Non-maximum suppression

For every pixel in the image (e.g., q) we have an estimate of edge direction and edge normal (shown at q).

Non-maximum suppression

Using normal at q, find two points p and r on adjacent rows (or columns).
We have a maximum if the value is larger than those at both p and at r.
Interpolate to get values.

Non-maximum suppression

Predicting the next edge point

Assume the marked point is an edge point. Then we construct the tangent to the edge curve (which is normal to the gradient at that point) and use this to predict the next points (here either r or s).

Linking using Hysteresis Tresholding

- Track edge points by starting at point where gradient magnitude > $\tau_{\text{high}}$.
- Follow edge in direction orthogonal to gradient.
- Stop when gradient magnitude < $\tau_{\text{low}}$.
- i.e., use a high threshold to start edge curves and a low threshold to continue them.
**What to do with edges?**
- Segment linked edge chains into curve features (e.g., line segments).
- Group unlinked or unrelated edges into lines (or curves in general).
- Accurately fitting parametric curves (e.g., lines) to grouped edge points.

**Finding lines in an image**
- A line in the image corresponds to a point in Hough space.
- To go from image space to Hough space:
  - Given a set of points \((x, y)\), find all \((m, b)\) such that \(y = mx + b\).

**Hough Transform: 20 colinear points**
- \(R, \theta\) representation of line.
- Maximum accumulator value is 20.

**Hough Transform: “Noisy line”**
- \(R, \theta\) representation of line.
- Maximum accumulator value is 6.

**Hough Transform for Curves**
(Generalized Hough Transform)
- The H.T. can be generalized to detect any curve that can be expressed in parametric form:
  - \(Y = f(x, a_1, a_2, \ldots, a_p)\)
  - \(a_1, a_2, \ldots, a_p\) are the parameters
  - The parameter space is \(p\)-dimensional
  - The accumulating array is LARGE!
Example: Finding circles

Equation for circle is

\[(x - x_c)^2 + (y - y_c)^2 = r^2\]

Where the parameters are the circle’s center \((x_c, y_c)\) and radius \(r\).

Three dimensional generalized Hough space.

- Work up circle example for next year

TEM Image of Keyhole Limpet Hemocyanin with detected particles

3D Maps of KLH

FIG. Three-dimensional maps of KLH at a resolution of 23.5 Å reconstructed using particles extracted either manually or automatically as described in the text. (a), (b) The side- and top- view of a 3D map reconstructed from a set of 1042 manually selected particle images. (c), (d) The side- and top- view of a 3D map from a set of automatically extracted 1243 particle images.

Processing in Stage 1 for KLH

- Canny edge detection.
- A sequence of ordered Hough transforms (HT’s) is applied in order from the computationally simplest one to the most complex one.
- Edges covered by the detected shapes are removed immediately from edge images following the application of the last HT.

Picking KLH Particles in Stage 1

Zhu et al., IEEE Transactions on Medical Imaging, In press, 2003
Line Fitting

Given \( n \) points \((x_i, y_i)\), estimate parameters of line \( ax_i + by_i + d = 0 \) subject to the constraint that \( a^2 + b^2 = 1 \).

Problem: minimize
\[
E(a, b, d) = \sum_{i=1}^{n} (ax_i + by_i + d)^2
\]
with respect to \((a, b, d)\).

1. Minimize \( E \) with respect to \( d \):
\[
\frac{\partial E}{\partial d} = 0 \Rightarrow d = \frac{1}{n} \sum_{i=1}^{n} x_i y_i - \bar{x} \bar{y}
\]
where \((\bar{x}, \bar{y})\) is the mean of the data points.

\[
\text{Sum of squared distances between each point and the line}
\]

Line fitting cont.

2. Substitute \( d \) back into \( E \) where \( n = (a, b)^T \).

3. Minimize \( E = n^T U n = n^T S n \) with respect to \( a, b \) subject to constraint \( n^T n = 1 \)
\[
S = \frac{1}{n^T} U = \left( \begin{array}{cc}
\sum_{i=1}^{n} x_i^2 & \sum_{i=1}^{n} x_i y_i - \bar{x} \bar{y} \\
\sum_{i=1}^{n} x_i y_i - \bar{x} \bar{y} & \sum_{i=1}^{n} y_i^2 - \bar{y}^2
\end{array} \right)
\]
where \( S \) is real, symmetric, positive definite.

Midterm

Thursday, May 11

- In class
- Full period
- Coverage – everything up to this point including readings
- “Cheat sheet” – you can prepare a one sided sheet of notes. It must be hand written. (After the midterm, save your sheet since you can use the other side for the final).

Incomplete list of topics covered...

- Human visual system
  - Physiology – from eye to brain
  - Phenomenological
  - Function
- Camera models
- Factors in producing images
- Projection models
  - Perspective
  - Orthographic
- Homogeneous Coordinates
- Vanishing points
- Lenses, Distortion
- Sensors
- Quantization/Resolution
- Illumination
- Reflectance
- BRDF
- Lambertian
- Specular
- Phong
- Color
  - Light Spectrum
  - Reflectance, source
  - Sensor response
  - Color spaces
  - Chromaticity, YUV, RGB

Topics cont.

- Binary Vision
  - Thresholding
  - Neighborhoods
  - Connected component exploration
  - Features, moments
- Noise
  - Additive, Gaussian noise
- Filtering, linear, convolution with Kernel
  - Averaging/smoothing
  - Sharpening
  - Derivatives
  - Gaussian filter
  - Separability
- Edges & Edge detection
- Edge sources
- Canny
  - Gaussian derivatives
  - Magnitude, orientation
  - Non-maximal suppression
  - Linking/thresholding
- Hough Transform
- Generalized Hough transform
Shape-from-X, Stereo Vision I

Introduction to Computer Vision
CSE 152
Lecture 11-b

Example: Helmholtz Stereo
Depth + Normals + BRDF

Binocular Stereopsis: Mars
Given two images of a scene where relative locations of cameras are known, estimate depth of all common scene points.

Two images of Mars

Shape-from-X (i.e., Reconstruction)

- Methods for estimating 3-D shape from image data. X can be one (or more) of many cues.
  - Stereo [two or more views, known viewpoints]
  - Motion [moving camera or object]
  - Shading
  - Changing lighting (Photometric Stereo)
  - Texture variation
  - Focus/blur
  - Prior knowledge/context
  - structured light/lasers

Stereo

An Application: Mobile Robot Navigation

The INRIA Mobile Robot, 1990.

Commercial Stereo Heads

Trinocular stereo  Binocular stereo

Stereo can work well

Need for correspondence