Hough Transform

COMP 41012A

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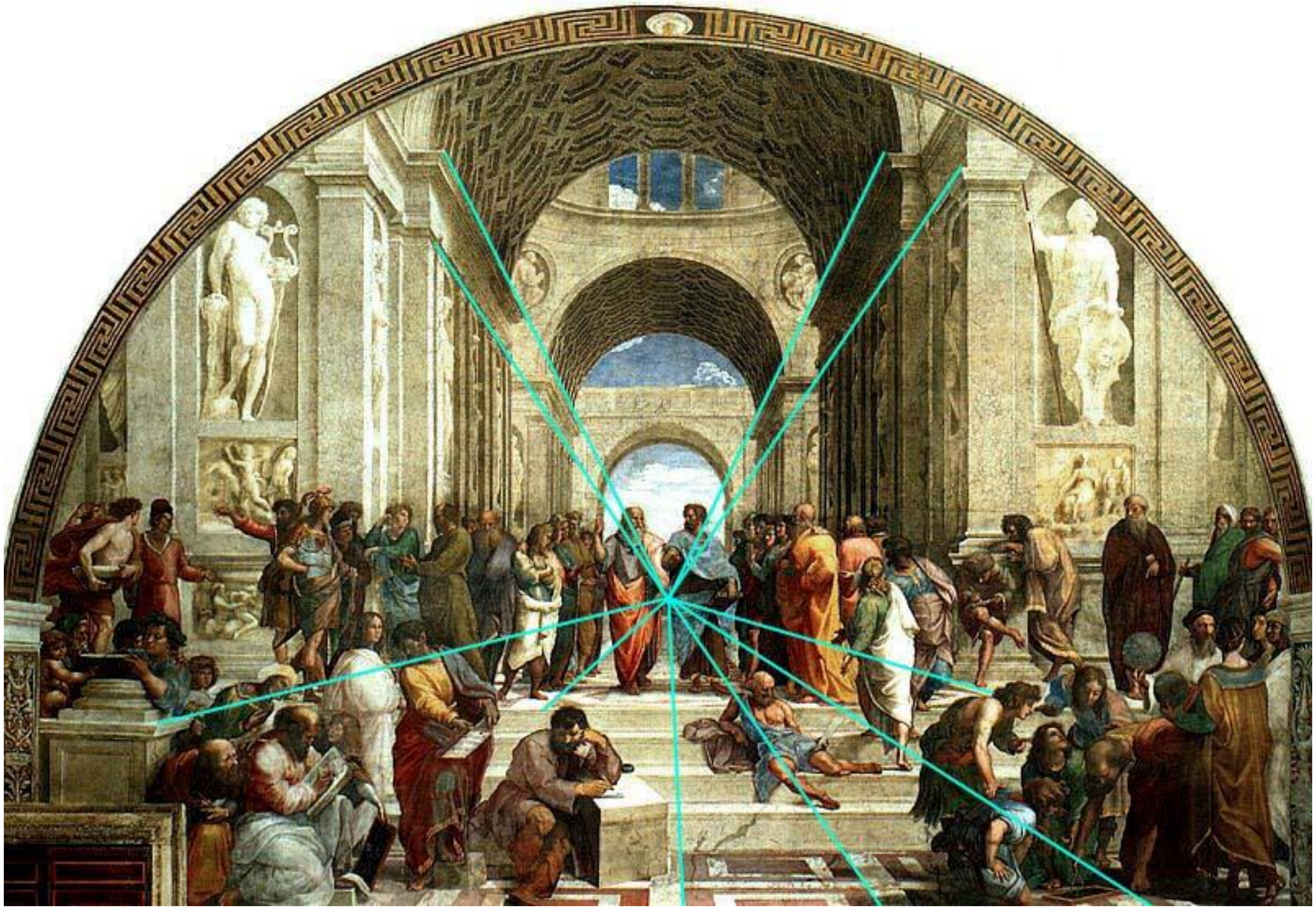
Winter 2015

Version 2

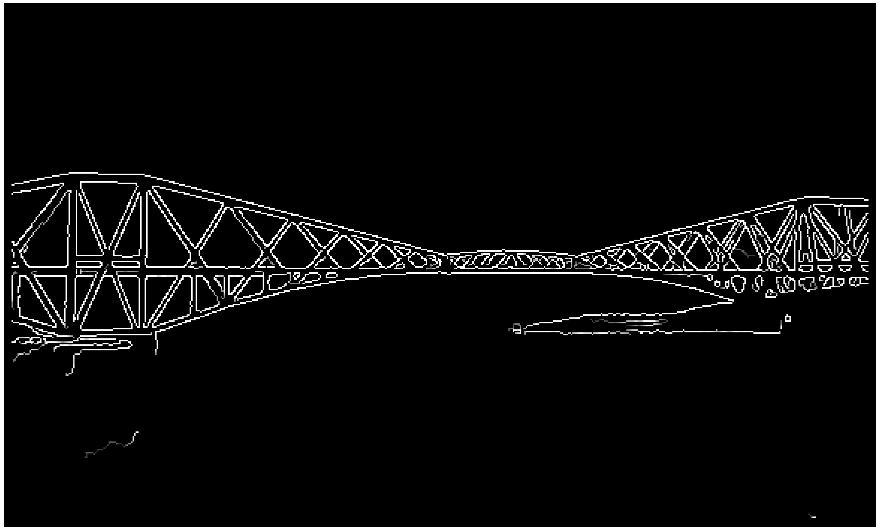
Lines

Lines



Rafael, The School of Athens (1518)

Line Detection



The problem:

- How many lines?
- Find the lines.

Equations for Lines

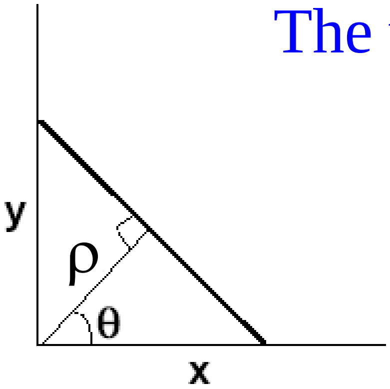
The slope-intercept equation of line

$$y = mx + b$$

What happens when the line is vertical? The slope *a* goes to infinity.

A better representation – the polar representation

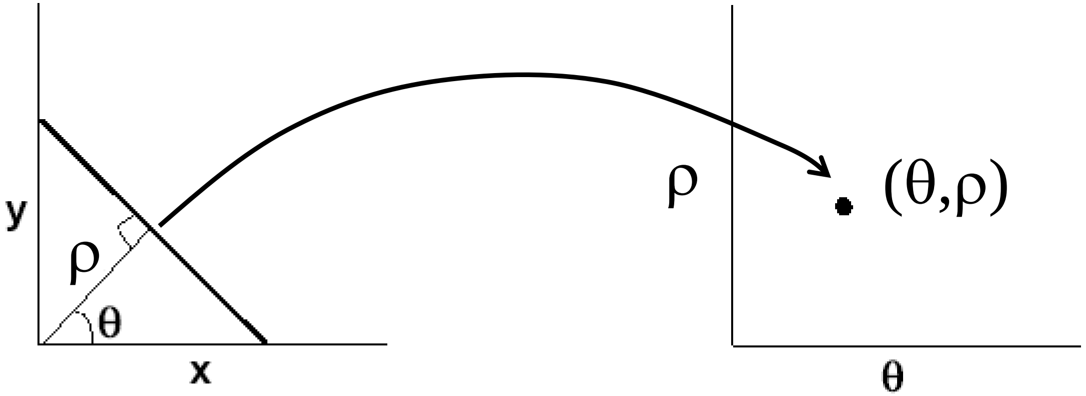
The two parameters ρ, θ defining line are bounded



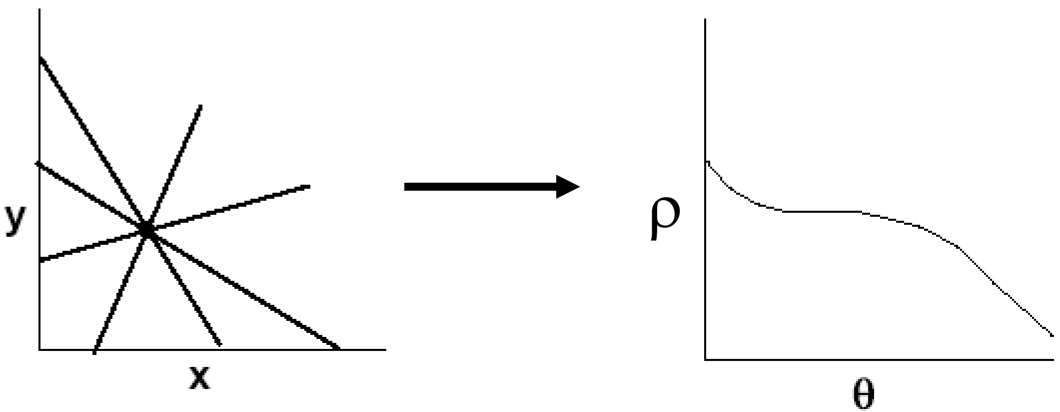
$$\rho = x\cos\theta + y\sin\theta$$

Hough Transform: line-parameter mapping

A line in the plane maps to a point in the θ-ρ space.

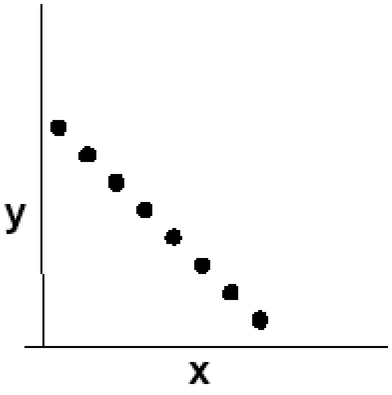


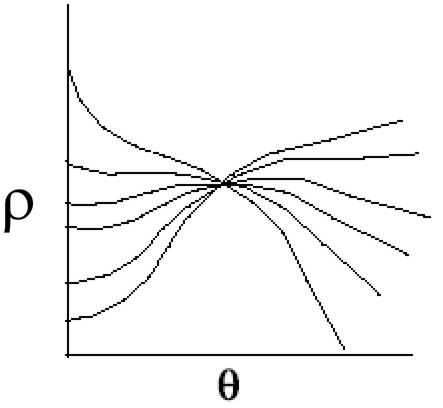
All lines passing through a point map to a sinusoidal curve in the θ-ρ (parameter) space.



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

Mapping of points on a line



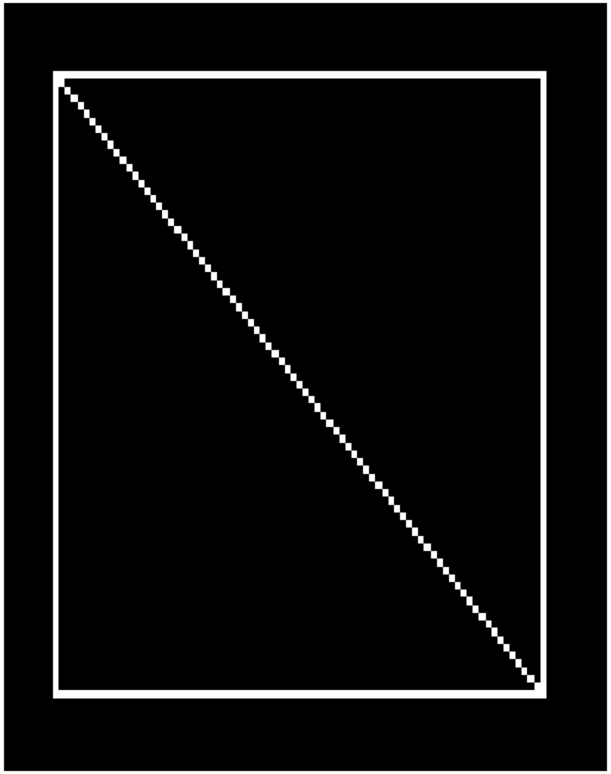


Points on the same line define curves in the parameter space that pass through a single point.

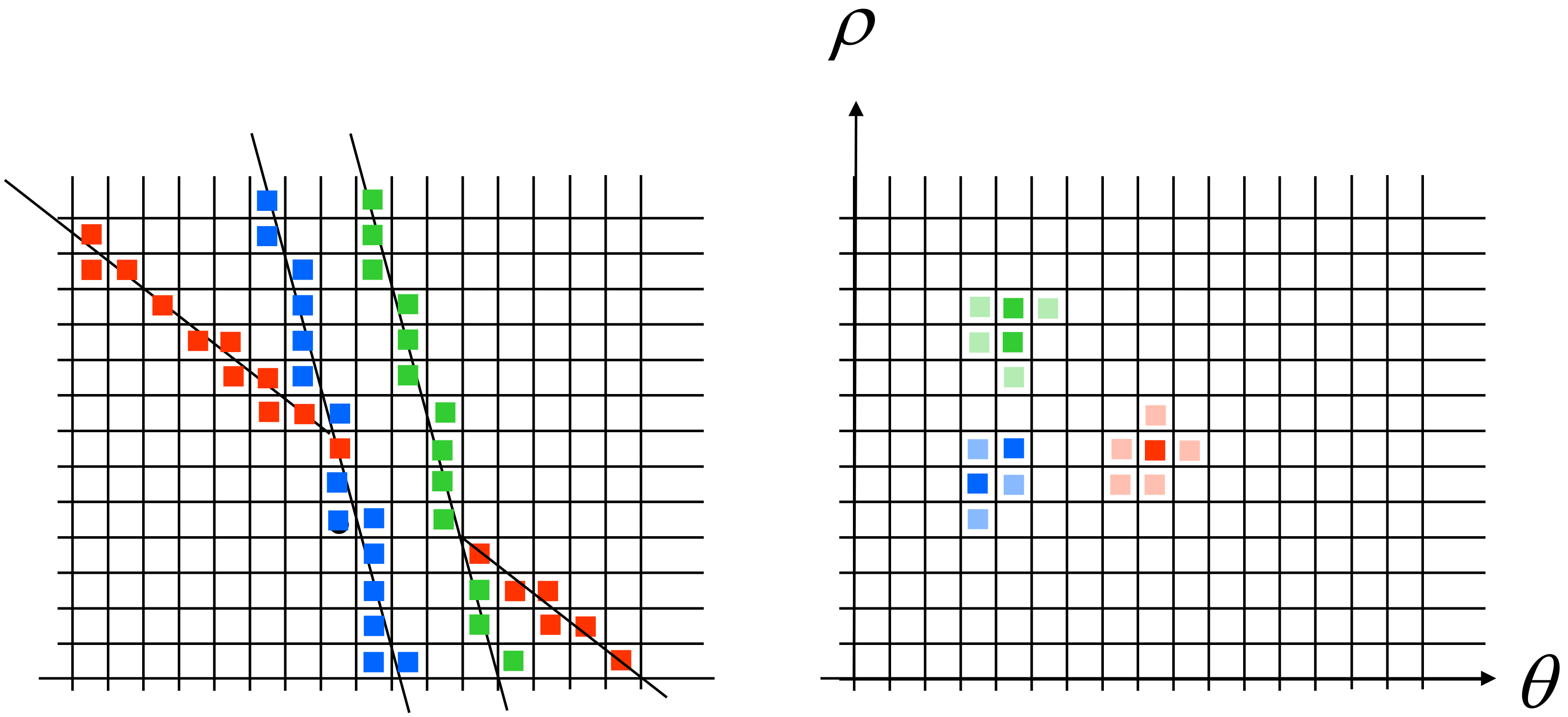
Main idea: transform edge points in *x*-*y* plane to curves in the parameter space. Then find the points in the parameter space that has many curves passing through it.

Hough Idea

- Each straight line in this image can be described by an equation
- Each white point if considered in isolation could lie on an infinite number of straight lines
- **In the Hough transform each point votes for every line it could be on**
- The lines with the most votes win

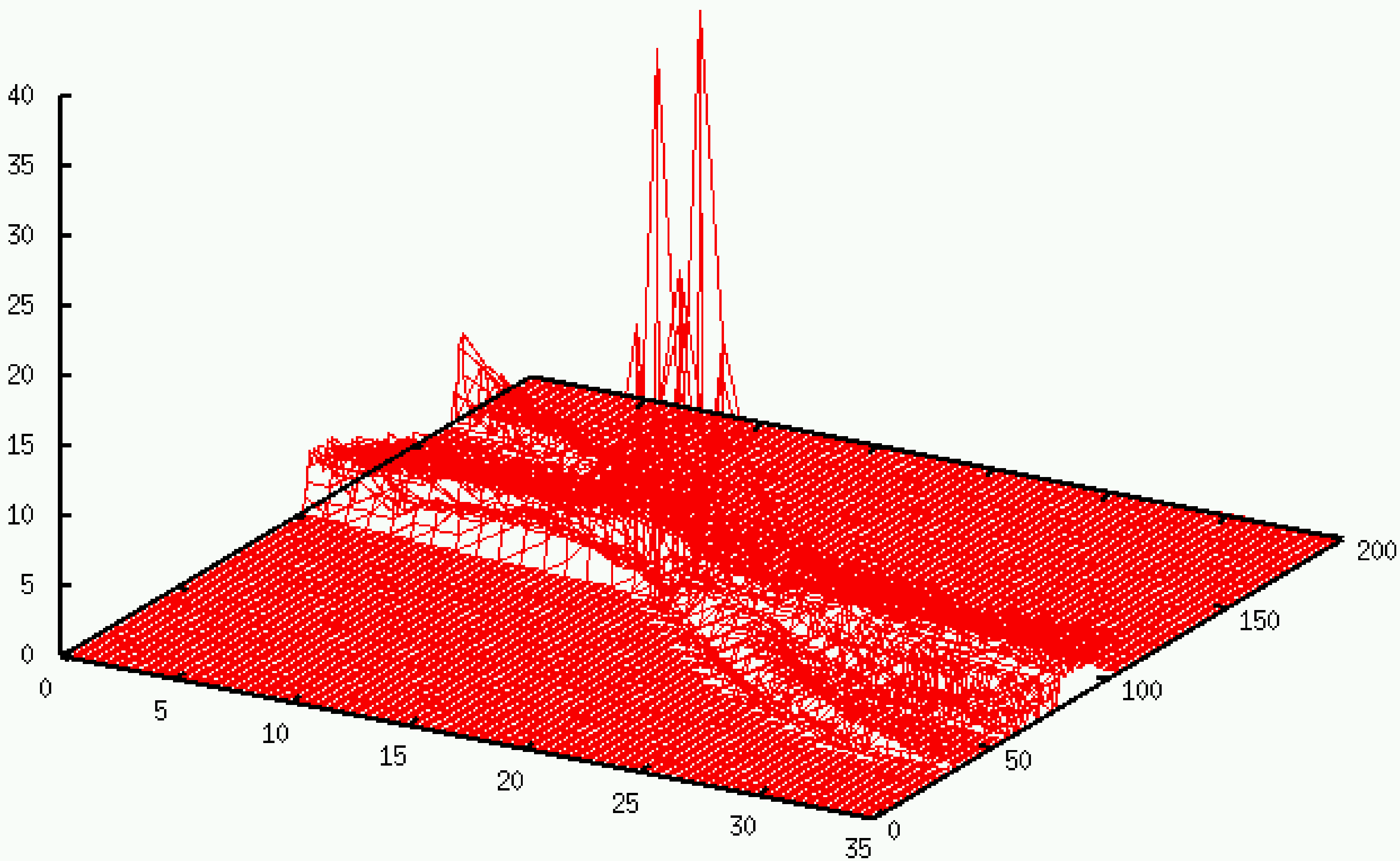


Quantize Parameter Space

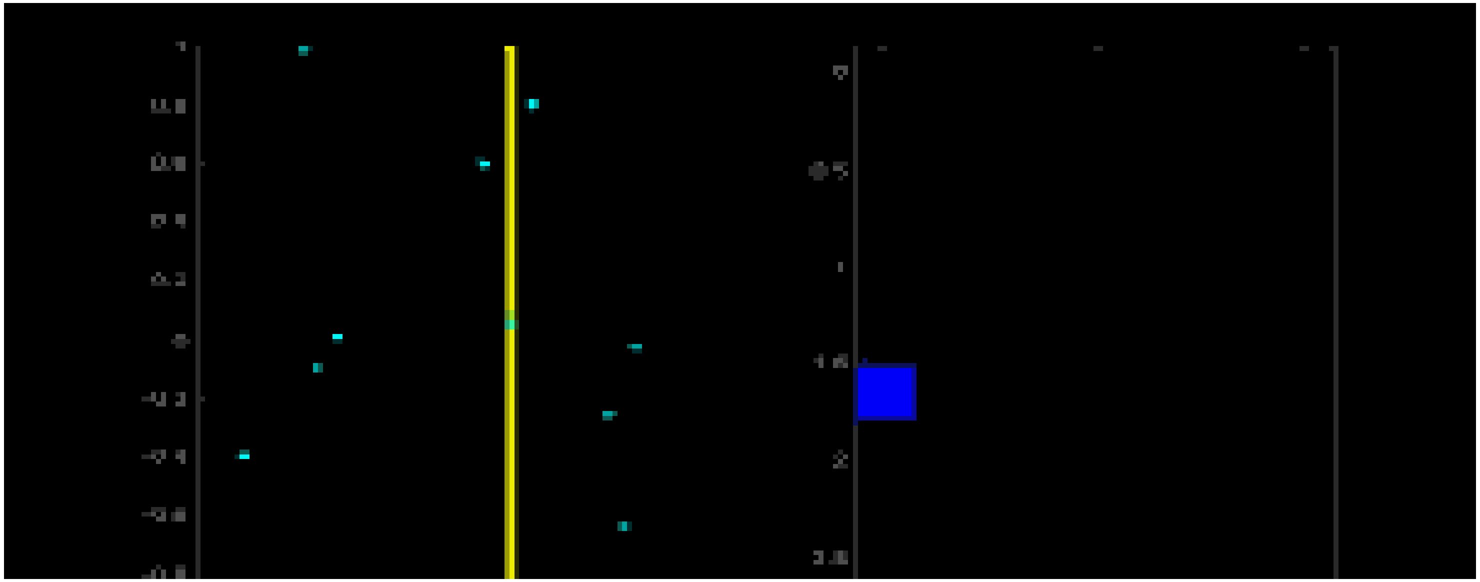


Detecting Lines by finding maxima / clustering in parameter space.

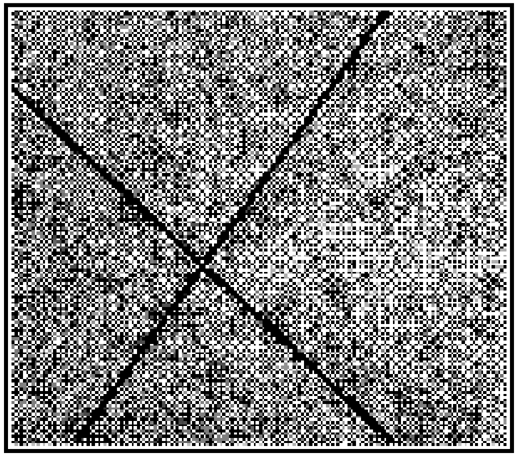
Parameter space – 3D view



A Voting Scheme



Hough Processing



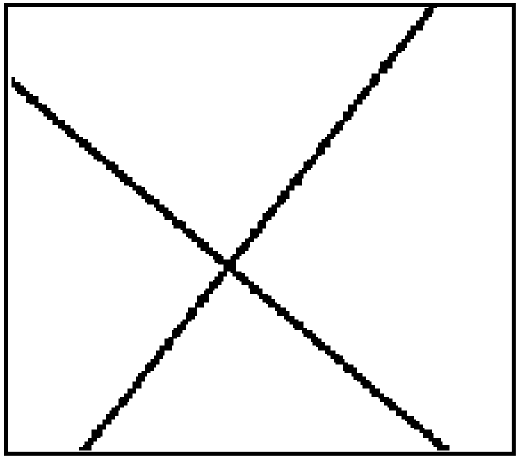
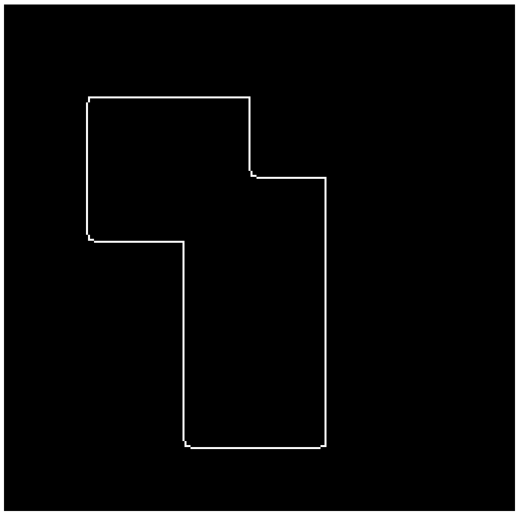


Image **Edge detection** **Hough Transform**

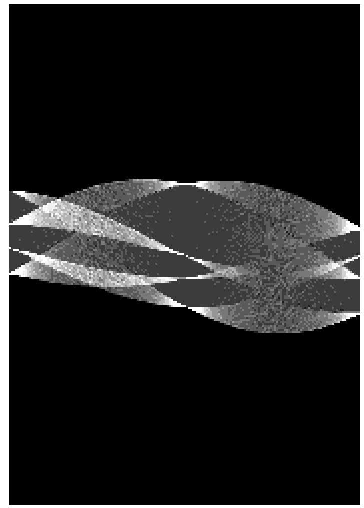
- Find the edges in the image (Canny operator common)
- Use each edge point to vote in the accumulator space
  - Accumulator space also called the Hough Space
- Find the peak(s) in the accumulator space

Examples

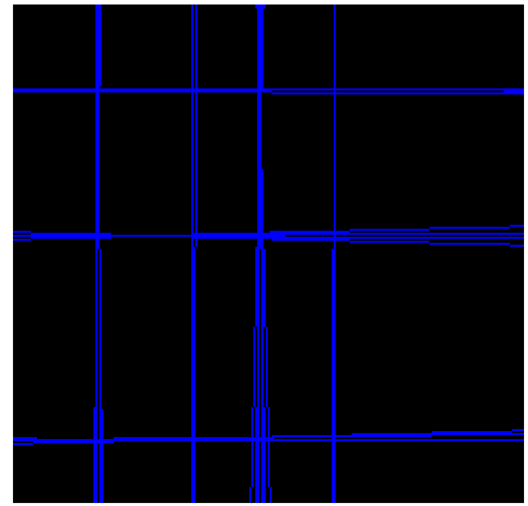
input image

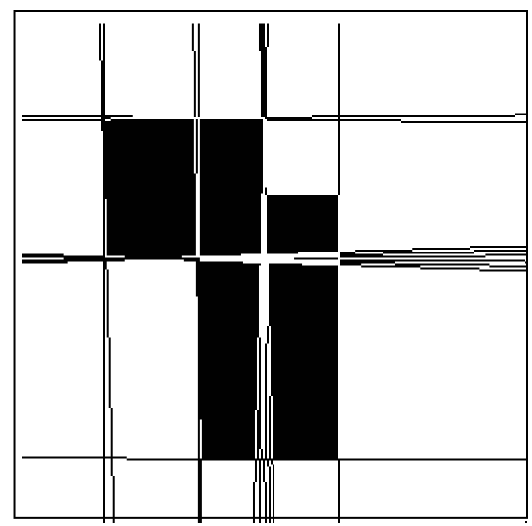


Hough space



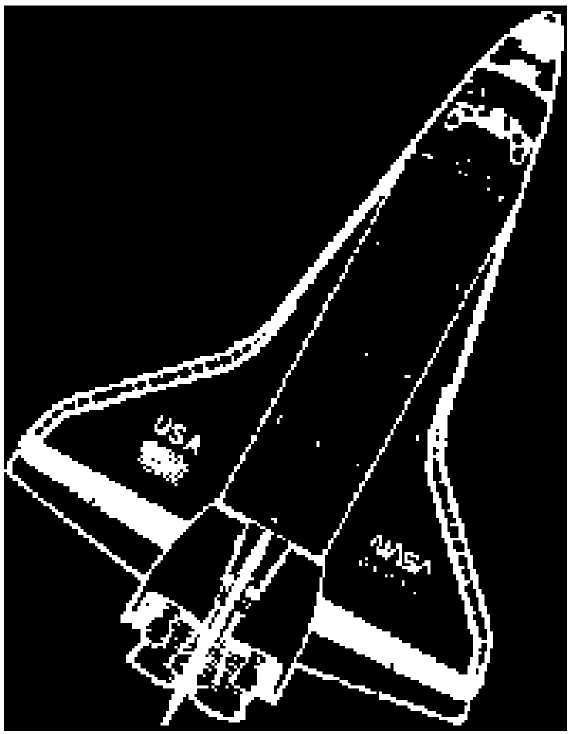
lines detected



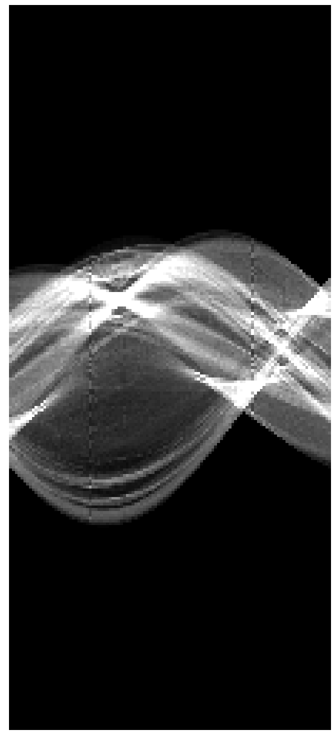


Examples

input image



Hough space



lines detected

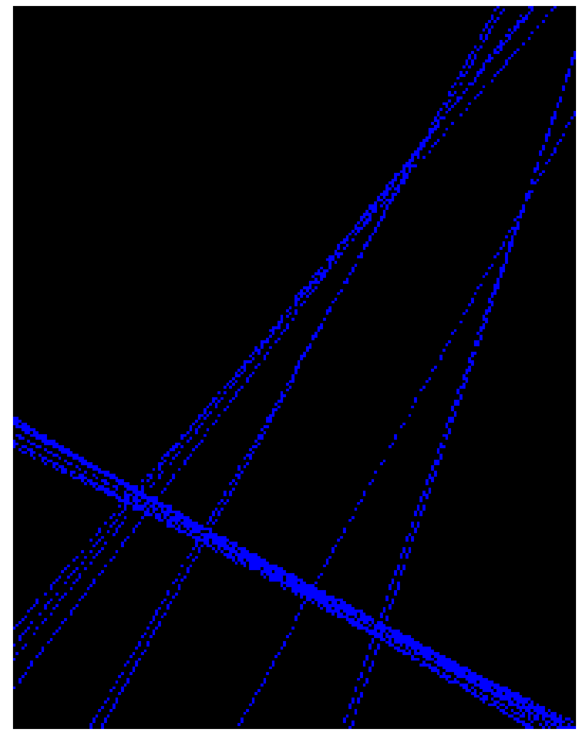
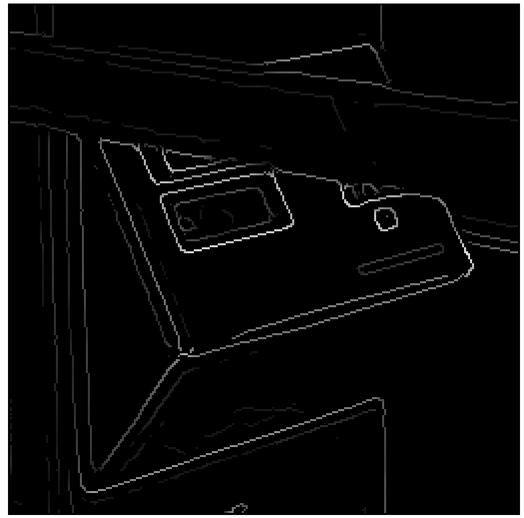


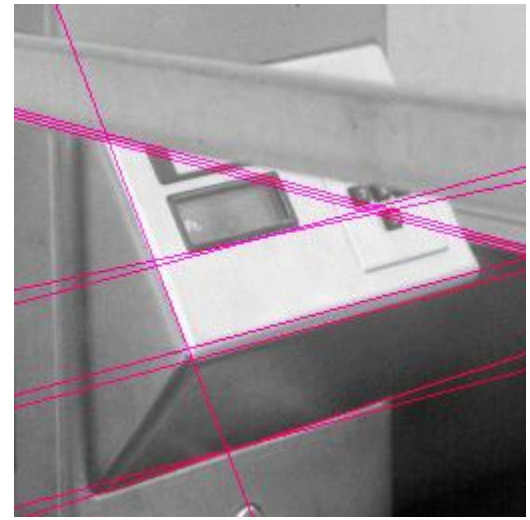
Image credit: NASA Dryden Research Aircraft Photo Archive

Examples – look at video

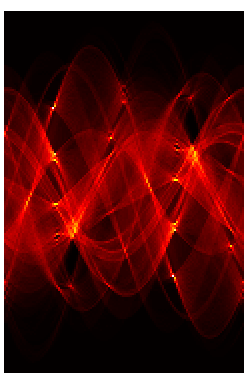
Original



Edge Detection



Found Lines



Parameter Space

Video showing Hough https://www.youtube.com/watch?v=ebfi7qOFLuo

Algorithm

1. Quantize the parameter space

   int P[0, ρ_{max}][0, θ_{max}]; // accumulators

2. For each edge point (x, y) {

   For (θ = 0; θ <= θ_{max}; θ = θ+$\Delta\theta$) {

   $\rho = x\cos\theta + y\sin\theta$ // round off to integer

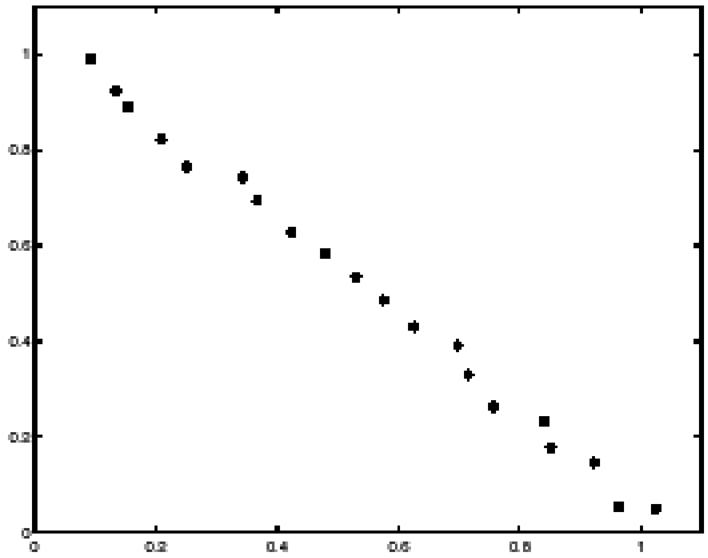
   (P[ρ][θ])++;

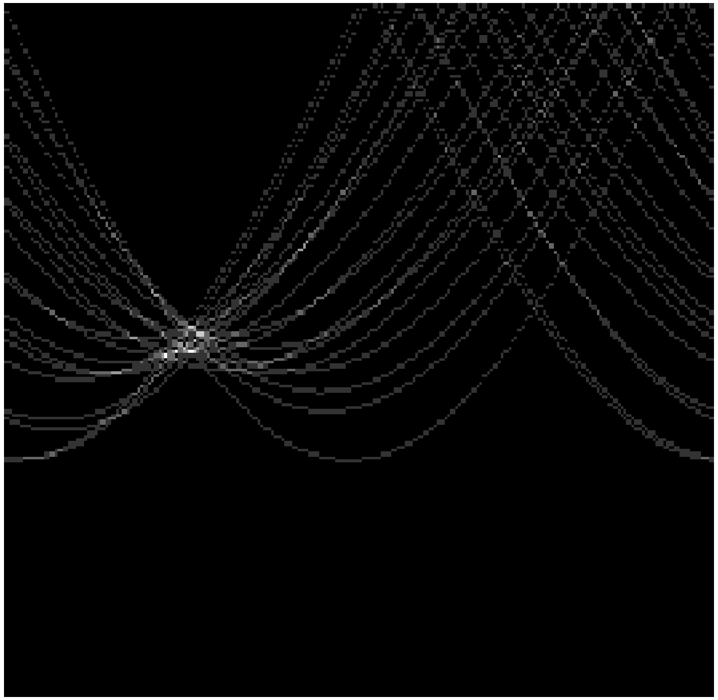
   }

   }

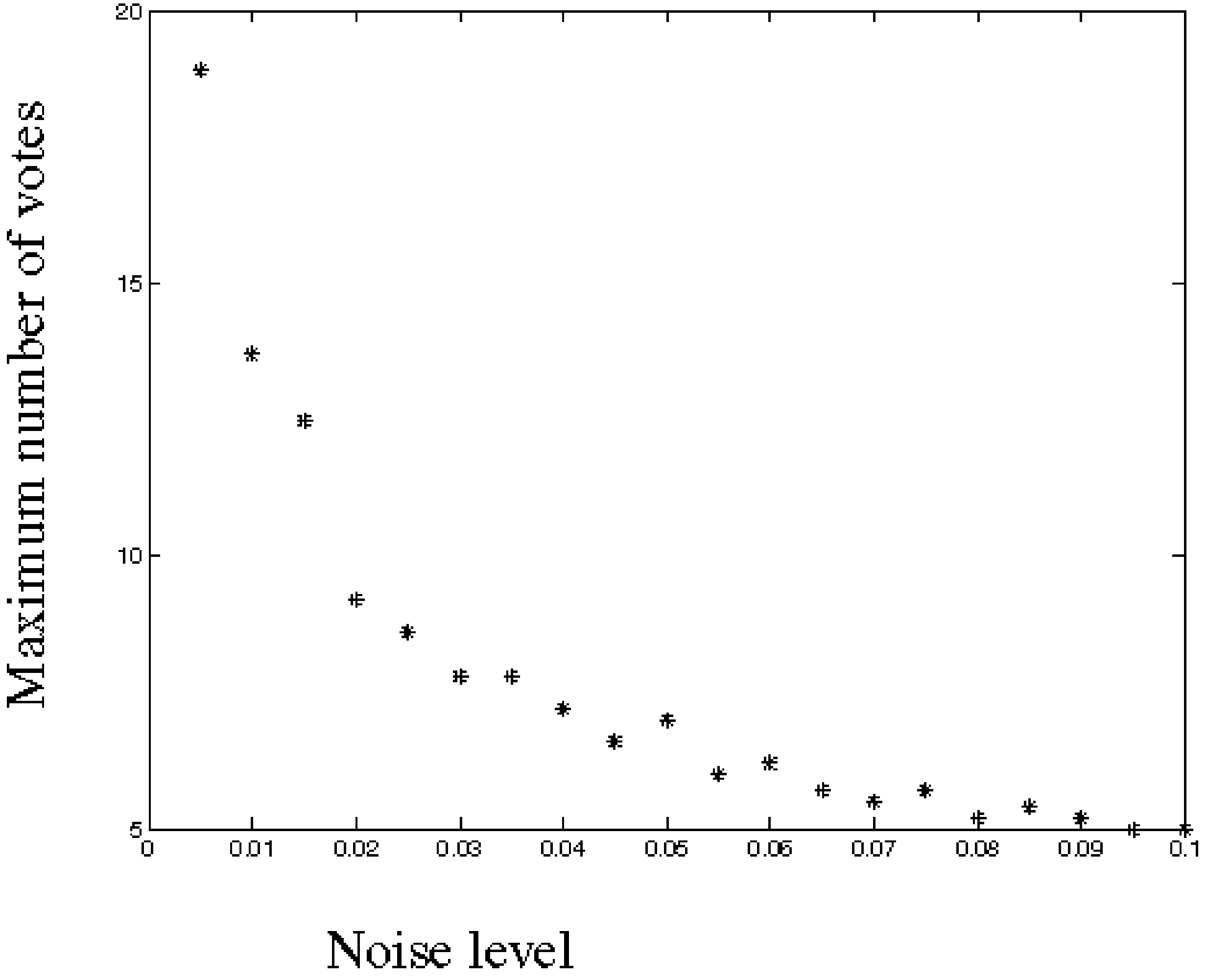
3. Find the peaks in P[ρ][θ].

Cell Size

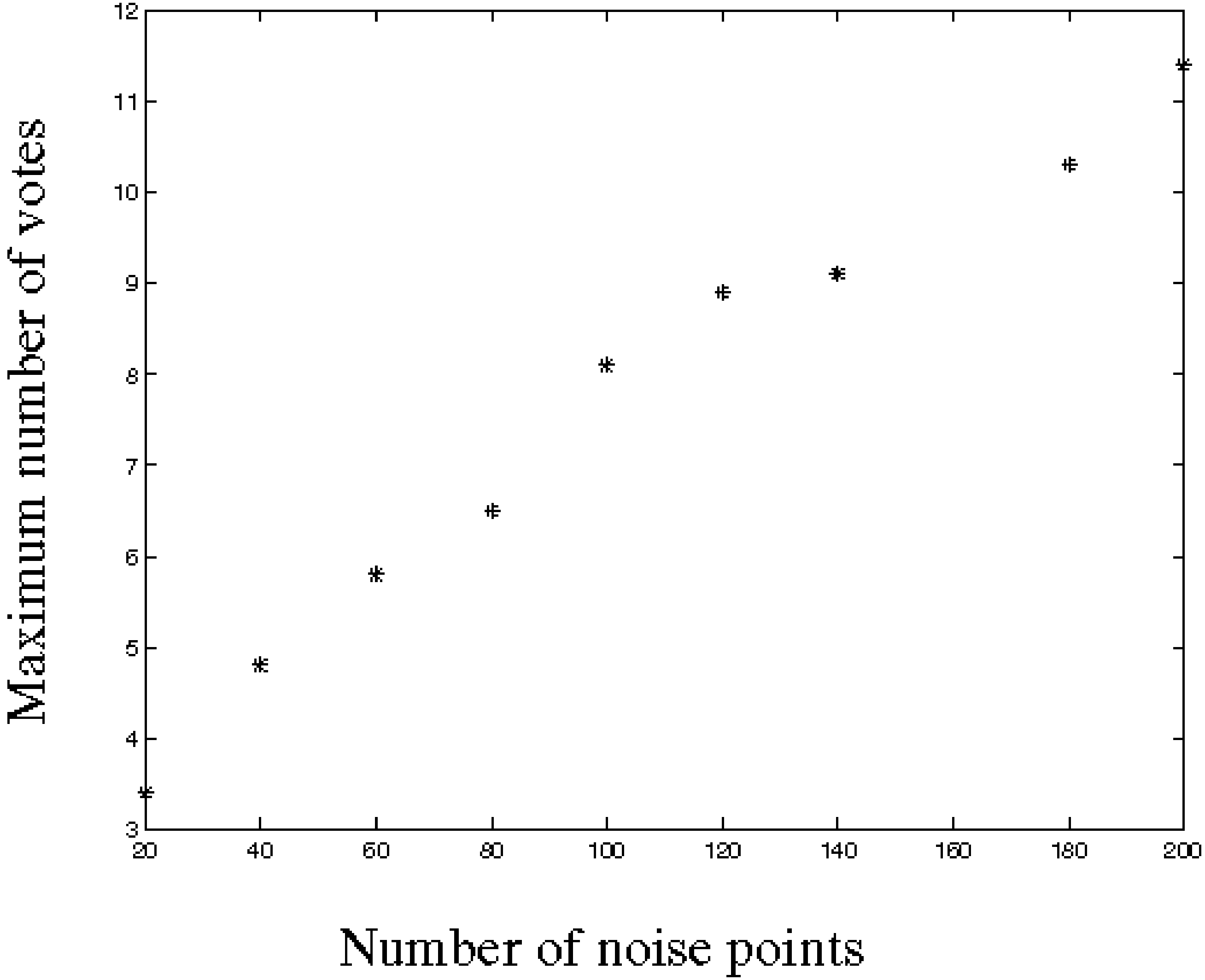




Choose the parameter cell size such that the algorithm is robust to noise.



Fewer votes land in a single bin when noise increases.

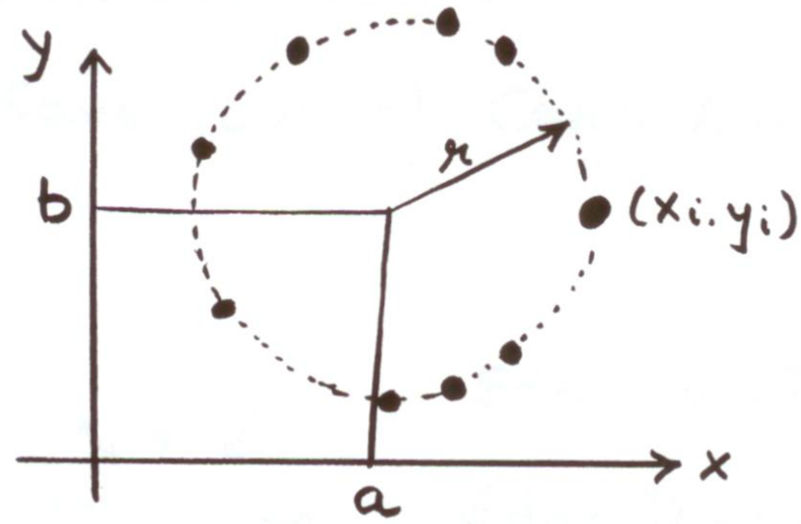


Adding more clutter increases number of bins with false peaks.

Finding Circles by Hough Transform

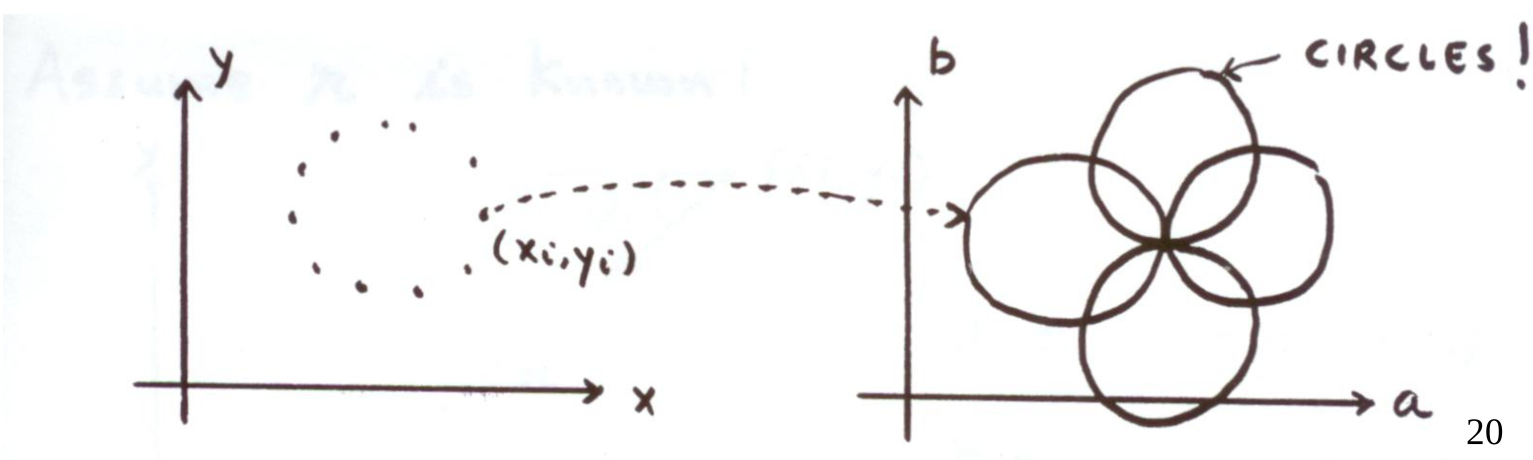
Equation of Circle:

$$(x_i - a)^2 + (y_i - b)^2 = r^2$$



If radius is known: (2D Hough Space)

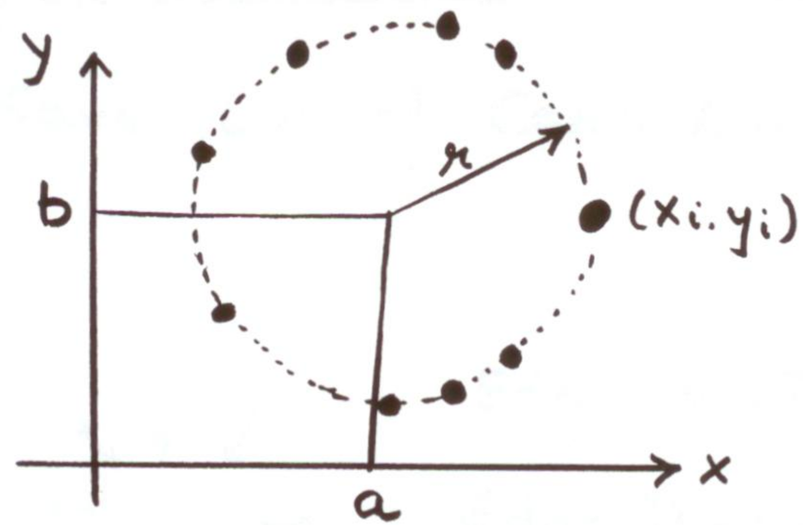
Accumulator Array $A(a, b)$



Finding Circles by Hough Transform

Equation of Circle:

$$(x_i - a)^2 + (y_i - b)^2 = r^2$$



If radius is not known: 3D Hough Space!

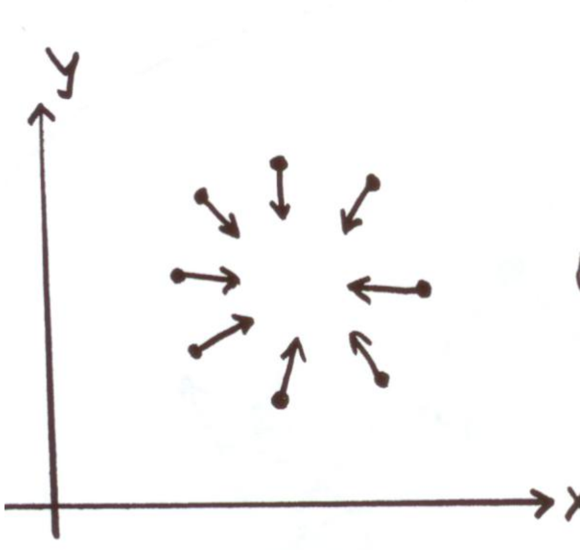
Use Accumulator array $A(a,b,r)$

Using Gradient Information

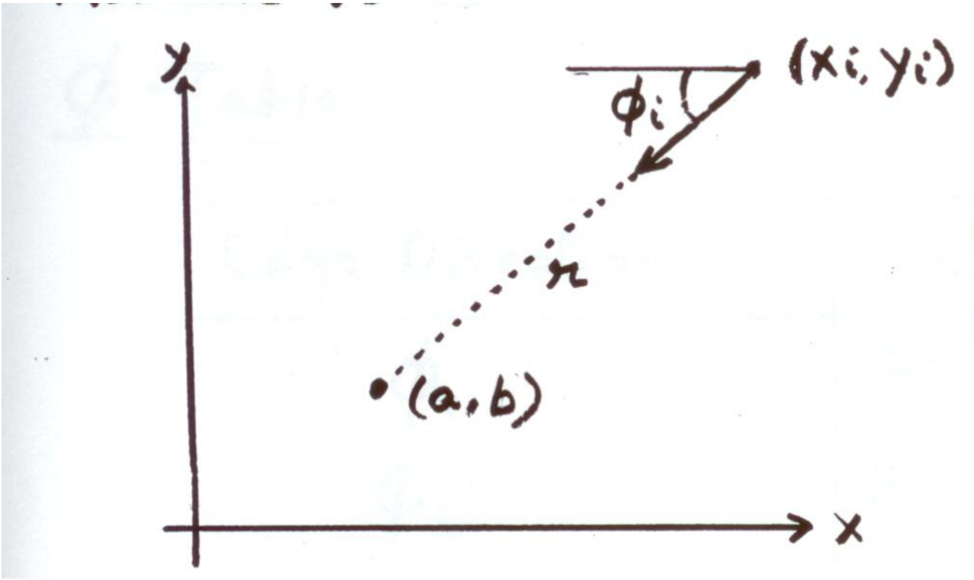
- Gradient information can save lot of computation:

Edge Location (x_i, y_i)

Edge Direction ϕ_i



Assume radius is known:



$$a = x - r\cos\phi$$

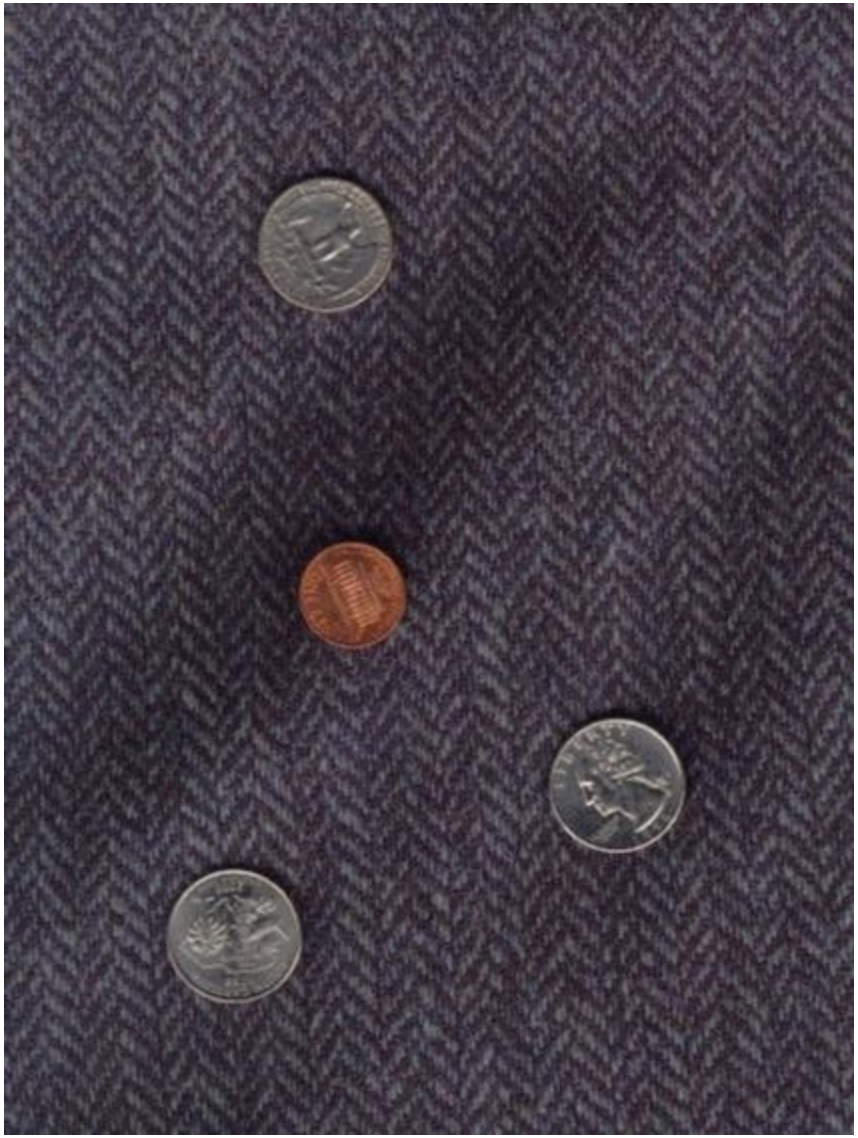
$$b = y - r\sin\phi$$

Need to increment only one point in Accumulator!!

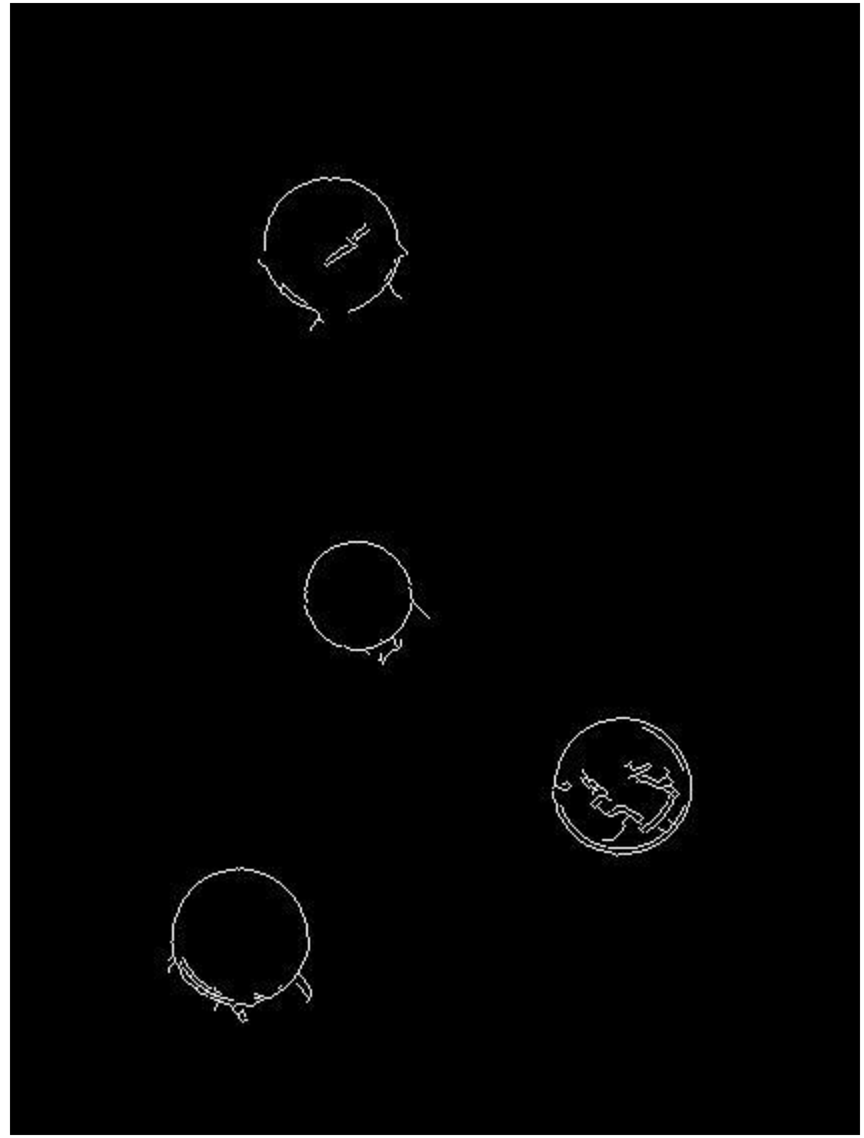
If radius is not known, accumulator is 2d using gradients

Finding Coins

Original

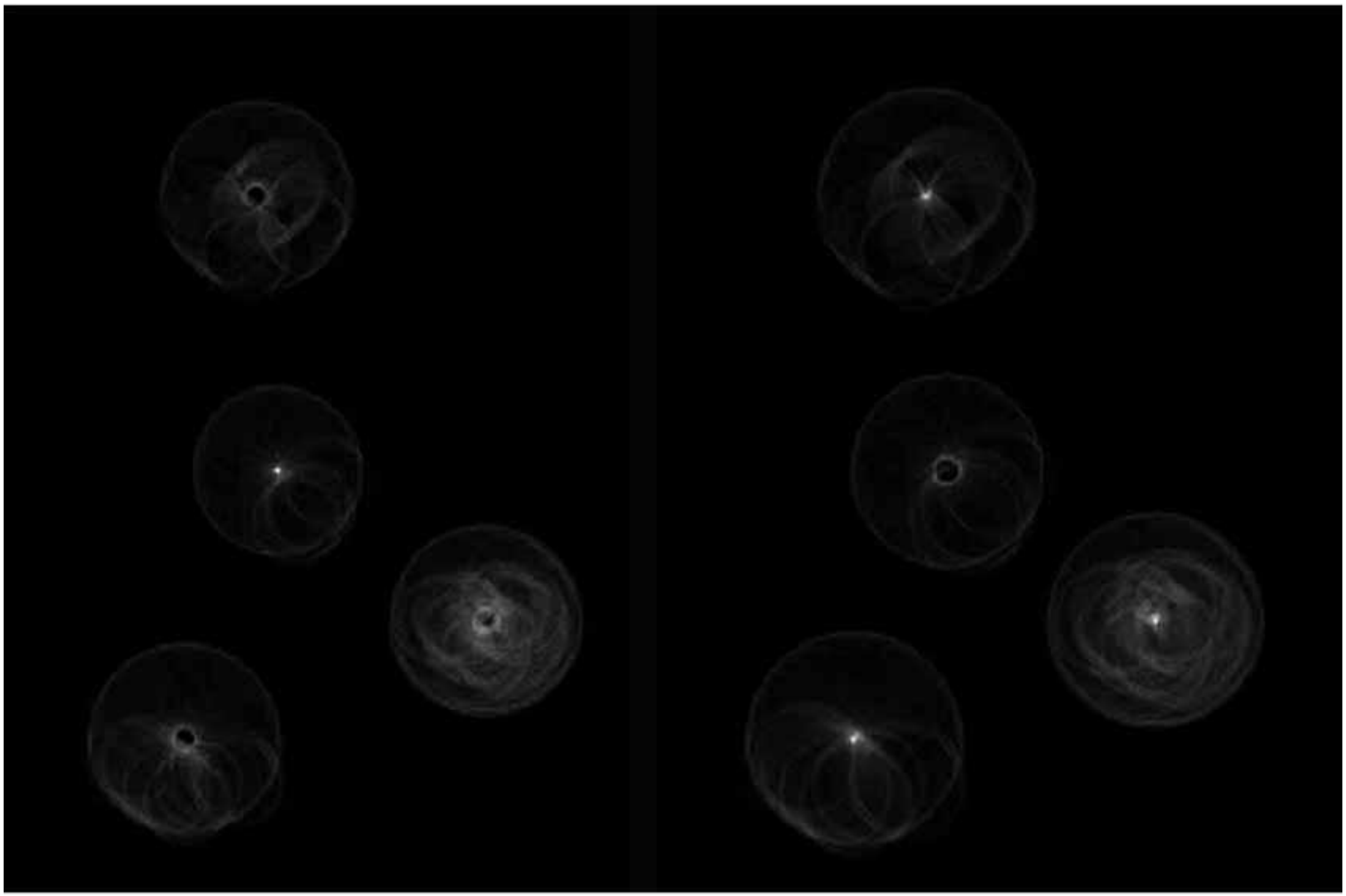


Edges (note noise)

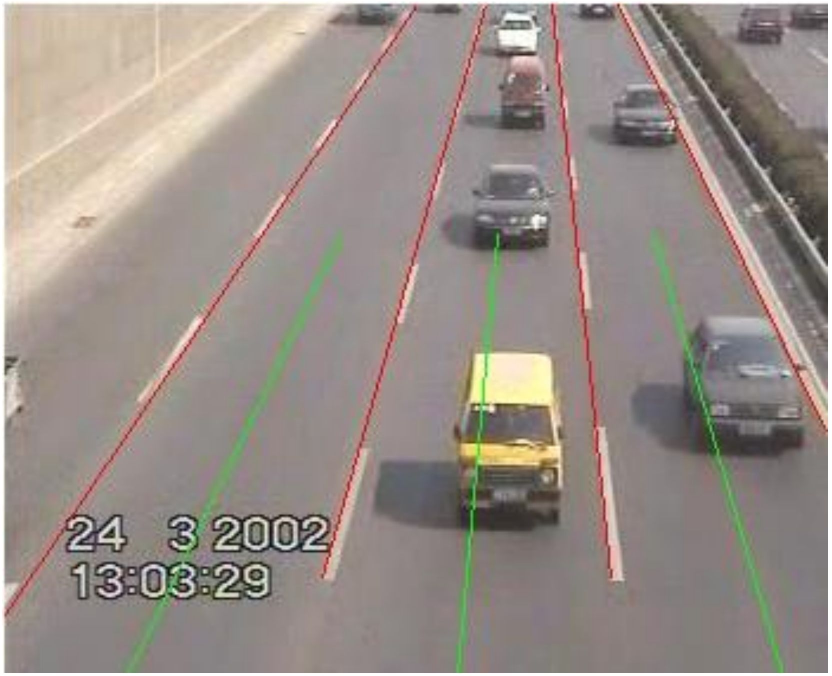


Finding Coins (Continued)

Penny Quarters



Application: Lane Detection



Hough Characteristics

- Detects all the curves in an image at once
- Running time proportional to the number of edge points that are in the image
- Can deal with disconnected edge points
  - Does not assume (require) any connectivity for edges
- Accumulator dimension (space) proportional to number of parameters that define the curve
  - Works well for lines (only 2d accumulator array necessary)
- Not easy to extend to more complex curves because of the space requirements
  - Can use image gradient to decrease space requirements
- Using gradients works well for circles

Probabilistic Hough Transform

- Given a set of p edge points in an image
  - Goal is to find a particular curve (line, or circle)
  - Idea is that given n edge points (n is 2 for line or 3 for circle) we can create a unique curve through just these points
- Do while we have enough edge points
  - For K times (a parameter)
    - Choose n random edge points (2 for line and 3 for circle)
    - Create a unique line or circle through these points
    - Count the number of edge points that are within d pixels (another parameter) of that unique line or circle
    - Save the best curve (has most points within distance d)
  - Endfor
- remove the edge points found for best curve
- Enddo

Probabilistic Hough Transform

- Two parameters distance d, and #samples K
  - Distance d is typically set in range 1 to 5 pixels
  - #samples K depends on how many curves you expect there to be in the image
- Given expectation of at most n curves in the image you can compute a value for K
  - K is an exponential function of n, the degrees of freedom (dof) of the curve, which is 2 for a line and 3 for a circle
  - Running time O(m K p) K is number of samples, p is the number of edge points, m is number of curves
- Space requirements are low so you could use this for complex curves (like ellipse, 5 dof)

Probabilistic HT relative to ordinary HT

- Ordinary HT space requirements where q is grid size are q^2 for line and q^3 for a circle
  - Running time is O(q p) with p edge points
- Probabilistic HT space requirements are simply O(p), the number of edge points
  - Time is O(m K p), m curves p edge points, K samples
- Which is faster for lines and circles?
  - Depends on how many lines and circles exist (n)
  - Remember for Prob. HT value of K is an exponential function of the number of expected lines or circles
  - With a small number of curves K is small, and Prob. HT is faster, large number of curves K is large and HT is faster
- For curves like ellipse Prob. HT is only choice