Roadmap

- Introduction to image analysis (computer vision)
  - Its connection with psychology and neuroscience
  - Why is image analysis difficult?
- Theory of edge detection
  - Gradient operator
  - Advanced operators
- Applications
  - Road/sign detection in intelligent driving systems
  - Pupil detection in iris recognition systems

Roadmap

- Introduction to analysis of grayscale images
  - Why grayscale images are more difficult to handle?
- Edge detection
  - Gradient operator
  - Advanced operators
- Image segmentation
  - Basic techniques
  - Texture segmentation*

Edge Detection

- Why detect edge?

  Edges characterize object boundaries and are useful features for segmentation, registration and object identification in scenes.

- What is edge (to human vision system)?

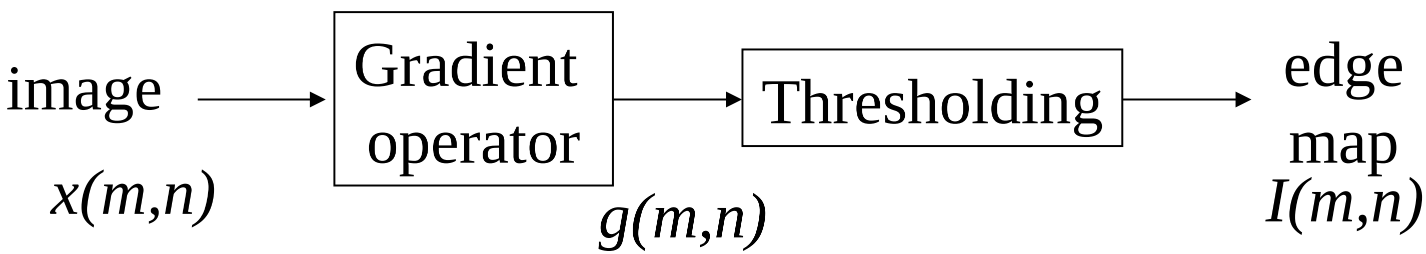
No rigorous definition exists

Intuitively, edge corresponds to singularities in the image (i.e. where pixel value experiences abrupt change)

Gradient Operators

- Motivation: detect changes

change in the pixel value → large gradient



$$I(m,n)=\begin{cases}1 & |g(m,n)|>th\\ 0 & otherwise\end{cases}$$

MATLAB function: > help edge

Common Operators

- Gradient operator

$$g(m,n) = \sqrt{g_1^2(m,n) + g_2^2(m,n)}$$

<u>Examples</u>: 1. Roberts operator

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

g_1 $\qquad$ g_2

Common Operators (cont'd)

2. Prewitt operator

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

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

3. Sobel operator

$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$

$\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$

Examples

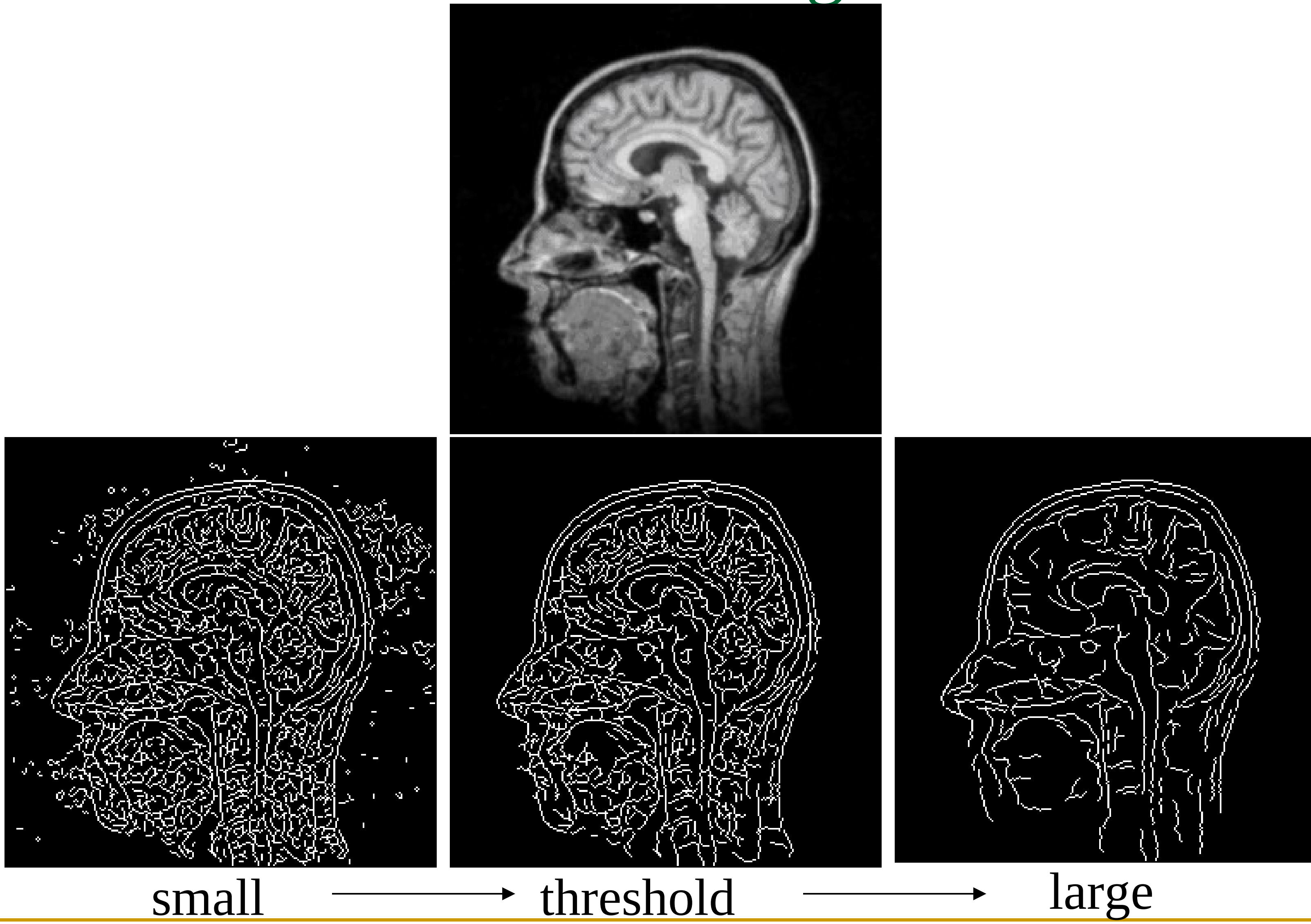
original image

horizontal edge

vertical edge

Prewitt operator (*th=48*)

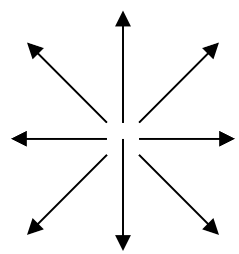
Effect of Thresholding Parameters



Compass Operators

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

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



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

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

$$g(m,n) = \max_k \{ | g_k(m,n) | \}$$

Examples


Compass operator (*th=48*)

Laplacian Operators

- Gradient operator: first-order derivative

sensitive to abrupt change, but not slow change

second-order derivative: $\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$

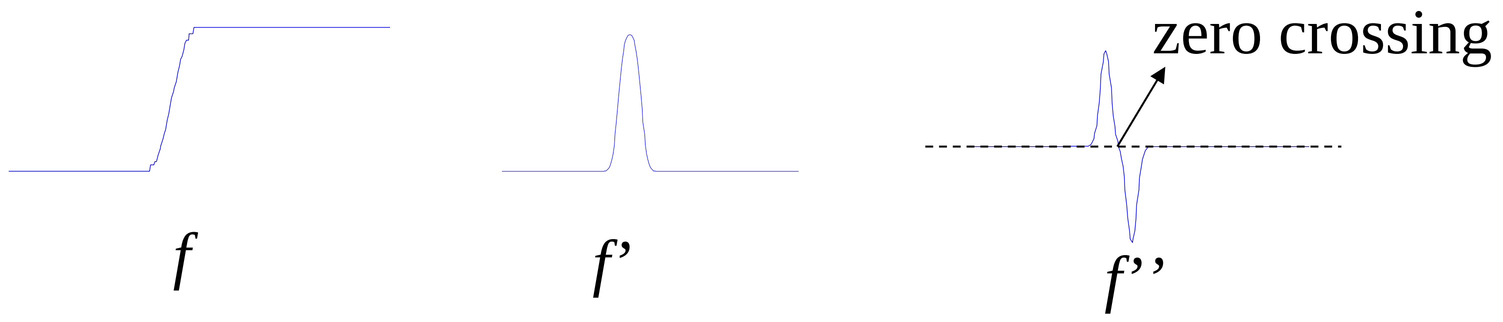
(Laplacian operator)

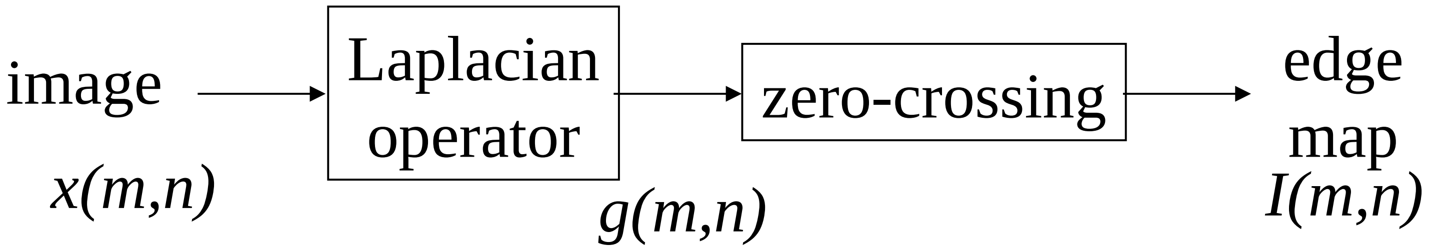
$\frac{\partial^2 f}{\partial x^2} = 0 \longrightarrow$ local extreme in f'

- Discrete Laplacian operator

$$\frac{1}{1+a}\begin{bmatrix} a & 1-a & a \\ 1-a & -4 & 1-a \\ a & 1-a & a \end{bmatrix} \qquad \underset{a=0}{\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}} \qquad \underset{a=0.5}{\begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix}}$$

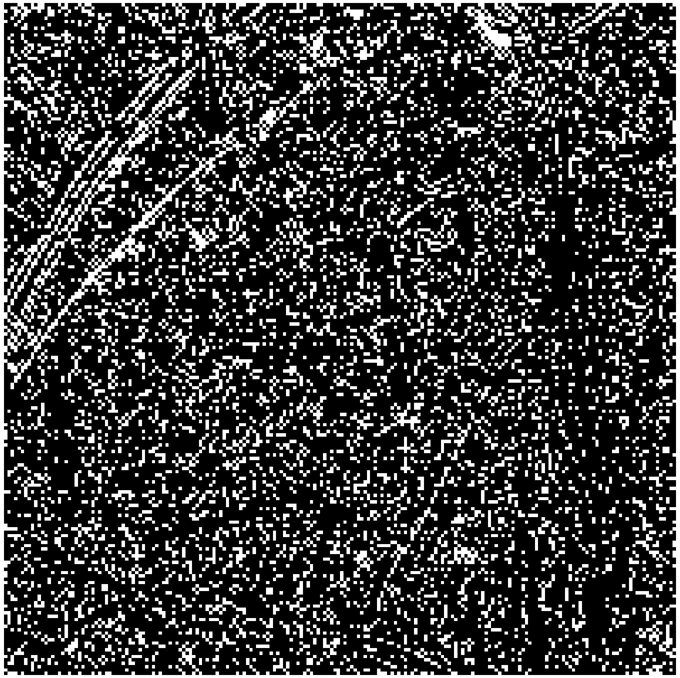
Zero Crossings





Examples

original image



zero-crossings

Question: why is it so sensitive to noise (many false alarms)?
Answer: a sign flip from 0.01 to -0.01 is treated the same as from 100 to -100

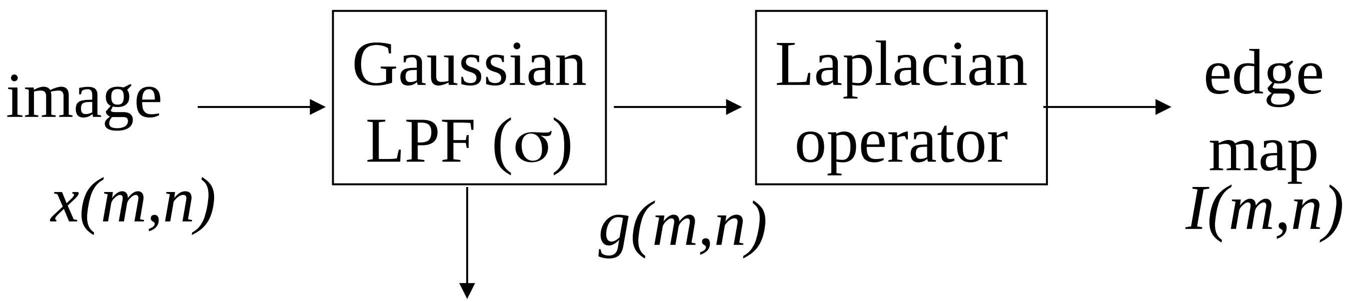
Ideas to Improve Robustness

- Linear filtering
  - Use a Gaussian filter to smooth out noise component → Laplacian of Gaussian
- Spatially-adaptive (Nonlinear) processing
  - Apply different detection strategies to smooth areas (low-variance) and non-smooth areas (high-variance) → Robust Laplacian edge detector
- Return single response to edges (not multiple edge pixels)
  - Hysteresis thresholding → Canny's edge detector

Laplacian of Gaussian

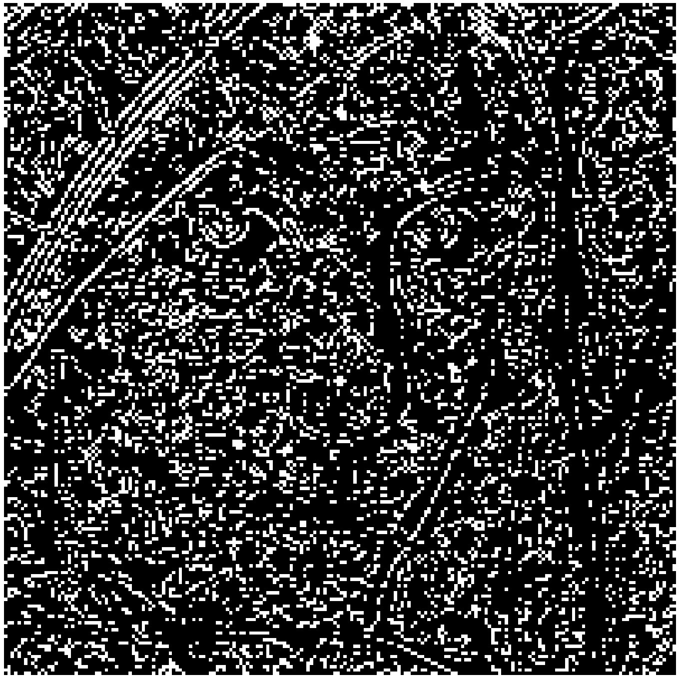
- Generalized Laplacian operator

$$h(m,n) = c\left[1 - \frac{(m^2+n^2)}{\sigma^2}\right]\exp\left(-\frac{m^2+n^2}{2\sigma^2}\right)$$



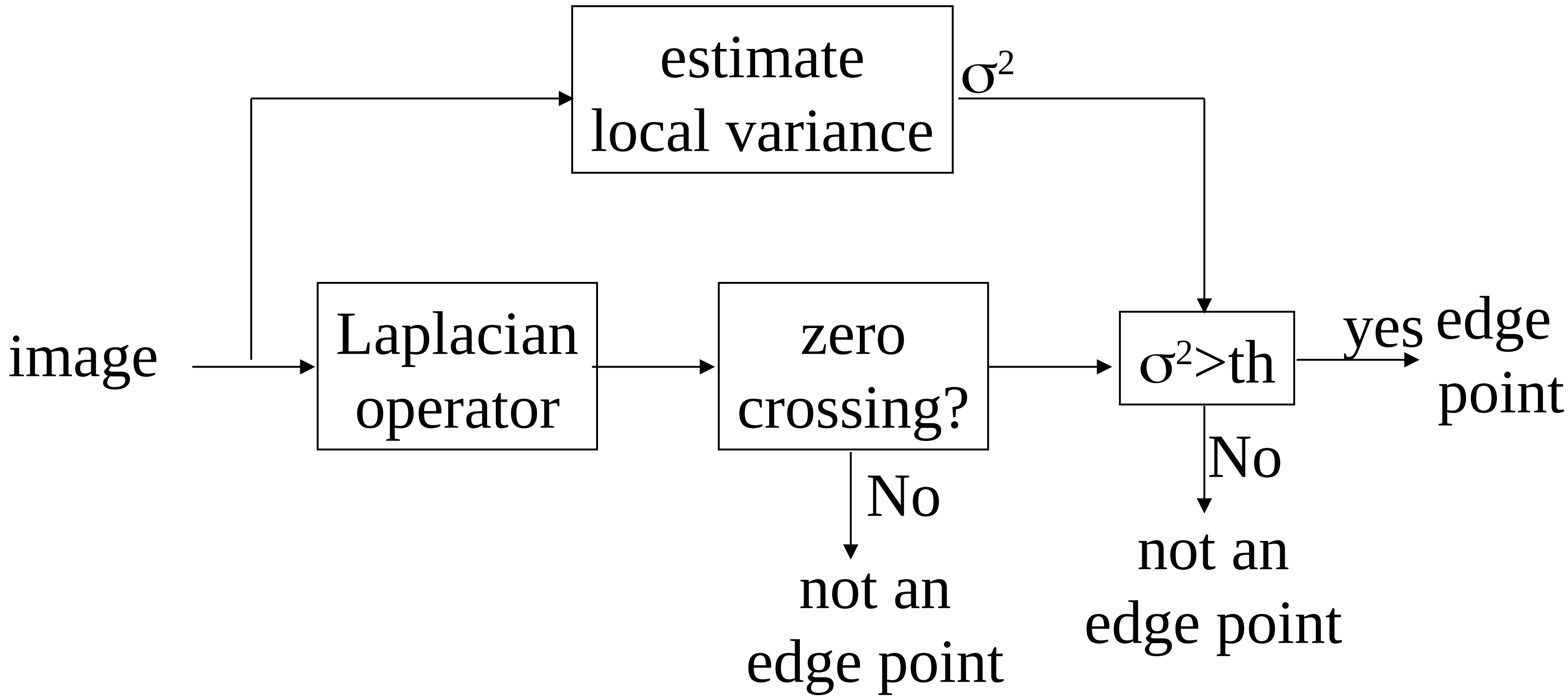
Pre-filtering: attenuate the noise sensitivity of the Laplacian

Examples

Better than Laplacian alone but still sensitive due to zero crossing

Robust Laplacian-based Edge Detector



Examples

More robust but return multiple edge pixels (poor localization)

Canny Edge Detector*

- Low error rate of detection
  - Well match human perception results
- Good localization of edges
  - The distance between actual edges in an image and the edges found by a computational algorithm should be minimized
- Single response
  - The algorithm should not return multiple edges pixels when only a single one exists

Flow-chart of Canny Edge Detector*

(*J. Canny'1986*)

Original image

↓

Smoothing by Gaussian convolution

↓

Differential operators along x and y axis

↓

Non-maximum suppression
finds peaks in the image gradient

↓

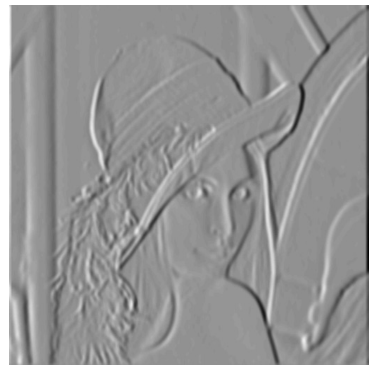
Hysteresis thresholding locates edge strings

↓

Edge map

Canny Edge Detector Example

original image



vertical edges

horizontal edges

norm of the gradient

after thresholding

after thinning

Marr and Hildreth's Method*

Edge is scale-dependent

$\downarrow$

A different edge map can be generated at different scale

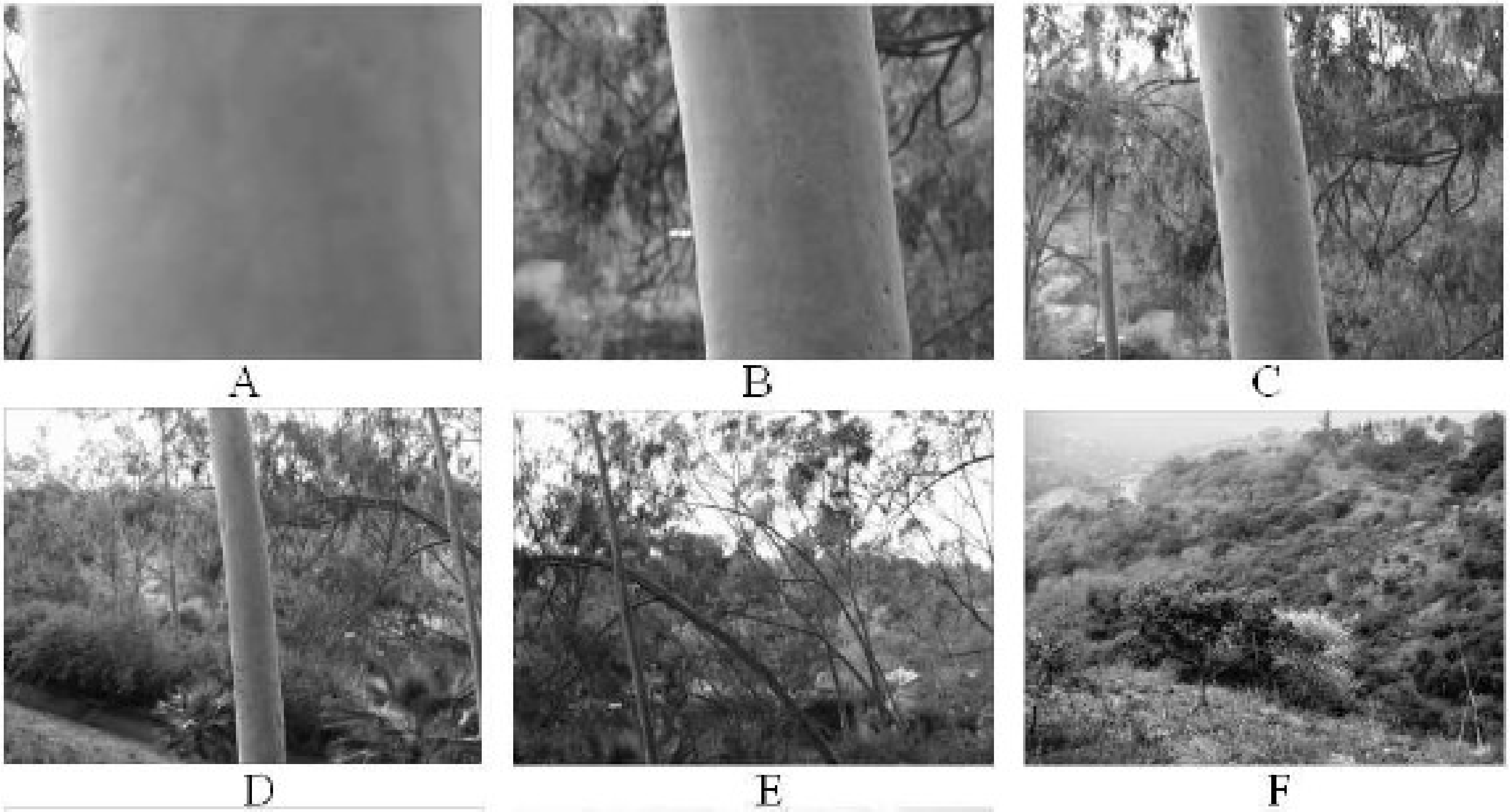
- Scale space representation

$$f(x,y;s) = f(x,y;0) \star g(x,y;s)$$

coarse-scale image   *fine-scale image*   *Gaussian kernel with width of s*

$$g(x,y;s) = \frac{1}{\sqrt{2\pi s}} \exp\left(-\frac{x^2+y^2}{2s}\right)$$

Importance of Scale



Scale-Space Edge Detection Examples

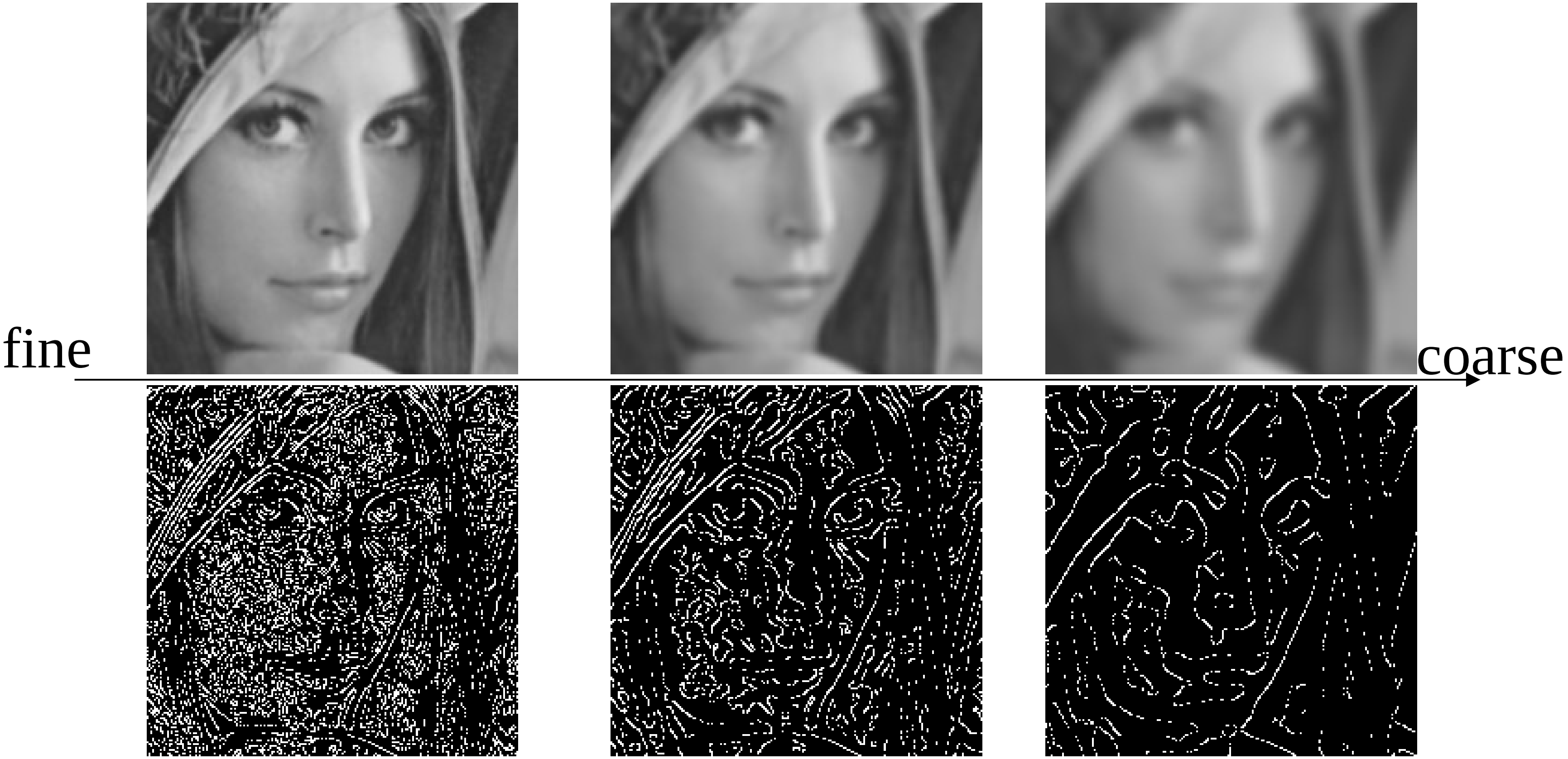


Image to Sketch Online Apps

http://sporkforge.com/imaging/sketch.php