

# Lecture 9: CS677

Sept 19, 2017

## Admin

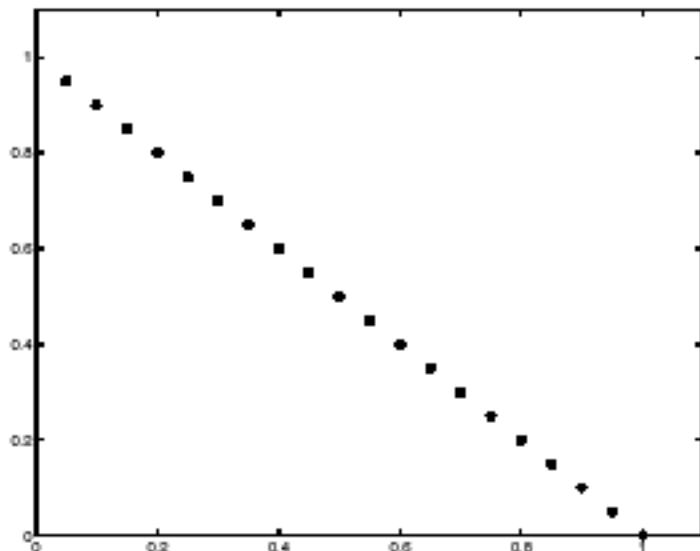
- HW2 due Sept 24, 9AM
- Exam 1, Oct 10, class period
  - Closed book, closed notes
  - Topics: whatever we cover until Oct 5
  - A detailed list will be provided later
- Make-up classes
  - No classes on Oct 24 and 26 (ICCV)
  - Make up classes on Oct 13 and Oct 20
  - OHE 3:30-5:00 pm

# Review

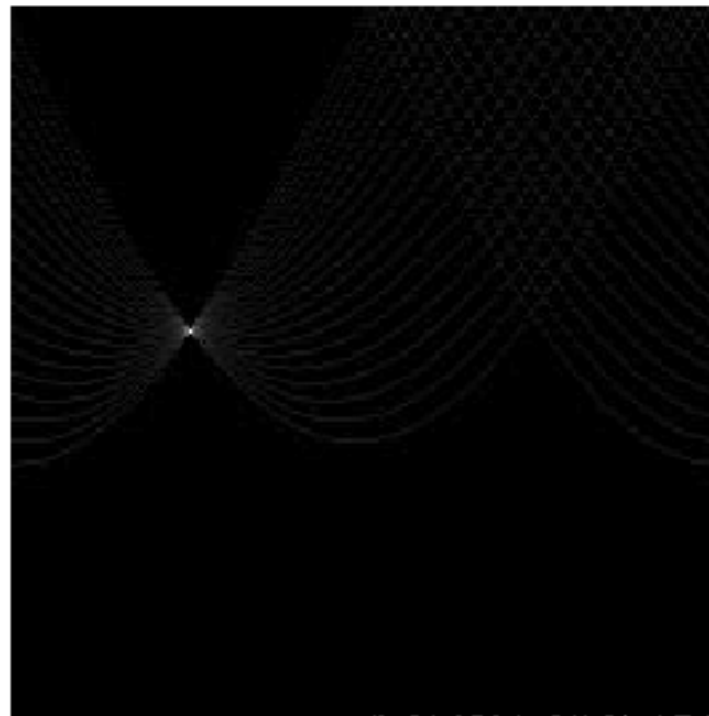
- Previous class
  - F-H graph-based agglomerative algorithm
  - Energy minimization methods
    - Grabcut
  - Canny edge detection
  - Line linking and iterative end-point fit
- Today's objective
  - Hough transform
  - SIFT features

# Fitting Without Linking

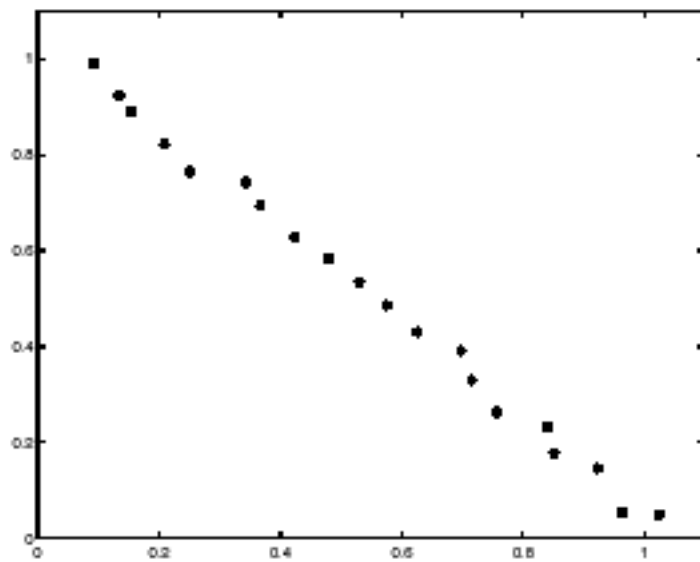
- Linking may create very short segments if many edgels are missing
  - Global view may allow linking of these edgels
    - *e.g.* only one of every three points along a line is detected
- Hough Transform
  - Line representation  $(\sin \theta) x + (\cos \theta) y = d$
  - Different choices of  $\theta$ ,  $d > 0$  give different lines
  - For any  $(x_i, y_i)$  there is a one parameter family of lines through this point, given by:  $(\sin \theta) x_i + (\cos \theta) y_i = d$
  - Each point gets to vote for each line in the family; if there is a line that has lots of votes, that should be the line passing through the points



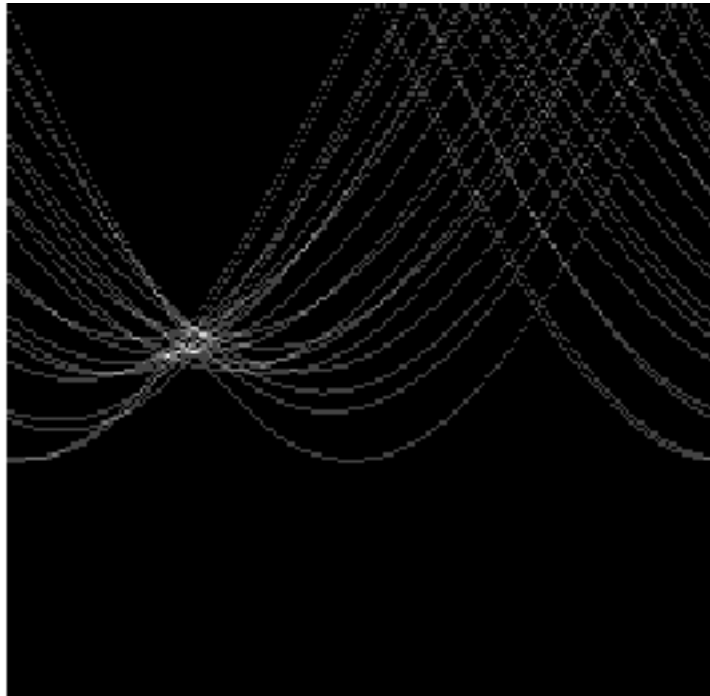
tokens



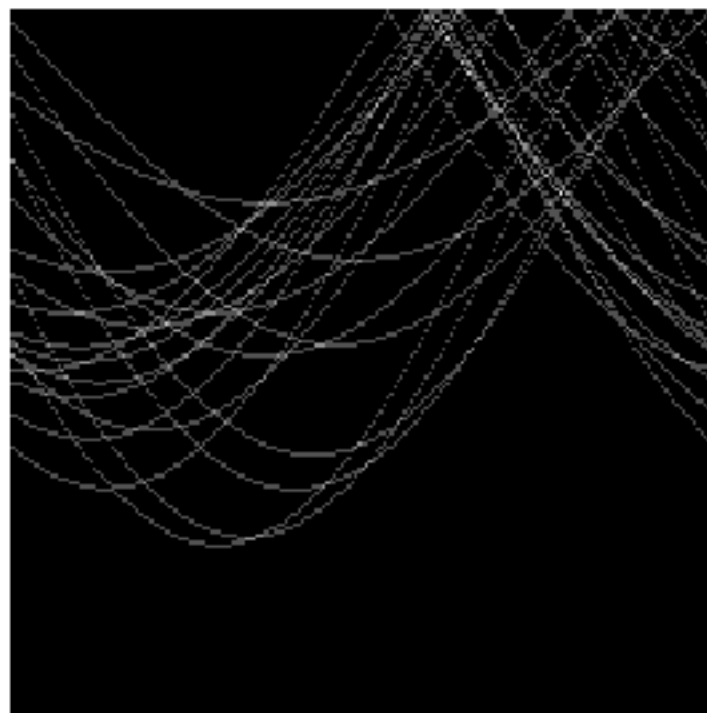
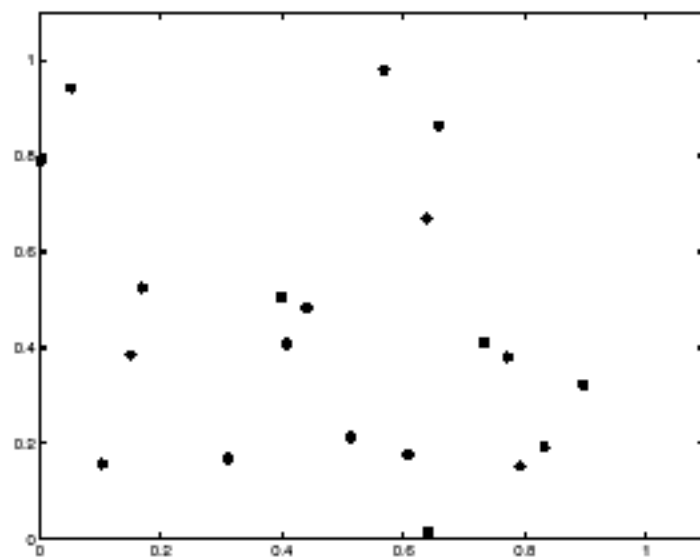
votes



tokens



votes



# Mechanics of the Hough transform

- Construct an array representing  $\theta$ ,  $d$
- For each point, render the curve  $(\theta, d)$  into this array, adding one at each cell
- Difficulties
  - how big should the cells be? (too big, and we cannot distinguish between quite different lines; too small, and noise causes lines to be missed)
- How many lines?
  - count the peaks in the Hough array
- Who belongs to which line?
  - tag the votes
- Difficulties:
  - Right selection of cell size
  - With extensive noise, accidental peaks may be stronger than peaks due to real lines



# Hough Transform for Curves

- A transform can be defined for any analytical curve
  - Circle, three unknowns (center, radius)
  - Ellipse (center, orientation, major and minor axis lengths)
  - Polynomials, quadrics, implicit functions...
- Dimension of Hough space equals number of unknown parameters
  - Filling high dimensional spaces is computationally expensive
  - Probability of finding intersections is reduced
  - Random sampling may be used to reduce cost
- Generalized Hough transform can be applied to fit any analytical model to a set of data points

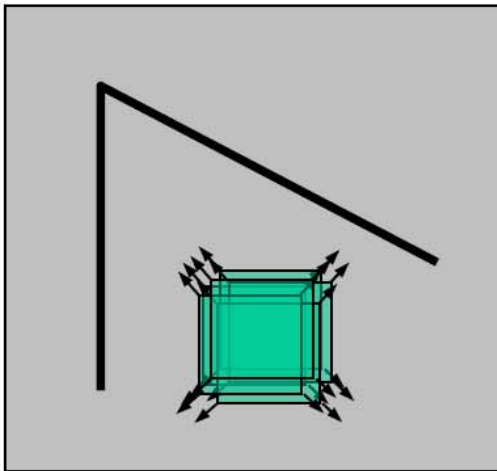
# Corner Features

- Corner-like features can be useful for various tasks, such as matching of points in stereo/motion images as they are more distinct than edge features
- Some corner-like features claim to be invariant to normally observed differences in images
  - Scale, rotation, affine transformation
- Can we detect corners locally (w/o finding corresponding lines)?
  - Gradient at a corner should be large
  - In a small neighborhood, gradient direction should swing sharply (corresponding to the line directions)
- Two common implementations:
  - Harris Corner Detector (cited by >14K authors)
  - SIFT features (cited by >40K authors!)

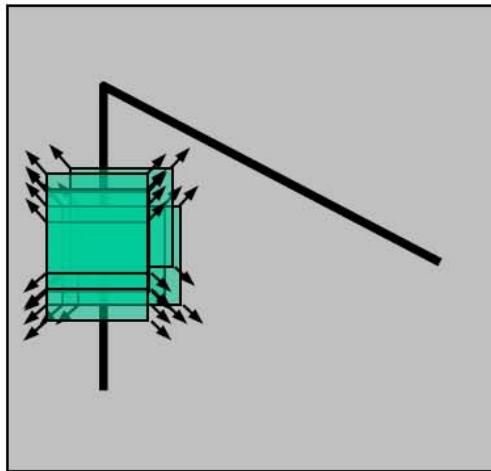
# Harris Corner Detector

Key Idea: examine how intensity changes in neighborhood of a point

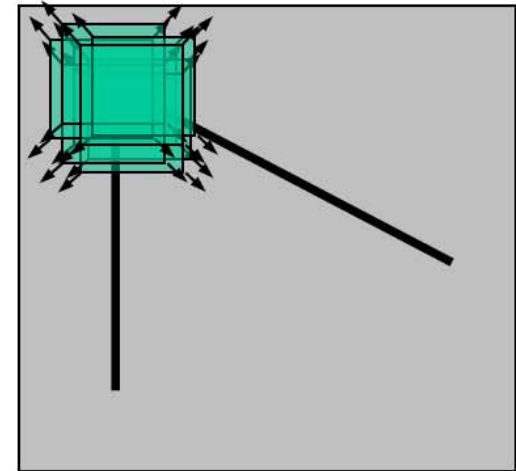
Different for flat, edge and corner points



“flat” region:  
no change in  
all directions



“edge”:  
no change along  
the edge direction



“corner”:  
significant change  
in all directions

Figure from notes by Prof. Freeman, MIT

# SIFT Features

- Determine key points
  - Extrema of DoG
    - Scale at which extrema found define scale of keypoint
    - DoG approximates filtering with Laplacian of Gaussians
      - Shown in previous work to give scale independent points
  - Clean up of keypoints
    - Low contrast, being on edge
- Find dominant gradient direction in neighborhood of a keypoint
  - All other directions measured respect to this direction
- Histogram of gradients in neighborhood
  - 4 x4 cells, 8 orientations (128D descriptor)
  - Total of 132 features (four for location, scale and orientation)