

Feature detection

Lecture 3.1 - Line features

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Edges and lines

An edge is a place of rapid change of image intensity, colour or texture, representing:

- Boundaries of objects
- Shadow boundaries
- Creases
- ...

Edge points (*edge/s*) can be grouped into:

- Curves/contours
- Straight line segments
- Piecewise linear contours
- ...



Edge operators (edge enhancement filters)

Edge pixels are found at extrema of the first derivative of the image intensity function.

Image gradient (noisy):

$$\nabla f = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

Gradient magnitude:

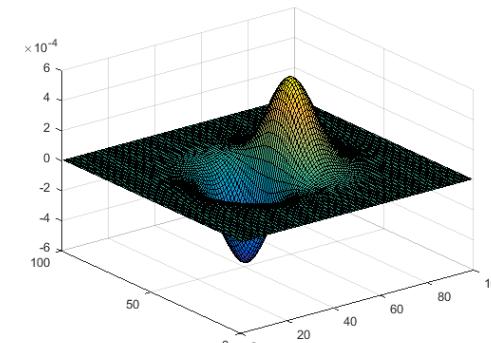
$$\|\nabla f\| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

Prewitt operator:

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

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

Derivative of Gaussian (smoother result):



$$\frac{\partial}{\partial u} h_\sigma(u, v)$$

$$h_\sigma(u, v) = \frac{1}{2\pi\sigma^2} e^{-\left(\frac{u^2+v^2}{2\sigma^2}\right)}$$

Sobel operator:

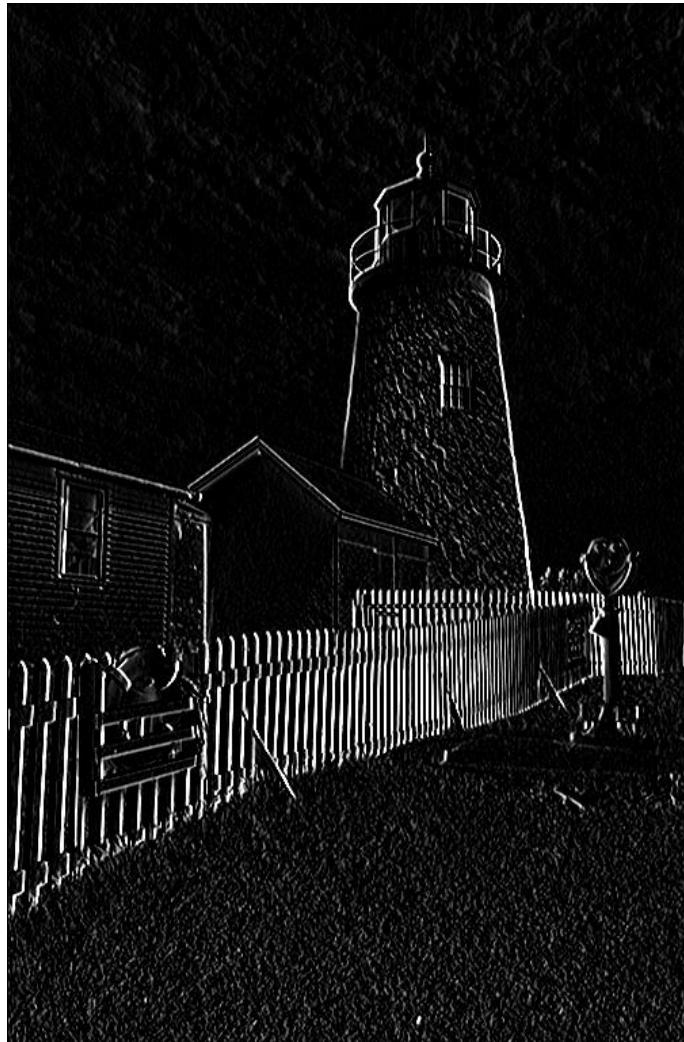
$$S_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

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

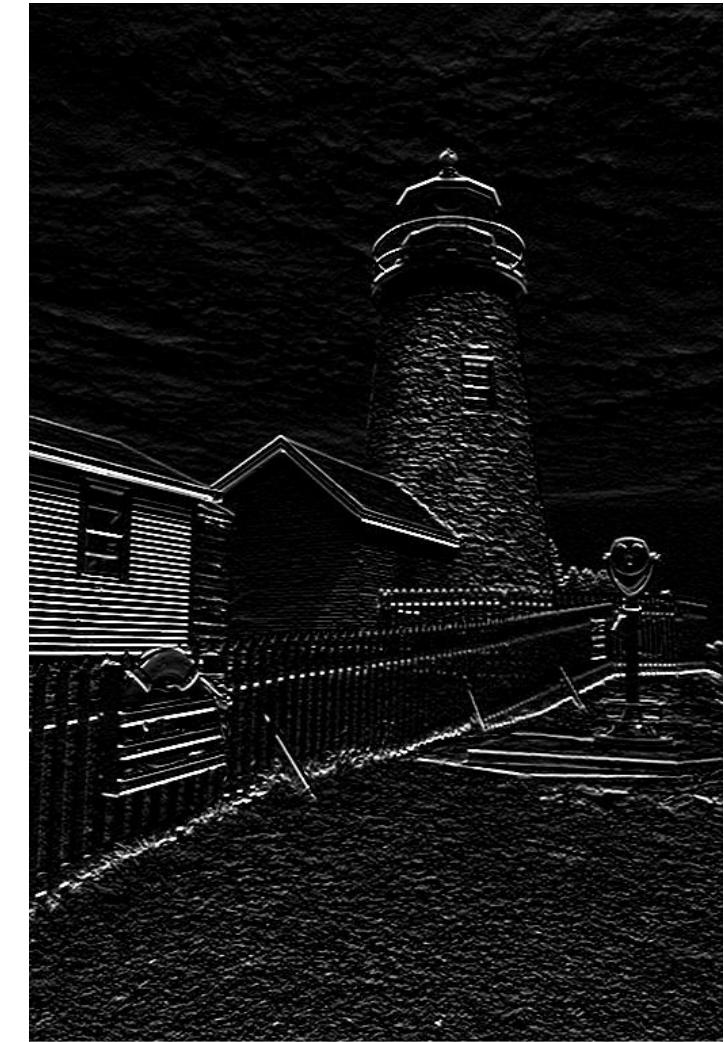
Image derivatives - Sobel



Gray level image



x-component

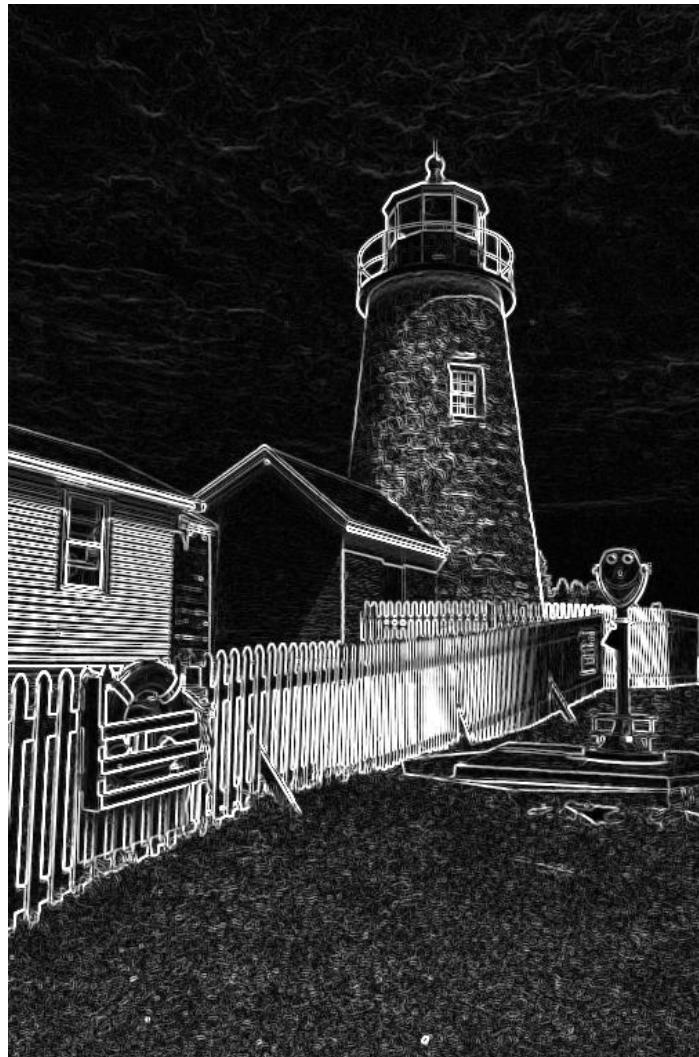


y-component

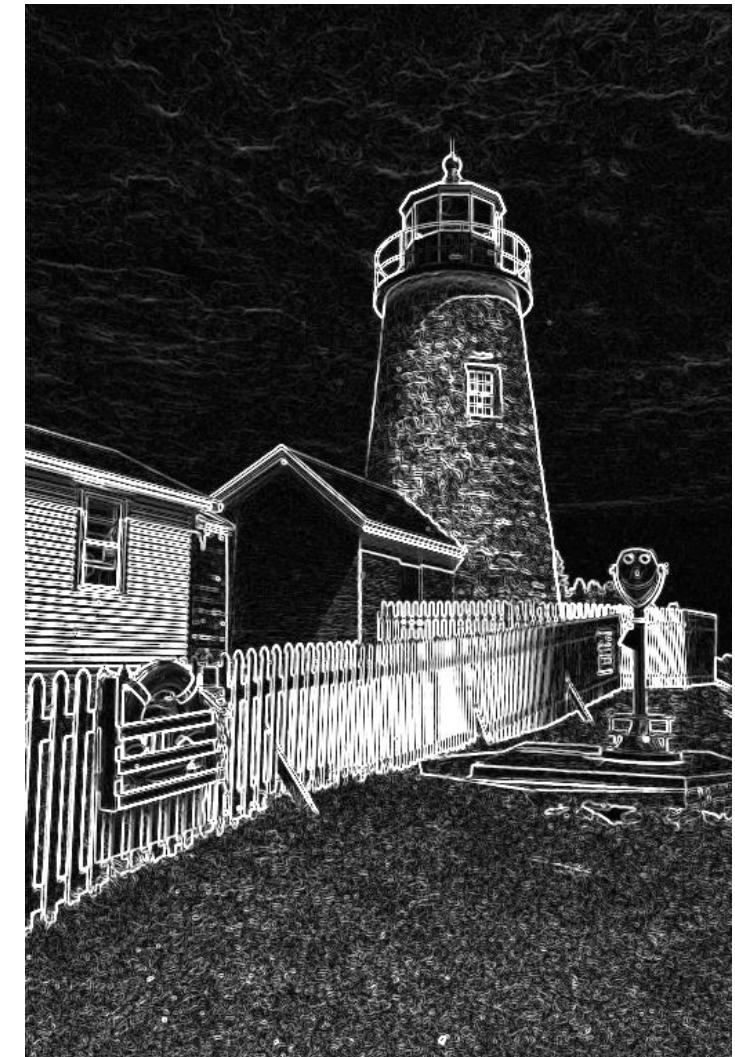
Gradient magnitude



Gray level image



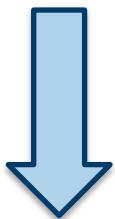
Gradient magnitude - Prewitt



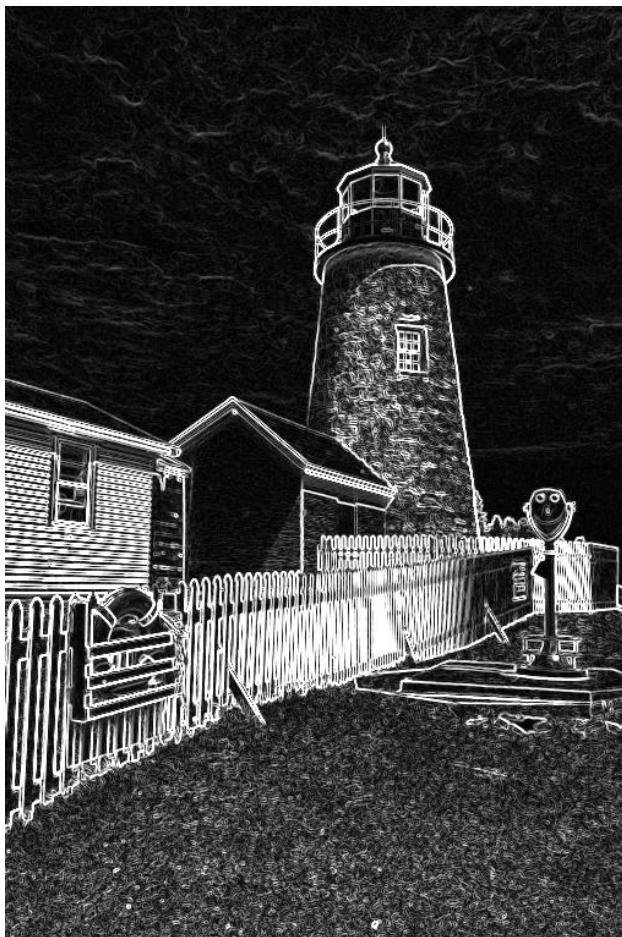
Gradient magnitude - Sobel

Thinning and thresholding

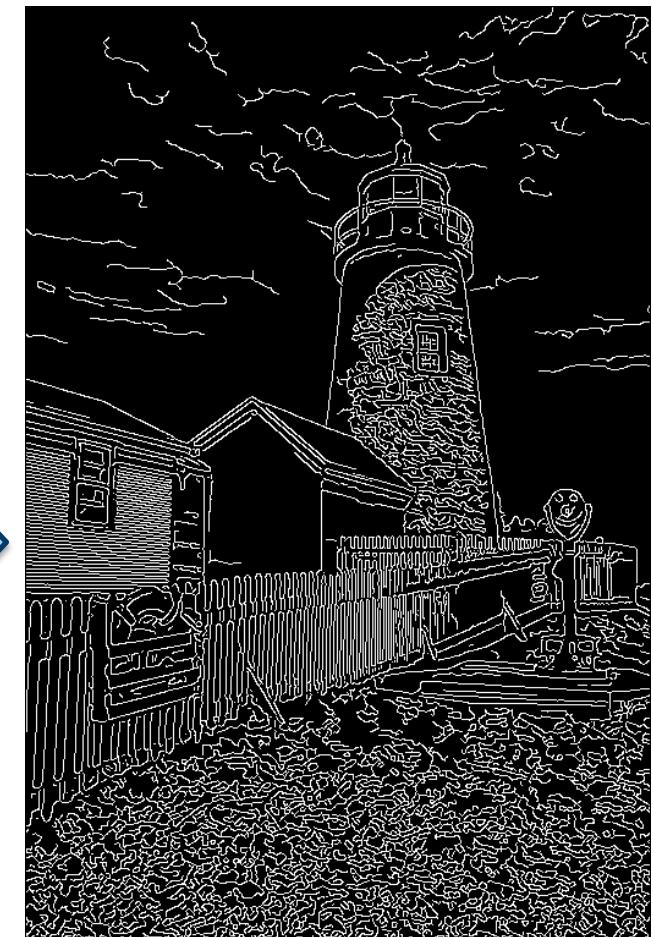
- Detection of local maxima (i.e. suppression of non-maxima)
- Thresholding



Binary image with isolated edges
(single pixels at discrete locations
along edge contours)



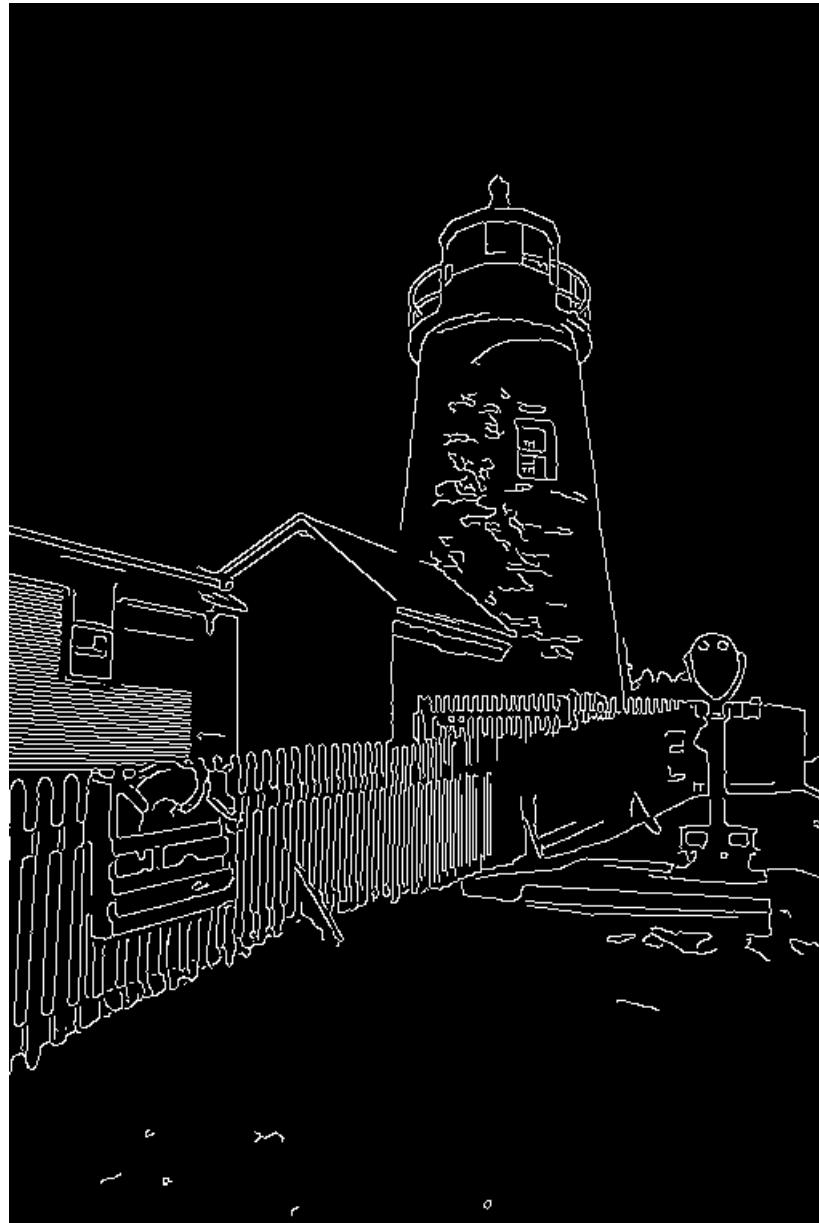
Edge enhanced image (Sobel)



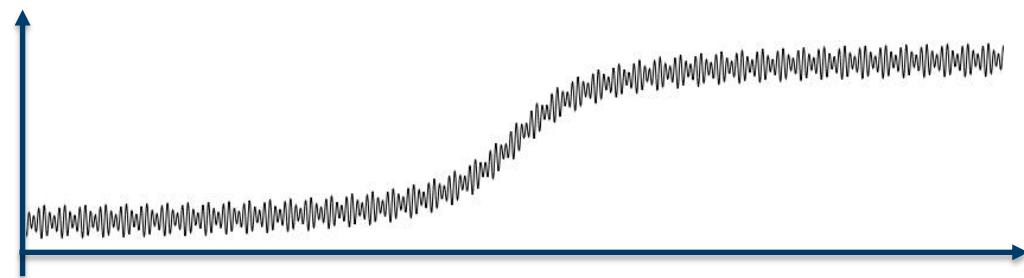
Edge image (Canny)

Canny edge detector

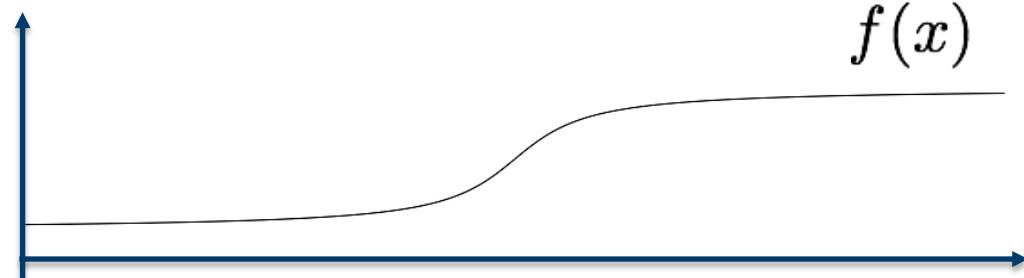
- Calculates a gradient image using the derivative of a Gaussian filter (i.e. Sobel operator)
- Detects local maxima of the gradient
- Thresholding using two thresholds:
 - **High** threshold for detection of strong edges
 - **Low** threshold for detection of weak edges
- Only weak edges connected to strong edges are retained in the output image
- This method is less likely to be fooled by noise than other methods, and
- More likely to detect true weak edges



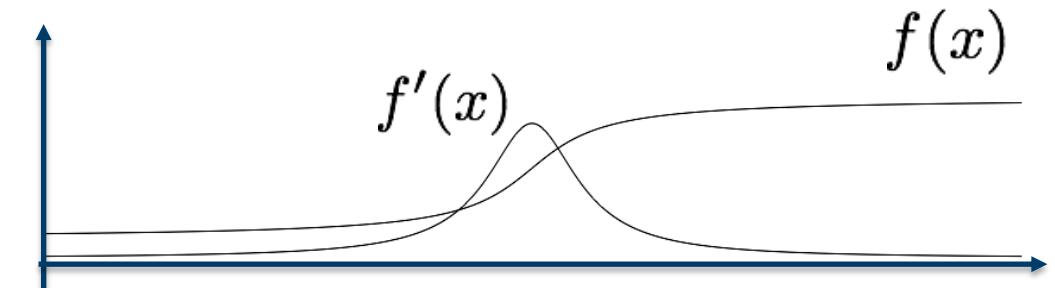
First and second derivatives



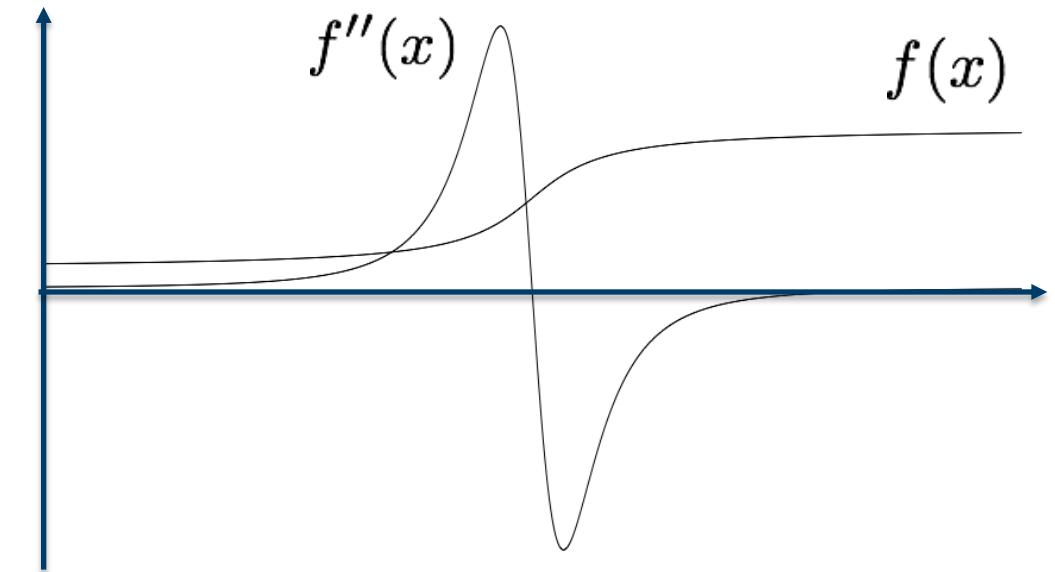
Noisy image function



Low-pass filtered image function



First derivative (Gradient)



Second derivative (Laplacian)

Laplacian operator

Gradient (in two dimensions):

$$\nabla = \begin{bmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \end{bmatrix}$$

Laplacian:

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

Discrete approximations (3 x3 kernels):

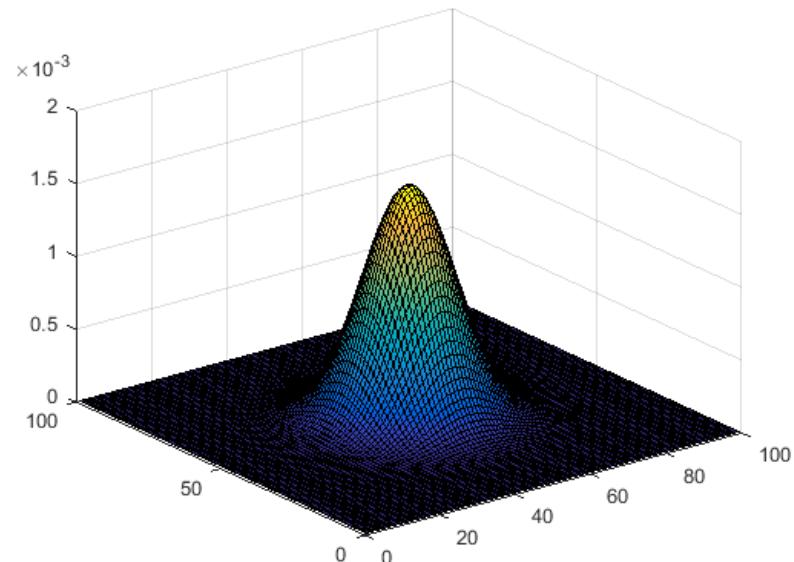
$\frac{1}{6}$

1	4	1
4	-20	4
1	4	1

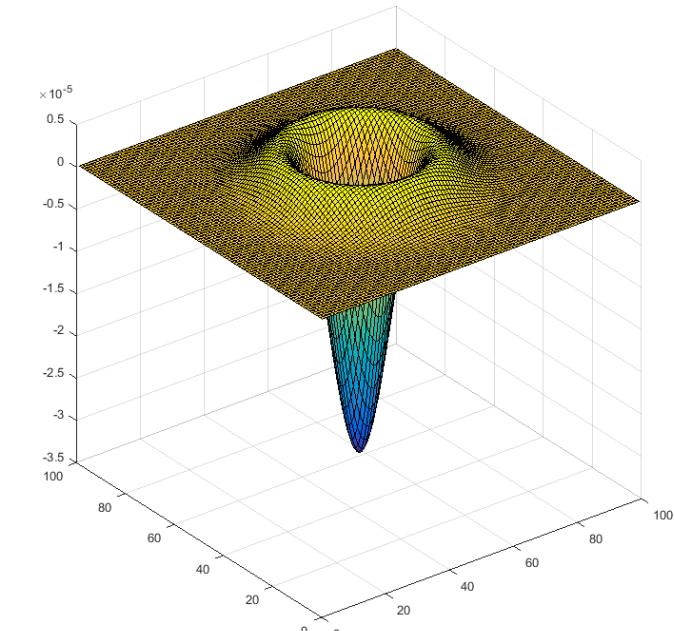
0	1	0
1	-4	1
0	1	0

Laplacian of Gaussian (LoG)

Gaussian



Laplacian of Gaussian



$$h_\sigma(u, v) = \frac{1}{2\pi\sigma^2} e^{-(\frac{u^2+v^2}{2\sigma^2})}$$

$$\nabla^2 h_\sigma(u, v)$$

Edge pixels at zero-crossings in the LoG image!

Laplacian of Gaussian - example

$$\nabla^2 h_\sigma(u, v)$$

Laplace

0	1	0
1	-4	1
0	1	0

*

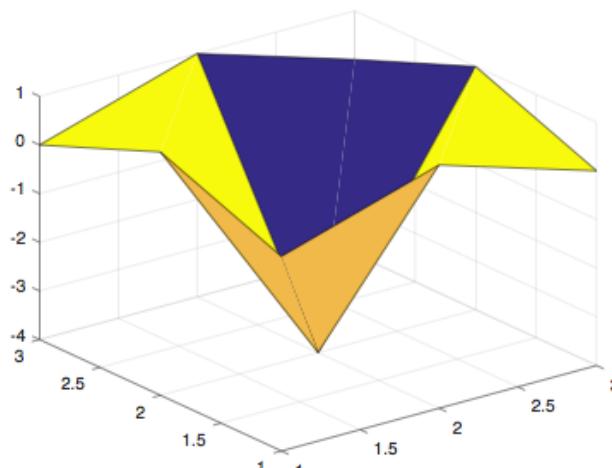
Gauss

0.0113	0.0838	0.0113
0.0838	0.6193	0.0838
0.0113	0.0838	0.0113

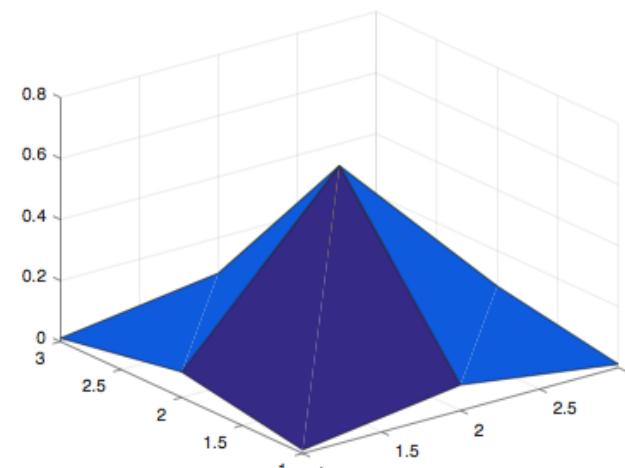
=

LoG

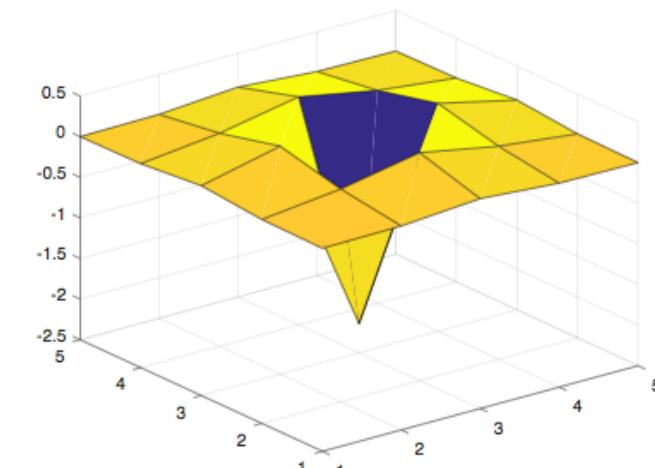
0.0000	0.0113	0.0838	0.0113	0.0000
0.0113	0.1223	0.3068	0.1223	0.0113
0.0838	0.3068	-2.1421	0.3068	0.0838
0.0113	0.1223	0.3068	0.1223	0.0113
0.0000	0.0113	0.0838	0.0113	0.0000



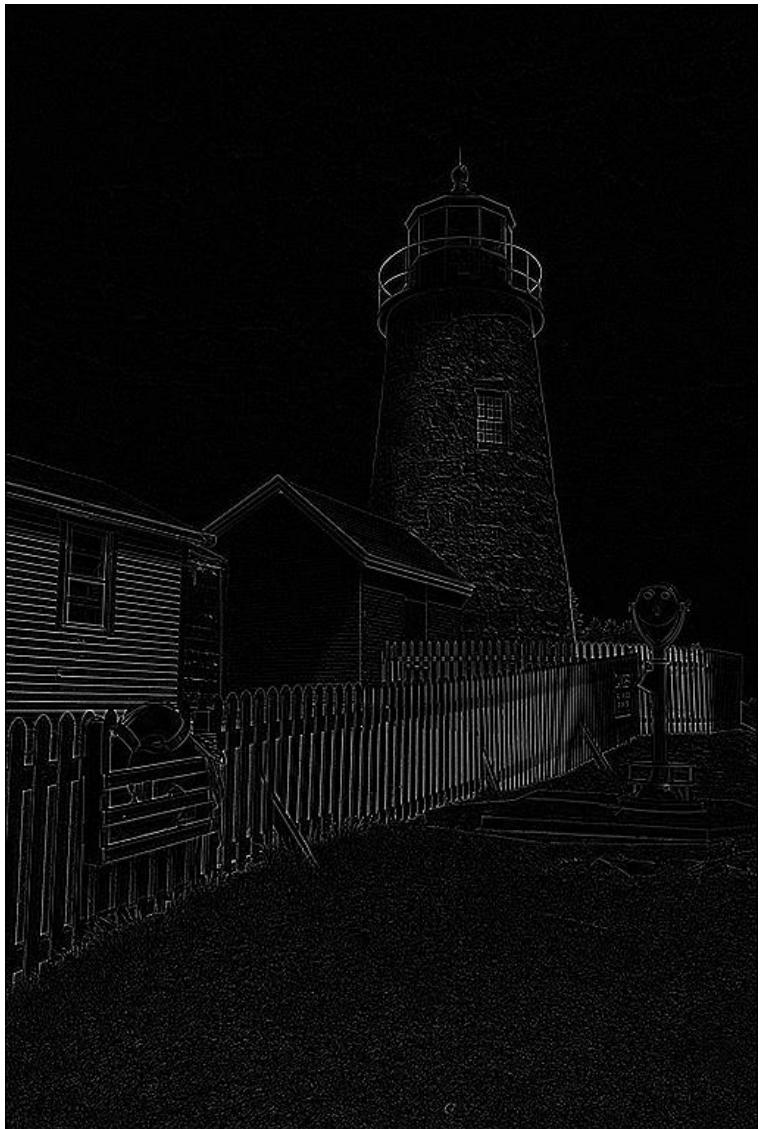
*



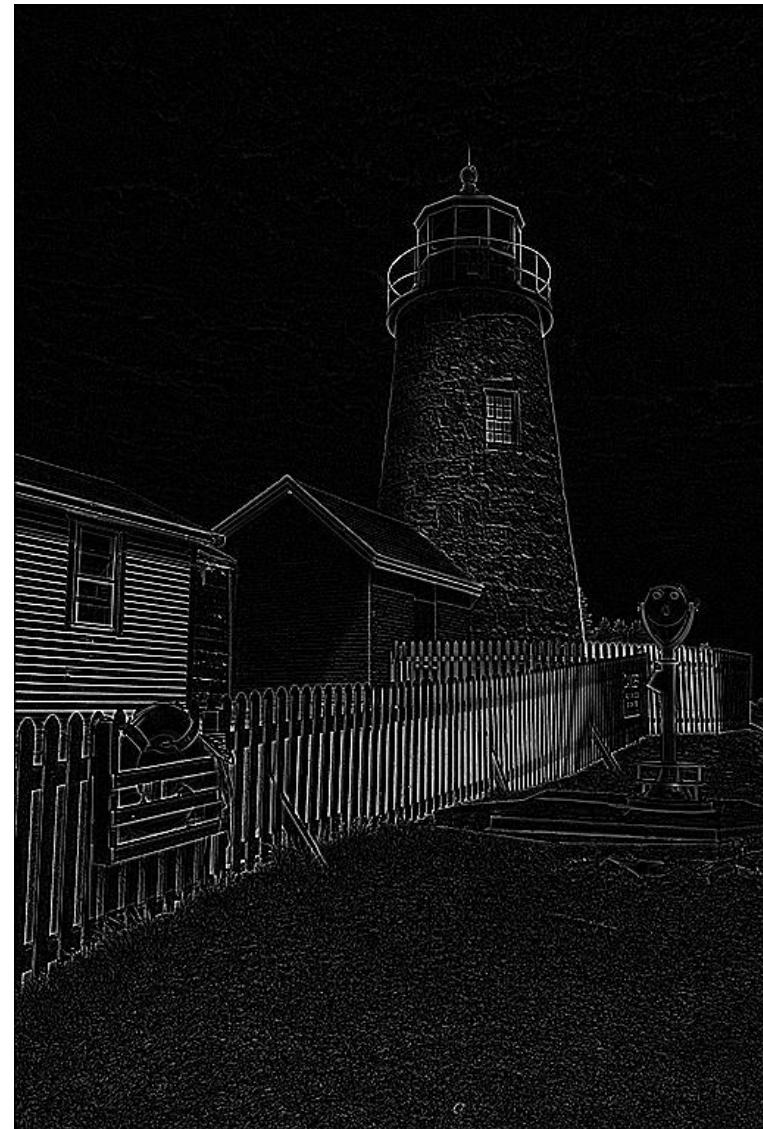
=



Examples - Laplacian and LoG

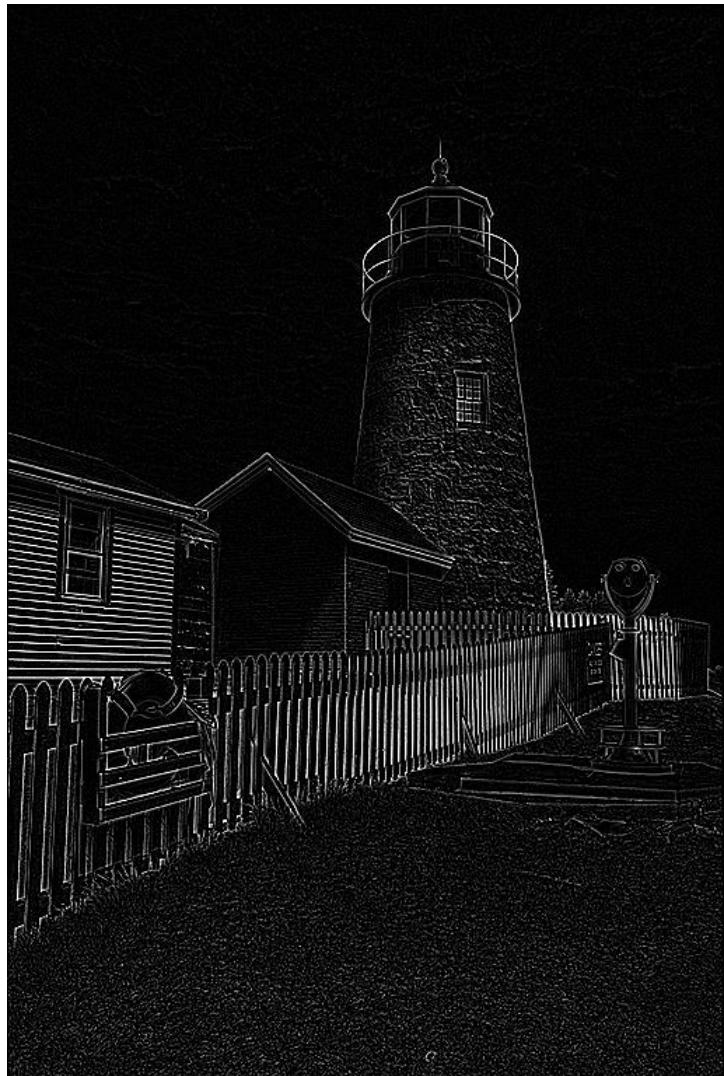


Laplace

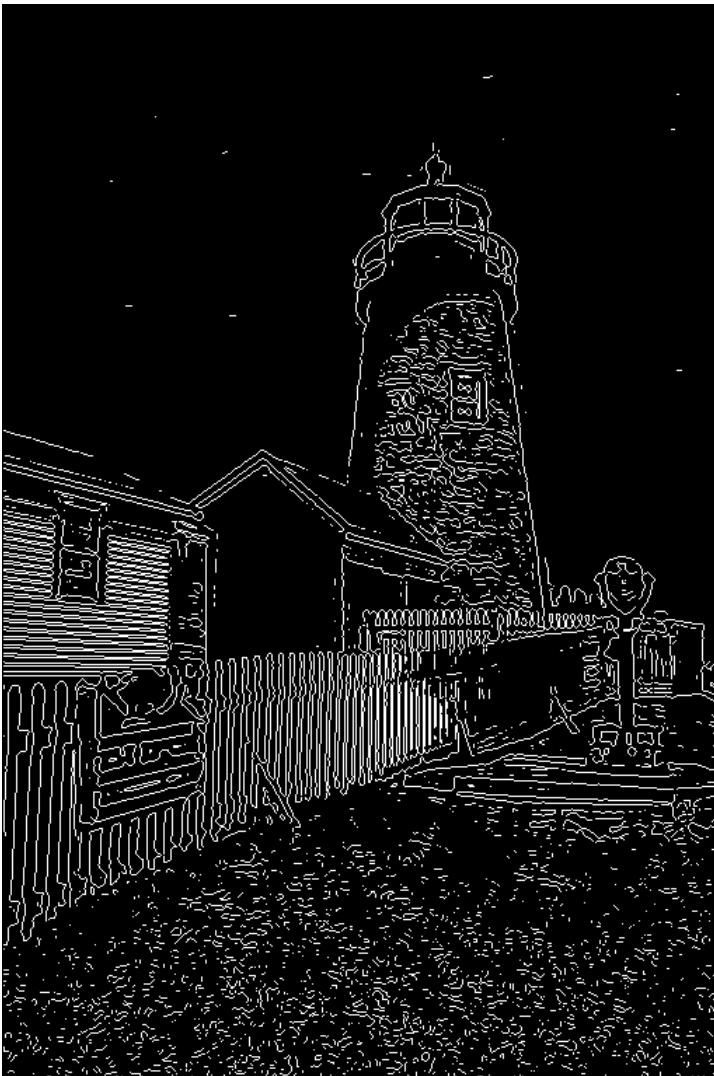


Laplacian of Gaussian

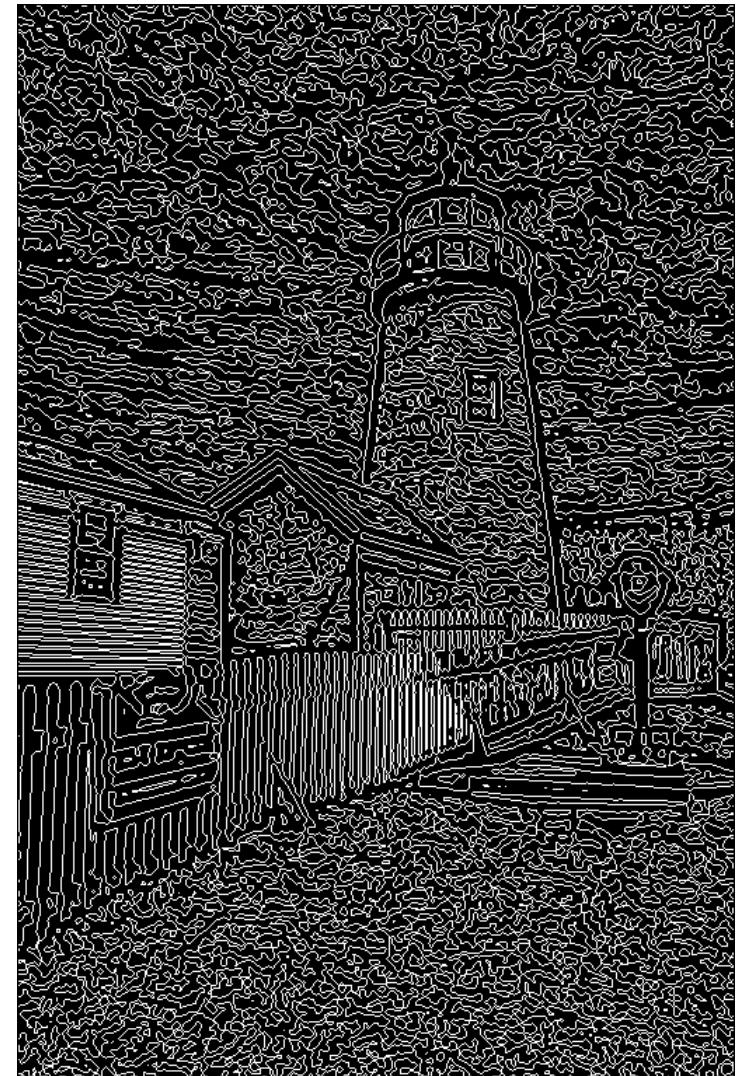
Edge detection - Laplacian of Gaussian (LoG)



LoG (gray level)

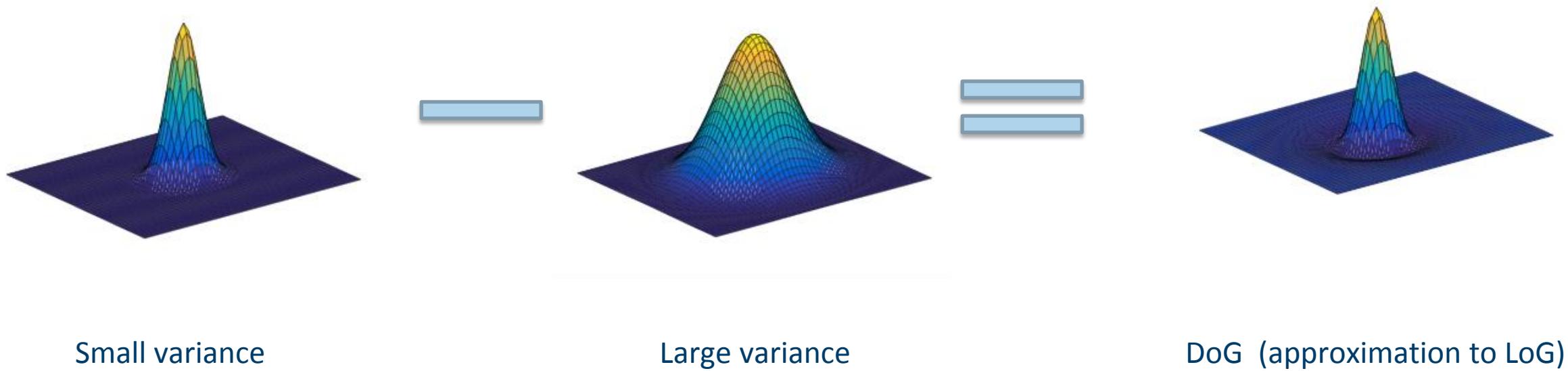


Thresholded (binary)

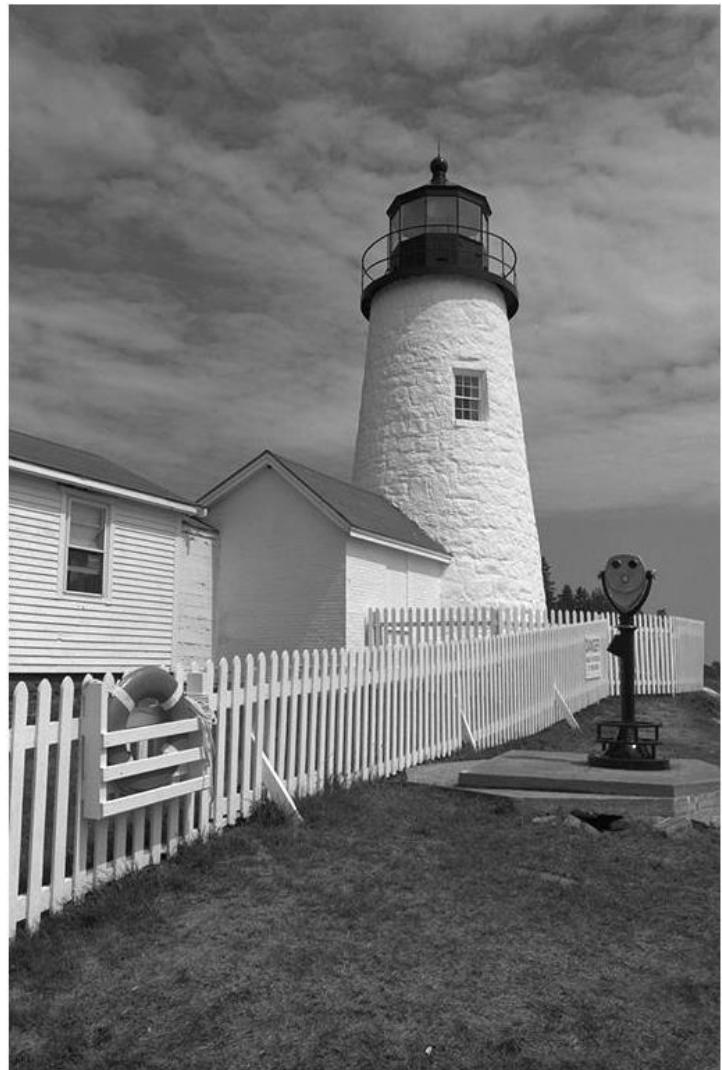


Zero crossing (binary)

Difference of Gaussians (DoG)



Difference of Gaussians - example



Another example



RGB original



Gray level

Laplace and LoG images



Laplace



LoG

DoG images



3 x 3 Gaussian kernel

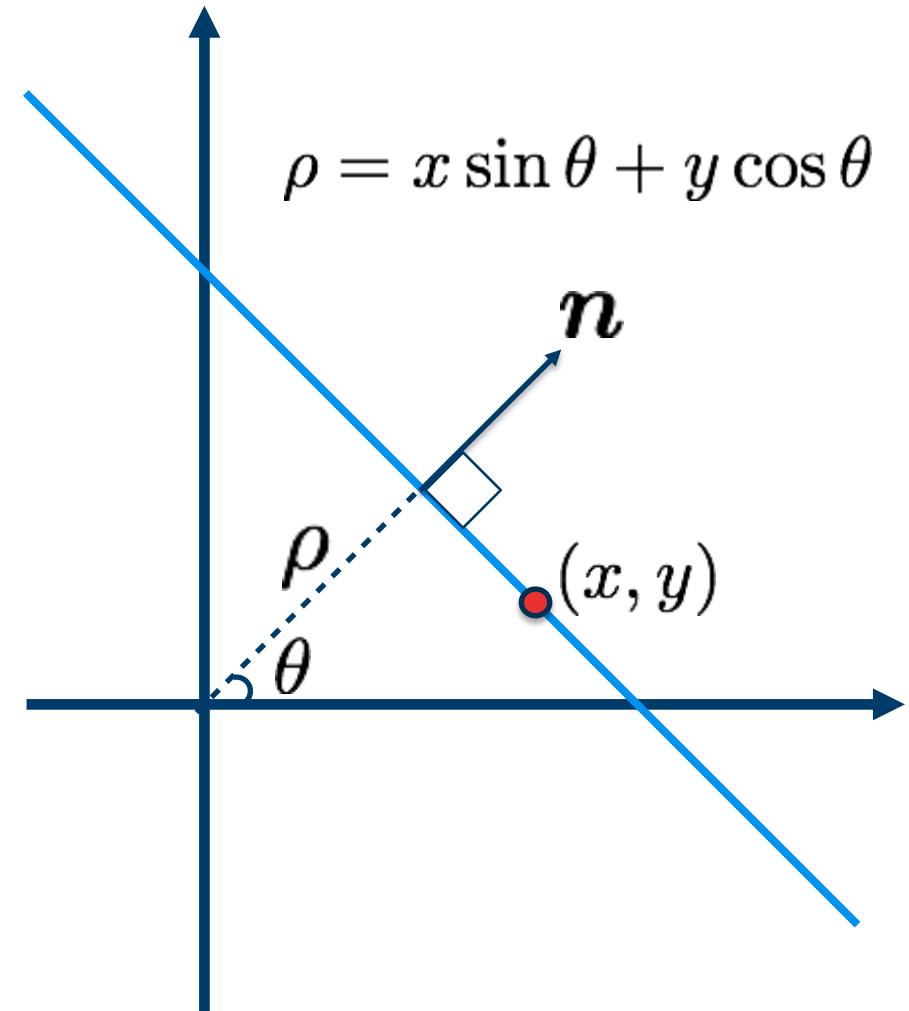
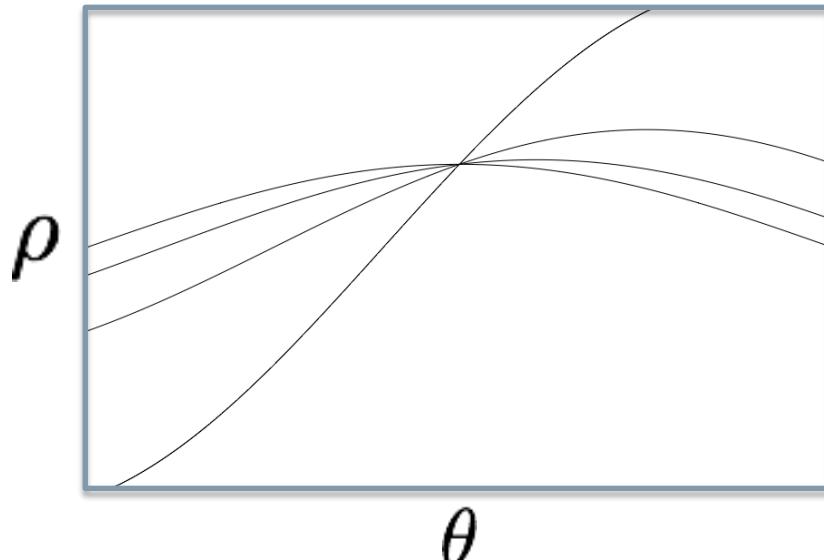


7 x 7 Gaussian kernel

Line detection - Hough transform

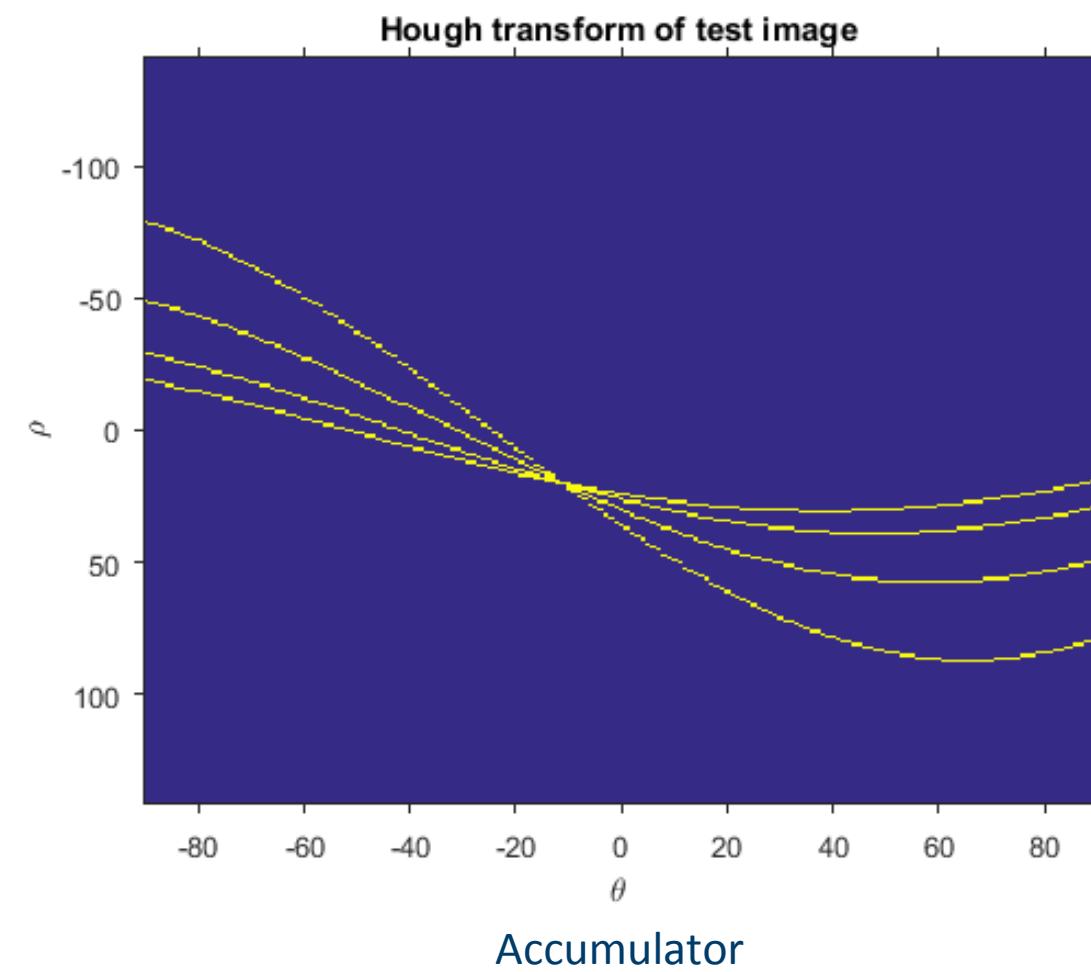
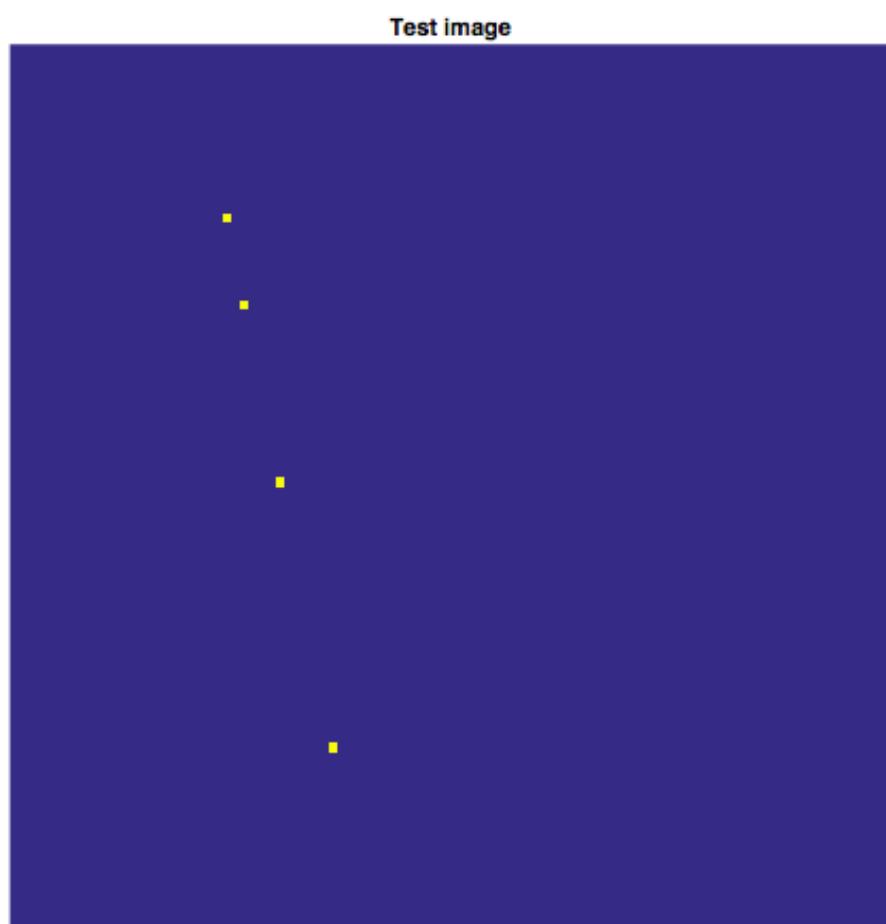
The set of all lines going through a given point corresponds to a sinusoidal curve in the (ρ, θ) plane.

Two or more points on a straight line will give rise to sinusoids intersecting at the point (ρ, θ) for that line.



The Hough transform can be generalized to other shapes.

Example



Hough transform

1. Clear the accumulator array
2. For each detected edgel (edge pixel) at location (x, y) and each orientation $\theta = \tan^{-1}(n_y/n_x)$, compute the value of:

$$\rho = x \sin \theta + y \cos \theta$$

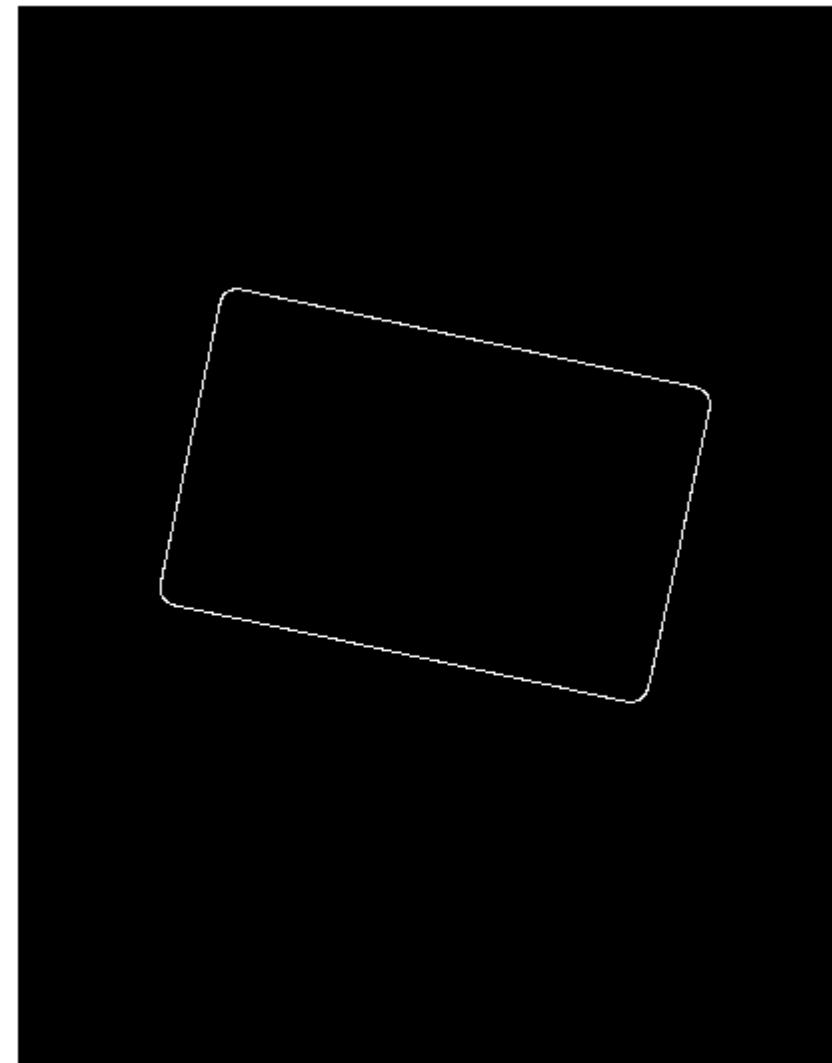
and increment the accumulator bin corresponding to (ρ, θ)

3. Find the peaks (local maxima) in the accumulator corresponding to lines
4. Optional post-processing to fit the lines to the constituent edgels.

Example 1

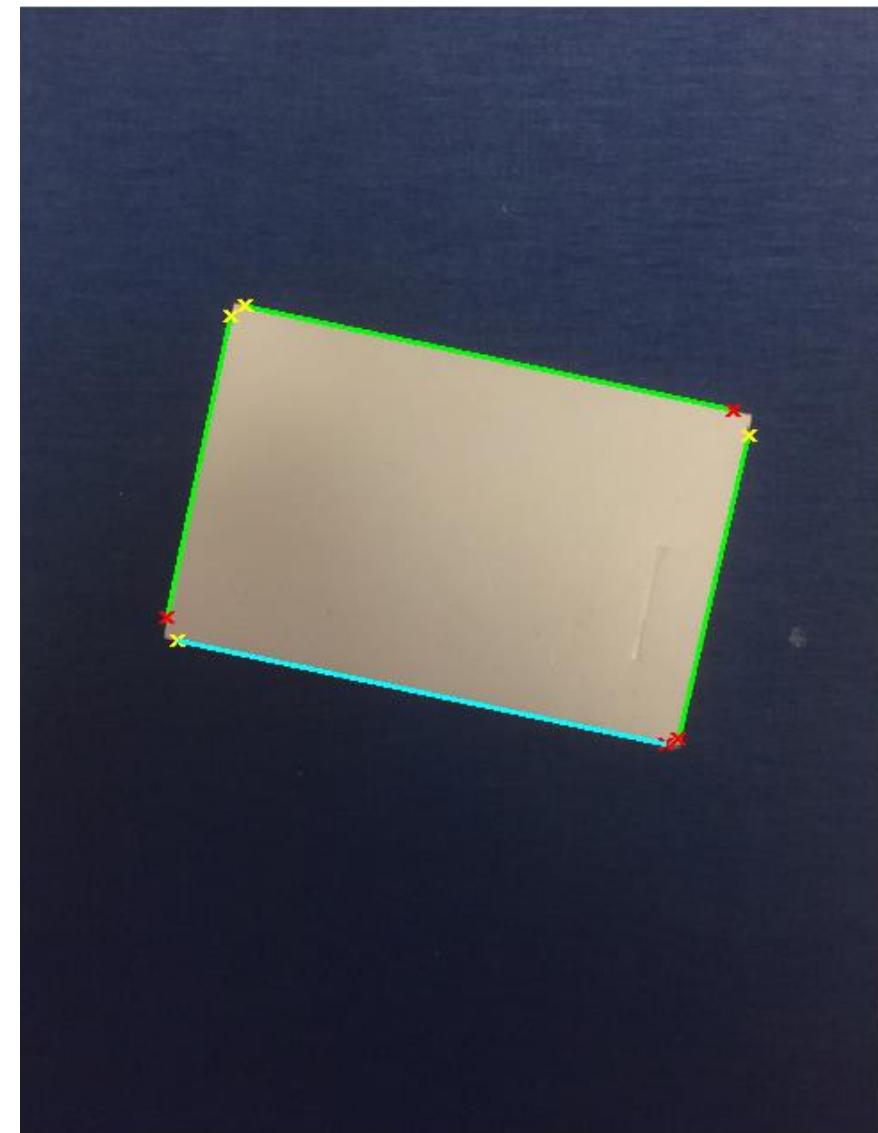
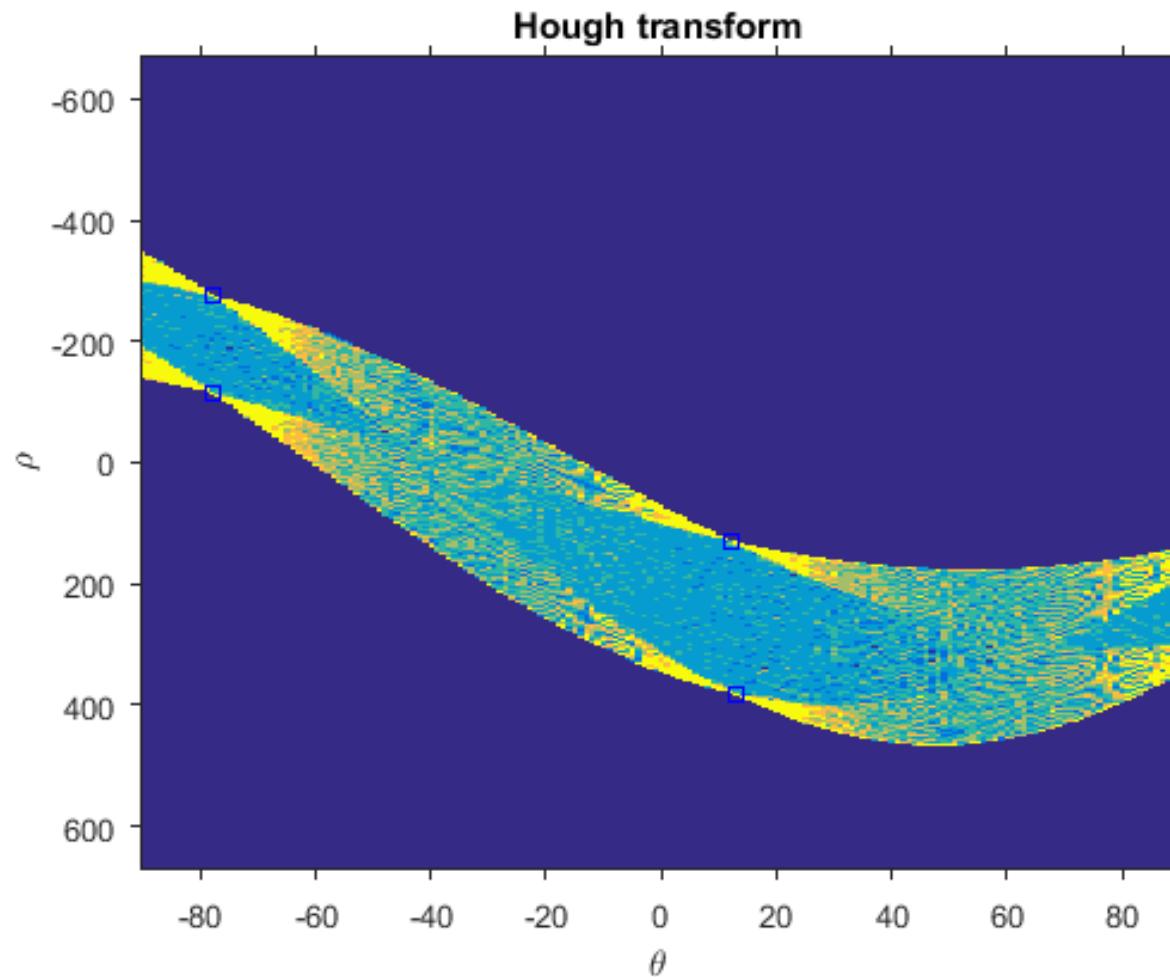


Original



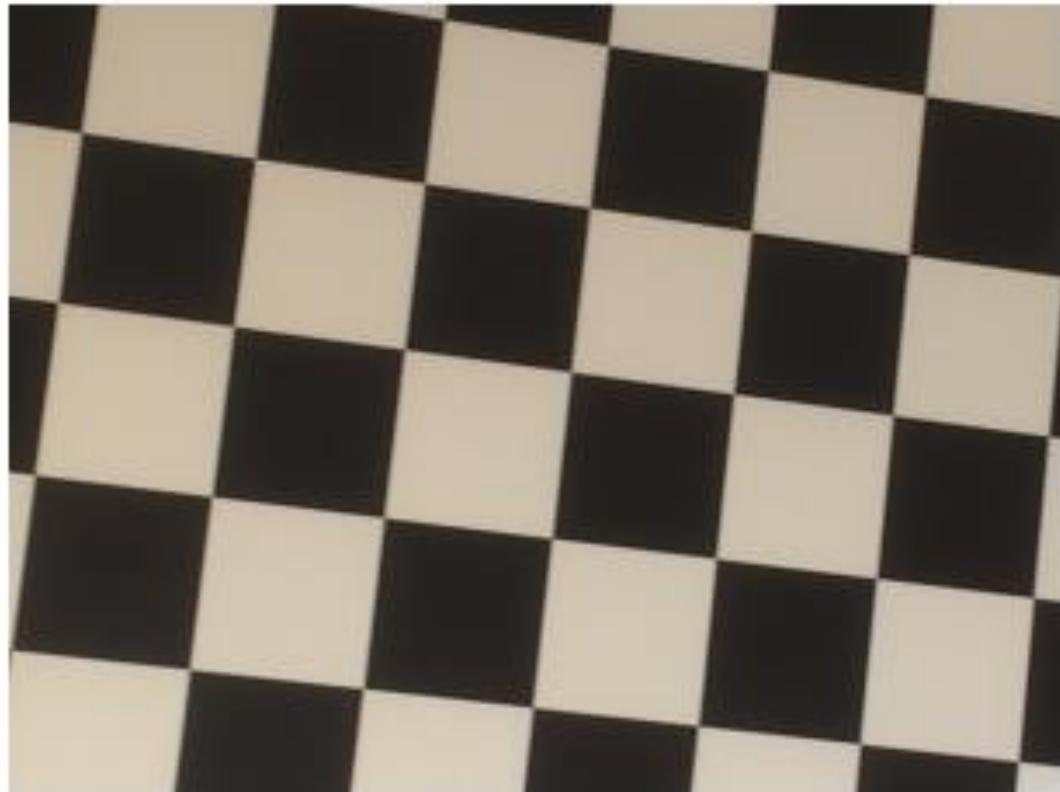
Edge image (Canny)

Example 1 (2)

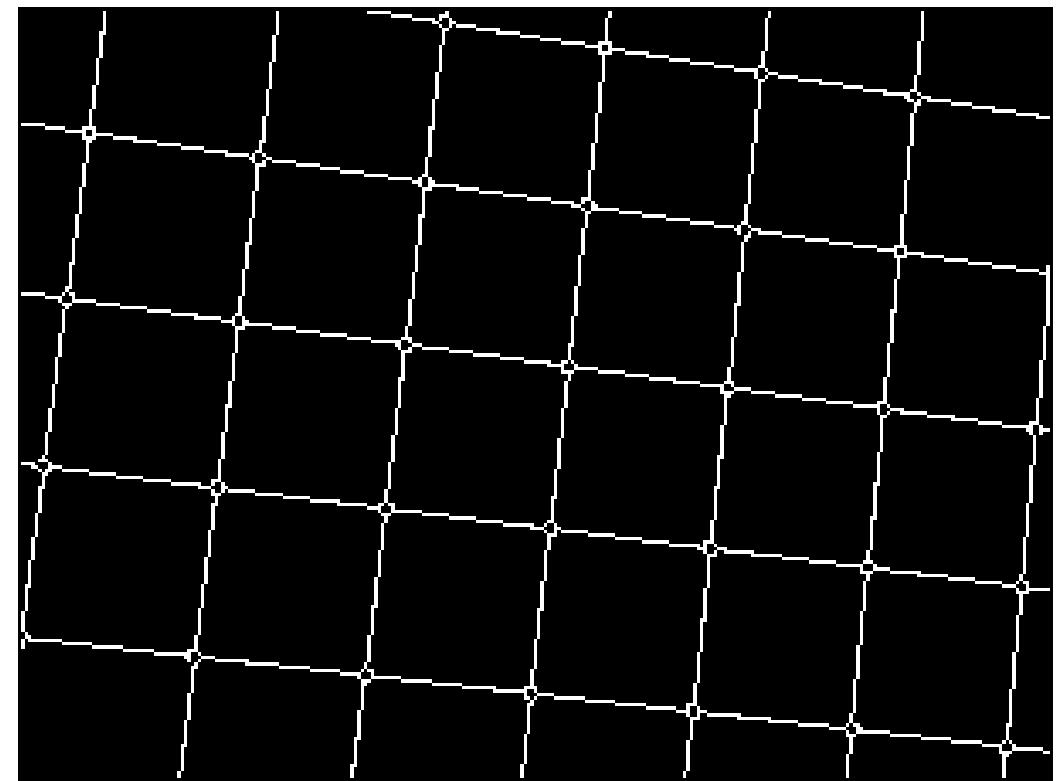


Detected lines

Example 2

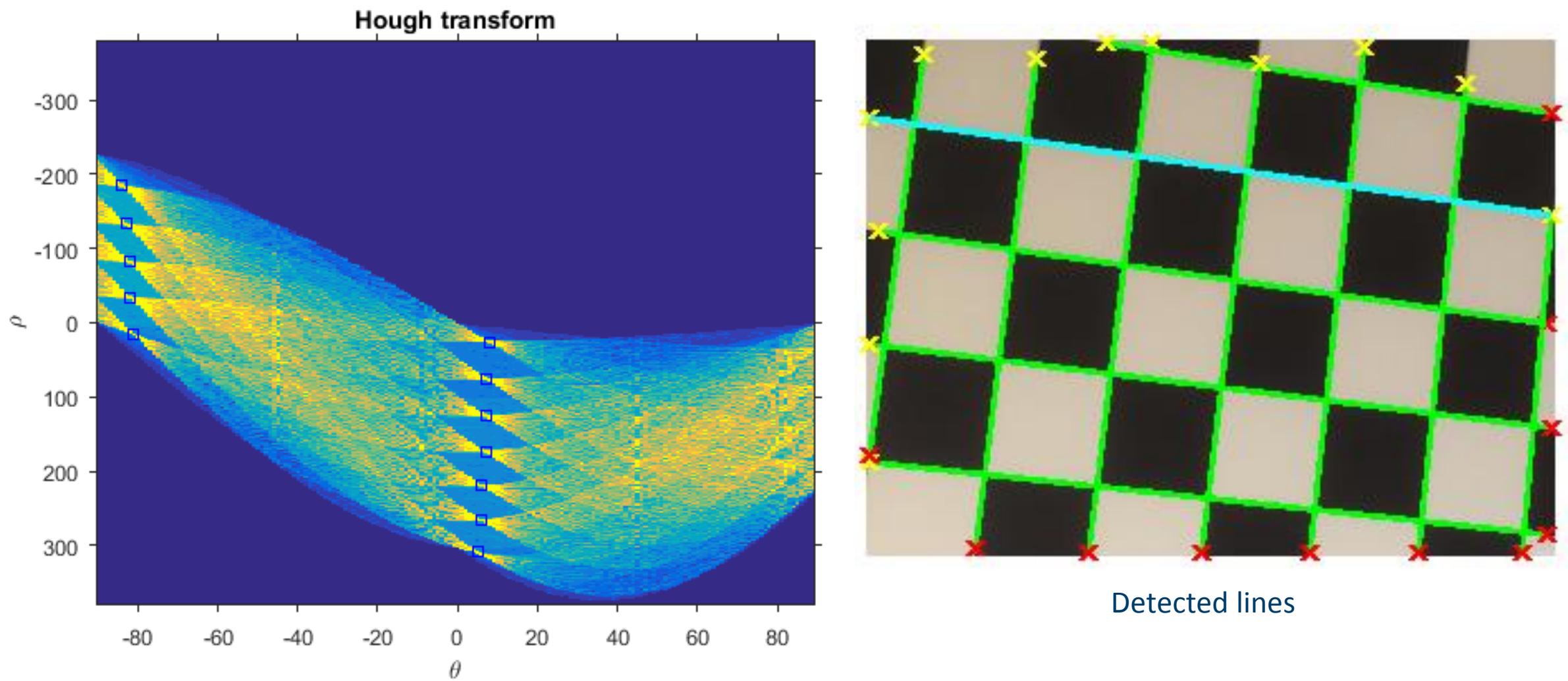


Original



Edge image (Canny)

Example 2 (2)



Example 3

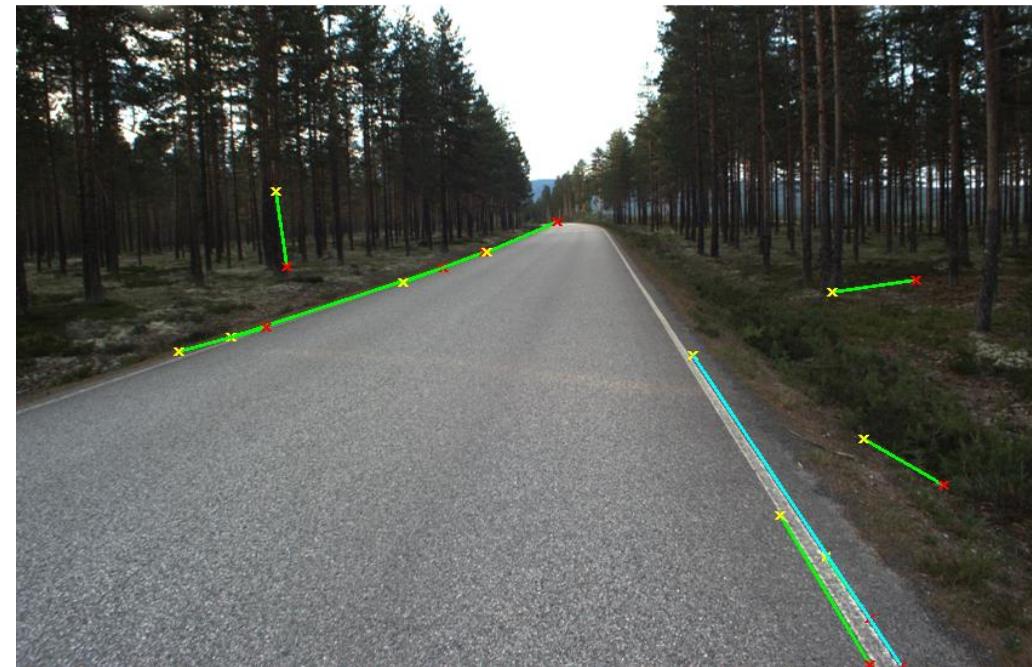


Original



Edge image (Canny)

Example 3 - some results



Line detection - complicated scene



Summary

Line features:

- Edge detectors
- Line detection with the Hough transform

More information: Szeliski 4.2 - 4.3.

