CSE6706:
Advanced Digital Image Processing

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Image Segmentation

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Image Segmentation

- Divides an image into semantically meaningful regions
- Doesn't need to go for unnecessary detail

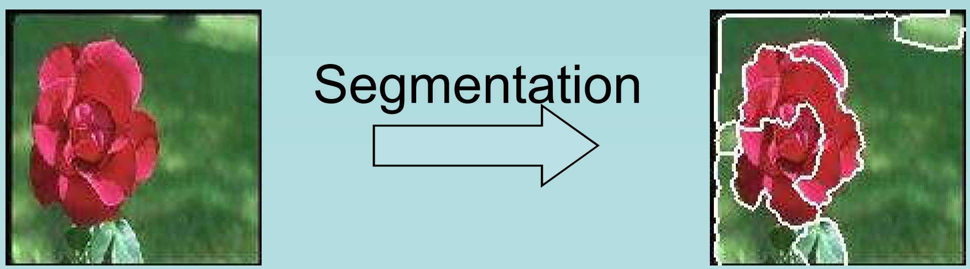

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Image Segmentation

- Nontrivial task
- Some control over the environment/background can help

Approaches in Image Segmentation

- Look for discontinuity and similarities

Approaches in Image Segmentation

- Look for discontinuity and similarities
- Discontinuity
  - Abrupt changes in gray level
  - Example: edges

Approaches in Image Segmentation

- Look for discontinuity and similarities
- Discontinuity
  - Abrupt changes in gray level
  - Example: edges
- Similarity
  - divides into regions which are similar based on some criteria
  - Example: thresholding,
    region growing
    region splitting and merging

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Approaches in Image Segmentation

- Look for discontinuity and similarities
- Discontinuity
  - Abrupt changes in gray level
  - Focus on detecting point, line and edges
  - Try to join edges to form regions/segments

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Detection of Discontinuity

- Remember the mask

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

Detection of Discontinuity

- Remember the mask

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

The response is given by

$$R = \sum_{i=1}^{9} w_i z_i$$

Detection of Isolated Point

- Isolated point: whose gray level is significantly different from its homogeneous/nearly homogeneous background

Detection of Isolated Point

- Isolated point: whose gray level is significantly different from its homogeneous/nearly homogeneous background

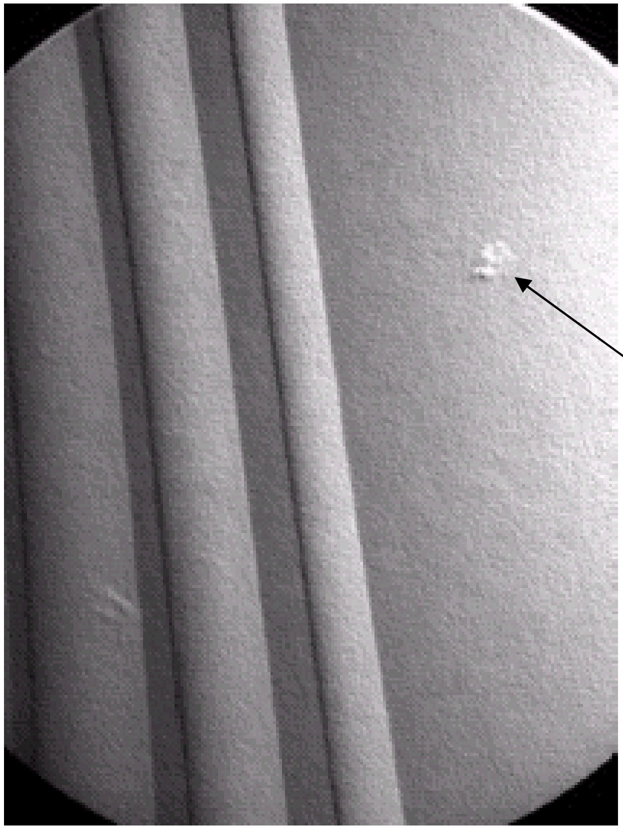
mask to isolated detect point

−1	−1	−1
−1	8	−1
−1	−1	−1

A point is detected if

$$|R| \geq T$$

Detection of Isolated Point



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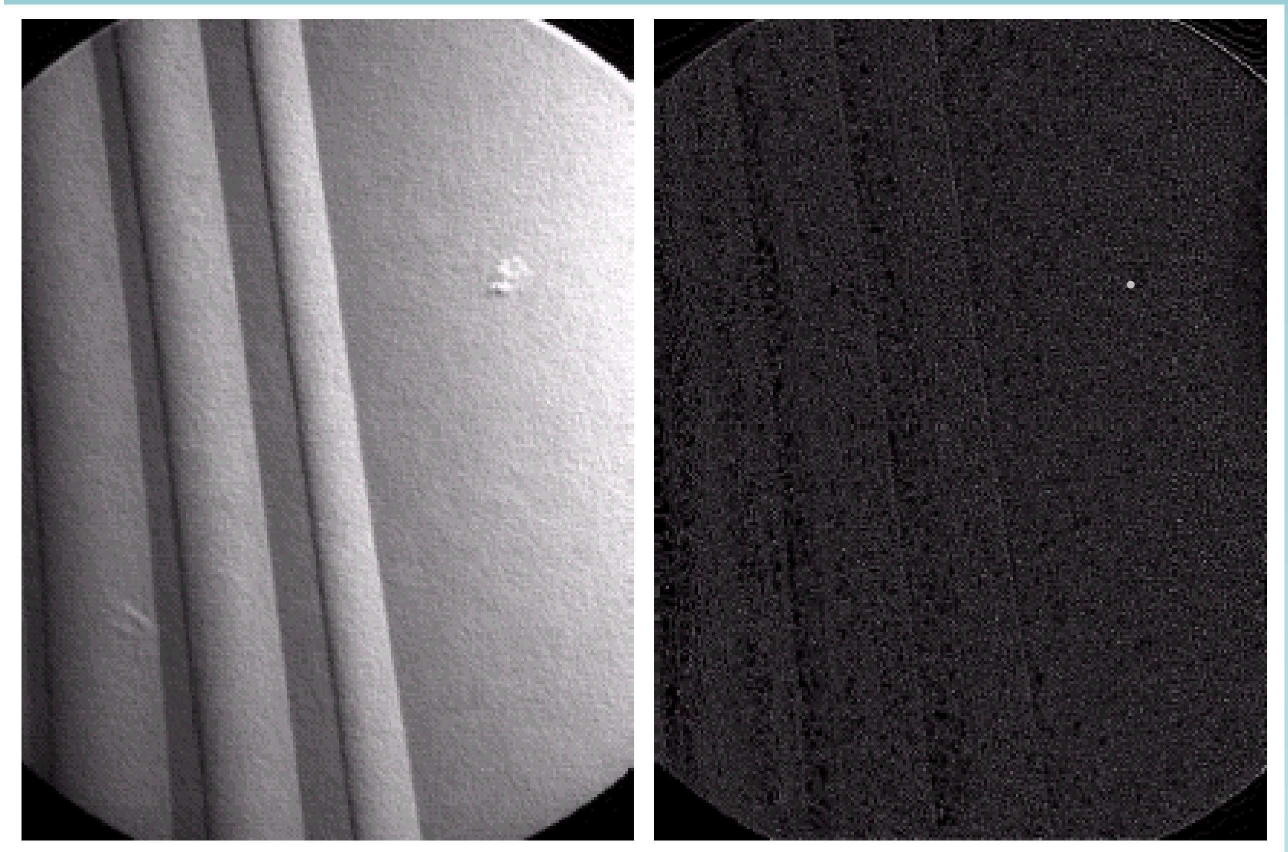
Detection of Isolated Point



After applying the mask

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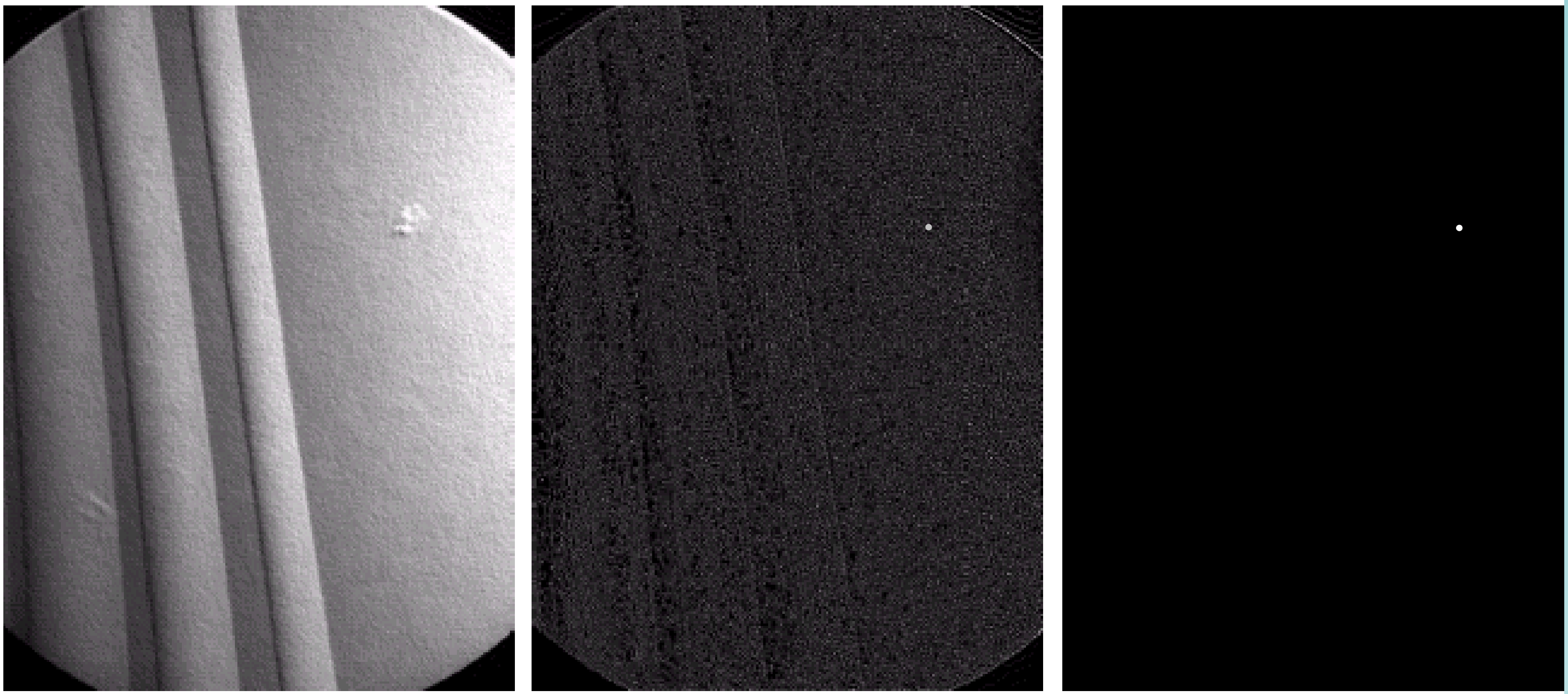
Detection of Isolated Point



After thresholding with T = 90% of max gray level

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Line Detection

−1	−1	−1
2	2	2
−1	−1	−1

Which direction will it detect?

Line Detection

−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

$-45°$

Line Detection

−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°

- Detects line of single pixel thick
- 2 ways to detect lines

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Line Detection

−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°

- Line detection (1)
  - To detect lines in every directions
  - Find masked (filtered or convolved) image with each mask
  - Let the responses be R_1, R_2, R_3, R_4

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Line Detection (1)

−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°

- A point is oriented to the direction of mask *i* if

$$|R_i| > |R_j| \quad \text{for all } j$$

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Line Detection (2)

−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°

- Use a single mask and use thresholding

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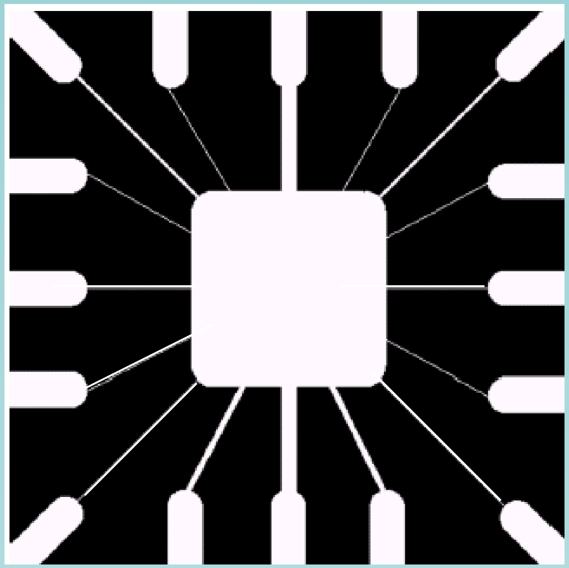
Line Detection (2)



Circuit board: binarized

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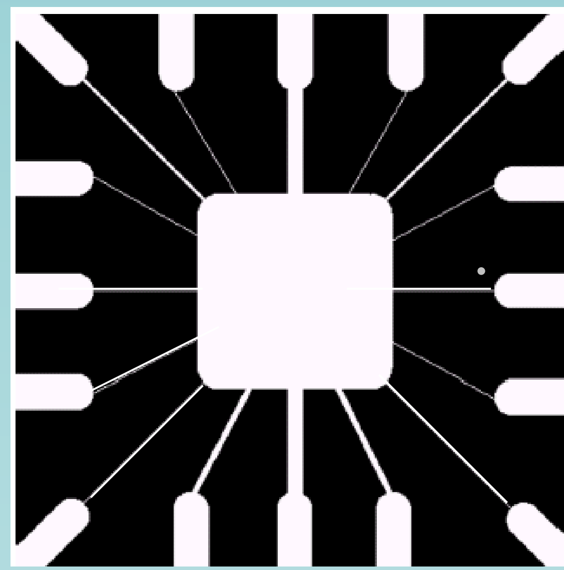
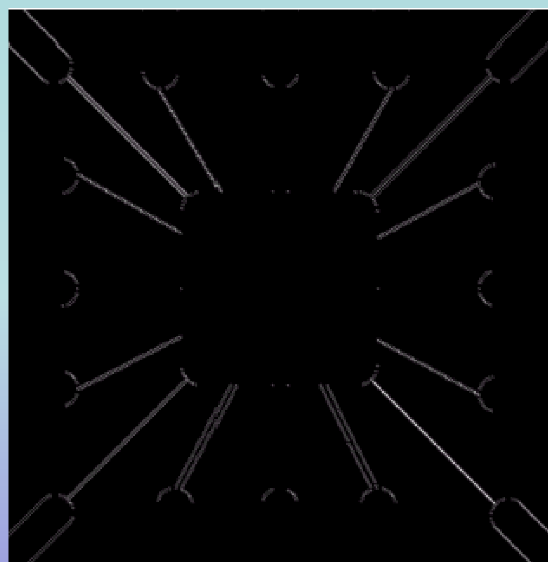
Line Detection (2)





Masked with

-45° line detector

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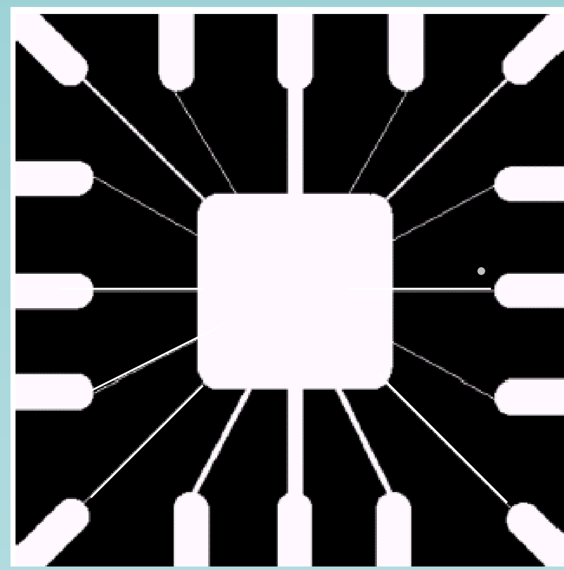
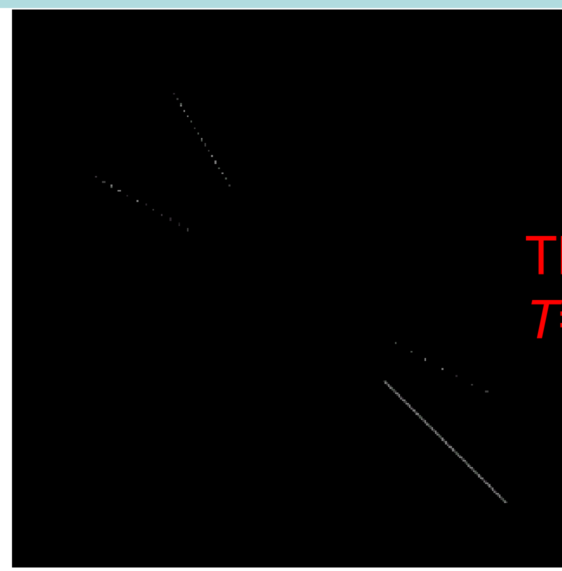
Line Detection (2)





Thresholded with
T= max gray level

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Edge Detection

- Review from Chapter 3:
  - Use 1^{st} and 2^{nd} order derivative
- Indicates boundary between regions

Edge Modeling

Model of an ideal edge

- Ideal edge is a set of connected pixels located at an orthogonal step transition

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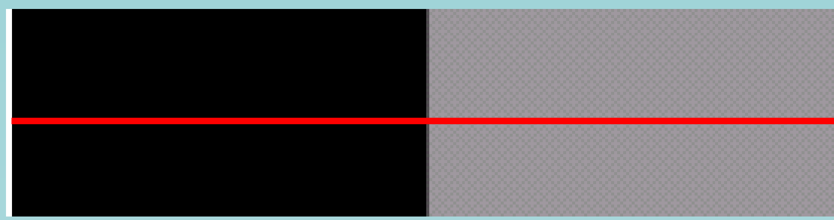
Edge Modeling

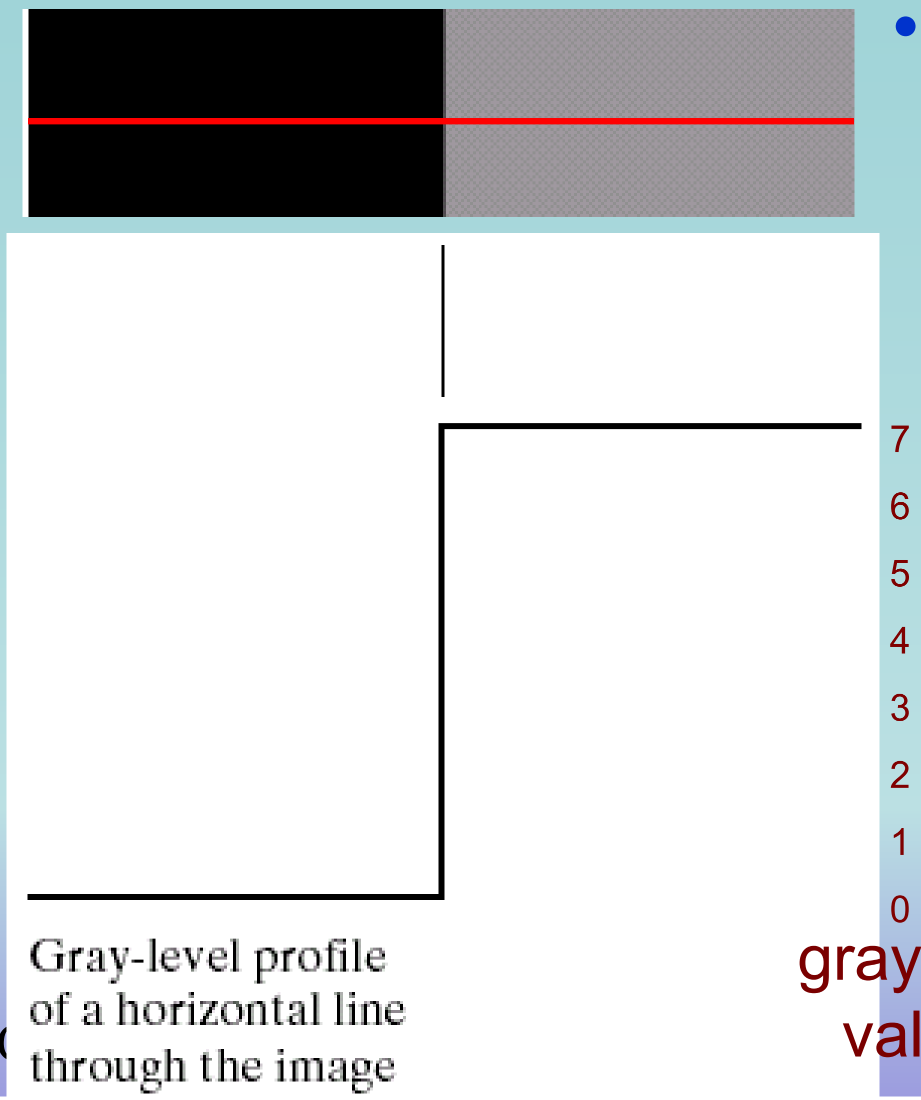
Model of an ideal edge



- Ideal edge is a set of connected pixels located at an orthogonal step transition

Edge Modeling

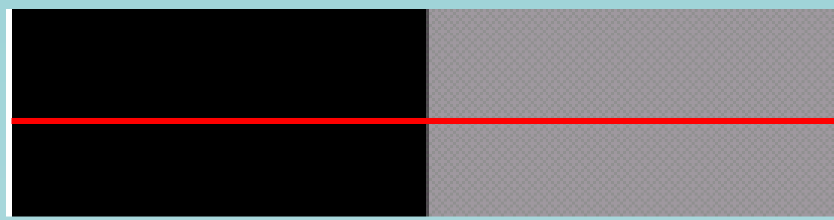
Model of an ideal edge

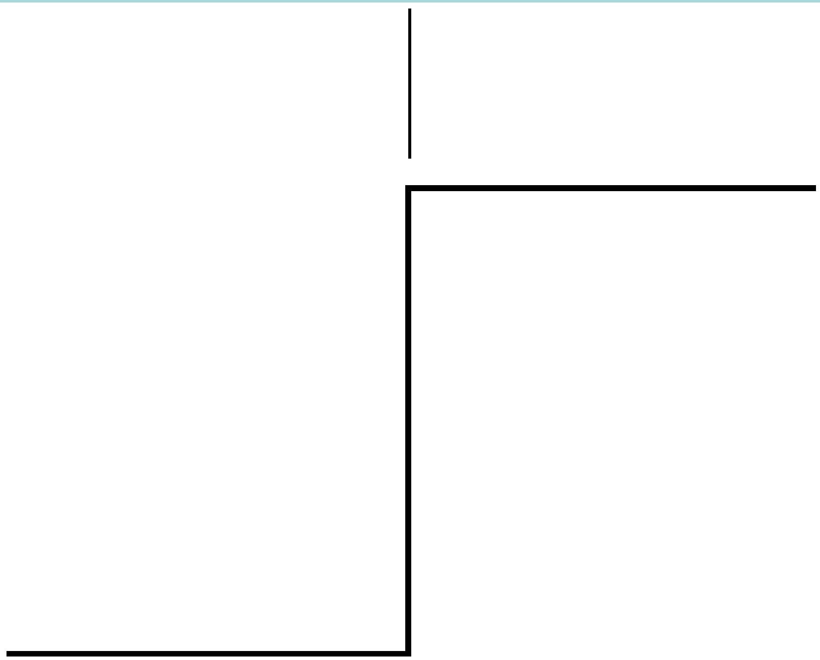


- Ideal edge is a set of connected pixels located at an orthogonal step transition

Edge Modeling

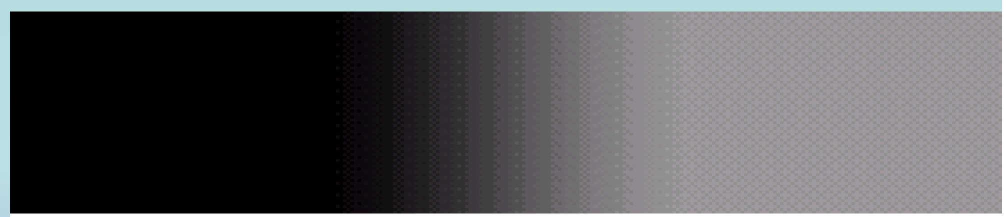
Model of an ideal edge



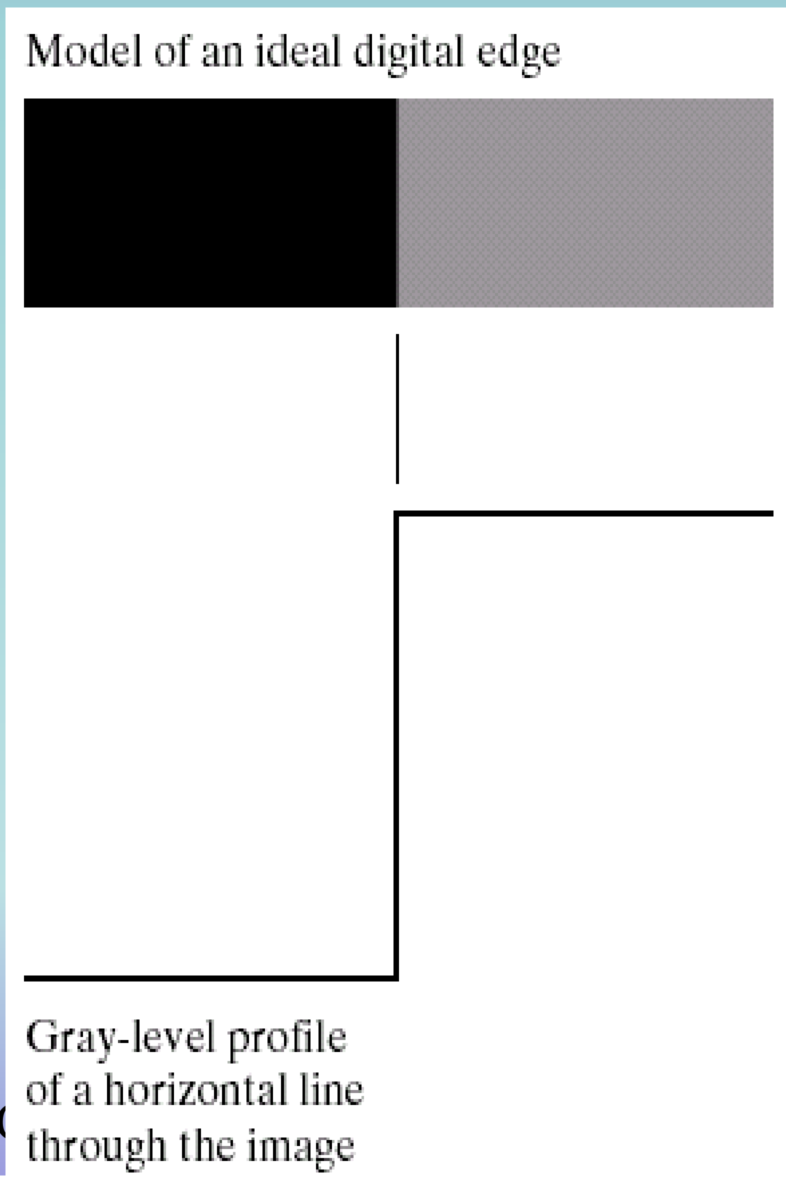


Gray-level profile of a horizontal line through the image

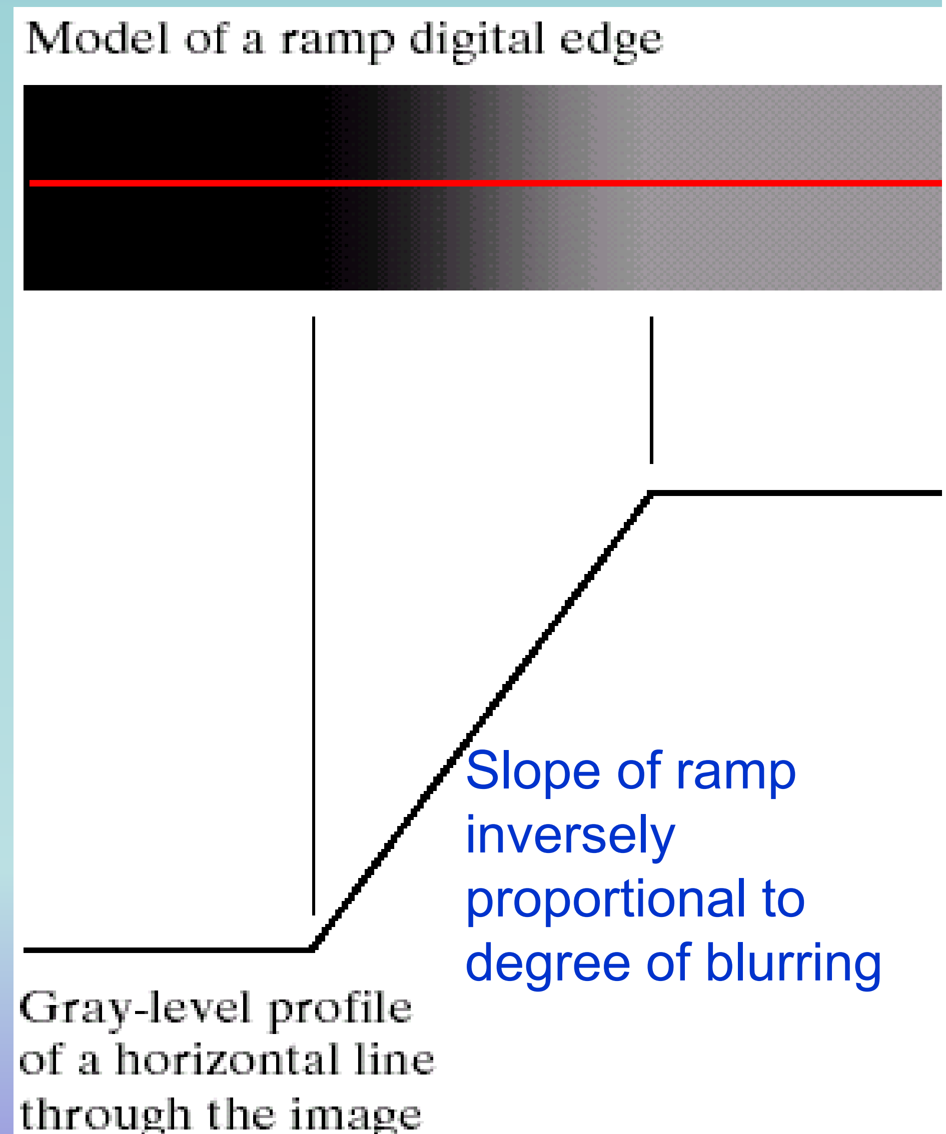
- Imperfection (noise, acquisition) leads to blurred and smooth transition



Edge Modeling

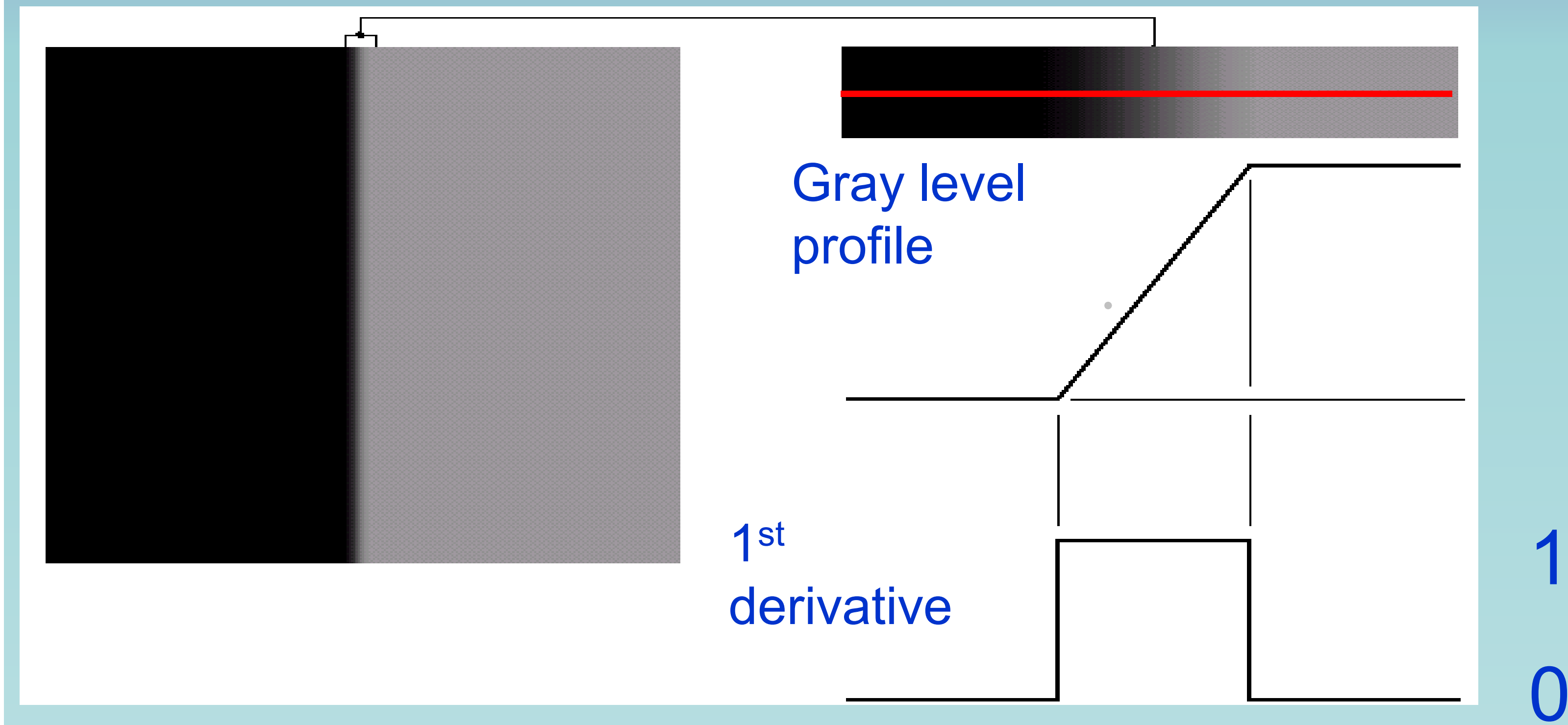


7
6
5
4
3
2
1
0



Slope of ramp inversely proportional to degree of blurring

Edge Modeling



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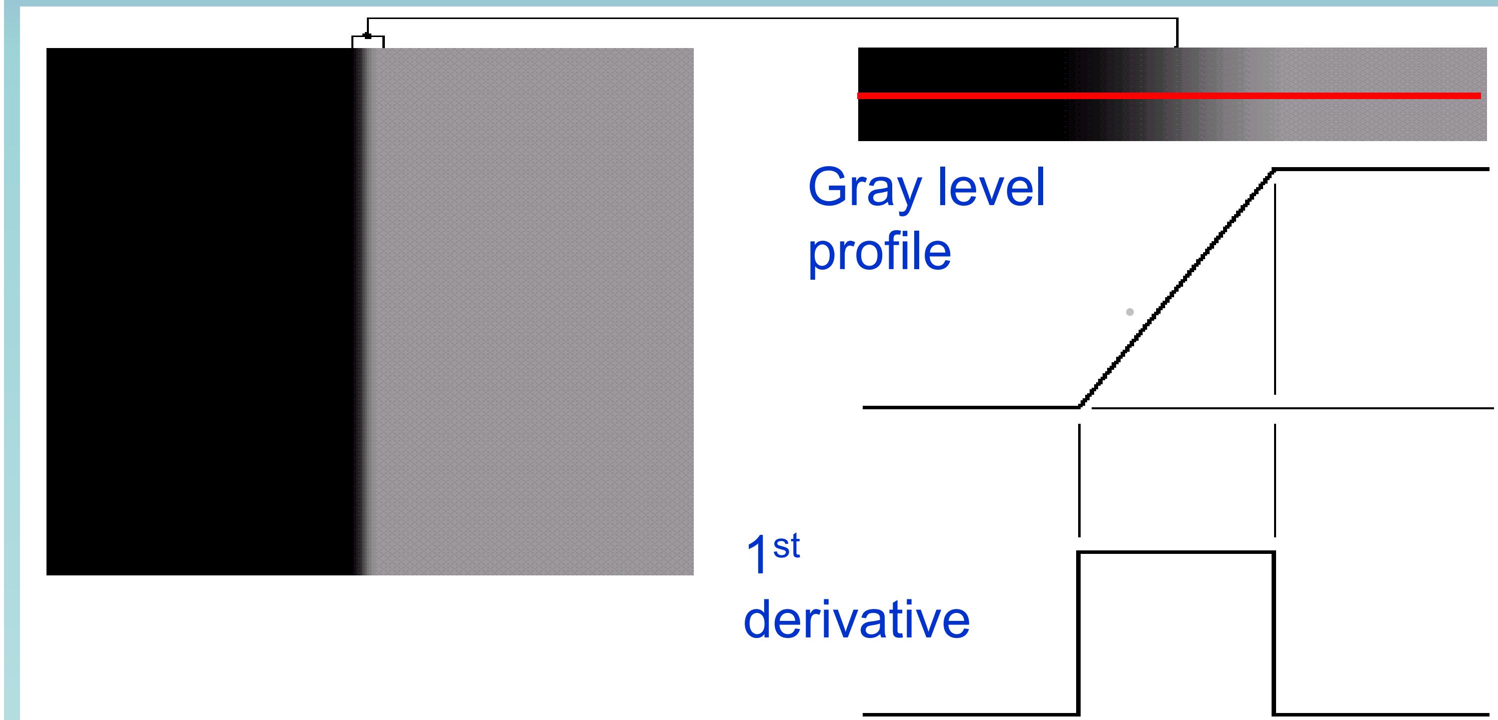
Edge Modeling



1

0

000001111100000

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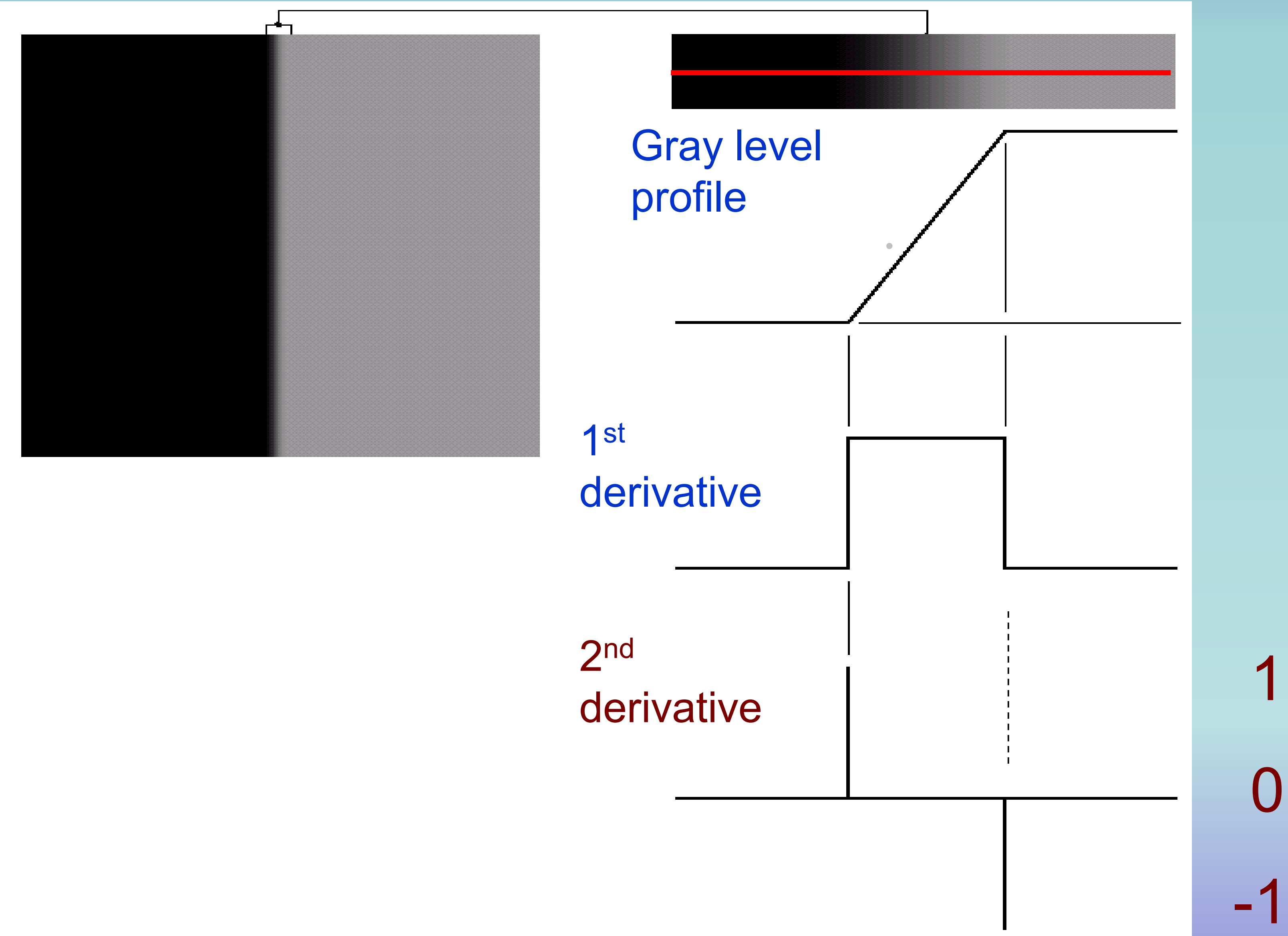
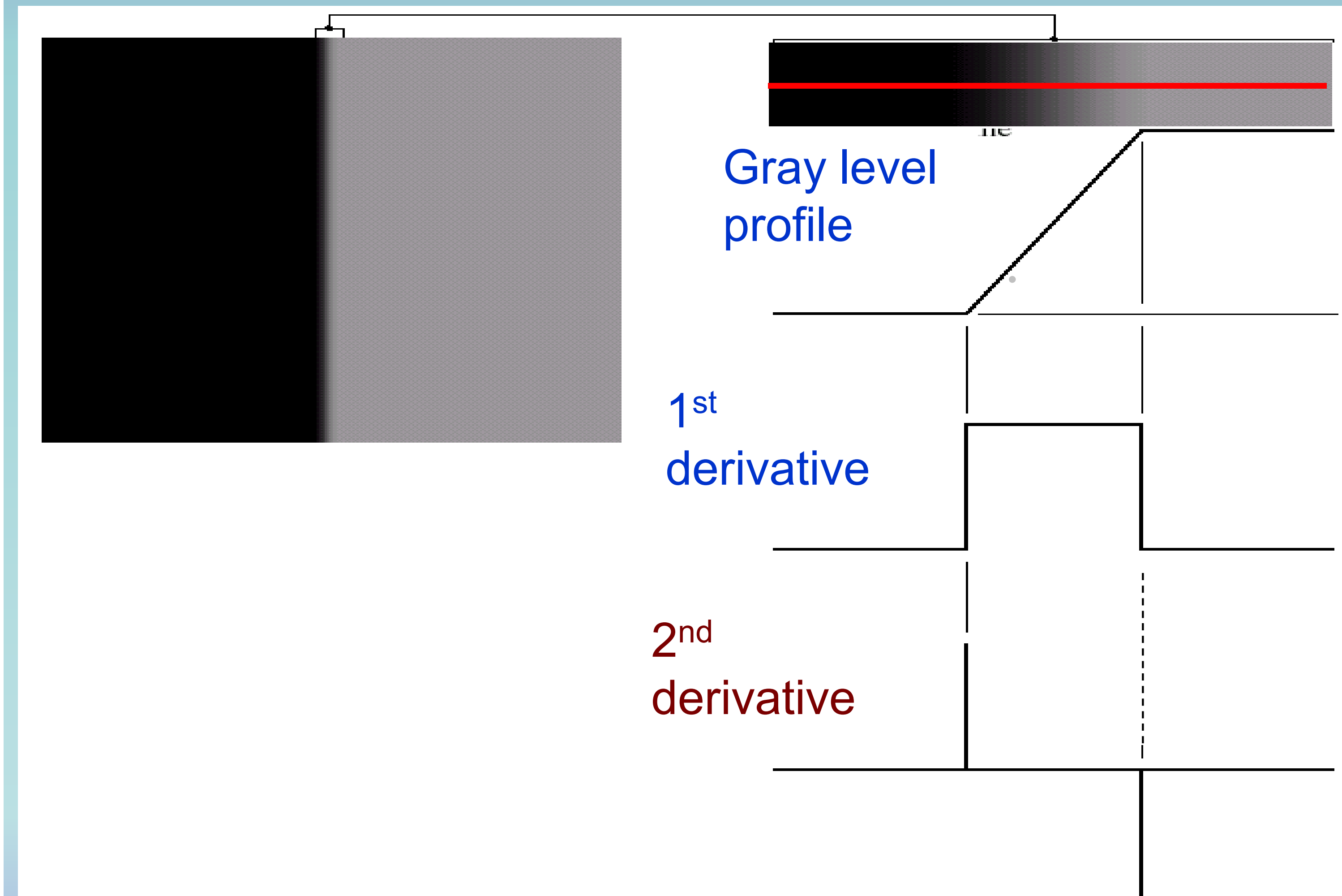
Edge Modeling



Edge Modeling



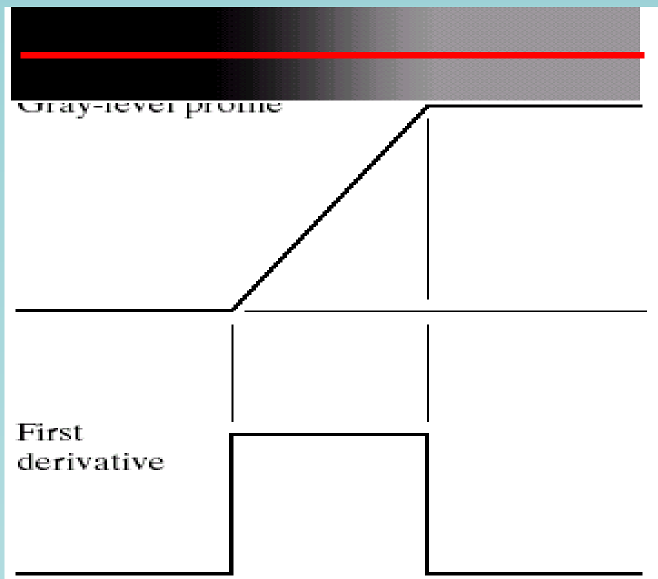
1

0

-1

0000010000-100000

Edge Modeling



000001111100000

0000010000-100000

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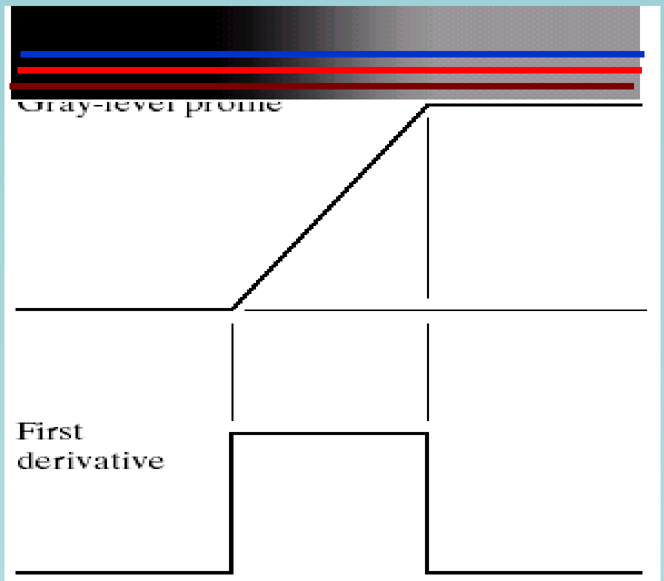
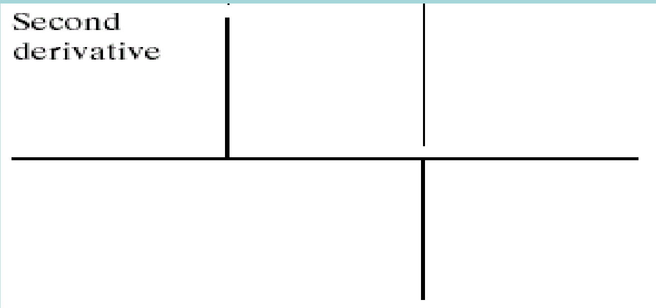
Edge Modeling



00000111110000
00000111110000
00000111110000



0000010000-100000
0000010000-100000
0000010000-100000

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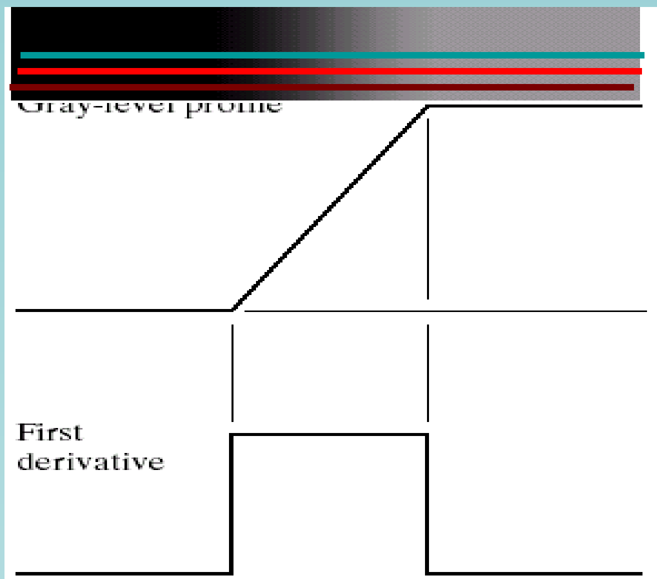
Edge Modeling



000001111100000
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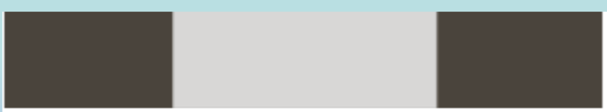
000001111100000



0000010000-100000
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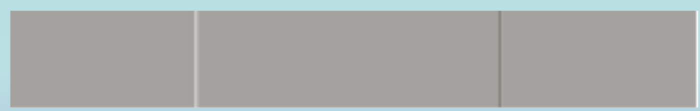
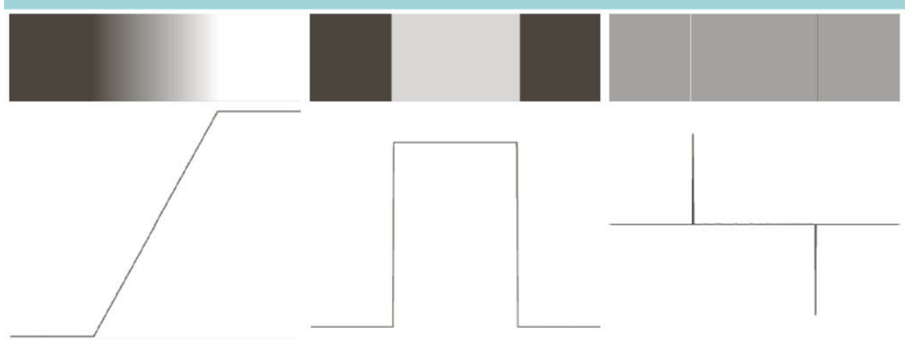
0000010000-100000



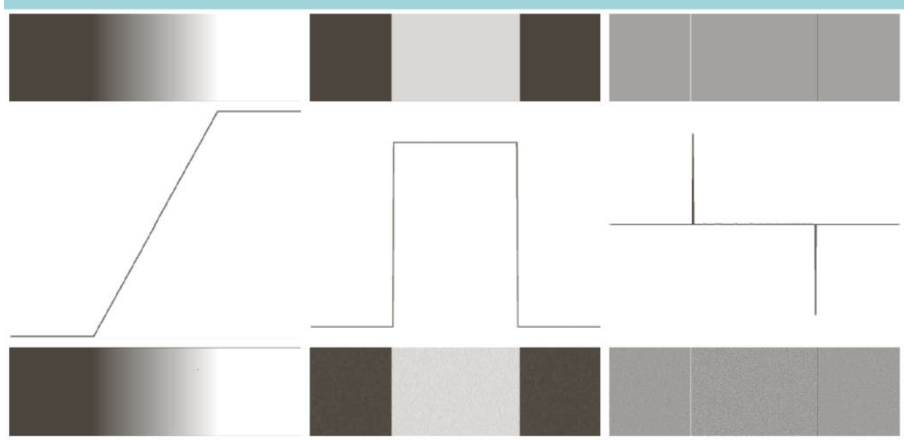
Edge Modeling in noisy images

Gray profile 1st derivative 2nd derivative



Edge Modeling in noisy images

Gray profile | 1st derivative | 2nd derivative

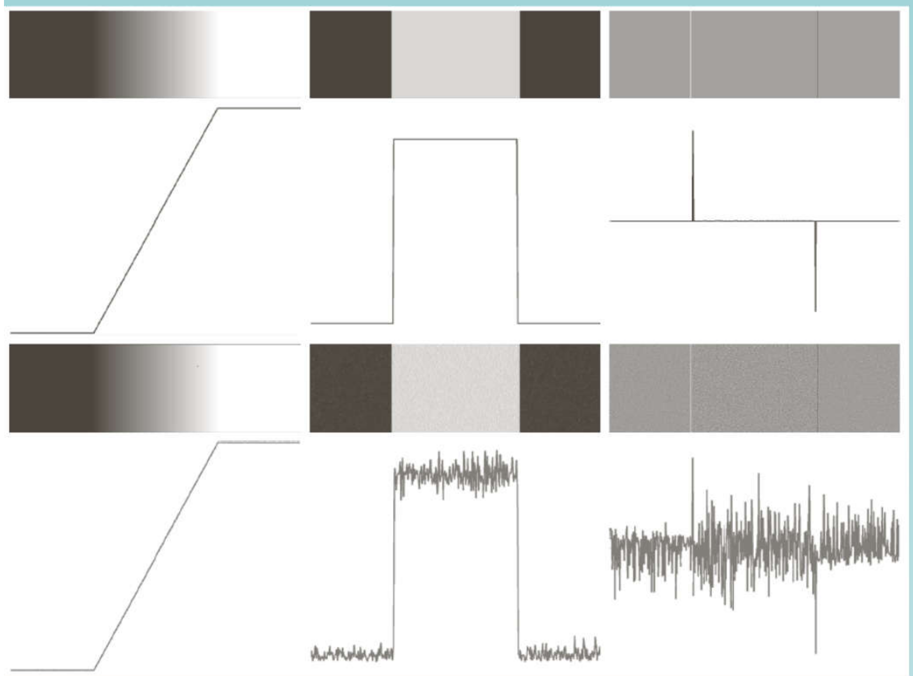


Noisy images: corrupted by Gaussian noise with

$\mu=0$ and $\sigma=0.1$

Edge Modeling in noisy images

Gray profile   1st derivative   2nd derivative



Noisy images: corrupted by Gaussian noise with

$\mu=0$ and $\sigma=0.1$

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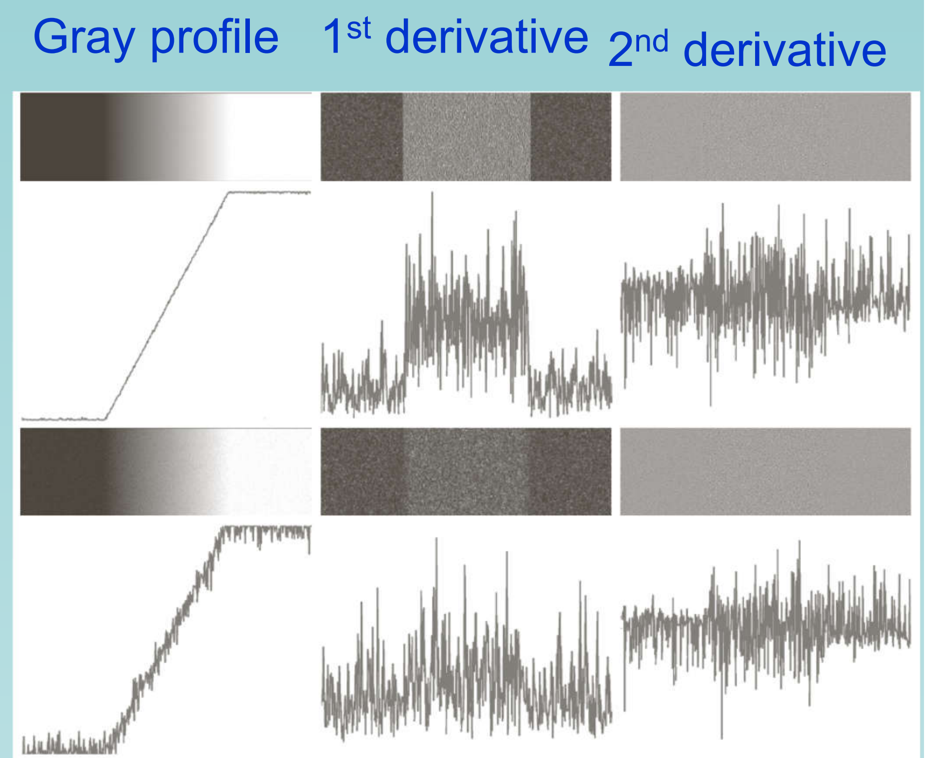
Edge Modeling in noisy images

Noisy images: corrupted by Gaussian noise with

μ=0, б =1.0

μ=0, б =10



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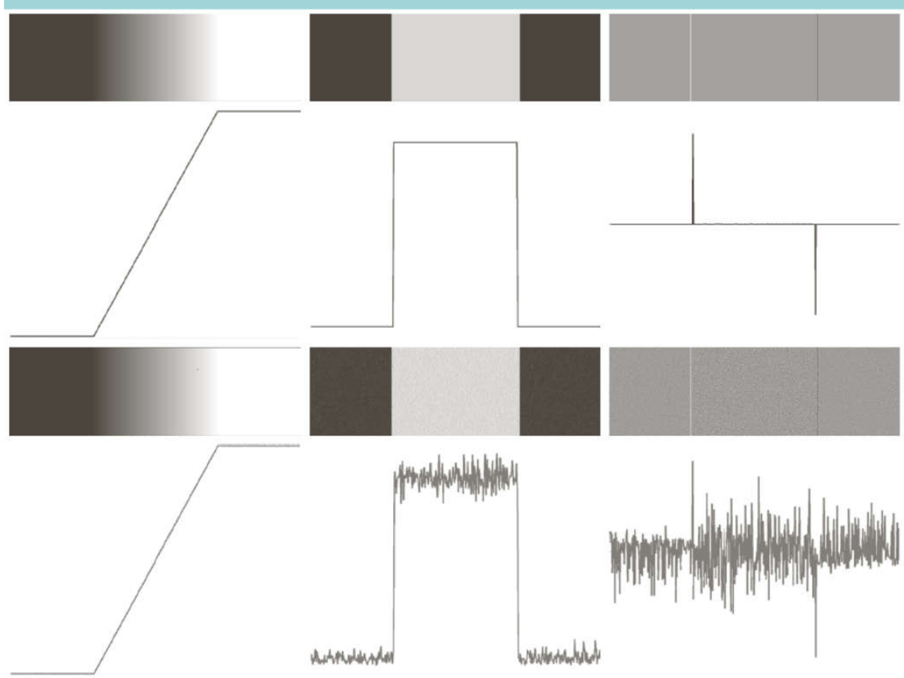
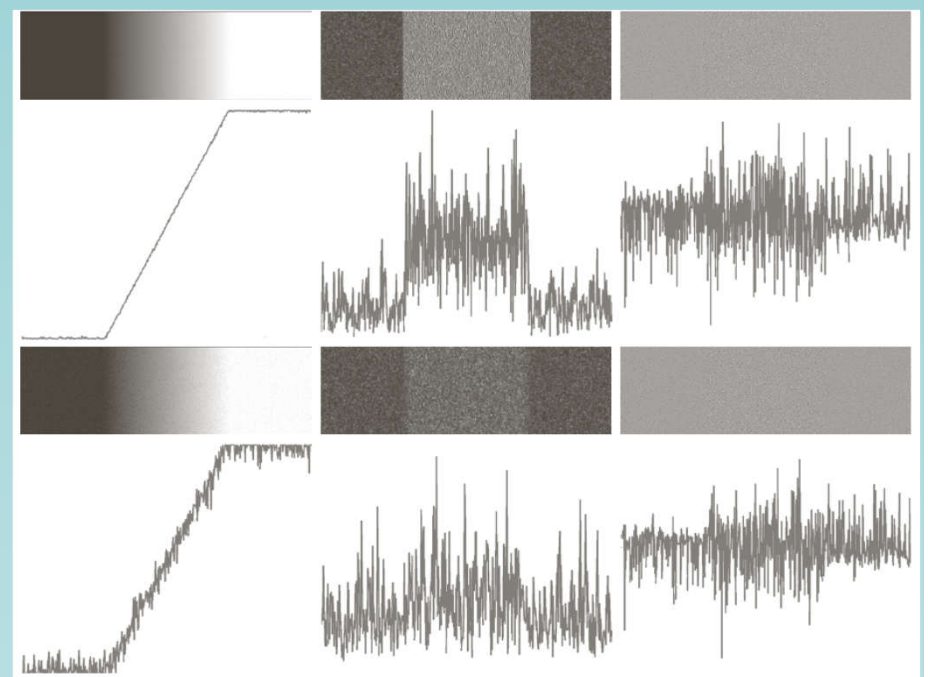
Edge Modeling in noisy images

Gray profile | 1st derivative | 2nd derivative



Gray profile | 1st derivative | 2nd derivative



Noisy images: corrupted by Gaussian noise with

μ=0 and

б =0, 0.1, 1.0, 10

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Edge Modeling

- Transition of gray level in edge point should be *significantly stronger* than that in background
- Thresholding can be used to determine *this transition*
- 1st order derivative should be greater than the threshold

Review of 1st Order Derivative – The Gradient

$$\nabla \mathbf{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \dfrac{\partial f}{\partial x} \\[2ex] \dfrac{\partial f}{\partial y} \end{bmatrix}$$

The Gradient

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

$$= \left[\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial x}\right)^2\right]^{1/2}$$

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Review of 1st Order Derivative – The Gradient

$$\nabla \mathbf{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \dfrac{\partial f}{\partial x} \\ \\ \dfrac{\partial f}{\partial y} \end{bmatrix}$$

The Gradient

Misnomer for gradient

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

$$= \left[\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial x}\right)^2\right]^{1/2}$$

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Direction of The Gradient Vector

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

- The edge is perpendicular to α

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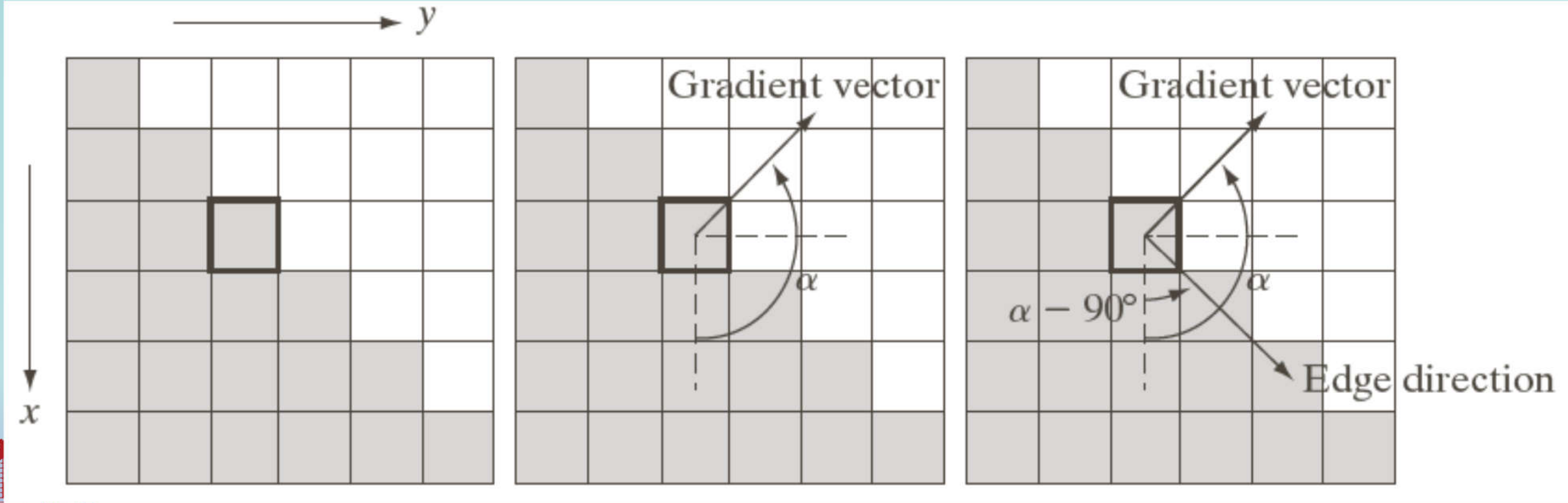
Direction of The Gradient Vector

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



Digital Approximation of The Gradient

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

−1	0
0	1

0	−1
1	0

$Z_9 - Z_5$ $\quad$ $Z_8 - Z_6$

- Many implementations

$$G_x = Z_9 - Z_5$$

$$G_y = Z_8 - Z_6$$

$$\nabla f \approx |z_9 - z_5| + |z_8 - z_6|$$

Robert's Operator

Digital Approximation of The Gradient

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

Sobel Operators

$$\nabla f = \left|(Z_7 + 2Z_8 + Z_9) - (Z_1 + 2Z_2 + Z_3)\right| + \left|(Z_3 + 2Z_6 + Z_9) - (Z_1 + 2Z_4 + Z_7)\right|$$

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Digital Approximation of The Gradient

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

−1	−1	−1
0	0	0
1	1	1

−1	0	1
−1	0	1
−1	0	1

Prewitt Operators

$$\nabla f = \left|(Z_7 + Z_8 + Z_9) - (Z_1 + Z_2 + Z_3)\right| + \left|(Z_3 + Z_6 + Z_9) - (Z_1 + Z_4 + Z_7)\right|$$

Prewitt and Sobel Operators for Diagonal Edges

0	1	1
−1	0	1
−1	−1	0

−1	−1	0
−1	0	1
0	1	1

Prewitt Operators

Sobel Operators

0	1	2
−1	0	1
−2	−1	0

−2	−1	0
−1	0	1
0	1	2

Horizontal and Vertical Edge Detection

Original Image

- Sobel operator will be used

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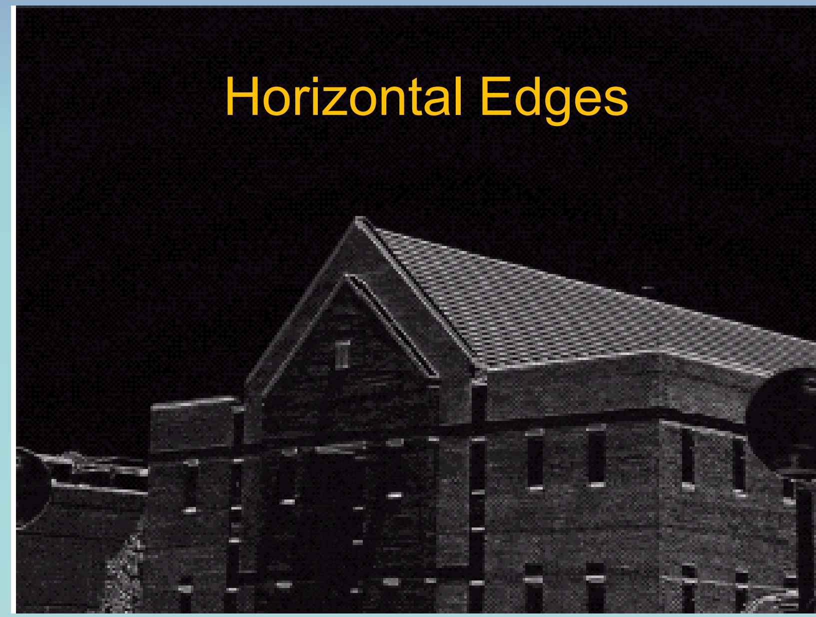
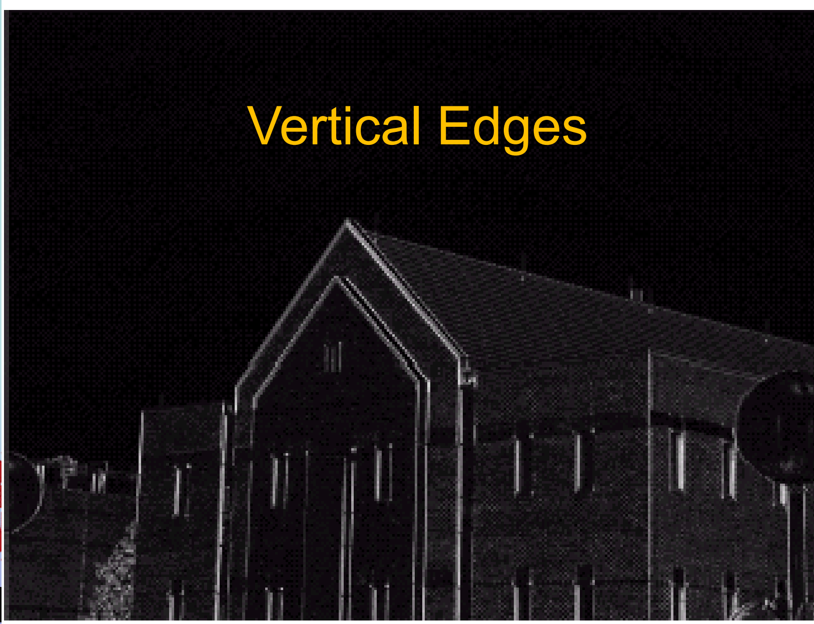
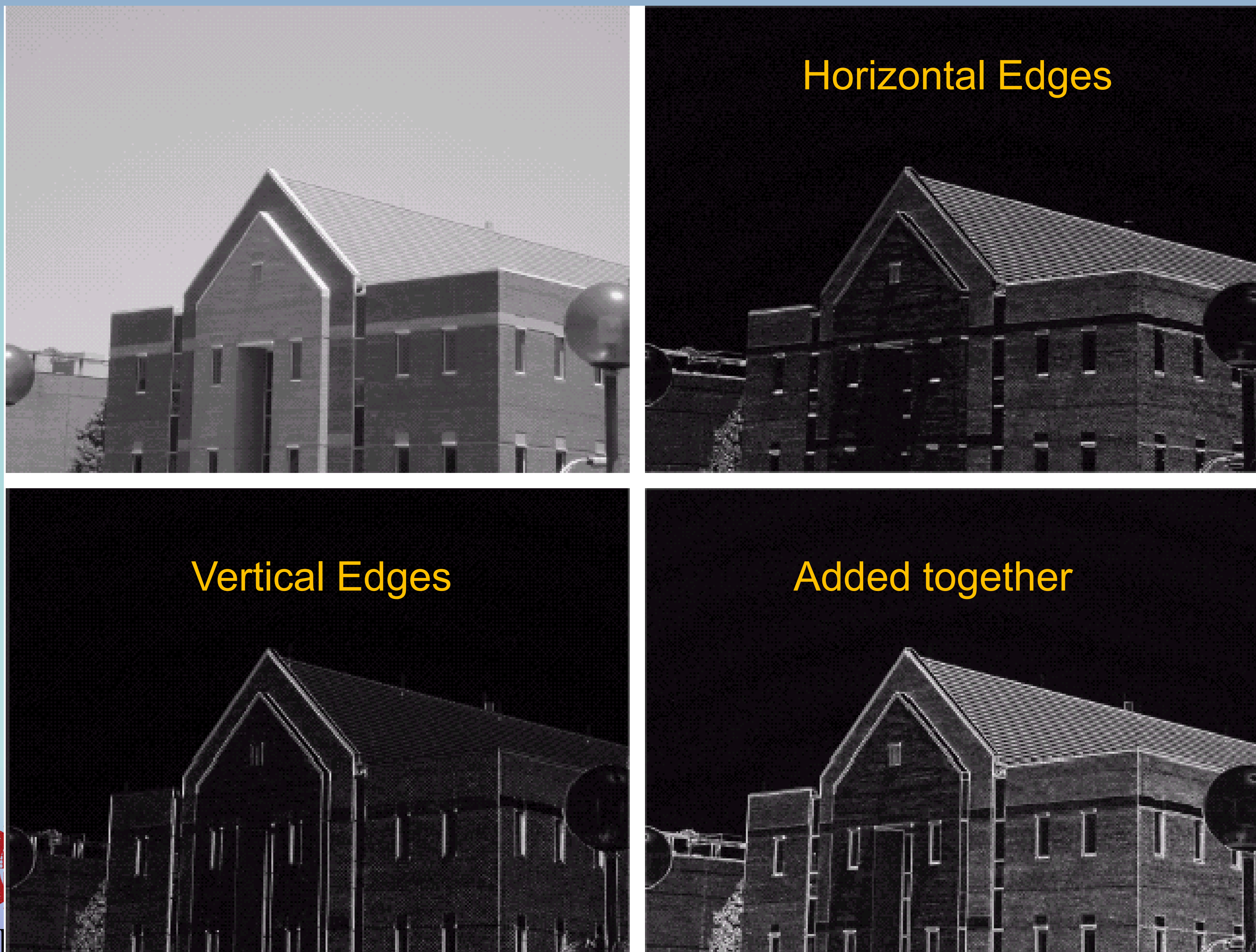
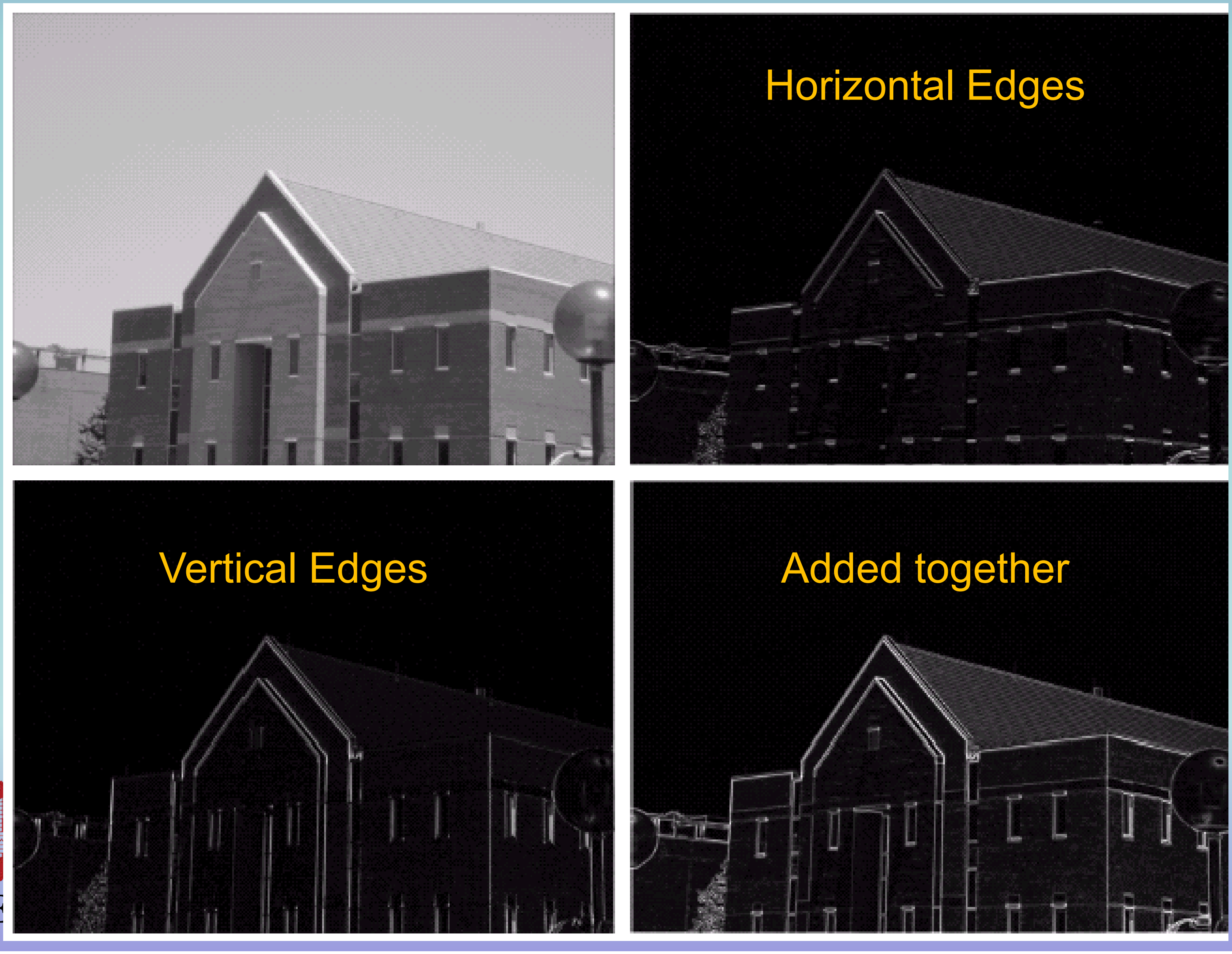

Horizontal Edges


Vertical Edges


Horizontal Edges
Vertical Edges
Added together

Hor/Vert Edge Detection after Smoothing



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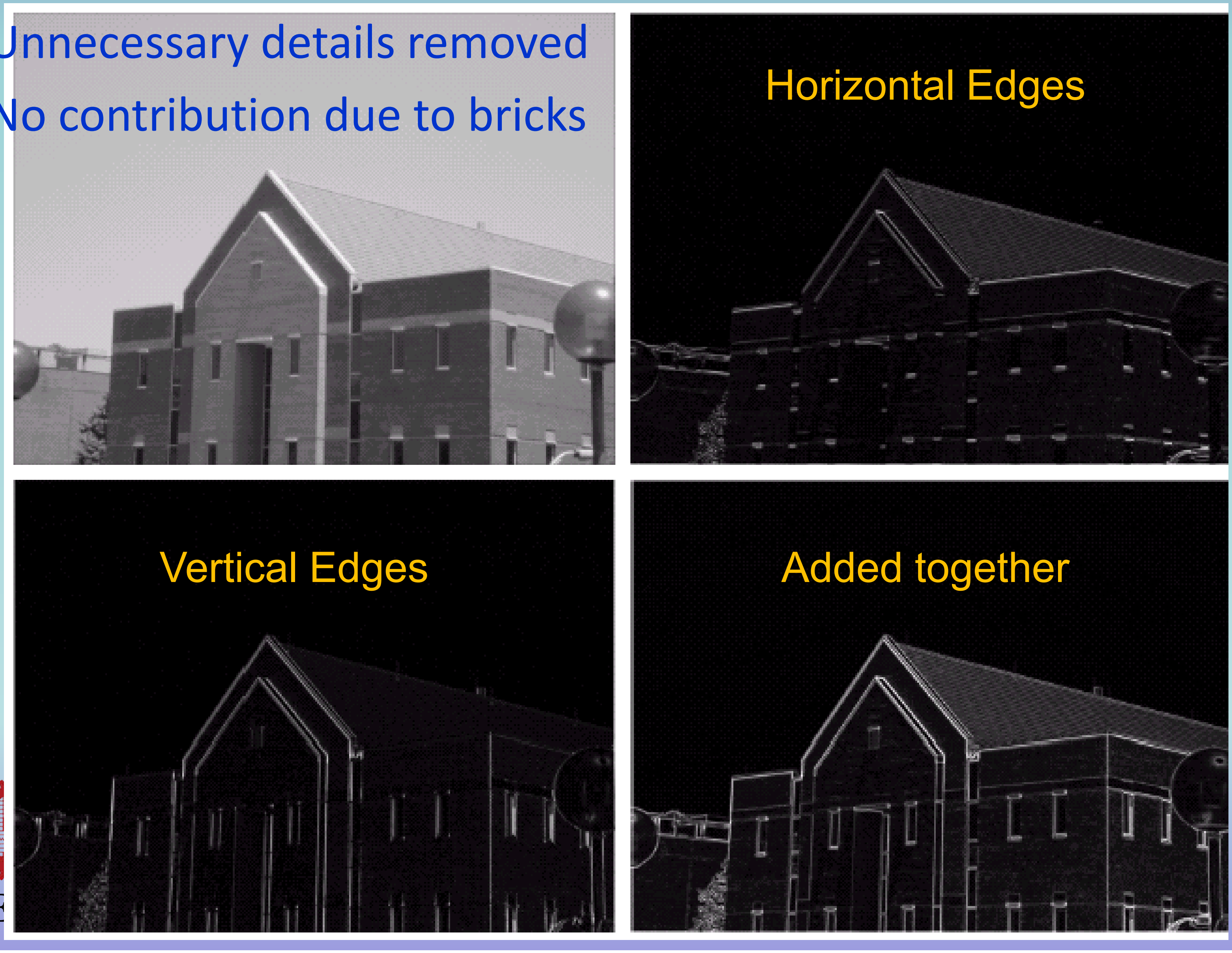
Hor/Vert Edge Detection after Smoothing

- Unnecessary details removed
- No contribution due to bricks



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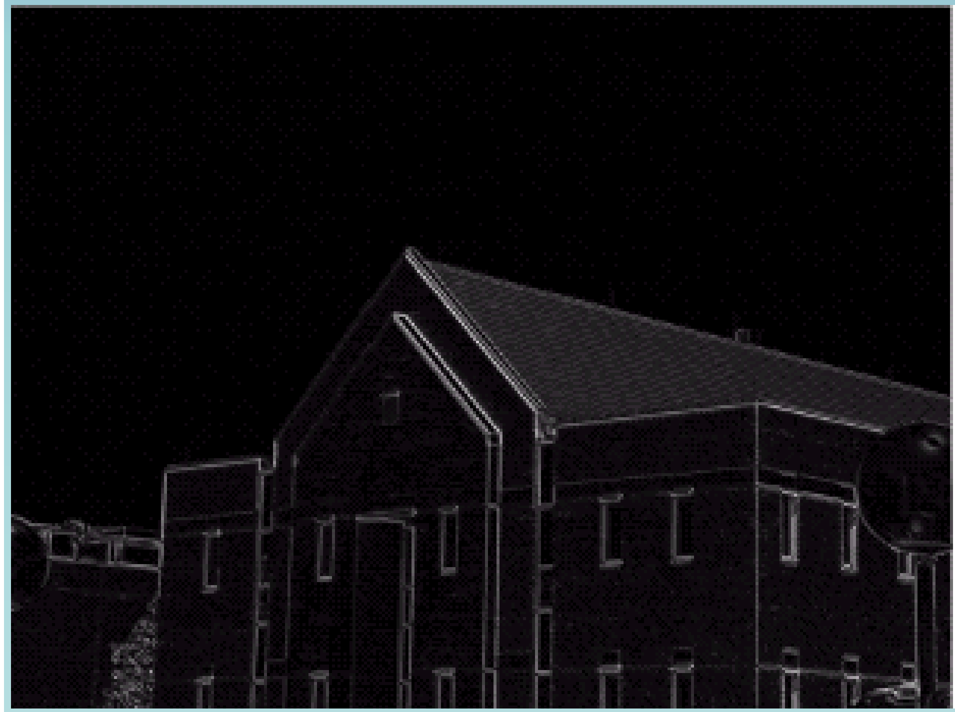
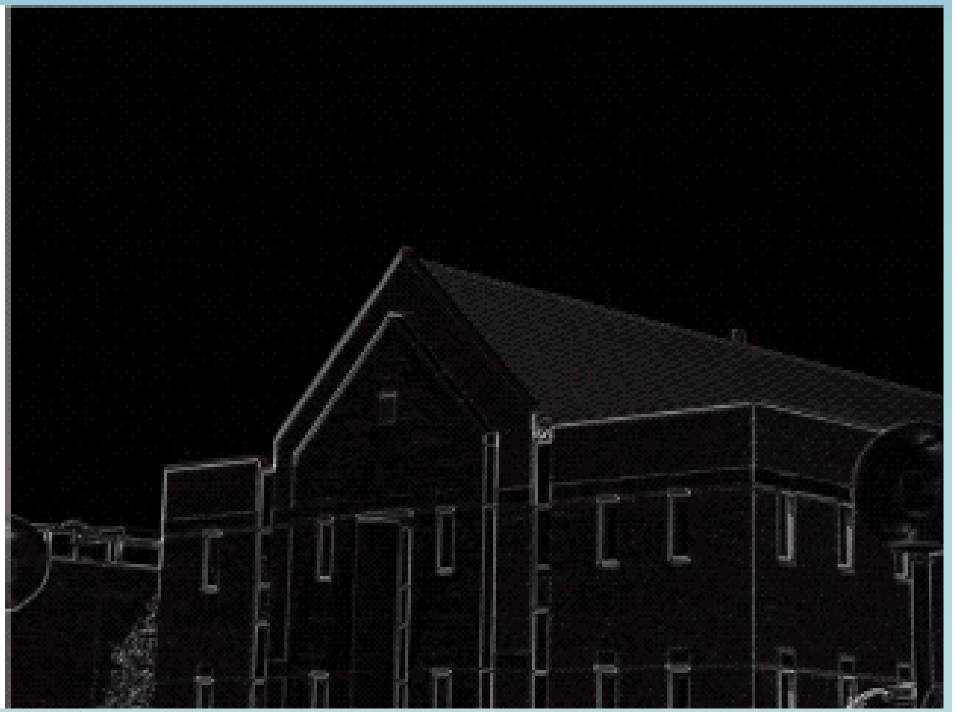
Diagonal Edge Detection



Off diagonal Edges



Diagonal Edges

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Review of 2nd Order Derivative- The Laplacian Operator

- Laplacian 2nd order derivative
  - Rotation invariant or isotropic

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

2nd Order Derivative

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

$$= 4f(x,y)$$

$$-[f(x+1,y) + f(x-1,y) + f(x,y+1) + f(x,y-1)]$$

Digital Approximation of The Laplacian

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

$$\nabla^2 f = 4Z_5 - (Z_2 + Z_4 + Z_6 + Z_8)$$

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Digital Approximation of The Laplacian

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

0	−1	0
−1	4	−1
0	−1	0

$$\nabla^2 f = 4Z_5 - (Z_2 + Z_4 + Z_6 + Z_8)$$

Digital Approximation of The Laplacian

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

−1	−1	−1
−1	8	−1
−1	−1	−1

$$\nabla^2 f = 8Z_5 - (Z_1 + Z_2 + Z_3 + Z_4 + Z_6 + Z_7 + Z_8 + Z_9)$$

Properties of 2nd order derivative

- Sensitive to noise
- Double response to edges
- However, has zero crossing property

Smoothing before Laplacian (2nd order derivative)

- Sensitive to noise
  - Smoothing will remove noise sensitivity

Smoothing before Laplacian (2nd order derivative)

- Sensitive to noise
  - Smoothing will remove noise sensitivity

$$h(r) = e^{-\frac{r^2}{2\sigma^2}}, \text{ where } r^2 = x^2 + y^2$$

Gaussian
Smoothing
Function

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Smoothing before Laplacian (2nd order derivative)

- 2^{nd} order derivative of Gaussian (LoG)
  - Marr-Hildreth Edge Detector

$$h(r) = e^{-\frac{r^2}{2\sigma^2}}$$

Gaussian Smoothing Function

$$\nabla^2 h(r) = \left[\frac{r^2 - 2\sigma^2}{\sigma^4}\right] e^{-\frac{r^2}{2\sigma^2}}$$

Gaussian Smoothing Function

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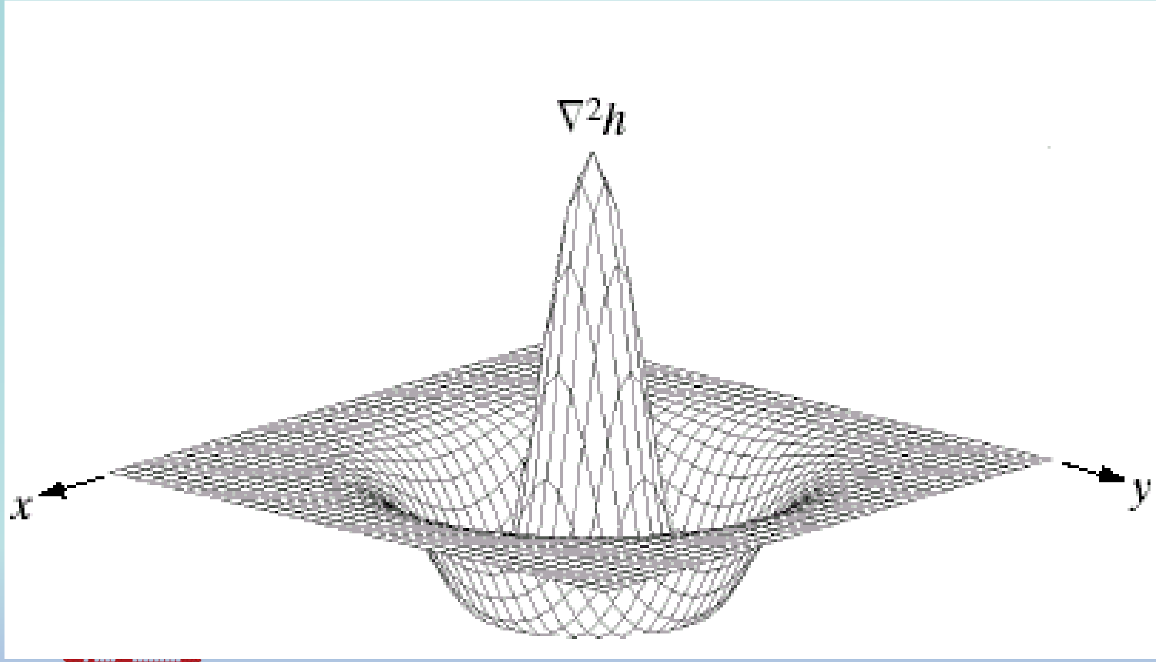
Smoothing before Laplacian (2nd order derivative)

$$\nabla^2 h(r) = \nabla^2 h(x,y) = \left[\frac{r^2 - 2\sigma^2}{\sigma^4}\right] e^{-\frac{r^2}{2\sigma^2}}$$



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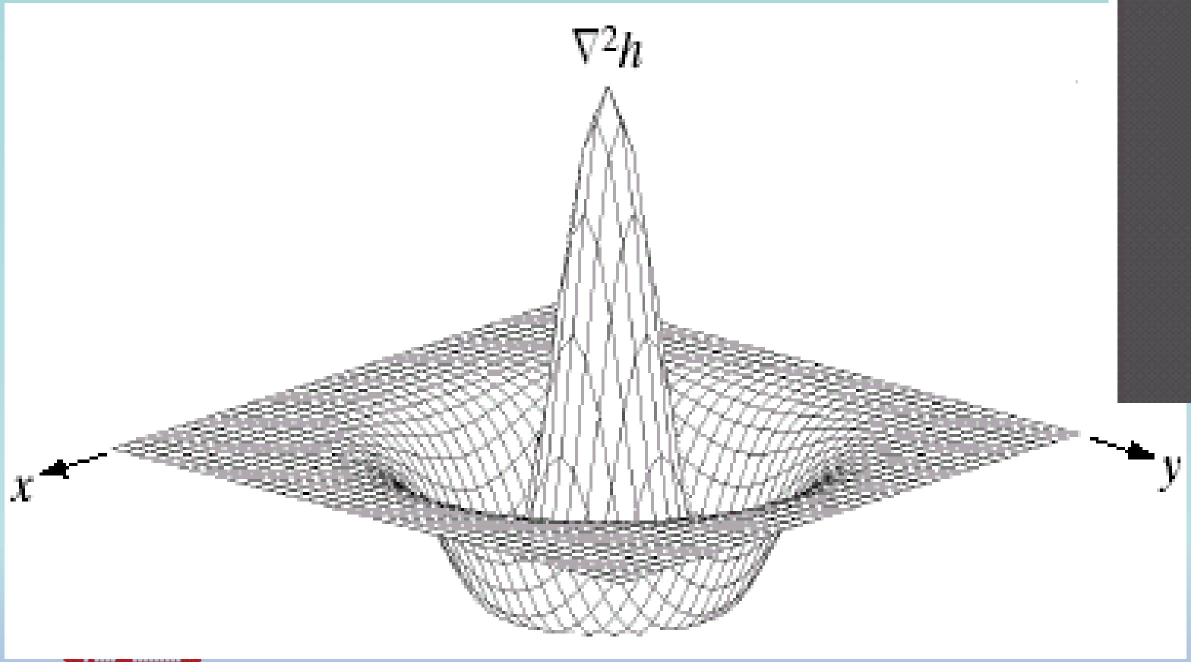
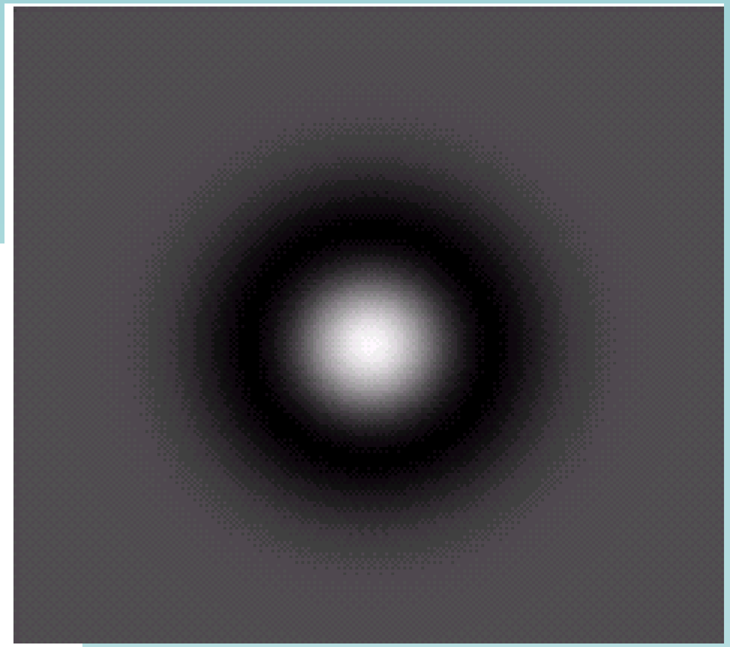
Smoothing before Laplacian (2nd order derivative)

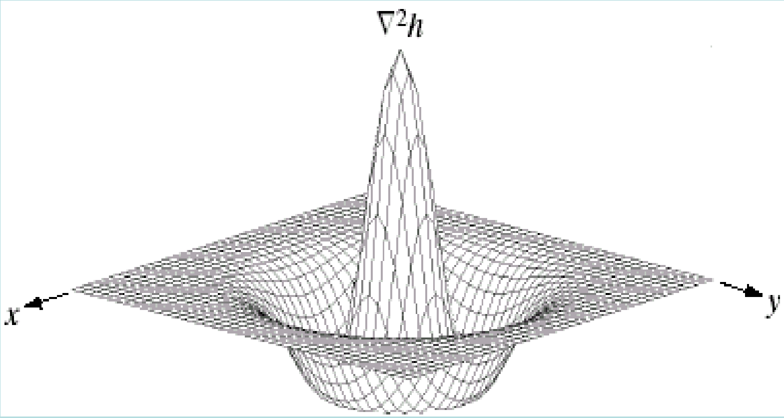
$$\nabla^2 h(r) = \nabla^2 h(x,y) = -\left[\frac{r^2 - \sigma^2}{\sigma^4}\right] e^{-\frac{r^2}{2\sigma^2}}$$

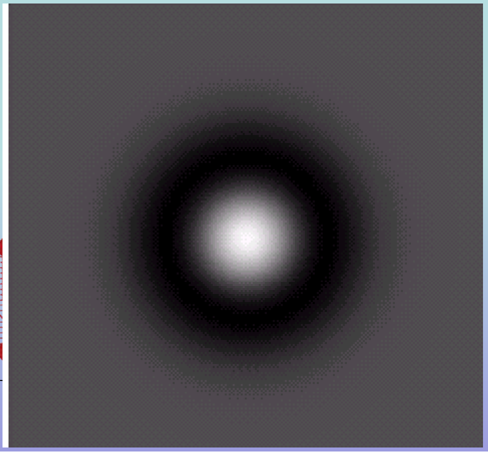


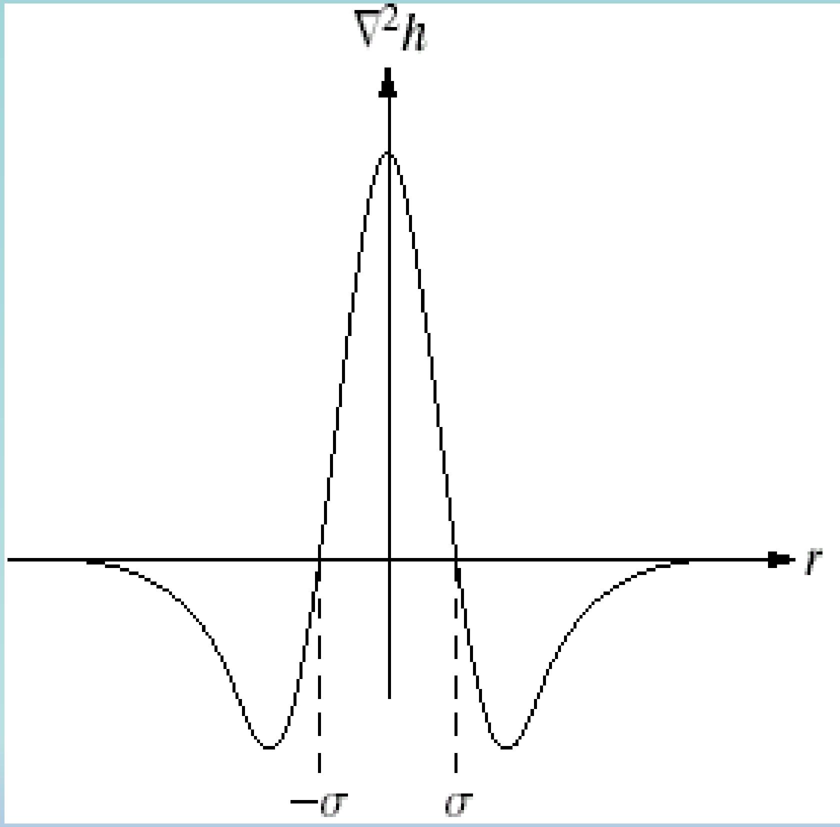


Smoothing before Laplacian (2nd order derivative)

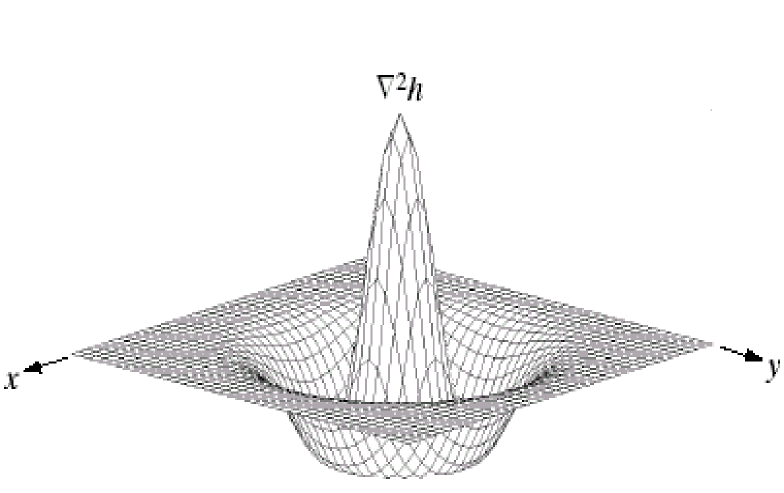
$$\nabla^2 h(r) = \nabla^2 h(x,y) = -\left[\frac{r^2-\sigma^2}{\sigma^4}\right] e^{-\frac{r^2}{2\sigma^2}}$$



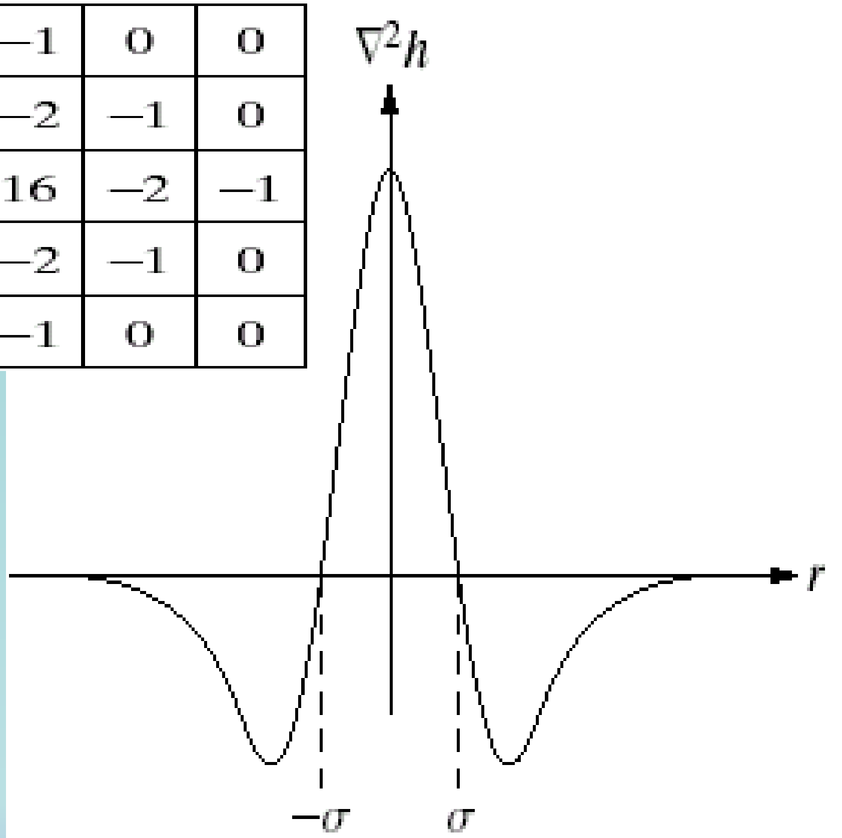


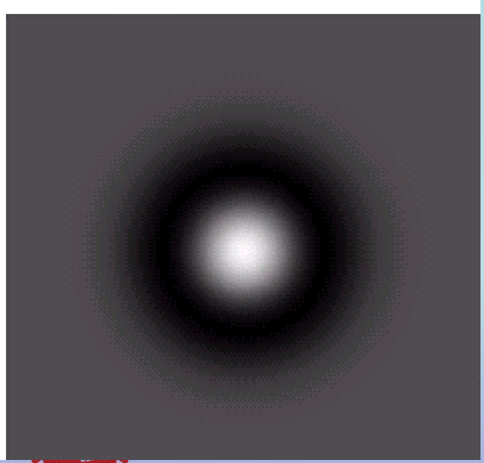


Smoothing before Laplacian (2nd order derivative)



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





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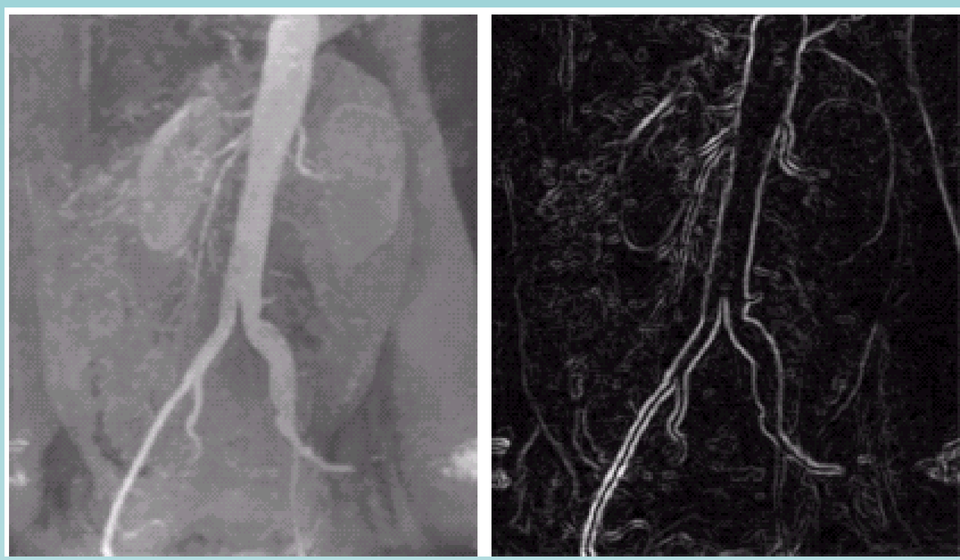
Example of Laplacian Edge Detection (1)



Original Image After Sobel-ing

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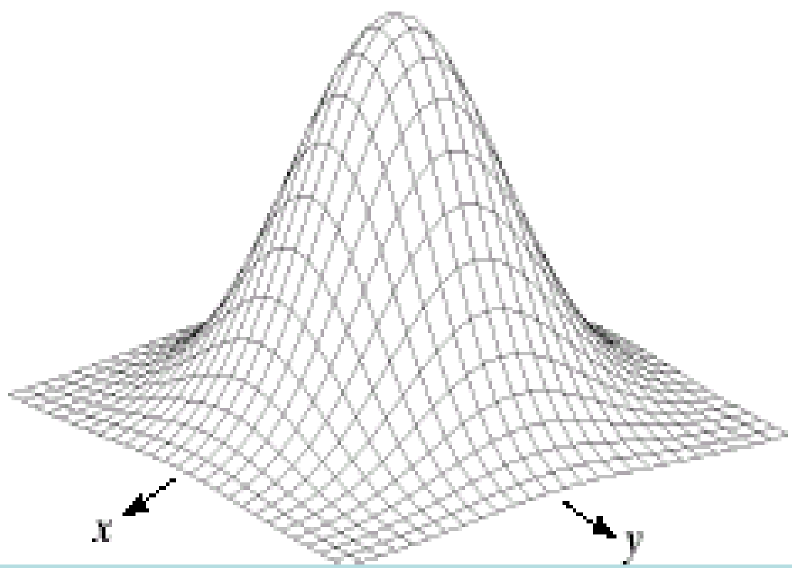
Example of Laplacian Edge Detection (1)



–1	–1	–1
–1	8	–1
–1	–1	–1

Gaussian function for smoothing

Laplacian for edging

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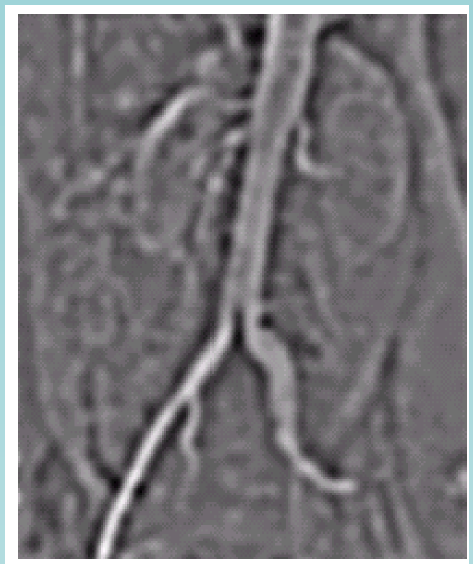
Example of Laplacian Edge Detection (1)



Applying 1) LoG

Or

2)Gauss, then Laplacian

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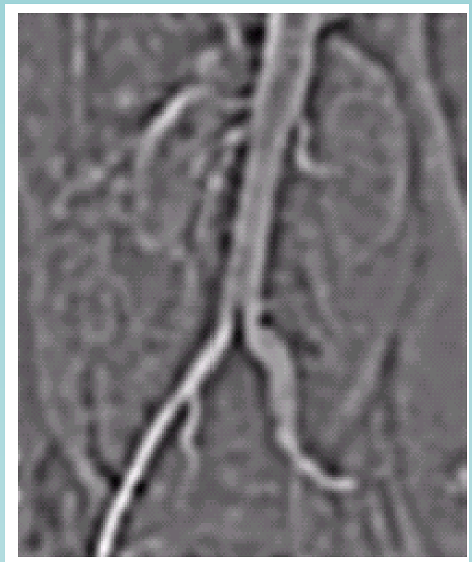
Example of Laplacian Edge Detection (1)

With Sobel



Applying 1) LoG

Or

2)Gauss, then Laplacian

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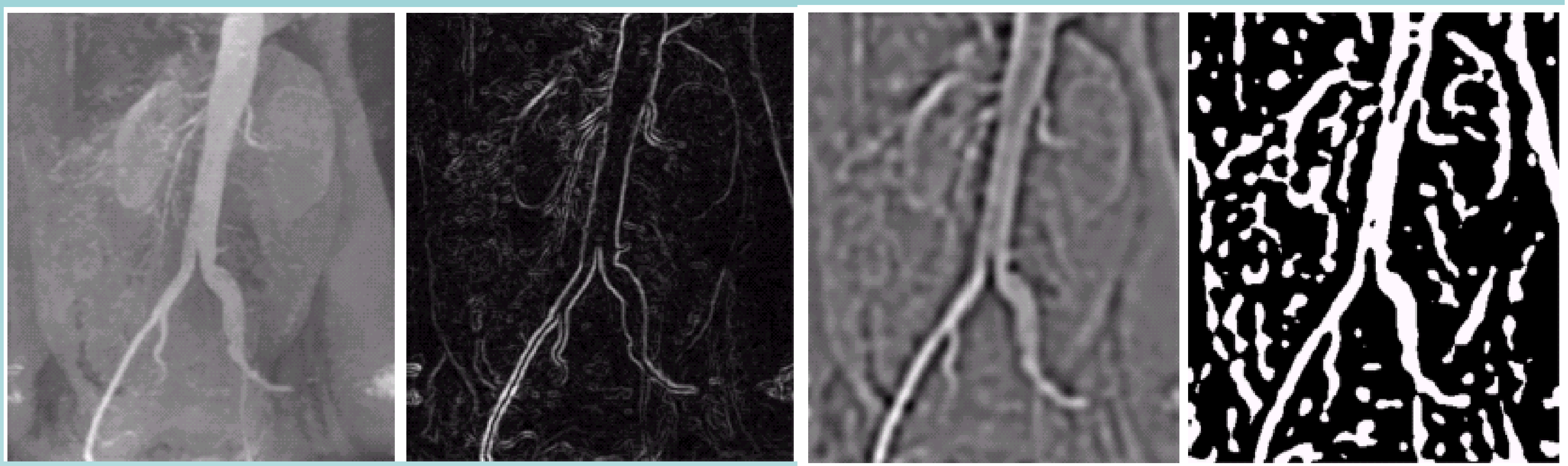
Example of Laplacian Edge Detection (1)

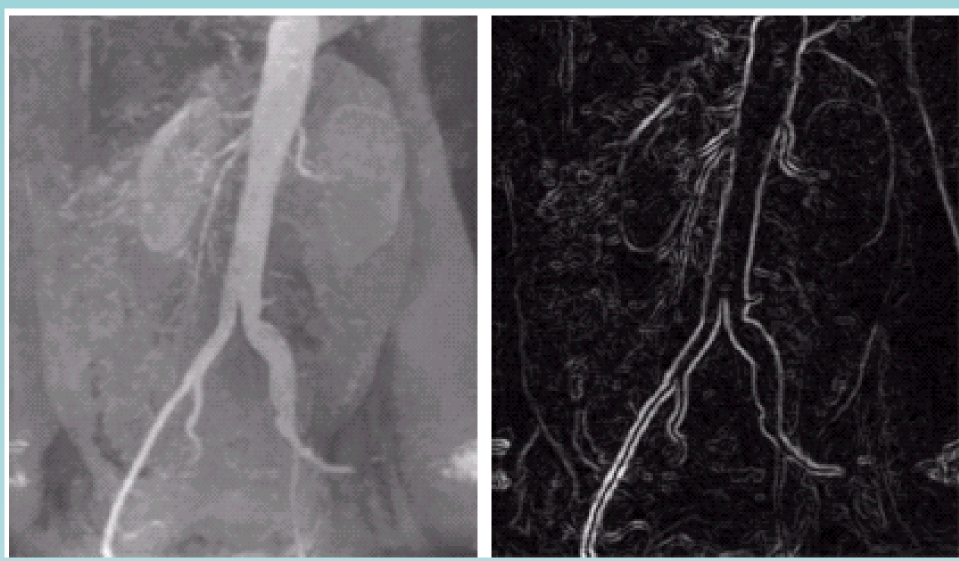


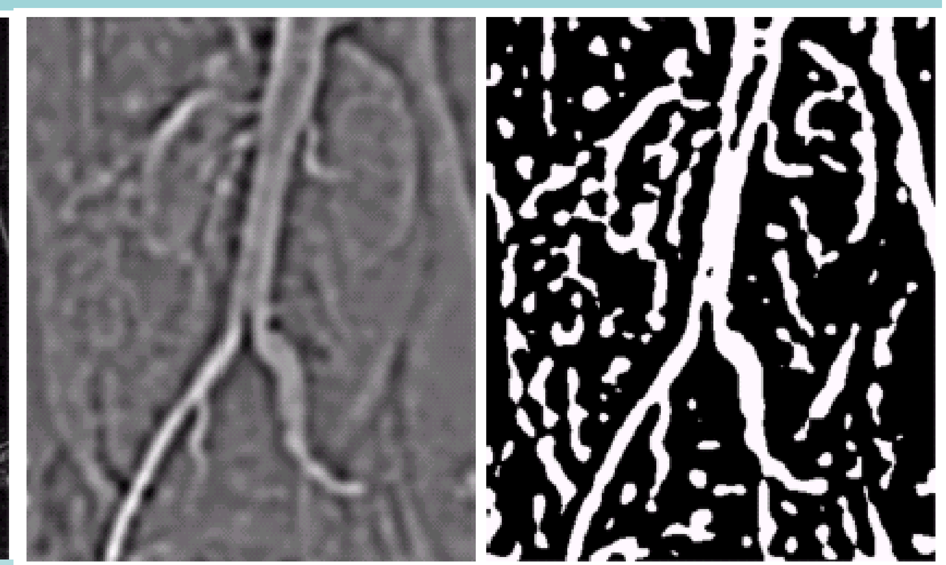
With Sobel

With LoG

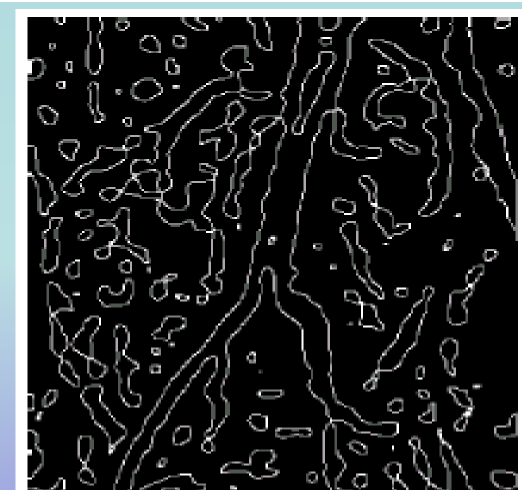
Thresholded

Example of Laplacian Edge Detection (1)





Zero crossing



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Example of Laplacian Edge Detection (1)

Original
Image

Using Sobel

Zero crossing

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Improvement of Laplacian Edge Detection

- Simultaneous Thresholding and Detection of Zero crossing

	P	
	x	
	N	

	N	
	x	
	P	

P	x	N

N	x	P

P		
	x	
		N

N		
	x	
		P

		P
	x	
N		

		N
	x	
P		

Probable Zero Crossing Pixel

- x is a *zero crossing* pixel if
  - Abs $(N- P) > T$
  - Gary vale $(x) > T$

P: Positive LoG value
N: Negative LoG value

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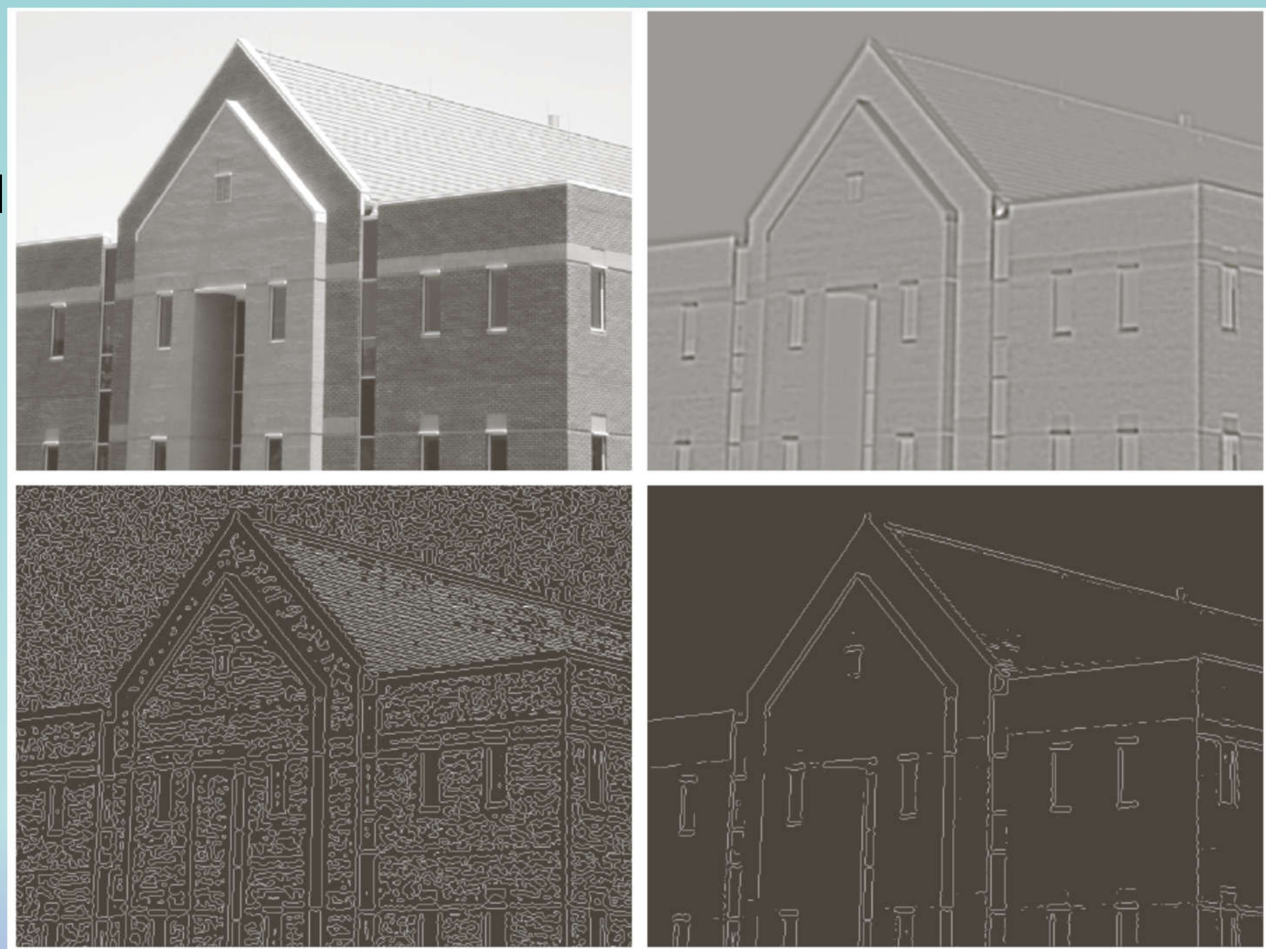
Example of Laplacian Edge Detection (2)

Original Image

LoG Image



Zero crossing with $T = 0$

Zero crossing with $T = 4\%$ of Max

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