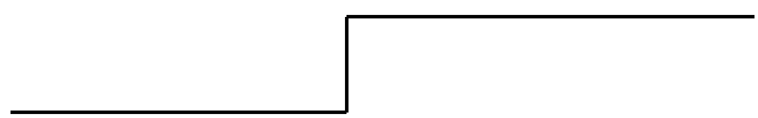
Edge Detection

Introduction

- Edges carry a lot of information about the various regions in the image.
- Edge detection is an operation to detect significant local changes in the intensity level in an image.
- Edges can be used in
  - Image segmentation
  - Stereo matching
  - Document analysis

Edge Detection

- Edge = a point where abrupt change occurs
- Basic idea: look for significant local changes in the intensity level in an image.
- Change can be measured by the derivatives. Edge is where
  - 1st derivative has maximum magnitude
  - Or 2nd derivative has a zero-crossing.



Main Approaches in Edge Detection

- Gradient
- Laplacian
- LoG (Laplacian of Gaussian)
- Canny Edge Detector

Gradient

- Attempt to approximate the gradient at a pixel via masks
- Threshold the gradient to select the edge pixels

Prewitt Operator

$$Sy = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \qquad Sx = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

- Let Gx be the response of image f to Sx
- Let Gy be the response of image f to Sy

Then the gradient is $\nabla \mathbf{f} = [Gx \ \ Gy]^T$

And $G = (Gx^2 + Gy^2)^{1/2}$ is the gradient magnitude.

$\theta = \mathrm{atan2}(Gy/Gx)$ is the gradient direction.

Digital Implementation of Gradient -- Masks

−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

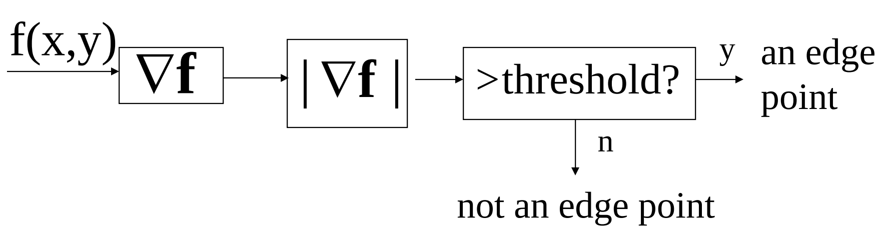
Prewitt

−1	−2	−1
0	0	0
1	2	1

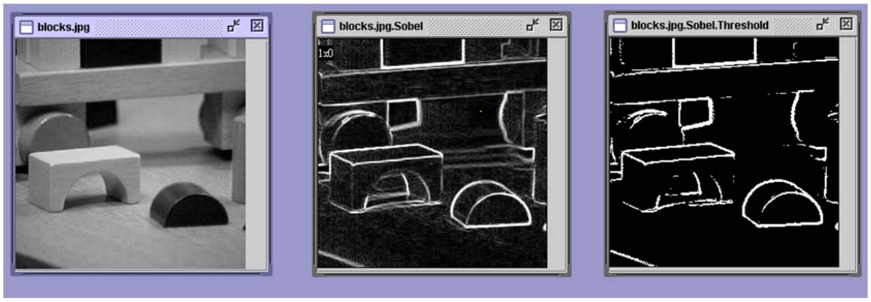
−1	0	1
−2	0	2
−1	0	1

Sobel

Gradient-Based Methods



Sobel Operator on the Blocks Image



Original image

Gradient magnitude

Thresholded gradient magnitude

Edge Detection Using Gradient

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, $|G_x| + |G_y|$.

Edge Detection Using Gradient

a b
c d

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

Diagonal Directional Gradient Filtering

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 10.9 Prewitt and Sobel masks for detecting diagonal edges.

Edge Detection Using Gradient

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).

How do we estimate the Second Derivative?

- Laplacian Filter: $\nabla^2 f = \dfrac{\partial^2 f}{\partial x^2} + \dfrac{\partial^2 f}{\partial y^2}$

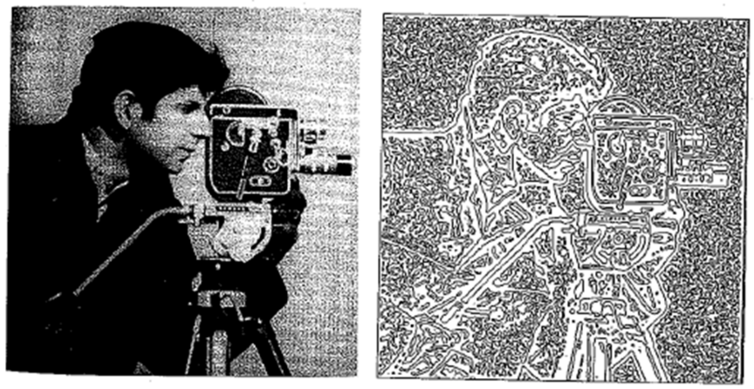
0	−1	0
−1	4	−1
0	−1	0

−1	−1	−1
−1	8	−1
−1	−1	−1

- The Laplacian mask estimates the 2D second derivative.
- Find its zero crossings

Laplacian-Based Methods

- Direct use of Laplacian-based methods generate many "false" edge contours.



(a) (b)

Figure 8.33 Edge map obtained by a Laplacian-based edge detector. (a) Image of 512 × 512 pixels; (b) result of convolving the image in (a) with $h(n_1, n_2)$ in Figure 8.32(a) and then finding zero-crossing points.

Laplacian of Gaussian (The Marr/Hildreth Edge Detector)

- Laplacian of a Gaussian (LoG) requires two steps:
  - Convolve the image with a Gaussian smoothing filter

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

  - Convolving the smoothed image with a Laplacian mask

- Edge pixels are the zero crossings of the Laplacian of the Gaussian.

Laplacian of a Gaussian (LoG)

- The two masks can be combined into one LoG mask

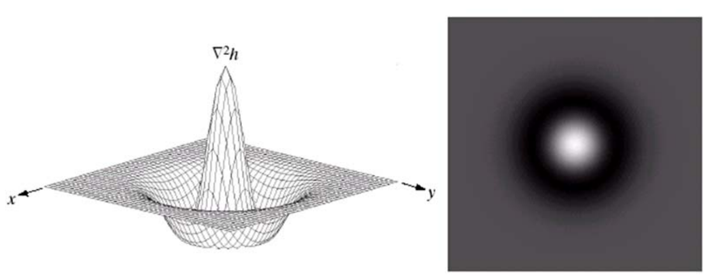
$$\nabla^2(f(x,y) * h(x,y)) = f(x,y) * [\nabla^2 h(x,y)]$$

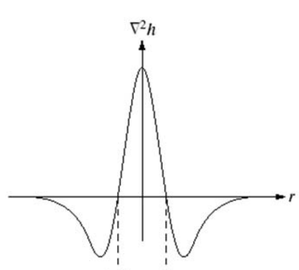
$$= f(x,y) * [\frac{\partial^2 h(x,y)}{\partial x^2} + \frac{\partial^2 h(x,y)}{\partial y^2}]$$

- The Laplacian of h is referred to as the Laplacian of a Gaussian (LoG) (Mexican hat function)

$$\nabla^2 h(x,y) = -\frac{(x^2 + y^2 - \sigma^2)}{\sigma^4} e^{-(x^2+y^2)/(2\sigma^2)}$$

Laplacian of a Gaussian (LoG)



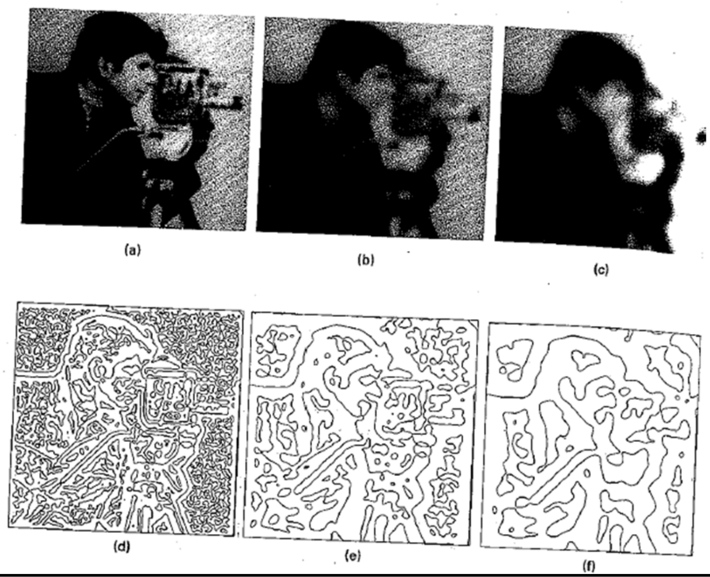


0	0	−1	0	0
0	−1	−2	−1	0
−1	−2	16	−2	−1
0	−1	−2	−1	0
0	0	−1	0	0

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).

Example of Using LoG



Properties of derivative masks

- Coefficients of derivative masks have opposite signs in order to obtain a high response in regions of high contrast.
- The sum of coefficients of derivative masks is zero, so that a zero response is obtained on constant regions.
- First derivative masks produce high absolute values at points of high contrast.
- Second derivative masks produce zero-crossings at points of high contrast.

Canny Edge Detector

- Apply a Gaussian filter mask to smooth the image to mitigate noise effects.
- Find the magnitude and direction of the gradient using masks similar to the Sobel or Prewitt edge detectors.
- Apply **nonmaxima suppresion** (zero out any pixel response ≤ the neighboring pixels on either side of it, along the direction of the gradient (quantize into one of four directions.)

$$\begin{bmatrix} \leftarrow 50 & 112 \rightarrow & 20 \rightarrow \\ \leftarrow 40 & 100 \rightarrow & 91 \rightarrow \\ \leftarrow 88 & 95 \rightarrow & 92 \rightarrow \end{bmatrix}$$

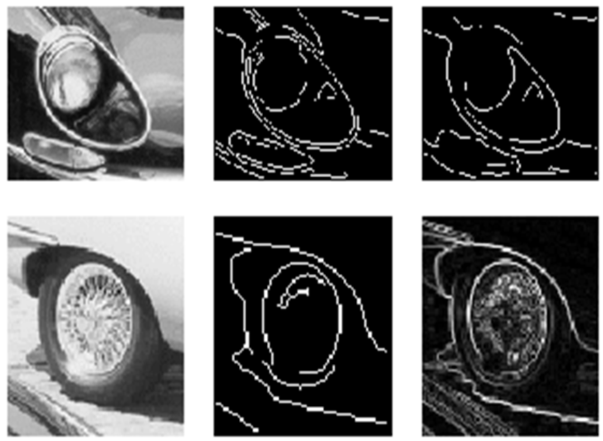
- Apply two thresholds to obtain the final result (also known as hysteresis thresholding).

Canny Characteristics

- The Canny operator gives single-pixel-wide edge maps with good continuation between adjacent pixels
- It is still widely used after 30 years; no one has done better since it came out in the late 80s. Many implementations are available.
- It is sensitive to its parameters, which need to be adjusted for different application domains.

Canny Examples

Canny σ=1 Canny σ=4



Canny σ=1 Roberts 2X2

Canny on the Blocks Image