Digital Image Processing

10B-Image Segmentation

Image Segmentation (Recall)

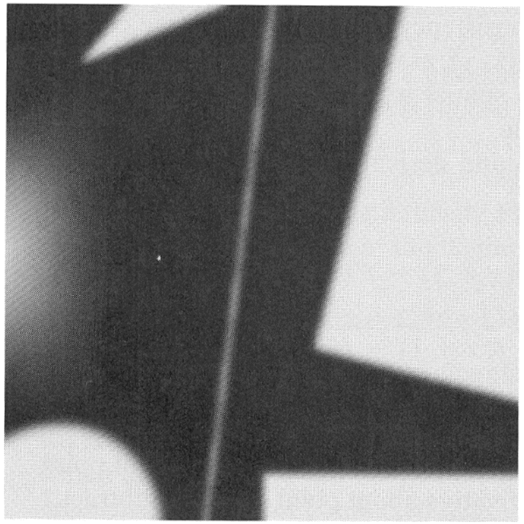
- Segmentation algorithms are based on one of two basic properties of gray-scale values:
  - Discontinuity
    - Partition an image based on abrupt changes in gray-scale levels.
    - Detection of isolated points, lines, and edges in an image.
  - Similarity
    - Thresholding, region growing, and region splitting/merging.

Overview

- Point Detection
- Line Detection
- Edge Detection

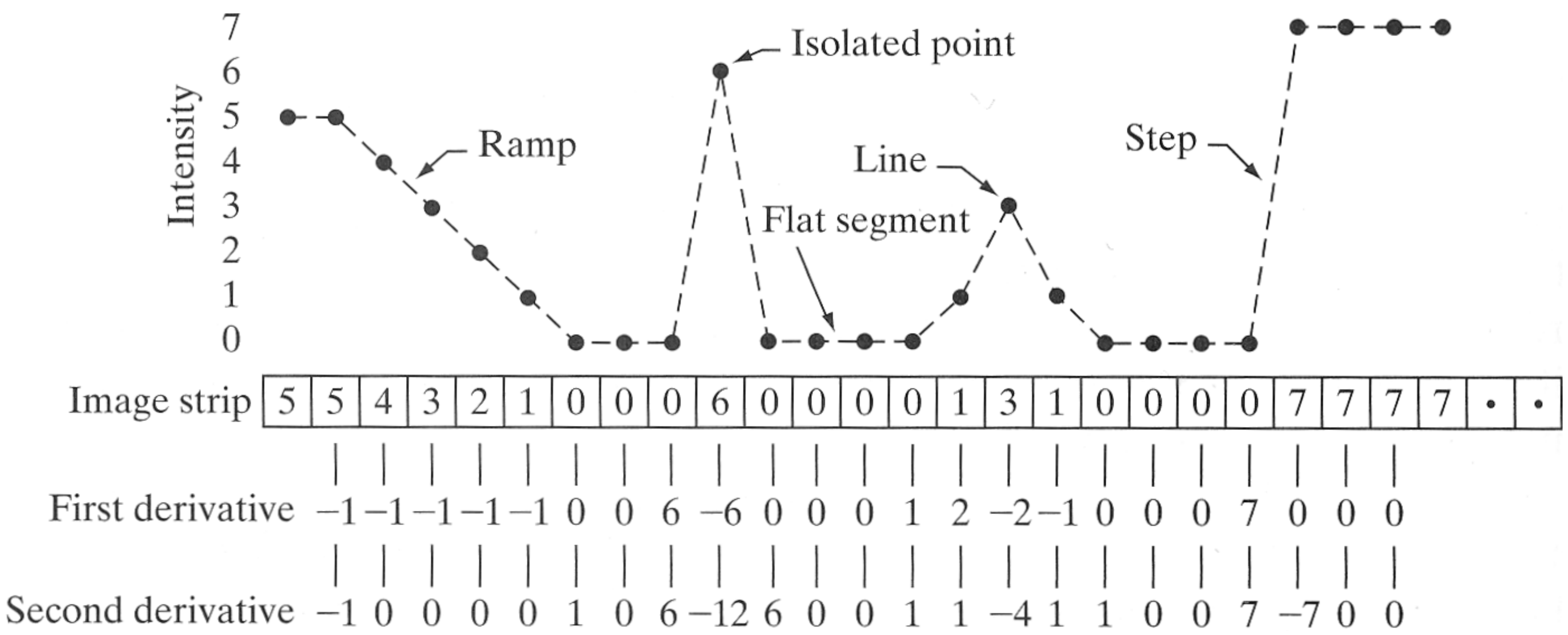
Recall – Chapter 3

- Example
  - This image contains various objects a line and an isolated noise point
  - We consider a horizontal line passing through the isolated point



Recall – Chapter 3

- We consider the properties of the first and the second order differences of the intensity as we traverse the line from left to right.



Recall – Key Points

- First order differences generally produce thicker edges in an image (see the ramp).
- Second order differences have a stronger response to fine detail, such as isolated points and thin lines (see isolated point and the line).
- The second order difference produces a double response as it transitions into and out of an edge (see ramp and step).
- The sign of the second order difference can determine if the transition is from light to dark, or vice-versa (see ramp and step).

Detection of Isolated Points

- Isolated Point
  - Gray level – Different from neighboring pixels

- Second Derivative – Laplacian (Recall)

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

$$\nabla^2 f(x,y) = f(x+1,y) + f(x-1,y) + f(x,y+1) + f(x,y-1) - 4f(x,y)$$

- Implementation – Spatial filters

$$\begin{matrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{matrix} \qquad \begin{matrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{matrix}$$

Detection of Isolated Points

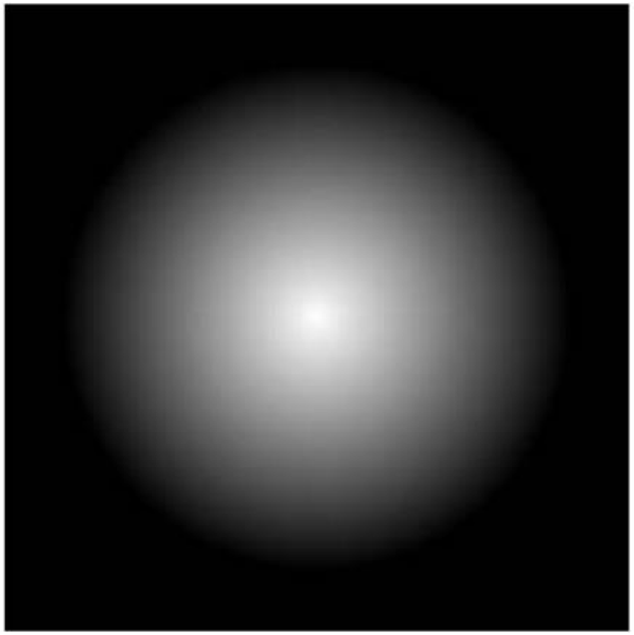
- We say that a point has been detected at the location (x,y), if the absolute value of the response is above a threshold T

- If the detected points are labelled 1 and all others are labelled 0, we can visualise the results of point detection by a binary image g(x,y)

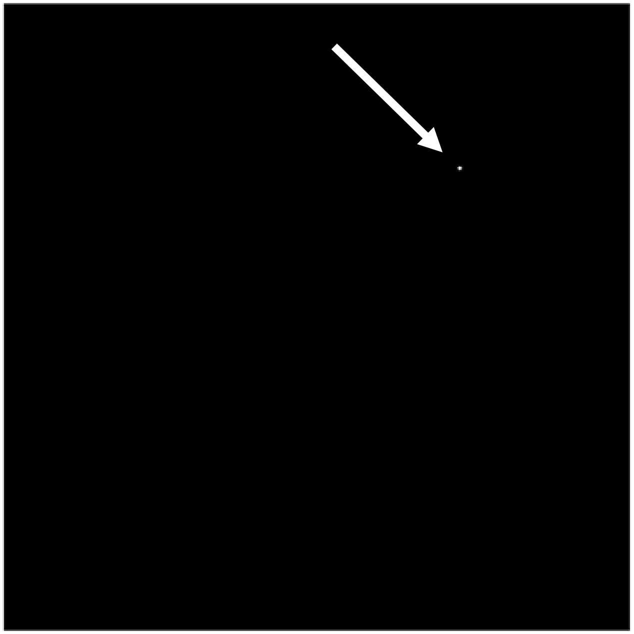
$$g(x,y)=\begin{cases}1 & \text{if } \left|R(x,y)\right| \geq T \\ 0 & \text{otherwise}\end{cases}$$

Detection of Isolated Points

- Example



Original image with a nearly invisible isolated dark point in the dark gray area



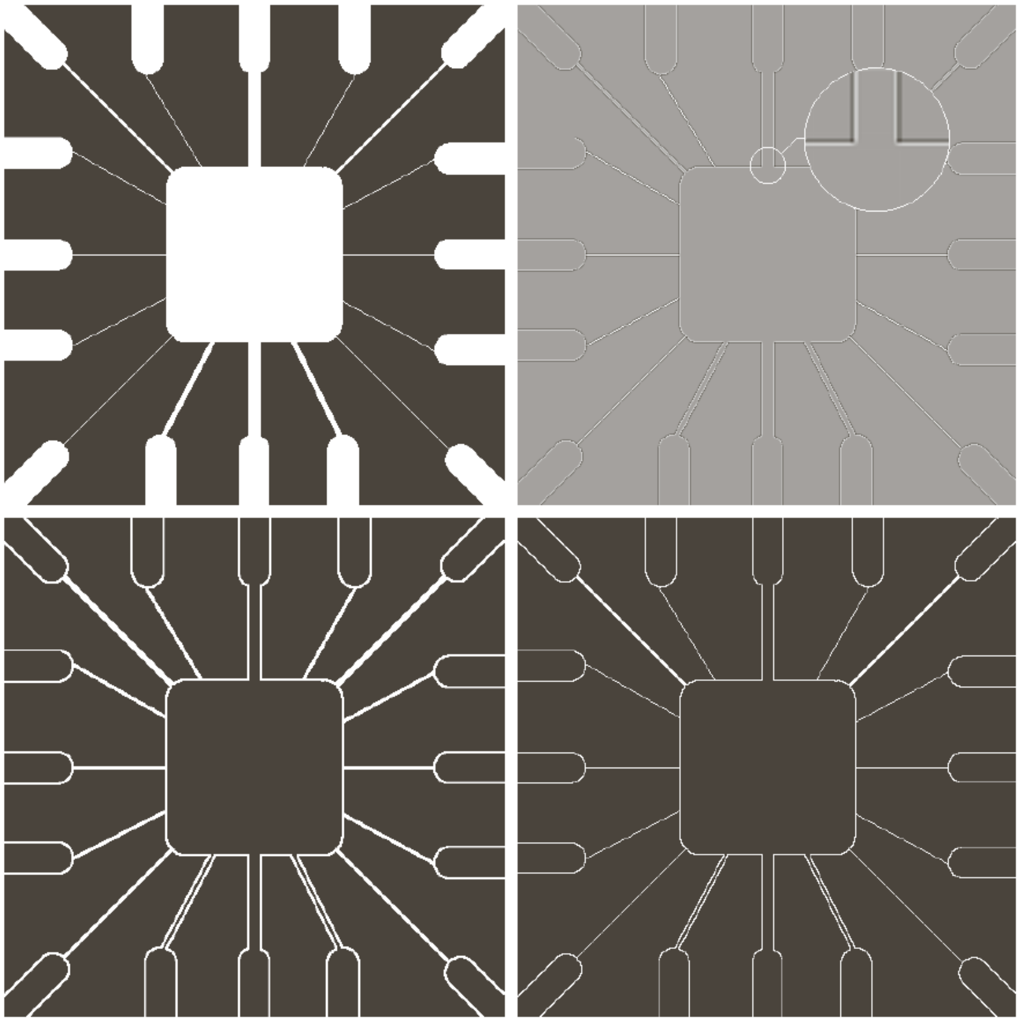
Binary image showing the detected point

Line Detection

- A line is an edge segment in which the intensity of the background on either side is either much higher or much lower than the intensity of the line pixels
- Assumption: Lines are thin w.r.t. size of detector
- Laplacian Mask – Line Detection

$$
\begin{matrix}
1 & 1 & 1 \\
1 & -8 & 1 \\
1 & 1 & 1
\end{matrix}
$$

Line Detection



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.

Line Detection

- Anisotropic masks

- The previous mask is isotropic – Does not have preference for any particular direction

- Anisotropic masks can be used to detect lines in specified directions

$$
\begin{array}{ccc} -1 & -1 & -1 \\ 2 & 2 & 2 \\ -1 & -1 & -1 \end{array}
\qquad
\begin{array}{ccc} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{array}
\qquad
\begin{array}{ccc} -1 & 2 & -1 \\ -1 & 2 & -1 \\ -1 & 2 & -1 \end{array}
\qquad
\begin{array}{ccc} -1 & -1 & 2 \\ -1 & 2 & -1 \\ 2 & -1 & -1 \end{array}
$$

Horizontal | -45° | Vertical | + 45°

Line Detection

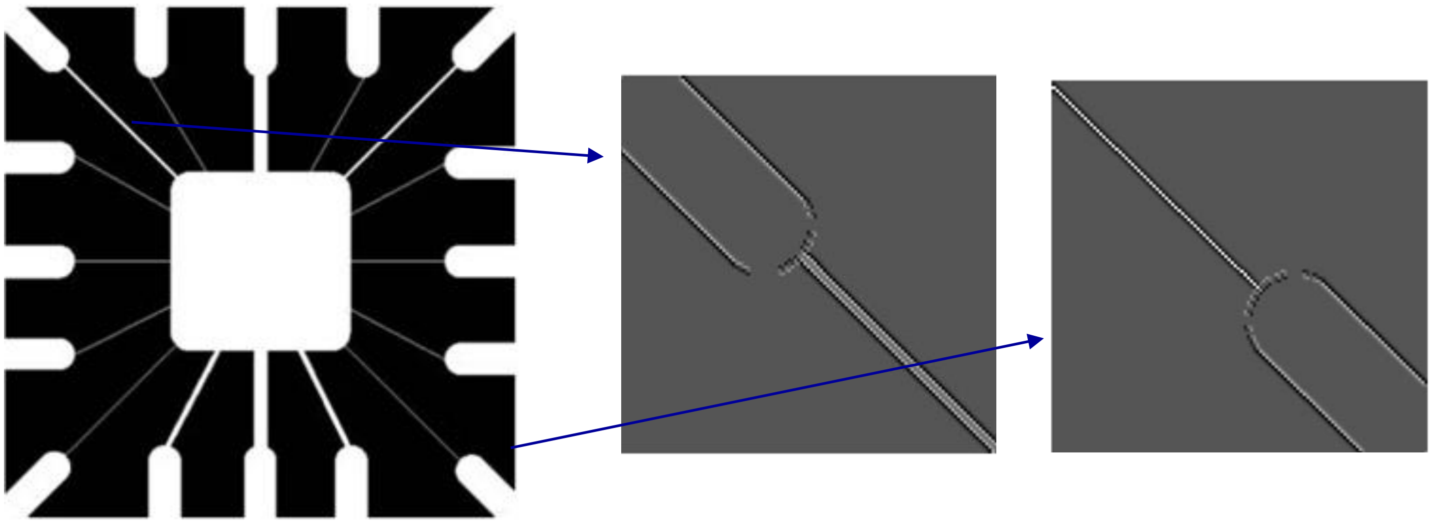
- Let R1, R2, R3, R4 be the responses of the previous four masks centred on (x,y)
- The pixel (x,y) is said to be more likely associated with the direction of the mask with the highest response in absolute values
- For example, if

$$|R_1| > |R_i| \quad i = 2,3,4$$

- we say that (x,y) is more likely associated with the horizontal direction

Line Detection

- To detect lines in a specified direction, we run the corresponding mask through the image and threshold the absolute values of the result
- Example

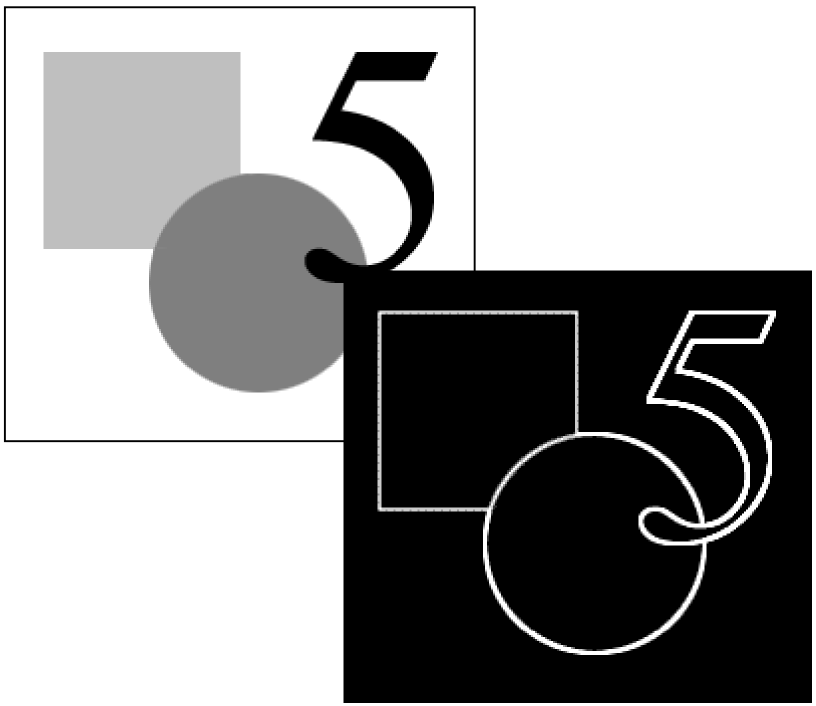


Original image

Response of the -45° line detection mask

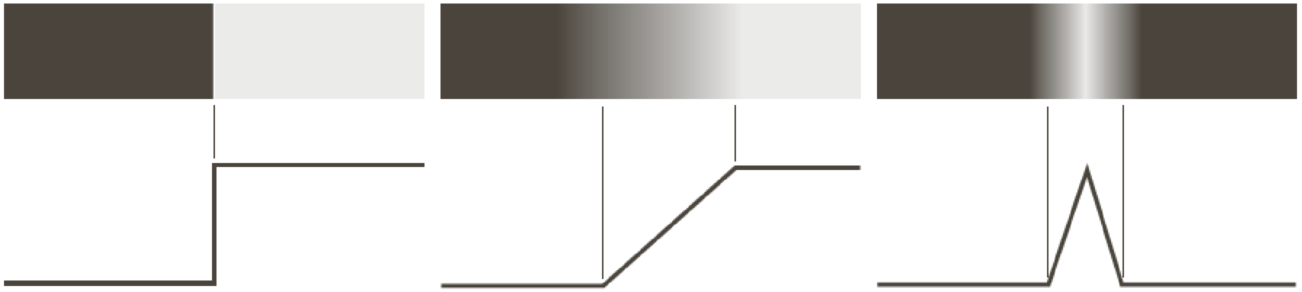
Edge Detection

- Edge – Area of significant change in intensity
- Edge Detection – Locating areas with strong intensity contrast
- Local changes of intensity can be detected using differences of neighbouring pixels



Types of Edges

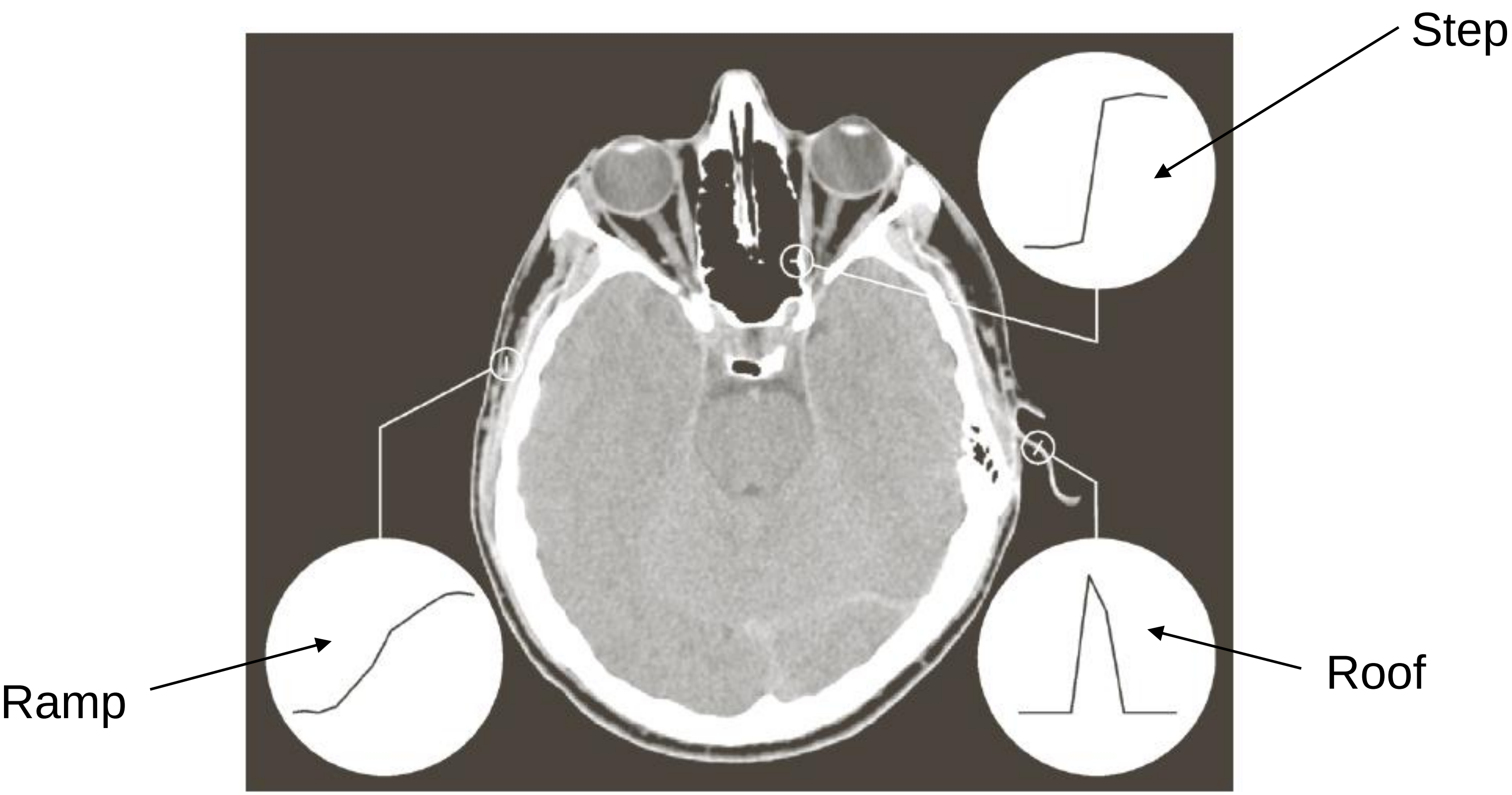
- Variation of intensity/gray level
  - Step Edge
  - Ramp Edge
  - Roof Edge



Step Edge Ramp Edge Roof Edge

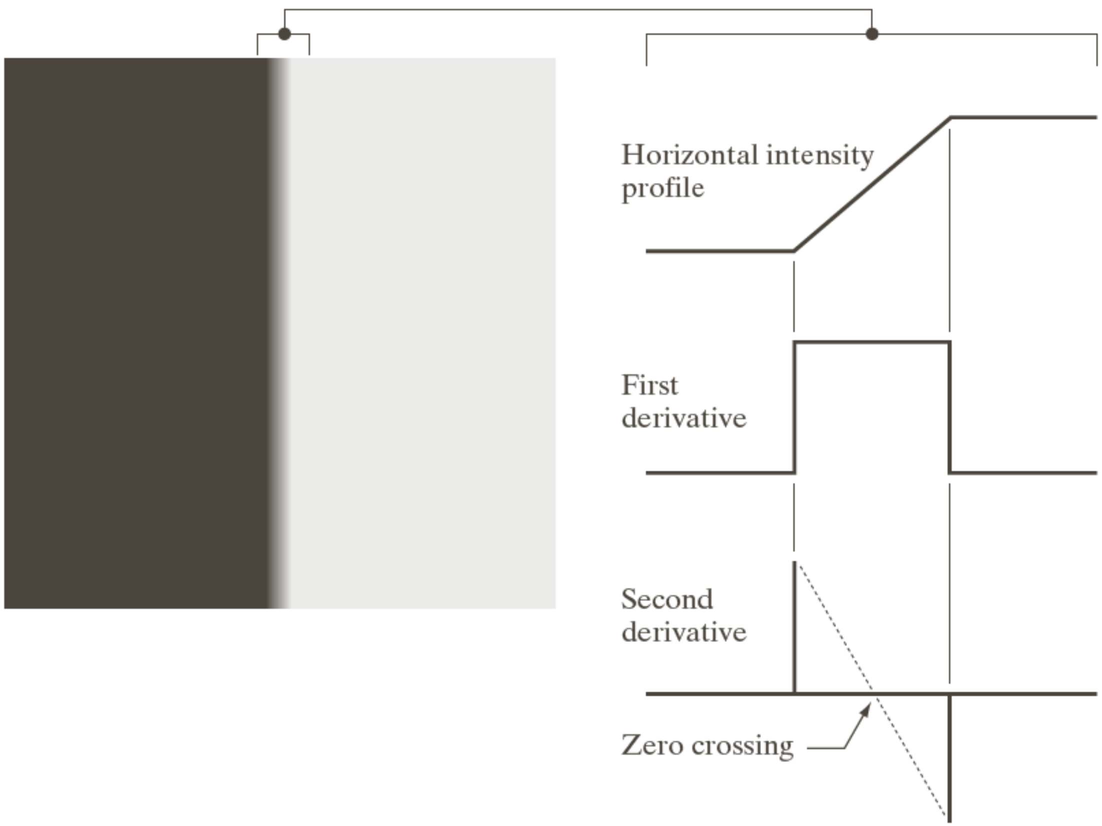
Types of Edges

- Example
  - Deviations from ideal models



Types of Edges

- Example



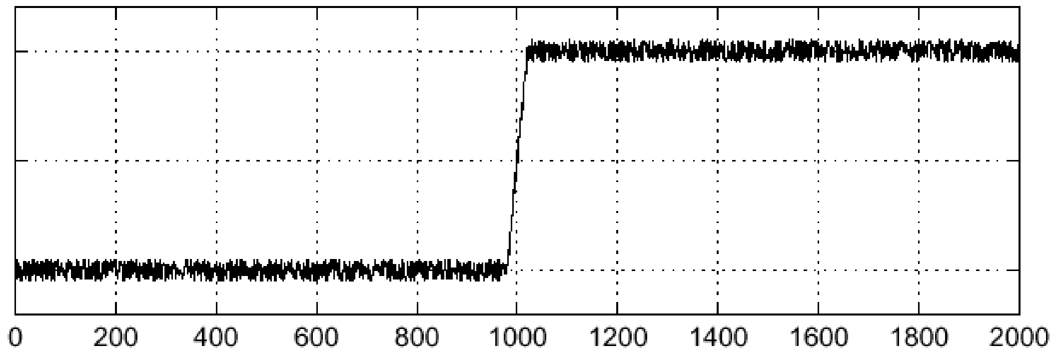
a b

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.

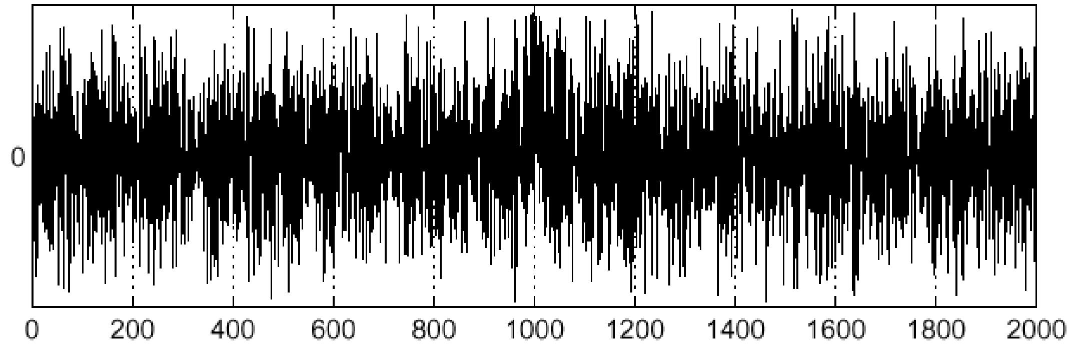
Edge Detection – Effects of Noise

- Consider a single row or column of the image
  - Plotting intensity as a function of position gives a signal

$f(x)$



$\frac{d}{dx}f(x)$



Where is the edge??

Effects of Noise - Solution

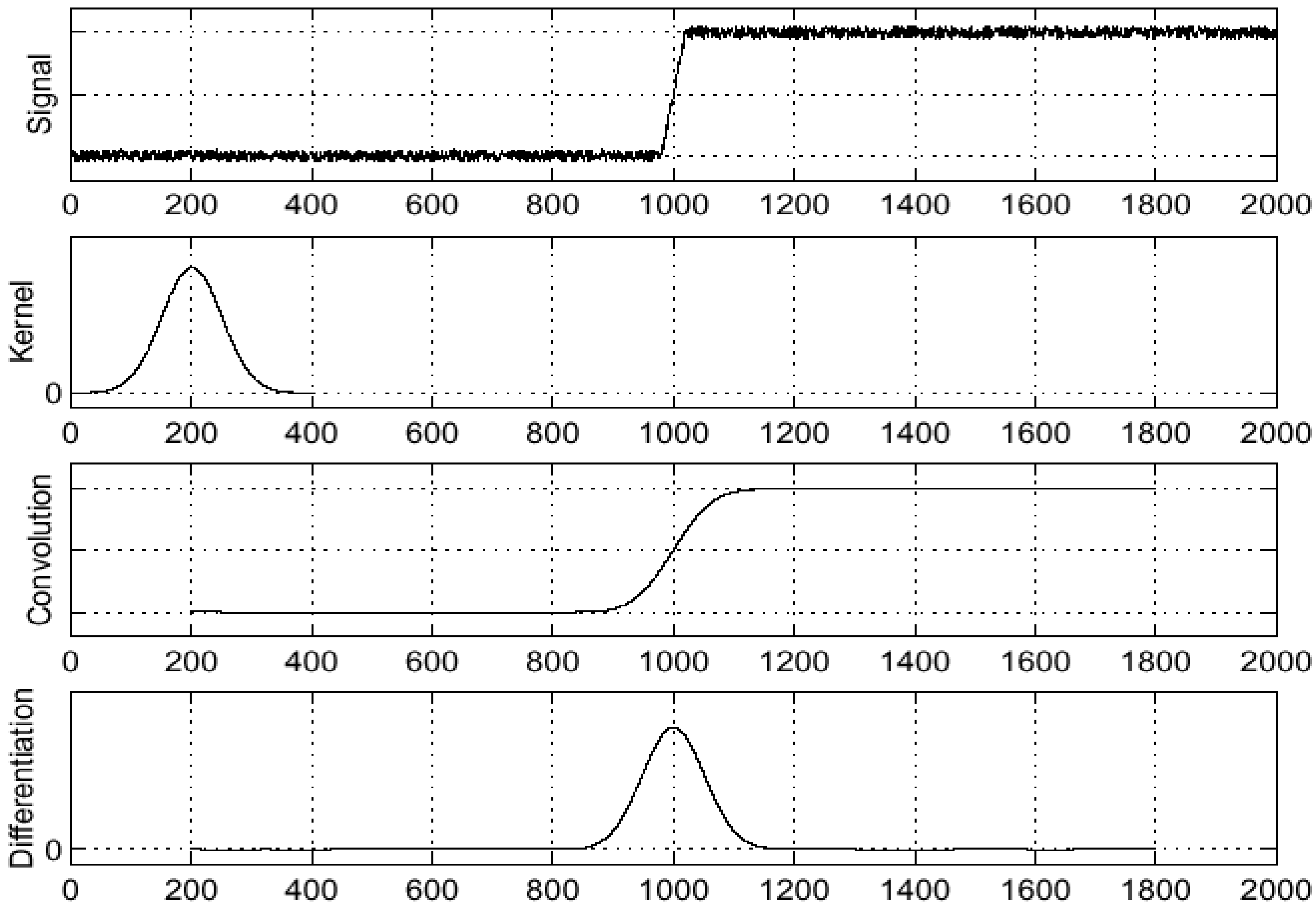
- Smoothing

f

h

$h \star f$

$\frac{\partial}{\partial x}(h \star f)$



Edge Detection

- Key Steps
  - Image Smoothing – Noise Reduction
  - Detection of Edge Points
  - Edge Localization

Detecting Edge Points

- First Derivative / Gradient Methods
  - Roberts Operator
  - Prewitt Operator
  - Sobel Operator

- Second Derivative
  - Laplacian
  - Laplacian of Gaussian

- Optimal Edge Detection
  - Canny Edge Detector

Gradient

- For a continuous two dimensional function Gradient is defined as

$$G[f(x,y)] = \begin{bmatrix} Gx \\ Gy \end{bmatrix} = \begin{bmatrix} \dfrac{\partial f}{\partial x} \\ \dfrac{\partial f}{\partial y} \end{bmatrix}$$

$$|G| = \sqrt{Gx^2 + Gy^2}$$

$$\alpha = \tan^{-1}\left(\frac{Gy}{Gx}\right)$$

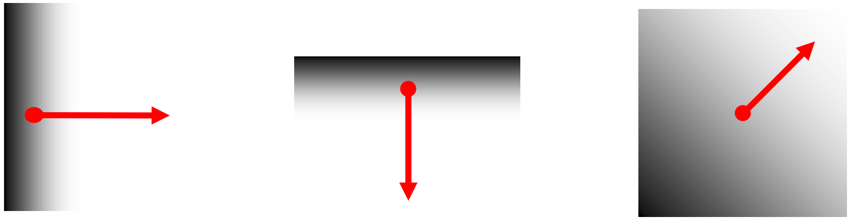
Gradient

- Approximation of Gradient for a discrete two dimensional function

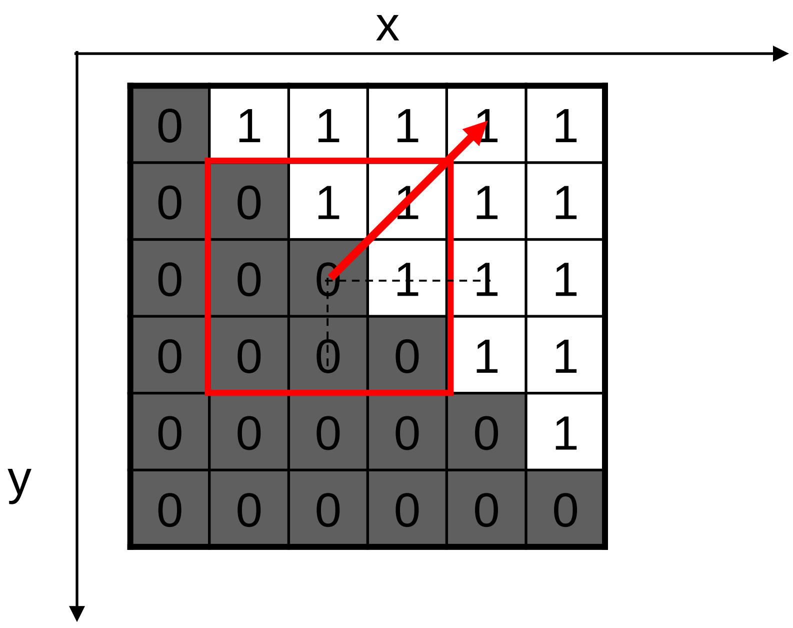
$$Gx = \frac{\partial f}{\partial x} = f(x+1, y) - f(x, y)$$

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

- Gradient Magnitude: ‘Strength’ of edge
- Gradient Direction: Points in the direction of most rapid change in intensity



Gradient



$$\frac{\partial f}{\partial x} = 2$$

$$\frac{\partial f}{\partial f} = -2$$

$$\alpha = \tan^{-1}\left(\frac{G_y}{G_x}\right) \qquad \alpha = \tan^{-1}\left(\frac{-2}{2}\right)$$

Gradient

- Implementation: Convolution Masks

-1
1

-1	1

- Diagonal Direction: Roberts cross-gradient operators

0	-1
1	0

-1	0
0	1

- 2x2 Masks: Differences are computed at interpolated points
- 3x3 Masks: Symmetric about the central pixel

Gradient

- Prewitt Operators

-1	-1	-1
0	0	0
1	1	1

-1	0	1
-1	0	1
-1	0	1

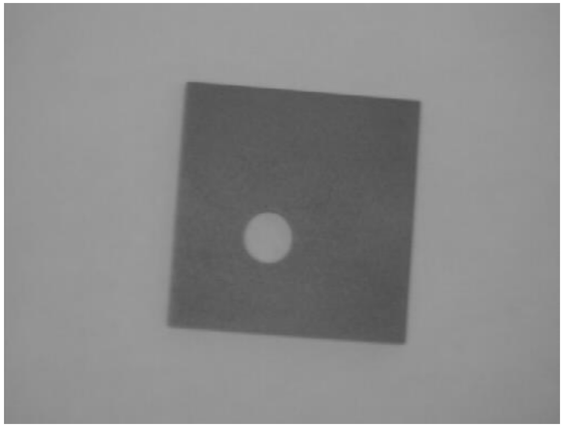
- Sobel Operators

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

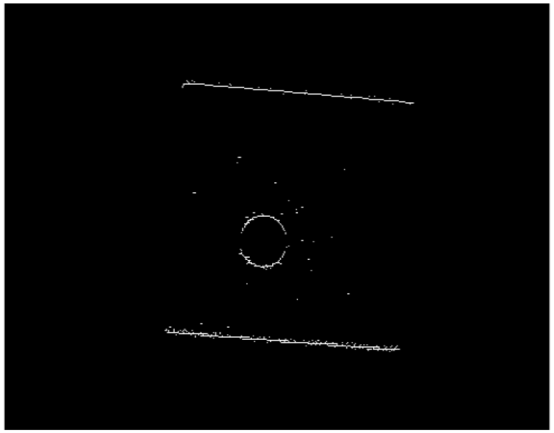
-1	0	1
-2	0	2
-1	0	1

Edge Detection

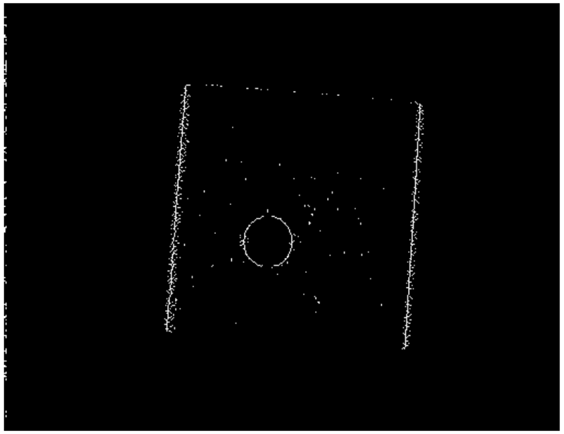
- Example



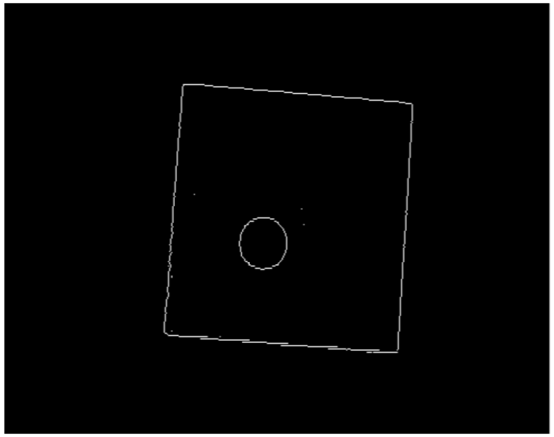
Original Image



Horizontal Edges



Vertical Edges

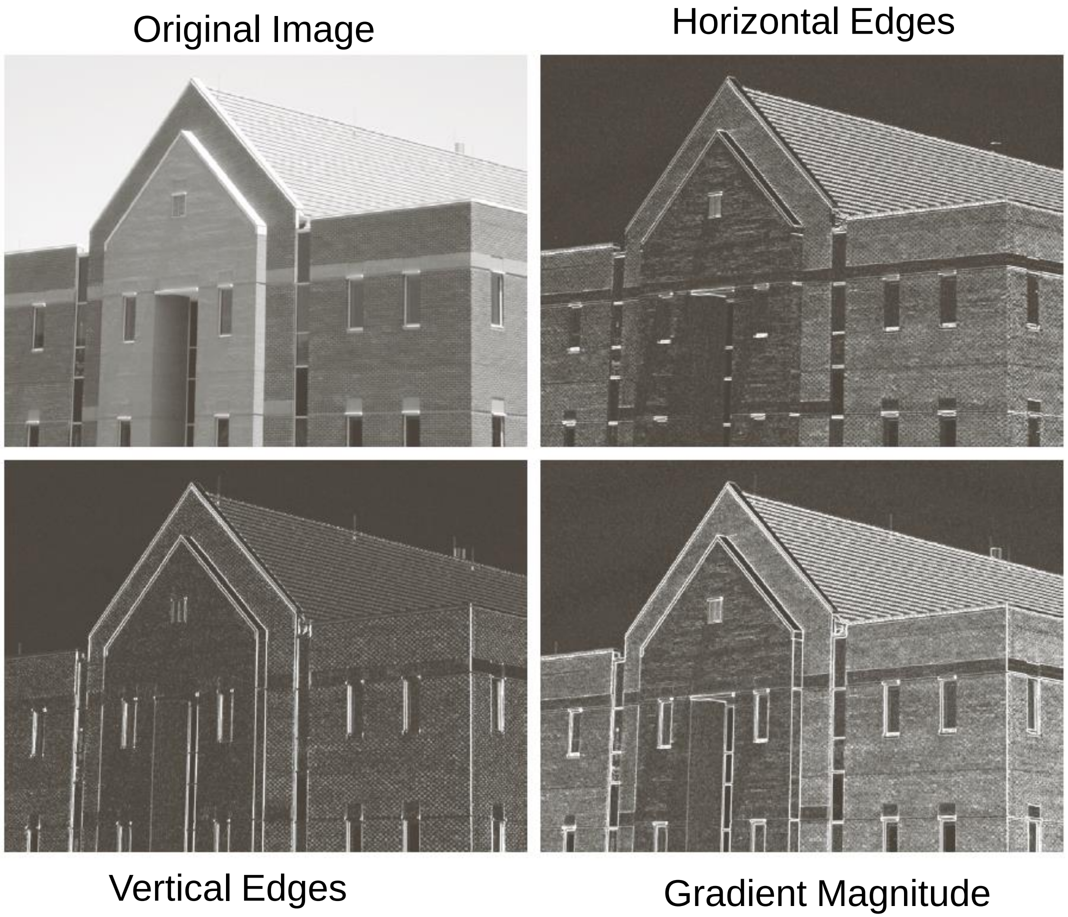


Horizontal + Vertical

$$M(x, y) \approx |g_x| + |g_y|$$

Edge Detection

- Example



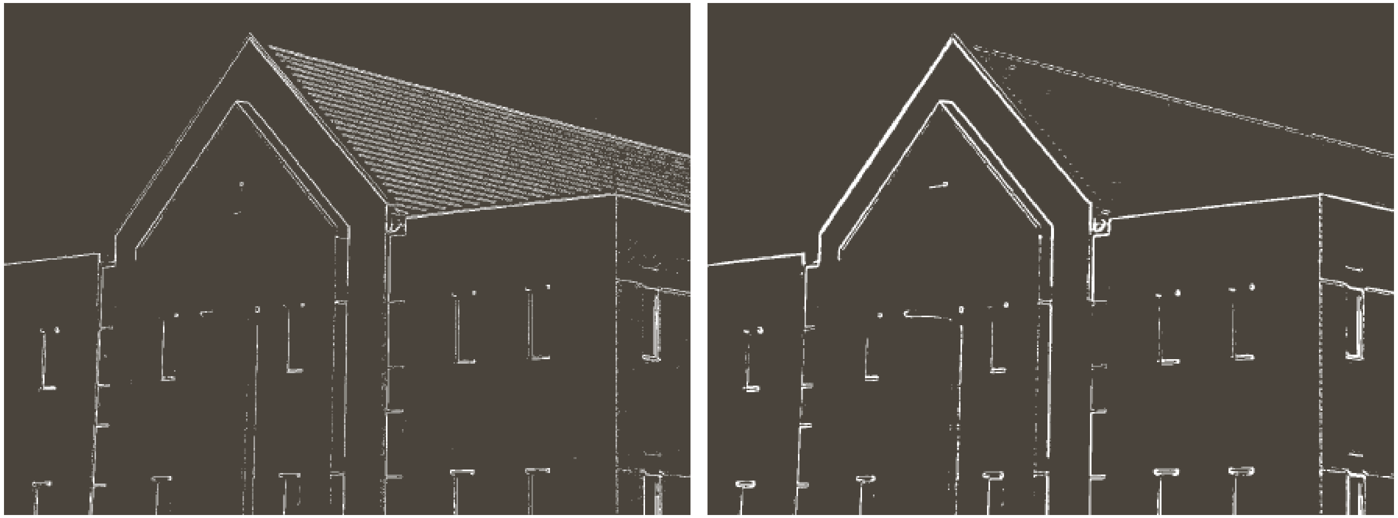
Edge Detection with Smoothing

- Example

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.

Edge Detection with Thresholding

- Example



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.

References

- Chapter # 10, DIP by Gonzalez & Woods
- Lecture slides by:
  - Cornelia Fermüller
  - Sumit Tandon
  - Ioannis Ivrissimtzis
  - Longin Jan Latecki
- http://homepages.inf.ed.ac.uk/rbf/HIPR2/