DIGITAL IMAGE PROCESSING

Image Segmentation

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Image Analysis

- Image analysis is the extraction of meaningful information from images
- Involves study of
  - Segmentation
  - Feature Extraction
  - Classification

Image Analysis: Edge Detection

Image Analysis: Segmentation

Image Segmentation

- Definitions
  - Segmentation subdivides an image into its constituent regions or objects
  - Segmentation is a process of grouping together pixels that have similar attributes
  - Image Segmentation is the process of partitioning an image into non-intersecting regions such that each region is homogeneous and the union of no two adjacent regions is homogeneous

Image Segmentation

- Objective
  - To find individual objects in an image

  OR

  - To subdivide an image into its constituent regions or objects to simplify and/or change the representation of an image into something that is more meaningful and easier to analyze

- Typically used to locate objects and boundaries (lines, curves, etc.) in images

Image Segmentation

- Segmentation algorithms generally are based on one of two basic properties of intensity values
  - Discontinuity
    - Partitioning based on abrupt changes in intensity such as edges
  - Similarity
    - Partitioning into regions based on predefined criteria (pixel intensity, color, texture etc.)

Example

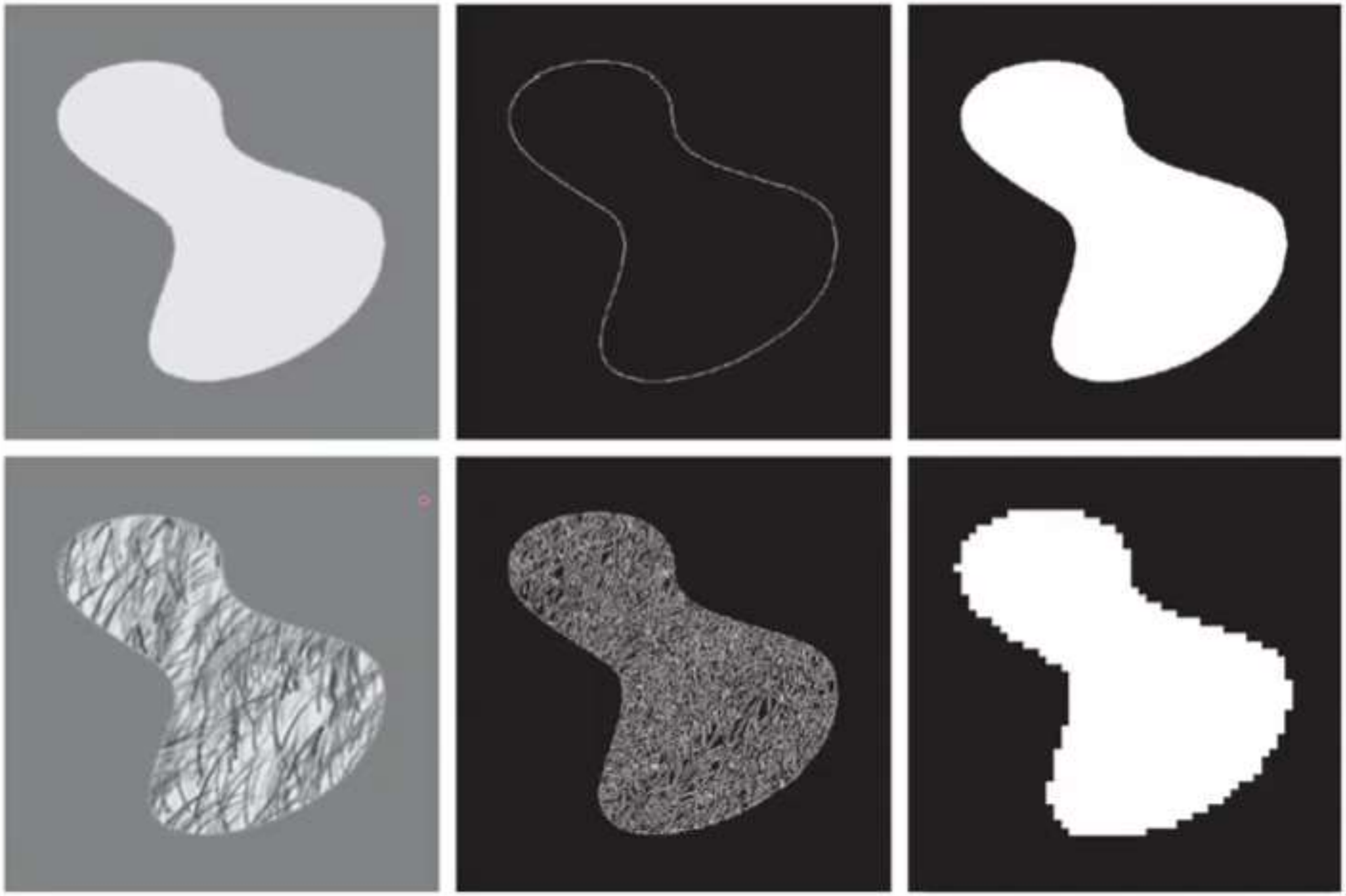


FIGURE 10.1
(a) Image of a constant intensity region.
(b) Boundary based on intensity discontinuities.
(c) Result of segmentation.
(d) Image of a texture region.
(e) Result of intensity discontinuity computations (note the large number of small edges).
(f) Result of segmentation based on region properties.

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

Background

a b
c

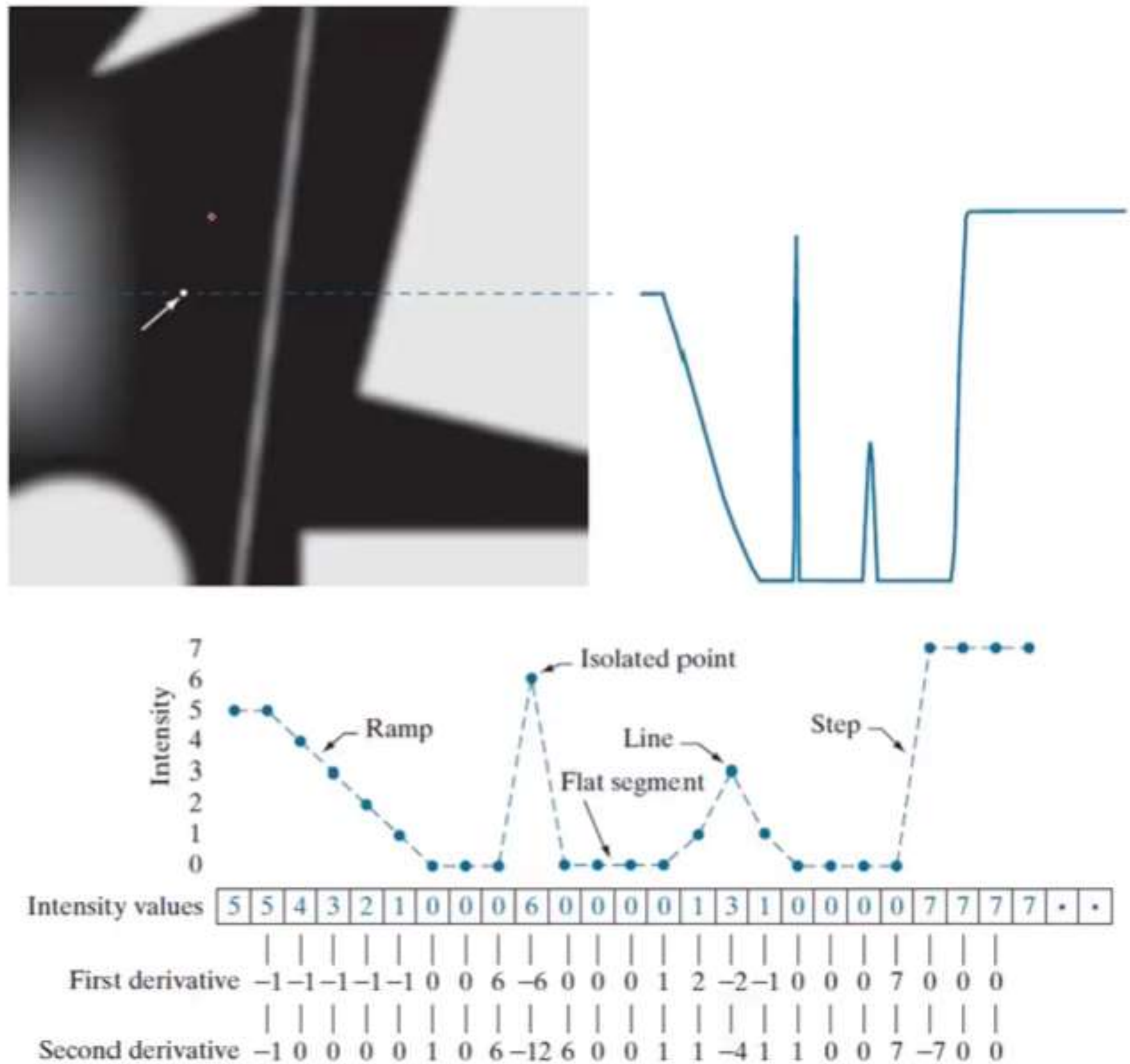


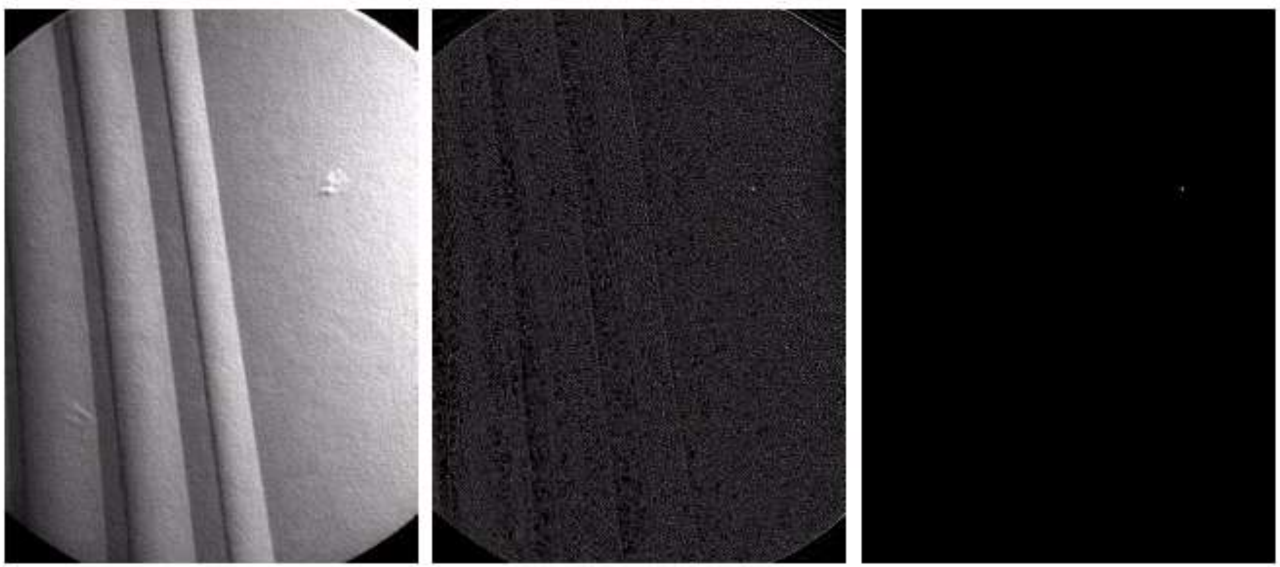
FIGURE 10.2 (a) Image. (b) Horizontal intensity profile that includes the isolated point indicated by the arrow. (c) Subsampled profile; the dashes were added for clarity. The numbers in the boxes are the intensity values of the dots shown in the profile. The derivatives were obtained using Eqs. (10-4) for the first derivative and Eq. (10-7) for the second.

Detection of Discontinuities
Point Detection

$$|R| \geq T$$

where T : a nonnegativ e 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.

−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°

Detection of Discontinuities
Line Detection

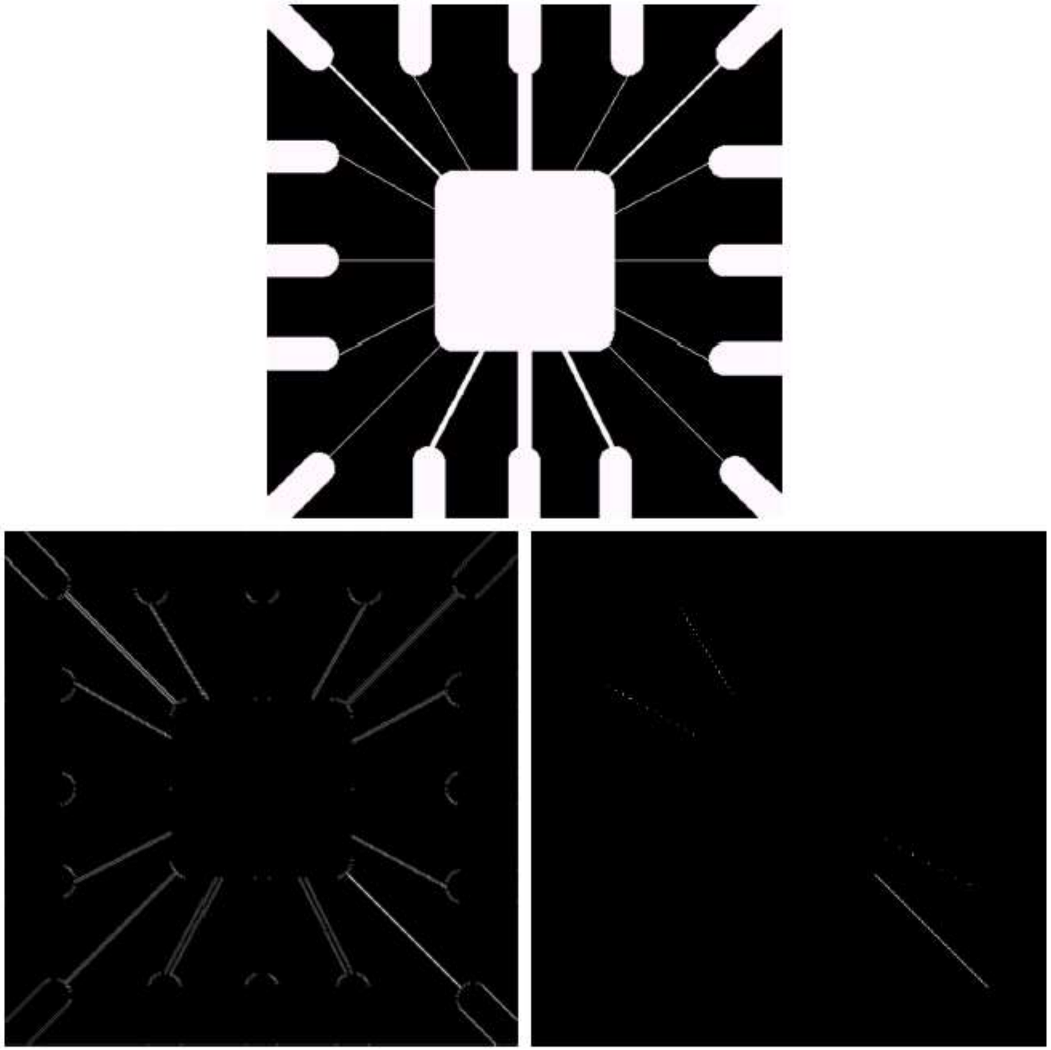


FIGURE 10.4 Illustration of line detection. (a) Binary wire-bond mask. (b) Absolute value of result after processing with $-45°$ line detector. (c) Result of thresholding image (b).

Edge Detection

- What is an edge?
  - Set of connected pixels that lie on the boundary between two regions

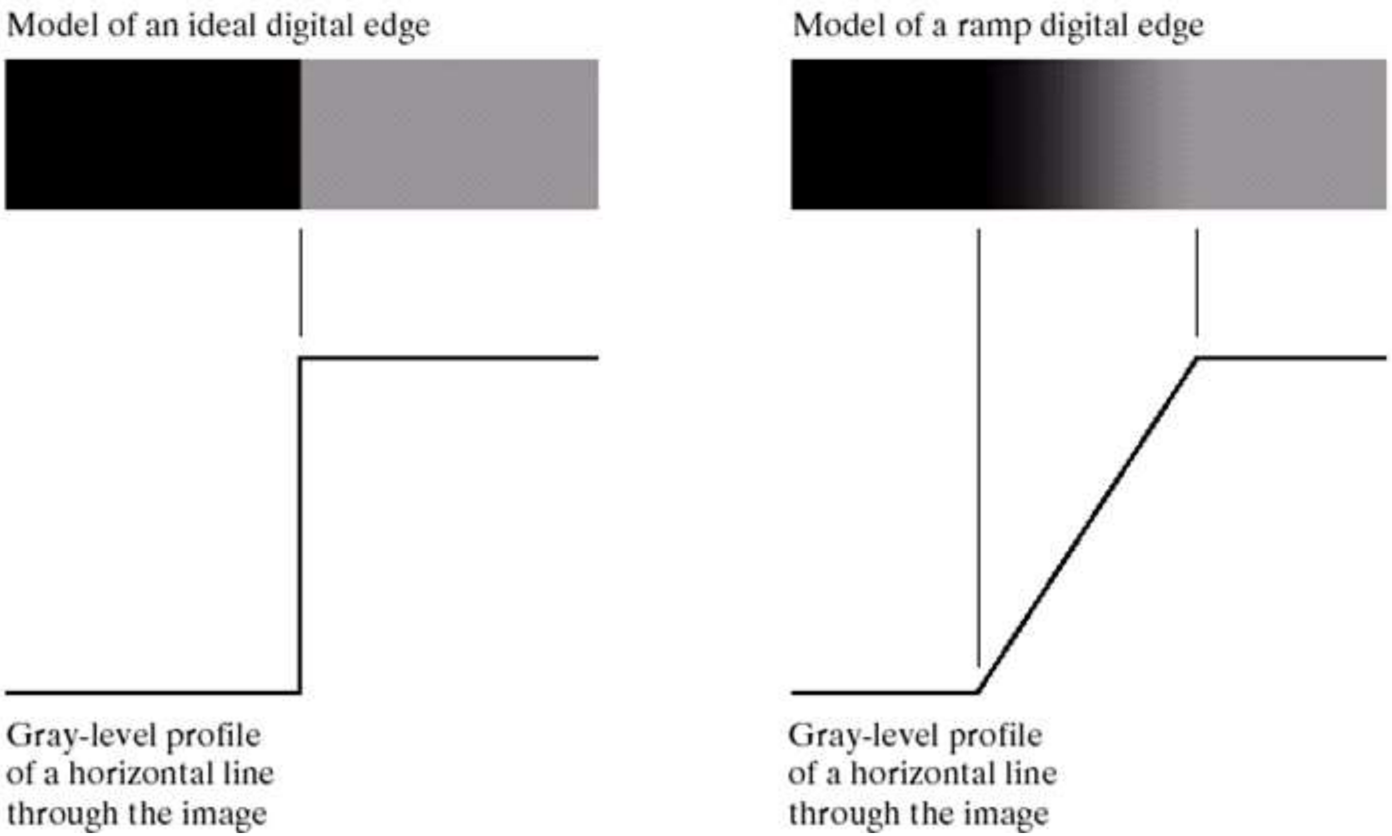
  - Edge pixels are pixels at which the intensity of an image changes abruptly, and edges (or edge segments) are sets of connected edge pixels

Edge Detection

- Approaches for implementing
  - first-order derivative (Gradient operator)
  - second-order derivative (Laplacian operator)

- Study of their properties for edge detection

Detection of Discontinuities
Edge Detection



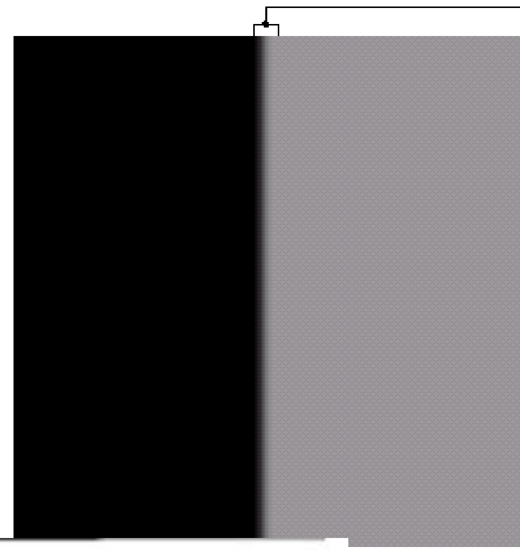
a b

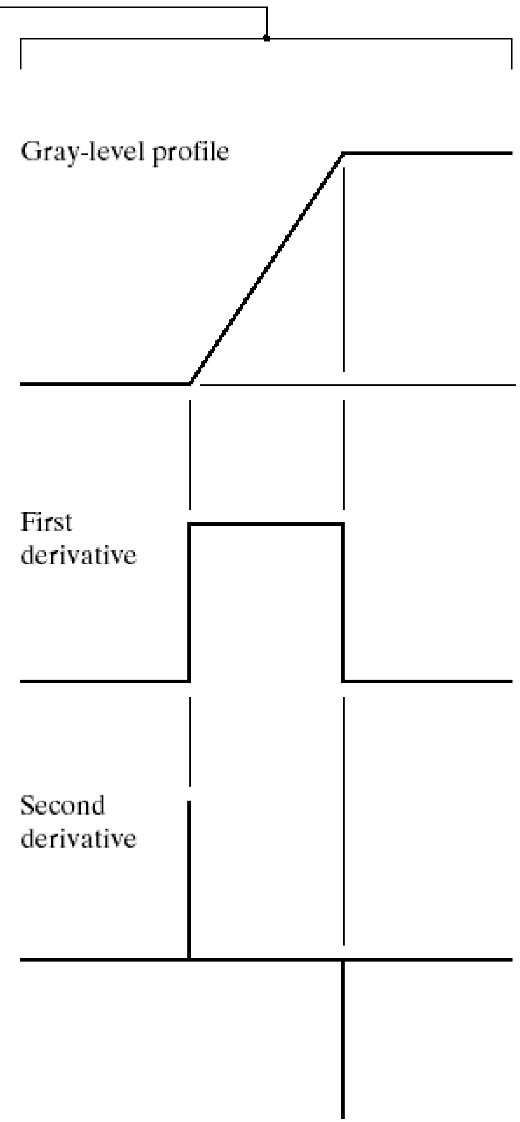
FIGURE 10.5 (a) Model of an ideal digital edge. (b) Model of a ramp edge.

Detection of Discontinuities
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.





First derivative

- Positive at the points of transitions into and out of the ramp (left to right)
- Constant for points in the ramp
- Zero in areas of constant gray levels

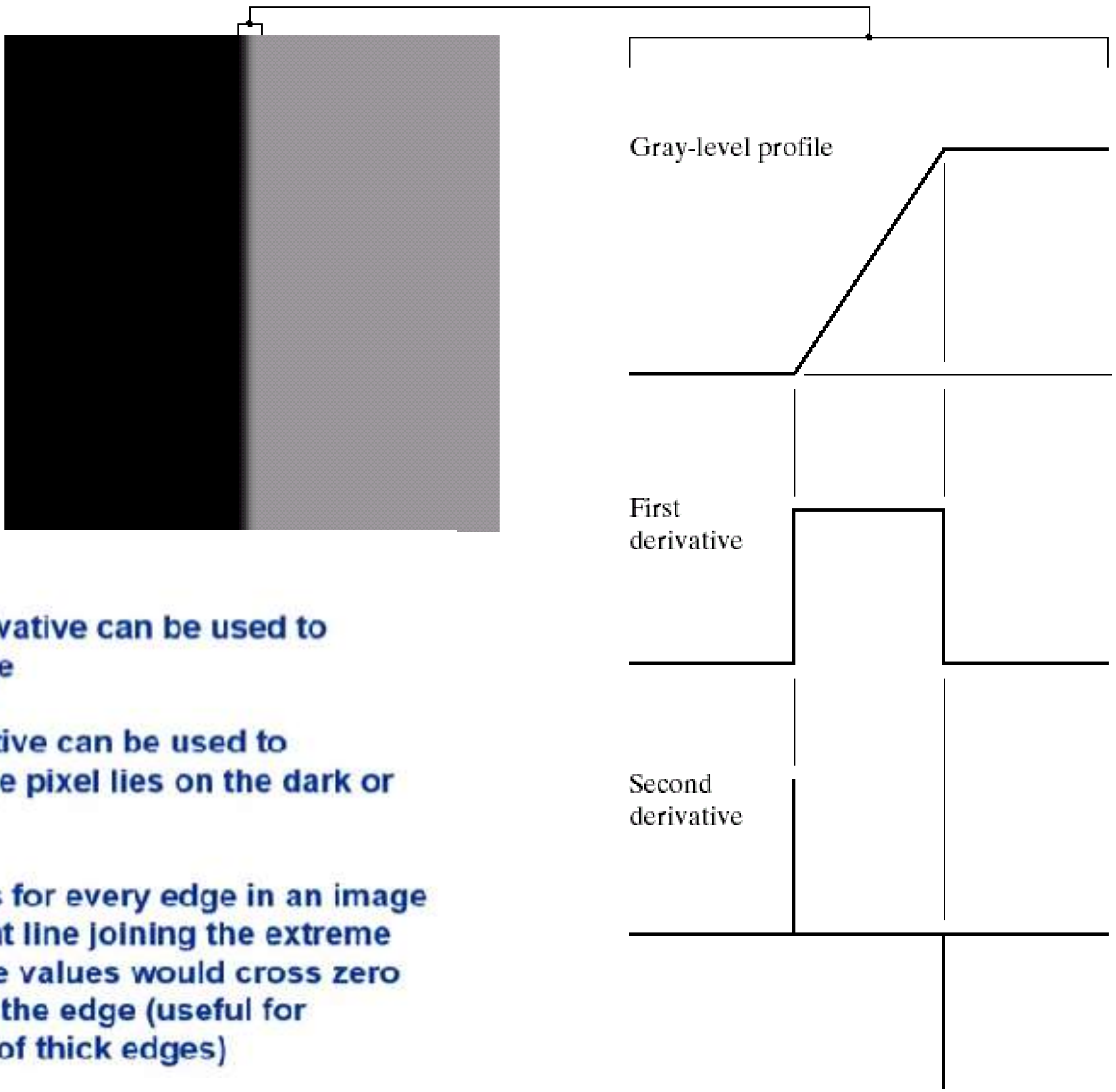
Second derivative

- Positive at the transition associated with the dark side of the edge
- Negative at the transition associated with the light side of the edge
- Zero along the ramp and in areas of constant gray levels

Detection of Discontinuities
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.



Conclusions

First derivative

- **Magnitude of the first derivative can be used to detect presence of an edge**

Second derivative

- **Sign of the second derivative can be used to determine whether an edge pixel lies on the dark or light side of an edge**
- **Additional properties:**
  - **Produces two values for every edge in an image**
  - **An imaginary straight line joining the extreme positive and negative values would cross zero near the midpoint of the edge (useful for locating the centers of thick edges)**

Detection of Discontinuities
Gradient Operators

Roberts cross-gradient operators

−1	0		0	−1
0	1		1	0

Roberts

Prewitt operators

−1	−1	−1		−1	0	1
0	0	0		−1	0	1
1	1	1		−1	0	1

Prewitt

Sobel operators

−1	−2	−1		−1	0	1
0	0	0		−2	0	2
1	2	1		−1	0	1

Sobel

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

- 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: $\alpha(x,y) = \tan^{-1}\left(\frac{G_x}{G_y}\right)$

Edge Detection : Gradient Operators

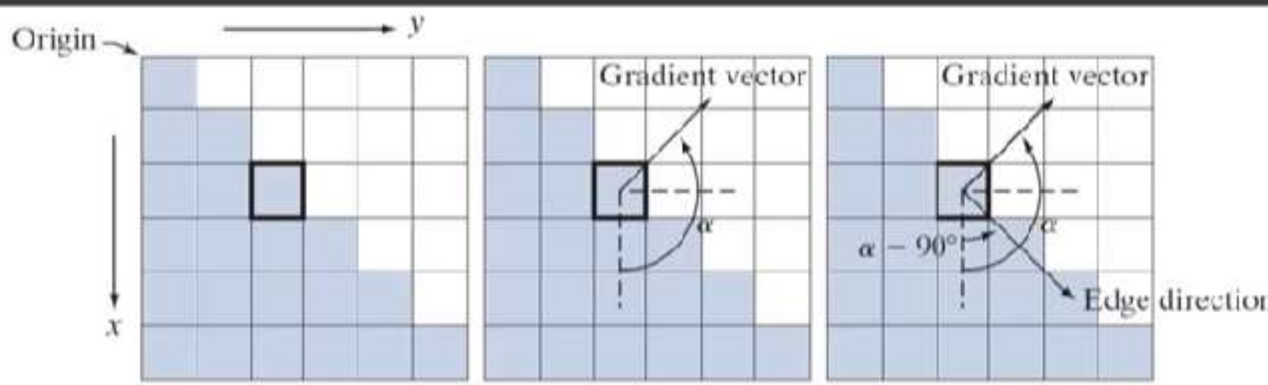
- Gradient Image

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

- Computational burden required by squares and square roots, and an approach used frequently is to approximate the magnitude of the gradient by absolute values:

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

Edge Detection : Gradient Operators



a b c

FIGURE 10.12 Using the gradient to determine edge strength and direction at a point. Note that the edge direction is perpendicular to the direction of the gradient vector at the point where the gradient is computed. Each square represents one pixel. (Recall from Fig. 2.19 that the origin of our coordinate system is at the top, left.)

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

The Drawback

Little visual noise can have such a significant impact on the two key derivatives used for detecting edges

Solution: Image smoothing should be a serious consideration prior to the use of derivatives in applications where noise with levels similar to those we have just discussed is likely to be present.

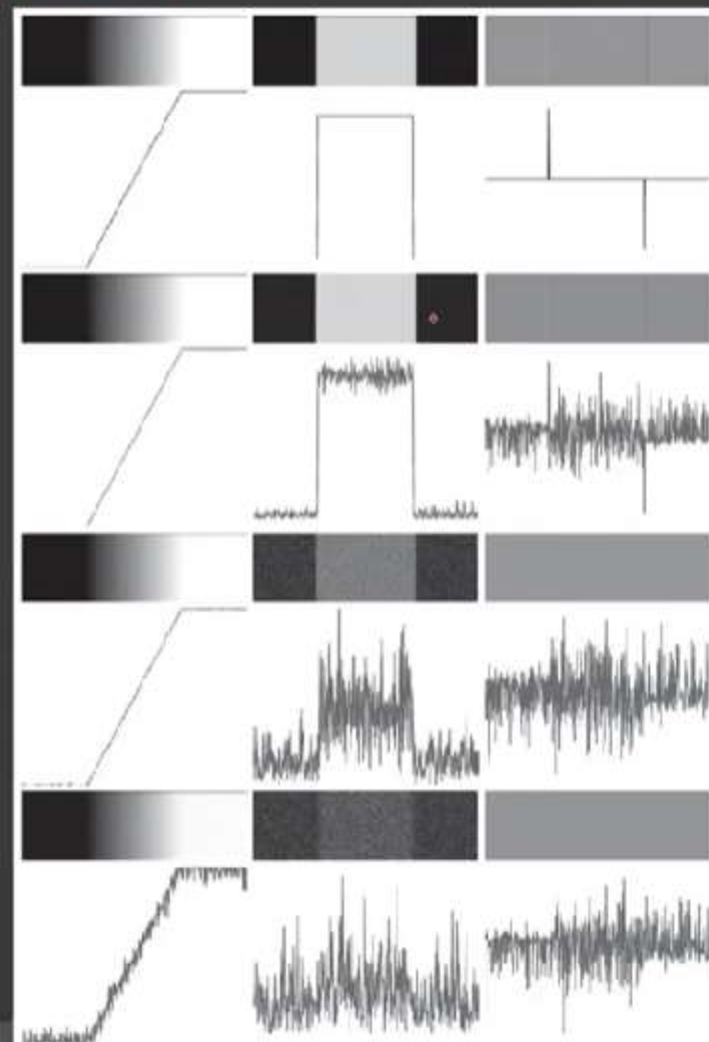


Fig: First column: 8-bit images with values in the range [0,255], and intensity profiles of a ramp edge corrupted by Gaussian noise of zero mean and standard deviations of 0.0, 0.1, 1.0, and 10.0 intensity levels, respectively. Second column: First-derivative images and intensity profiles. Third column: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

Marr-Hildreth Edge Detector

- Statement: An operator used for edge detection should have <u>two salient features</u>:
  1. It should be a differential operator capable of computing a digital approximation of the first or second derivative at every point in the image.
  2. It should be capable of being "tuned" to act at any desired scale, so that large operators can be used to detect blurry edges and small operators to detect sharply focused fine detail.

Marr-Hildreth Edge Detector

- Observed: Filter $\nabla^2 G$ fulfils these conditions

$$G(x,y) = e^{-\frac{x^2+y^2}{2\sigma^2}}$$

2-D Gaussian function, σ is std. deviation

- The Laplacian (∇^2) of G(x,y)

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

$$= \frac{\partial}{\partial x}\left(\frac{-x}{\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}\right) + \frac{\partial}{\partial y}\left(\frac{-y}{\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}\right)$$

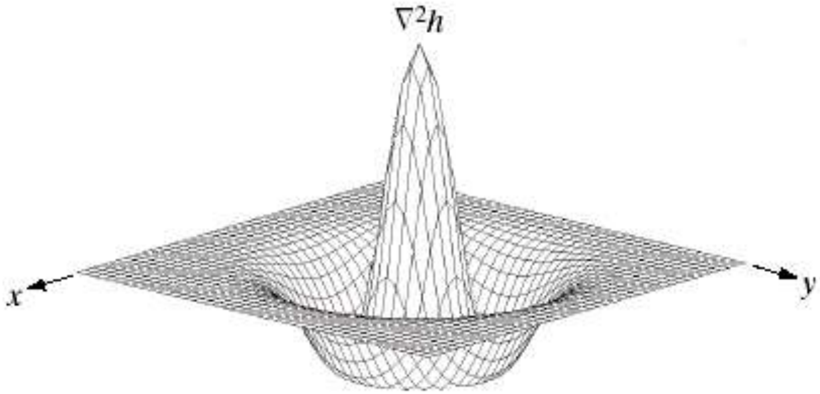
$$= \left(\frac{x^2}{\sigma^4} - \frac{1}{\sigma^2}\right) e^{-\frac{x^2+y^2}{2\sigma^2}} + \left(\frac{y^2}{\sigma^4} - \frac{1}{\sigma^2}\right) e^{-\frac{x^2+y^2}{2\sigma^2}}$$

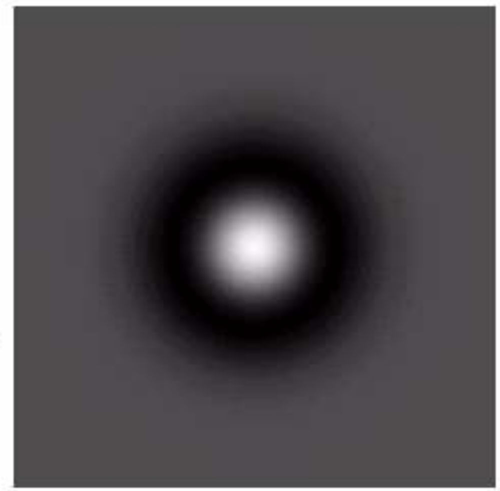
Collecting terms, we obtain

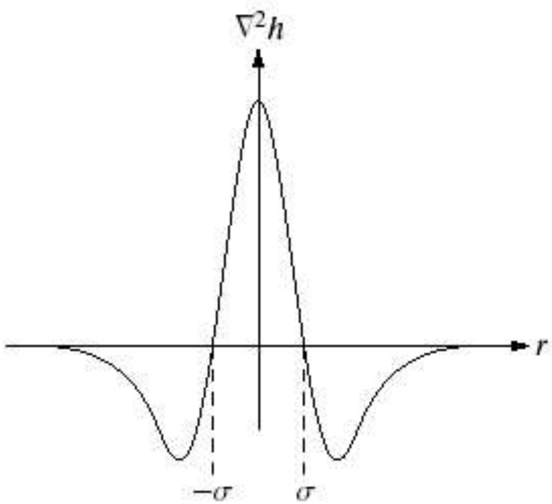
$$\nabla^2 G(x,y) = \left(\frac{x^2+y^2-2\sigma^2}{\sigma^4}\right) e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Expression is known as the "Laplacian of a Gaussian" (LoG)

Detection of Discontinuities
Gradient Operators







0	0	−1	0	0
0	−1	−2	−1	0
−1	−2	16	−2	−1
0	−1	−2	−1	0
0	0	−1	0	0

a	b
c	d

FIGURE 10.14 Laplacian of a Gaussian (LoG). (a) 3-D plot. (b) Image (black is negative, gray is the zero plane, and white is positive). (c) Cross section showing zero crossings. (d) 5×5 mask approximation to the shape of (a).