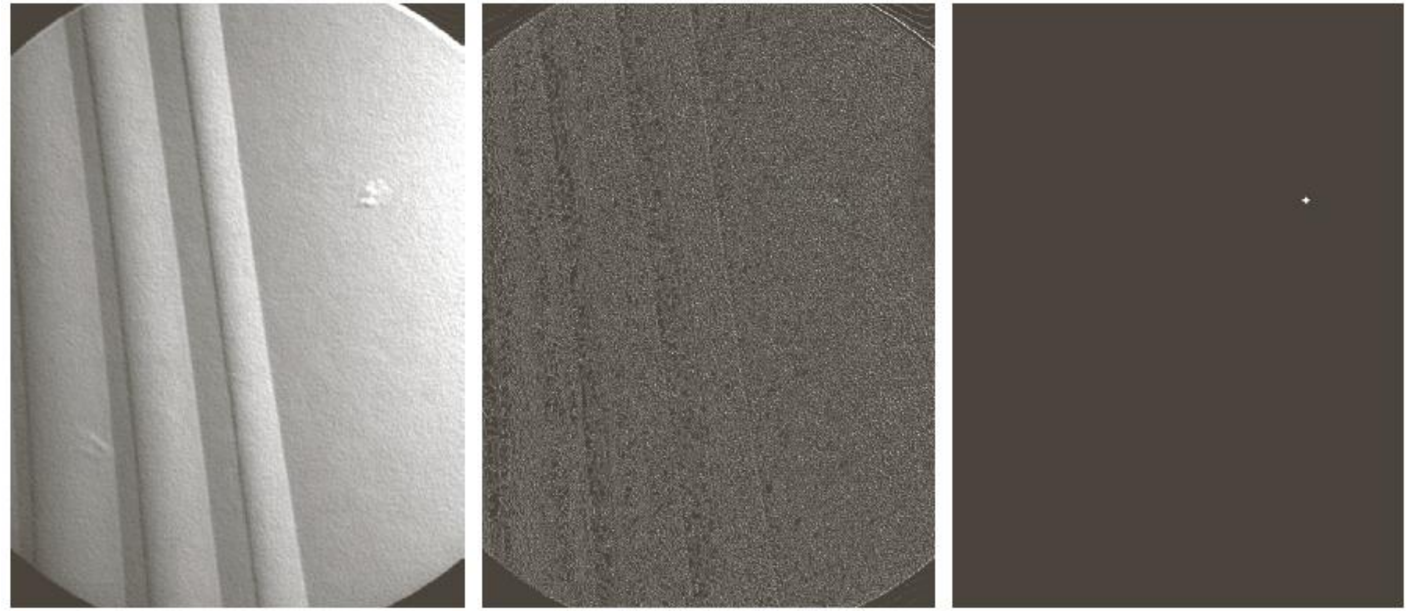
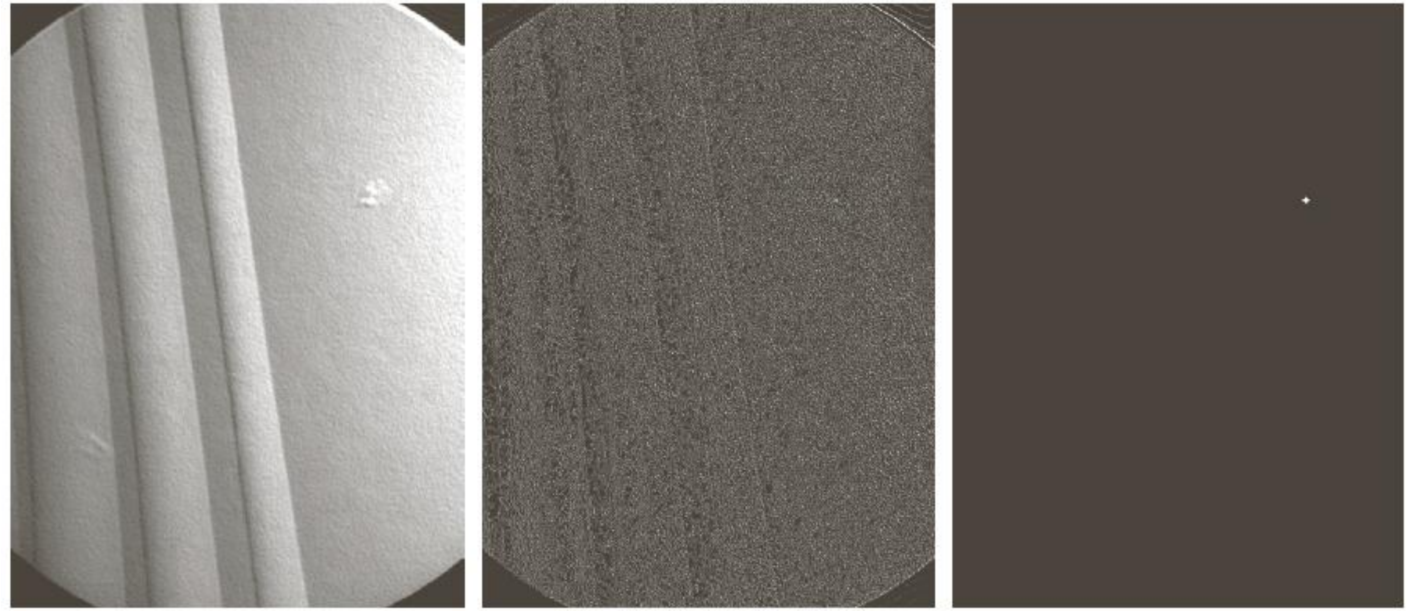
1	1	1
1	−8	1
1	1	1



a
b c d

FIGURE 10.4
(a) Point detection (Laplacian) mask. (b) X-ray image of turbine blade with a porosity. The porosity contains a single black pixel. (c) Result of convolving the mask with the image. (d) Result of using Eq. (10.2-8) showing a single point (the point was enlarged to make it easier to see). (Original image courtesy of X-TEK Systems, Ltd.)

1	1	1
1	−8	1
1	1	1



a
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Detection of Isolated Points

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孤立点的检测

- 拉普拉斯

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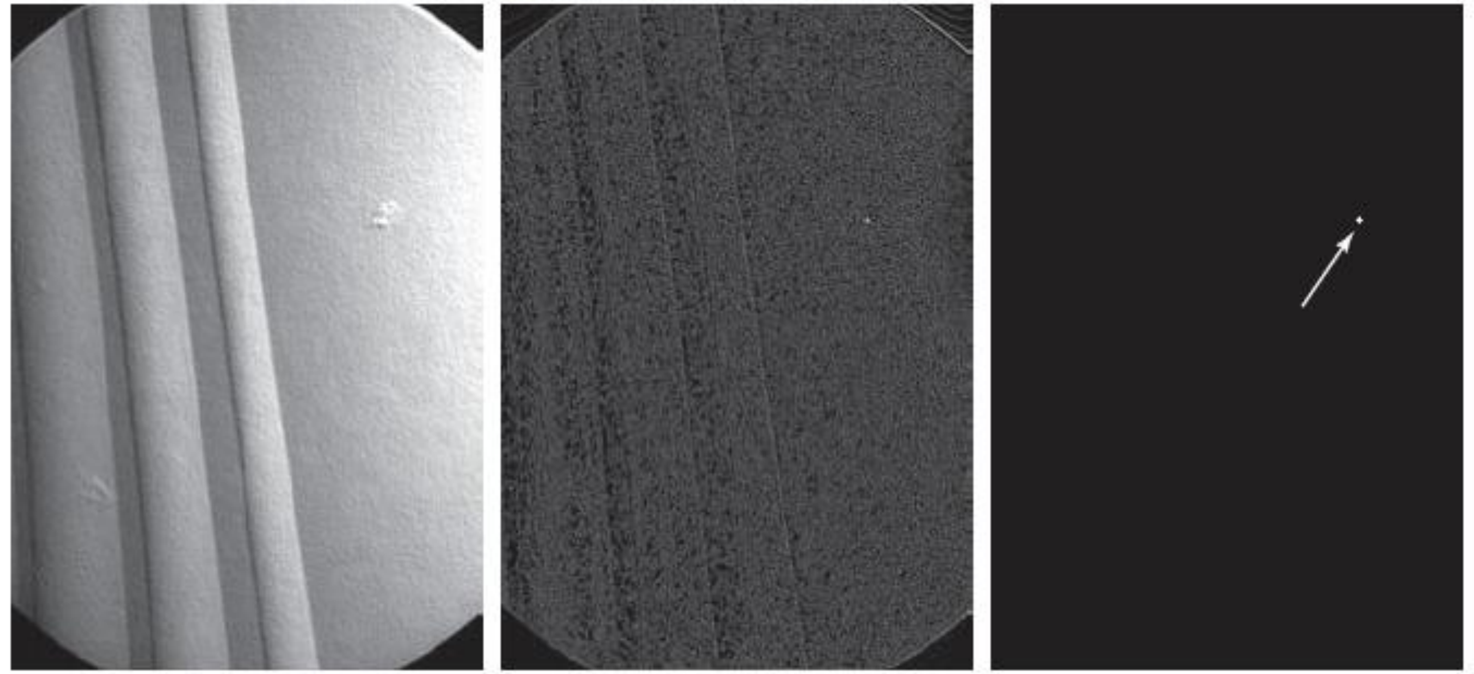
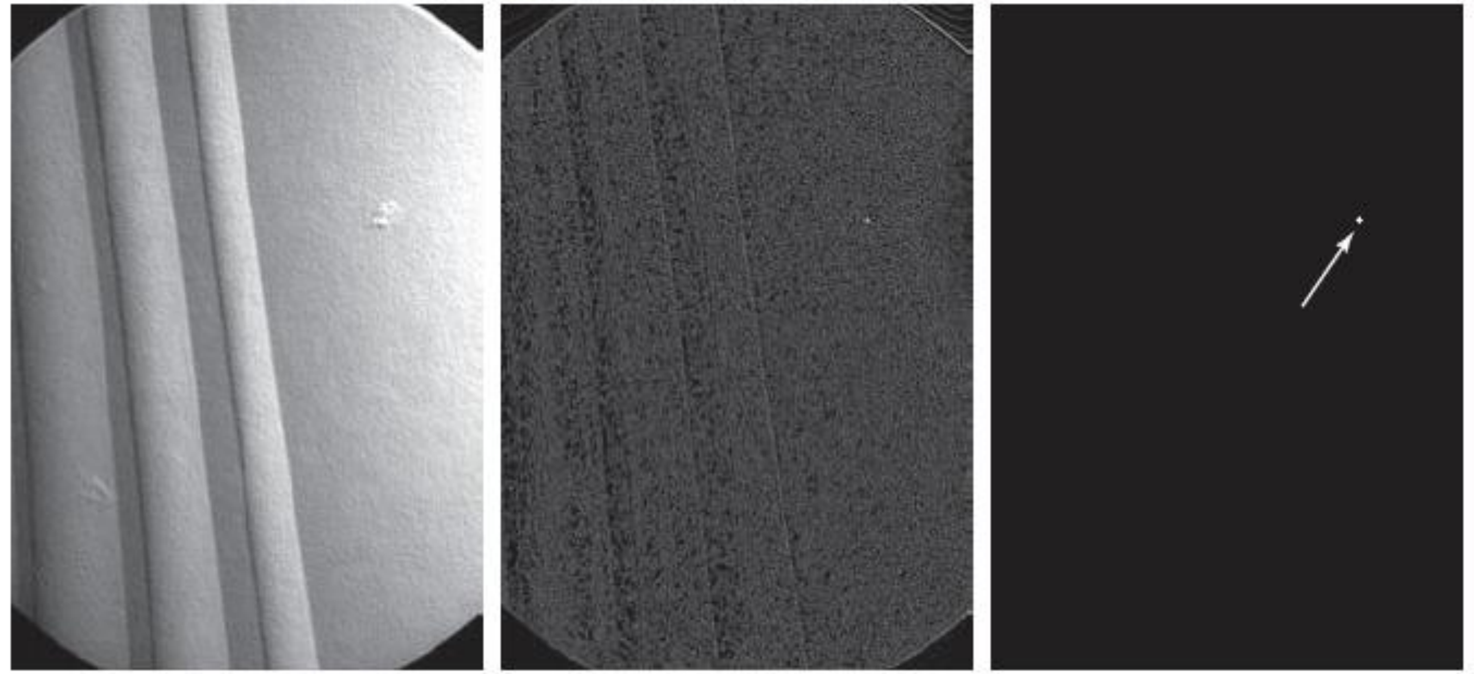


a
b c d

FIGURE 10.4
(a) Laplacian kernel used for point detection. (b) X-ray image of a turbine blade with a porosity manifested by a single black pixel. (c) Result of convolving the kernel with the image. (d) Result of using Eq. (10-15) was a single point (shown enlarged at the tip of the arrow). (Original image courtesy of X-TEK Systems, Ltd.)

1	1	1
1	−8	1
1	1	1



a
b c d

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Line Detection

- Second derivatives to result in a stronger response and to produce thinner lines than first derivatives

- Double-line effect of the second derivative must be handled properly

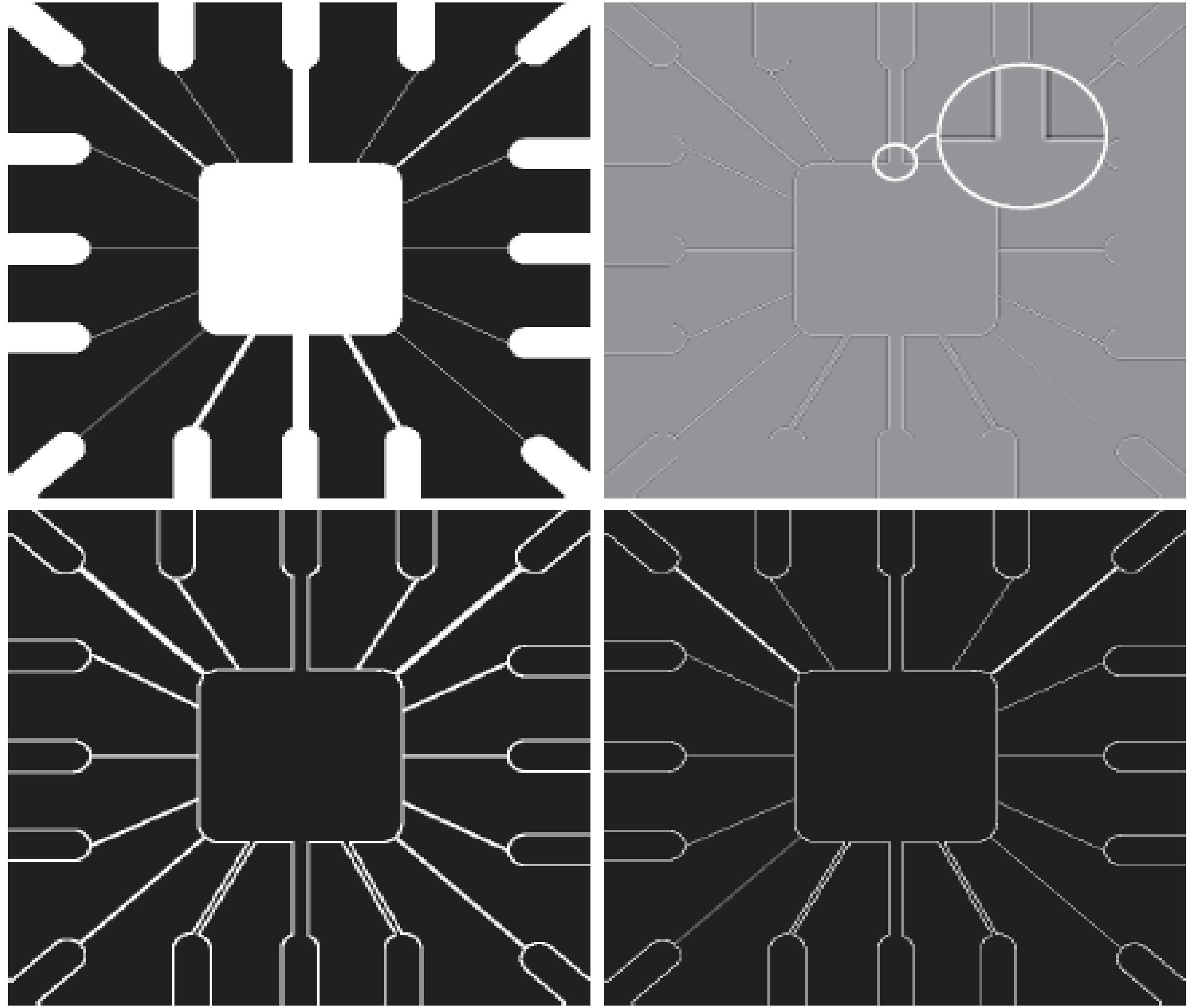
线条检测

- 二阶导数导致更强的响应并产生 比一阶导数更细的线

- 二阶导数的双线效应 必须妥善处理

a b
c d

FIGURE 10.5
(a) Original image.
(b) Laplacian image; the magnified section shows the positive/negative double-line effect characteristic of the Laplacian.
(c) Absolute value of the Laplacian.
(d) Positive values of the Laplacian.



a b
c d

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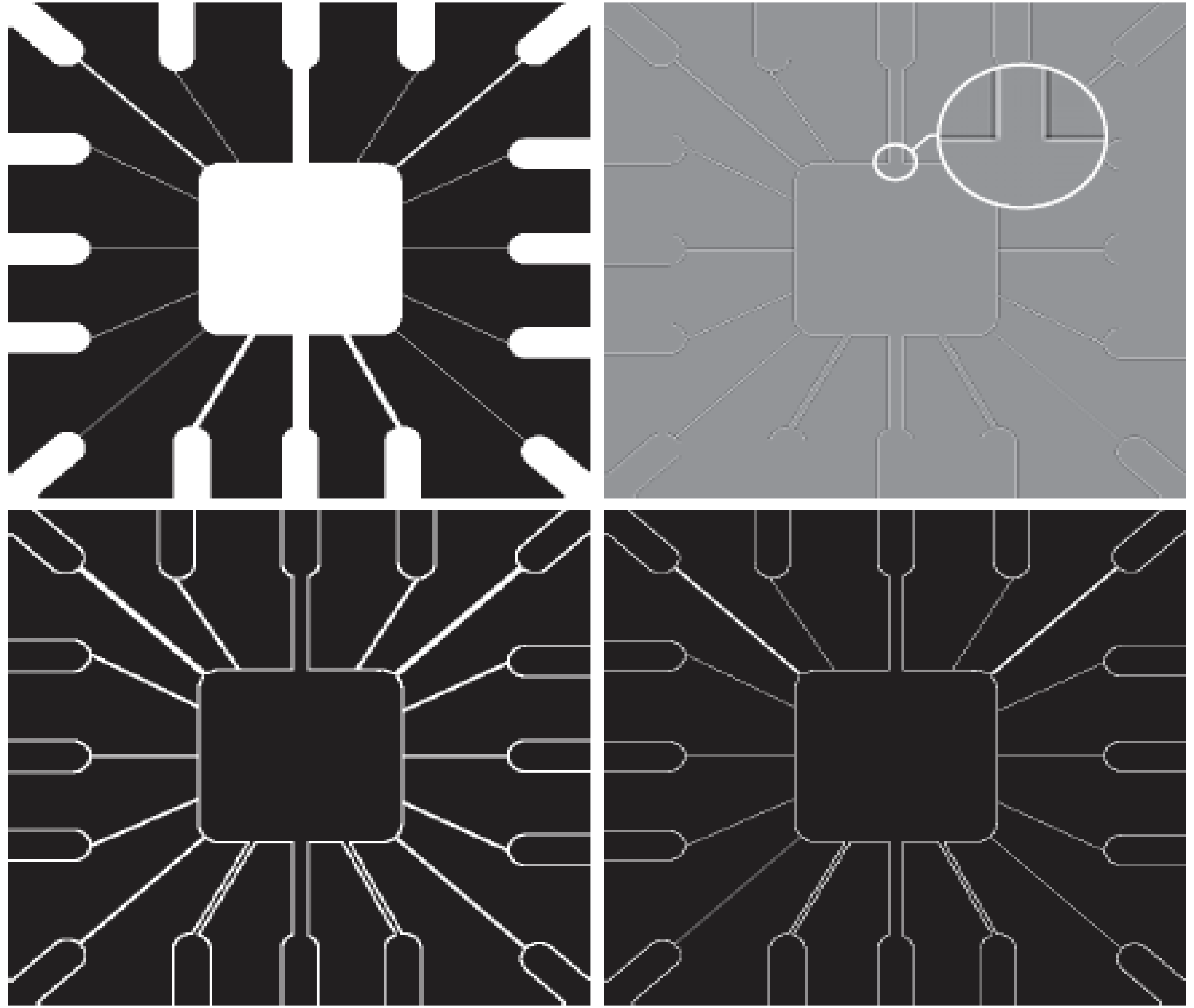

Line Detection

- The Laplacian detector kernel is isotropic
  - Its response is independent of direction (with respect to the four directions of the 3×3 kernel: vertical, horizontal, and two diagonals).
- How to detect lines in *specified direction*?

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

线条检测

- 拉普拉斯检测器核是 各向同性– 它的响应是 与方向无关 (相对于 3×3 核的四个方向： 垂直、水平和两个对角线).

- 如何检测线条在指定方向?

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

Detecting Line in Specified Directions

- Sobel operator for Horizontal and Vertical Lines

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

在指定方向上检测线

- 索贝尔算子用于水平和垂直线

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

Detecting Line in Specified Directions

−1	−1	−1	2	−1	−1	−1	2	−1	−1	−1	2
2	2	2	−1	2	−1	−1	2	−1	−1	2	−1
−1	−1	−1	−1	−1	2	−1	2	−1	2	−1	−1
Horizontal			+45°			Vertical			−45°		

a b c d

FIGURE 10.6 Line detection kernels. Detection angles are with respect to the axis system in Fig. 2.19, with positive angles measured counterclockwise with respect to the (vertical) *x*-axis.

在指定方向上检测线

−1	−1	−1	2	−1	−1	−1	2	−1	−1	−1	2
2	2	2	−1	2	−1	−1	2	−1	−1	2	−1
−1	−1	−1	−1	−1	2	−1	2	−1	2	−1	−1
Horizontal			+45°			Vertical			−45°		

a b c d

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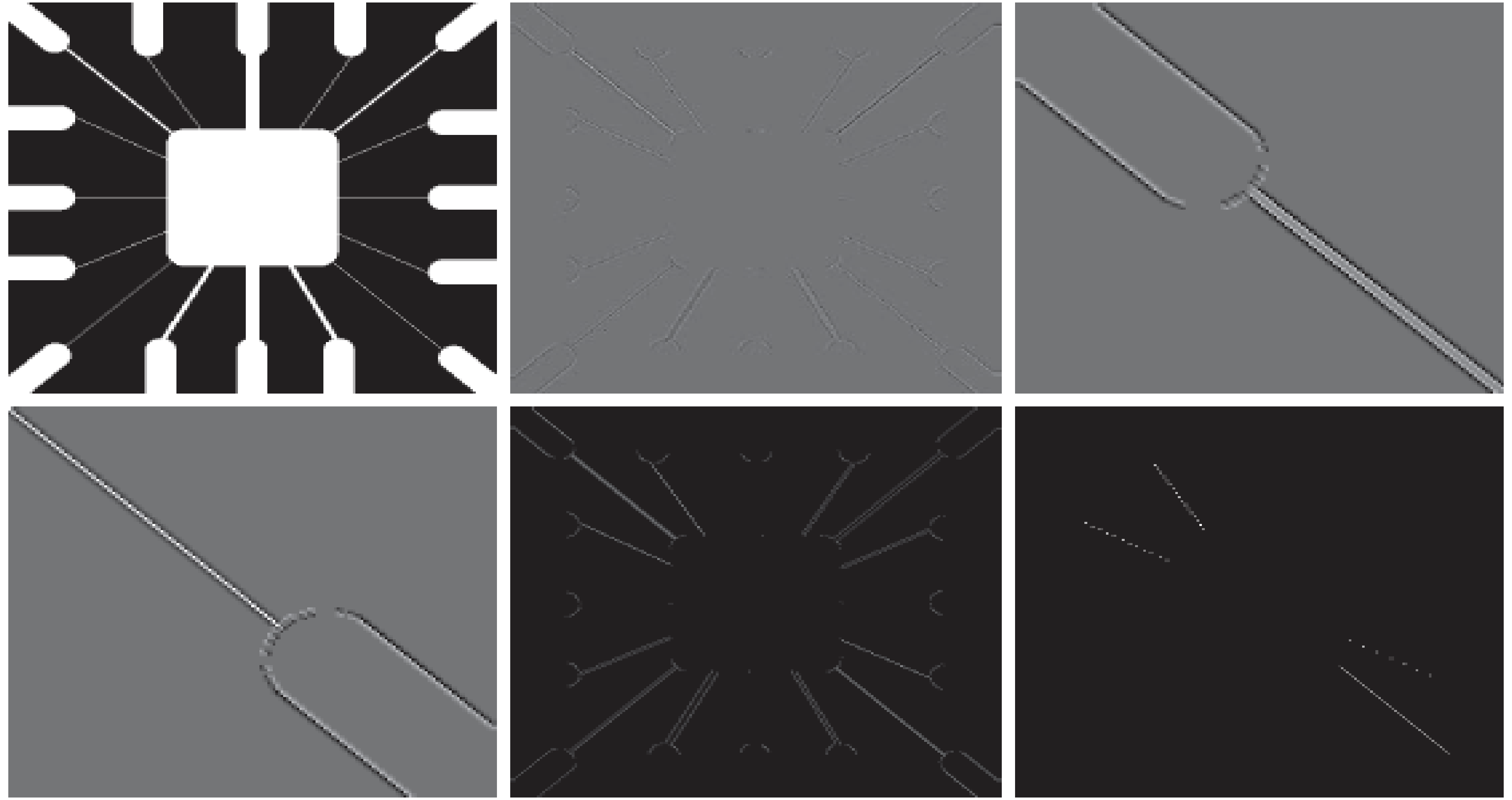
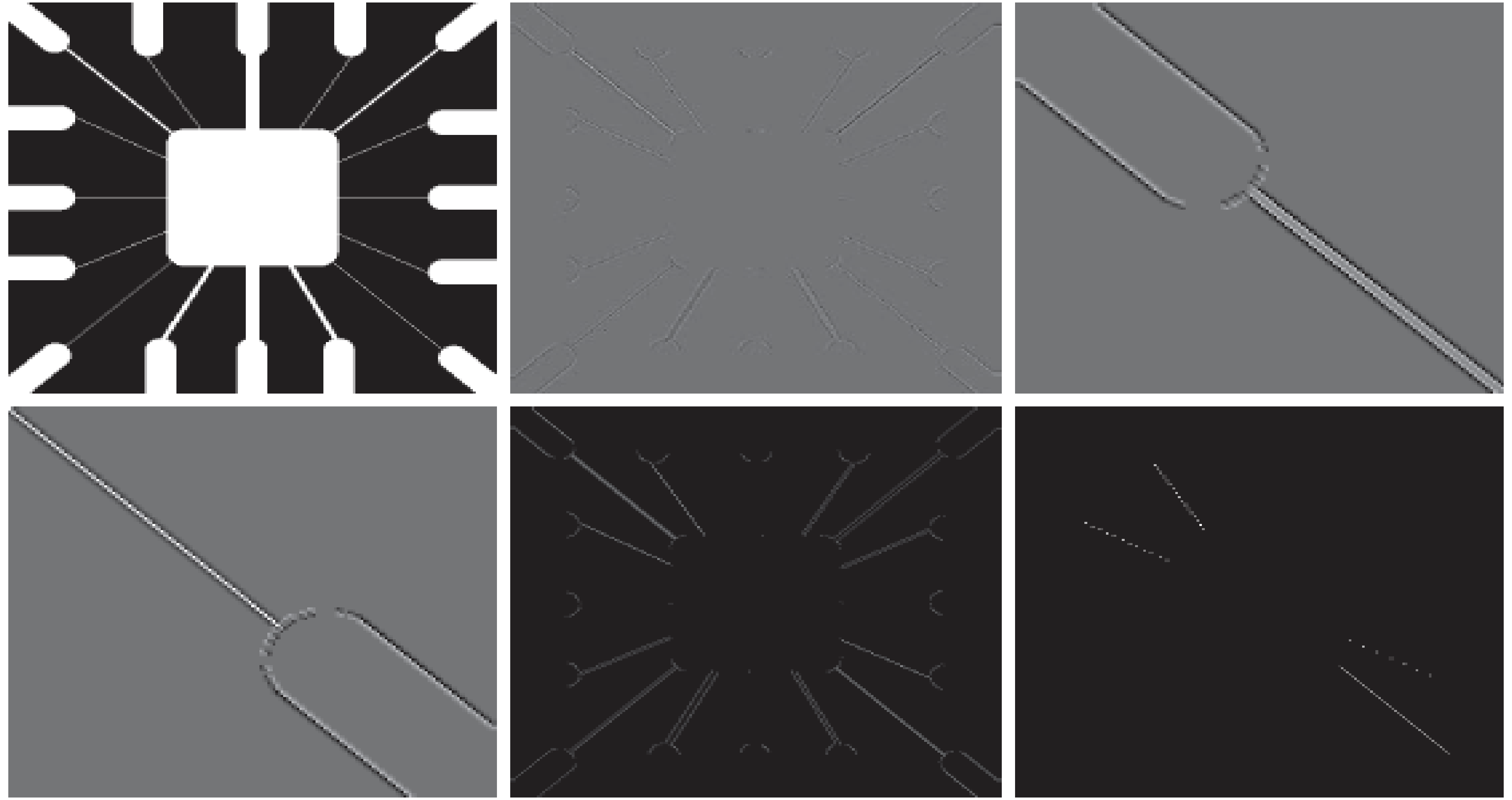


a b c
d e f

FIGURE 10.7 (a) Image of a wire-bond template. (b) Result of processing with the +45° line detector kernel in Fig. 10.6. (c) Zoomed view of the top left region of (b). (d) Zoomed view of the bottom right region of (b). (e) The image in (b) with all negative values set to zero. (f) All points (in white) whose values satisfied the condition $g > T$, where g is the image in (e) and $T = 254$ (the maximum pixel value in the image minus 1). (The points in (f) were enlarged to make them easier to see.)



a b c
d e f

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Edge Detection

- Edge detection is an approach used frequently for segmenting images.
- Edges are based on abrupt (local) changes in intensity.
- There are several ways to model edges
- A number of approaches for edge detection.

边缘检测

- 边缘检测是一种常用的方法用于分割图像。
- 边缘是基于强度的突变（局部）变化。
- 有几种方法可以建模边缘
- 多种边缘检测的方法。

Edge Detection

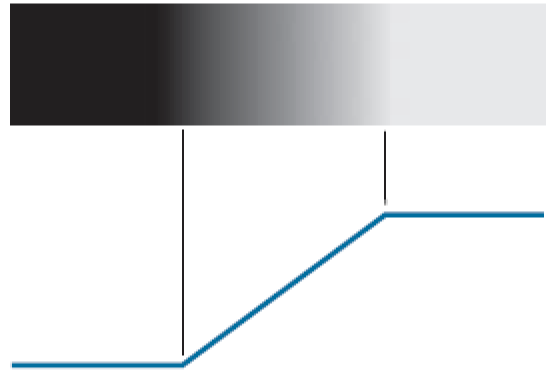
- Edge models are classified according to their intensity profiles.
- A *step edge* is characterized by a transition between two intensity levels occurring ideally over the distance of one pixel.
- Step edges occur mostly in images generated by a computer.

边缘检测

- 边缘模型根据其强度轮廓进行分类。
- A 阶梯边缘 的特征是两个强度水平之间的过渡理想情况下发生在 一个像素的距离.
- 阶梯边缘主要出现在计算机生成的图像中。

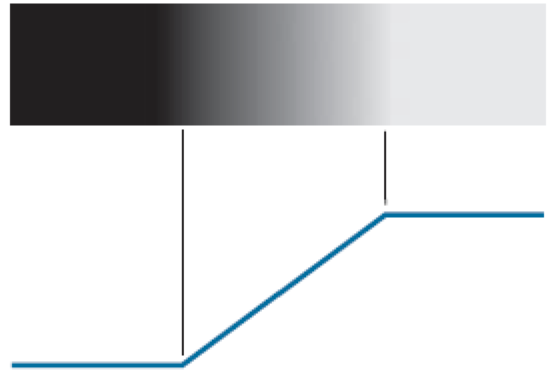
Edge Detection

- In practice, digital images have edges that are blurred and noisy.
  - Limitations in the focusing mechanism
  - Noise level determined principally by electronic components of the imaging system.
- Edges are closely modeled as having an intensity *ramp* profile.
- The slope of the ramp is inversely proportional to the degree to which the edge is blurred.



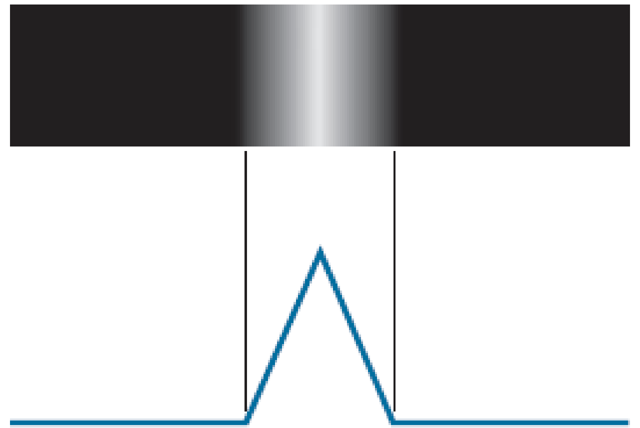
边缘检测

- 在实践中，数字图像的边缘是模糊和噪声的。
  - 聚焦机制的局限性
  - 噪声水平主要由 电子元件 的成像系统决定。
- 边缘被紧密建模为具有 强度 斜坡 特征。
- 斜坡模糊的斜率边缘与程度成反比。



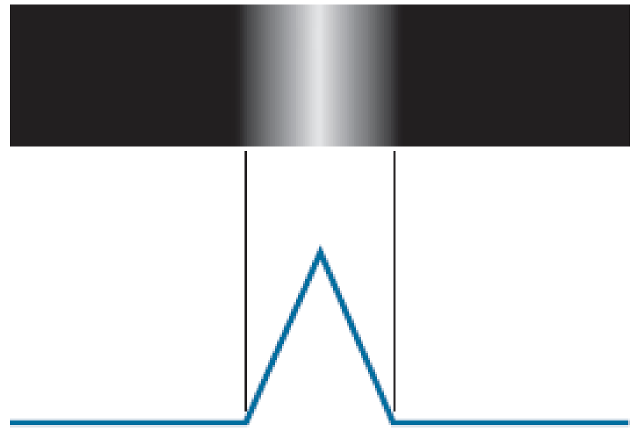
Edge Detection

- **Roof edges** are models of lines through a region
- The base (width) of the edge being determined by the thickness and sharpness of the line.
- For example, roads can be modeled by this type of edges



边缘检测

- 屋顶边缘 是 区域中的线
- 边缘被确定的 基础（宽度） 由 厚度和锐度 决定。
- 例如， 道路可以通过这种类型的边缘建模 。



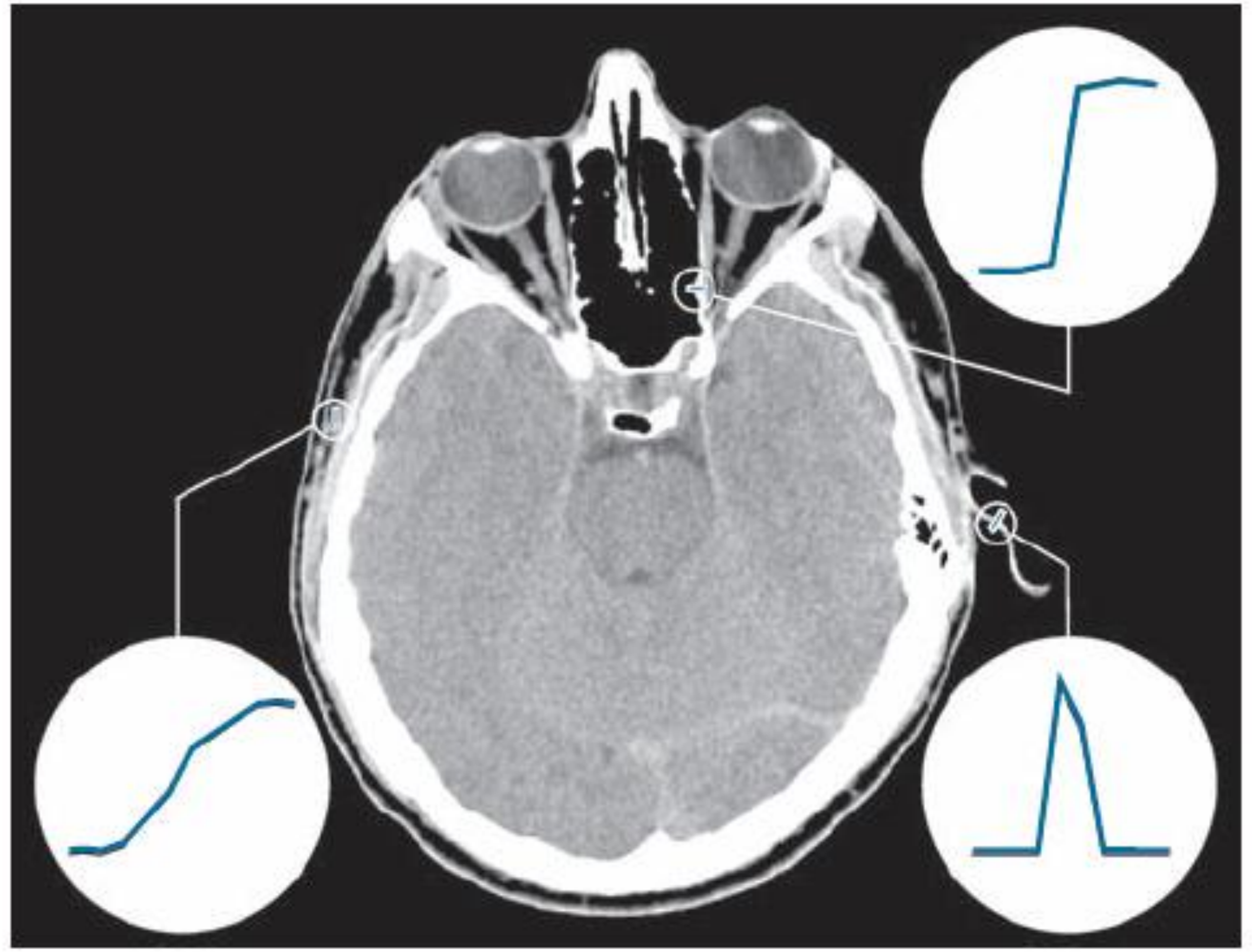
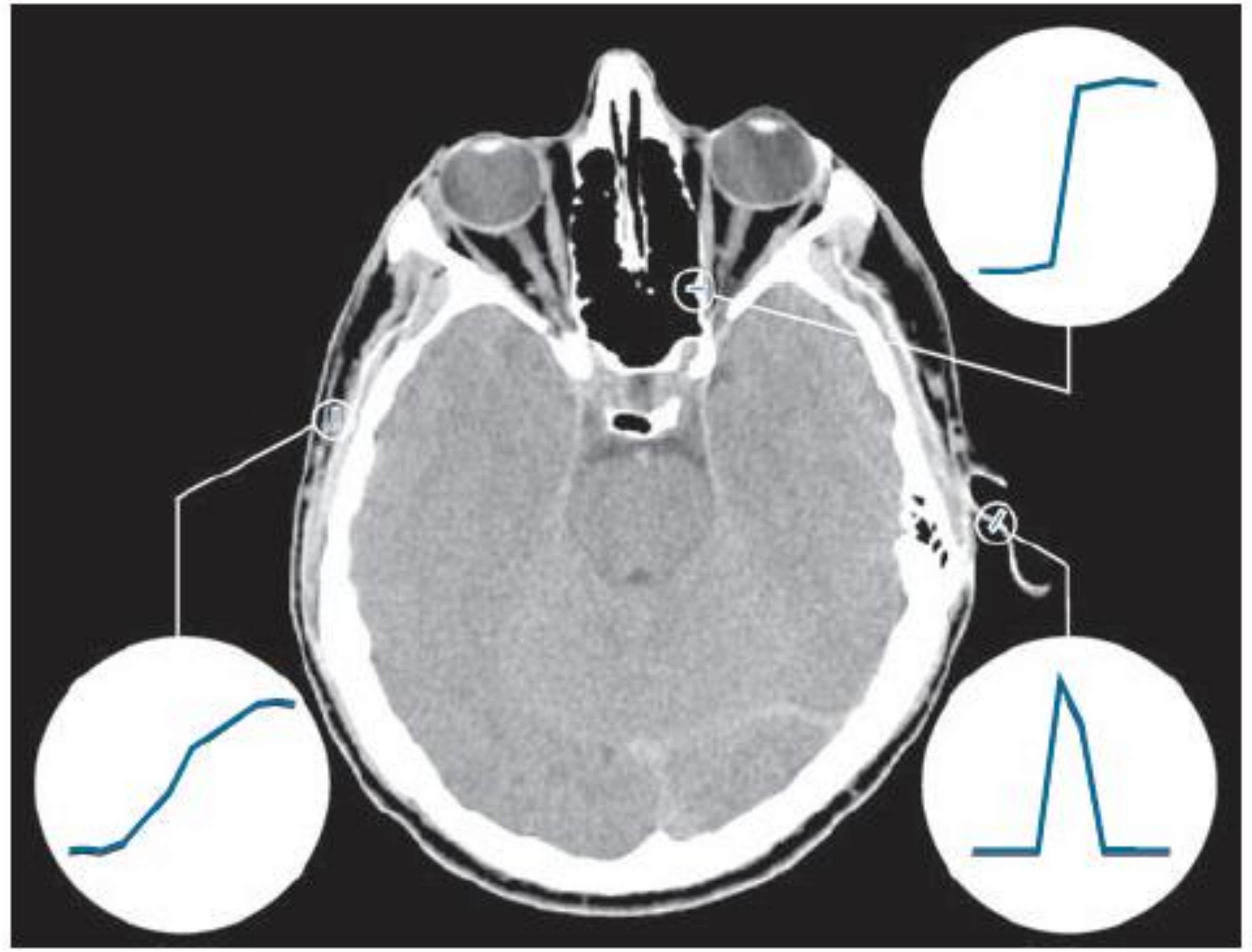


FIGURE 10.9 A 1508 × 1970 image showing (zoomed) actual ramp (bottom, left), step (top, right), and roof edge profiles. The profiles are from dark to light, in the areas enclosed by the small circles. The ramp and step profiles span 9 pixels and 2 pixels, respectively. The base of the roof edge is 3 pixels. (Original image courtesy of Dr. David R. Pickens, Vanderbilt University.)



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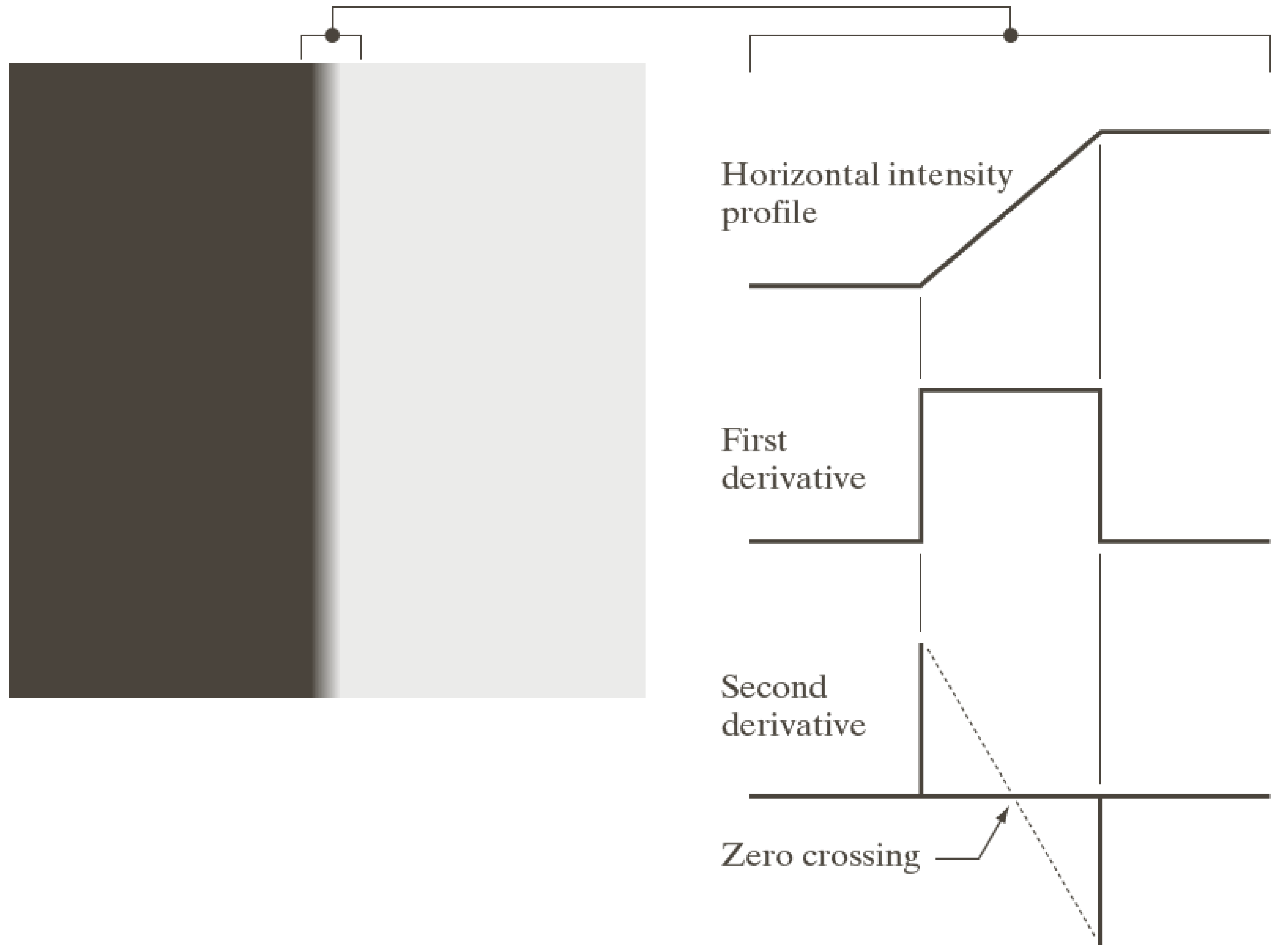
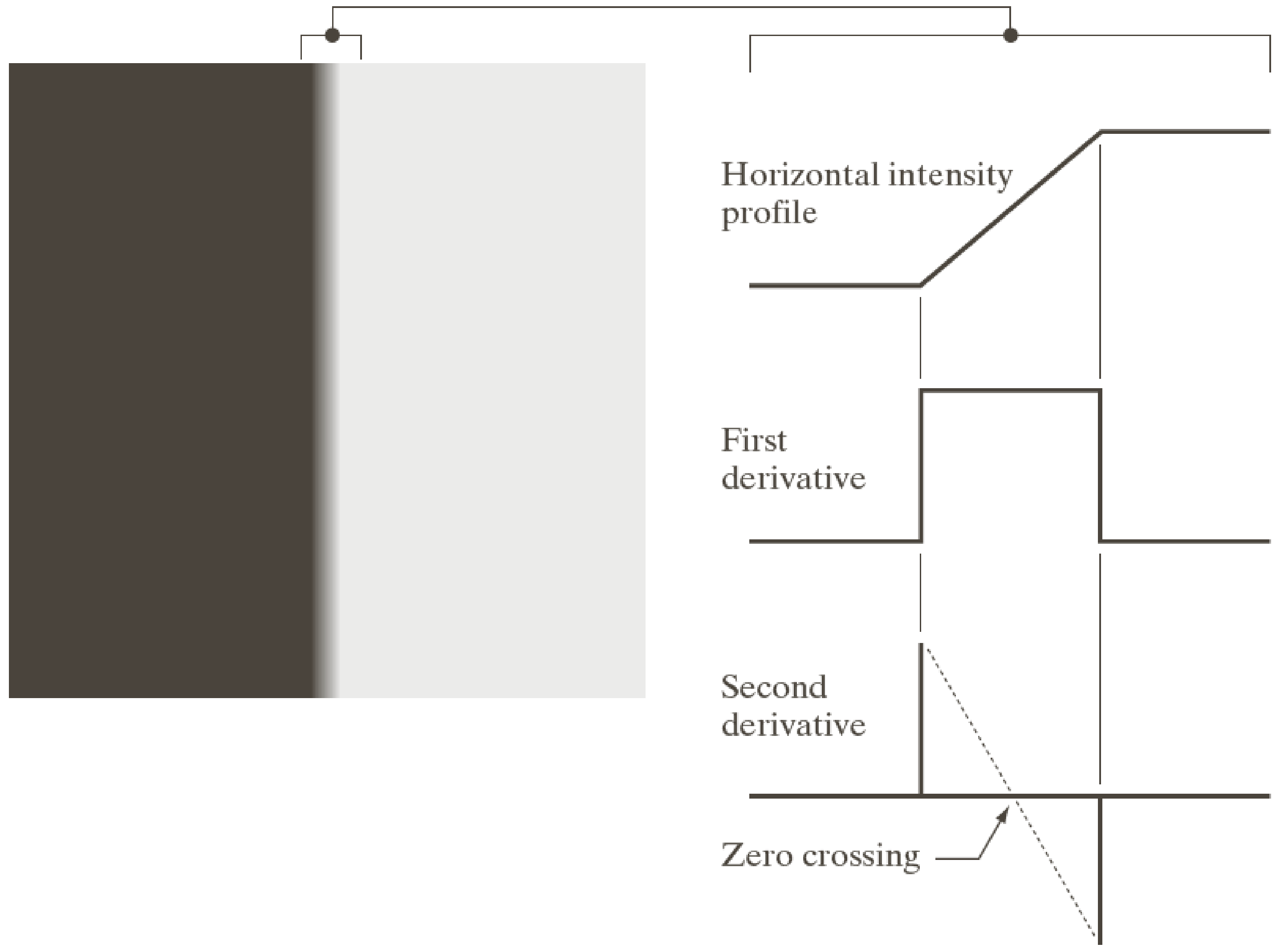


a b

FIGURE 10.10 (a) Two regions of constant intensity separated by an ideal vertical ramp edge. (b) Detail near the edge, showing a horizontal intensity profile, together with its first and second derivatives.



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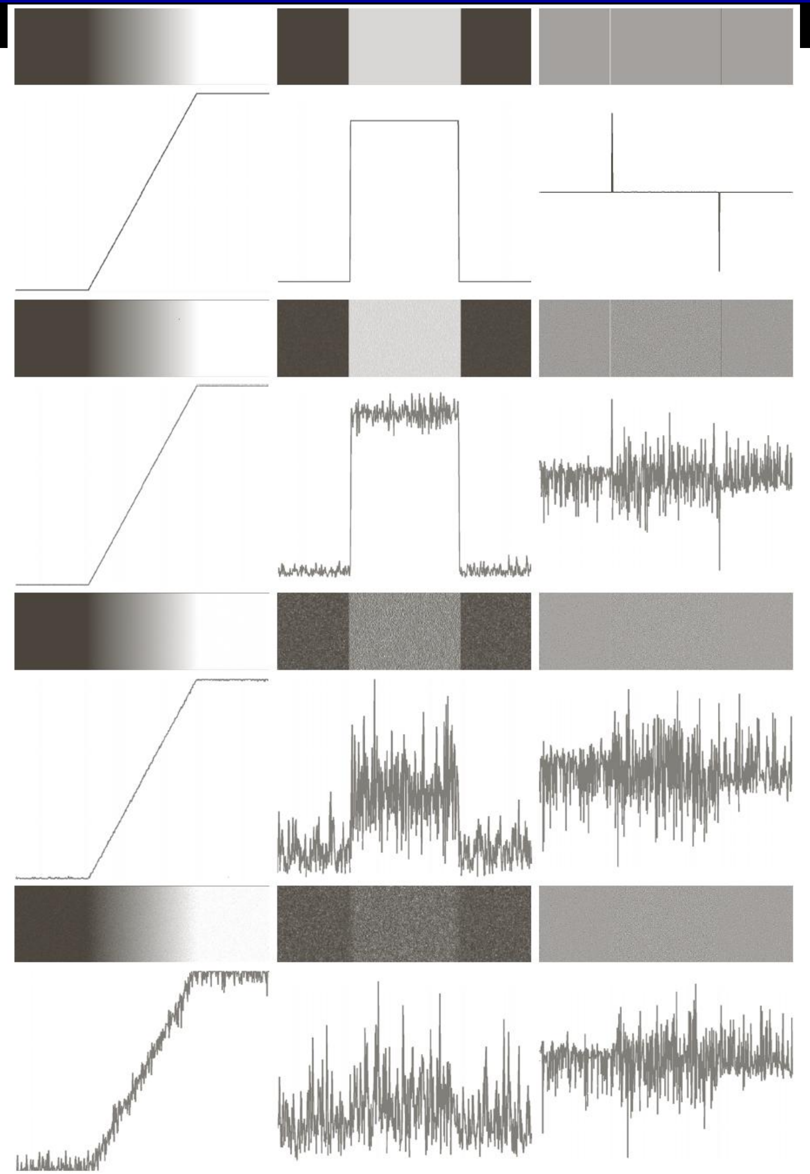
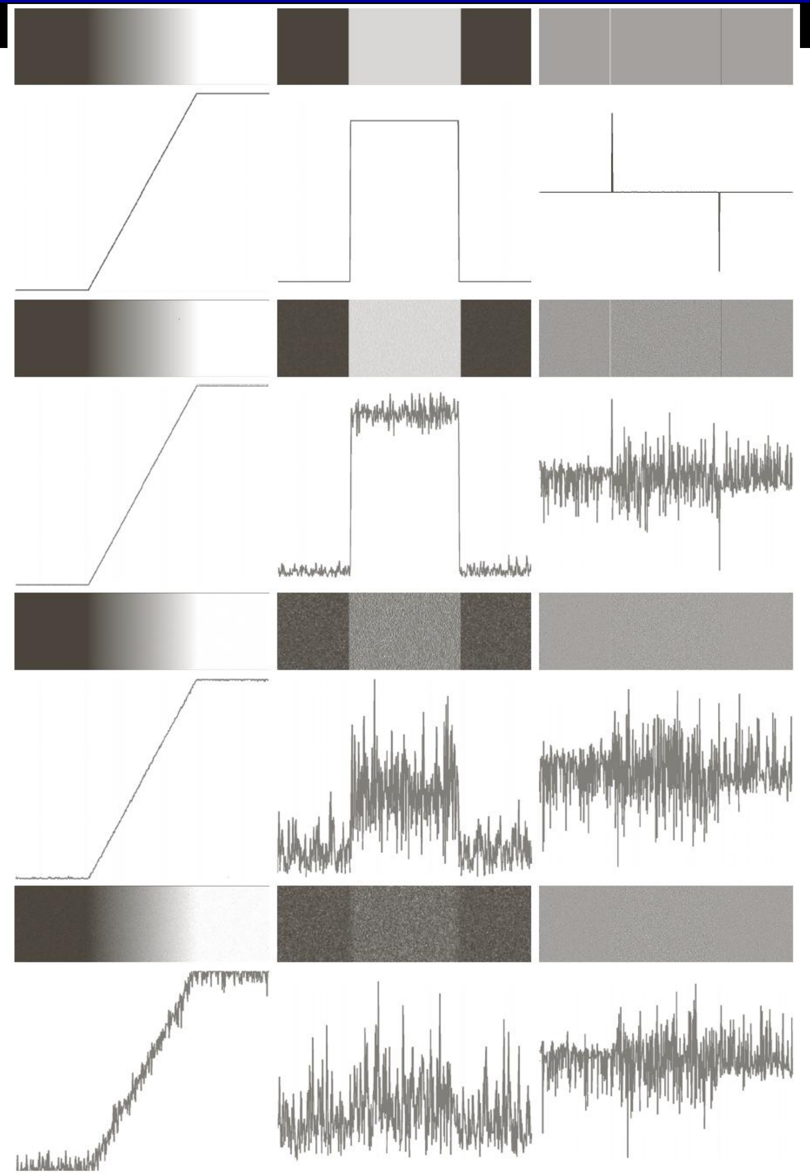


FIGURE 10.11 First column: Images and intensity profiles of a ramp edge corrupted by random Gaussian noise of zero mean and standard deviations of 0.0, 0.1, 1.0, and 10.0 intensity levels, respectively. Second column: First-derivative images and intensity profiles. Third column: Second-derivative images and intensity profiles.



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Edge Detection with Noise

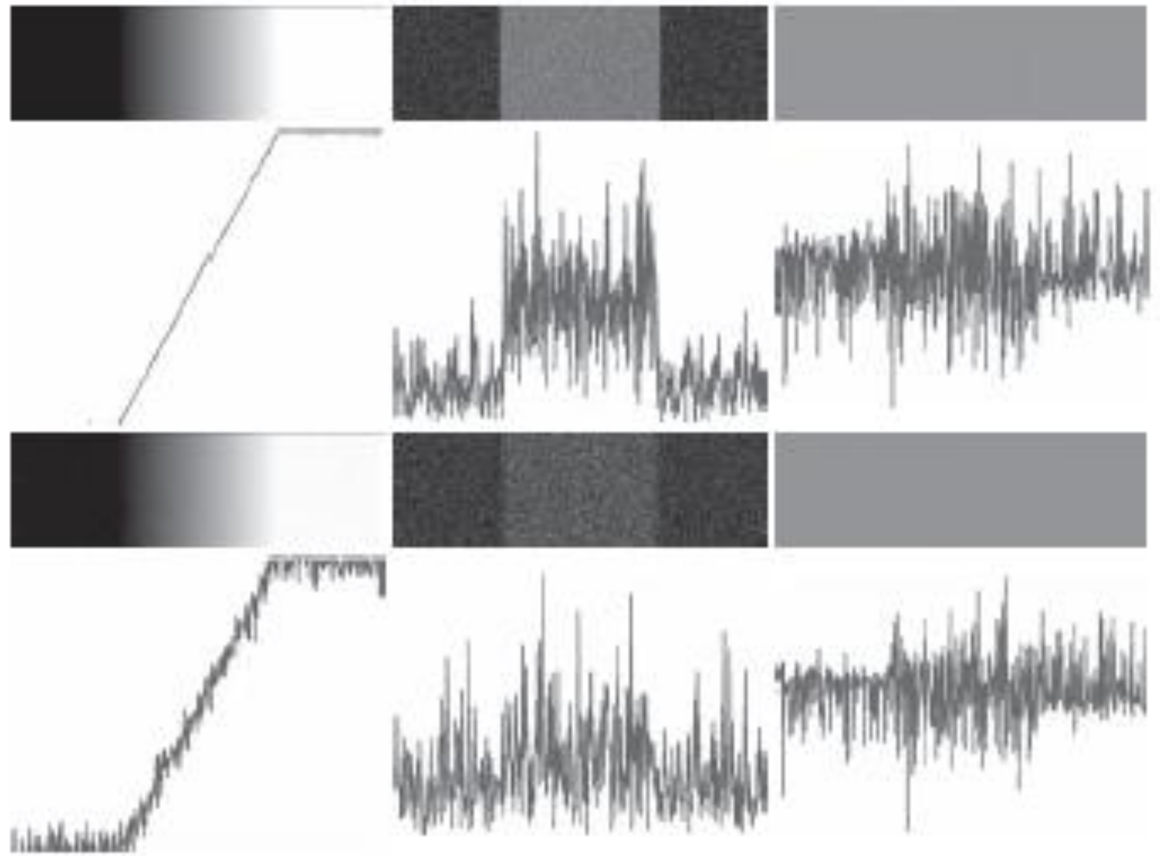
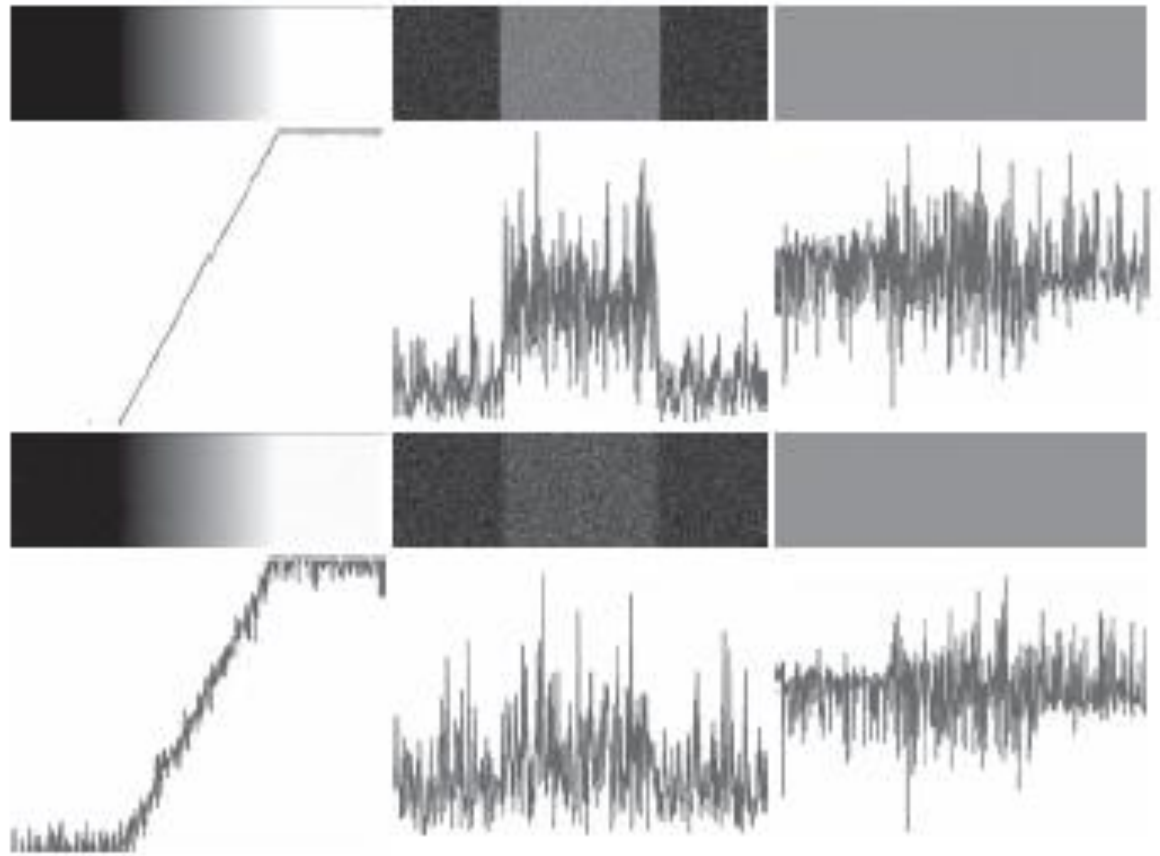


FIGURE 10.11 First column: 8-bit images with values in the range [0, 255], and intensity profiles of a ramp edge corrupted by Gaussian noise of zero mean and standard deviations of 0.0, 0.1, 1.0, and 10.0 intensity levels, respectively. Second column: First-derivative images and intensity profiles. Third column: Second-derivative images and intensity profiles.

带噪声的边缘检测



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- The magnitude of the first derivative can be used to detect the presence of an edge at a point in an image.
- the sign of the second derivative can be used to determine whether an edge pixel lies on the dark or light side of an edge.
- Two additional properties of the second derivative around an edge are: (1) it produces two values for every edge in an image; and (2) its zero crossings can be used for locating the centers of thick edges.

- 一阶[illegible]。
- 二阶[illegible]还是亮侧。
- 二阶[illegible]图像中的每个边缘产生两个值；以及 (2) 它的零交叉可以用于定位厚边缘的中心。

Edge Detection with Noise

- Three steps are typically performed for edge detection are:
- **1.** *Image smoothing for noise reduction*.
- **2.** *Detection of edge points.* Find pixels that are potential edge-point candidates.
- **3.** *Edge localization.* The objective of this step is to select from the candidate points only the points that are members of the set of points comprising an edge.

带噪声的边缘检测

- 边缘检测通常执行三个步骤:
- **1.** 图像平滑以减少噪声.
- **2.** 边缘点的检测. 找到潜在的边缘点候选像素。
- **3.** 边缘定位. 此步骤的目标是从候选点中选择仅属于构成边缘的点集的点。

BASIC EDGE DETECTION

- The tool of choice for finding edge strength *and* direction at an arbitrary location (*x*,*y*) of an image, *f*, is the *gradient*, denoted by *f* and defined as the *vector*
- *Gradient*

$$\nabla f(x,y) \equiv \mathrm{grad}\left[f(x,y)\right] \equiv \begin{bmatrix} g_x(x,y) \\ g_y(x,y) \end{bmatrix} = \begin{bmatrix} \dfrac{\partial f(x,y)}{\partial x} \\ \dfrac{\partial f(x,y)}{\partial y} \end{bmatrix}$$

- *Magnitude*

$$M(x,y) = \left\| \nabla f(x,y) \right\| = \sqrt{g_x^2(x,y) + g_y^2(x,y)}$$

- *Direction*

$$\alpha(x,y) = \tan^{-1}\left[\frac{g_y(x,y)}{g_x(x,y)}\right]$$

基本边缘检测

- 在图像 f 的任意位置 (x,y) 查找边缘强度和方向的首选工具是梯度，表示为 f，并定义为向量
- 梯度

$$\nabla f(x,y) \equiv \mathrm{grad}\left[f(x,y)\right] \equiv \begin{bmatrix} g_x(x,y) \\ g_y(x,y) \end{bmatrix} = \begin{bmatrix} \dfrac{\partial f(x,y)}{\partial x} \\ \dfrac{\partial f(x,y)}{\partial y} \end{bmatrix}$$

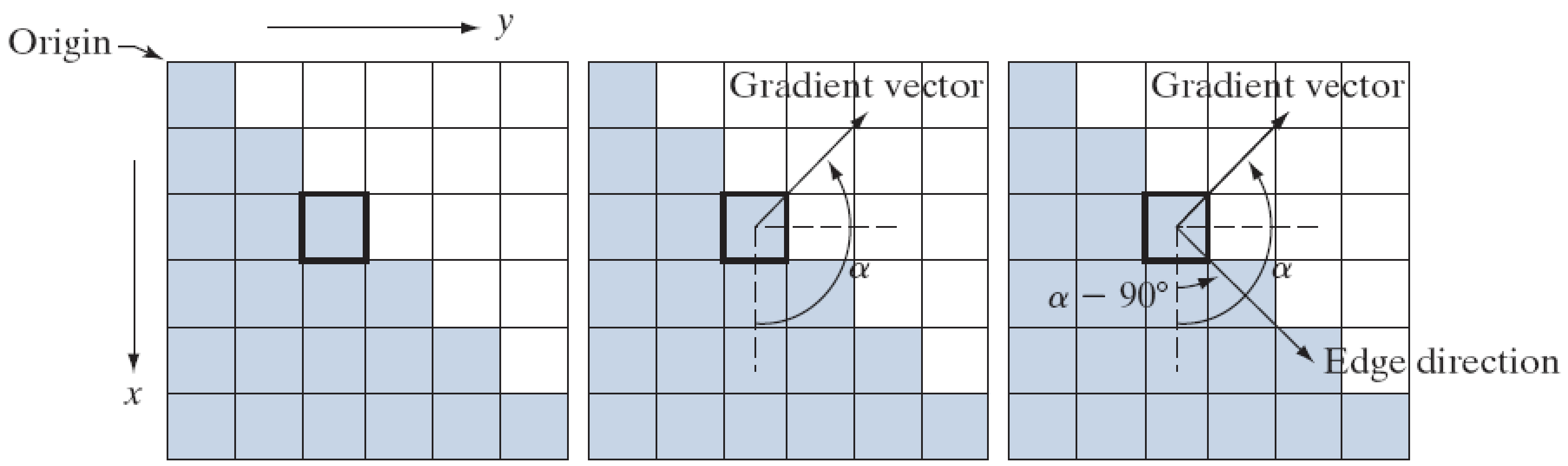
- 大小

$$M(x,y) = \left\| \nabla f(x,y) \right\| = \sqrt{g_x^2(x,y) + g_y^2(x,y)}$$

- 方向

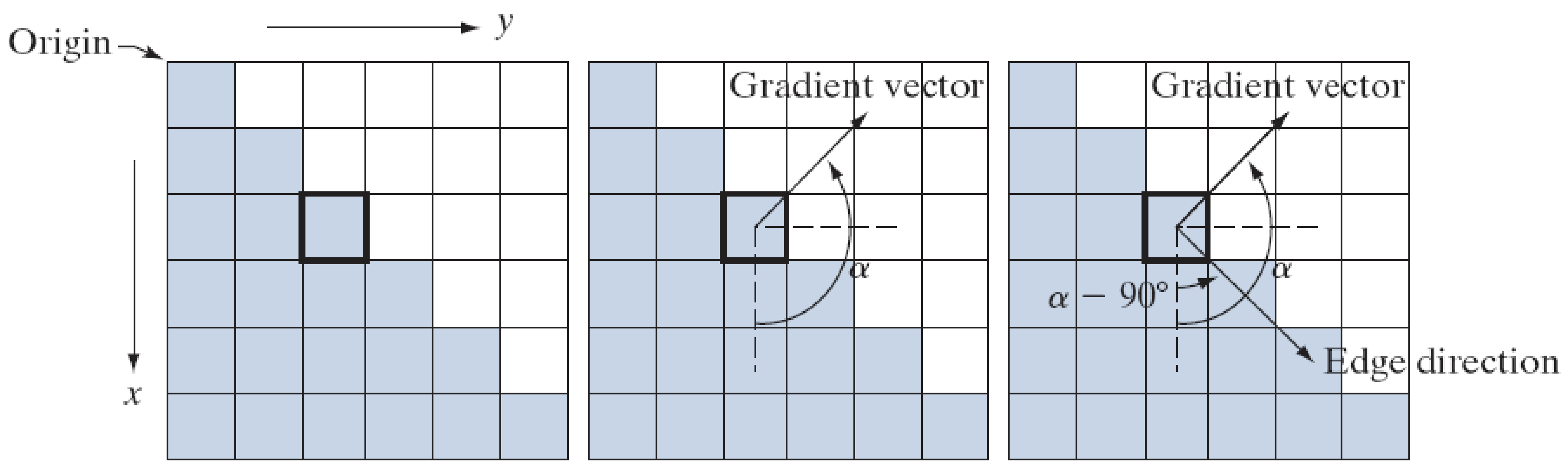
$$\alpha(x,y) = \tan^{-1}\left[\frac{g_y(x,y)}{g_x(x,y)}\right]$$

BASIC EDGE DETECTION



The edge direction is perpendicular to the direction of the gradient vector

基本边缘检测



边缘方向与梯度向量的方向垂直

BASIC EDGE DETECTION

−1
1

−1	1

a b

FIGURE 10.13 One-dimensional masks used to implement Eqs. (10.2-12) and (10.2-13).

基本边缘检测

−1
1

−1	1

a b

FIGURE 10.13 One-dimensional masks used to implement Eqs. (10.2-12) and (10.2-13).

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

−1	0
0	1

0	−1
1	0

Roberts

−1	−1	−1
0	0	0
1	1	1

−1	0	1
−1	0	1
−1	0	1

Prewitt

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

Sobel

a
b c
d e
f g

FIGURE 10.14 A 3 × 3 region of an image (the z's are intensity values) and various masks used to compute the gradient at the point labeled z_5.

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

−1	0
0	1

0	−1
1	0

Roberts

−1	−1	−1
0	0	0
1	1	1

−1	0	1
−1	0	1
−1	0	1

Prewitt

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

Sobel

a
b c
d e
f g

FIGURE 10.14 A 3 × 3 region of an image (the z's are intensity values) and various masks used to compute the gradient at the point labeled z_5.

BASIC EDGE DETECTION

0	1	1
−1	0	1
−1	−1	0

−1	−1	0
−1	0	1
0	1	1

Prewitt

0	1	2
−1	0	1
−2	−1	0

−2	−1	0
−1	0	1
0	1	2

Sobel

a b
c d

FIGURE 10.15 Prewitt and Sobel masks for detecting diagonal edges.

基本边缘检测

0	1	1
−1	0	1
−1	−1	0

−1	−1	0
−1	0	1
0	1	1

Prewitt

0	1	2
−1	0	1
−2	−1	0

−2	−1	0
−1	0	1
0	1	2

Sobel

a b
c d

FIGURE 10.15 Prewitt and Sobel masks for detecting diagonal edges.

a b
c d

FIGURE 10.16
(a) Original image of size 834×1114 pixels, with intensity values scaled to the range [0, 1]. (b) $|g_x|$, the component of the gradient in the x-direction, obtained using the Sobel mask in Fig. 10.14(f) to filter the image. (c) $|g_y|$, obtained using the mask in Fig. 10.14(g). (d) The gradient image, $|g_x| + |g_y|$.

a b
c d

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BASIC EDGE DETECTION

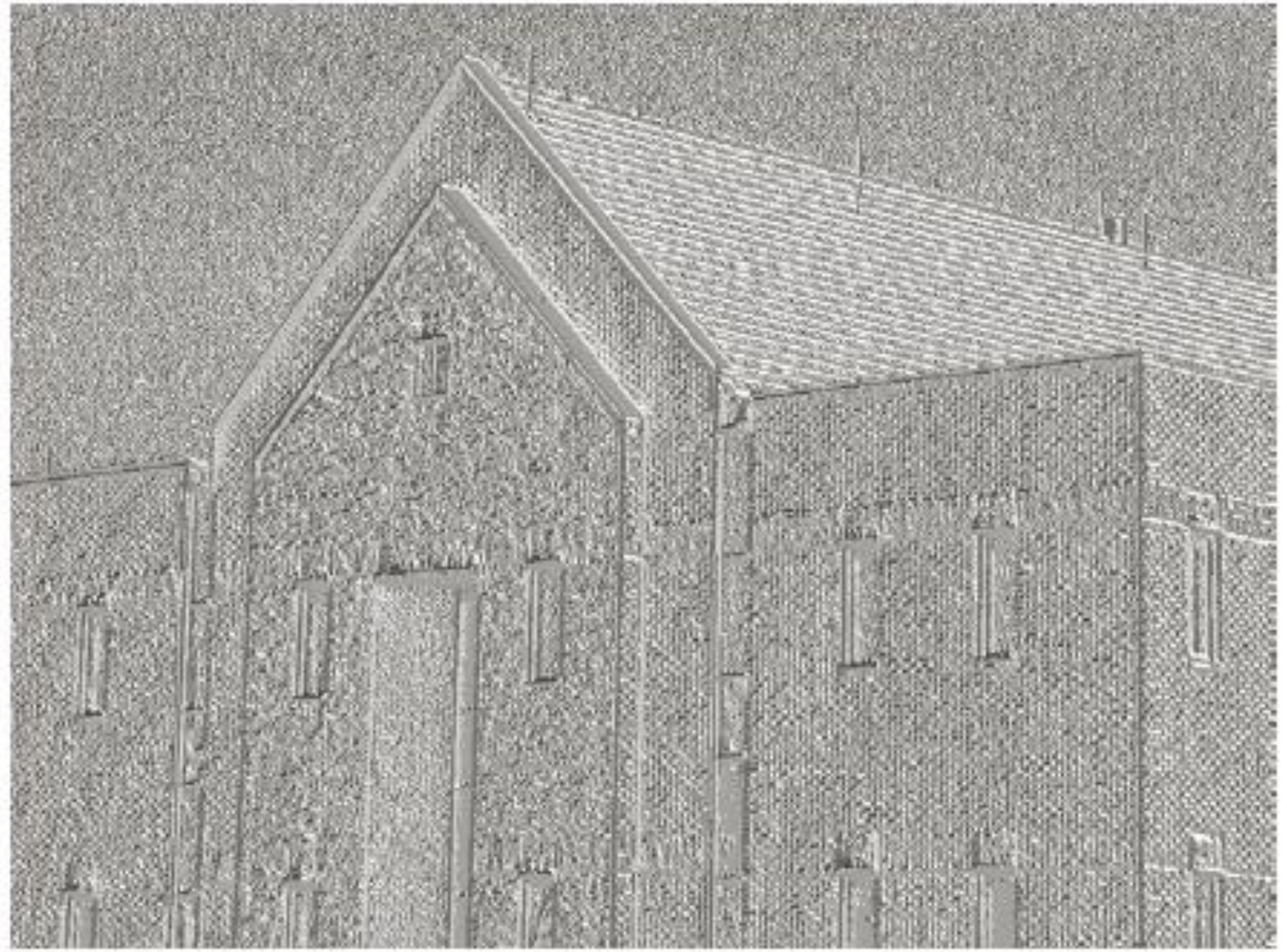
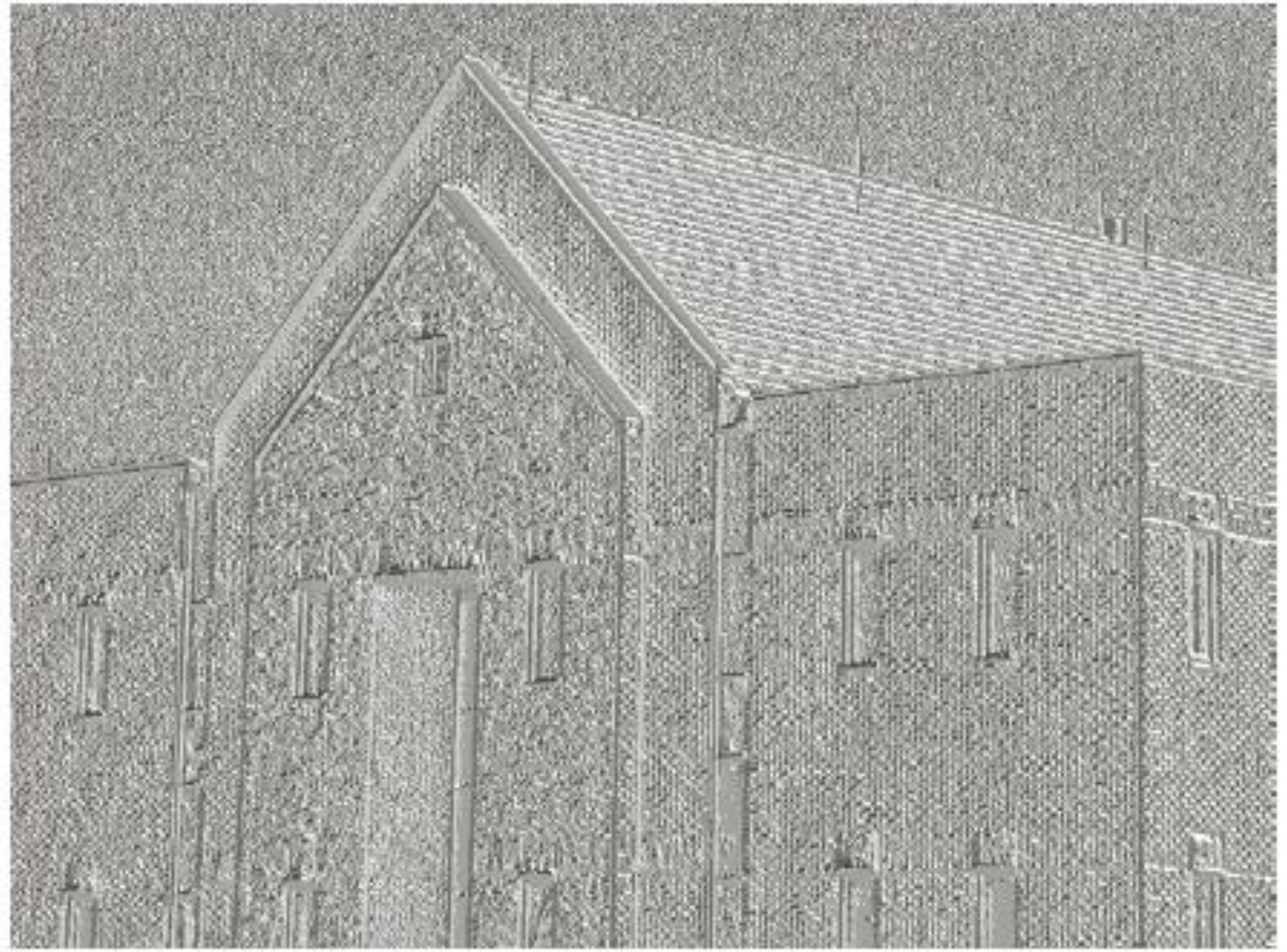


FIGURE 10.17 Gradient angle image computed using Eq. (10.2-11). Areas of constant intensity in this image indicate that the direction of the gradient vector is the same at all the pixel locations in those regions.

基本边缘检测



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a b
c d

FIGURE 10.18 Same sequence as in Fig. 10.16, but with the original image smoothed using a 5 × 5 averaging filter prior to edge detection.

a b
c d

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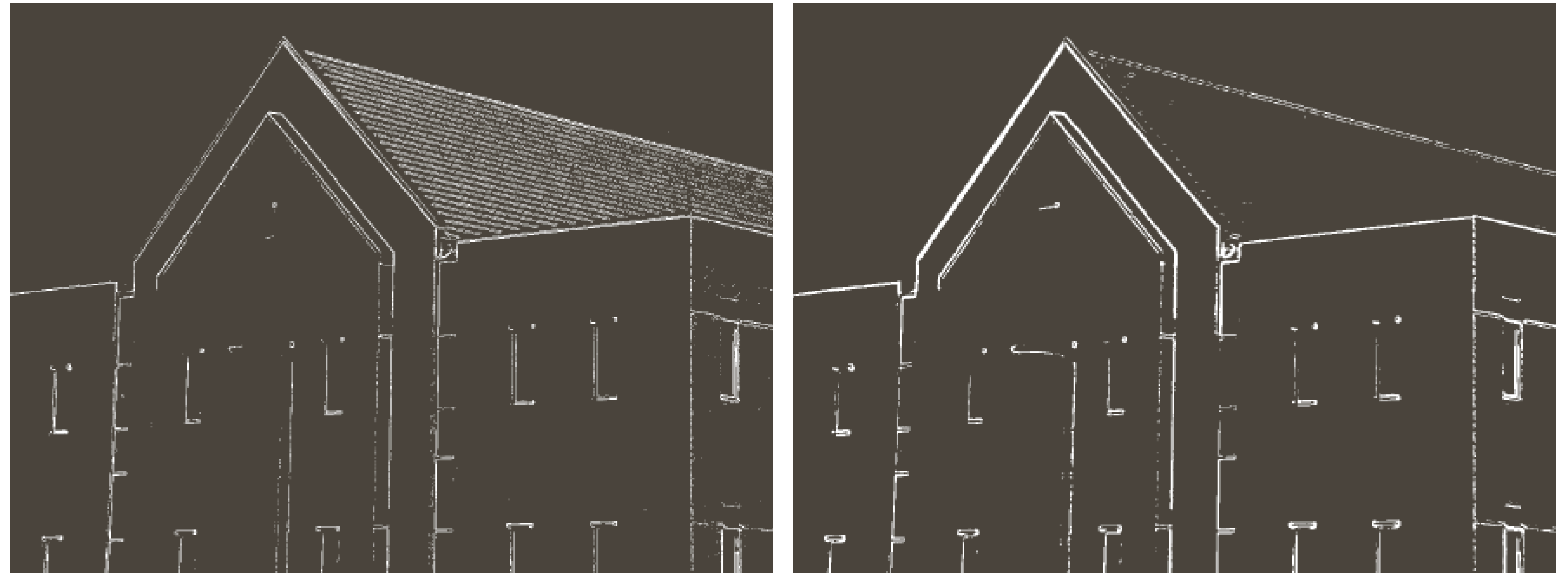
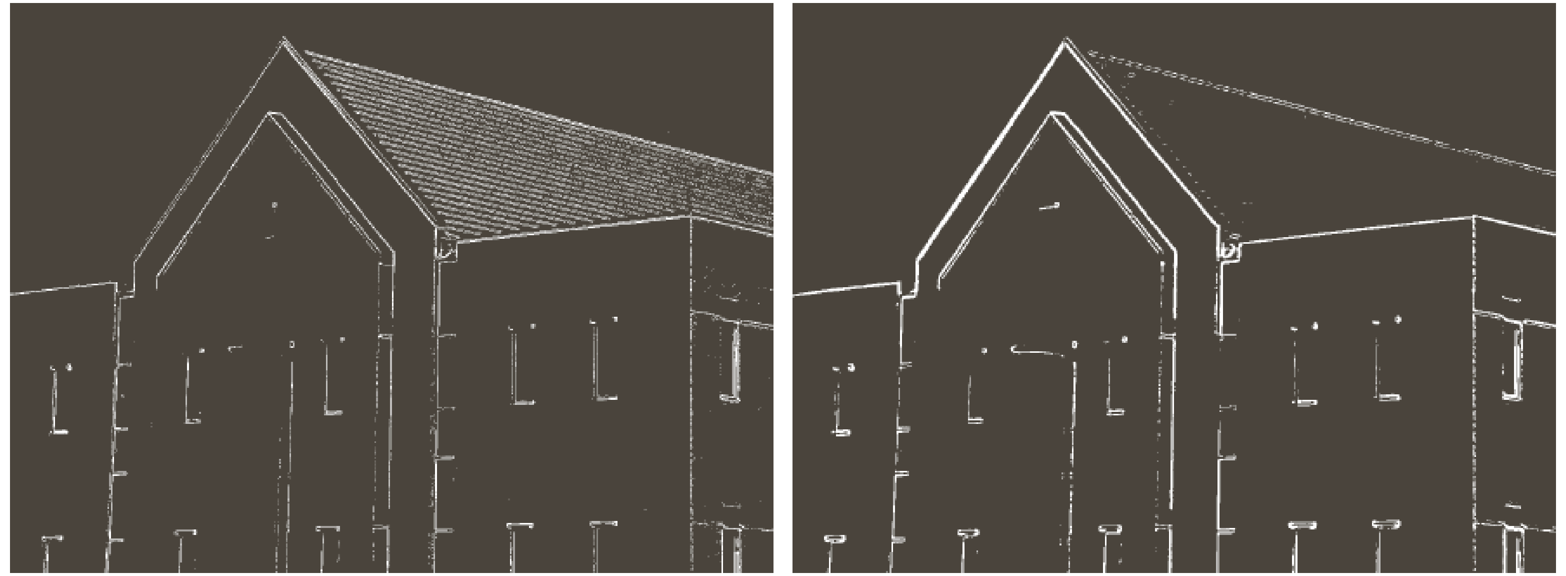


a b

FIGURE 10.20 (a) Thresholded version of the image in Fig. 10.16(d), with the threshold selected as 33% of the highest value in the image; this threshold was just high enough to eliminate most of the brick edges in the gradient image. (b) Thresholded version of the image in Fig. 10.18(d), obtained using a threshold equal to 33% of the highest value in that image.



a b

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Operator	Type	Edge Direction	Noise Sensitivity	Usage Example
Roberts	First derivative (2×2)	Diagonal edges	Very high	Simple, fast edge detection
Prewitt	First derivative (3×3)	Horizontal & Vertical	High	Basic edge detection
Sobel	First derivative (3×3, weighted)	Horizontal & Vertical	Medium (better than Prewitt)	Feature extraction, vision tasks
Laplacian	Second derivative (3×3)	All directions (isotropic)	Very high	Edge detection + sharpening (with smoothing)

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1. Medical Imaging (X-rays, MRI, Ultrasound)

Goal: Detect organ/tissue boundaries.

Best choice:

- **Sobel** → when you want **direction** + **edge strength** (e.g., detecting blood vessel edges).
- **Laplacian (with Gaussian smoothing → LoG)** → for **precise boundary localization** (e.g., tumor outline).

Why? Sobel keeps orientation info, Laplacian finds closed contours.

2. Object Detection in Computer Vision

Goal: Detect objects (cars, faces, pedestrians).

Best choice:

- **Sobel** → for **feature extraction** (edges + directions feed into algorithms like HOG, SIFT, or CNNs).

Why? Orientation info is critical for recognizing object shapes.

Not ideal: Laplacian → too sensitive to noise, can create false edges.

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3. Document Scanning / Text Recognition (OCR)

Goal: Extract characters from scanned text.

Best choice:

- **Sobel/Prewitt** → clean edge extraction of text strokes.

Why? Characters are mostly vertical/horizontal edges → Sobel handles this well.

4. Satellite & Aerial Images

Goal: Detect roads, buildings, rivers.

Best choice:

- **Sobel** → for road/river boundaries (directional info).
- **Laplacian** → to sharpen blurred aerial images (enhance details).

Workflow: Often combine Sobel edges + Laplacian sharpening.

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5. Image Sharpening (Photography, Enhancement)

Goal: Enhance details, make image crisper.

Best choice:

- **Laplacian** → add second-derivative edges back to original image.
- (This is like **unsharp masking**).

Why? Laplacian emphasizes fine details (high-frequency components).

Use Sobel (or Prewitt/Roberts) → when you need **edge orientation + magnitude** (for feature extraction, edge maps).

Use Laplacian → when you need **sharpening or isotropic edge detection** (no direction needed, just “where” the edges are).

Use Laplacian + Gaussian (LoG) → when the image has **noise**, to smooth + detect edges robustly.

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Contour Detection

- Contour is a curve joining all the continuous points (along the boundary) of an object.
- The object has same intensity.
- Useful tool for shape analysis and object detection and recognition.
- Before obtaining contours, convert input images into binary images.
  - Objects in white background in black
  - Recommended

轮廓检测

- 轮廓是连接物体边界上所有连续点的曲线。
- 物体具有相同强度。
- 用于形状分析和物体检测和识别的有用工具。
- 在获取轮廓之前，将输入图像转换为二值图像。
  - 黑色背景中的白色背景物体– 推荐

Reading Assignments

- Getting started with Contours: OpenCV
- Explore all Contour Properties provided by OpenCV
- Particularly read following :
  - https://docs.opencv.org/4.x/d4/d73/tutorial_py_contours_begin.html
  - https://docs.opencv.org/4.x/dd/d49/tutorial_py_contour_features.html

阅读作业

- 开始使用轮廓：OpenCV
- 探索 OpenCV 提供的所有轮廓属性
- 特别阅读以下内容：
  - https://docs.opencv.org/4.x/d4/d73/tutorial_py_contours_begin.html
  - https://docs.opencv.org/4.x/dd/d49/tutorial_py_contour_features.html

Reference

- Read 10th Chapter Digital image processing
- https://docs.opencv.org/4.x/d5/daf/tutorial_py_histogram_equalization.html
- https://iq.opengenus.org/connected-component-labeling/
- https://ajlearn.net/opencv_contours

参考

- 阅读第十章数字图像处理
- https://docs.opencv.org/4.x/d5/daf/tutorial_py_histogram_equalization.html
- https://iq.opengenus.org/连通组件标记/
- https://ajlearn.net/opencv_contours

Thank You ☺

谢谢 ☺