VC 10/11 – T8
Segmentation

Mestrado em Ciência de Computadores

Mestrado Integrado em Engenharia de Redes e Sistemas Informáticos

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U. PORTO FC

Outline

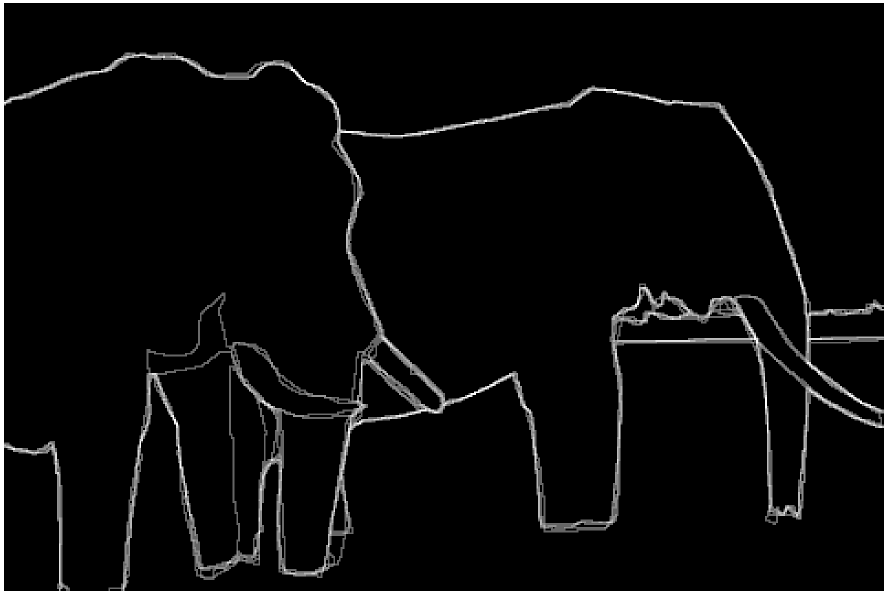
- Thresholding
- Geometric structures
- Hough Transform

Acknowledgements: Most of this course is based on the excellent courses offered by Prof. Shree Nayar at Columbia University, USA and by Prof. Srinivasa Narasimhan at CMU, USA. Please acknowledge the original source when reusing these slides for academic purposes.

Topic: Thresholding

- Thresholding
- Geometric structures
- Hough Transform

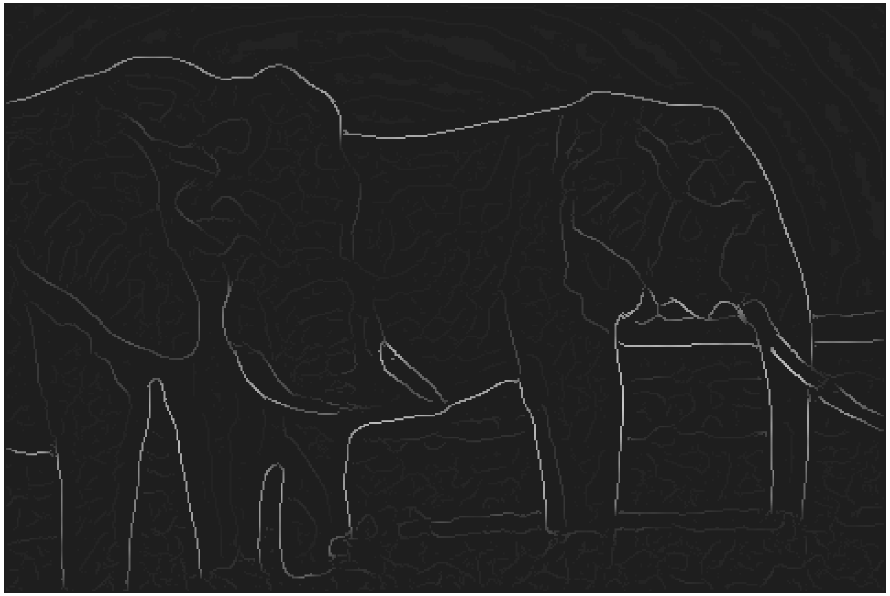
Boundaries of Objects



Marked by many users

http://www.eecs.berkeley.edu/Research/Projects/CS/vision/grouping/segbench/bench/html/images.html

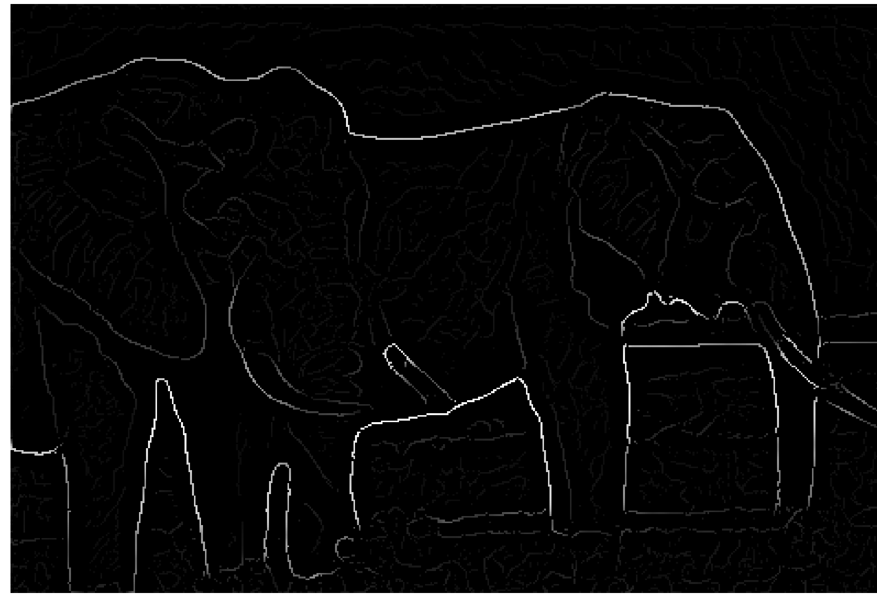
Boundaries of Objects from Edges



Brightness Gradient (Edge detection)

- Missing edge continuity, many spurious edges

Boundaries of Objects from Edges

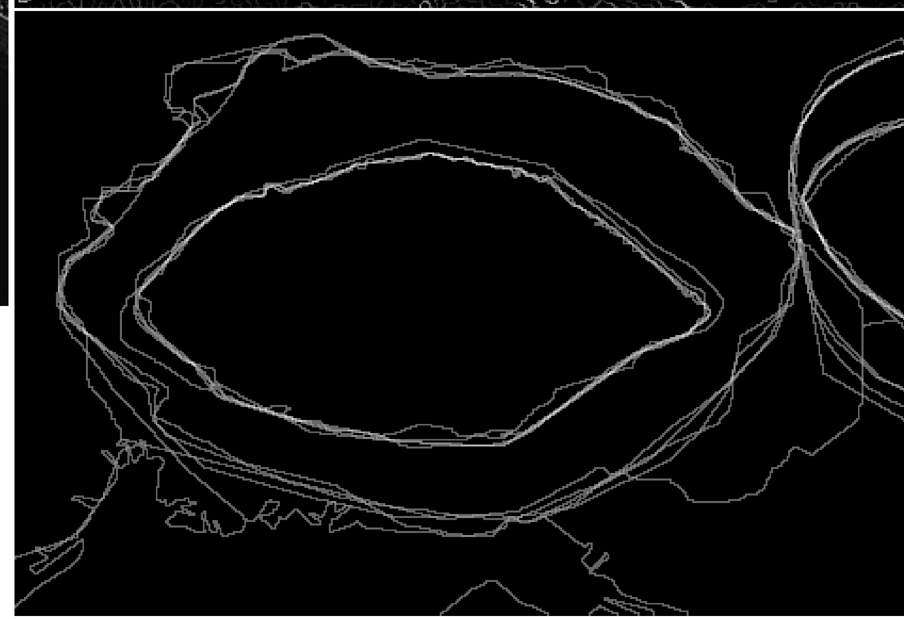


Multi-scale Brightness Gradient

- But, low strength edges may be very important

Machine Edge Detection

Image



Human Boundary Marking

Boundaries in Medical Imaging

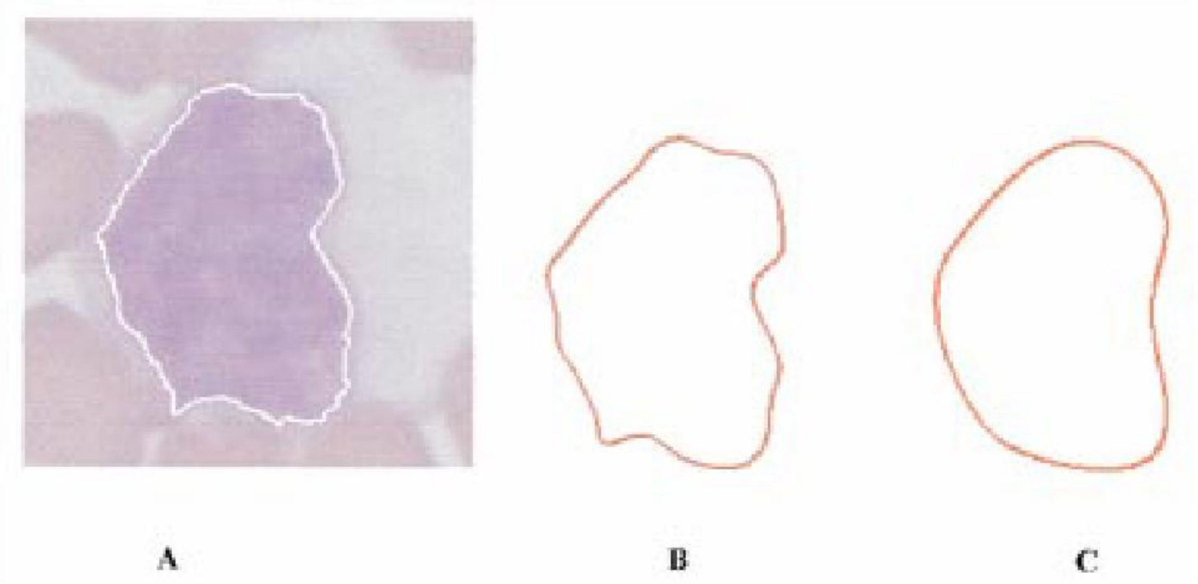
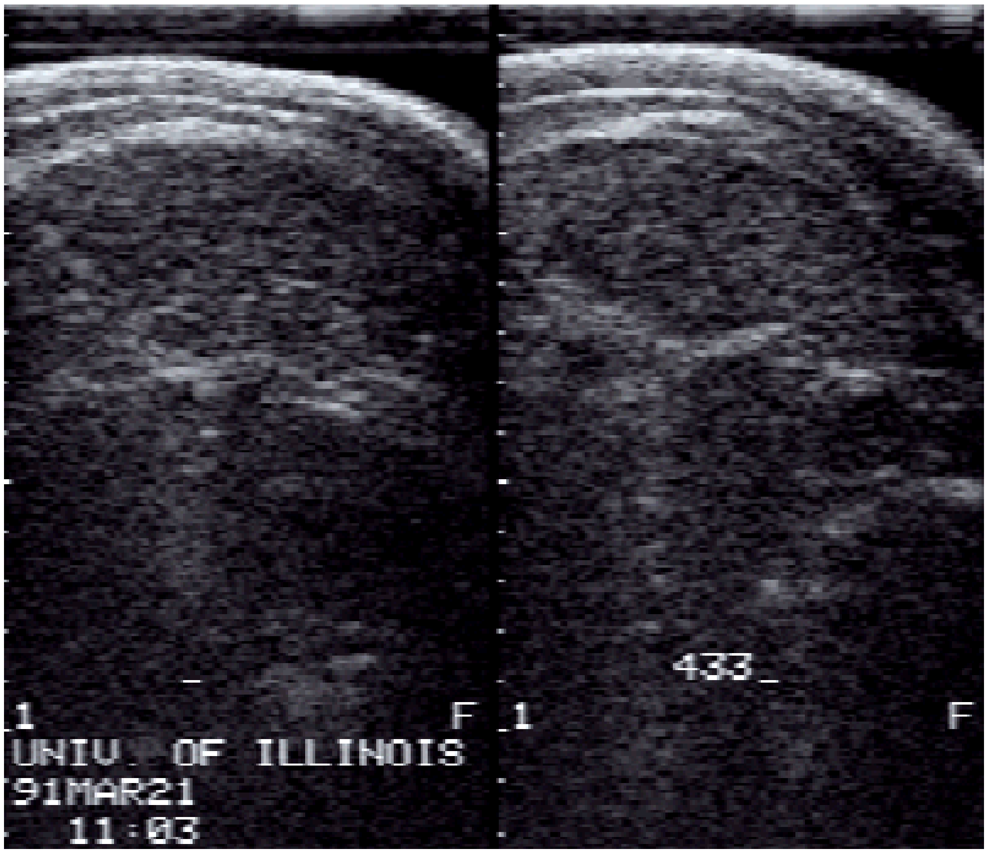


Fig. 2. Representation of a closed contour by elliptic Fourier descriptors. (a) Input. (b) Series truncated at 16 harmonics. (c) Series truncated to four harmonics.

Detection of cancerous regions.

[Foran, Comaniciu, Meer, Goodell, 00]

Boundaries in Ultrasound Images



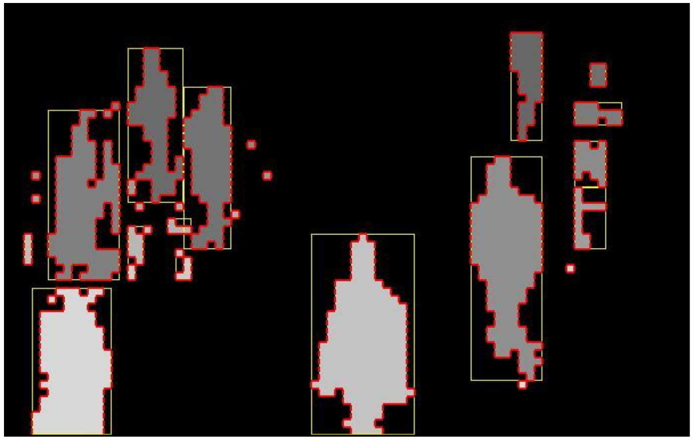
Hard to detect in the presence of large amount of speckle noise

Sometimes hard even for humans!

What is ‘Segmentation’?

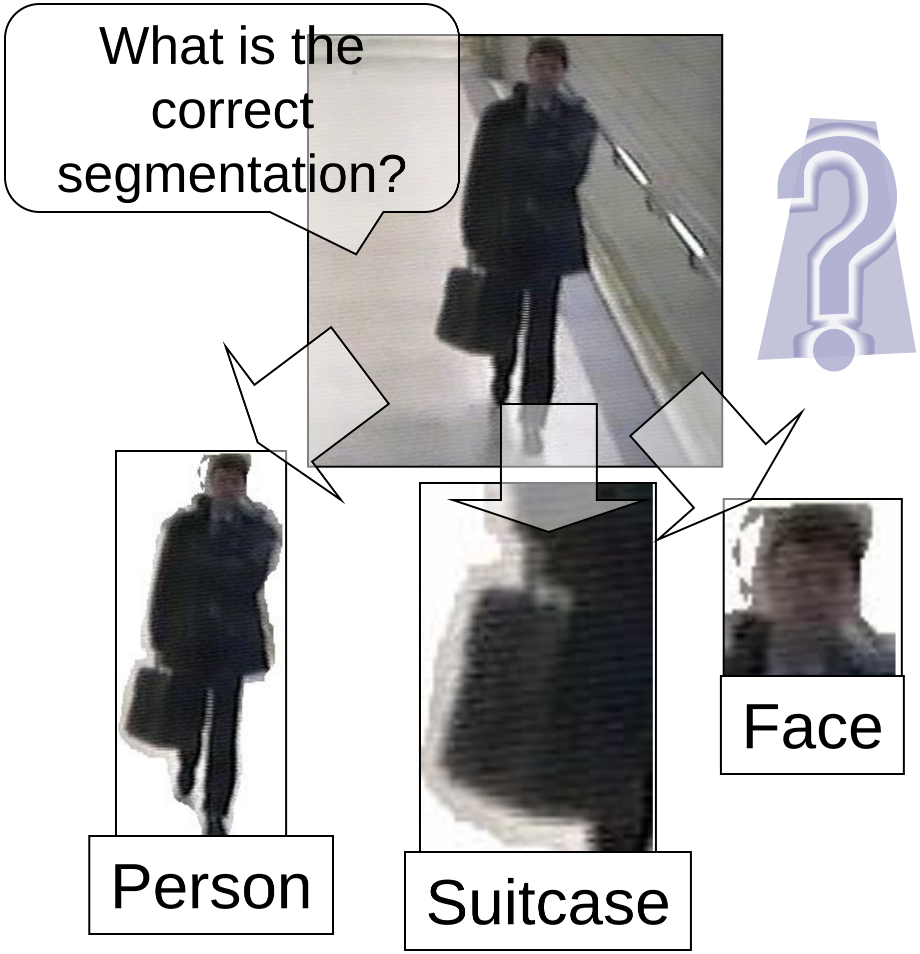
- Separation of the image in different areas.
  - Objects.
  - Areas with similar visual or semantic characteristics.

Not trivial! It is the holy grail of most computer vision problems!



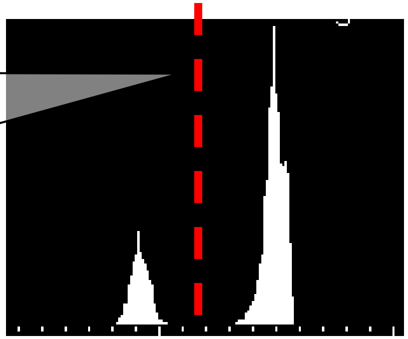
Subjectivity

- A 'correct' segmentation result is only valid for a specific context.
  - Subjectivity!
  - Hard to implement.
  - Hard to evaluate.

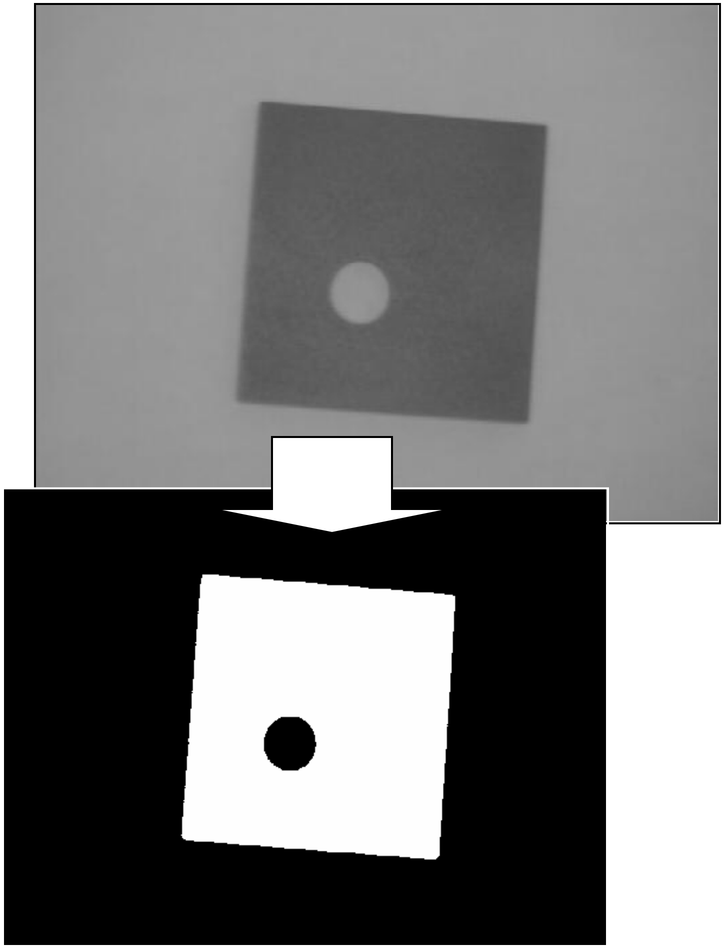


Core Technique: *Thresholding*

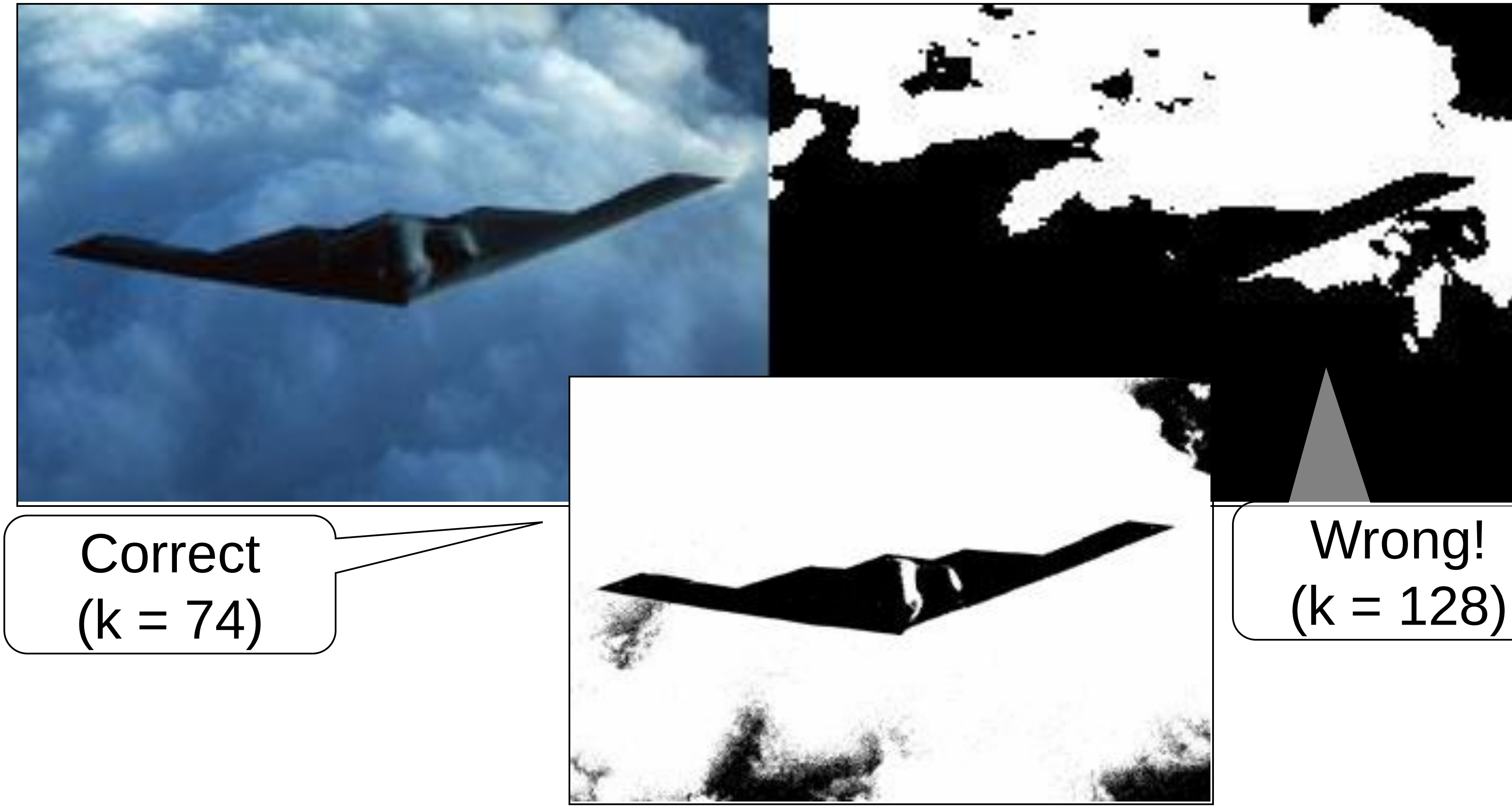
- Divide the image into two areas:
  - 1, if *f(x,y)>K*
  - 0, if *f(x,y)<=K*
- Not easy to find the ideal ***k*** *magic number.*
- Core segmentation technique
  - Simple
  - Reasonably effective



Adequate *threshold*

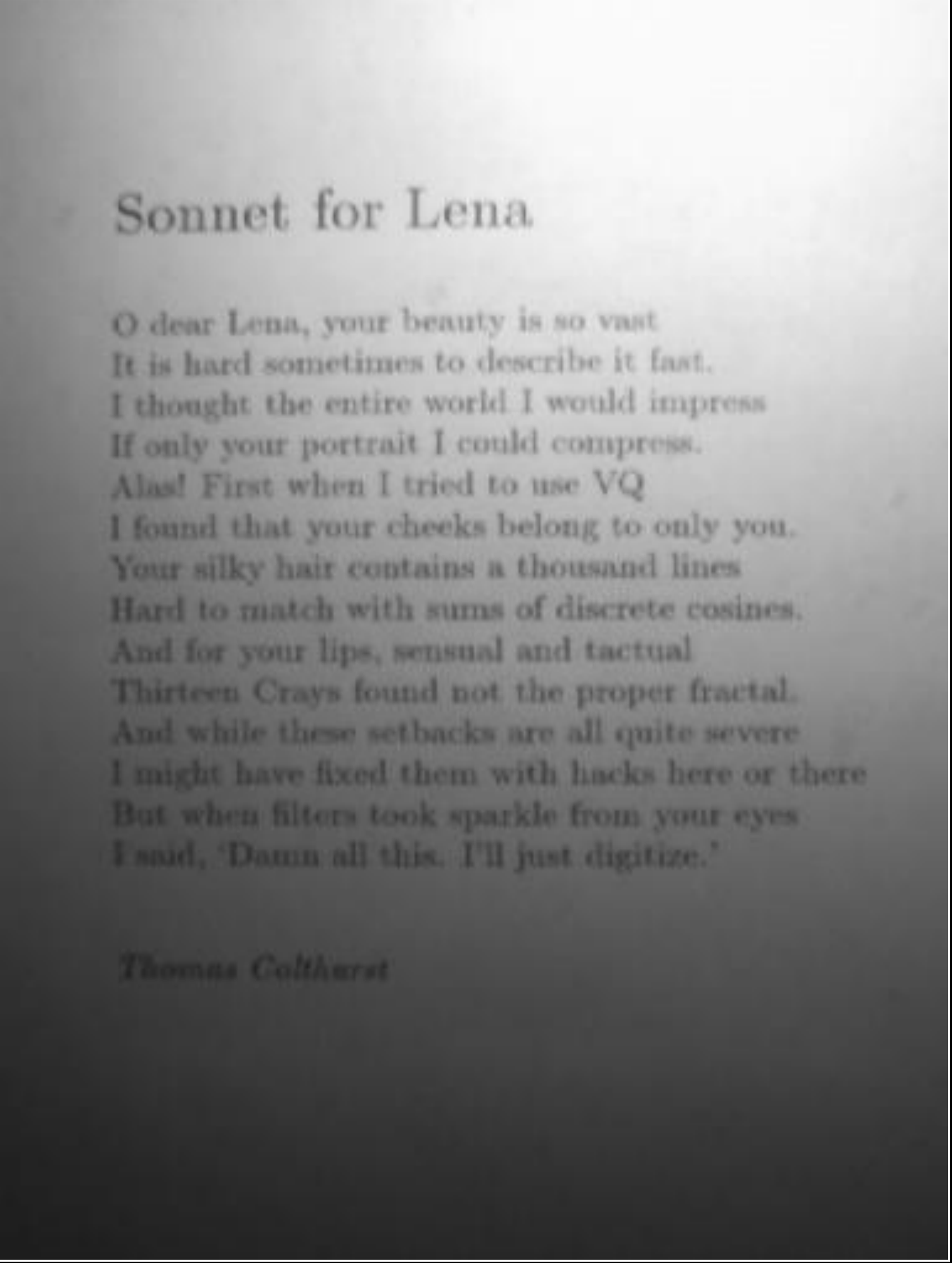


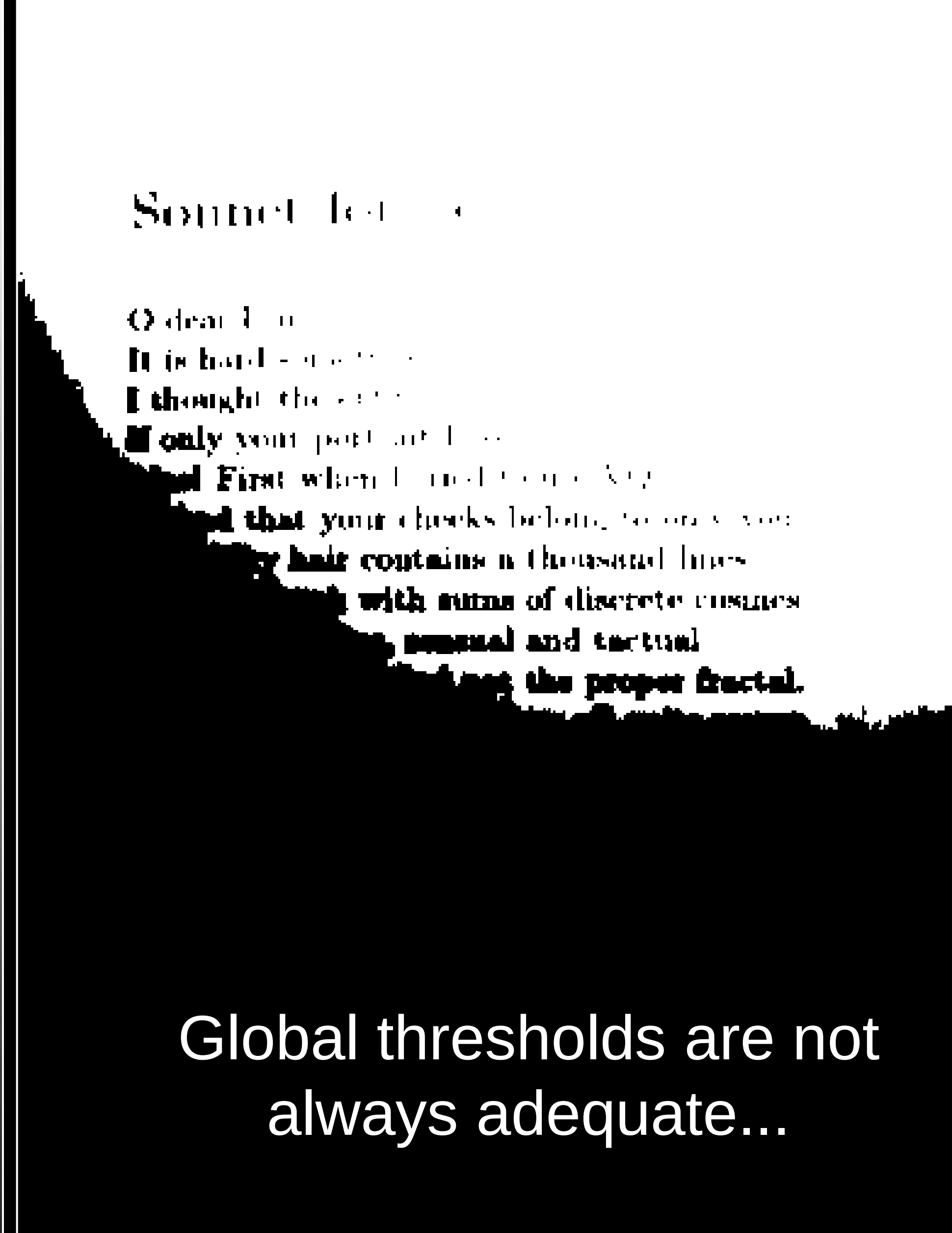
Finding the ‘magic number’



Correct
(k = 74)

Wrong!
(k = 128)



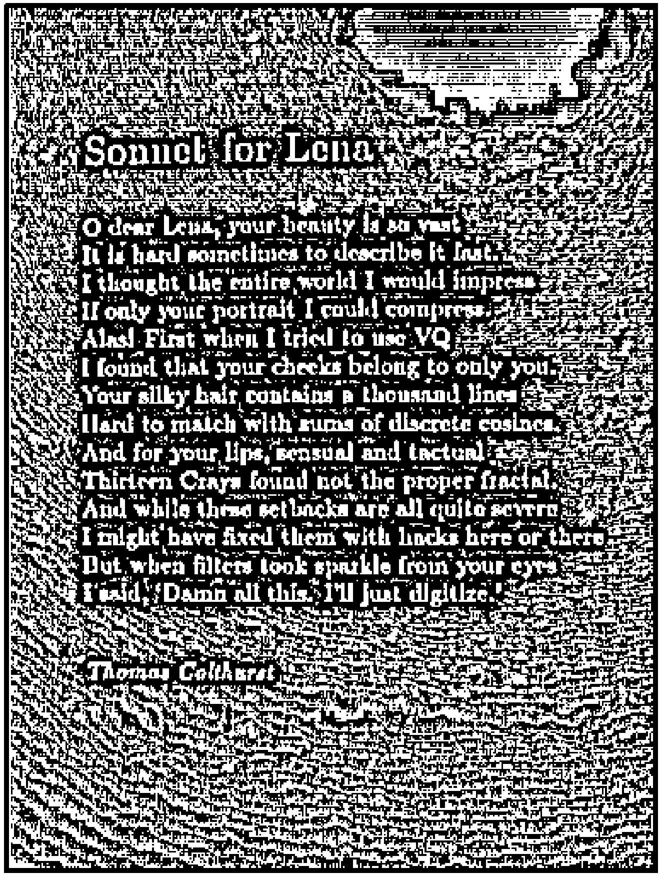


Global thresholds are not always adequate...

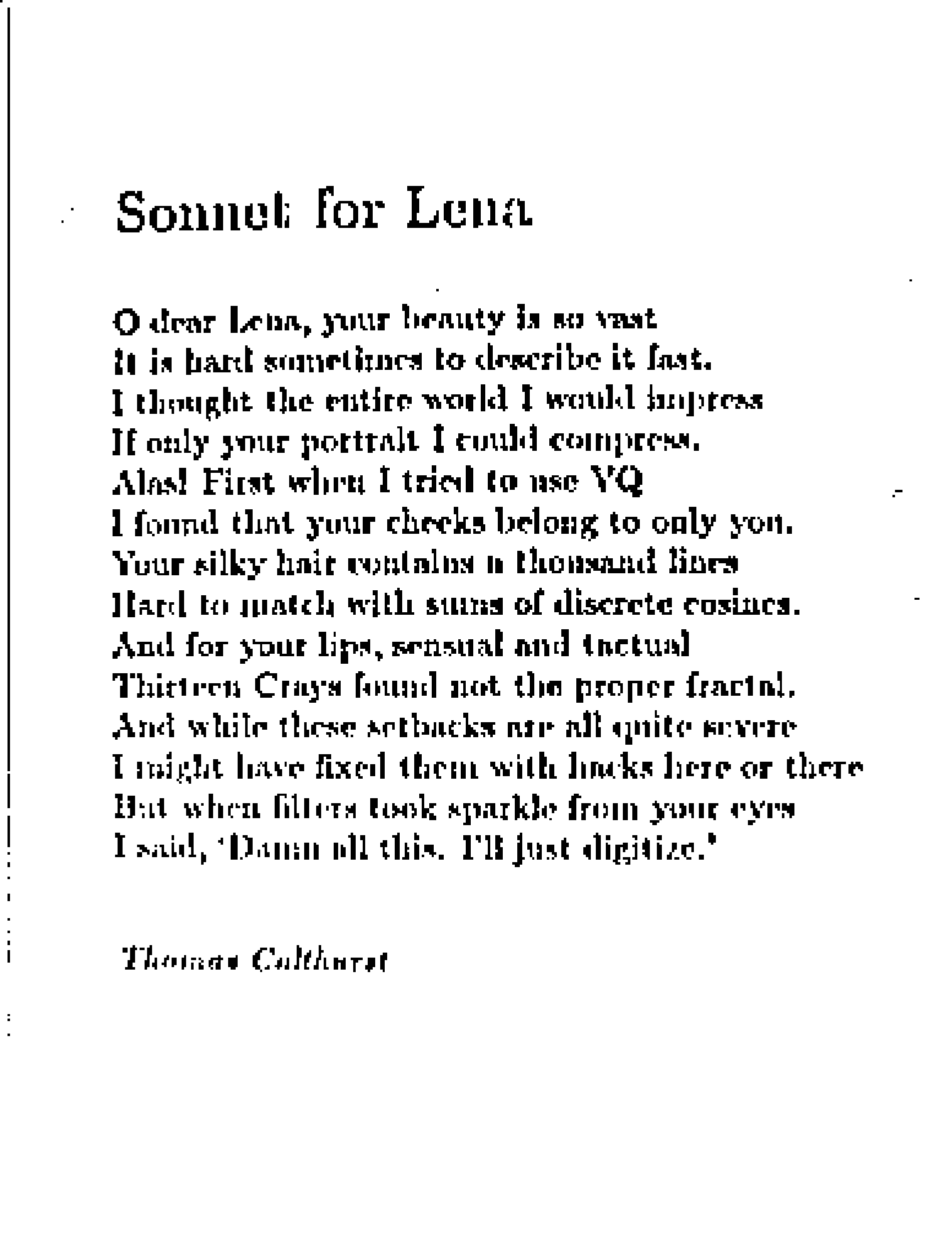
http://www.cee.hw.ac.uk/hipr/html/adpthrsh.html

Adaptive Thresholding

- Adapt the threshold value for each pixel.
- Use characteristics of nearby pixels.
- How?
  - Mean
  - Median
  - Mean + K
  - ...



Mean of 7x7 neighborhood

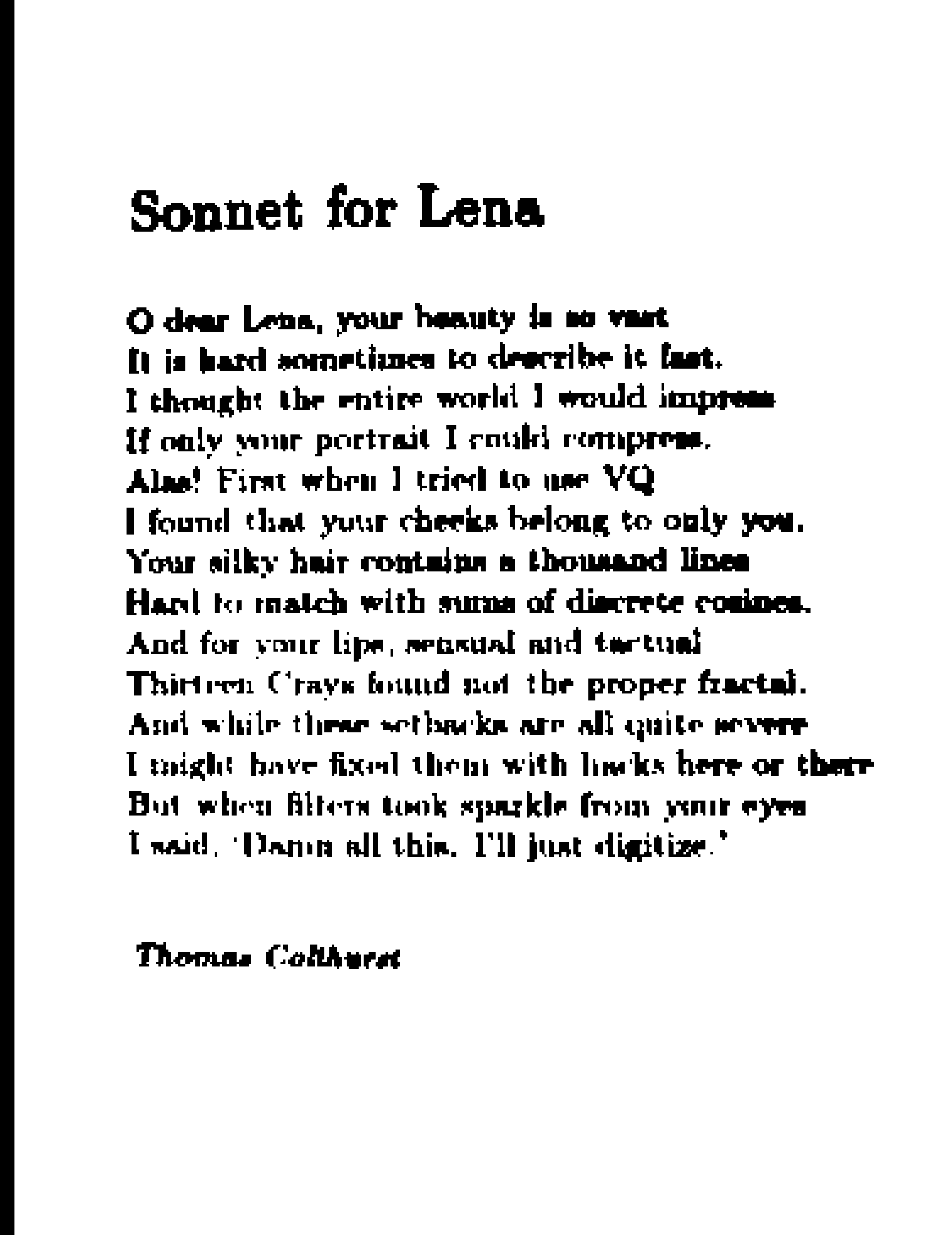


Sonnet for Lena

O dear Lena, your beauty is so vast
It is hard sometimes to describe it fast.
I thought the entire world I would impress
If only your portrait I could compress.
Alas! First when I tried to use VQ
I found that your cheeks belong to only you.
Your silky hair contains a thousand lines
Hard to match with sums of discrete cosines.
And for your lips, sensual and tactual
Thirteen Crays found not the proper fractal.
And while these setbacks are all quite severe
I might have fixed them with hacks here or there
But when filters took sparkle from your eyes
I said, 'Damn all this. I'll just digitize.'

Thomas Colthurst

7x7 window; K = 7



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Thomas Colthurst

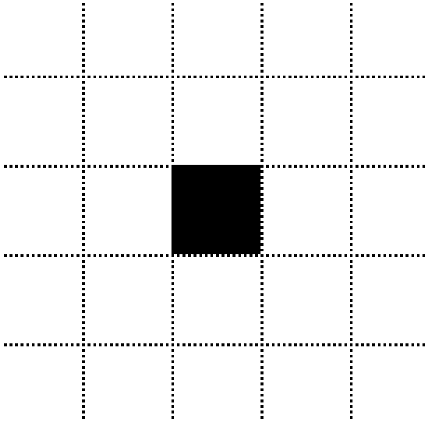
75x75 window; K = 10

Topic: Geometric structures

- Thresholding
- Geometric structures
- Hough Transform

Points

- What is a point?
  - Pixel with a significant illumination difference to its neighbors.
  - Group of pixels?



- Spatial Mask!
- Need to define a threshold K.

-1	-1	-1
-1	8	-1
-1	-1	-1

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

$$|R| > K \Leftarrow \text{point!}$$

Lines

- Spatial filter
  - One per line direction
  - Sensitive to line width

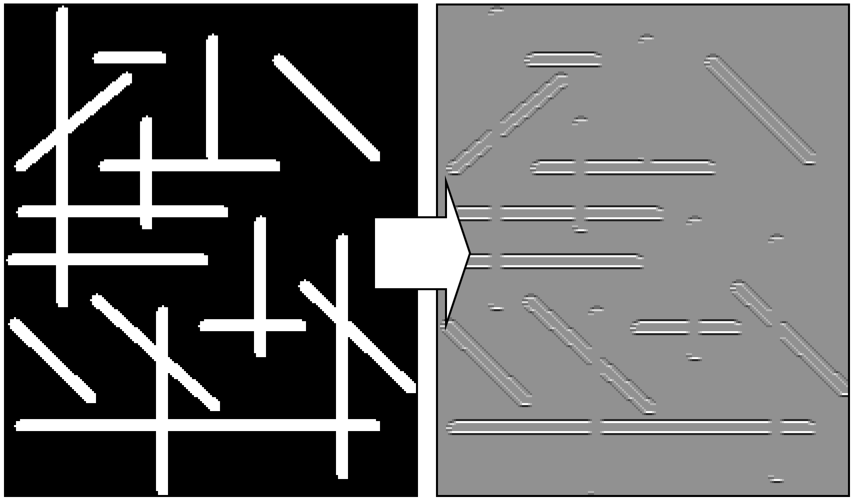
-1	-1	-1
2	2	2
-1	-1	-1

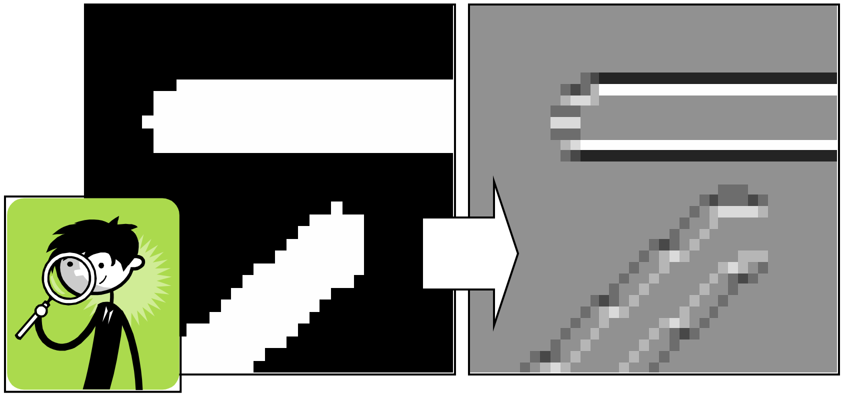
Horizontal

-1	2	-1
-1	2	-1
-1	2	-1

Vertical

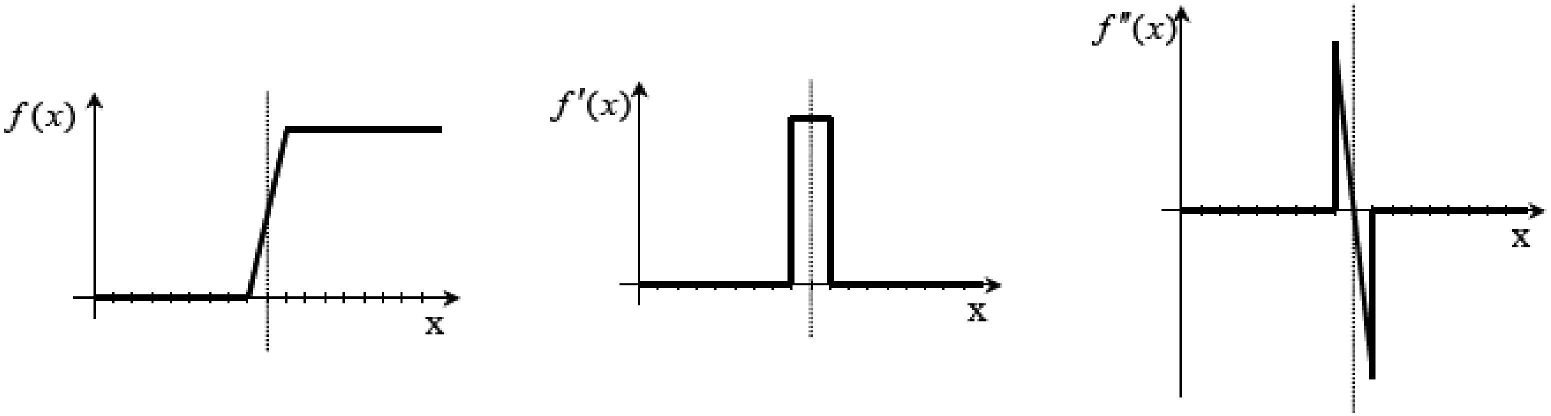
Diagonal?





Edges

- Edge:
  - Spatial discontinuity of pixel amplitude.
  - High spatial gradient
    - First derivative (*peak*)
    - Second derivative (*zero crossing*)



Popular operators

- Edge detection
  - Great utility for several problems.
  - Well studied problem.
- A variety of solutions exists.

$$G_x \rightarrow \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad G_y \rightarrow \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

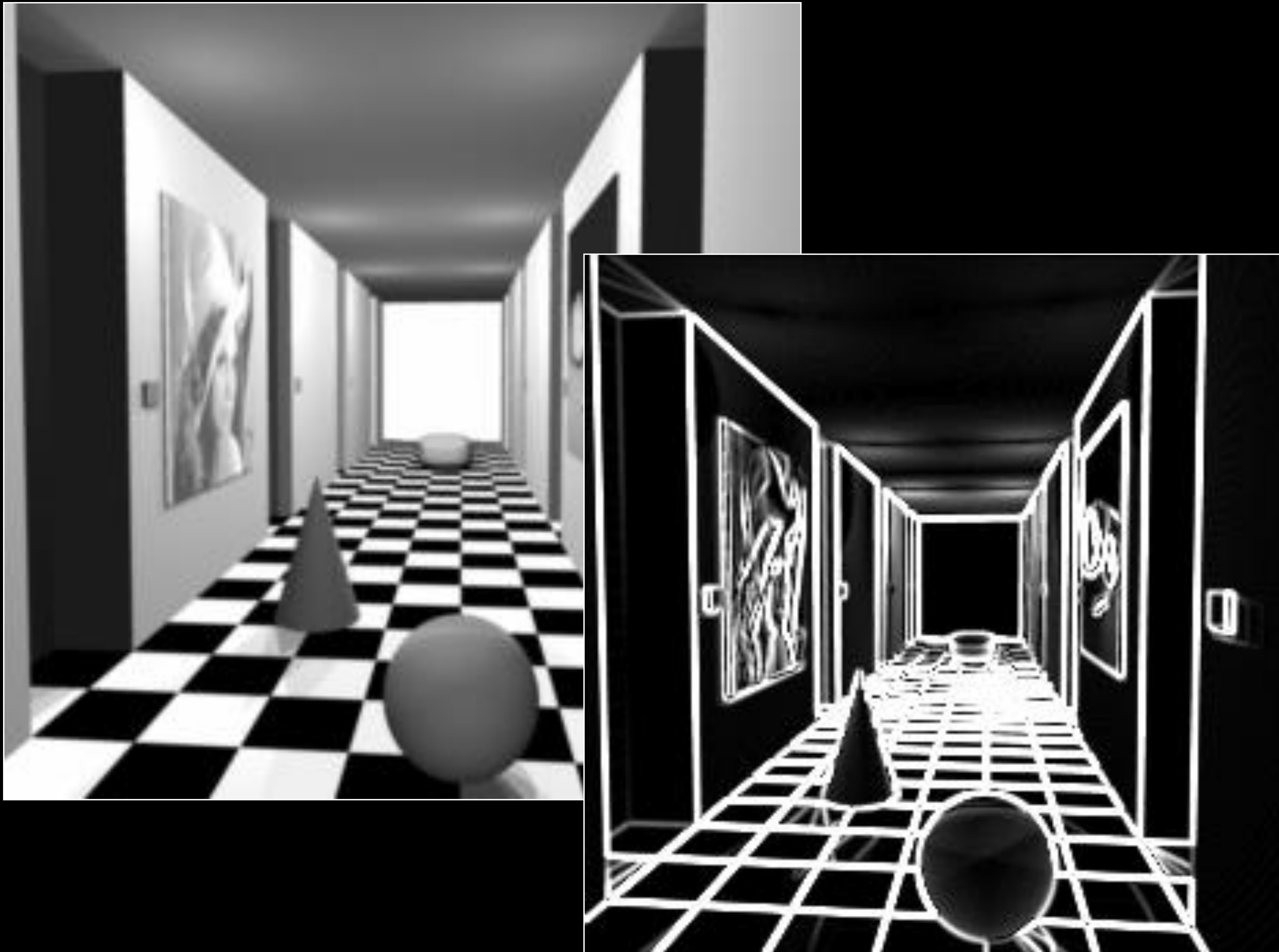
a) Sobel edge detector

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

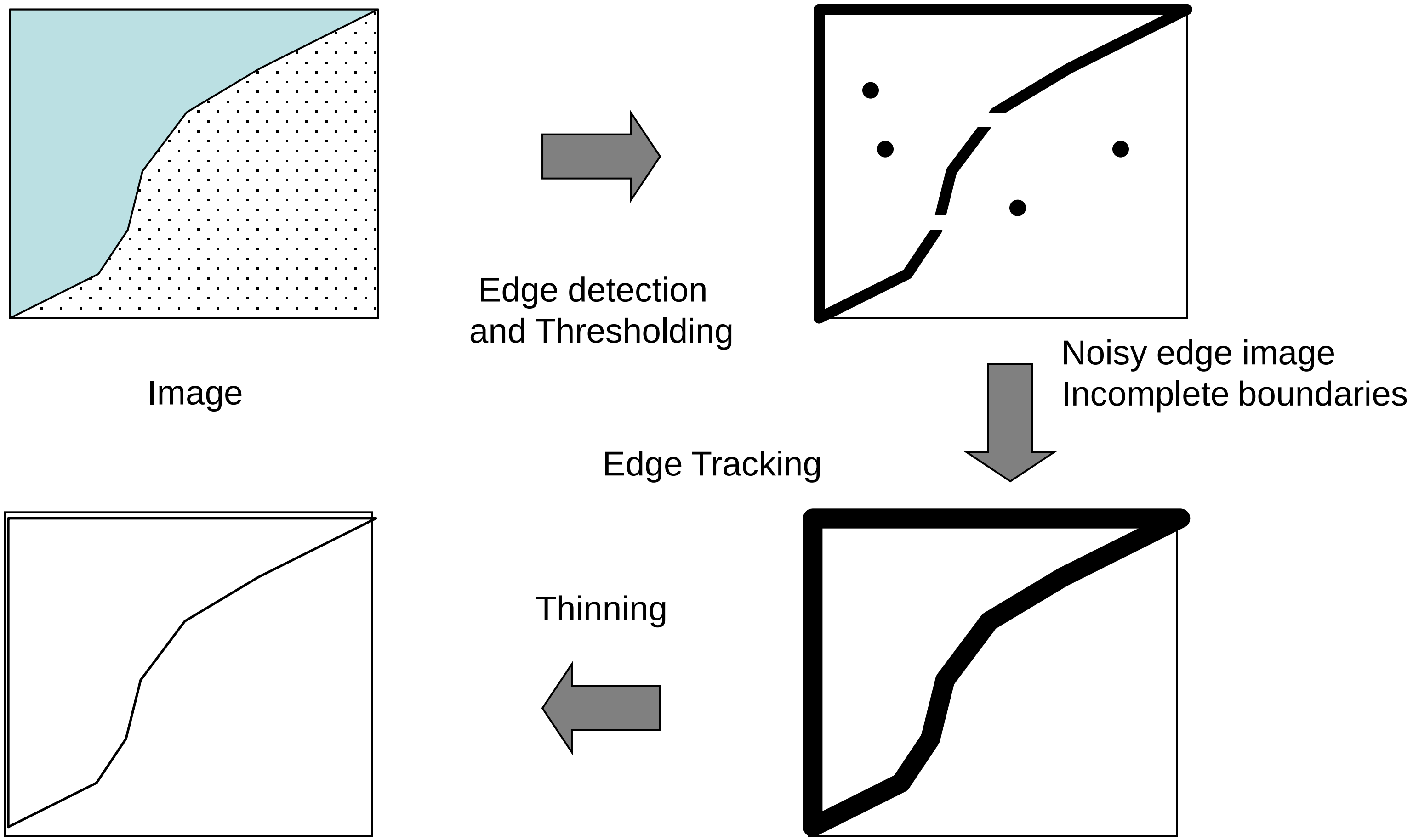
b) Prewitt edge detector

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

c) Roberts edge detector



Processing Edge Images



Edge Tracking Methods

- Adjusting a priori Boundaries

Given: Approximate Location of Boundary
Task: Find Accurate Location of Boundary

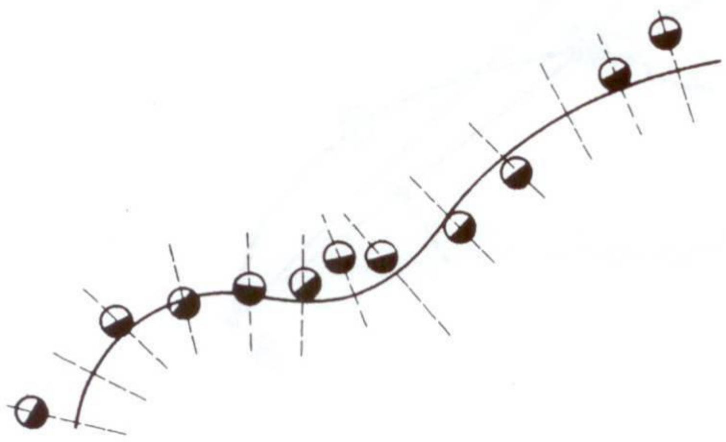


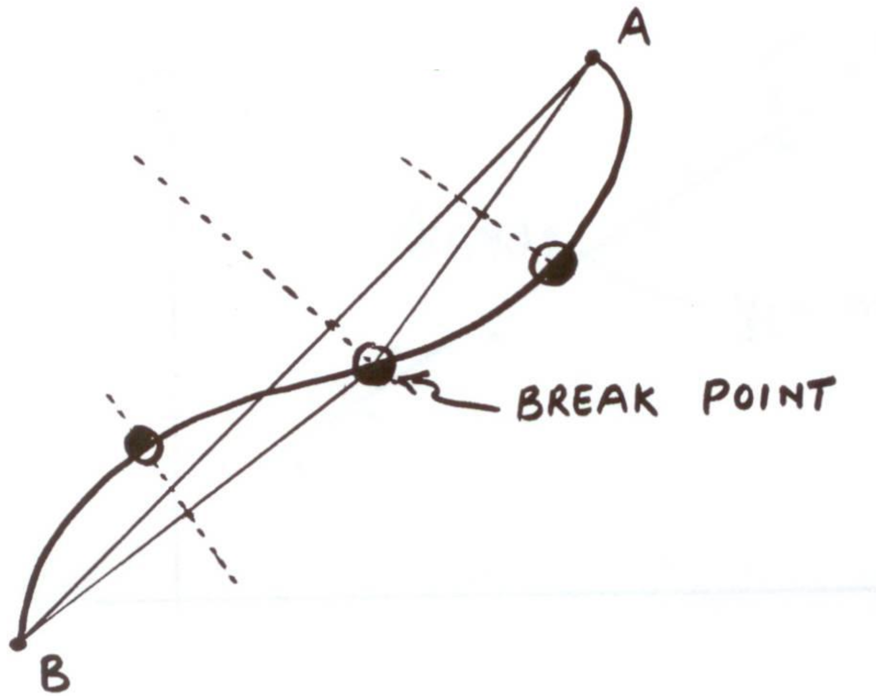
Fig. 4.2 Search orientations from an approximate boundary location.

- Search for STRONG EDGES along normals to approximate boundary.
- Fit curve (eg., polynomials) to strong edges.

Edge Tracking Methods

- Divide and Conquer

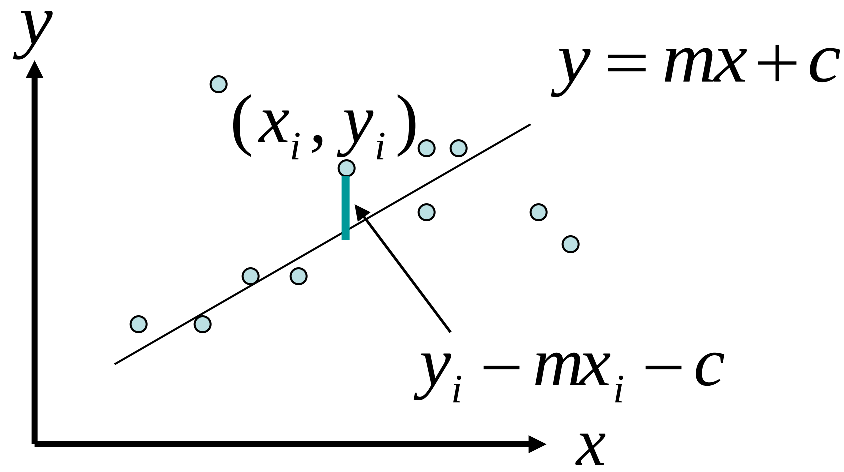
Given: Boundary lies between points A and B
Task: Find Boundary



- Connect A and B with Line
- Find strongest edge along line bisector
- Use edge point as break point
- Repeat

Fitting Lines to Edges (Least Squares)

Given: Many (x_i, y_i) pairs
Find: Parameters (m, c)



Minimize: Average square distance:

$$E = \sum_i \frac{(y_i - mx_i - c)^2}{N}$$

Using:

$$\frac{\partial E}{\partial m} = 0 \quad \& \quad \frac{\partial E}{\partial c} = 0$$

Note:

$$\bar{y} = \frac{\sum_i y_i}{N} \qquad \bar{x} = \frac{\sum_i x_i}{N}$$

$$c = \bar{y} - m\bar{x}$$

$$m = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sum_i (x_i - \bar{x})^2}$$

Topic: Hough Transform

- Thresholding
- Geometric structures
- Hough Transform

Hough Transform

- Elegant method for direct object recognition
- Edges need not be connected
- Complete object need not be visible
- Key Idea: Edges **VOTE** for the possible model

Image and Parameter Spaces

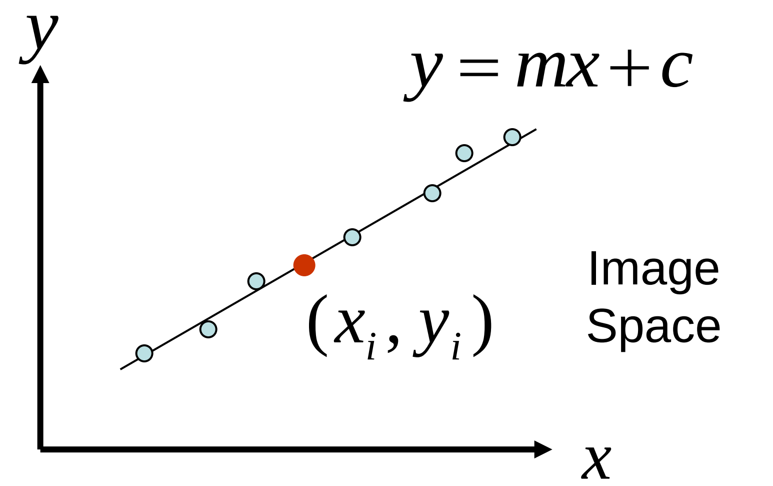
Equation of Line: $y = mx + c$

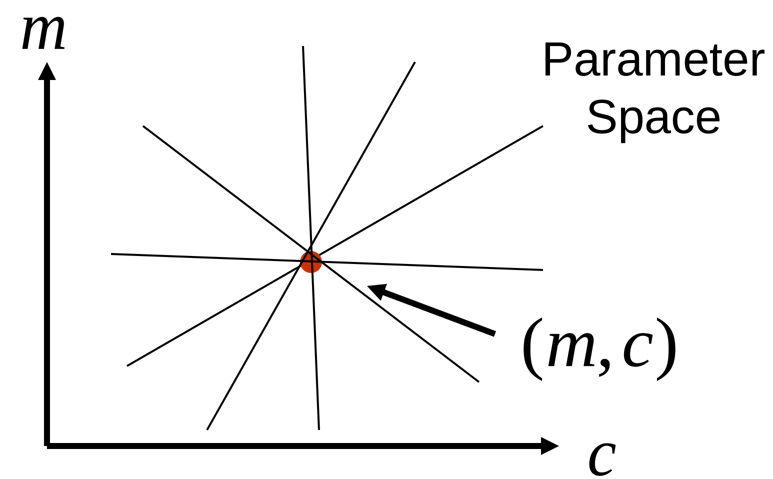
Find: (m, c)

Consider point: (x_i, y_i)

$$y_i = mx_i + c \quad or \quad c = -x_i m + y_i$$

Parameter space also called Hough Space





Line Detection by Hough Transform

Algorithm:

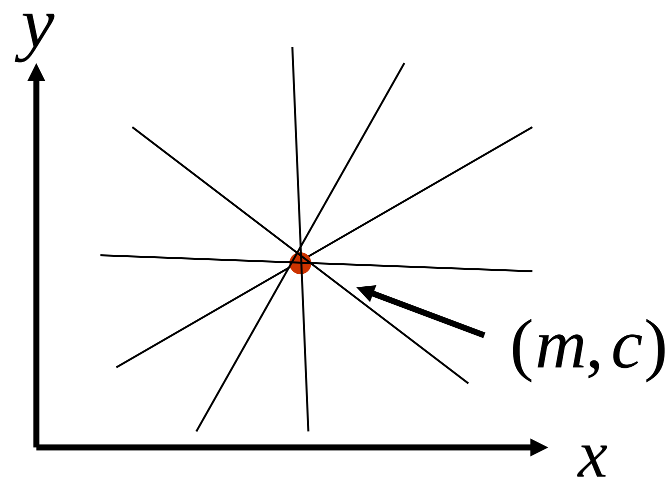
- Quantize Parameter Space (m, c)
- Create Accumulator Array $A(m, c)$
- Set $A(m, c) = 0 \quad \forall m, c$
- For each image edge (x_i, y_i) increment:

$$A(m, c) = A(m, c) + 1$$

- If (m, c) lies on the line:

$$c = -x_i m + y_i$$

- Find local maxima in $A(m, c)$



Parameter Space

$A(m, c)$

	1						1		
		1				1			
			1		1				
				2					
			1		1				
		1				1			
	1						1		

Better Parameterization

NOTE: $-\infty \leq m \leq \infty$

Large Accumulator

More memory and computations

Improvement: (Finite Accumulator Array Size)

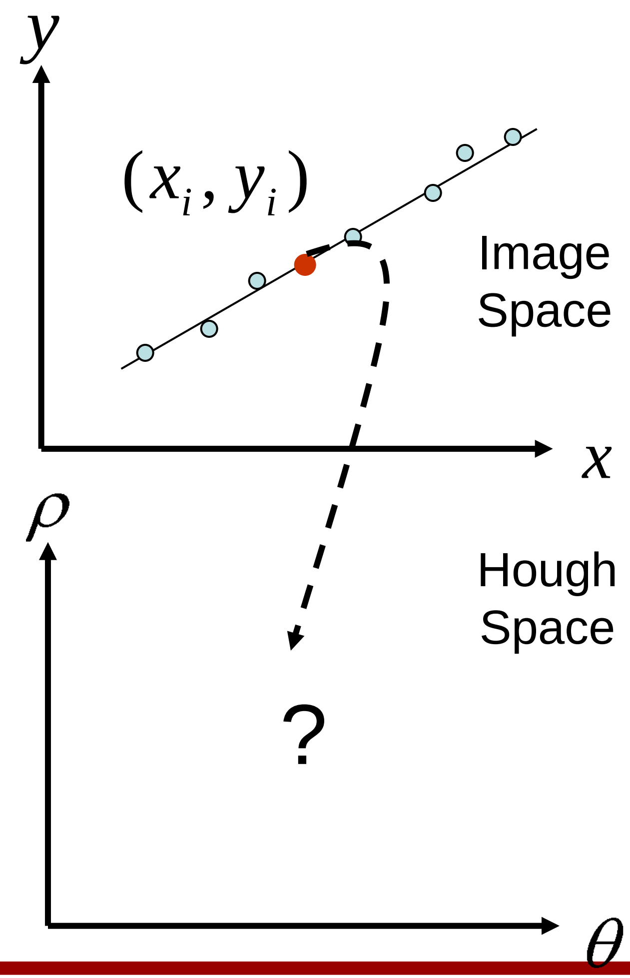
Line equation: $\rho = -x\cos\theta + y\sin\theta$

Here $0 \leq \theta \leq 2\pi$

$0 \leq \rho \leq \rho_{\max}$

Given points (x_i, y_i) find (ρ, θ)

Hough Space Sinusoid



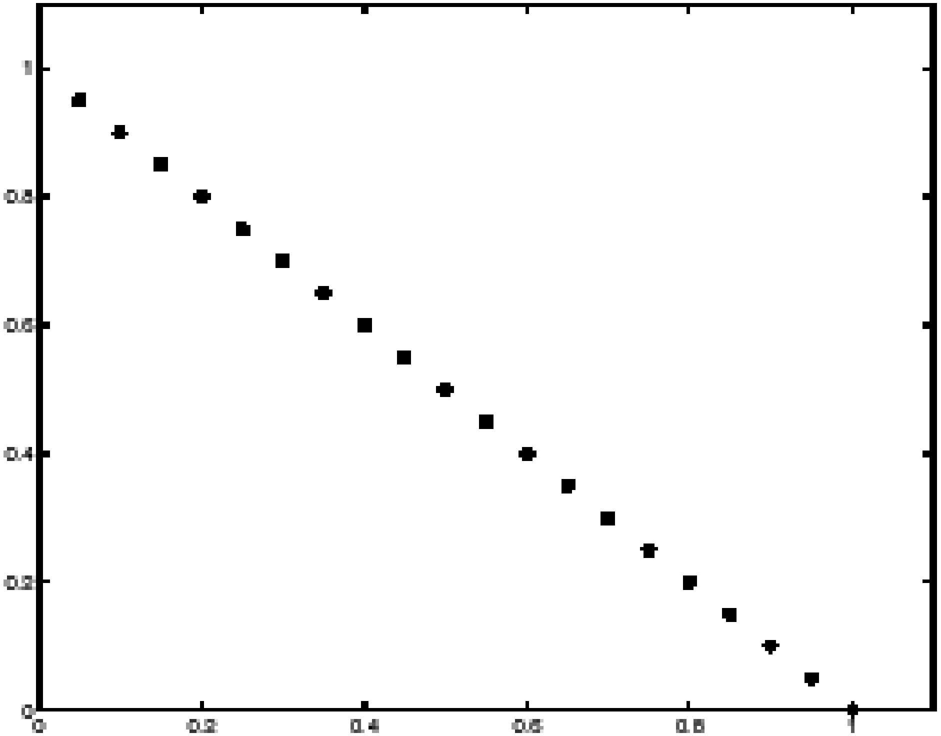
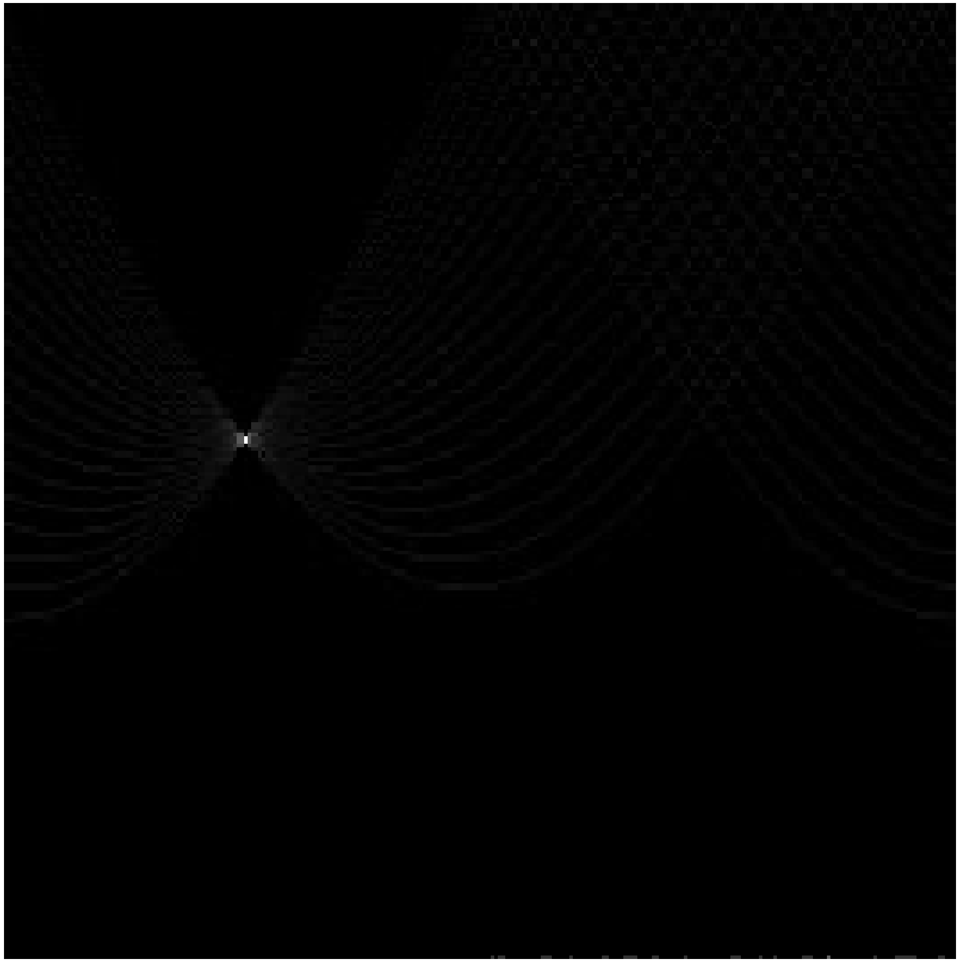
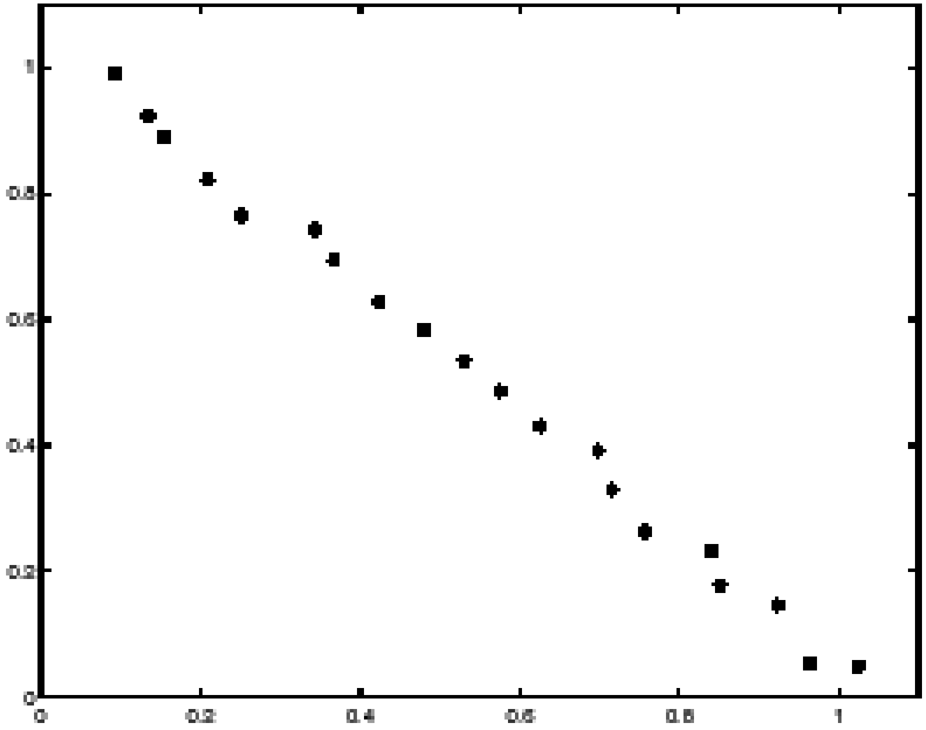


Image space

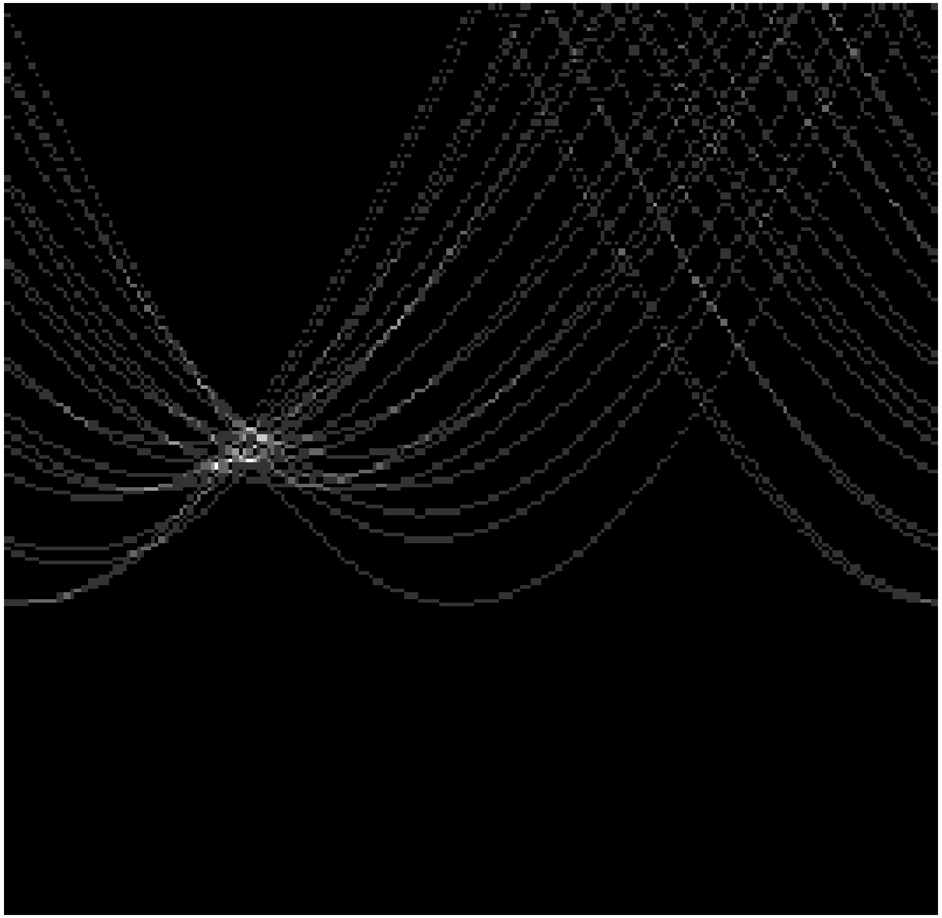


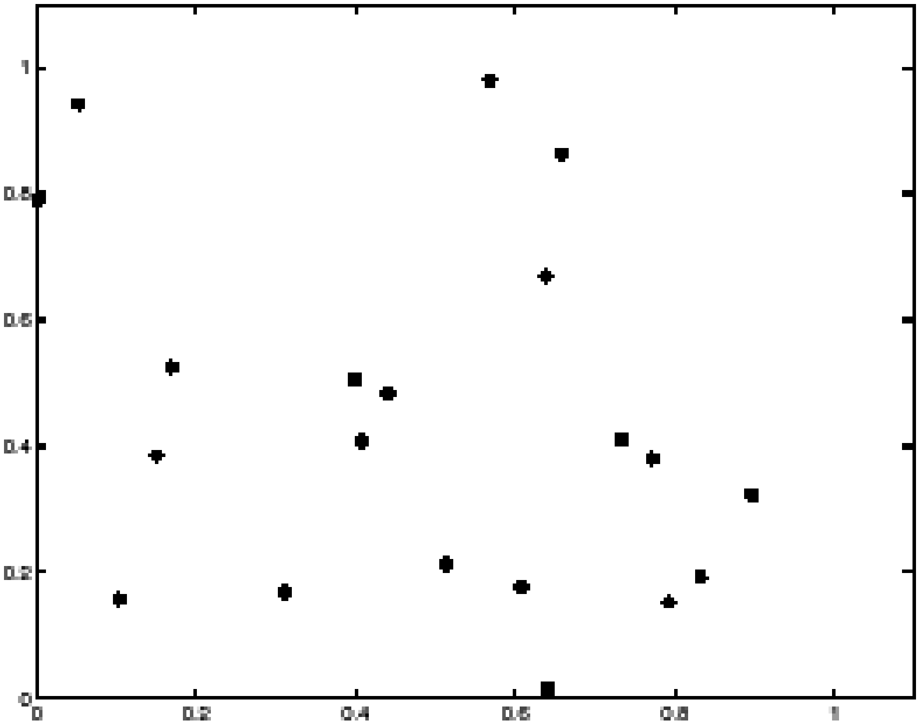
Votes

Horizontal axis is θ, vertical is rho.

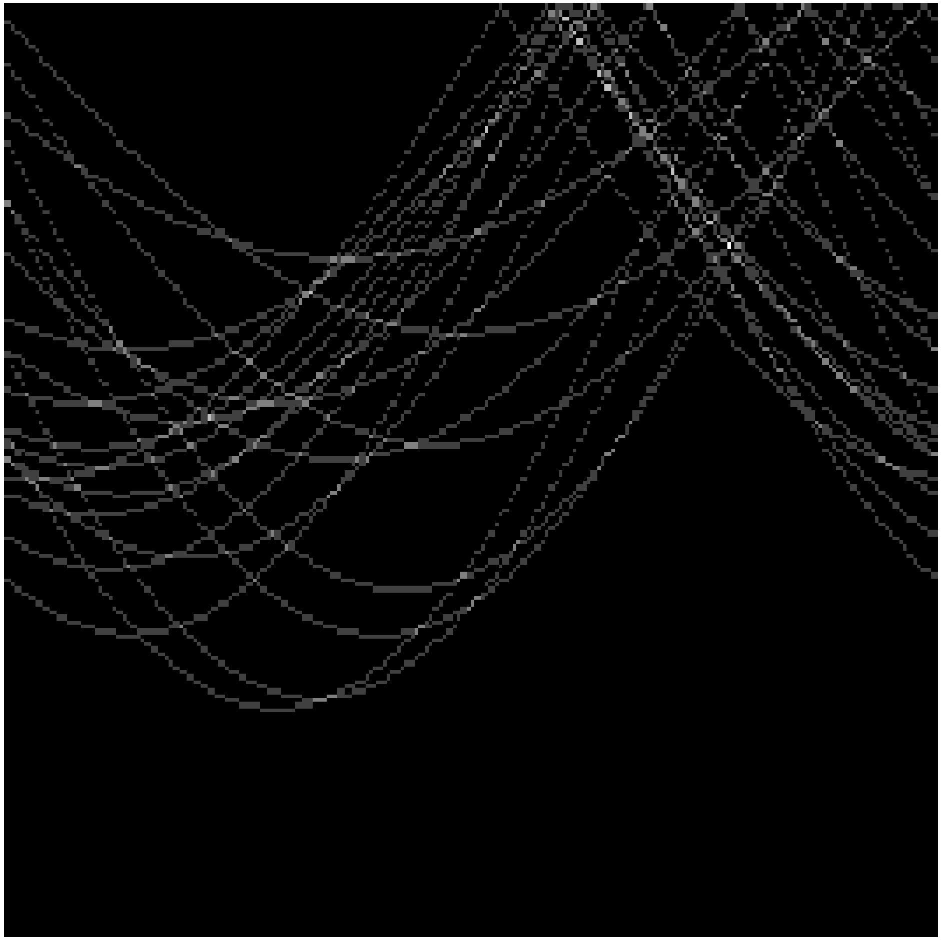


1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1



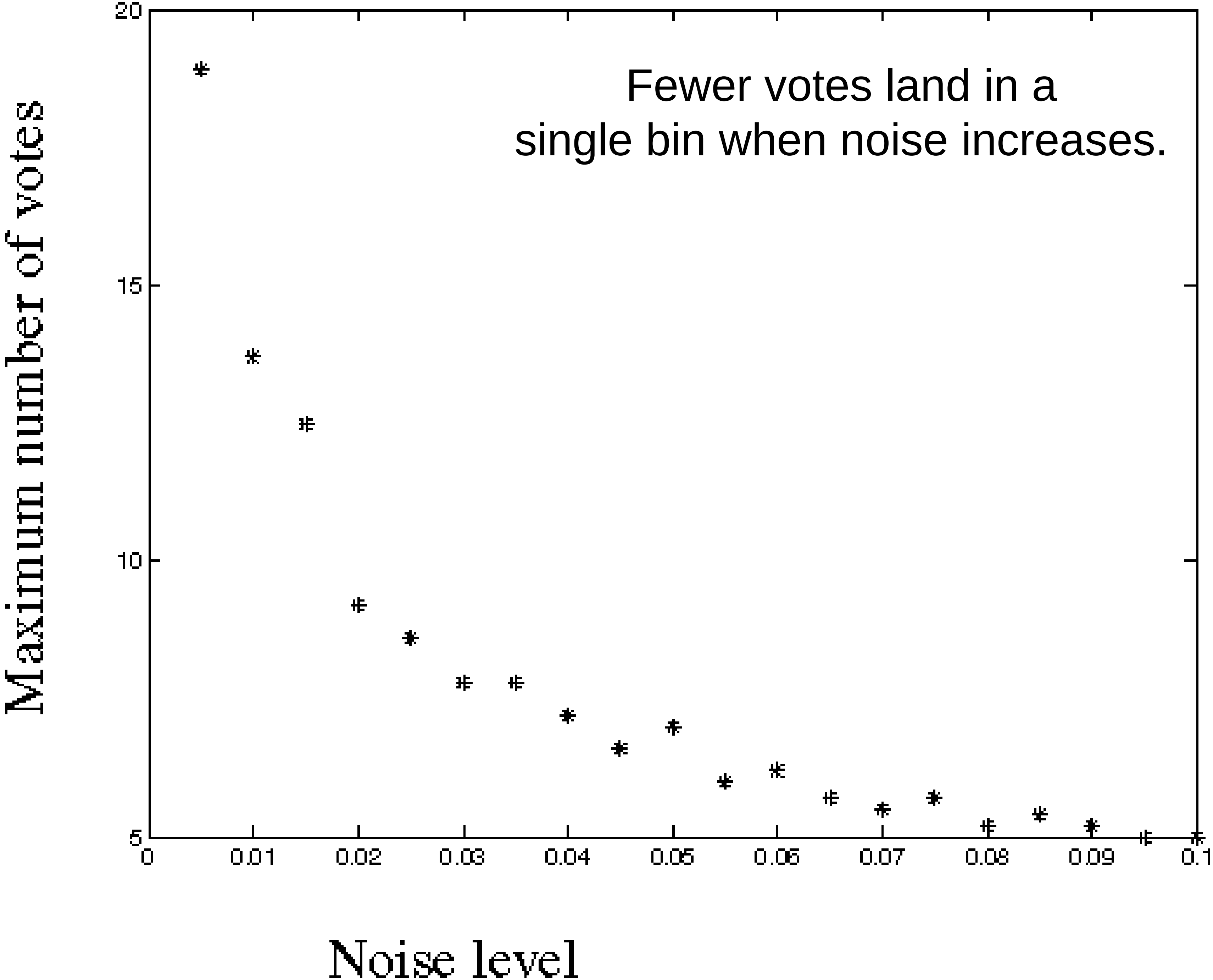


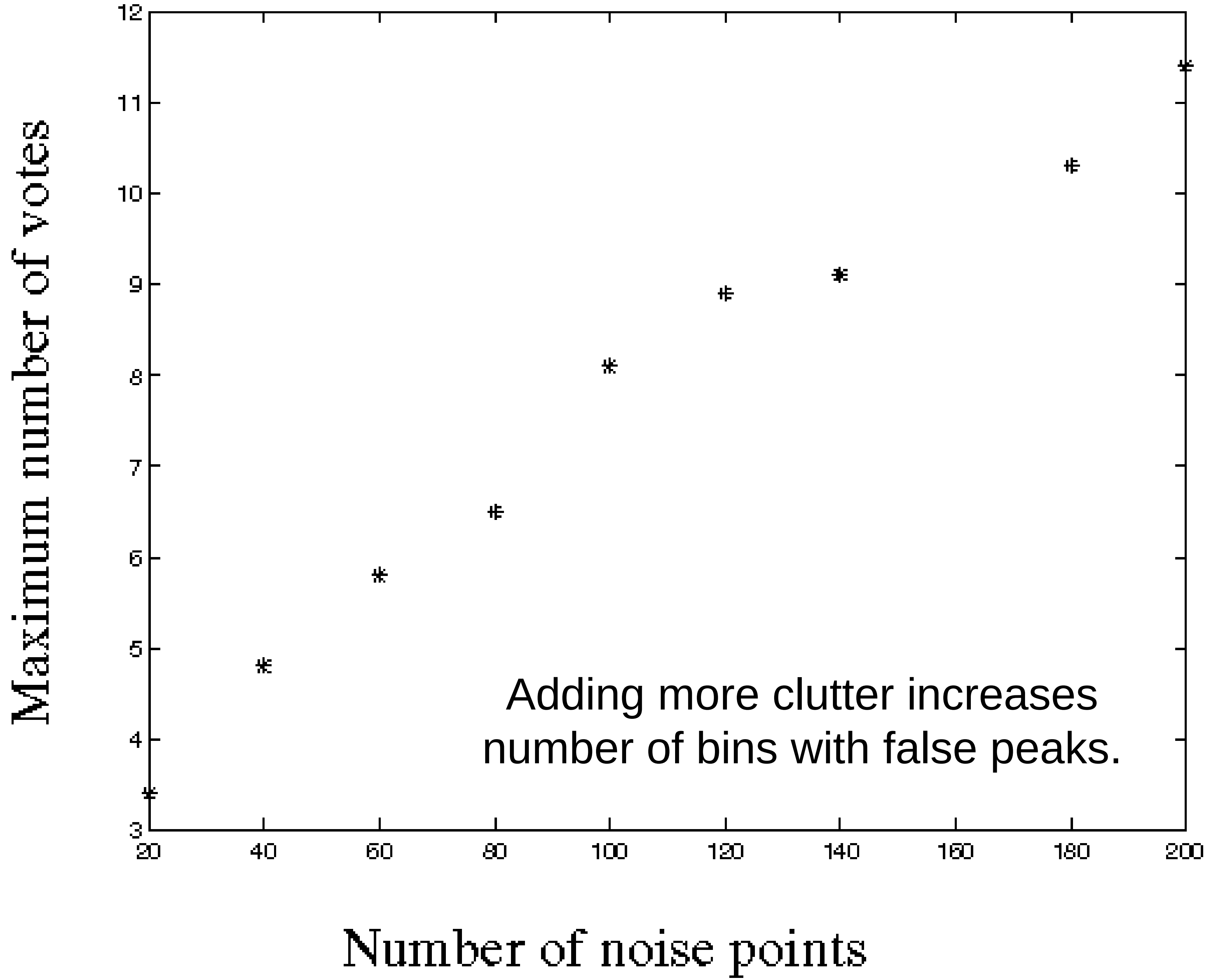
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1



Mechanics of the Hough Transform

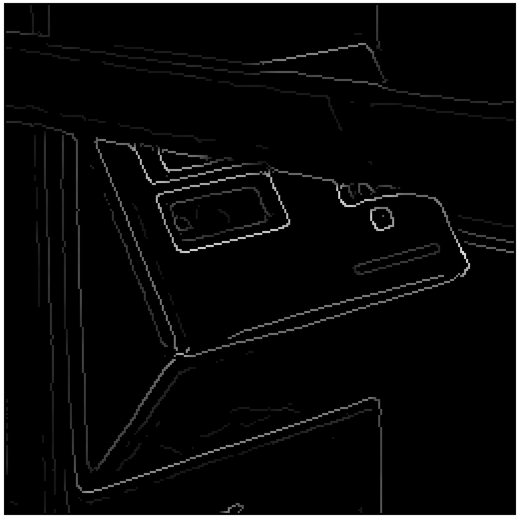
- Difficulties
  - how big should the cells be? (too big, and we merge quite different lines; too small, and noise causes lines to be missed)
- How many lines?
  - Count the peaks in the Hough array
  - Treat adjacent peaks as a single peak
- Which points belong to each line?
  - Search for points close to the line
  - Solve again for line and iterate


Fewer votes land in a
single bin when noise increases.
Maximum number of votes
Noise level
20
15
10
5
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

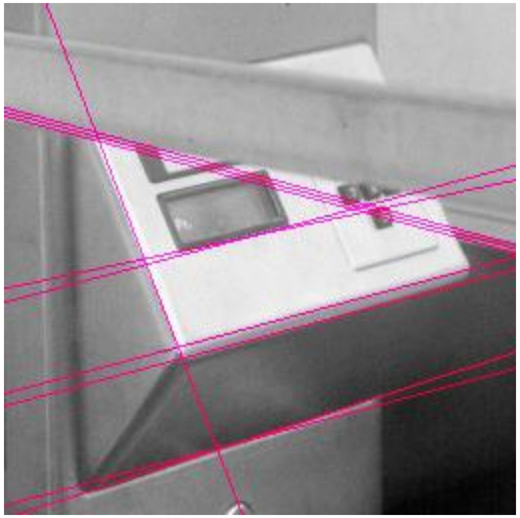

Maximum number of votes
12
11
10
9
8
7
6
5
4
3
20
40
60
80
100
120
140
160
180
200
Adding more clutter increases
number of bins with false peaks.
Number of noise points

Real World Example

Original



Edge Detection

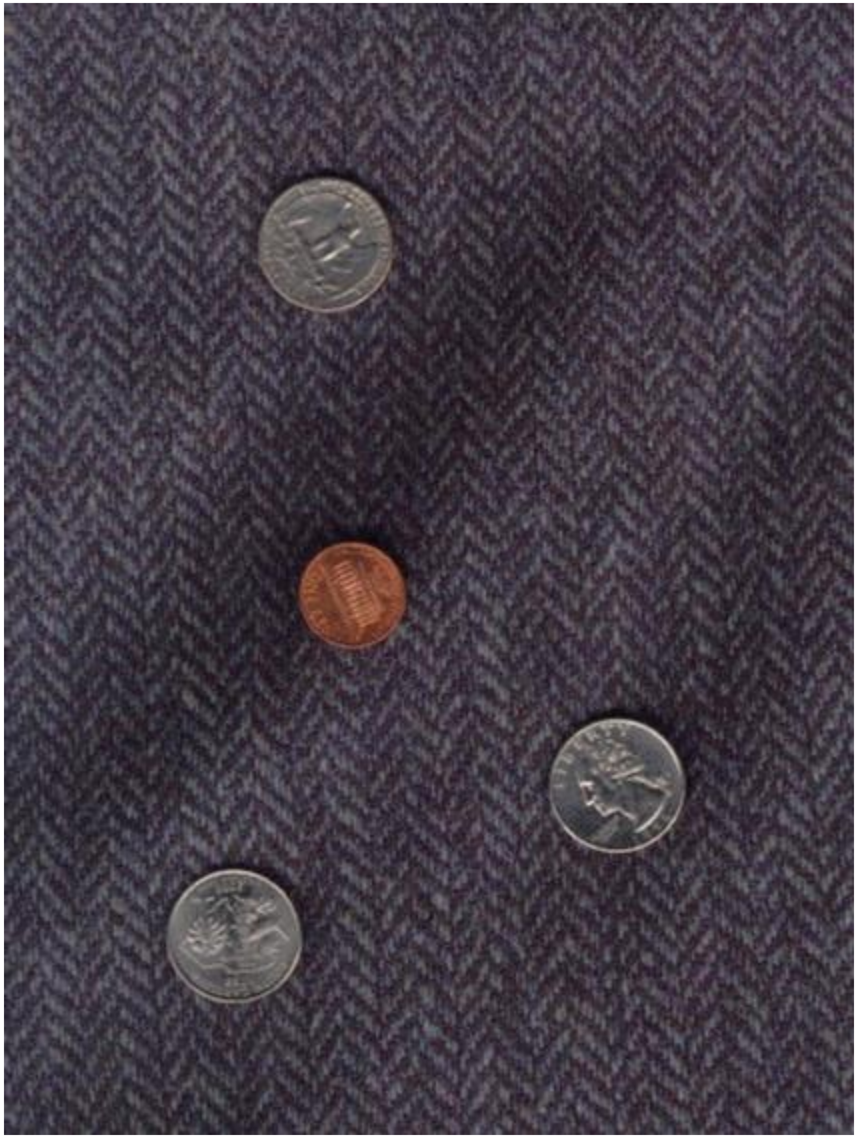


Found Lines

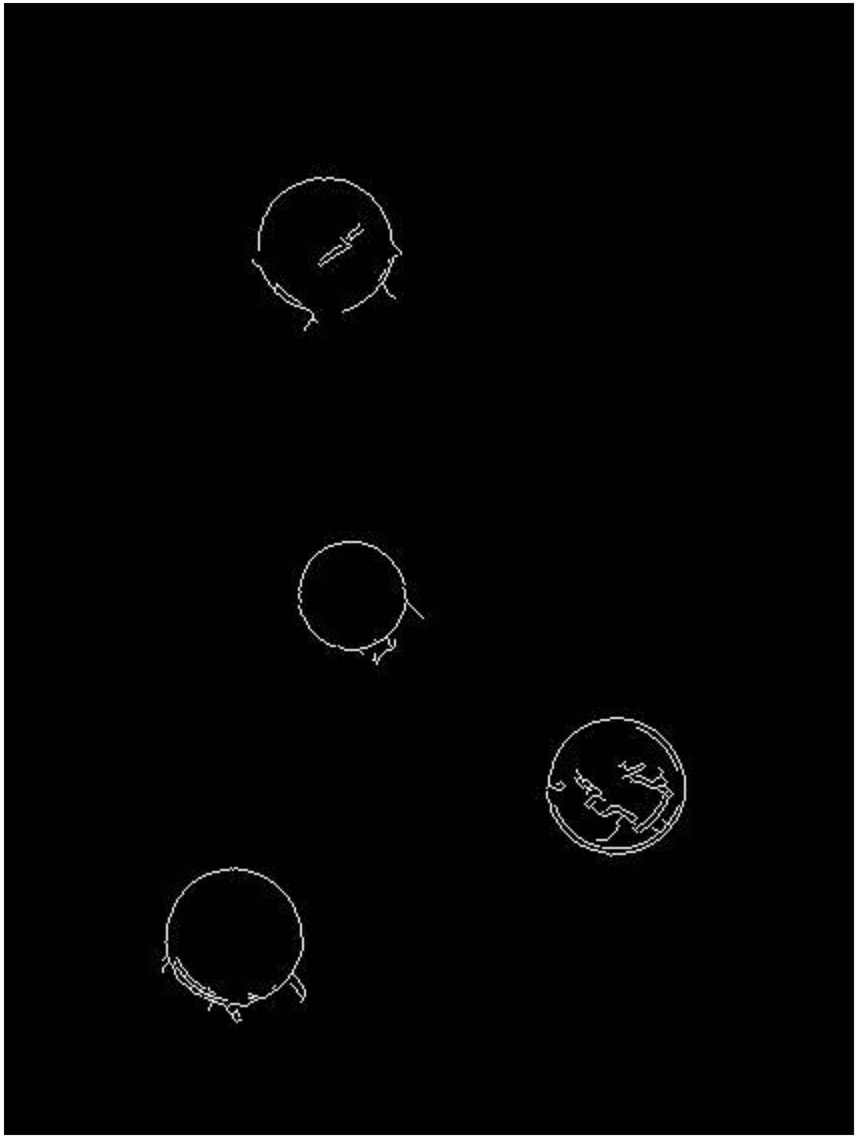
Parameter Space

Other shapes

Original



Edges when using circle model



Resources

- Gonzalez & Woods – Chapter 7
- Russ – Chapter 7
- N. Otsu, “A threshold selection method from gray-level histograms,” IEEE Trans. Sys., Man., Cyber., vol. 9, pp. 62–66, 1979.