Computer Vision

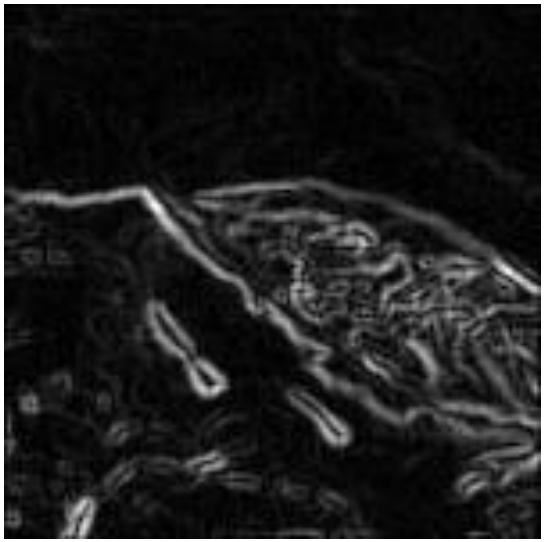
CSC-455

Muhammad Najam Dar

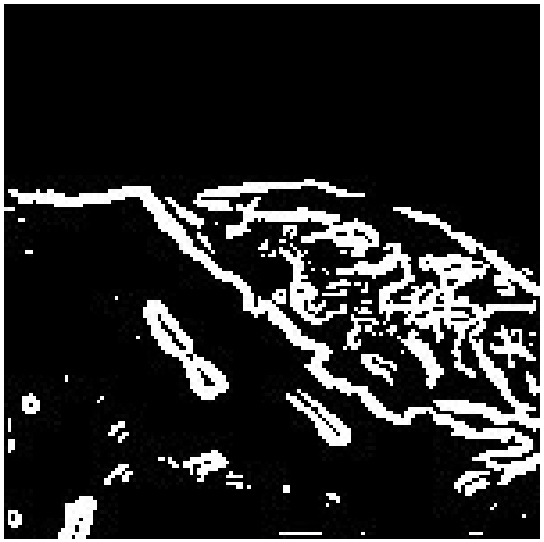
Image Segmentation & Feature Extraction through Hough Transform

Motivation

Original image



Edge detection



Thresholding

How do we find image boundaries (lines)?

Edges don’t have to be connected

Lines can be occluded

Key idea: edges **vote** for the possible models

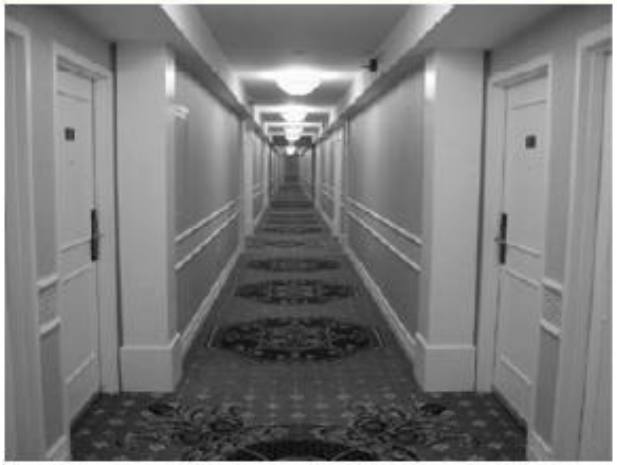
Generic framework for detecting a shape/object

Introduction to Hough transform

- The Hough transform (HT) can be used to detect lines, circles or other parametric curves.
- It was introduced in 1962 (Hough 1962) and first used to find lines in images a decade later (Duda 1972).
- The goal is to find the location of lines in images.
- This problem could be solved by e.g. Morphology and a linear structuring element, or by correlation.
  - Then we would need to handle rotation, zoom, distortions etc.
- Hough transform can detect lines, circles and other structures if their parametric equation is known.
- It can give robust detection under noise and partial occlusion.

An image with linear structures

- Borders between the regions are straight lines.
- These lines separate regions with different grey levels.
- Edge detection is often used as preprocessing to Hough transform.



Example

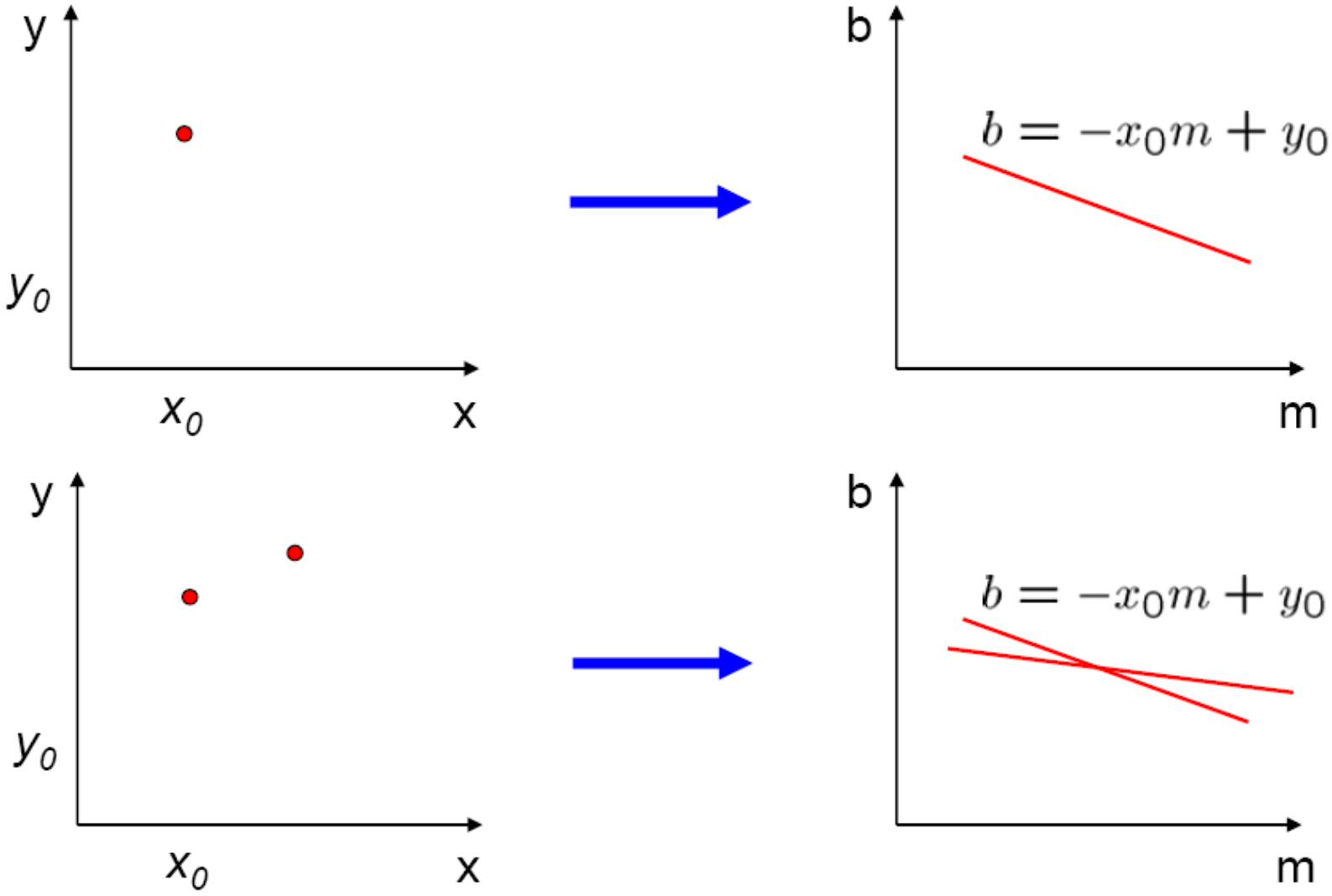


Image and parameter space

variables

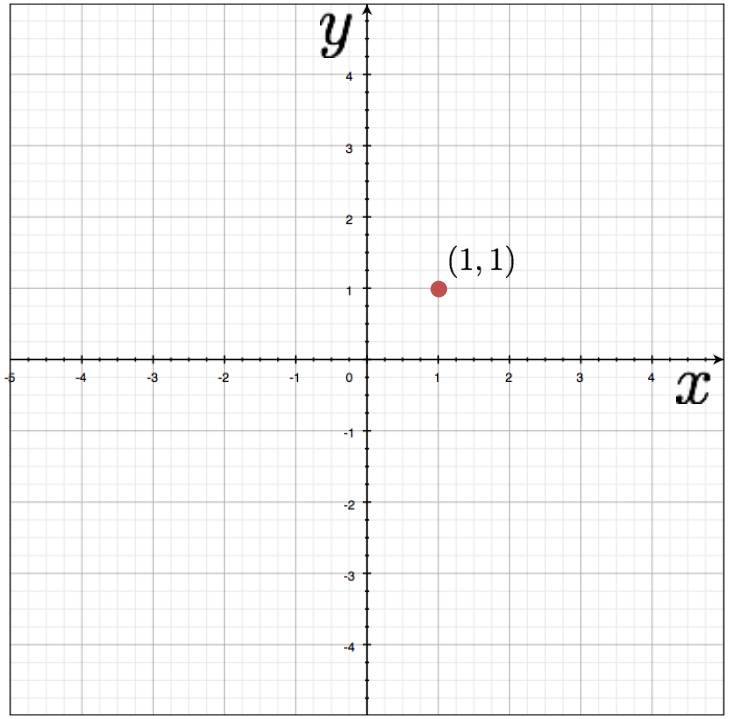
$$y = mx + b$$

parameters

variables

$$y - mx = b$$

parameters



a point becomes a line

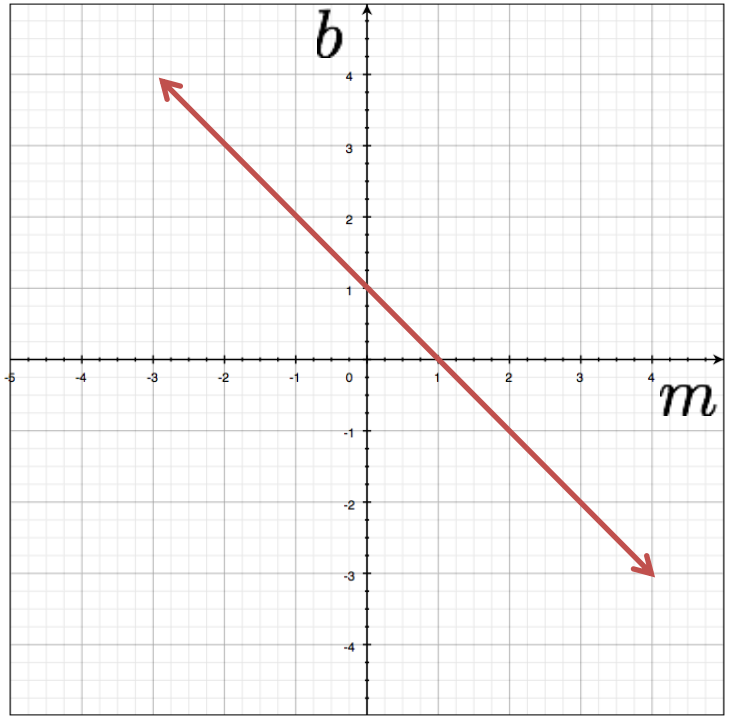


Image space

Parameter space

Image and parameter space

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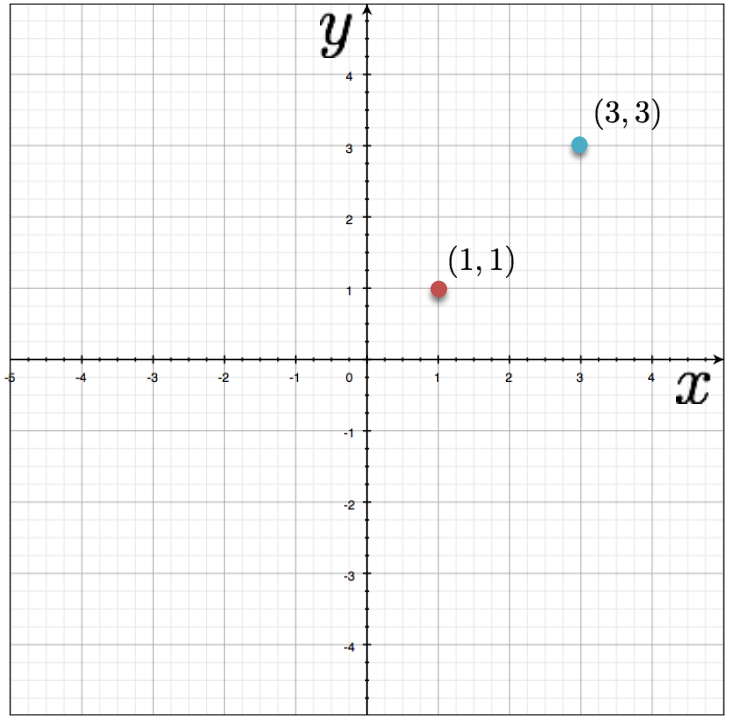
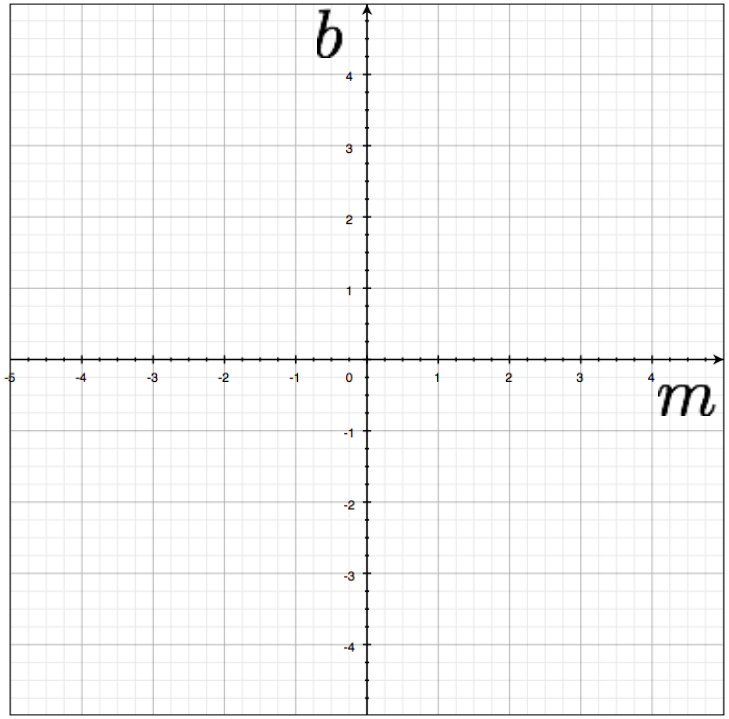


two points become ?



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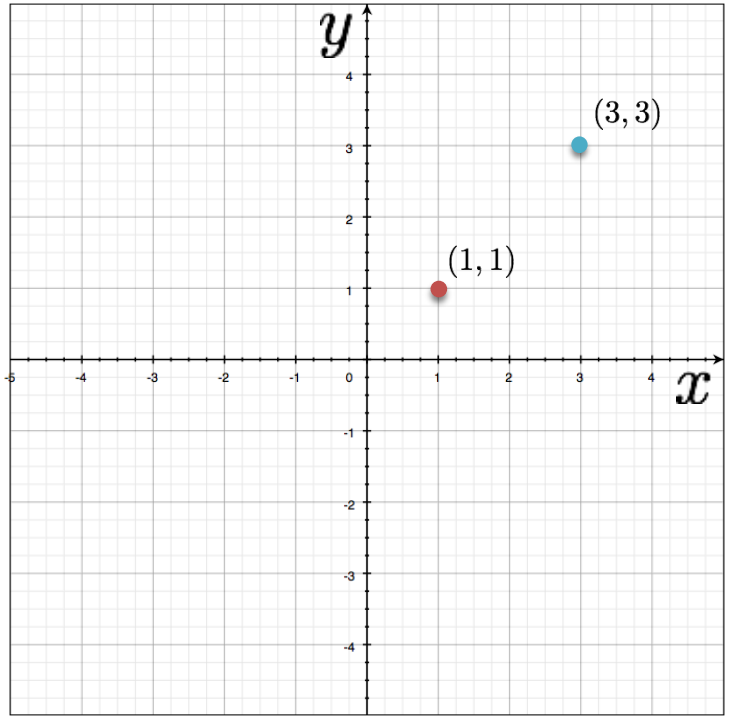
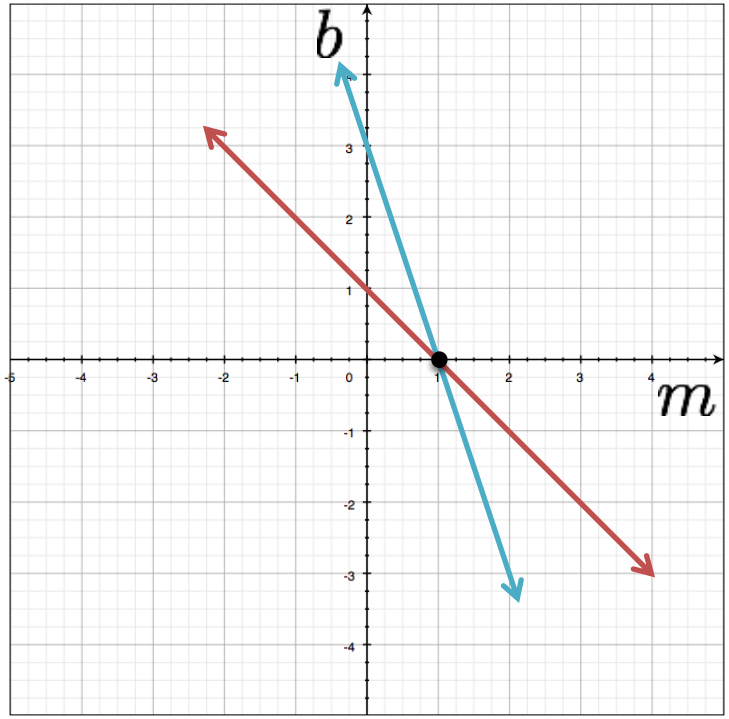


two points become ?



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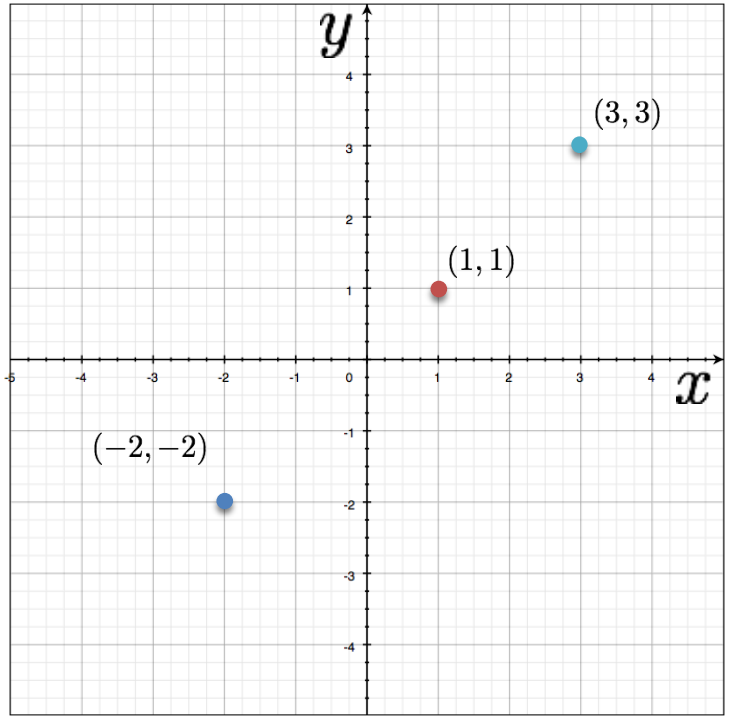
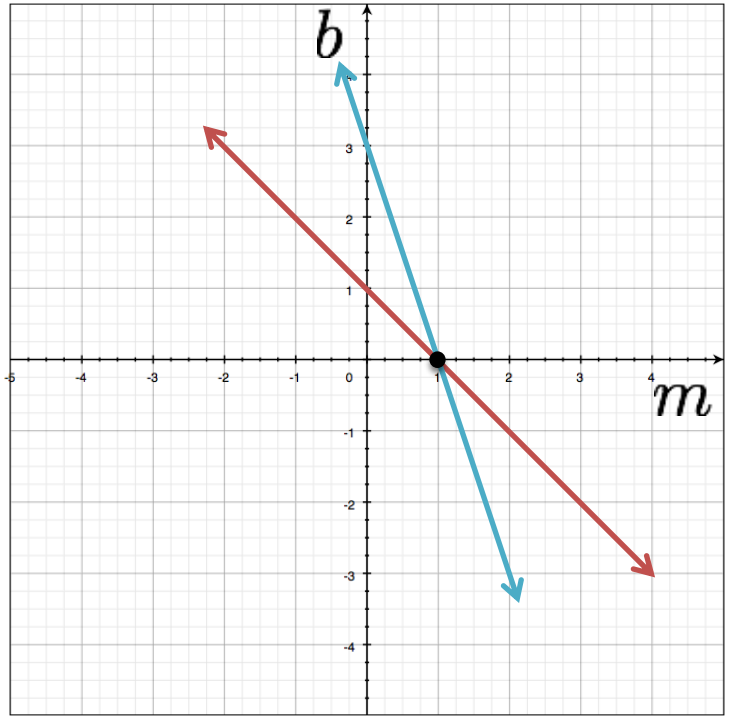


three points become ?



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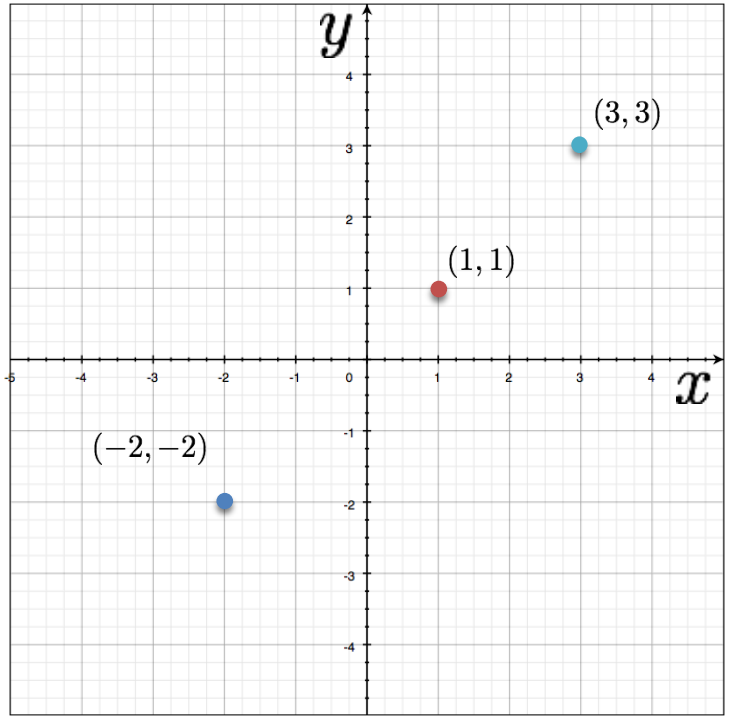
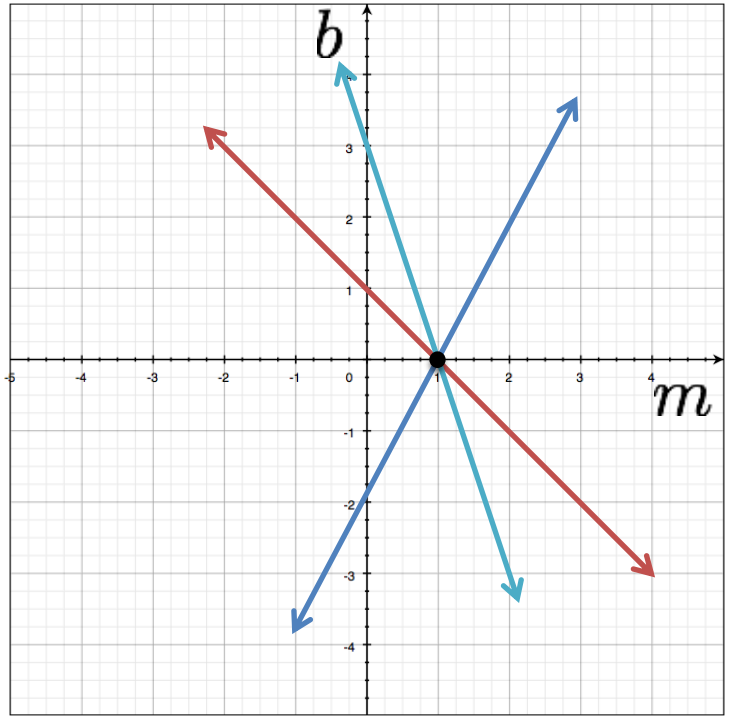


three points become ?



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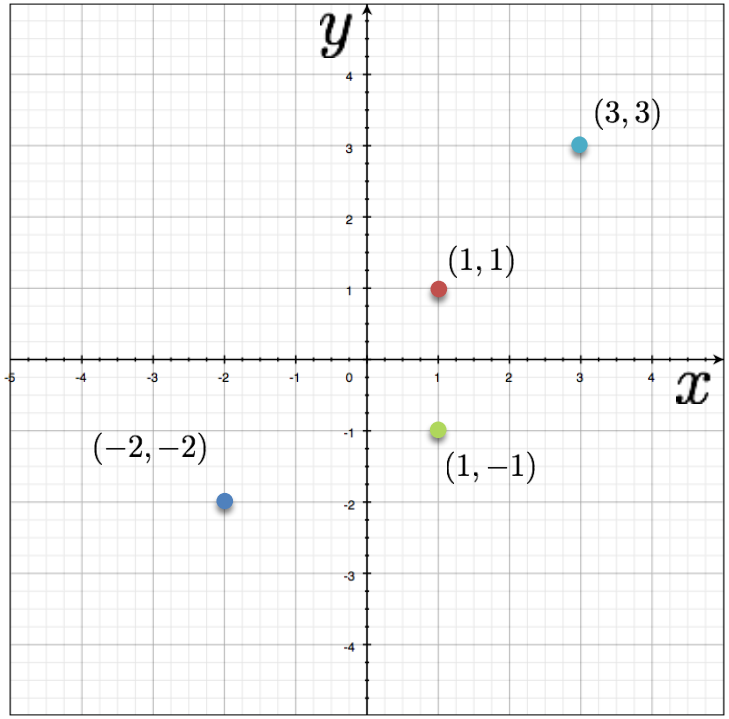
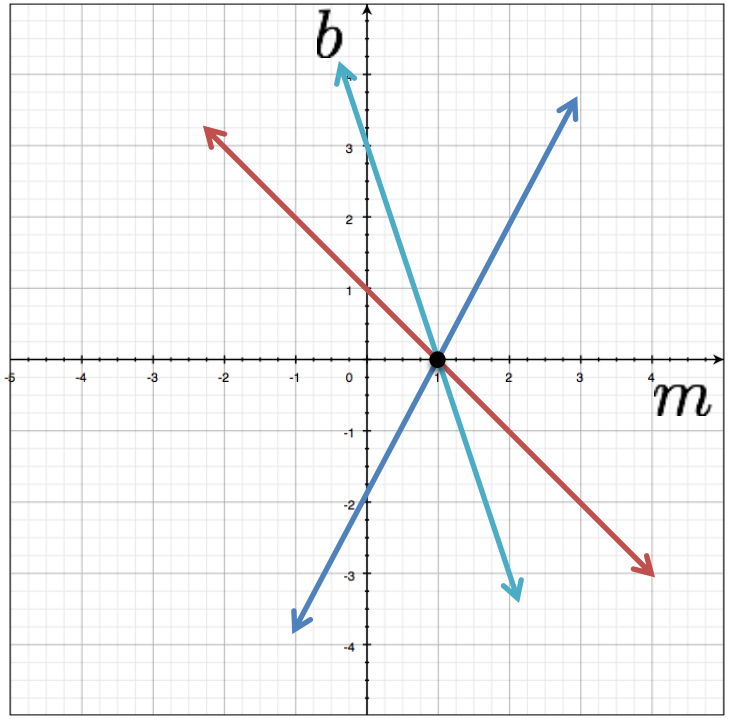


four points become ?



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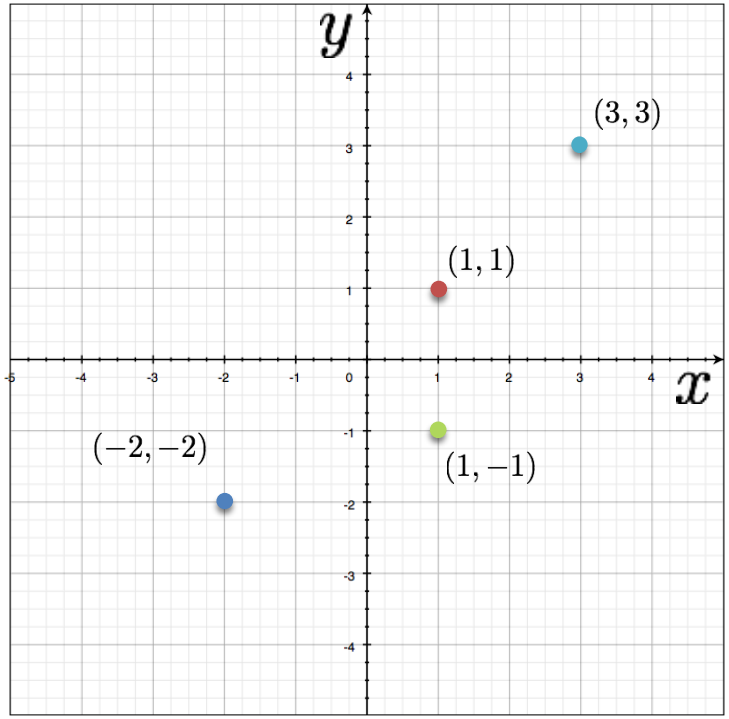


four points become ?

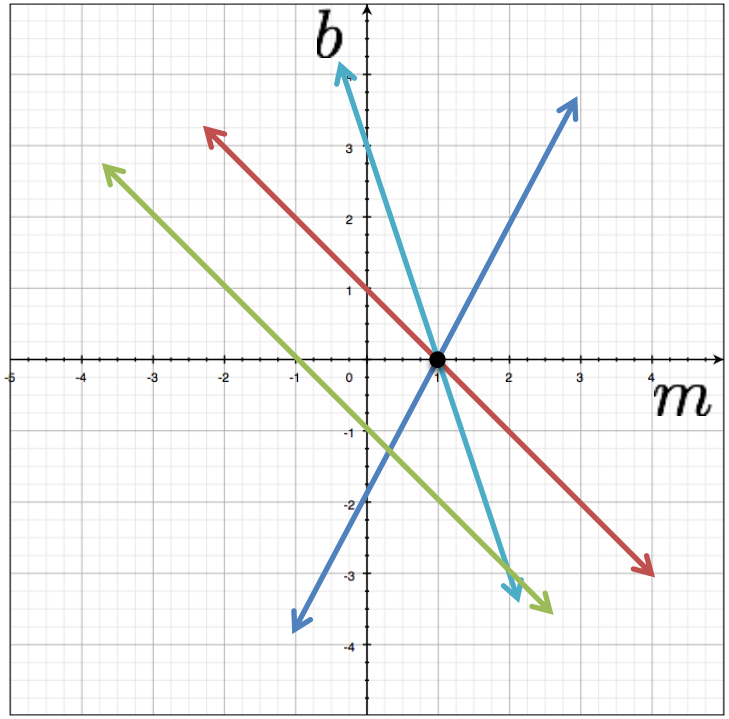
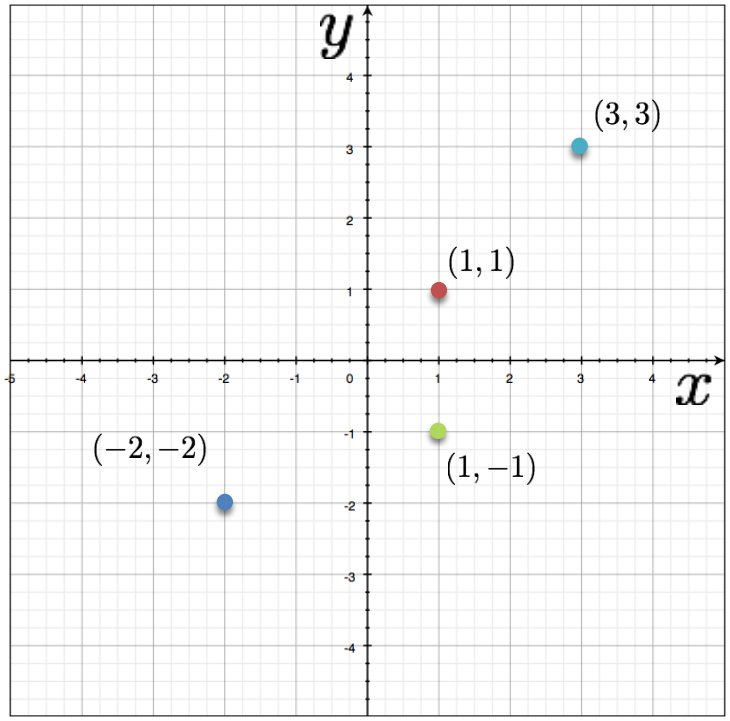


Image space

Parameter space

How would you find the best fitting line?



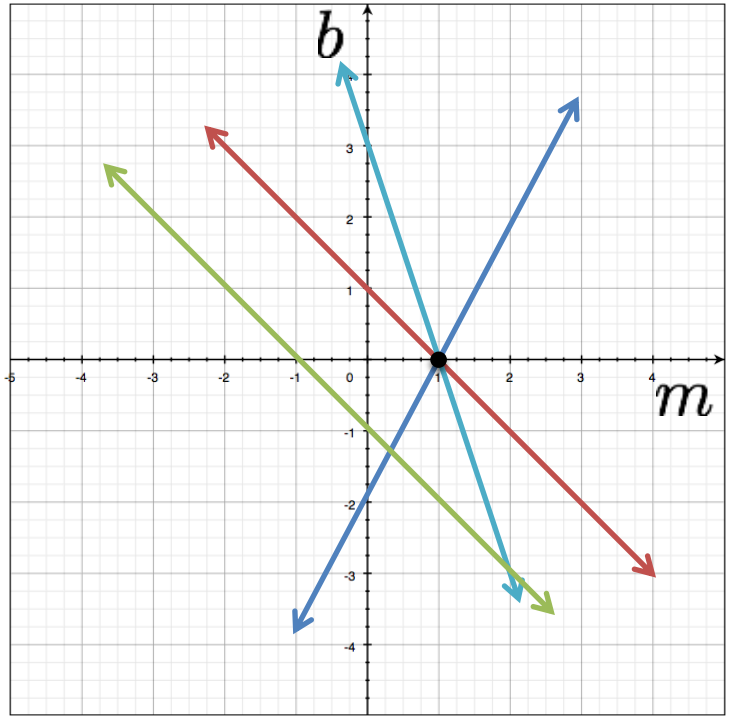


Image space

Parameter space

Is this method robust to outliers?

Is this method robust to measurement noise?

Line Detection by Hough Transform

Algorithm:

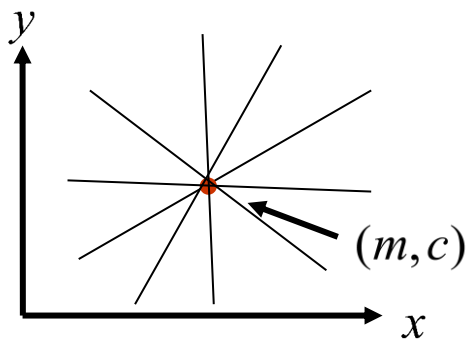
1. Quantize Parameter Space (m,c)

2. Create Accumulator Array $A(m,c)$

3. Set $A(m,c) = 0 \quad \forall m,c$

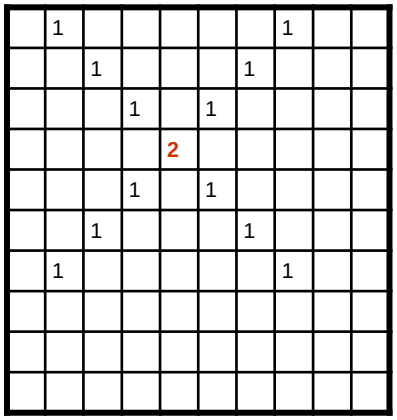
4. For each image edge (x_i, y_i)
   For each element in $A(m,c)$
   If (m,c) lies on the line: $c = -x_i m + y_i$
   Increment $A(m,c) = A(m,c) + 1$

5. Find local maxima in $A(m,c)$



Parameter Space

$A(m,c)$



Perceptual Grouping

Up to now we've focused on local properties of images.

Perceptual grouping is about putting parts together into a whole:

- Finding regions with a uniform property
- Linking edges into object boundaries

Surfaces and objects are critical.

Also, simpler ``objects'' such as lines

- Gestalt movement claimed atomic stimulus and response don't exist.

  -The mind perceives world as objects, as wholes, not as atomic primitives.

  - Can't understand psych without understanding how we perceive the world.

I stand at the window and see a house, trees, sky.

Theoretically I might say there were 327 brightnesses and nuances of colour. Do I *have* "327"? No. I have sky, house, and trees. It is impossible to achieve "327 " as such. And yet even though such droll calculation were possible and implied, say, for the house 120, the trees 90, the sky 117 -- I should at least have *this* arrangement and division of the total, and not, say, 127 and 100 and 100; or 150 and 177.

Max Wertheimer, 1923

I. A row of dots is presented upon a homogeneous ground. The alternate intervals are 3 mm. and 12 mm.

Normally this row will be seen as *ab/cd*, not as *a/bc/de*. As a matter of fact it is for most people impossible to see the whole series simultaneously in the latter grouping.

Max Wertheimer

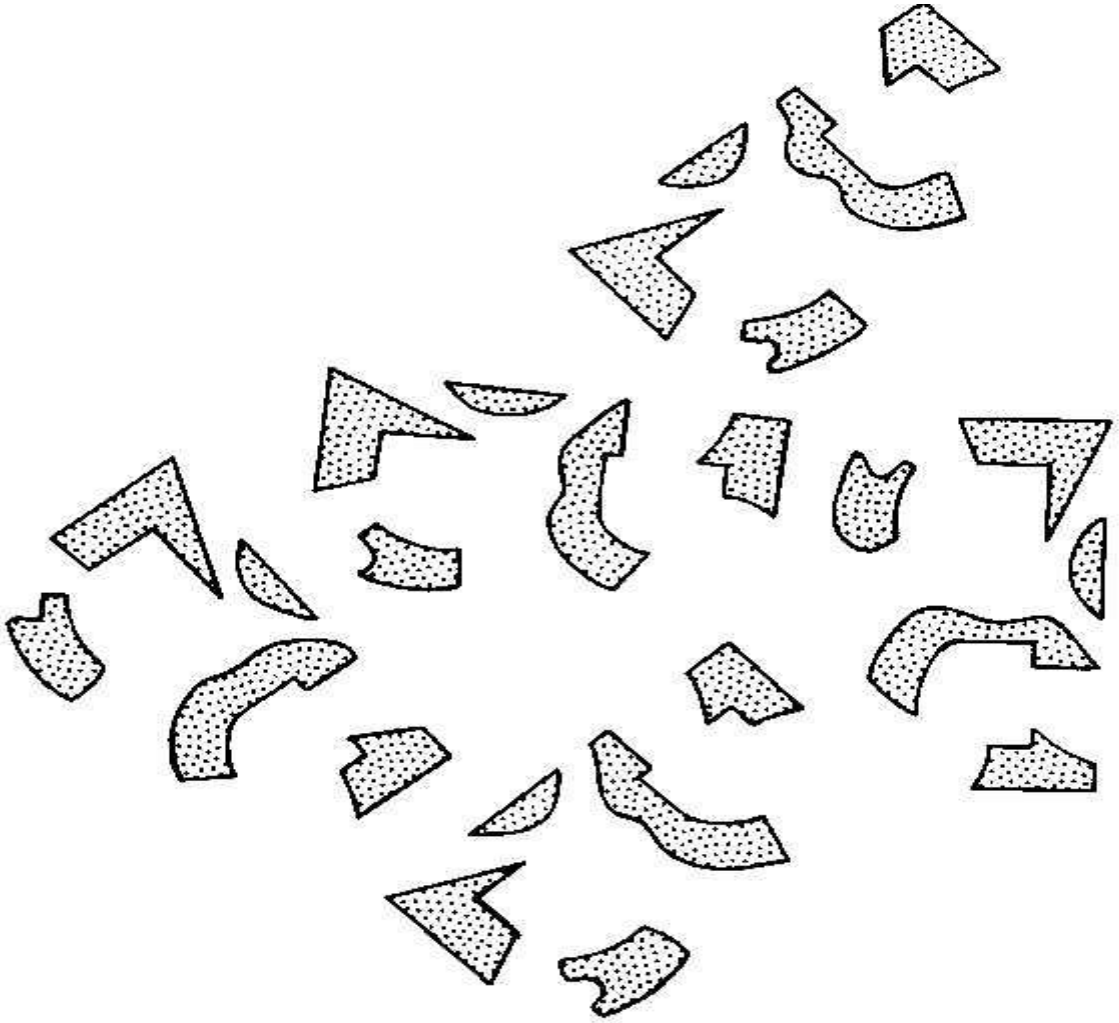
Gestalt Movement

Perceptual organization was a big issue.

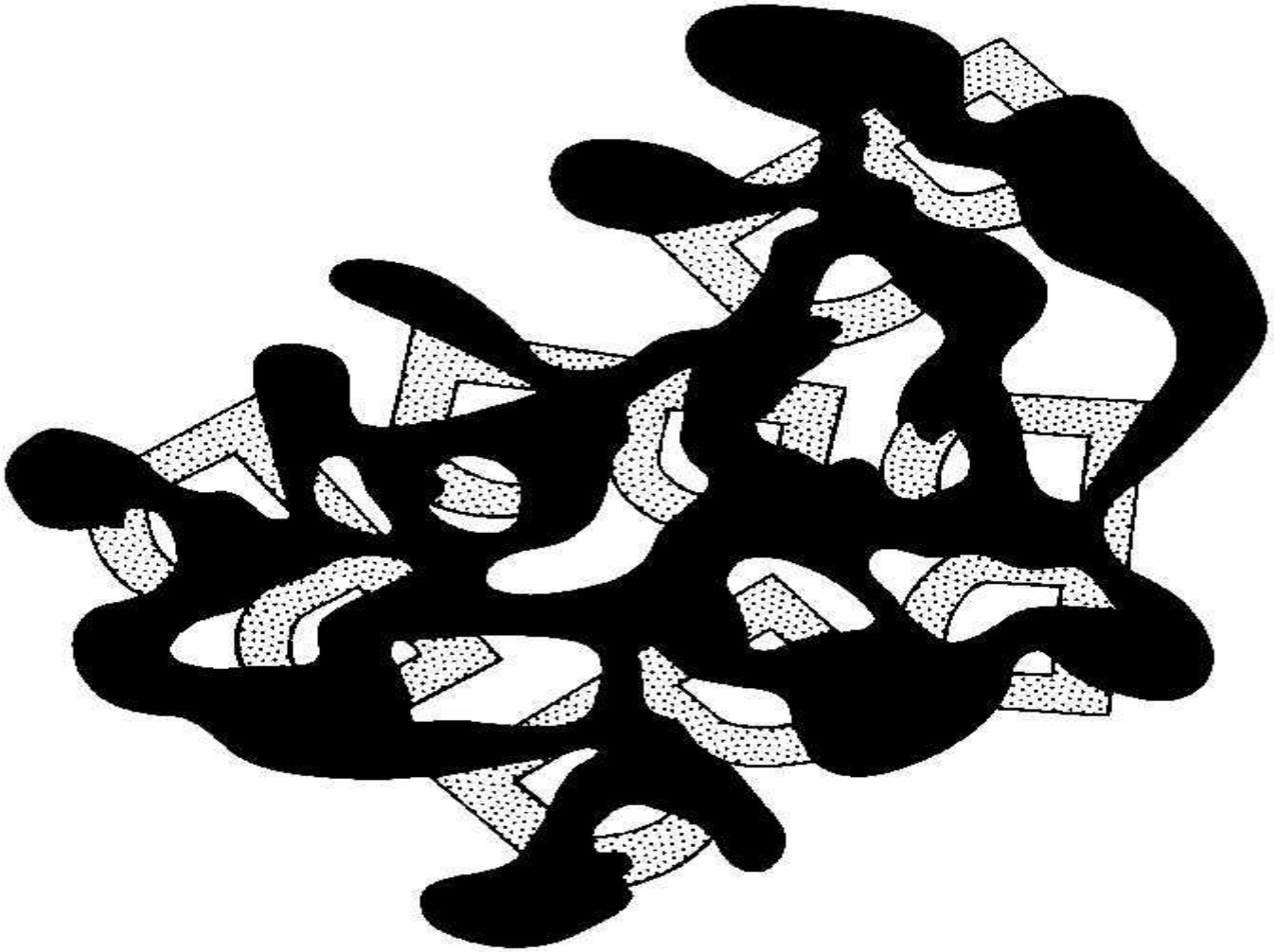
- How we perceive the world in terms of things/objects, not pixels.

This was part of broader attack on behaviorism.

- Gestalt viewed mind as constructing representations of the world, no learning/behavior could be understood without understanding this.



(Bregman)

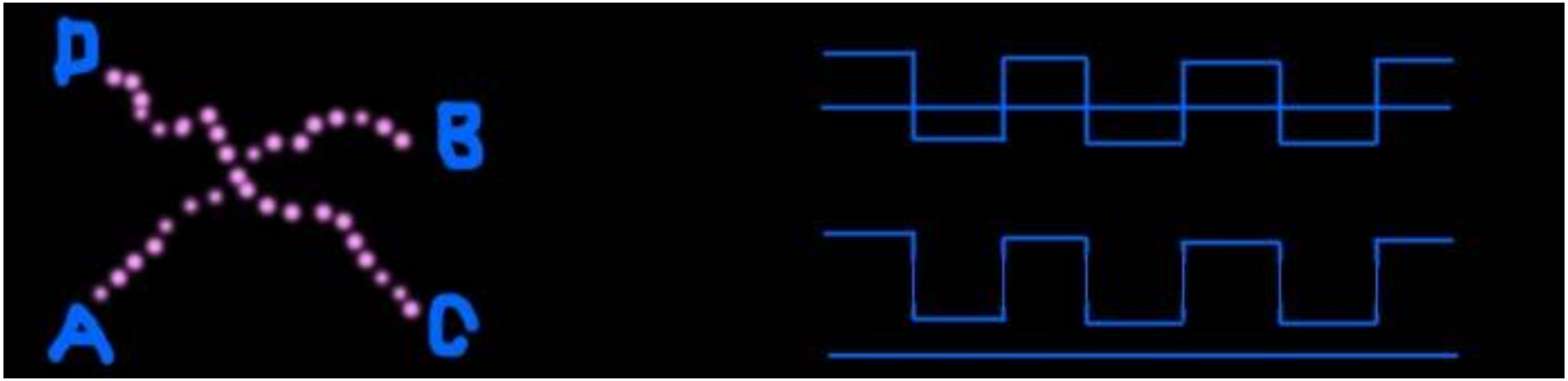


Issues in Perceptual Organization

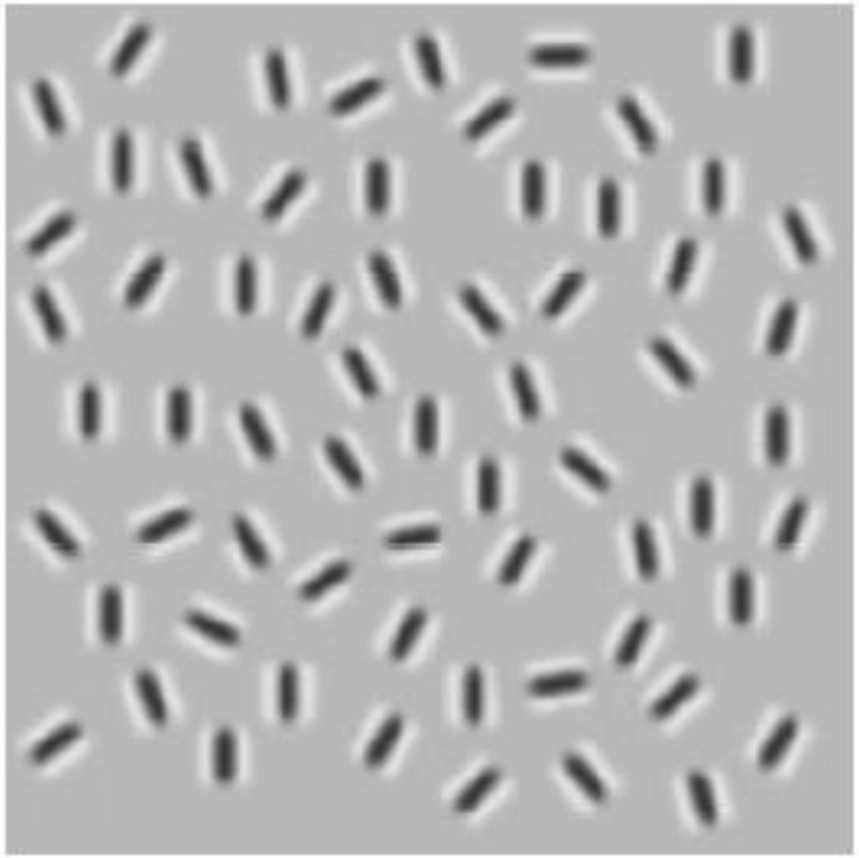
What factors determine which parts of an image are combined in the same object?

Proximity

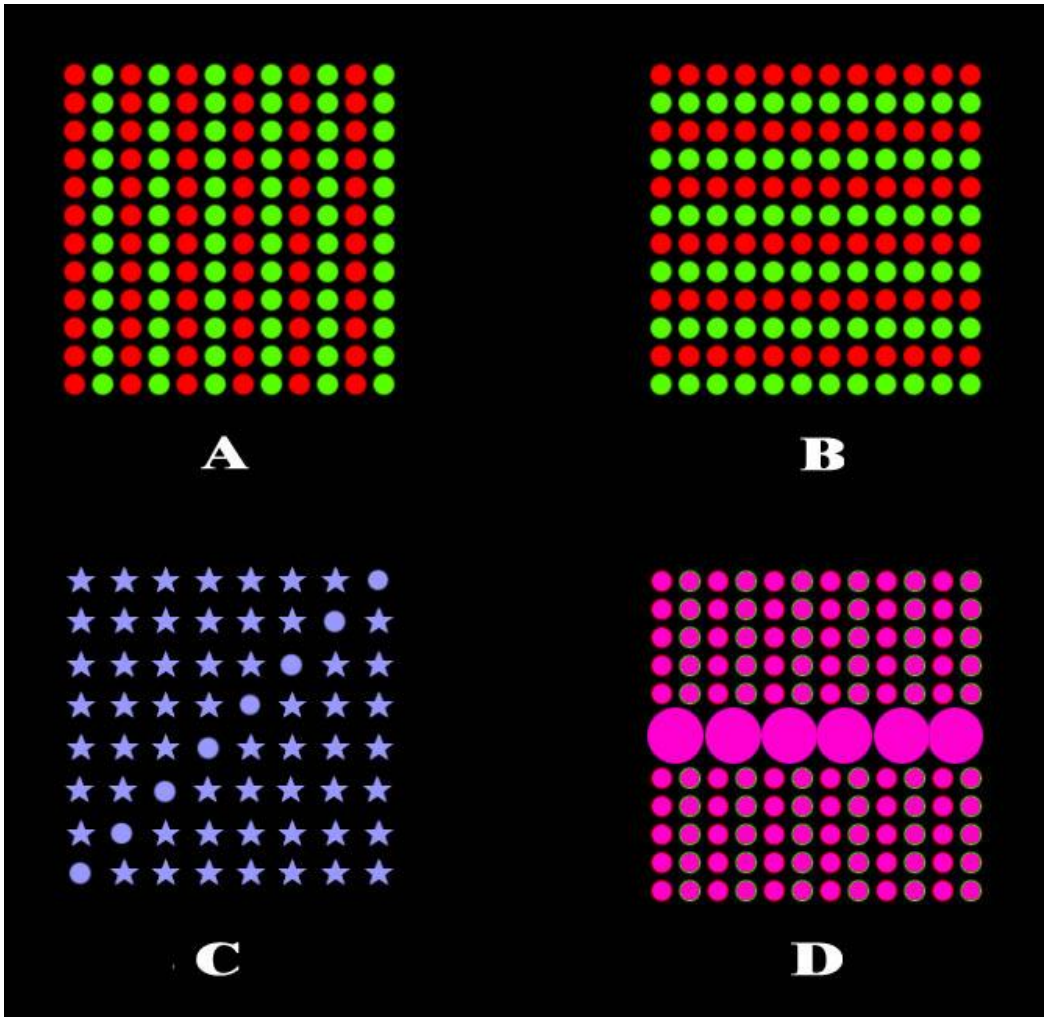
Good Continuation



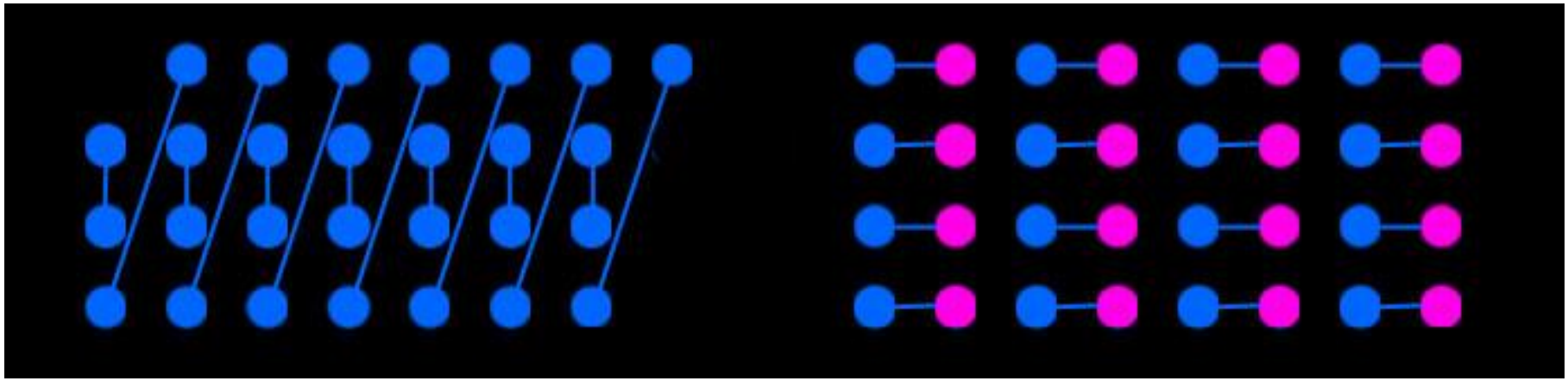
Good Continuation



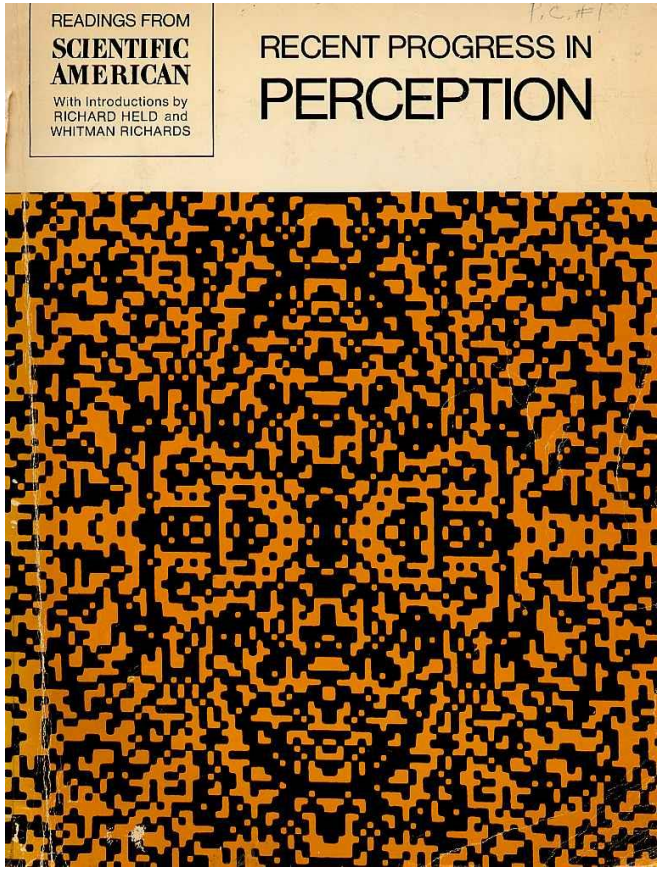
Common Form: (includes color and texture)



Connectivity



Symmetry


READINGS FROM
SCIENTIFIC AMERICAN
With Introductions by
RICHARD HELD and
WHITMAN RICHARDS
RECENT PROGRESS IN
PERCEPTION

Symmetry

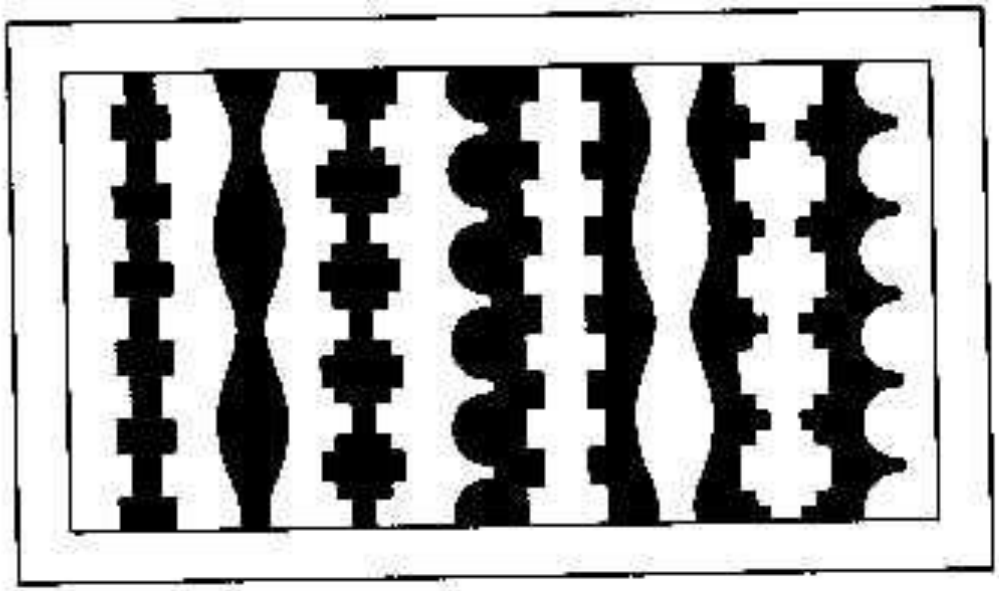
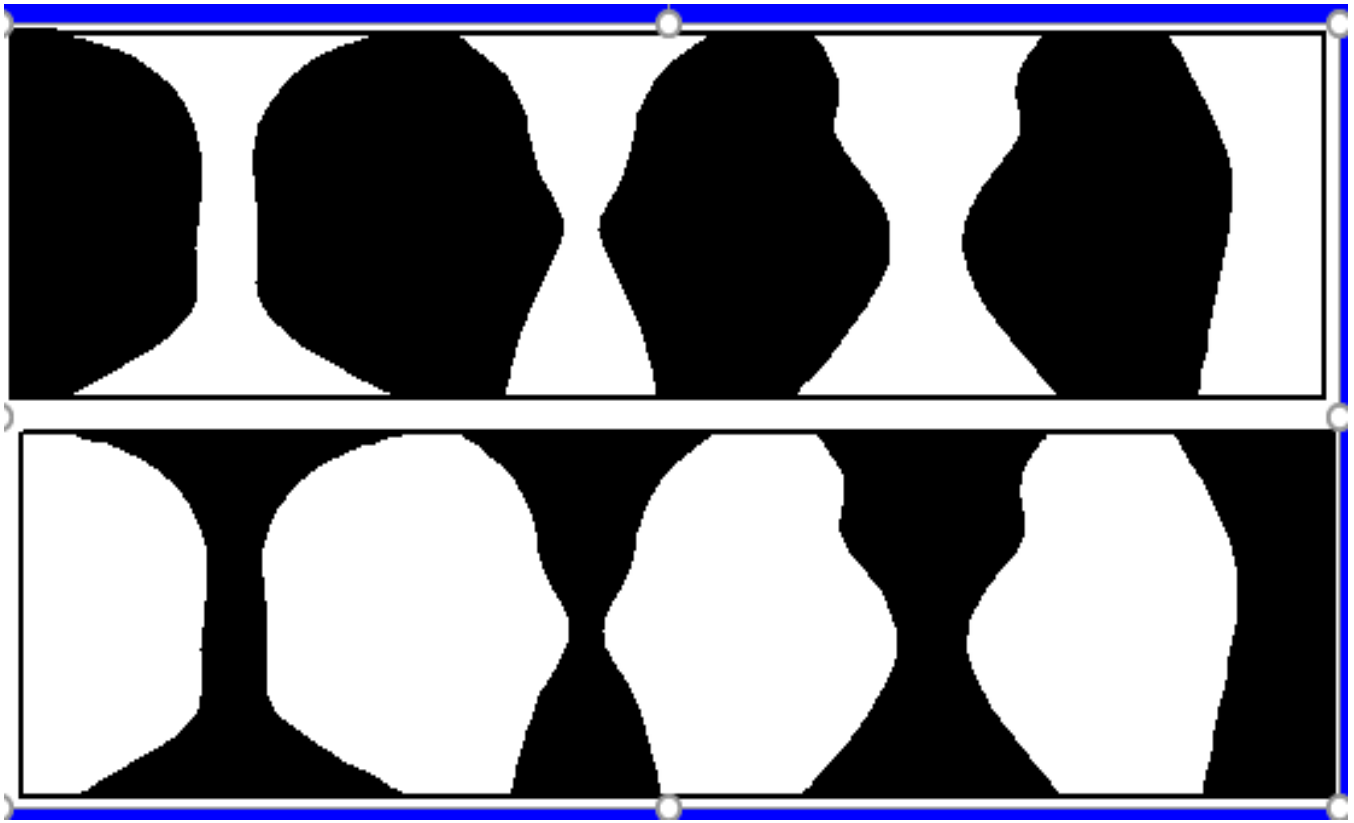


Figure 7.25
Symmetry and figure ground. Look to the left and to the right, and observe which colors become figure and which become ground. (Adapted from Hochberg, 1971.)

Convexity (stronger than symmetry?)



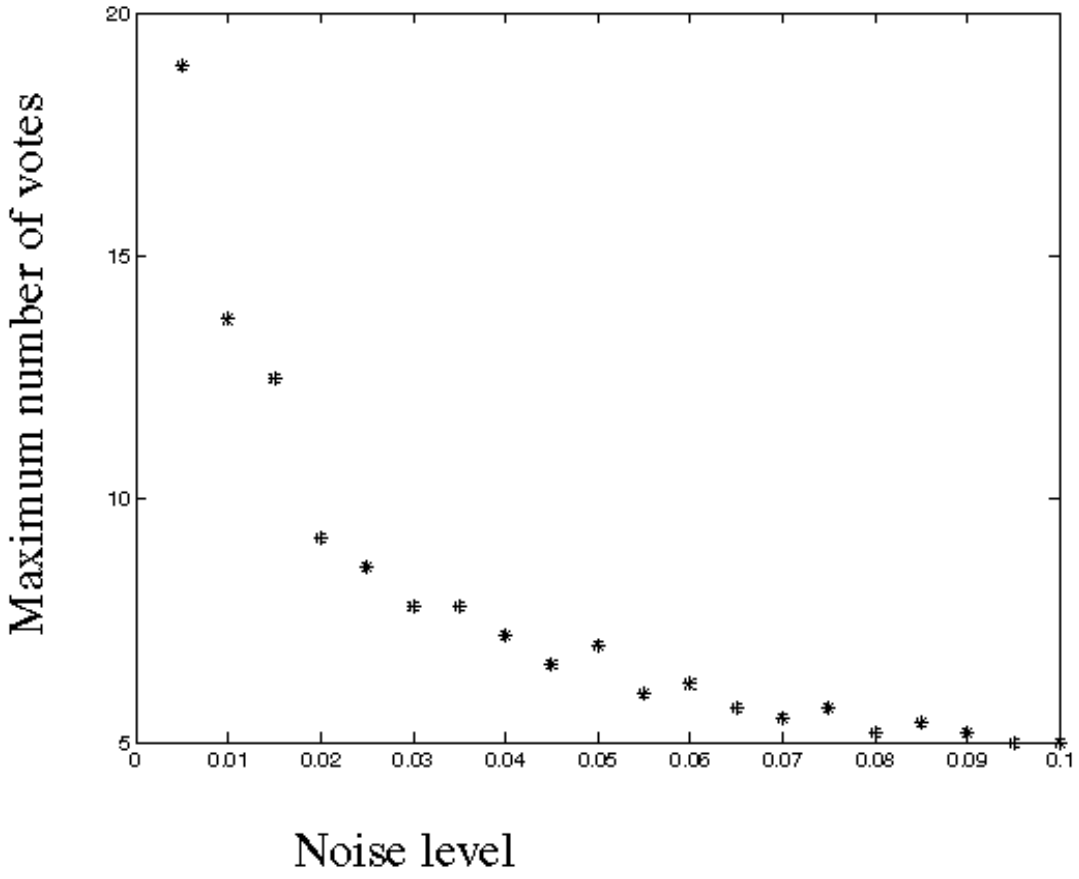
Closure

Higher level Knowledge

If you know what is in the next image, silently raise your hand.
Don’t call out.

Noise Limitations of Hough Transform

- Two main limitations:noise and cell size



Results for a specimen of line with 20 points, with different amounts of noise

In practice, measurements are noisy…

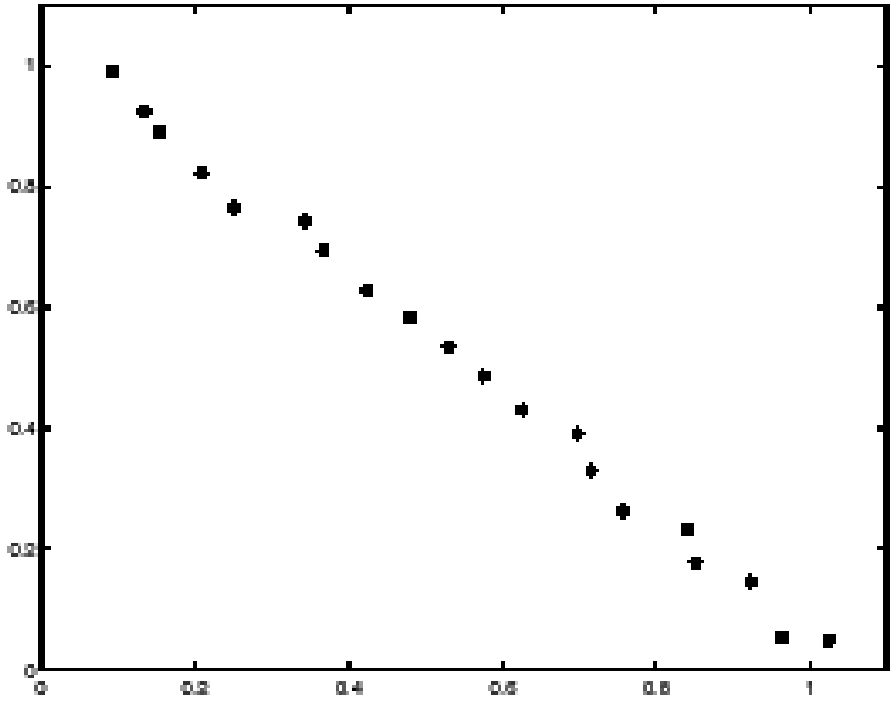
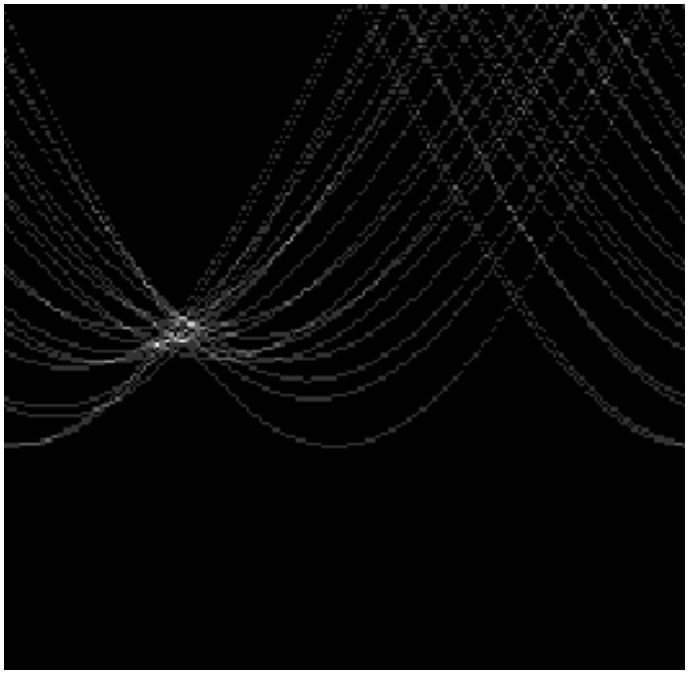


Image space



Votes

Computer Vision Again
Improved Hough Transform Using Perceptual Features

Divide P.O. approaches into two groups.

Parametric: We have a description of what we want, with parameters:

- Examples: lines, circles, constant intensity, constant intensity + Gaussian noise.

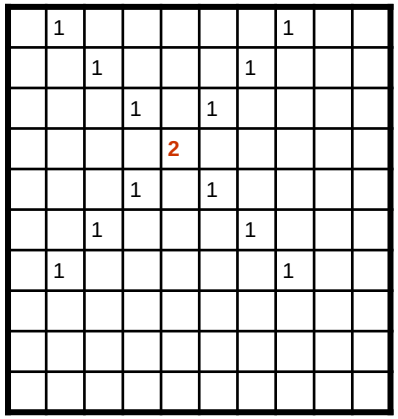
Non-parametric: We have constraints the group should satisfy, or optimality criteria.

- Example: Find the closed curve that is smoothest and that also best follows strong image gradients.

Problems with parameterization
Failure of Hough Transform

How big does the accumulator need to be for the parameterization (m, c)*?*

$A(m, c)$



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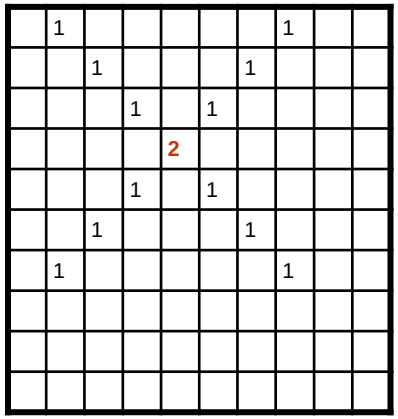


The space of m is huge!

$$-\infty \leq m \leq \infty$$

The space of c is huge!

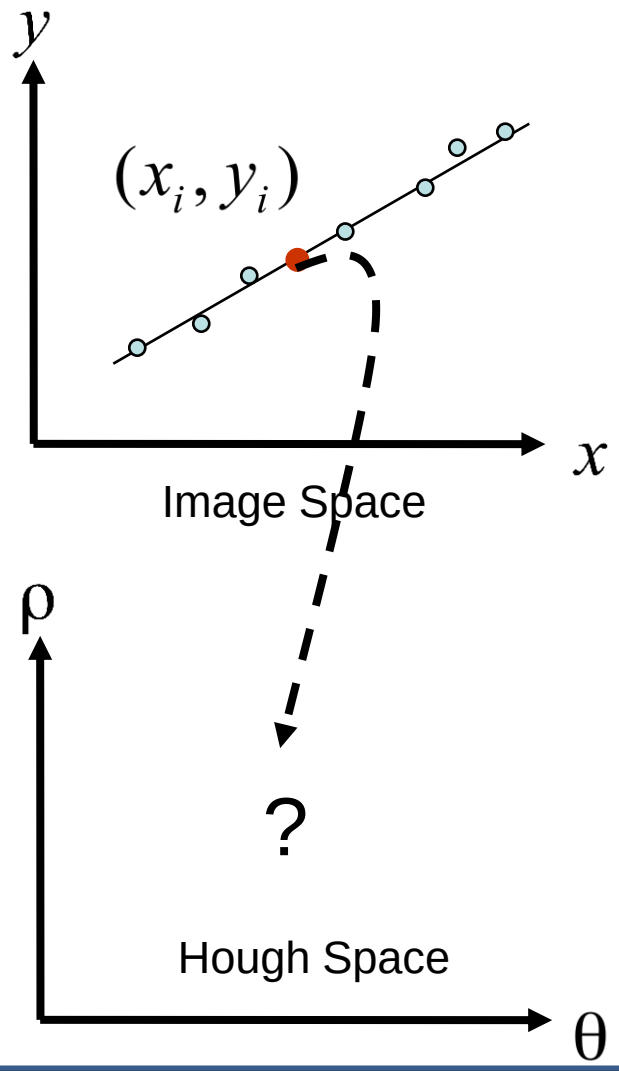
$$-\infty \leq c \leq \infty$$

Better Parameterization
Grouping Line Segments into Curves

Use normal form:

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

Given points find (x_i, y_i) (ρ, θ)



Hough Space Sinusoid

$$0 \le \theta \le 2\pi$$

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

(Finite Accumulator Array Size)

Image and parameter space

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

variables

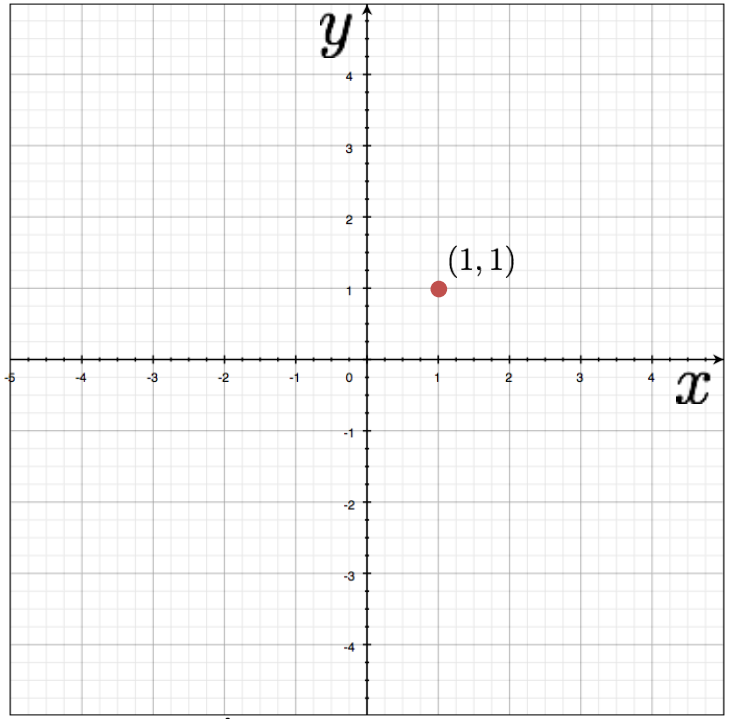
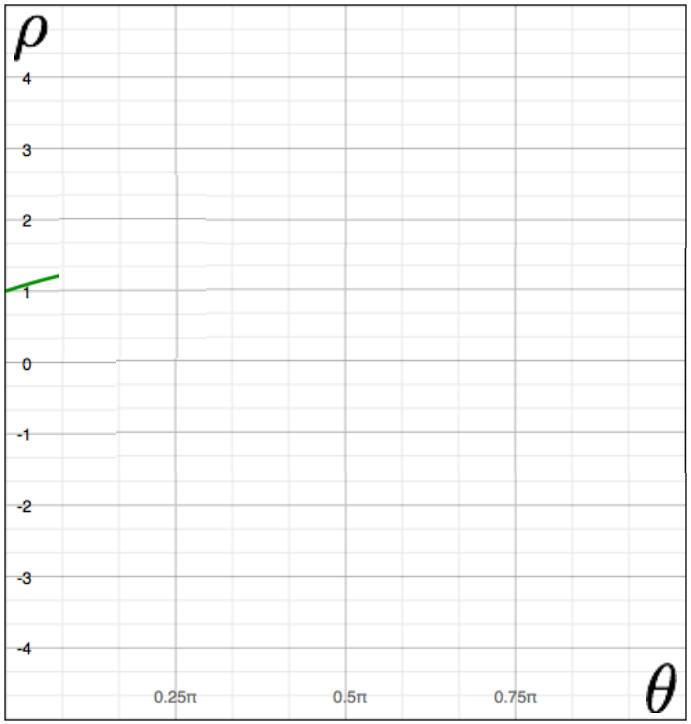


Image space

a point becomes?



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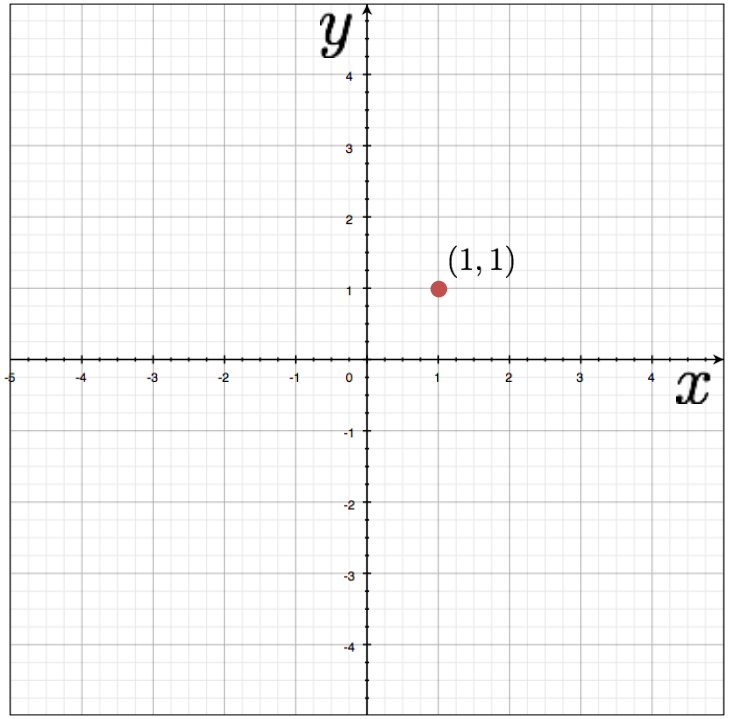

Image space

a point becomes a wave

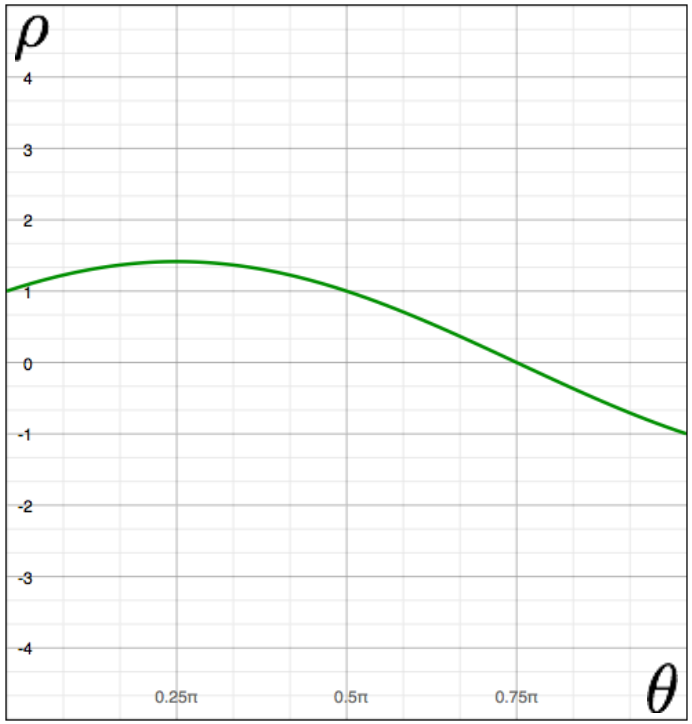

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Image and parameter space

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

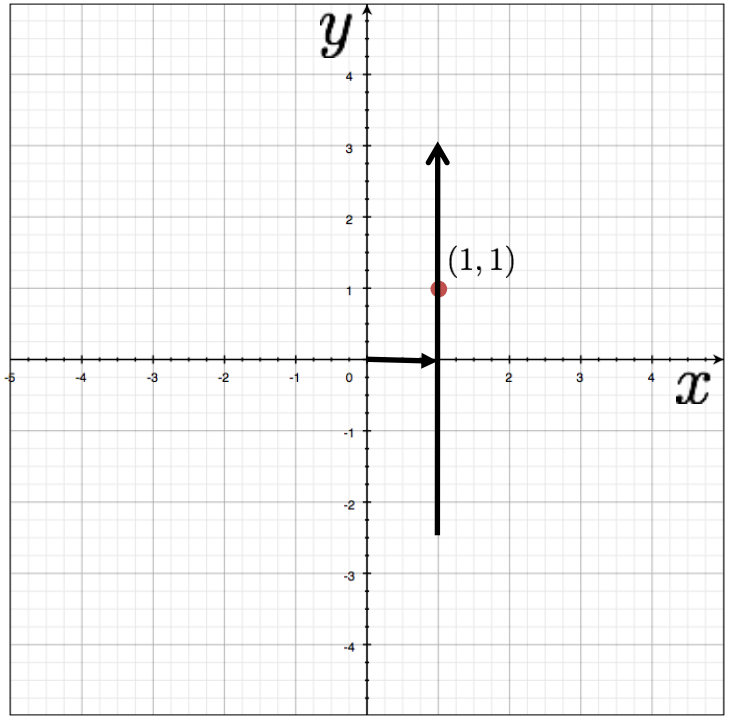
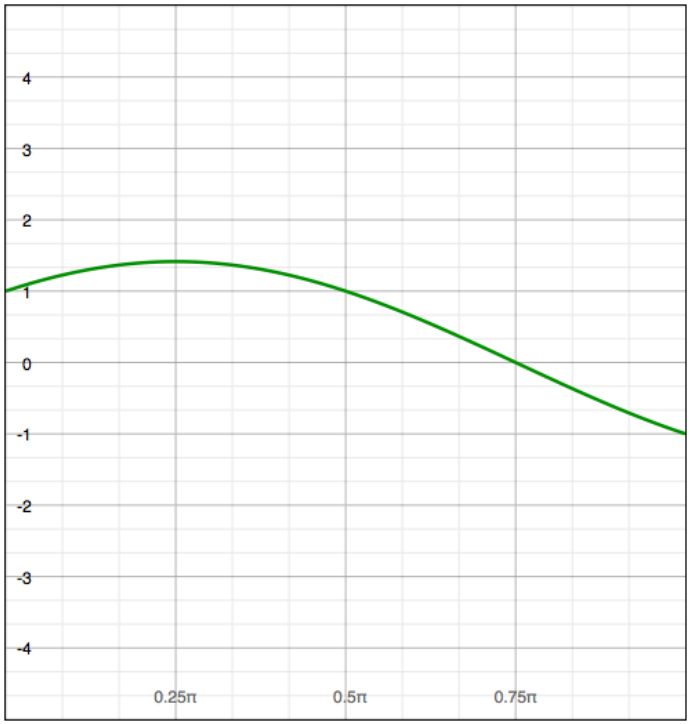


Image space

a line becomes?



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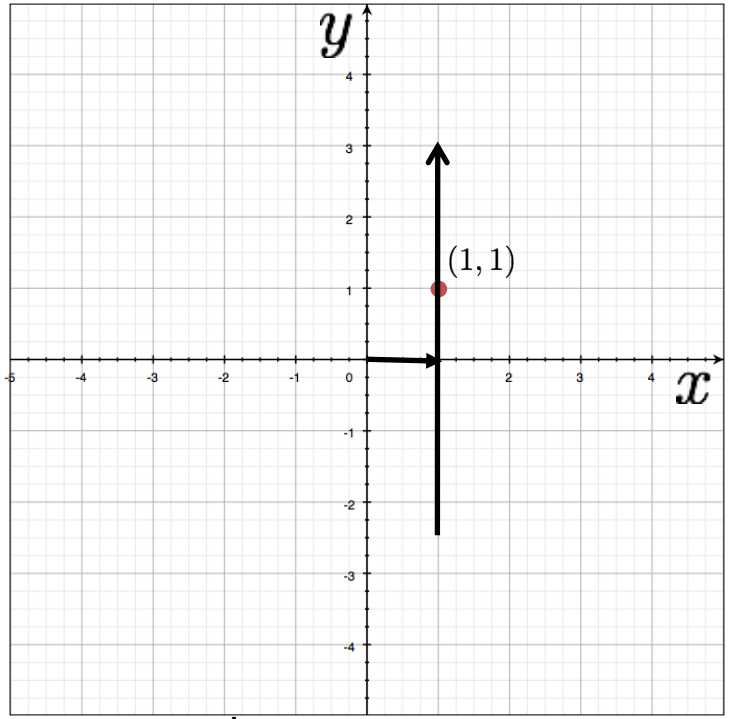
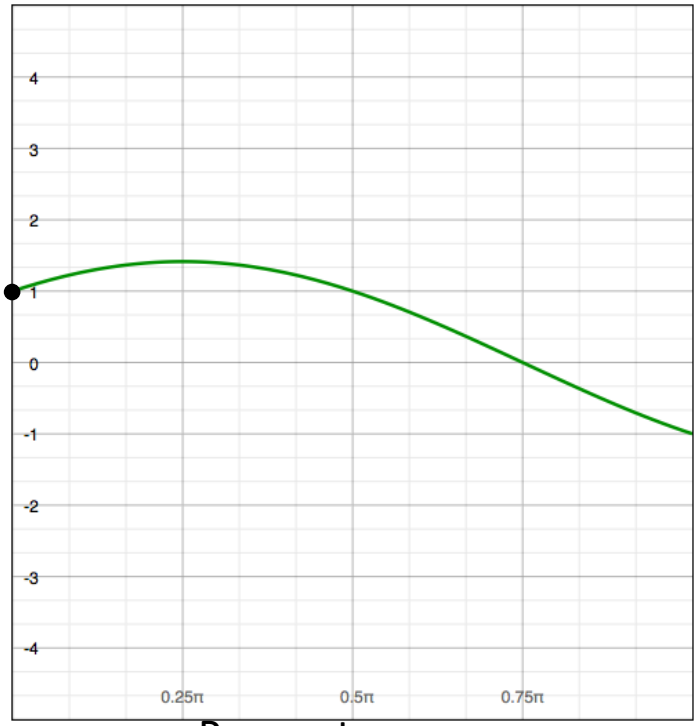


Image space

a line becomes a point



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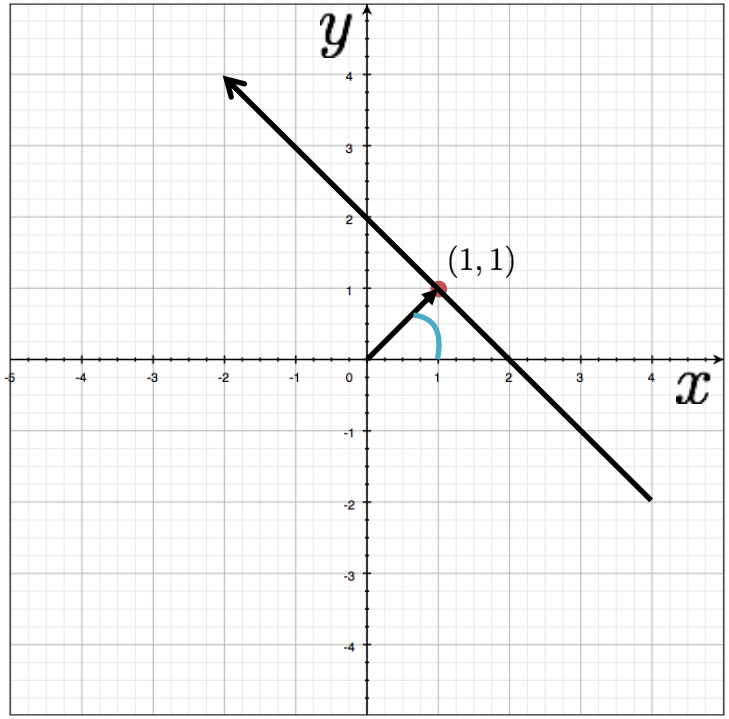
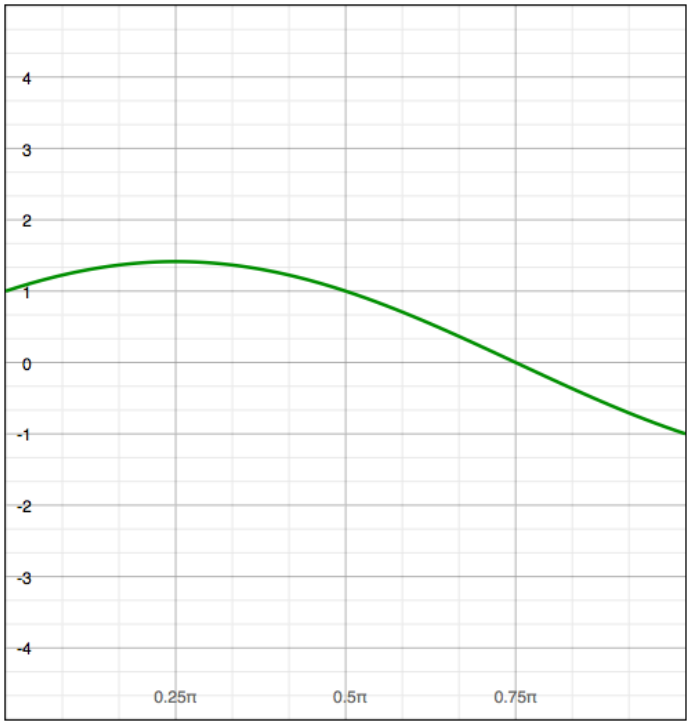


Image space

a line becomes?



Parameter space

Image and parameter space

variables

$$y = mx + b$$

parameters

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

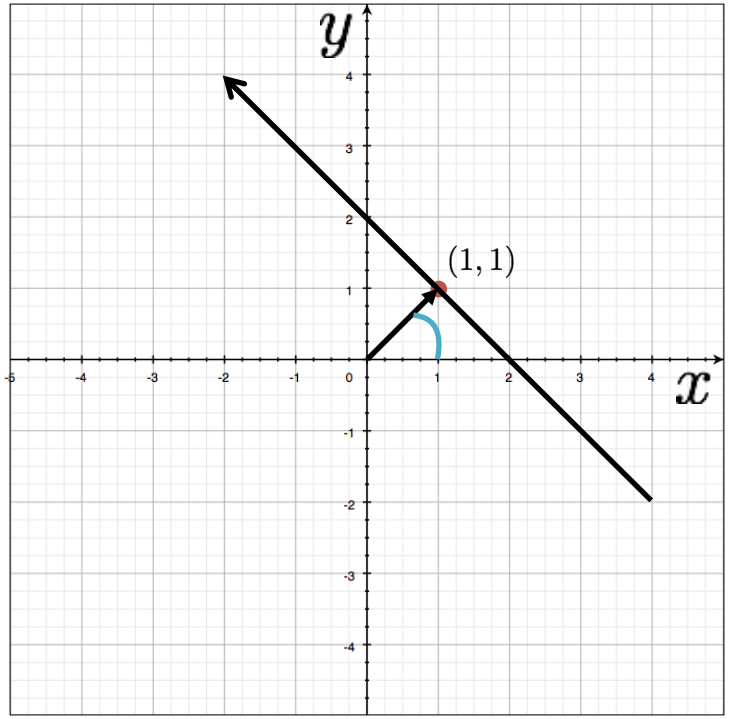
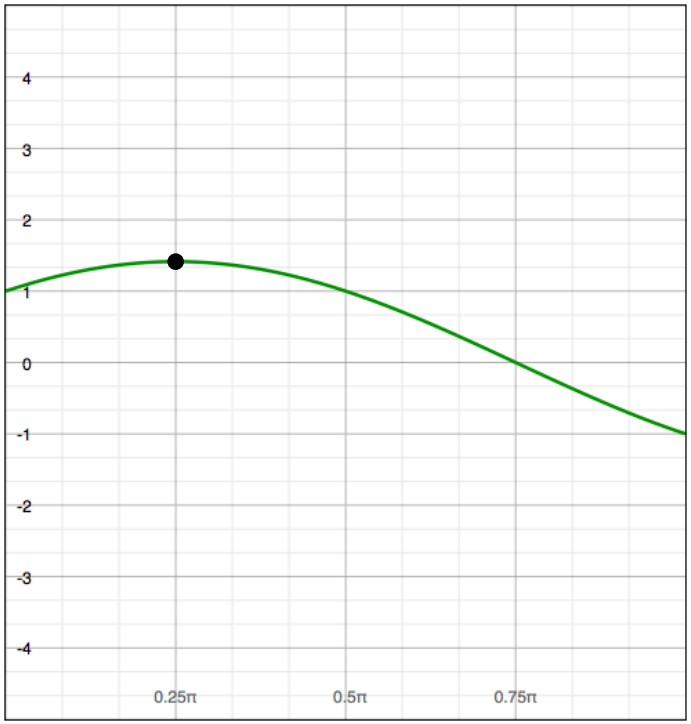


Image space

a line becomes a point



Parameter space

variables

$$y = mx + b$$

parameters

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

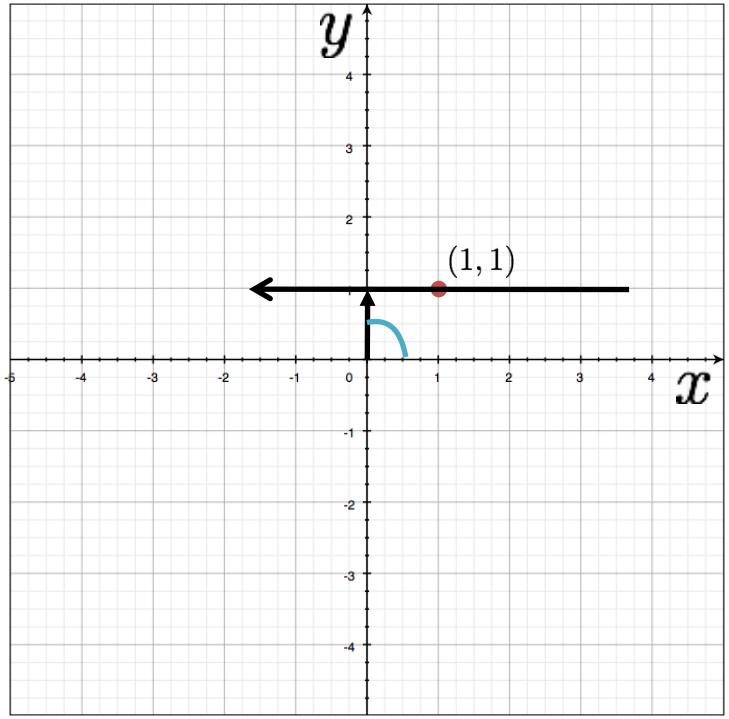
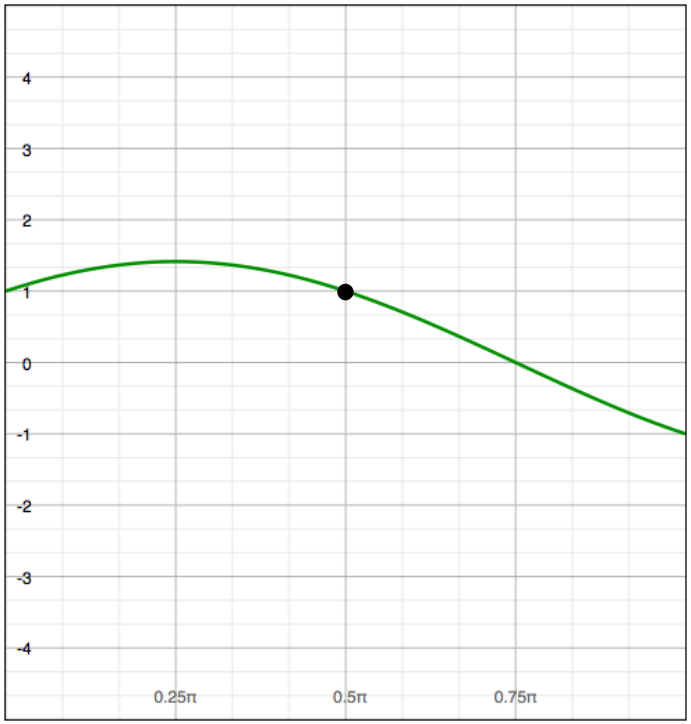


Image space

a line becomes a point



Parameter space

Image and parameter space

variables

$$y = mx + b$$

parameters

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

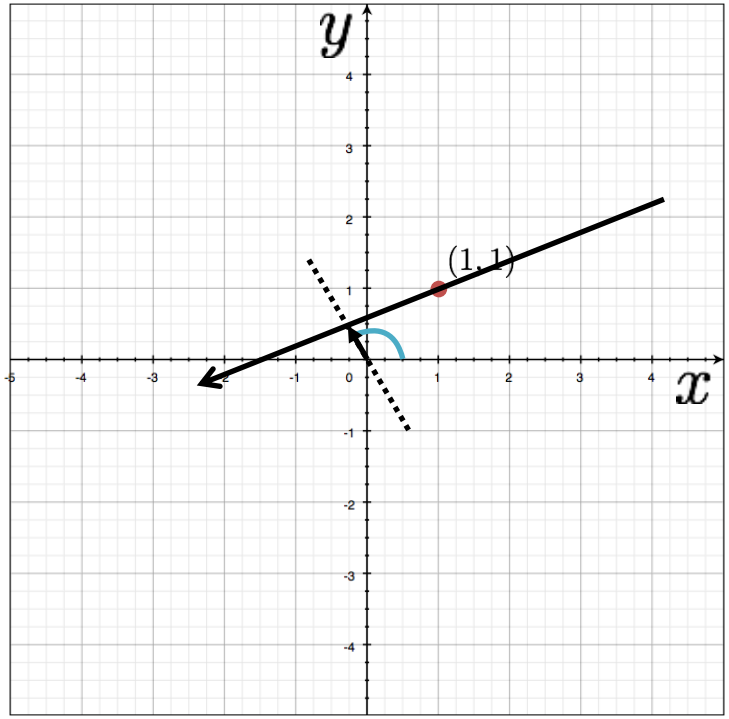
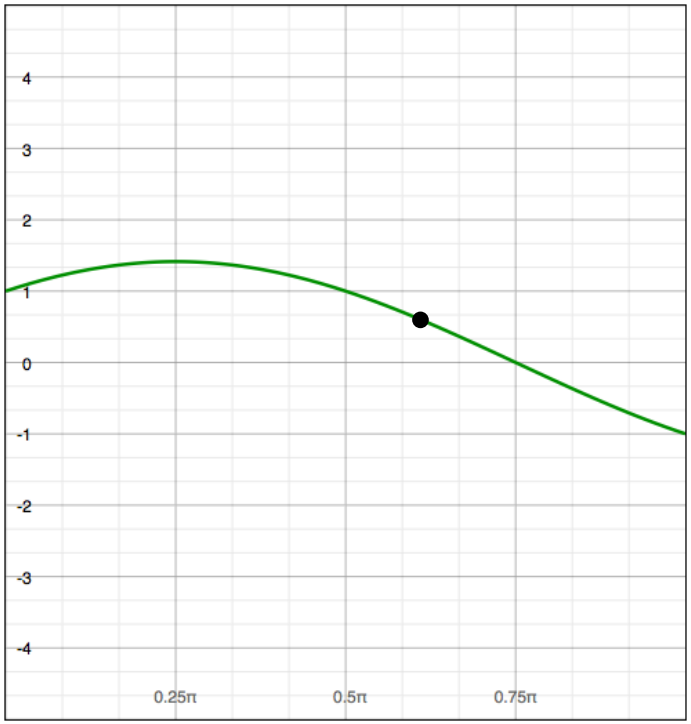


Image space

a line becomes a point



Parameter space

Image and parameter space

variables

$$y = mx + b$$

parameters

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

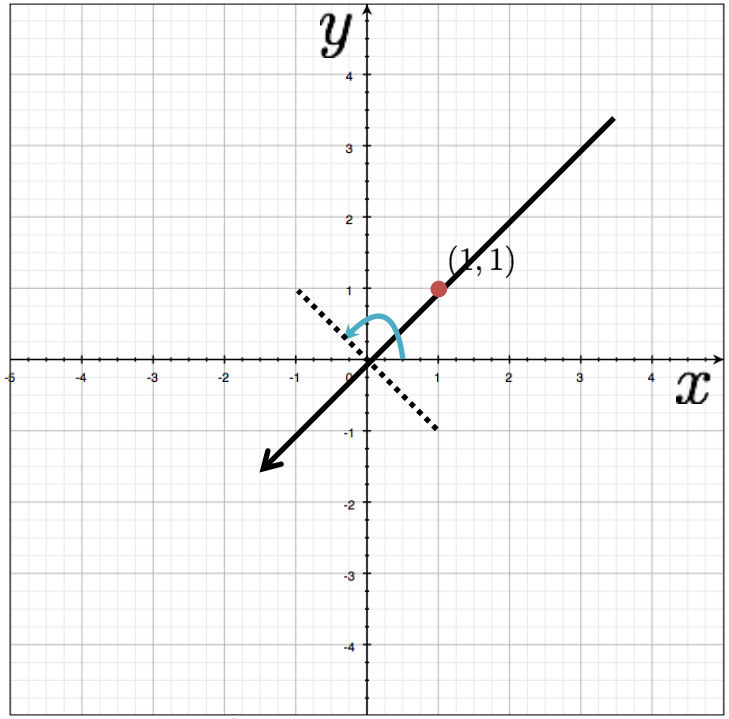
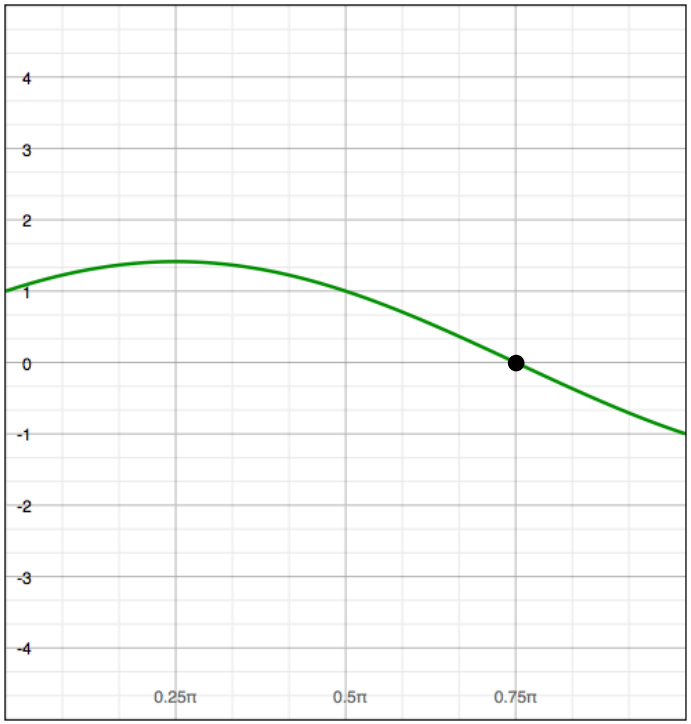


Image space

a line becomes a point



Parameter space

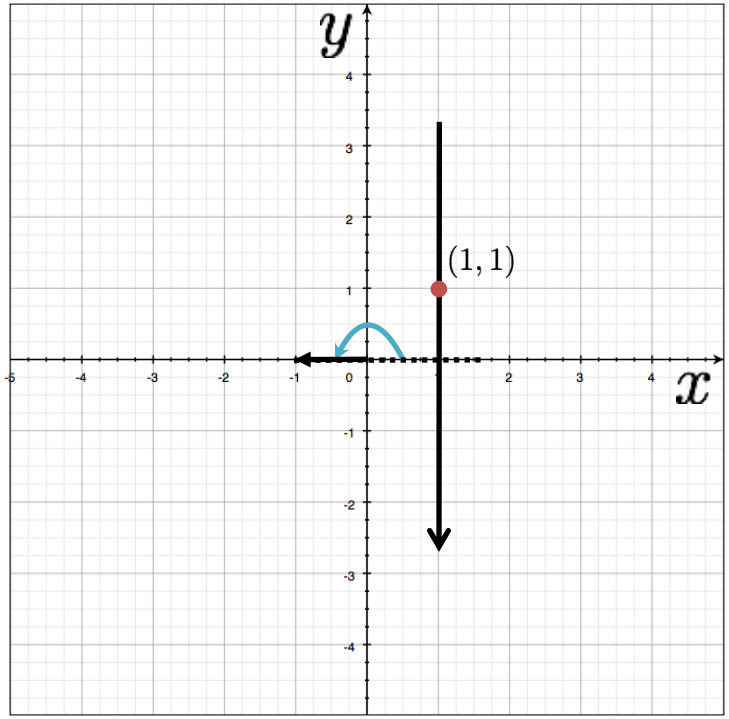
Image and parameter space

variables

$$y = mx + b$$

parameters

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



a line becomes a point

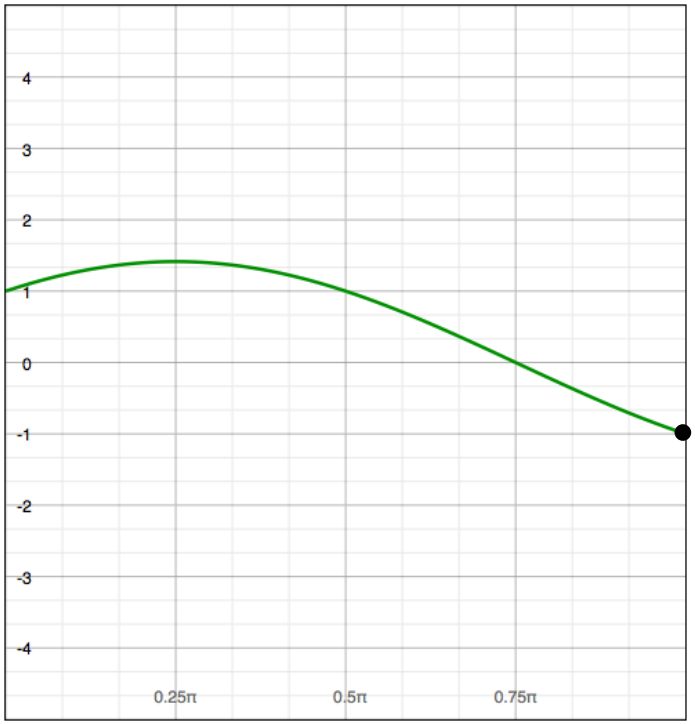


Image and parameter space

variables

$$y = mx + b$$

parameters

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

Wait …why is rho negative?

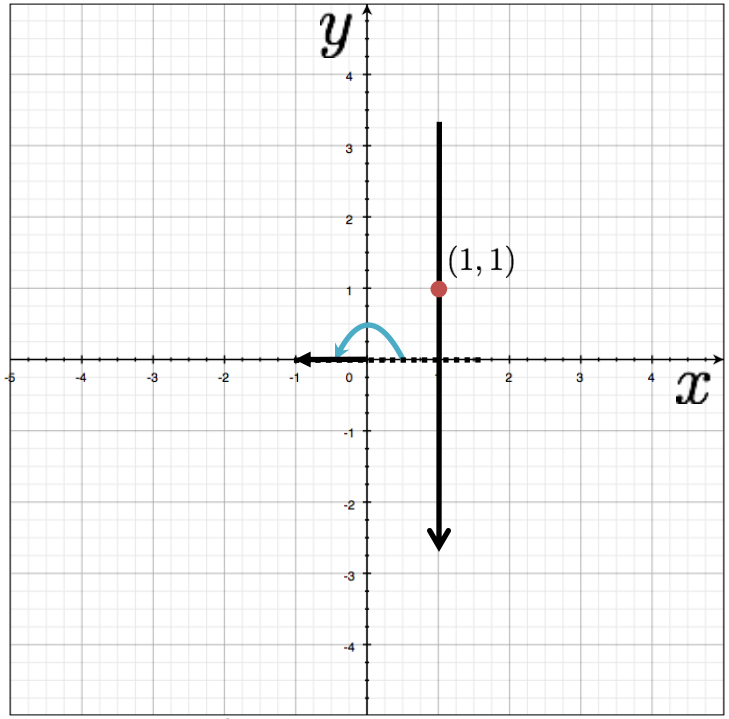
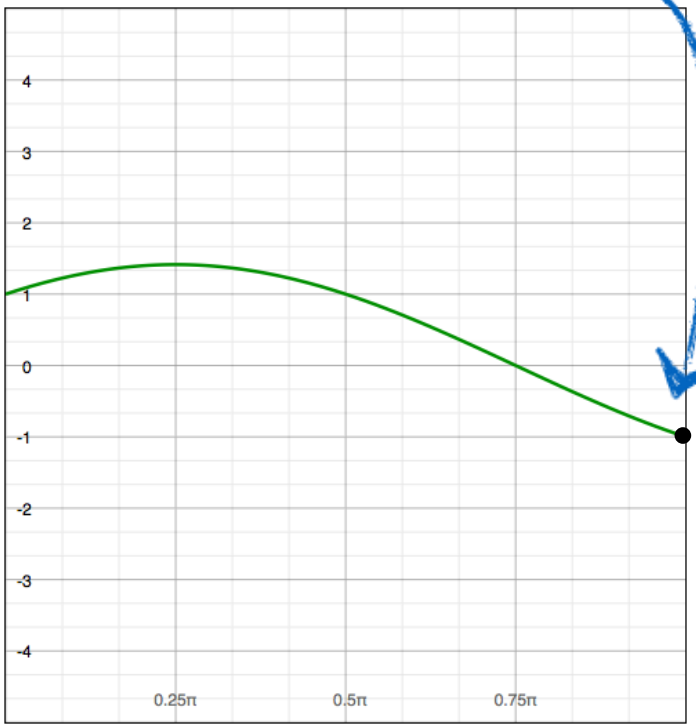


Image space

a line becomes a point



Parameter space

Image and parameter space

variables

$$y = mx + b$$

parameters

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

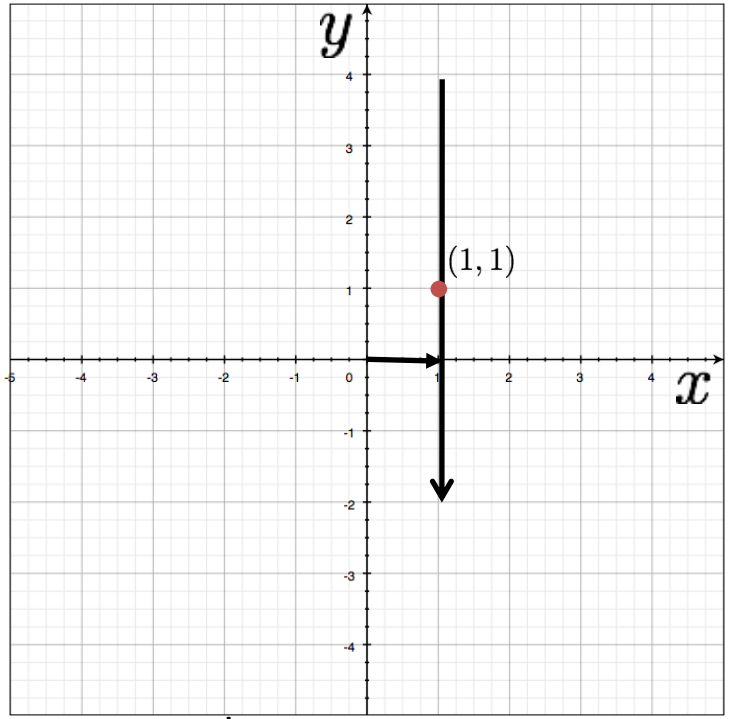
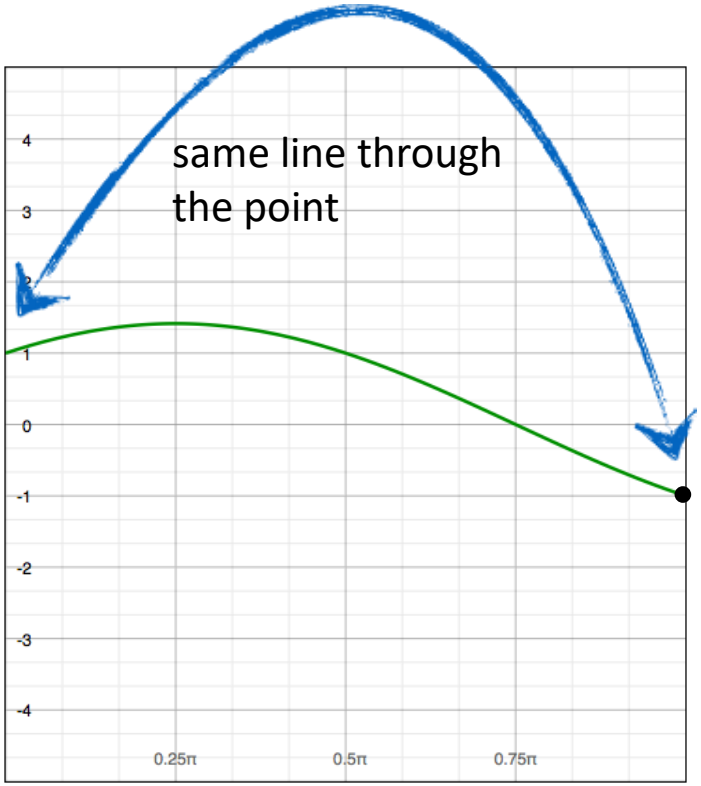


Image space

a line becomes a point



Parameter space

Image and parameter space

variables

$$y = mx + b$$

parameters

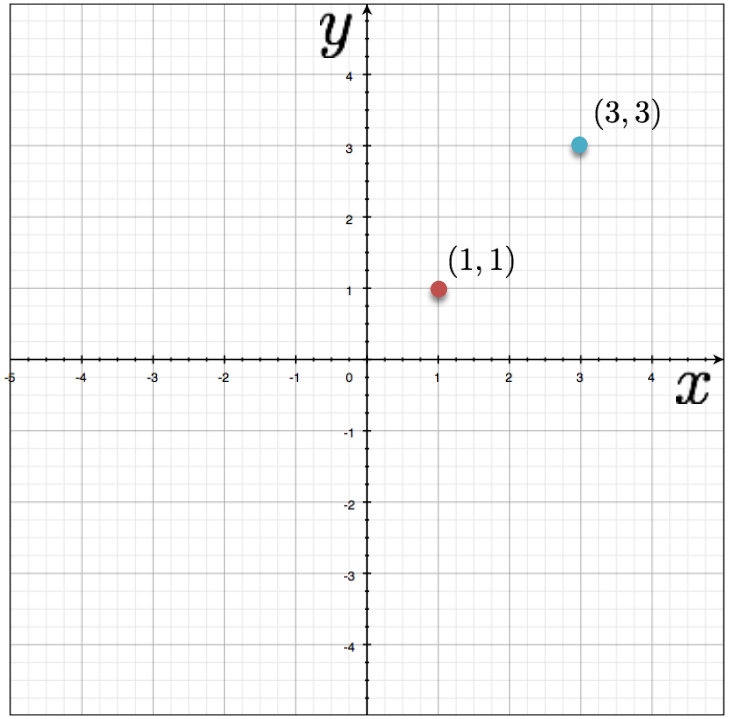
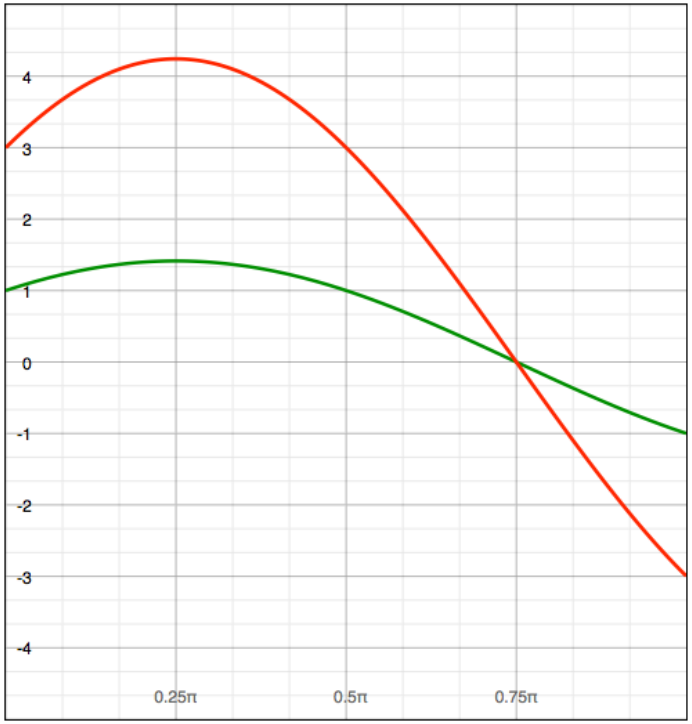


Image space

two points become ?



Parameter space

Image and parameter space

variables

$$y = mx + b$$

parameters

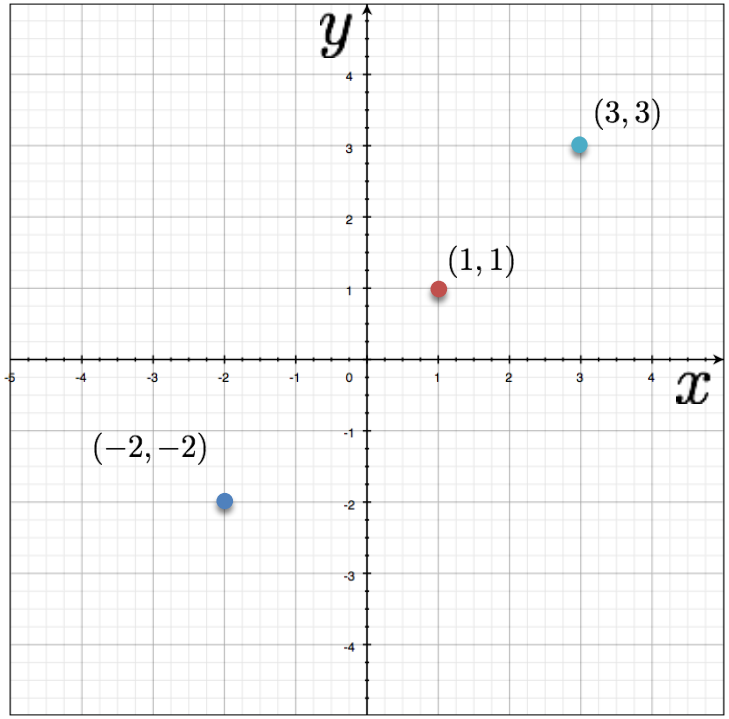
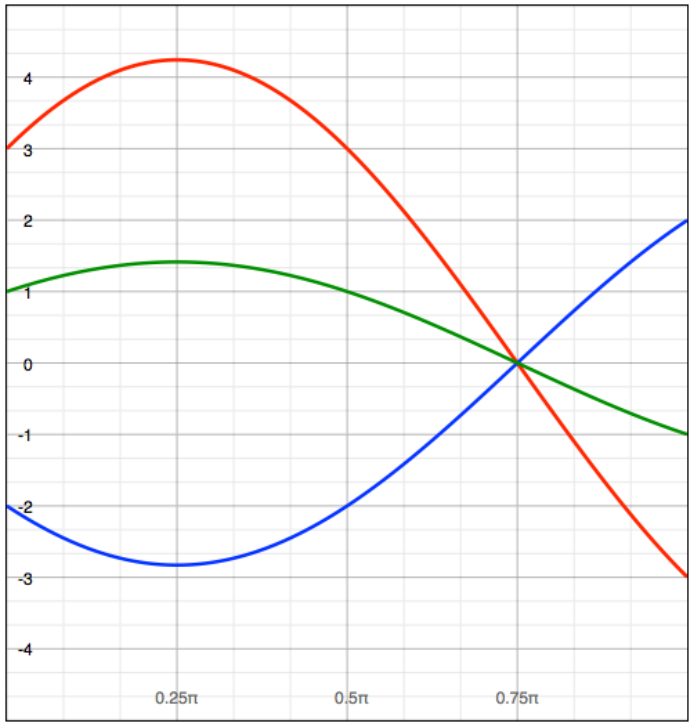


Image space

three points become ?



Parameter space

Image and parameter space

variables

$$y = mx + b$$

parameters

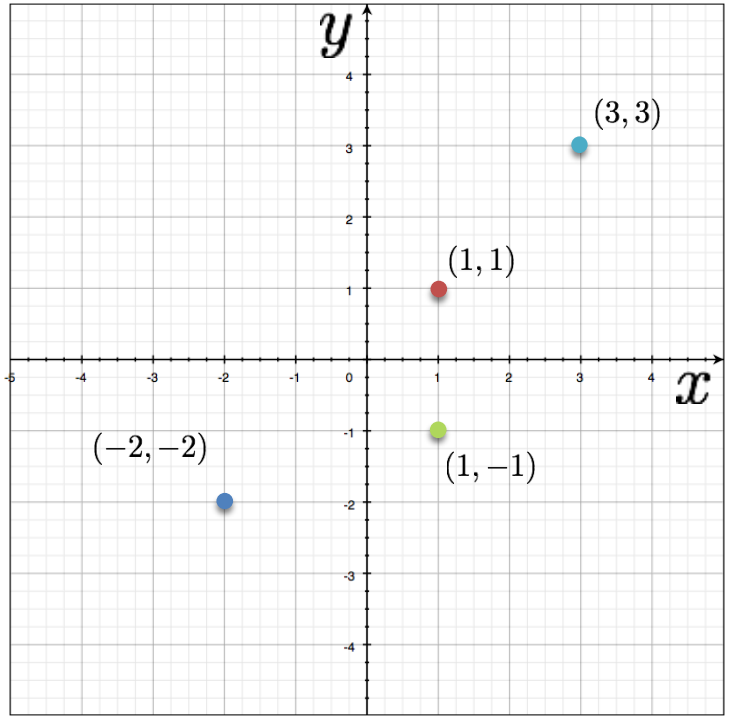
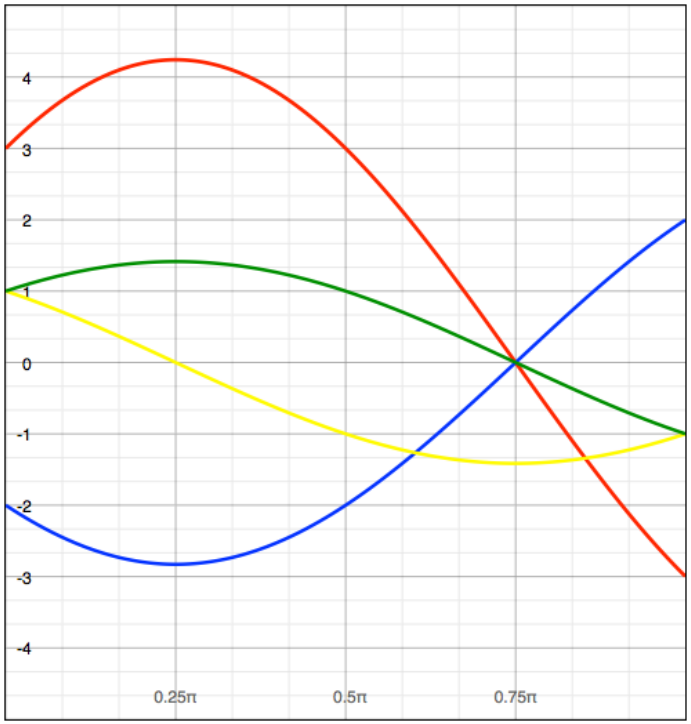


Image space

four points become ?



Parameter space

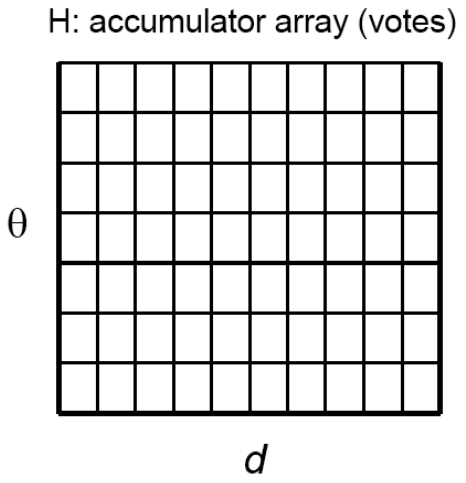
Implementation

1. Initialize accumulator H to all zeros

2. For each edge point (x,y) in the image
   For θ = 0 to 180
   ρ = x cos θ + y sin θ
   H(θ, ρ) = H(θ, ρ) + 1
   end
   end

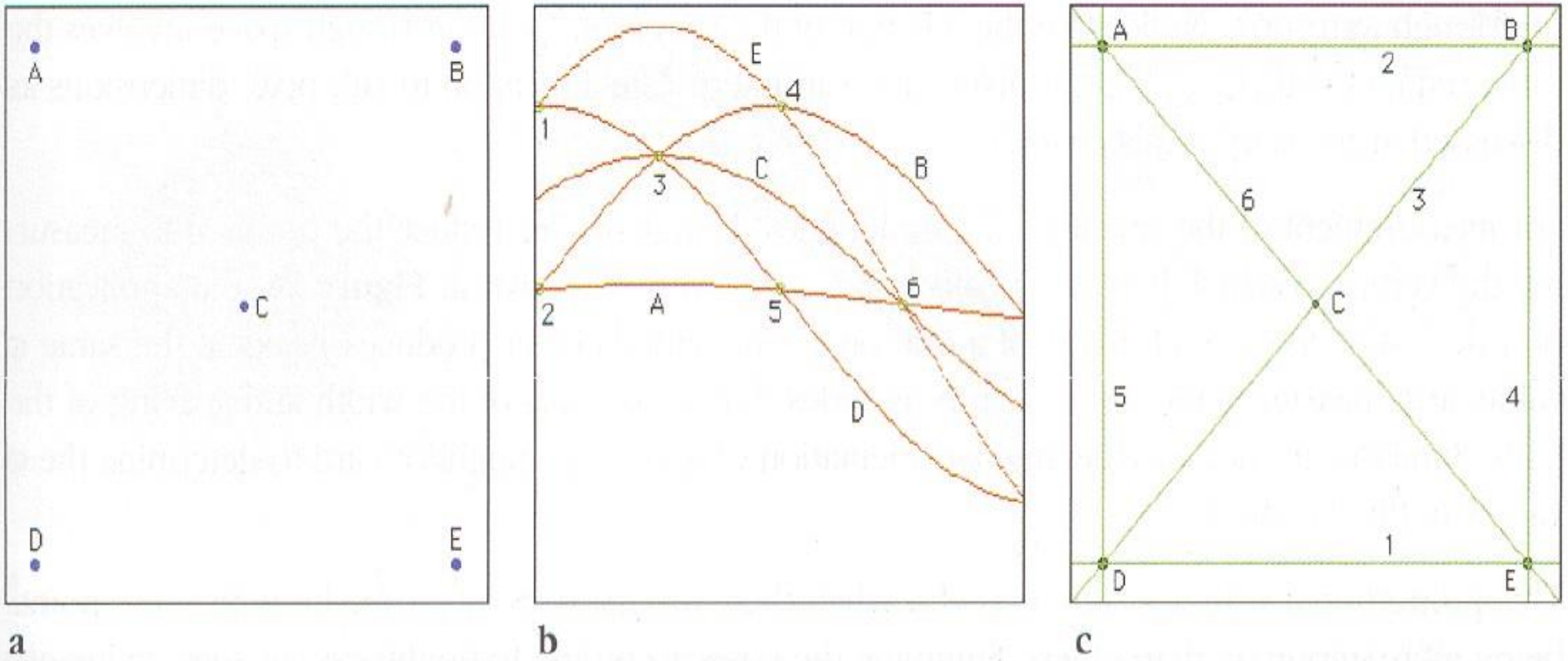
3. Find the value(s) of (θ, ρ) where H(θ, ρ) is a local maximum

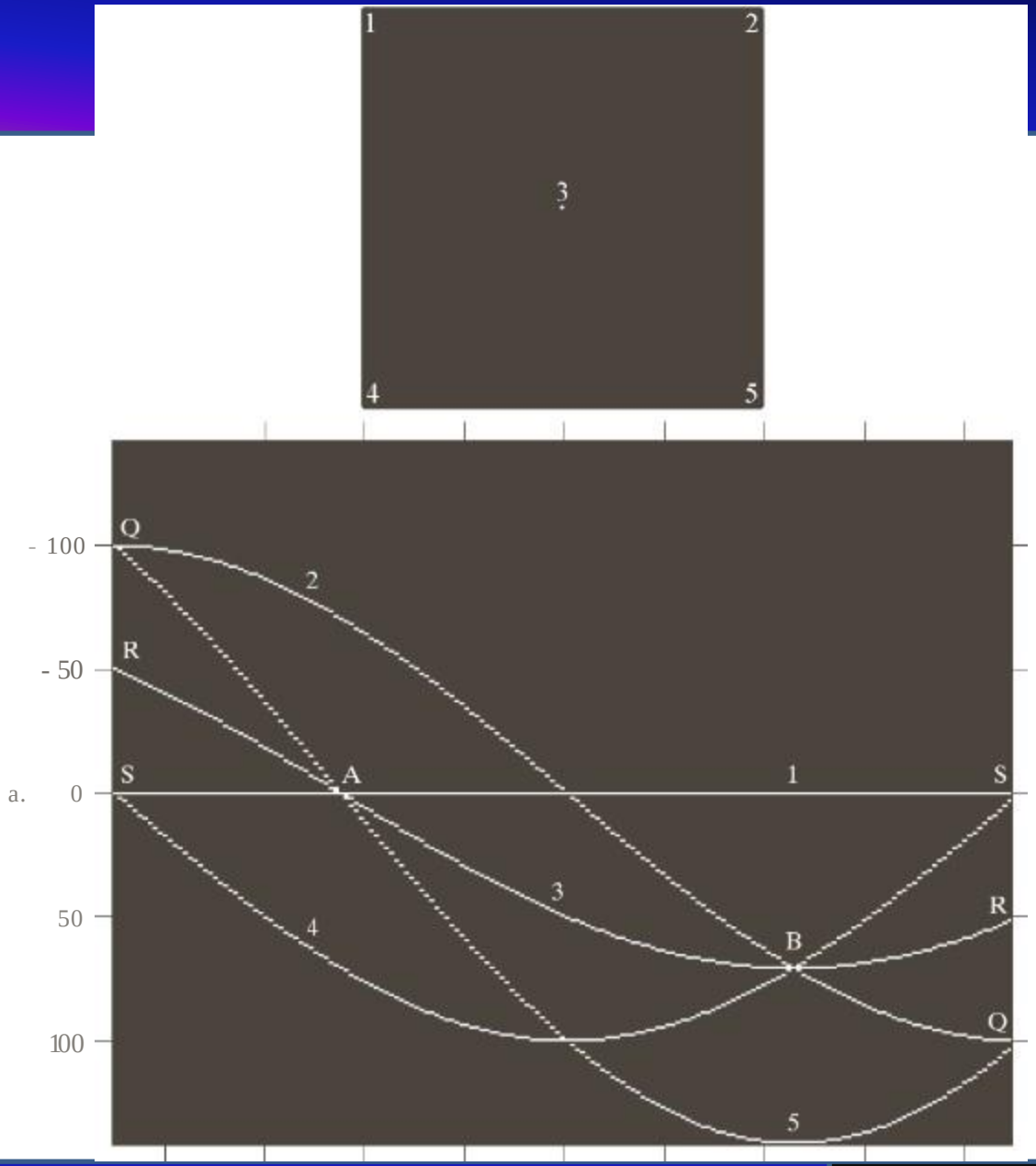
4. The detected line in the image is given by
   ρ = x cos θ + y sin θ



NOTE: Watch your coordinates. Image origin is top left!

Example





a.

a
b

FIGURE 10.33
(a) In1agc of size 101 x 101 pixels, containing five points.
(b) Corresponding parameter space. (The points in (a) were enlarged to make them easier to see.)

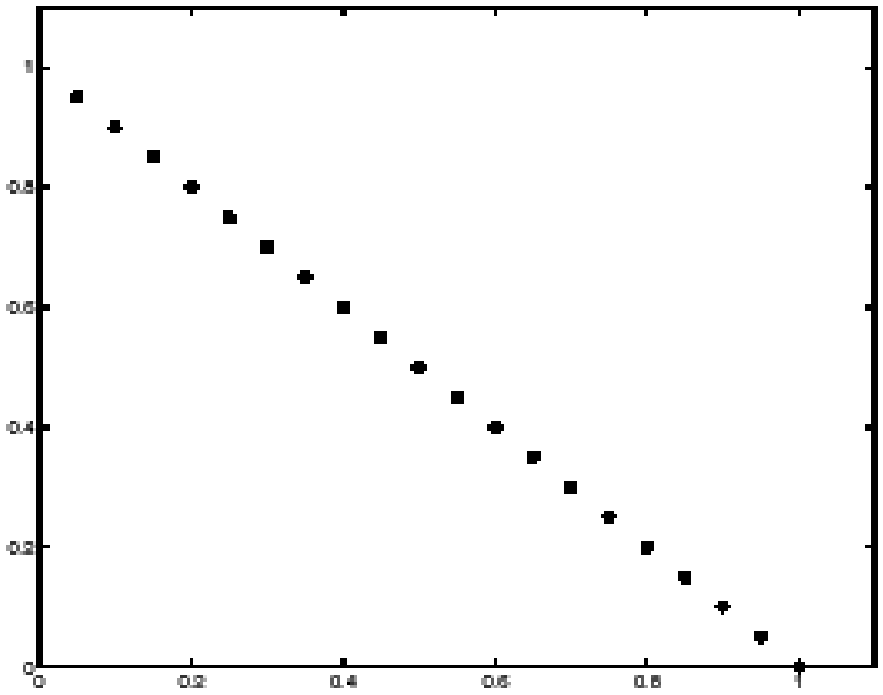
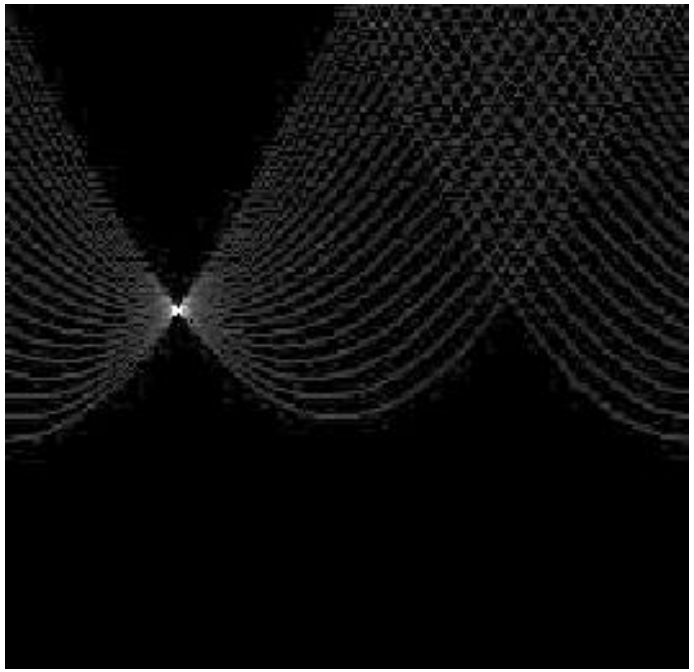
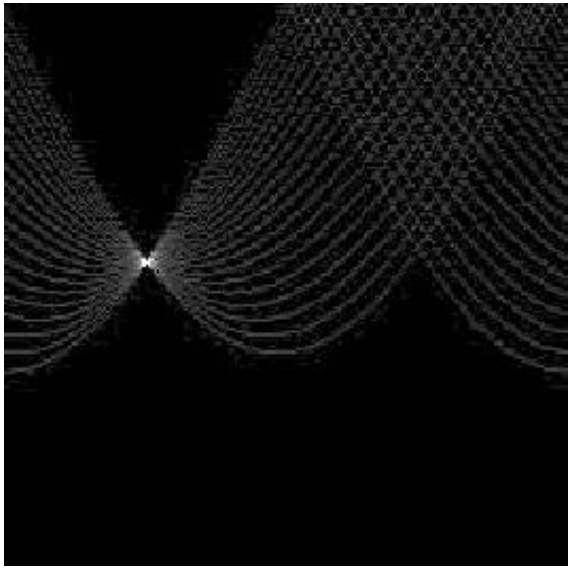
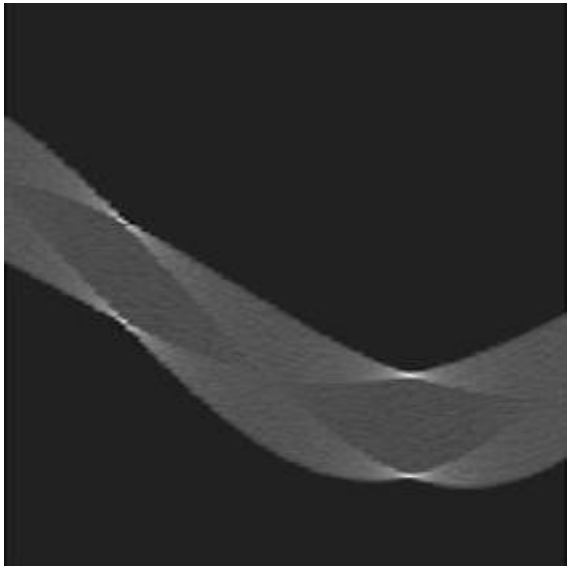
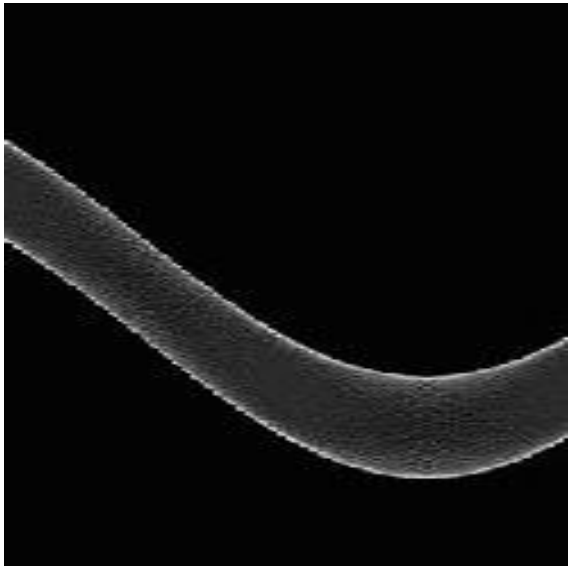


Image space



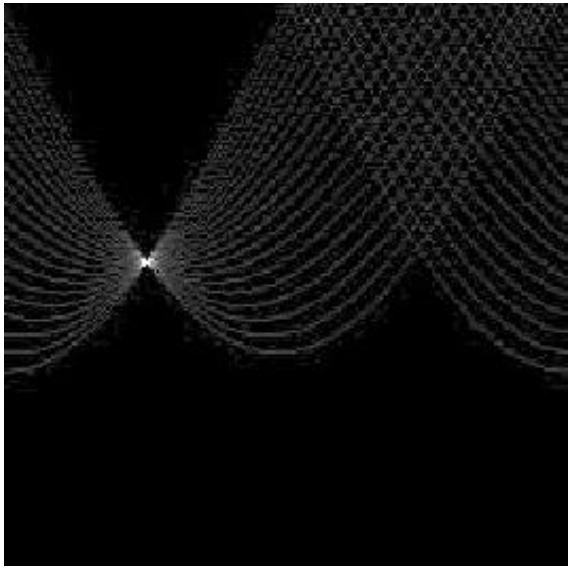
Votes

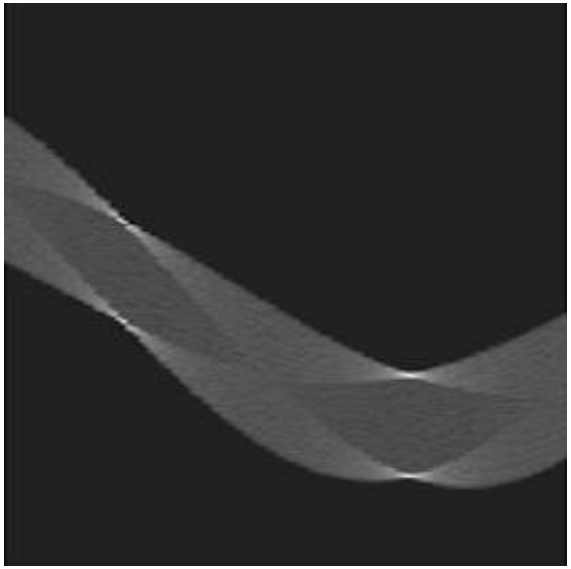
Basic shapes
(in parameter space)

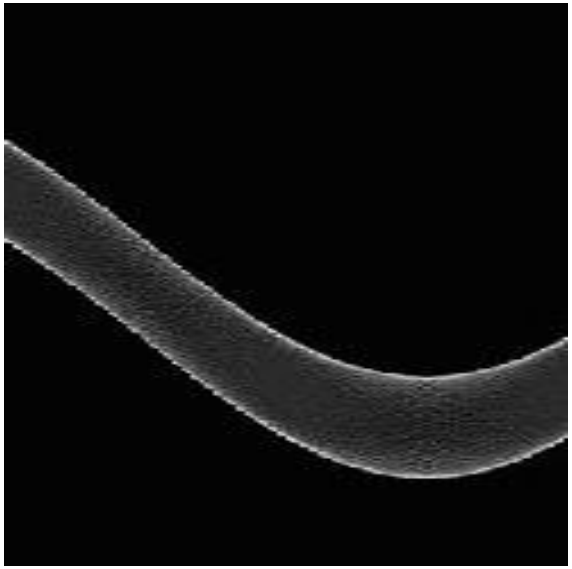




can you guess the shape?

Basic shapes
(in parameter space)

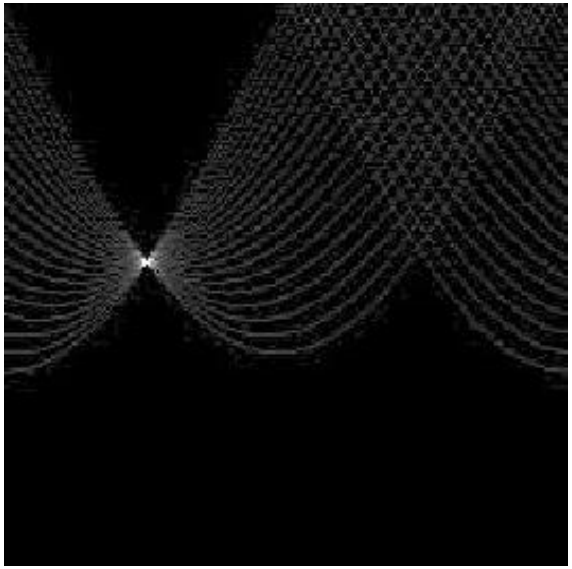




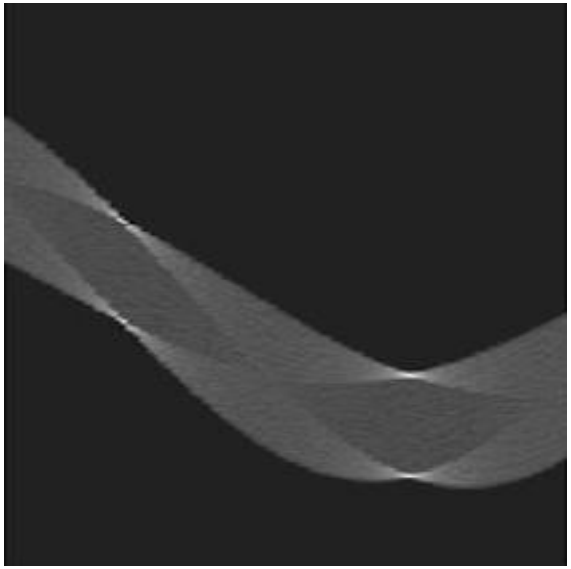


line

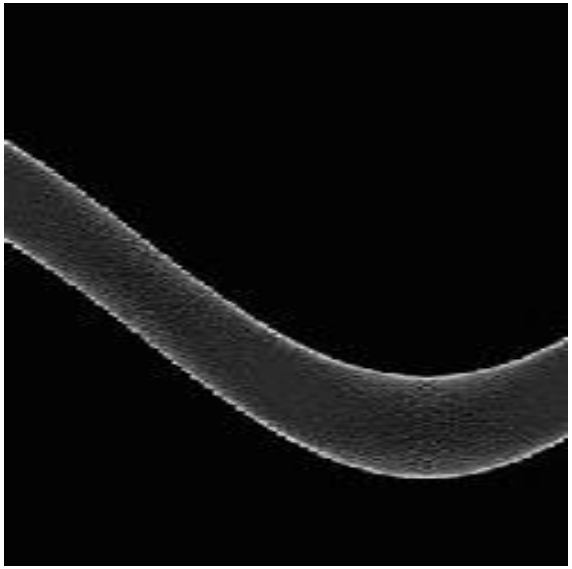
Basic shapes
(in parameter space)



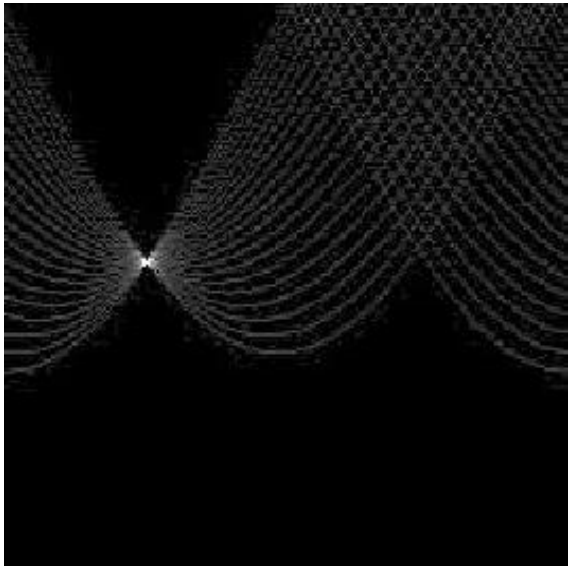
line



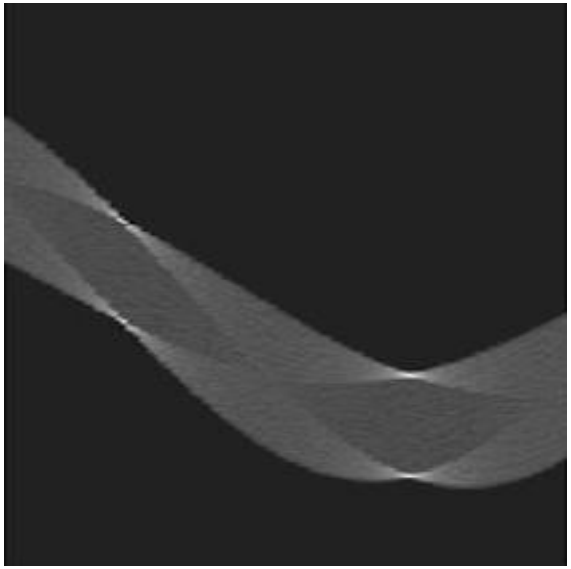
rectangle



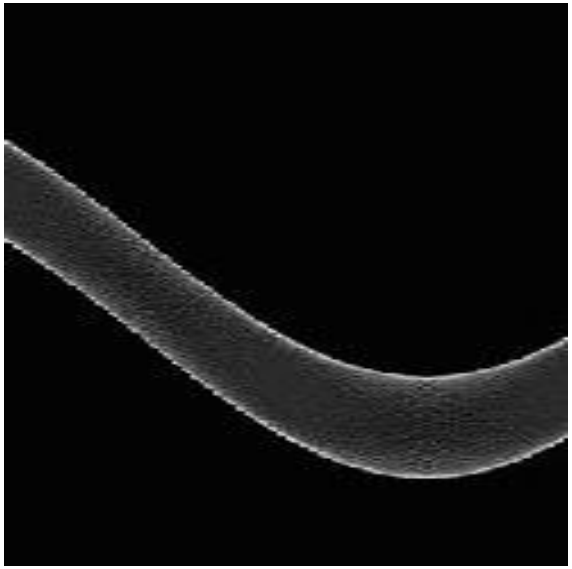
Basic shapes
(in parameter space)



line

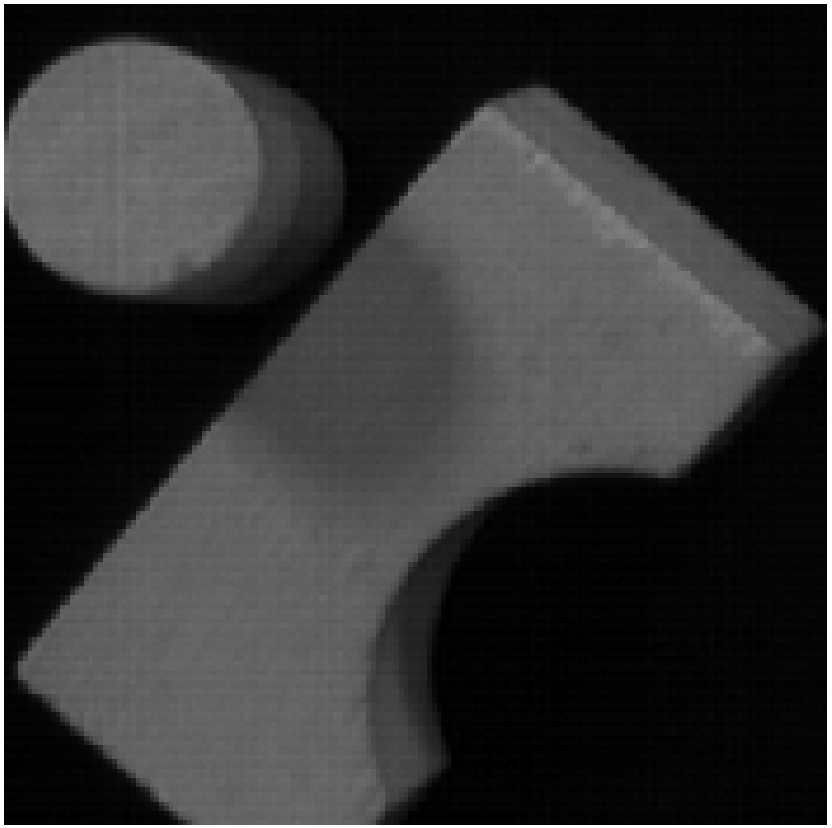


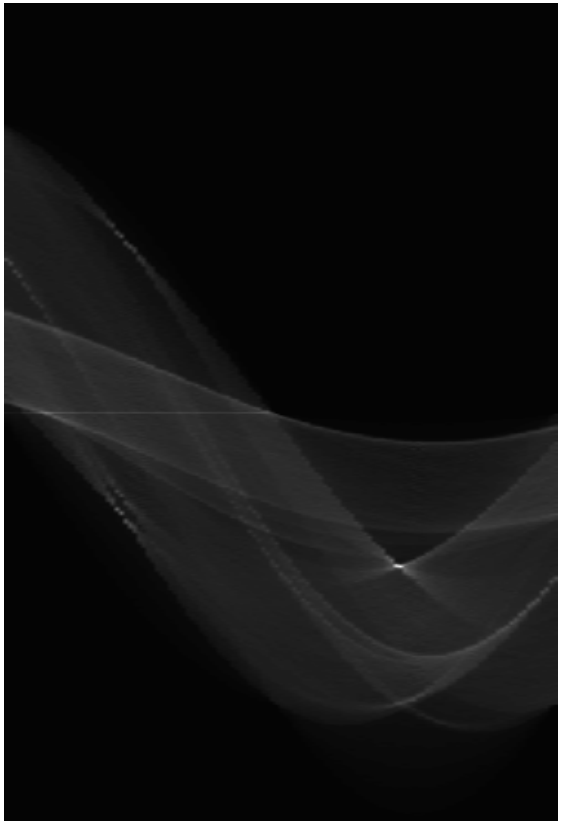
rectangle



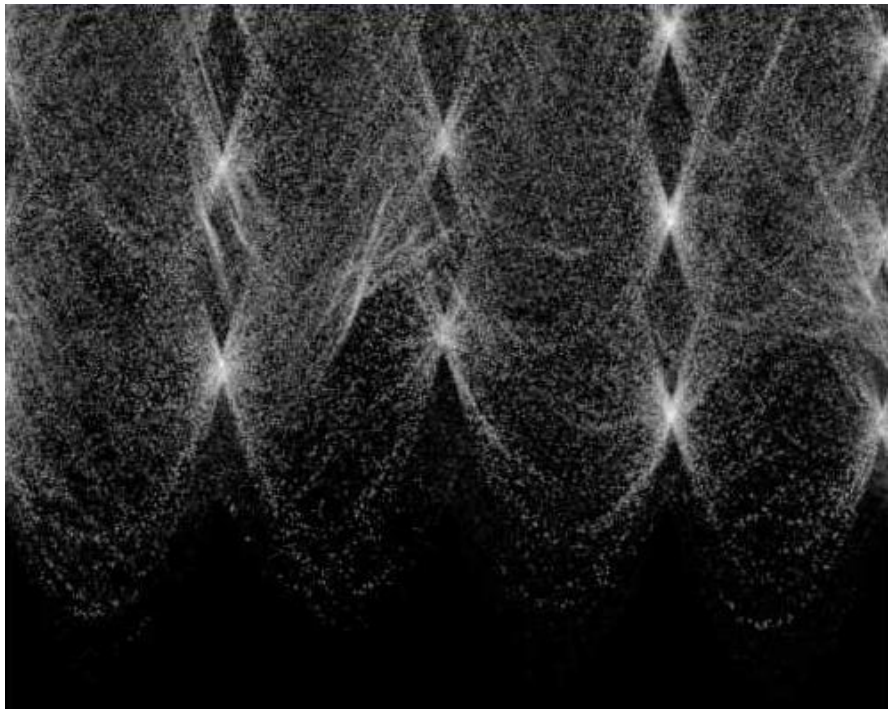
circle

Basic shapes
(in parameter space)



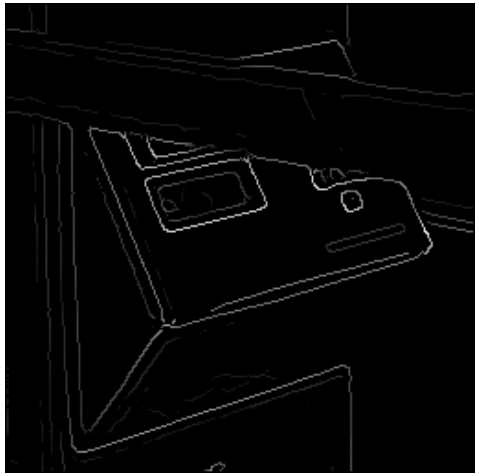


More complex image

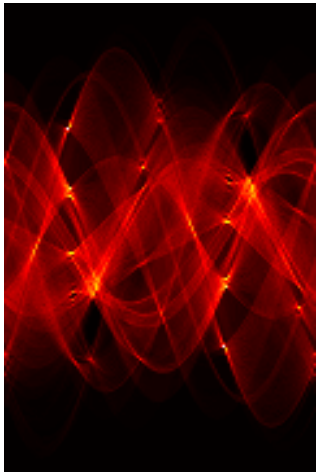


Real-world example

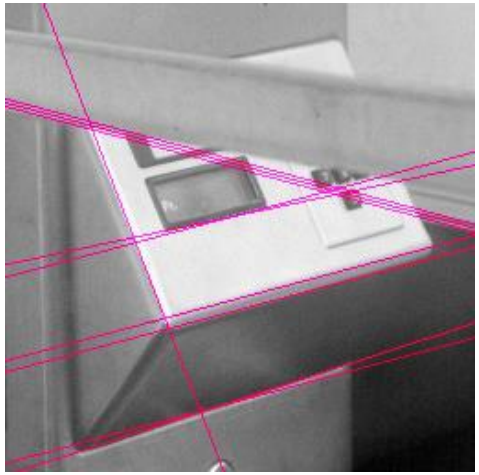
Original



Edges



parameter space



Hough Lines

Hough Circles

Let's assume radius known

parameters

$$(x-a)^2+(y-b)^2=r^2$$

variables

parameters

$$(x-a)^2+(y-b)^2=r^2$$

variables

What is the dimension of the parameter space?

Hough Circles

parameters

$$(x-a)^2+(y-b)^2=r^2$$

variables

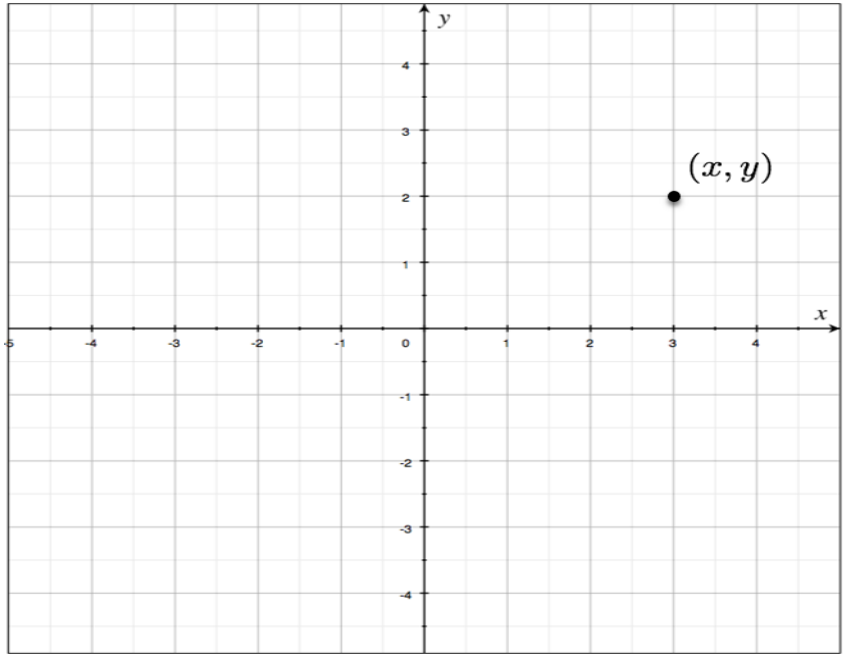
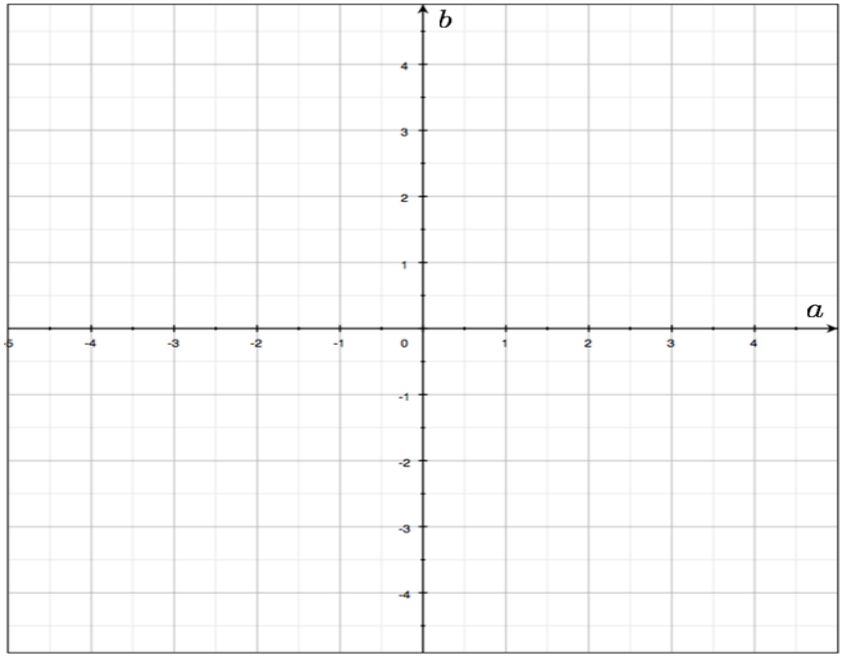


Image space

parameters

$$(x-a)^2+(y-b)^2=r^2$$

variables



Parameter space

What does a point in image space correspond to in parameter space?

Hough Circles

parameters

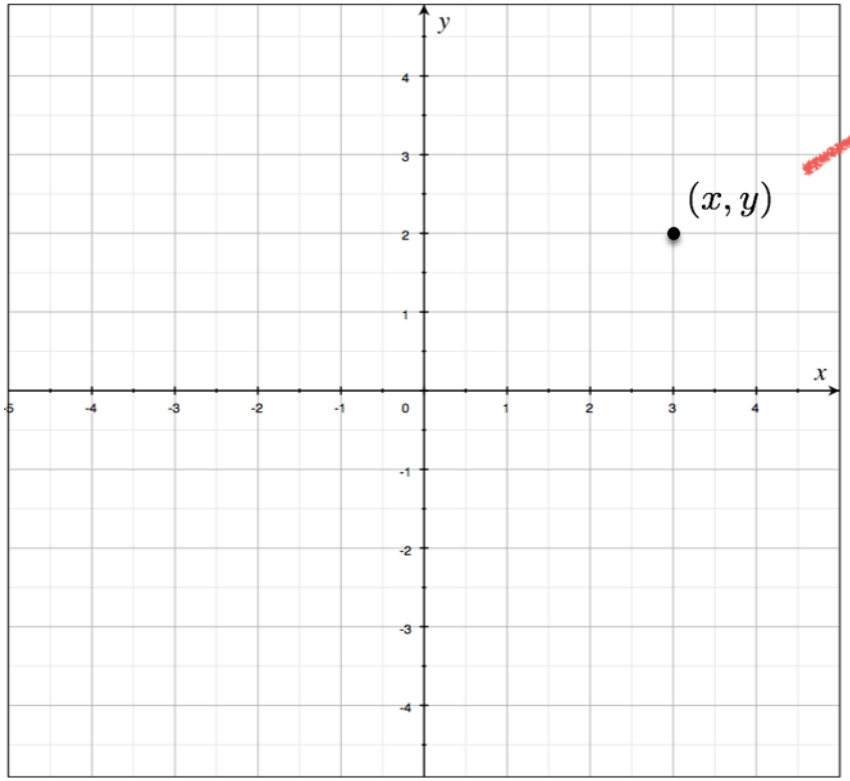
$$(x-a)^2+(y-b)^2=r^2$$

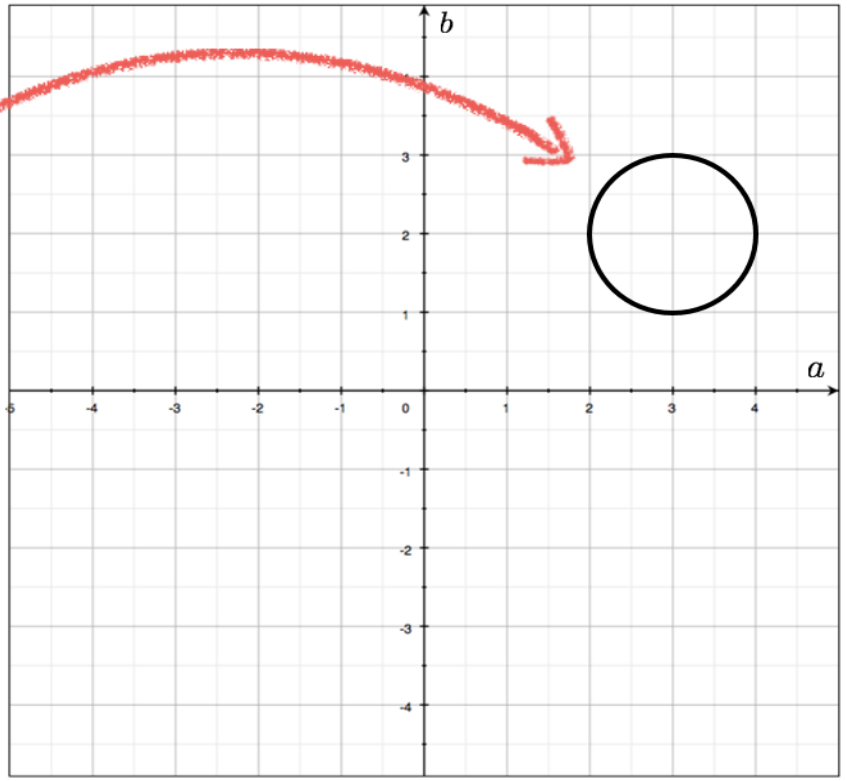
variables

parameters

$$(x-a)^2+(y-b)^2=r^2$$

variables



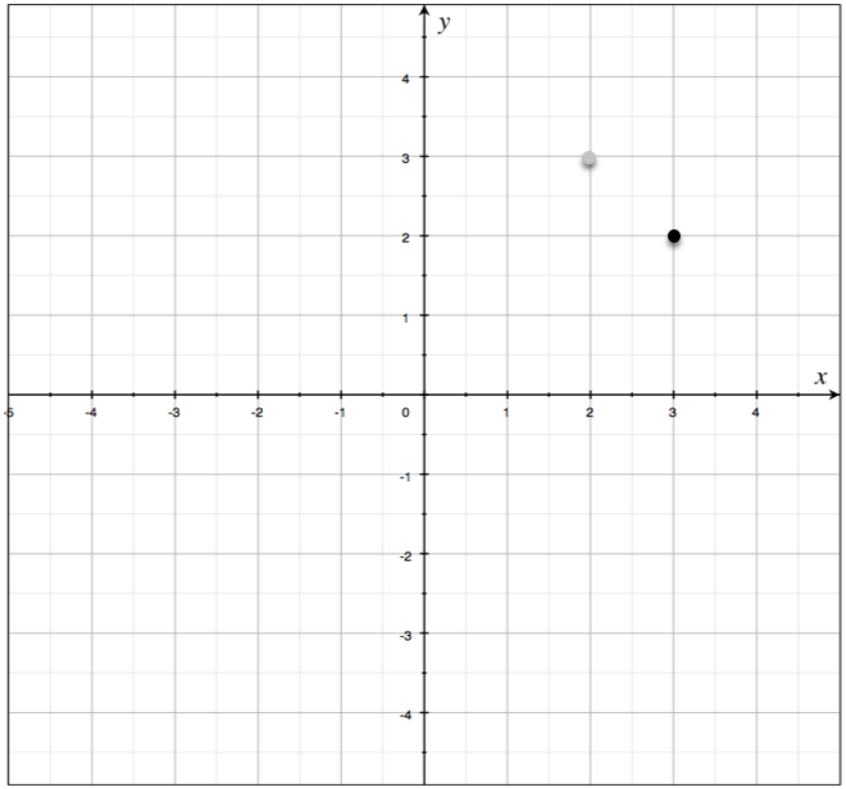


Hough Circles

parameters

$$(x-a)^2+(y-b)^2=r^2$$

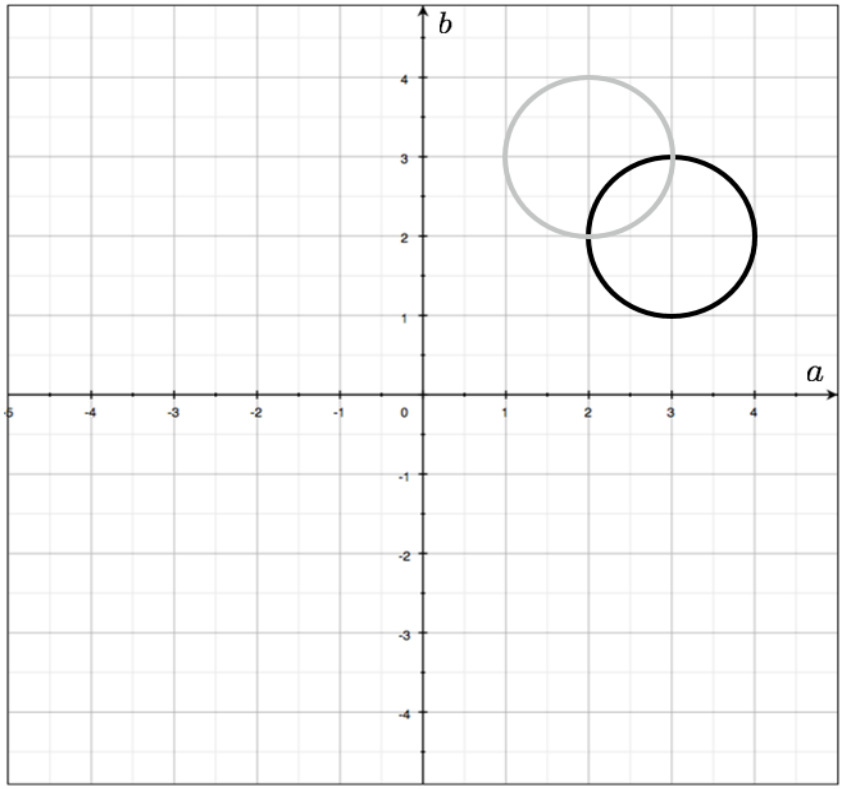
variables



parameters

$$(x-a)^2+(y-b)^2=r^2$$

variables

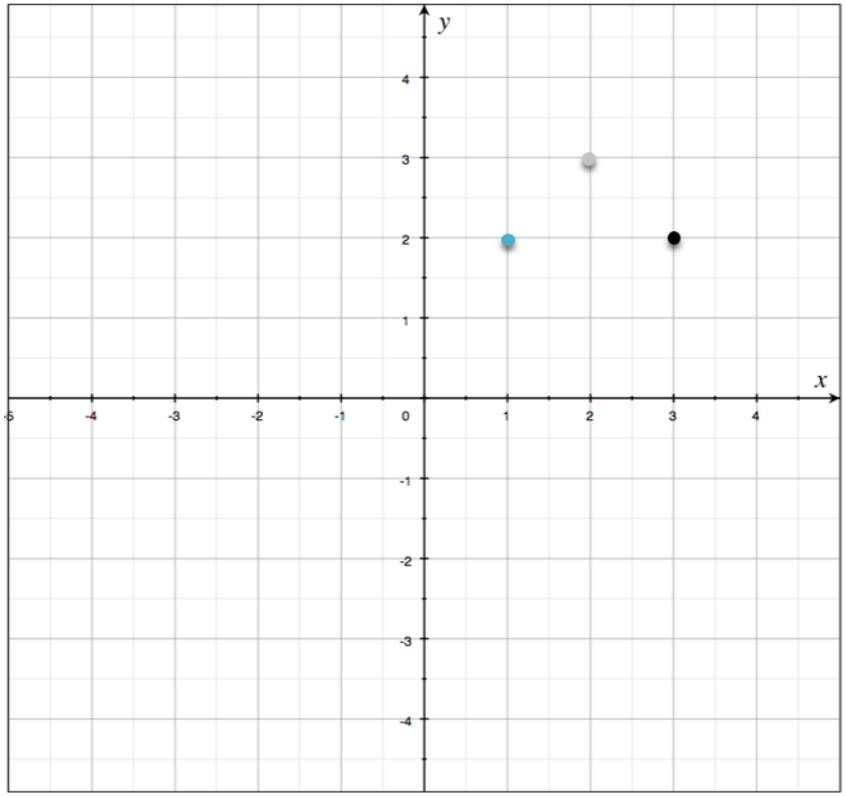


Hough Circles

parameters

$$(x-a)^2+(y-b)^2=r^2$$

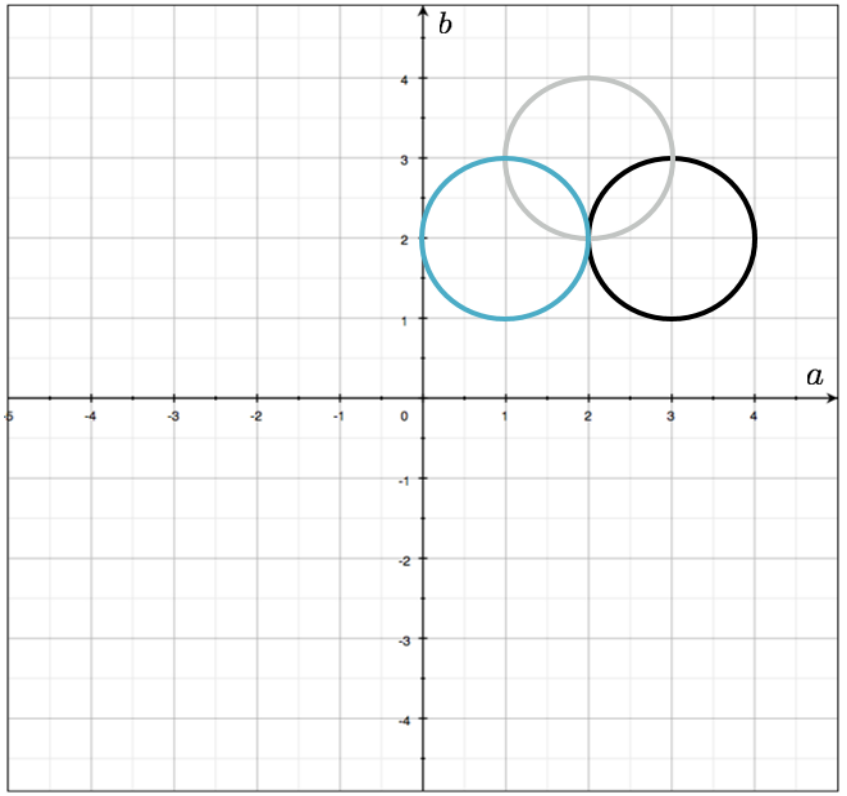
variables



parameters

$$(x-a)^2+(y-b)^2=r^2$$

variables

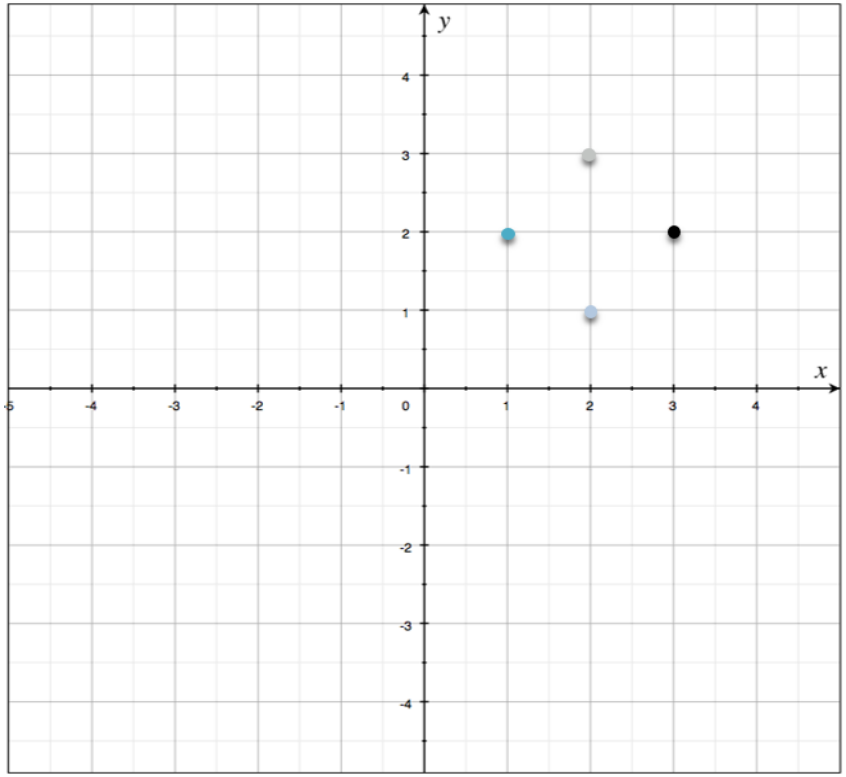


Hough Circles

parameters

$$(x-a)^2+(y-b)^2=r^2$$

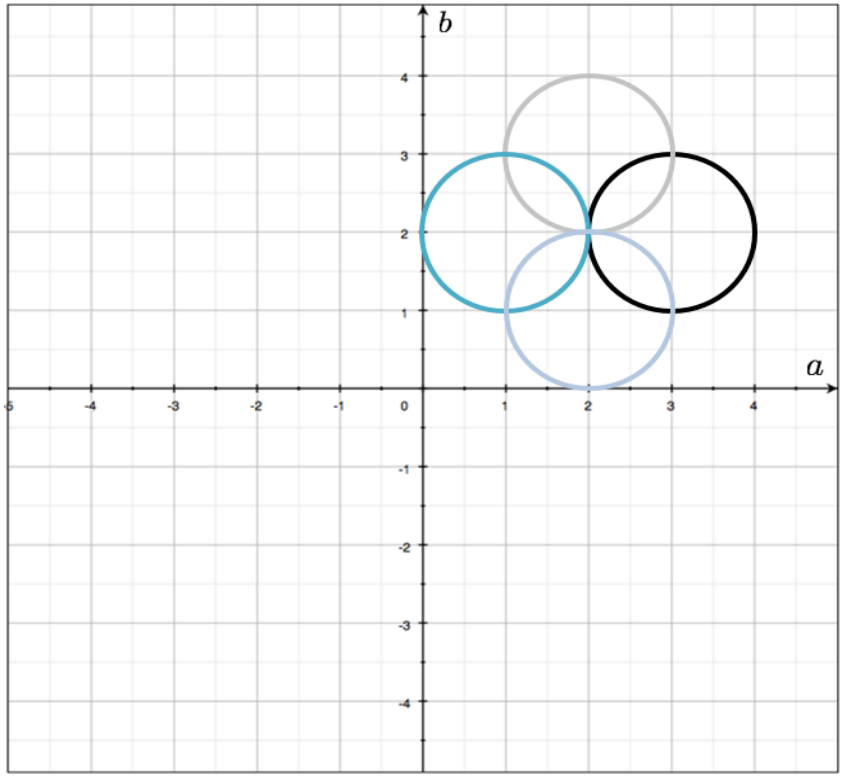
variables

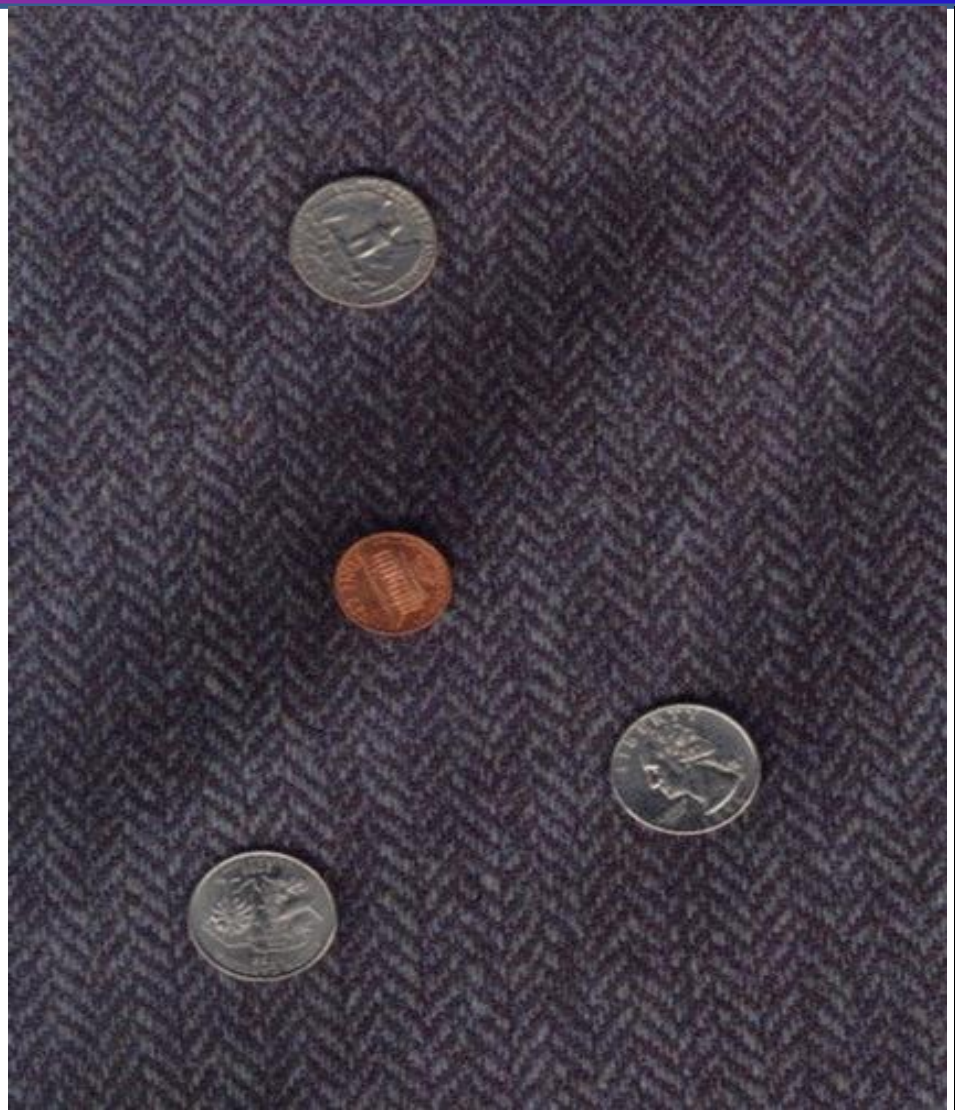


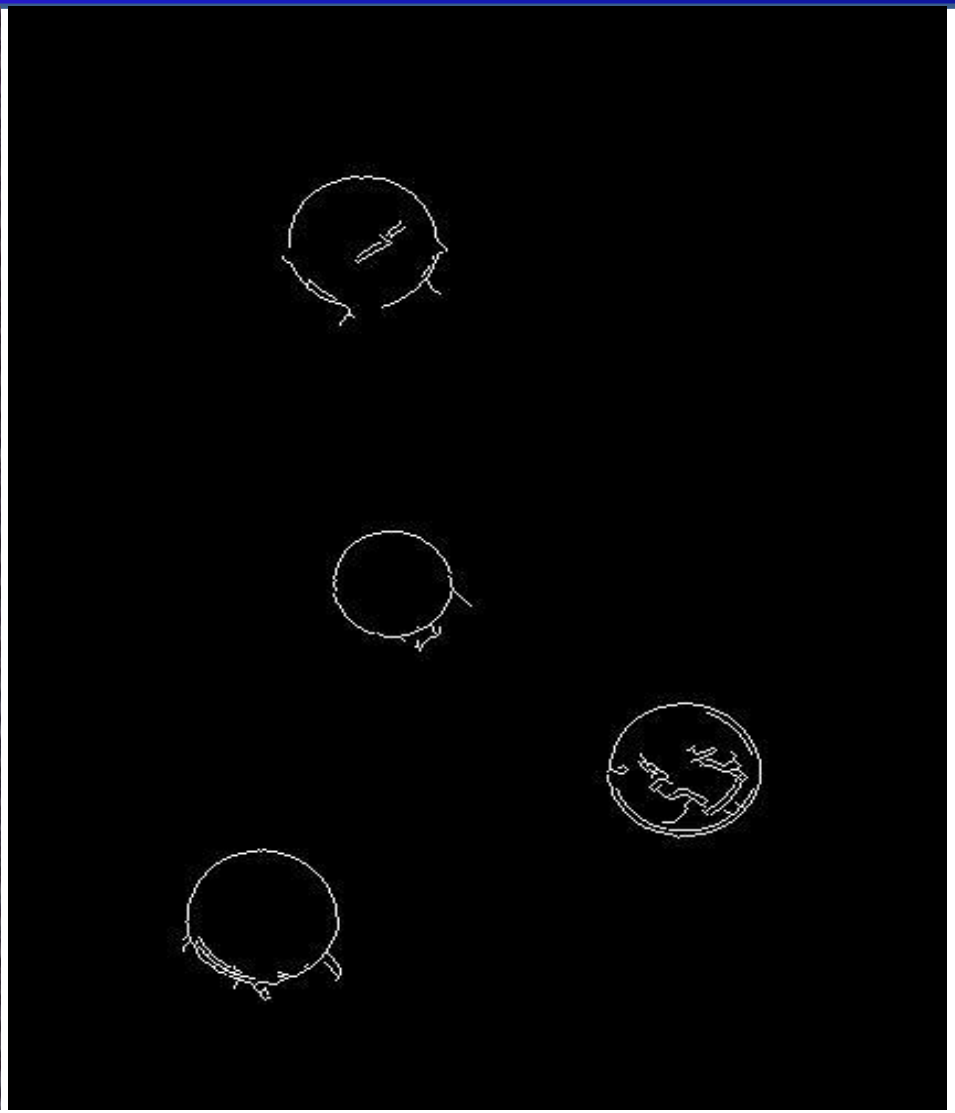
parameters

$$(x-a)^2+(y-b)^2=r^2$$

variables

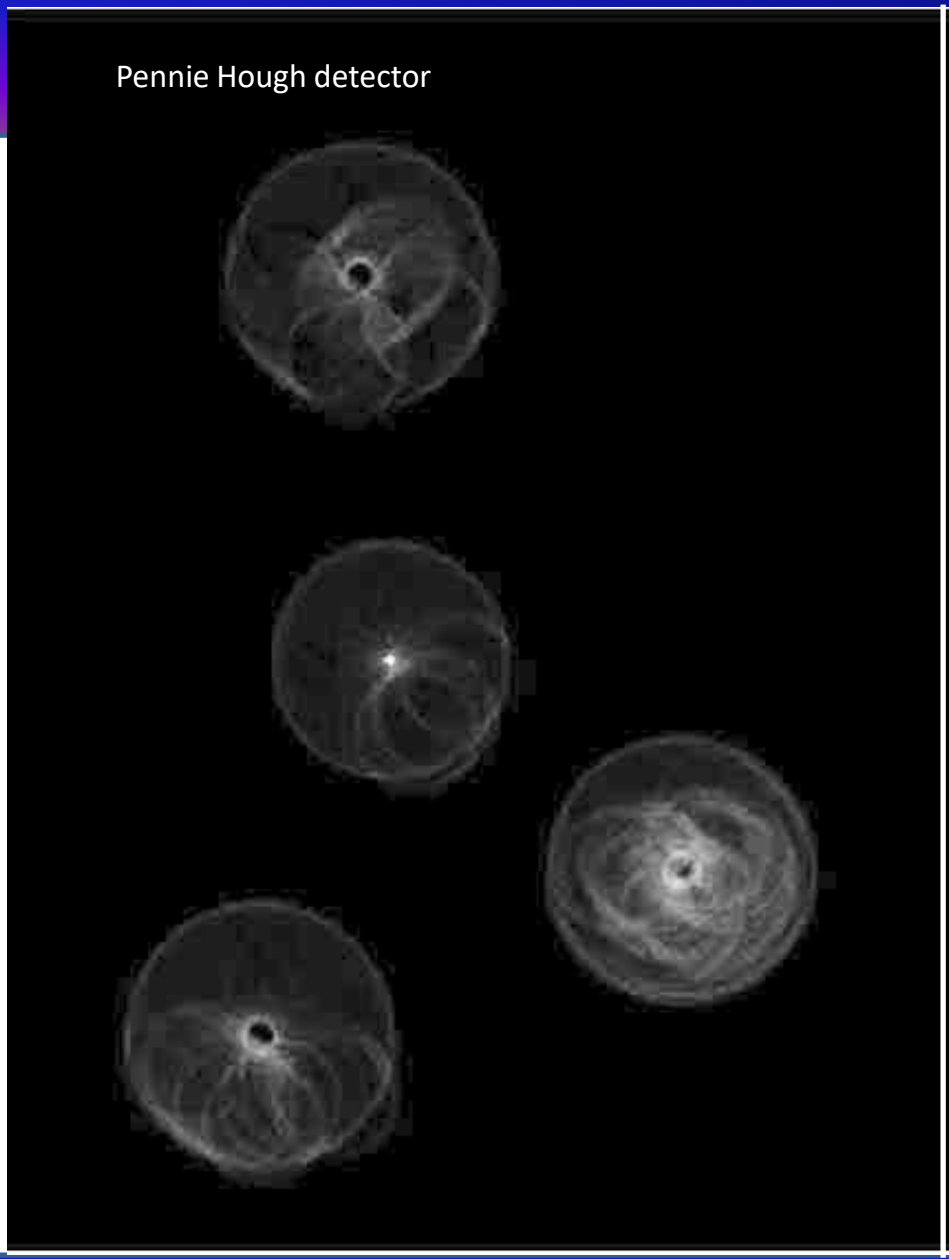


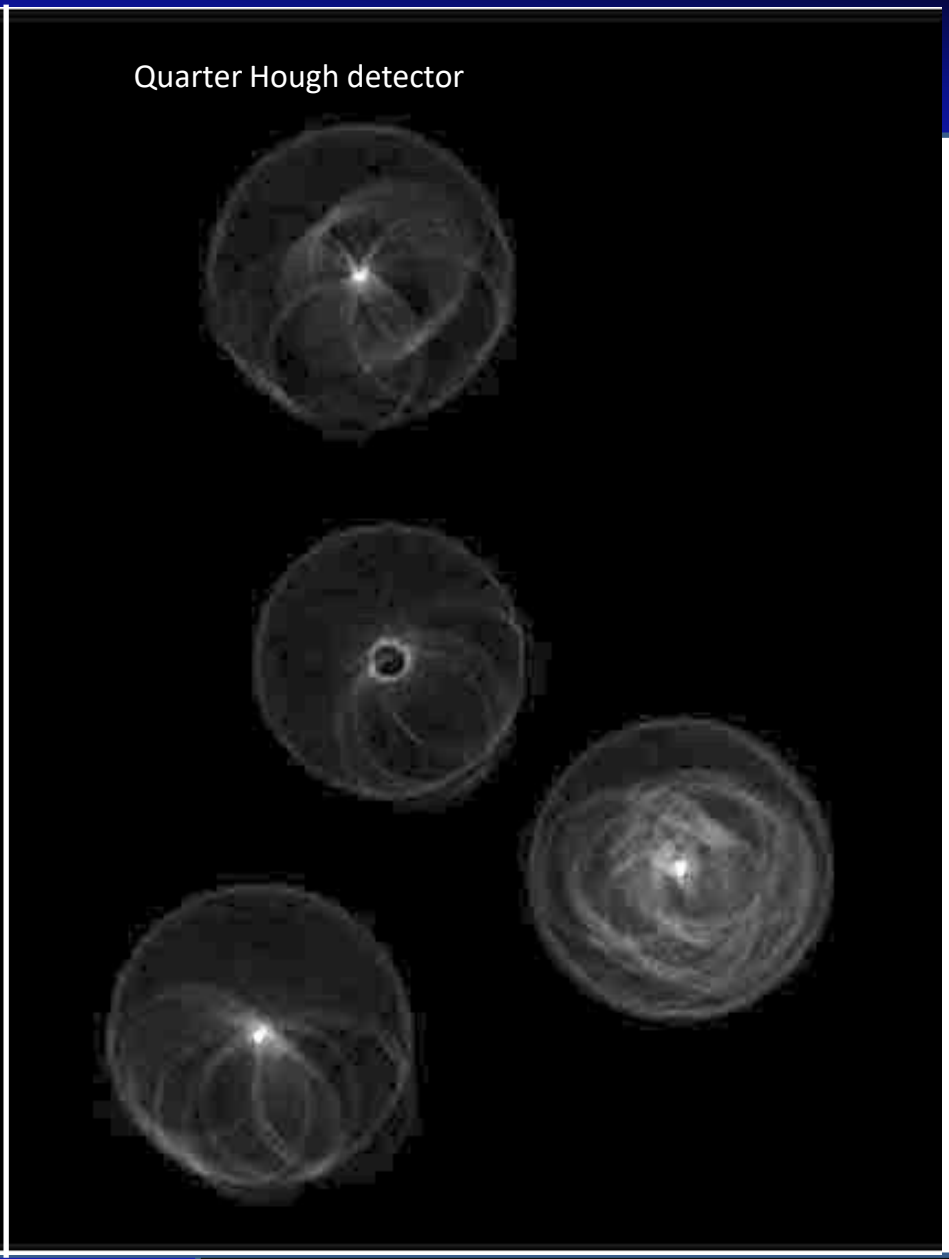





Pennie Hough detector


Quarter Hough detector


Pennie Hough detector


Quarter Hough detector

The Hough transform …

Can you use Hough Transforms for other objects, beyond lines and circles?

Deals with occlusion well?

Detects multiple instances?

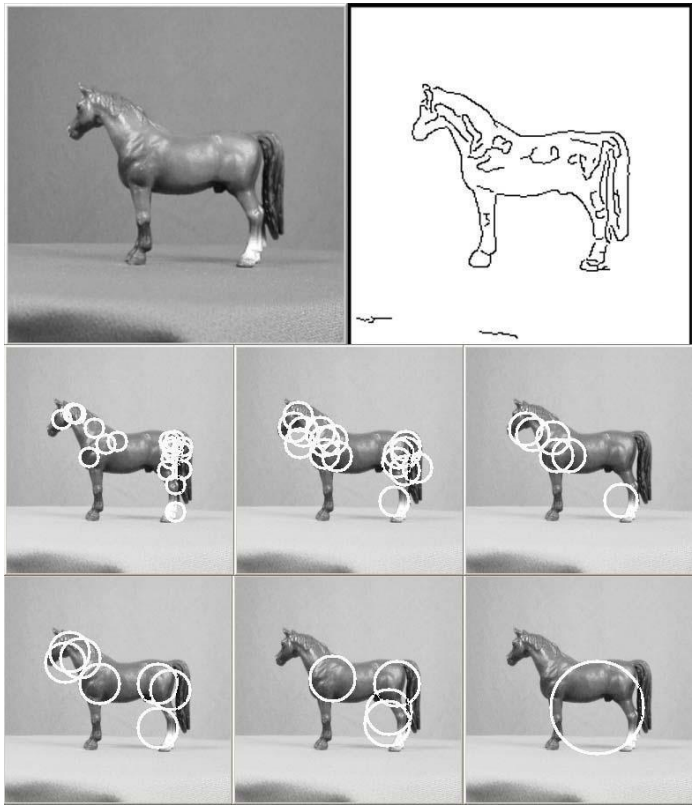
Robust to noise?

Good computational complexity?

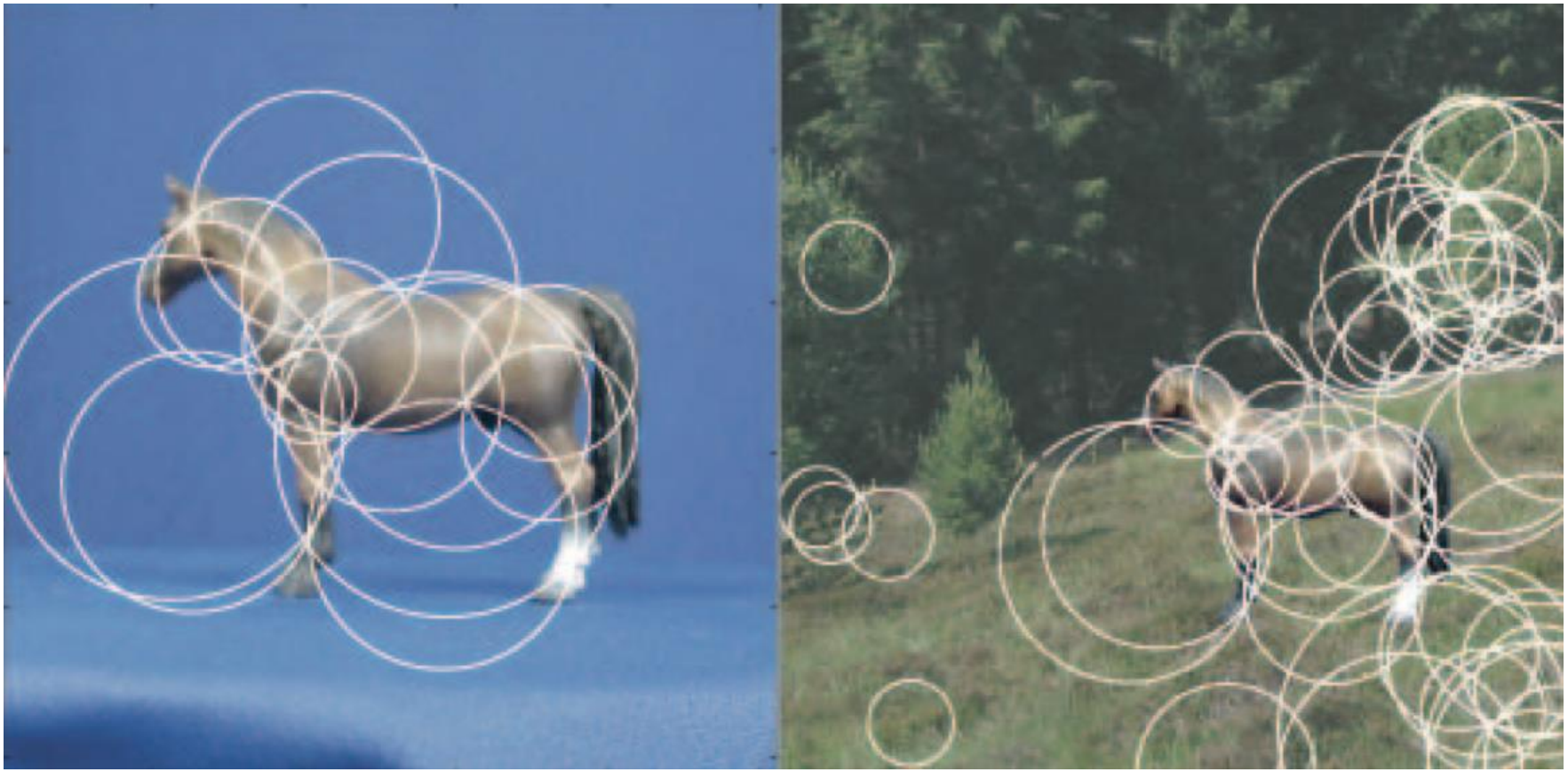
Easy to set parameters?

Application of Hough transforms

Detecting shape features



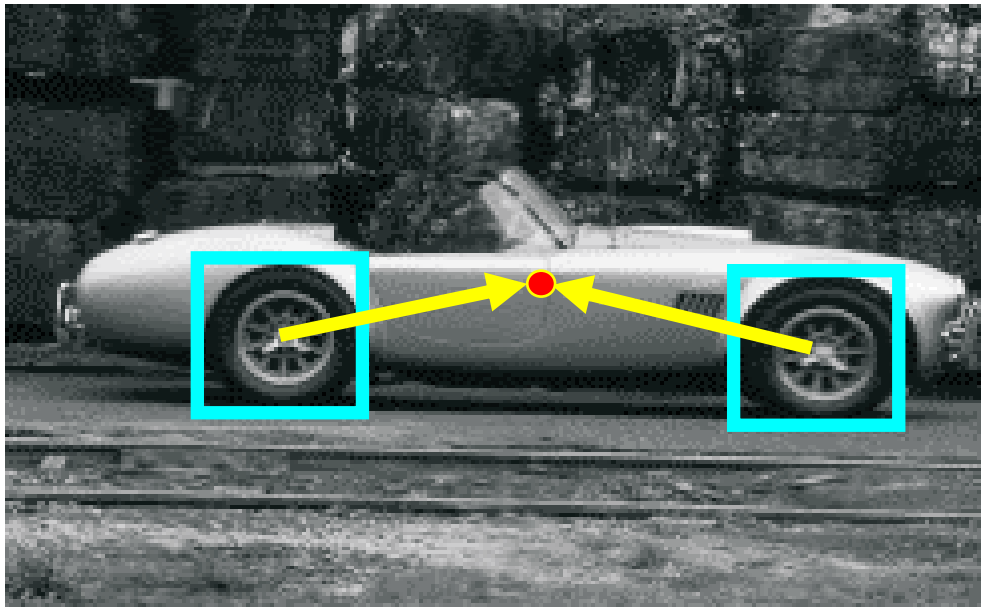
F. Jurie and C. Schmid, Scale-invariant shape features for recognition of object categories, CVPR 2004



Robustness to scale and clutter

Object detection

Index displacements by “visual codeword”



training image

visual codeword with displacement vectors

B. Leibe, A. Leonardis, and B. Schiele, Combined Object Categorization and Segmentation with an Implicit Shape Model,
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