Announcement

Homework #5 has been posted in Blackboard and course website

Due: 2:20pm, Monday, April 8

Today's Agenda

- Image Compression
- Image Segmentation

Paper Reading Presentation

Strength:

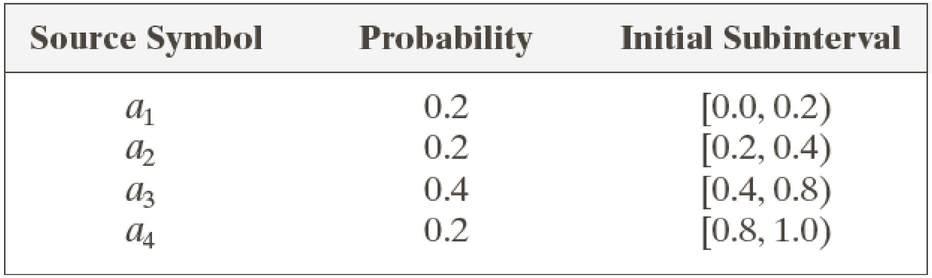
- **Nice introduction of background and related work**
- **Visual aids for better illustration**

Weakness

- **Missing reference**
- **Missing conclusion & critical comments**
- **Too many words in slides**

Arithmetic Coding -- Nonblock Code

- Used in JBIG, JBIG2, JPEG2000, and MPEG4
- Non-block: the whole message is encoded into a single code word (real value in [0, 1])



Source Symbol	Probability	Initial Subinterval
a_1	0.2	[0.0, 0.2)
a_2	0.2	[0.2, 0.4)
a_3	0.4	[0.4, 0.8)
a_4	0.2	[0.8, 1.0)

TABLE 8.6 Arithmetic coding example.

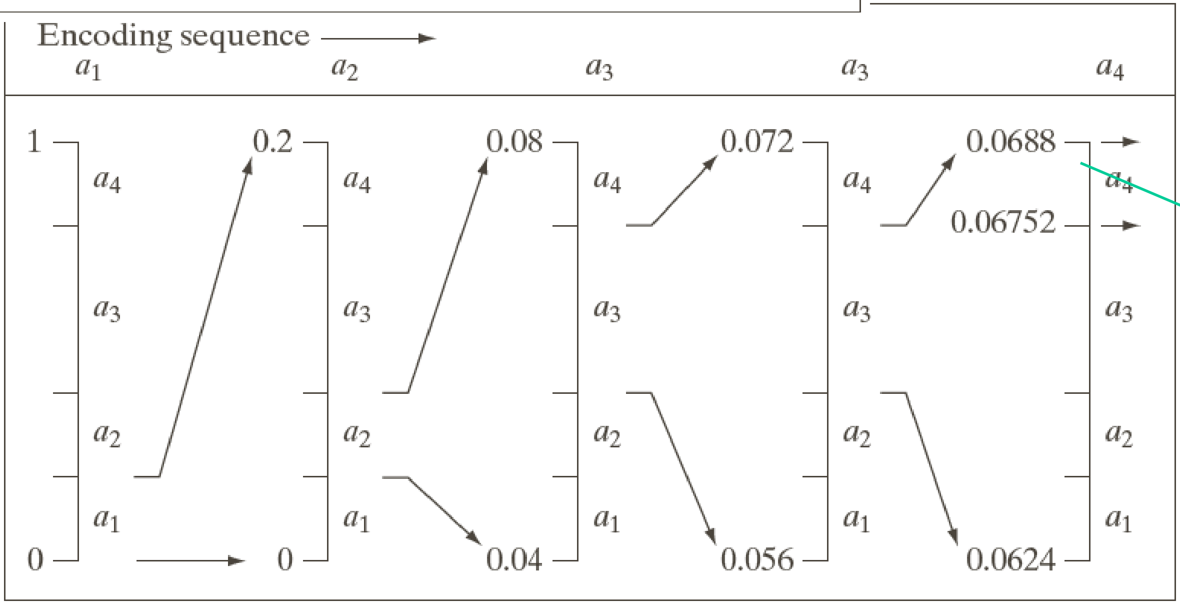


FIGURE 8.12 Arithmetic coding procedure.

Any number in the range can be used

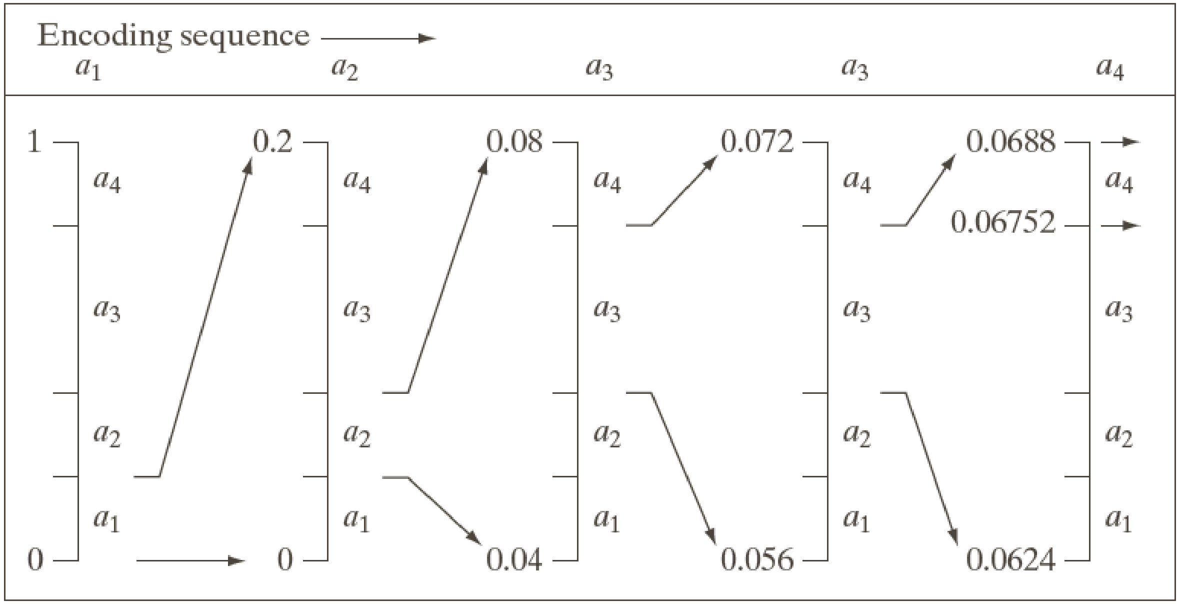
Arithmetic Coding

Decoding

- final value
- probabilities of the input symbols

Two decoding methods:

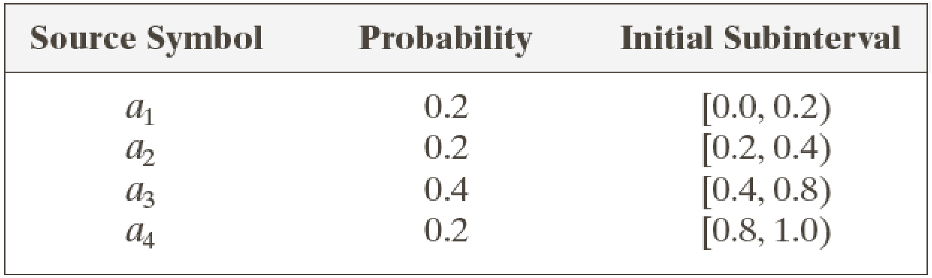
- Straightforward decoding



Arithmetic Coding

Decoding

- final value
- probabilities of the input symbols



Source Symbol	Probability	Initial Subinterval
a_1	0.2	[0.0, 0.2)
a_2	0.2	[0.2, 0.4)
a_3	0.4	[0.4, 0.8)
a_4	0.2	[0.8, 1.0)

Two decoding methods:

- Straightforward decoding
- An efficient method

Step0: $v_t = v_0$

Repeat:

step1: find symbol s_t satisfying $low(s_t) \leq v_t \leq up(s_t)$

step2: $$v_{t+1} = \frac{v_t - low(s_t)}{p(s_t)}$$

Until: s_t is the end symbol

Arithmetic Coding

Require an end-of-message indicator

Potential issues:

- Decoding starts when all the message is received
- Sensitive to the noise during transmission
- Limited by the precision – solved by scaling

Run-Length Encoding (RLE)

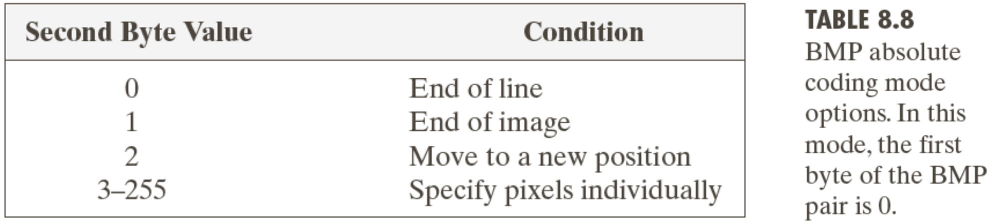
- Eliminate spatial redundancy – groups of identical symbols
- Used in CCITT, JPEG, and fax machines

Encoded Mode: two bytes

# of consecutive pixels, the color index

Absolute Mode: two bytes

0, conditional signals



Second Byte Value	Condition
0	End of line
1	End of image
2	Move to a new position
3–255	Specify pixels individually

TABLE 8.8 BMP absolute coding mode options. In this mode, the first byte of the BMP pair is 0.

Run-Length Encoding (RLE)

C=0.98

C=1.35

C=128

- Effective on binary images (black and white)
- Not effective on natural images - increase the file size if there are few runs of identical symbols
- Combine with other variable-length coding

Motion Compensation

Eliminate temporal redundancy

- Step1 : Capture differences between a reference frame and the target frame
- Step2 : Model the difference in terms of transformation function
- Step3 : Video/image sequences are synthesized by the reference frame according to the estimate transformation

Motion Compensation

Eliminate temporal redundancy

- Step1 : Capture differences between a reference frame and the target frame
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Global motion compensation

- Few parameters; no partition;
- Static objects; not applicable for moving objects

Local motion compensation

- Block motion compensation
- Overlapped block motion compensation

Reading Assignments

Other methods covered in Chapter 8.2

Image Processing → Image Analysis

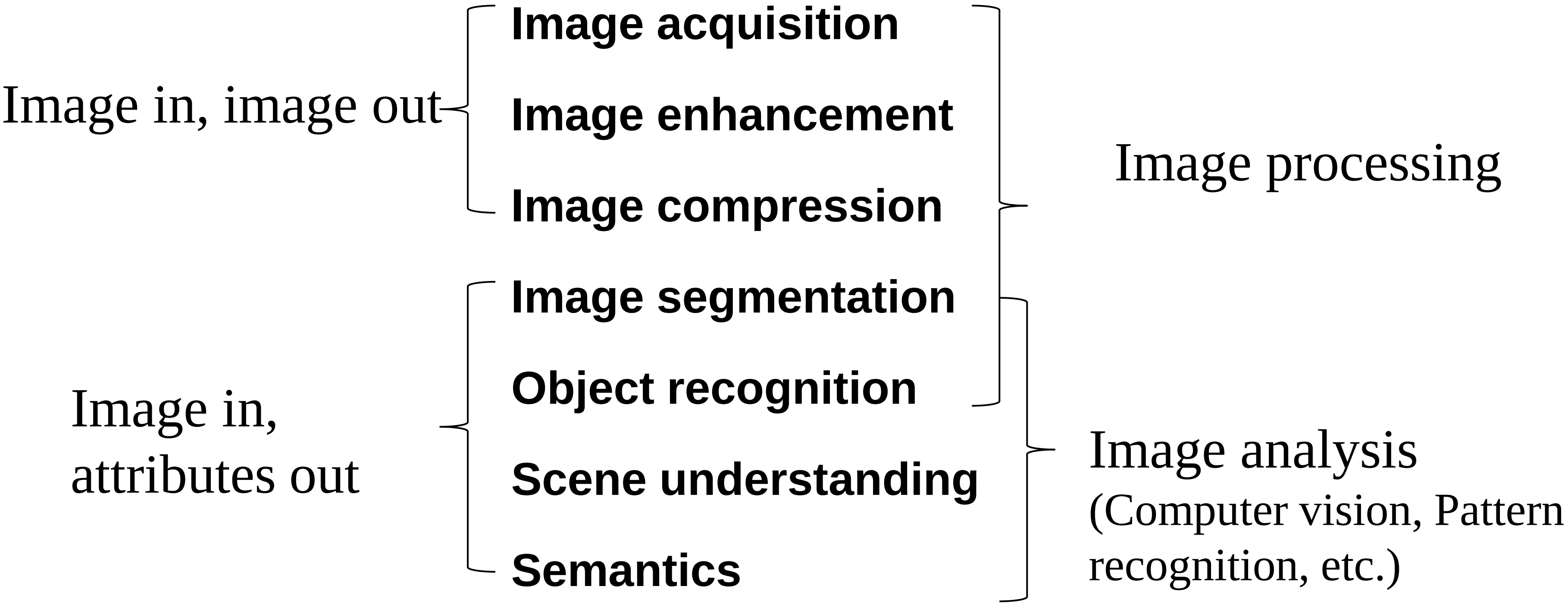


Image in, image out

- **Image acquisition**
- **Image enhancement**
- **Image compression**

Image in, attributes out

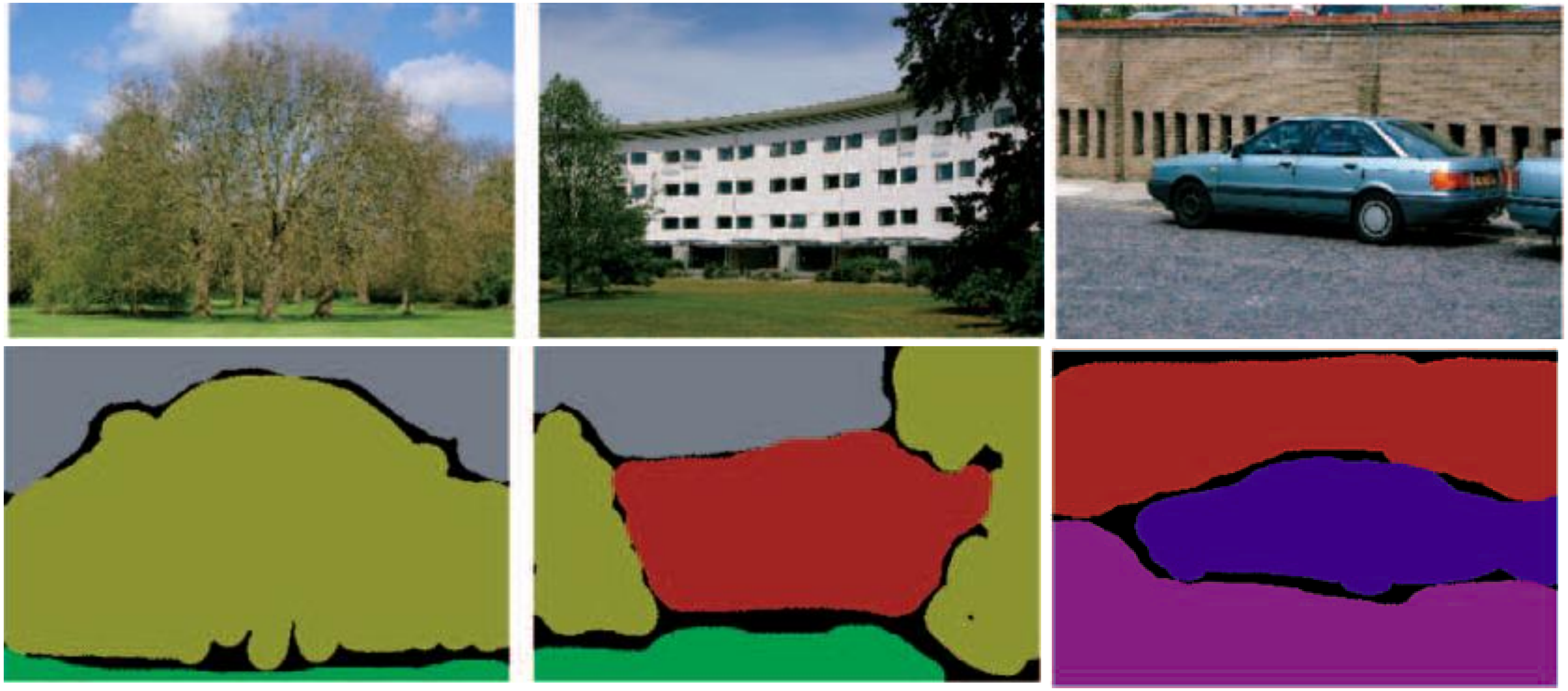
- **Image segmentation**
- **Object recognition**
- **Scene understanding**
- **Semantics**

Image processing

Image analysis
(Computer vision, Pattern recognition, etc.)

Image Segmentation

A process that partitions R into subregions $R_1, R_2, ..., R_n$



Microsoft multiclass segmentation data set

Image Segmentation – Applications

Object localization

Object recognition

Specially important for medical imaging

Brief Review of Connectivity

- Path from p to q: a sequence of distinct pixels with coordinates

$$\text{Starting point p} \leftarrow \underbrace{(x_0, y_0), (x_1, y_1)}_{\text{adjacent}}, \ldots, (x_n, y_n) \rightarrow \text{ending point q}$$

- p and q are *connected*: if there is a path from p to q in S
- *Connected component*: all the pixels in S connected to p
- *Connected set*: S has only one connected component
- R is a region if R is a connected set
- R_i and R_j are adjacent if $R_i \cup R_j$ is a connected set

Image Segmentation

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

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

(c) $R_i \cap R_j = \phi, \forall i \neq j$

(d) $Q(R_i) = TRUE$ ← Q is a criterion

(e) $Q(R_i \cup R_j) = FALSE$ for adjacent regions R_i and R_j

Two categories based on intensity properties:

- Discontinuity – edge-based algorithms
- Similarity – region-based algorithms

Edge-based and Region-based Segmentation

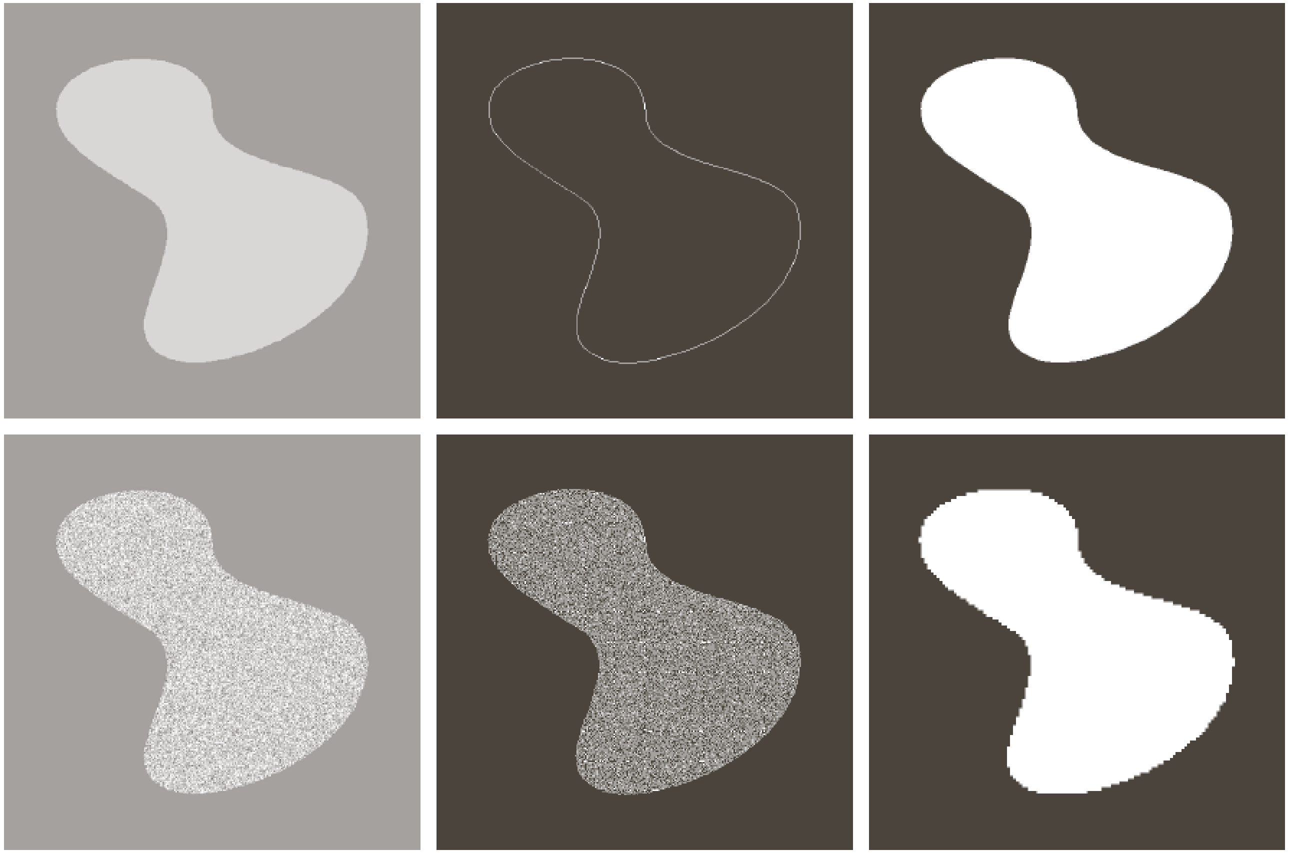
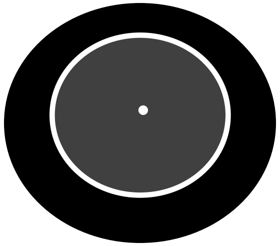


FIGURE 10.1 (a) Image containing a region of constant intensity. (b) Image showing the boundary of the inner region, obtained from intensity discontinuities. (c) Result of segmenting the image into two regions. (d) Image containing a textured region. (e) Result of edge computations. Note the large number of small edges that are connected to the original boundary, making it difficult to find a unique boundary using only edge information. (f) Result of segmentation based on region properties.

Point, Line and Edge Detection

Segmentation based on detecting sharp, local changes in intensity

- **Edge pixels: pixels at which the intensity changes abruptly**
- **Edges: sets of connected edge pixels**
  - Edge detectors: methods to detect edges
- **Line (roof edges): edge segments in which the intensity on either side of the line is either higher or lower than the intensity of line pixels**
  - isolated point: a line with one-pixel length



Background

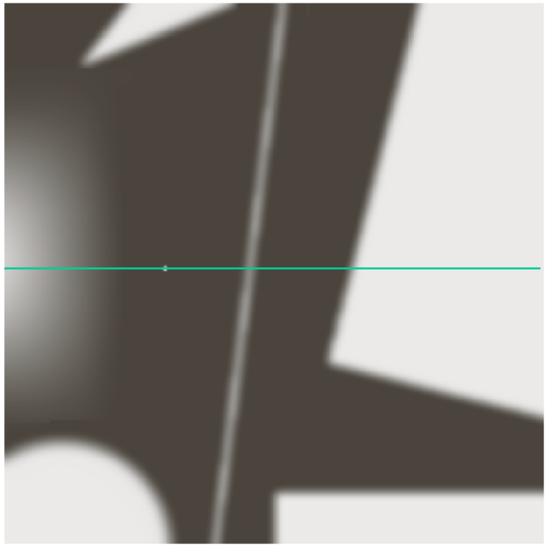
The first-order derivative

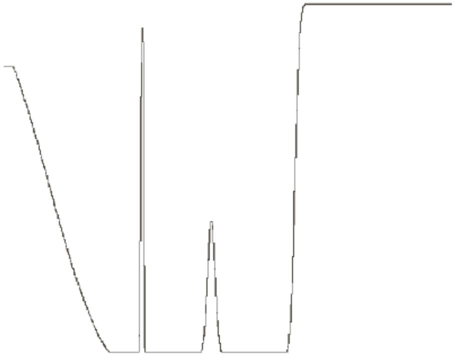
$$\frac{\partial f}{\partial x} = f'(x) = f(x+1) - f(x)$$

The second-order derivative

$$\frac{\partial^2 f}{\partial x^2} = f''(x)$$

$$= f(x+1) - 2f(x) + f(x-1)$$





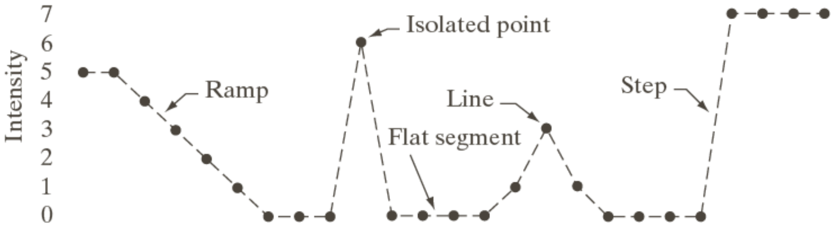
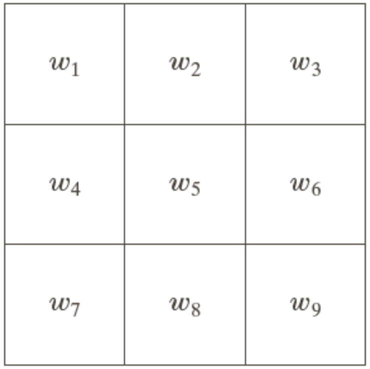


Image strip	5	5	4	3	2	1	0	0	0	6	0	0	0	0	1	3	1	0	0	0	0	7	7	7	7	•	•
First derivative		−1	−1	−1	−1	−1	0	0	6	−6	0	0	0	1	2	−2	−1	0	0	0	7	0	0	0			
Second derivative		−1	0	0	0	0	1	0	6	−12	6	0	0	1	1	−4	1	1	0	0	7	−7	0	0			

Some Observations

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

Implementation by filtering



w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

FIGURE 10.3
A general 3 × 3 spatial filter mask.

Detection of Isolated Points

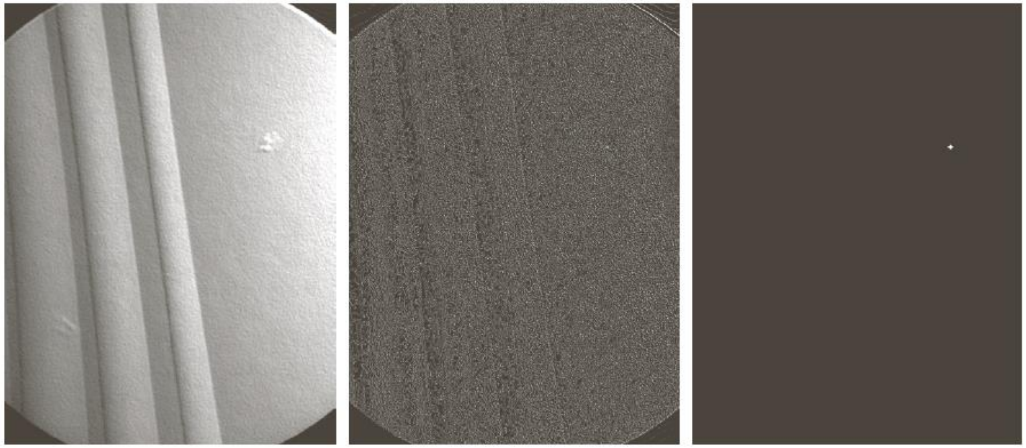
Laplacian

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

$$g(x,y) = \begin{cases} 1 & if\left|R(x,y)\right| \geq T \\ 0 & otherwise \end{cases}$$

$$\text{R}=\sum_{k=1}^{9} w_k z_k$$

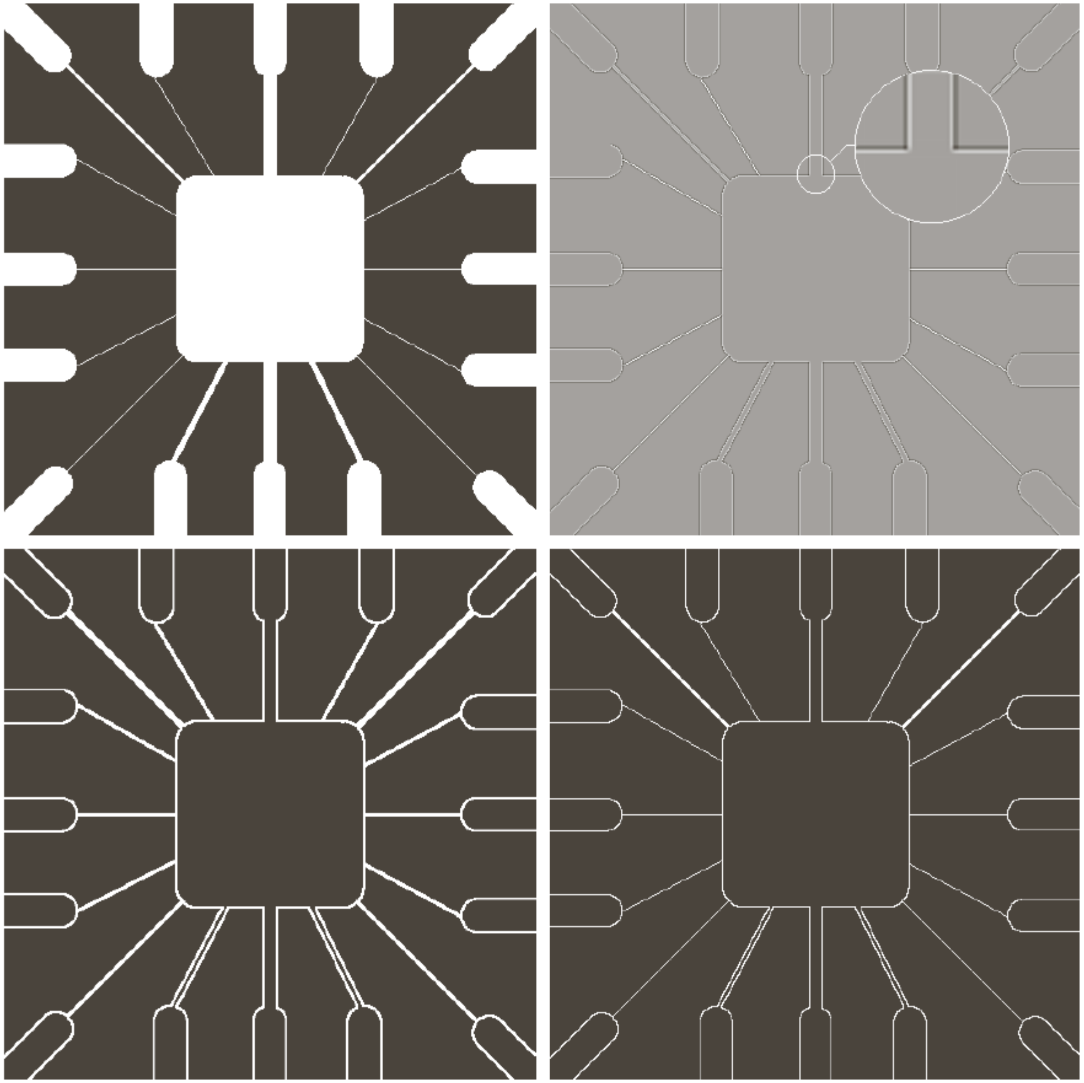
1	1	1
1	−8	1
1	1	1



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.)

Line Detections by Laplacian

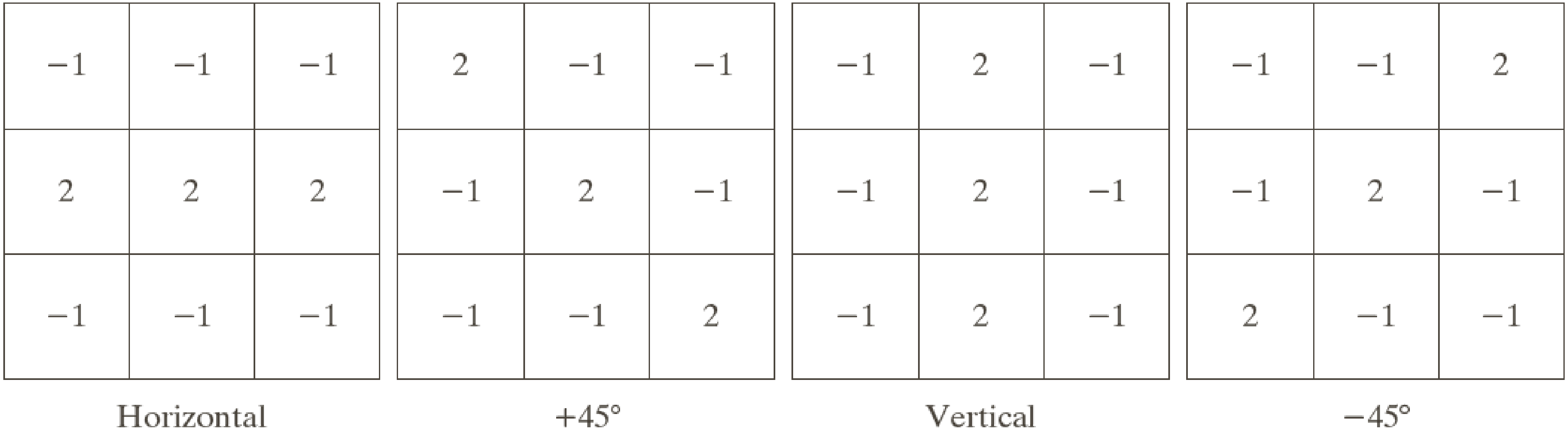


a b
c d

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.

The line detection is insensitive to the direction

Line Detections In Specified Directions



−1	−1	−1
2	2	2
−1	−1	−1

Horizontal

2	−1	−1
−1	2	−1
−1	−1	2

+45°

−1	2	−1
−1	2	−1
−1	2	−1

Vertical

−1	−1	2
−1	2	−1
2	−1	−1

−45°

FIGURE 10.6 Line detection masks. Angles are with respect to the axis system in Fig. 2.18(b).

An Example

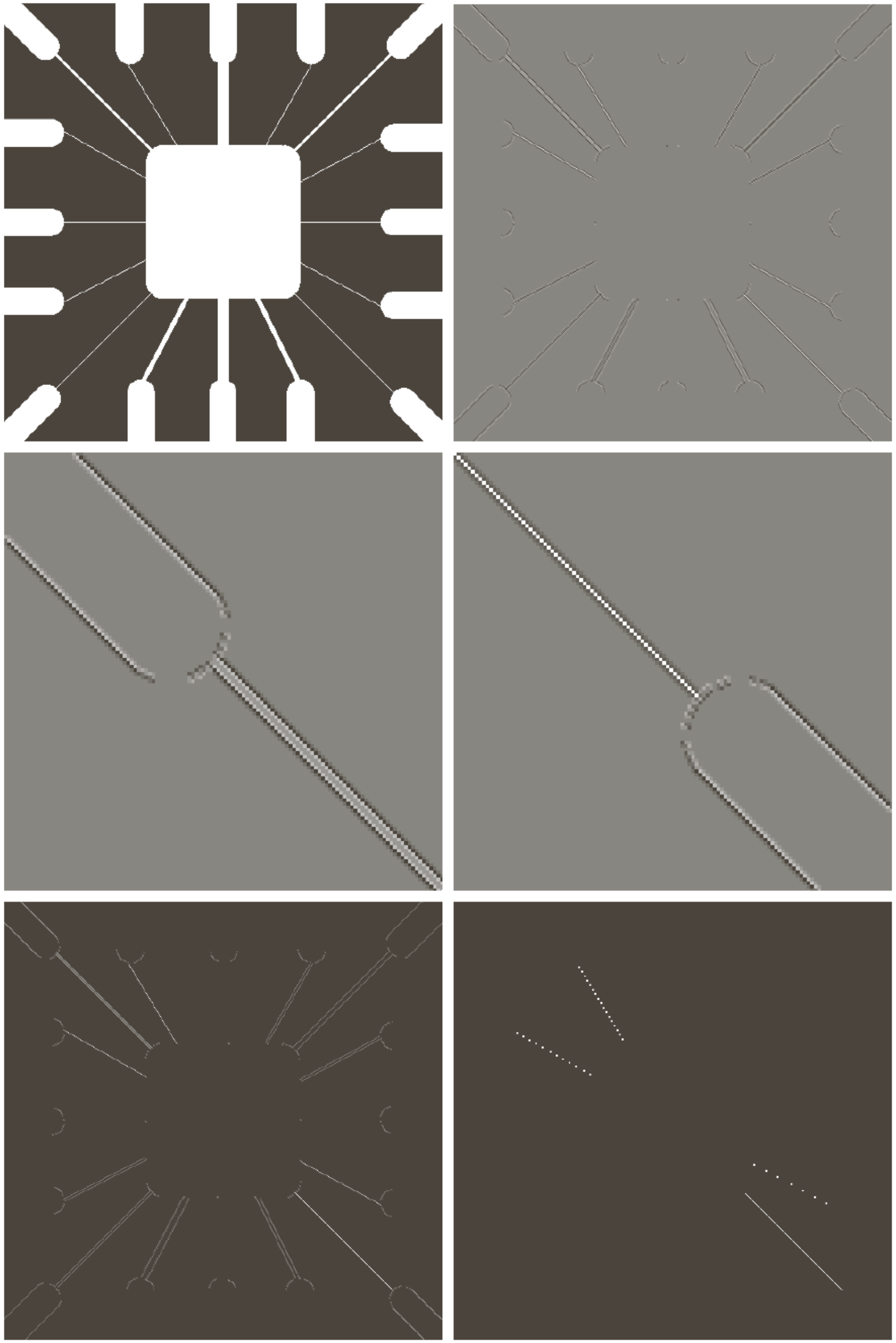
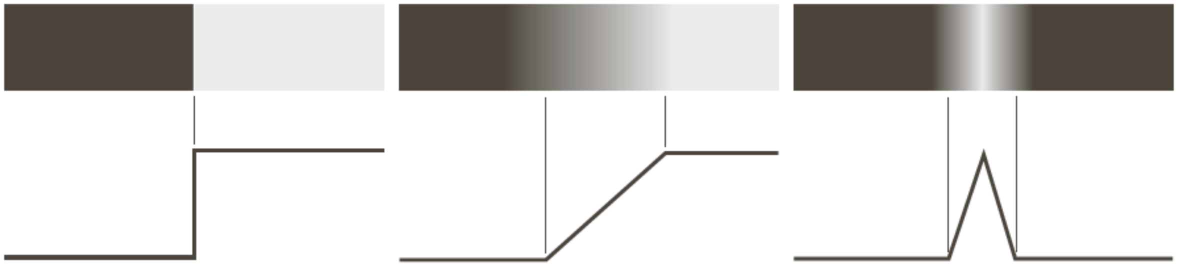


FIGURE 10.7 (a) Image of a wire-bond template. (b) Result of processing with the +45° line detector mask in Fig. 10.6. (c) Zoomed view of the top left region of (b). (d) Zoomed view of the bottom right region of (b). (e) The image in (b) with all negative values set to zero. (f) All points (in white)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

Edge Models



a b c

FIGURE 10.8 From left to right, models (ideal representations) of a step, a ramp, and a roof edge, and their corresponding intensity profiles.

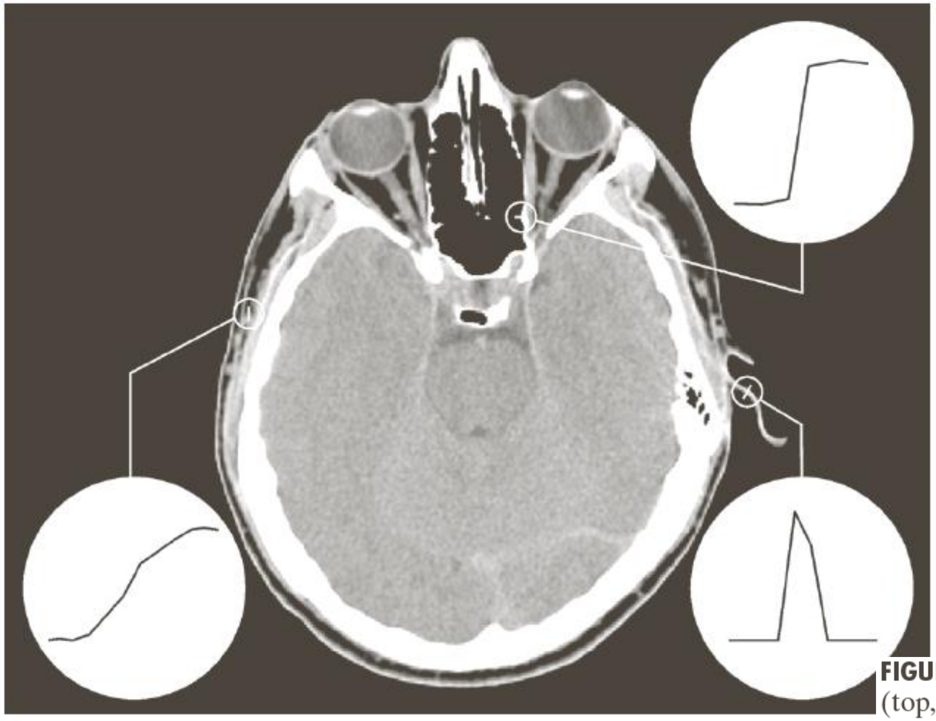
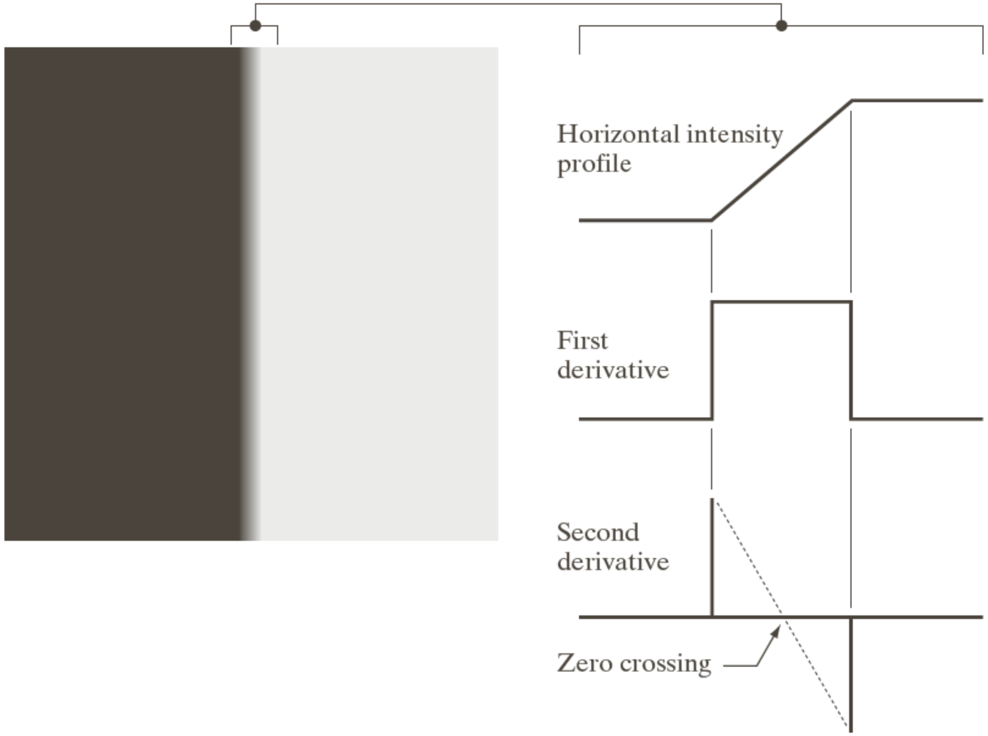


FIGURE 10.9 A 1508 × 1970 image showing (zoomed) actual ramp (bottom, left), step (top, right), and roof edge profiles. The profiles are from dark to light, in the areas indicated by the short line segments shown in the small circles. The ramp and "step" profiles span 9 pixels and 2 pixels, respectively.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

Derivatives – Idea Cases

Observation:



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.

Conclusion

- The magnitude of first derivative -- the presence of an edge
- The sign of second derivative -- the intensity transition direction
  - double edge
  - zero crossing – the center of ramp

But, In Practice …

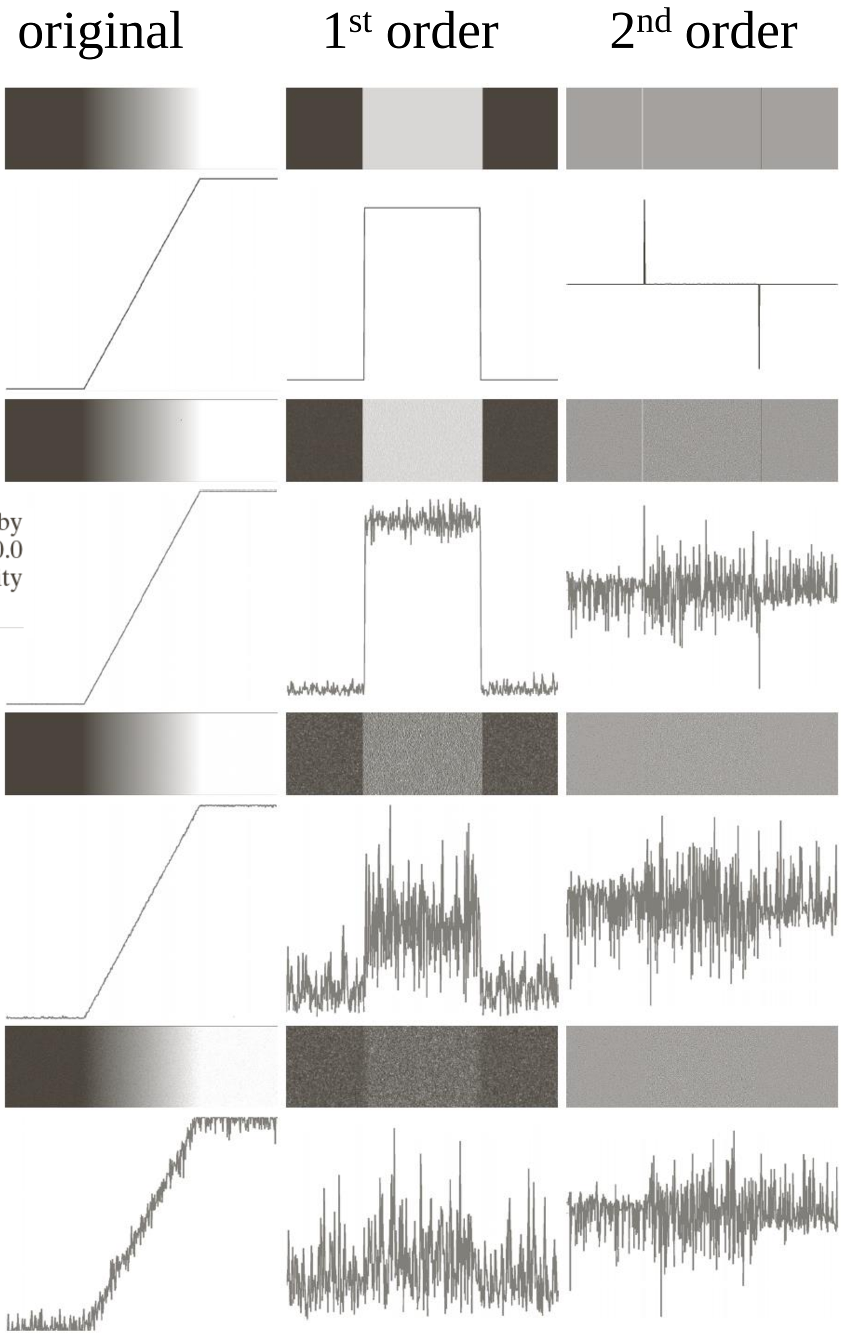


FIGURE 10.11 First column: Images and intensity profiles of a ramp edge corrupted by random Gaussian noise of zero mean and standard deviations of 0.0, 0.1, 1.0, and 10.0 intensity levels, respectively. Second column: First-derivative images and intensity profiles. Third column: Second-derivative images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

1. **Image Smoothing**
2. **Detecting edge points**
3. **Edge localization**

Basic Edge Detection

First-order derivative:

Gradient $$\nabla f(x,y) = grad(f) = \begin{bmatrix} g_x \\ g_y \end{bmatrix} = \begin{bmatrix} \partial f / \partial x \\ \partial f / \partial y \end{bmatrix}$$

Edge strength $$M(x,y) = \sqrt{g_x^2 + g_y^2}$$

$$\approx |g_x| + |g_y|$$

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

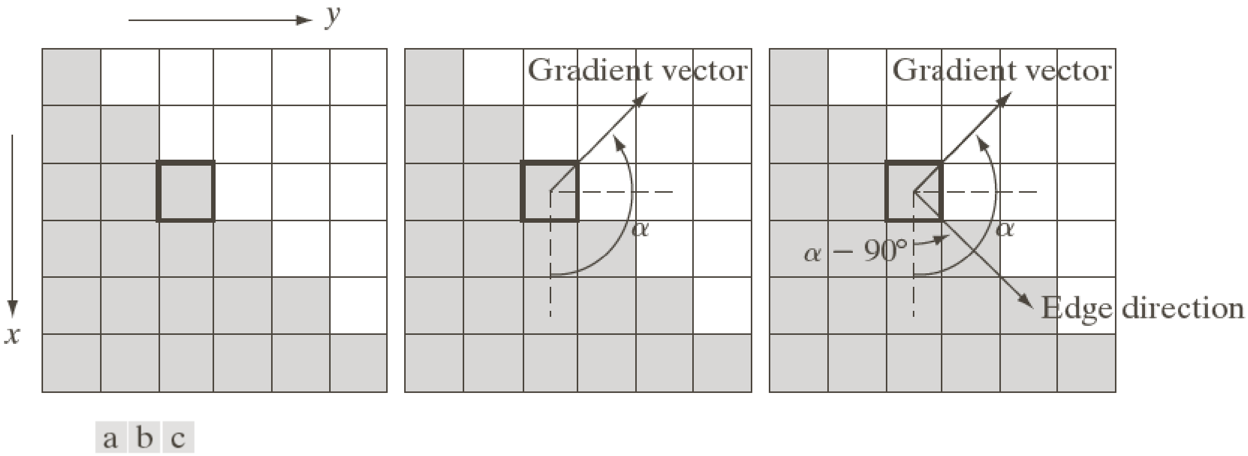


FIGURE 10.12 Using the gradient to determine edge strength and direction at a point. Note that the edge is perpendicular to the direction of the gradient vector at the point where the gradient is computed. Each square in the figure represents one pixel.

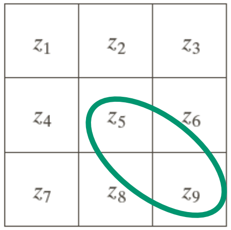
Masks for Calculating the Gradient (2x2)

Gradient in vertical/horizontal direction

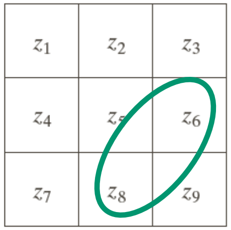
−1
1

−1	1

Gradient in diagonal direction



−1	0
0	1



0	−1
1	0

Masks for Calculating the Gradient (3x3)

Gradient in vertical/horizontal

−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

Gradient in diagonal

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

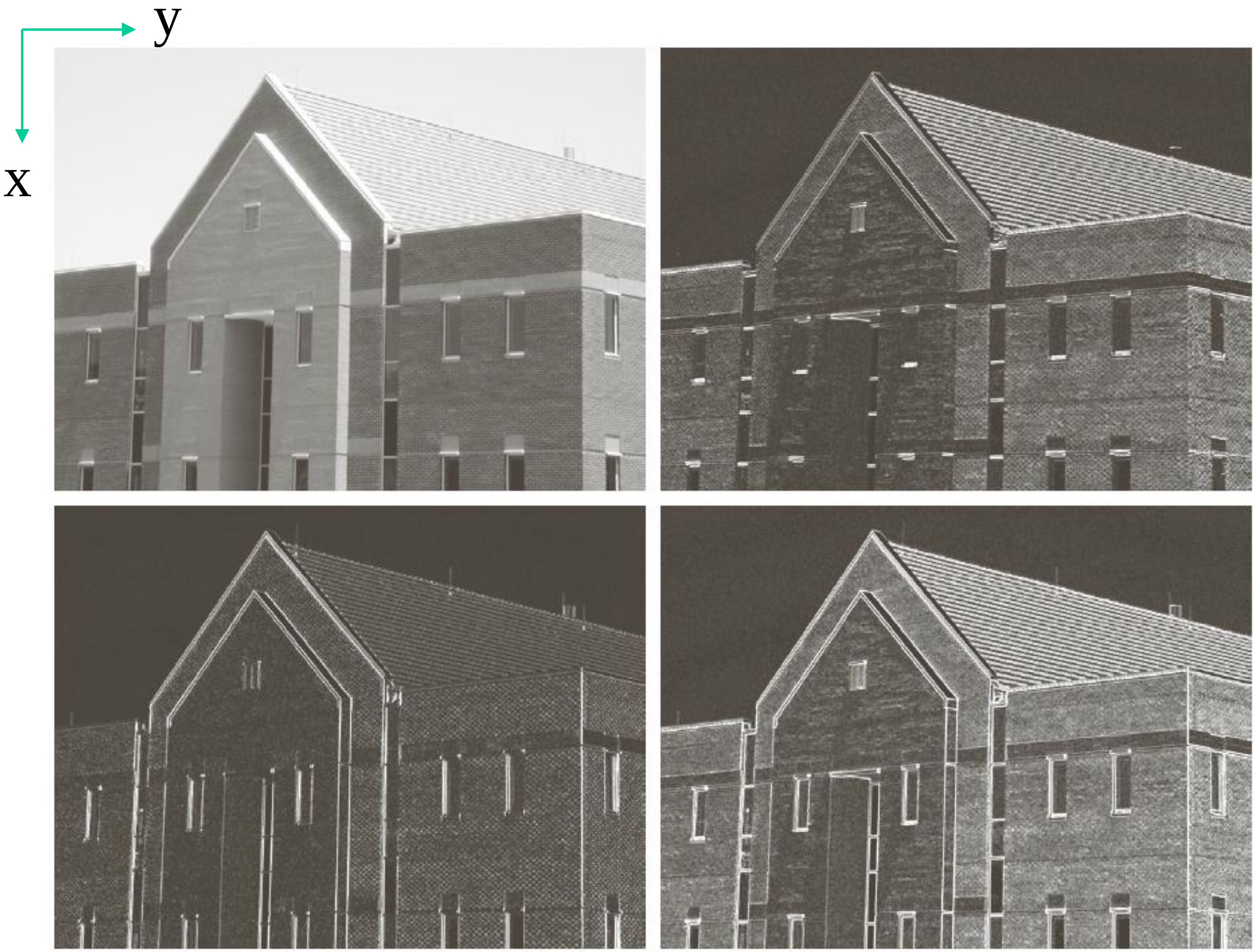
Sobel operator performs edge detection and smoothing simultaneously.

An Example

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

Sobel



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, $|g_x| + |g_y|$.

An Example – Cont.

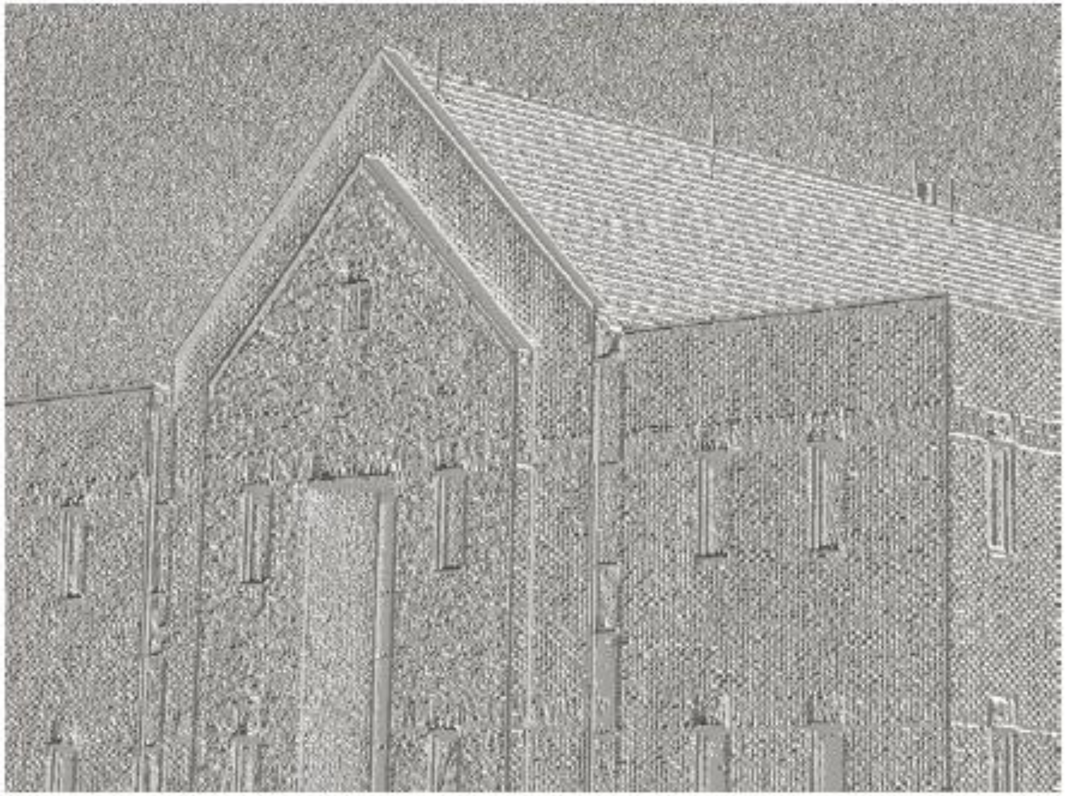


FIGURE 10.17 Gradient angle image computed using Eq. (10.2-11). Areas of constant intensity in this image indicate that the direction of the gradient vector is the same at all the pixel locations in those regions.

Angle information is employed in Canny edge detector and other feature representation, such as Histogram of Orientation (HOG).

An Example – Cont.

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.

An Example – Cont.

45 degree

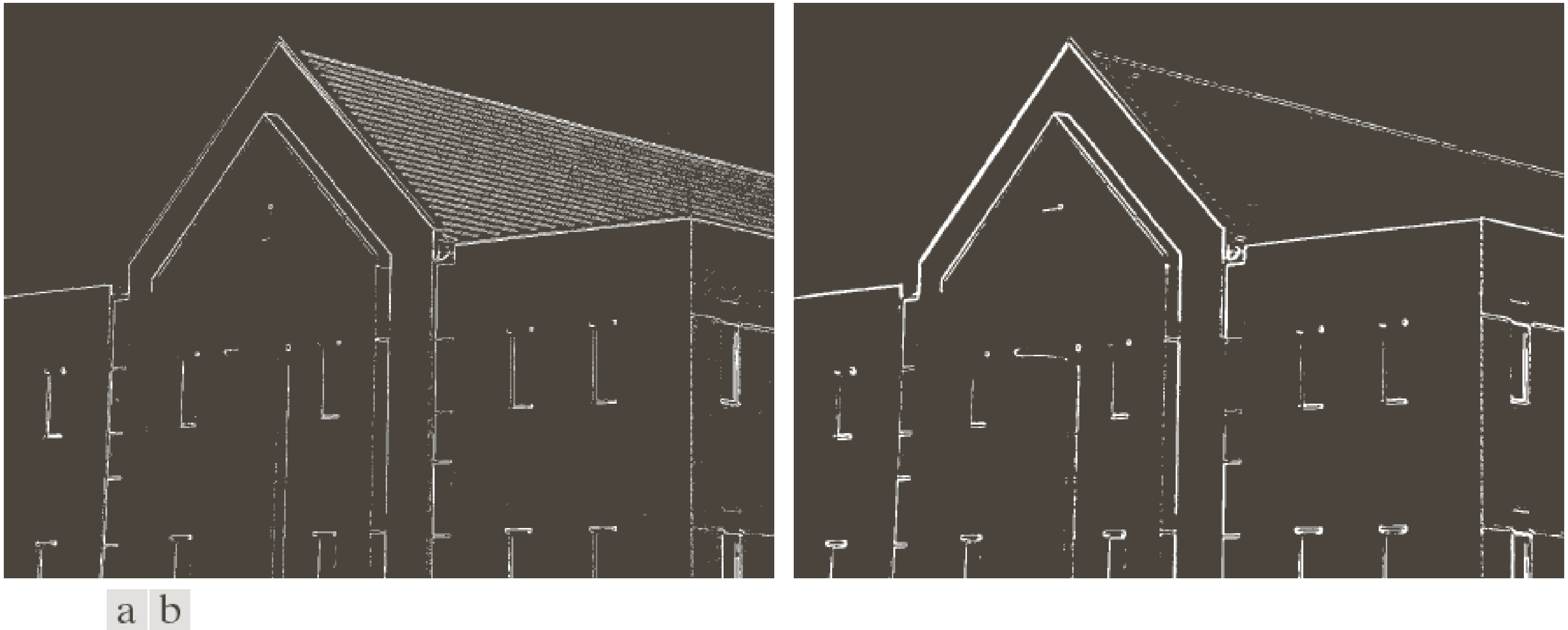
-45 degree

a b

FIGURE 10.19 Diagonal edge detection. (a) Result of using the mask in Fig. 10.15(c). (b) Result of using the mask in Fig. 10.15(d). The input image in both cases was Fig. 10.18(a).

Edge detection in diagonal directions.

Combining the Gradient with Thresholding



Smoothed input

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.

Summary on Simple Edge Detectors

- **First-order derivative**
  - Roberts (2x2)
  - Prewitt (3x3)
  - Sobel (3x3, smooth + difference)
  - Issues:
    - Thicker edge
    - One operator for one edge direction

- **Second-order derivative**
  - Laplacian (3x3)
  - Issues:
    - Double edge
    - Zero-crossing

- **Common issues:**
  - Sensitive to image noise
  - Cannot deal with the scale change of the image