Bioimage Informatics

Lecture 12, Spring 2012

Bioimage Data Analysis (III):

Line/Curve Detection

Bioimage Data Analysis (IV)

Image Segmentation (part 1)

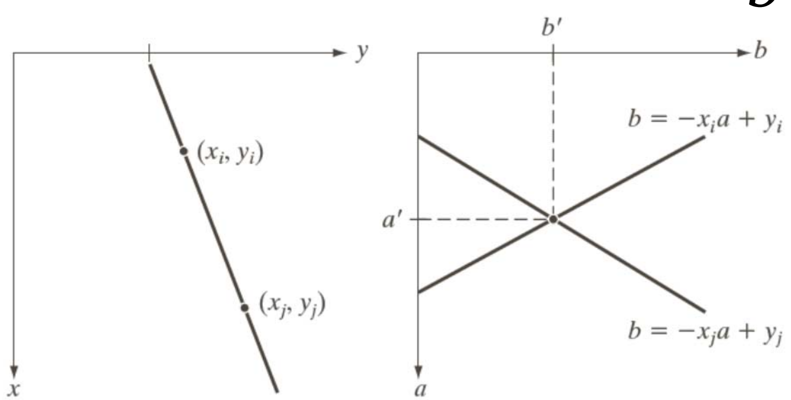
Outline

- Review: Line/curve detection using the Hough transform
- Steger’s line/curve detection algorithm
- Intensity thresholding based image segmentation
- A brief introduction to ITK

- Review: Line/curve detection using the Hough transform
- Steger's line/curve detection algorithm
- Intensity thresholding based image segmentation
- A brief introduction to ITK

Basic Concept of Hough Transform

- A simple example: representing the lines passing through (x_0, y_0) in the parameter space.



$$y_1 = a \cdot x_1 + b \qquad y_2 = a \cdot x_2 + b$$

$$b = (-x_1)a + y_1 \qquad b = (-x_2)a + y_2$$

$$y_1 = \tilde{a} \cdot x_1 + \tilde{b}$$

$$y_2 = \tilde{a} \cdot x_2 + \tilde{b}$$

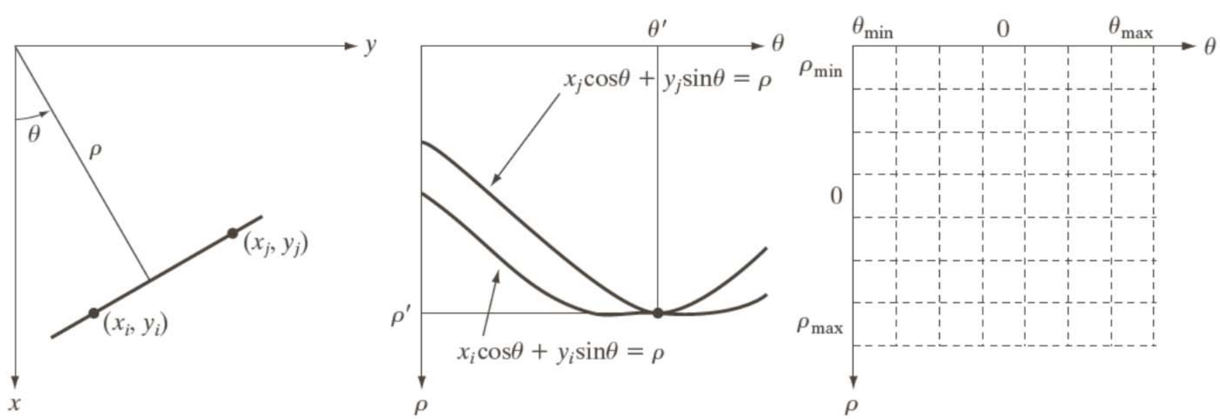
The two lines in the transform domain must intersect at (a,b)

HT Algorithm Implementation Details

- Parameterization using y=ax+b fails for the case of vertical lines.
- A different way of parameterization:

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

- Exhaustive search the space of [ρ, θ] can be time-consuming.



Generalization of the HT Algorithm for Curve Detection

- The HT algorithm is a voting algorithm. The key idea is to convert a (difficult) pattern recognition problem into a (simple) peak detection problem.

- Hough transform can be generalized to detect circles, ellipses, or any curve that can be parameterized.

- Examples

Circles with known radius but unknown center

$$(x-x_c)^2+(y-y_c)^2=R^2 \quad \Longrightarrow \quad (x_c-x_i)^2+(y_c-y_i)^2=R^2$$

Ellipses with known major and minor semi-axes but unknown center

$$\frac{(x-x_c)^2}{a^2}+\frac{(y-y_c)^2}{b^2}=1 \quad \Longrightarrow \quad \frac{(x_c-x_i)^2}{a^2}+\frac{(y_c-y_i)^2}{b^2}=1$$

Evaluation of Parametric Transform Based Curve Detection

- The curve to be detected can be of arbitrary form as long as it can be parameterized.

- There are many extensions to HT based feature detection.

- Strengths:
  - Handles occlusion and partial line/curves well.
  - Relatively robust to noise
  - Capable of detecting multiple instances

- Limitations

  → For curves with multiple parameters, the voting/search can be costly.

  → Other shapes can also generate spurious peaks.

M. Nixon & A. Aguado, *Feature Extraction & Image Processing*, Academic Press, 2nd ed., 2008.

Some General Comments on HT-Based Techniques

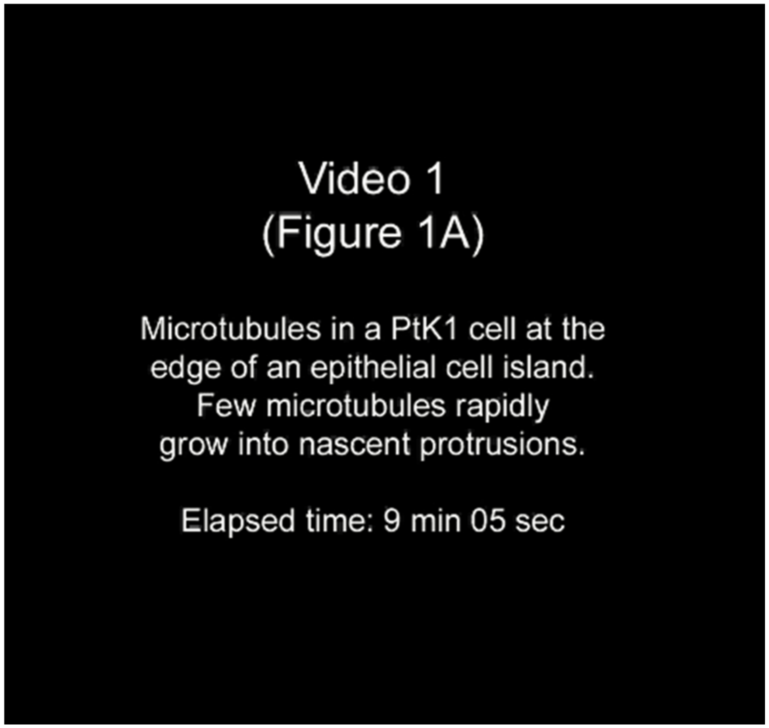
- Hough transform based feature detection is a evidence-gathering technique. It is equivalent to template matching but is sometimes less costly computationally.

- Hough transform is often used in machine vision.

- Machine vision often refers to application of computer vision in industrial applications.
  - Imaging condition can be controlled.
  - Feature geometry is often known or well defined.

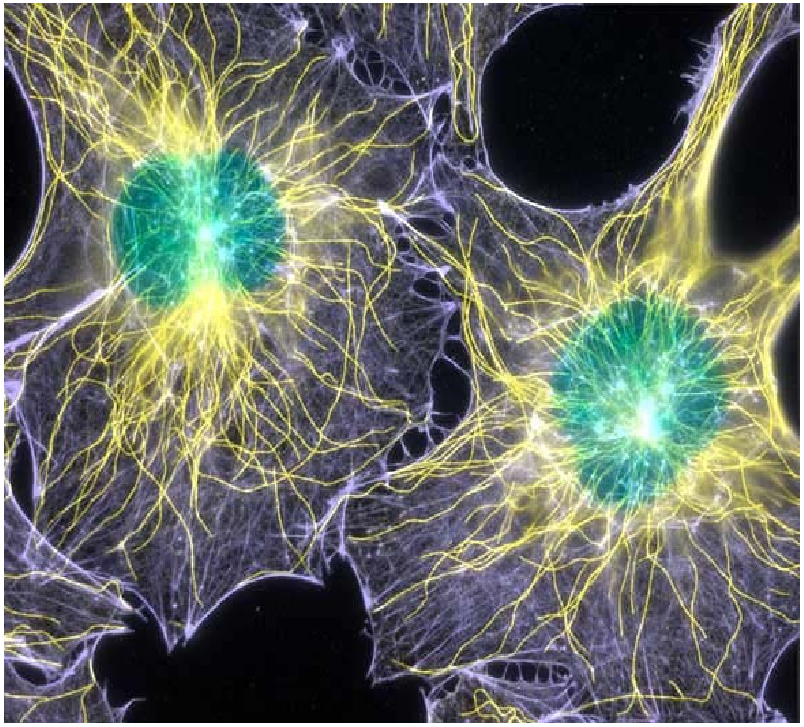
- Feature geometry in biological imaging data often is irregular and dynamic. This limits the application of HT-based approaches.

Feature Detection: Lines/Curves



T. Wittmann et al, *J. Cell Biol.*, 161:845, 2003.

http://www.cell.com/cell_picture_show



Nikon Small World, 2003
Torsten Wittmann, UCSF
Filamentous actin and microtubules (structural proteins) in mouse fibroblasts (cells) (1000x)

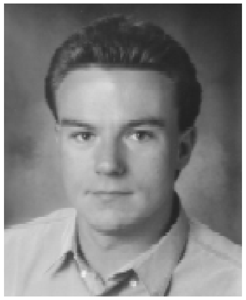
- Review: Line/curve detection using the Hough transform
- Steger's line/curve detection algorithm
- Intensity thresholding-based image segmentation
- A brief introduction to ITK

Steger's Line/Curve Detection Algorithm

IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE, VOL. 20, NO. 2, FEBRUARY 1998 113

An Unbiased Detector of Curvilinear Structures

Carsten Steger



Abstract—The extraction of curvilinear structures is an important low-level operation in computer vision that has many applications. Most existing operators use a simple model for the line that is to be extracted, i.e., they do not take into account the surroundings of a line. This leads to the undesired consequence that the line will be extracted in the wrong position whenever a line with different lateral contrast is extracted. In contrast, the algorithm proposed in this paper uses an explicit model for lines and their surroundings. By analyzing the scale-space behavior of a model line profile, it is shown how the bias that is induced by asymmetrical lines can be removed. Furthermore, the algorithm not only returns the precise subpixel line position, but also the width of the line for each line point, also with subpixel accuracy.

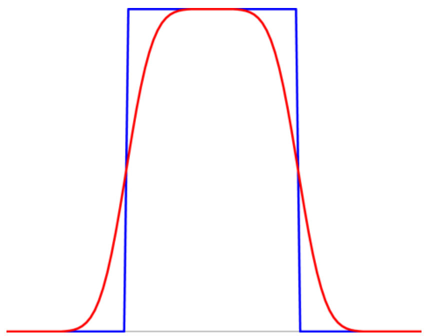
Index Terms—Feature extraction, curvilinear structures, lines, scale-space, contour linking, low-level processing, aerial images, medical images.

http://ias.in.tum.de/people/steger

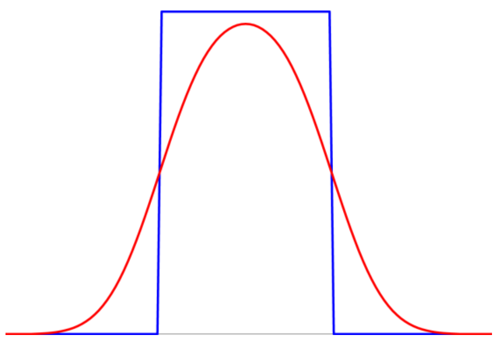
C. Steger, M. Ulrich, C. Wiedemann, Machine Vision Algorithms and Applications, Wiley-VCH, 2008

Basic Ideas of the Algorithm

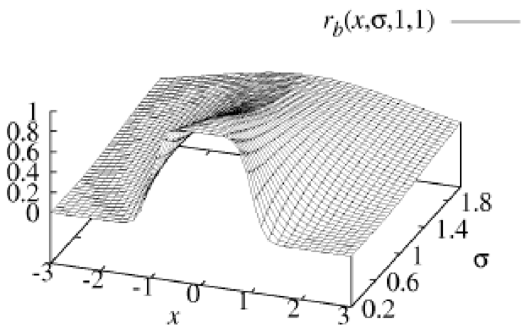
- Identify the center of the line by searching for the maximum of the second order directional derivative.



- To choose a kernel size such that there is one well defined peak.



$$\sigma \geq \frac{w}{\sqrt{3}}$$



Local Curvature of a 1D Function

- First derivative

$$f'(x_0) = 0$$

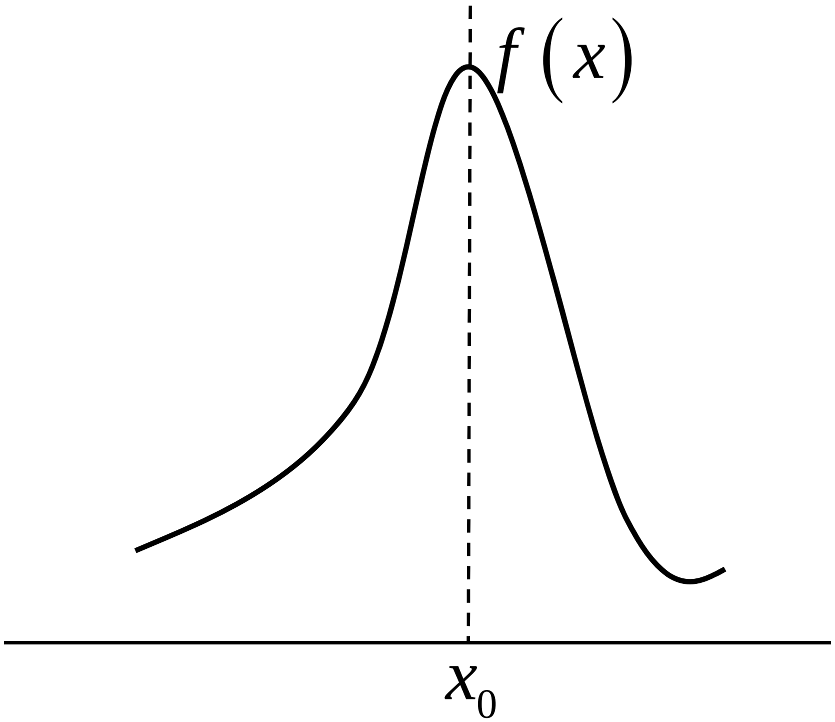
- Second derivative

$f''(x_0) > 0 \quad x_0$ is a local minimum

$f''(x_0) < 0 \quad x_0$ is a local maximum

- Curvature

$$K = \frac{|f''(x)|}{\left(1 + f'(x)^2\right)^{\frac{3}{2}}}$$



Frist Directional Derivative of a 2D Function

- The gradient vector of function f defines the maximum rate of change and direction of change.

$$\nabla f = \begin{bmatrix} \dfrac{\partial f}{\partial x} \\ \dfrac{\partial f}{\partial y} \end{bmatrix}$$

- The first directional derivative of a function

$$\begin{aligned} f'_\beta &= \lim_{h \to 0} \frac{f\left(x + h\sin\beta, y + h\cos\beta\right) - f(x, y)}{h} \\ &= \frac{\partial f}{\partial x}\sin\beta + \frac{\partial f}{\partial y}\cos\beta \\ &= \left[\sin\beta \quad \cos\beta\right]\nabla f \end{aligned}$$

Second Directional Derivative of a 2D Function

- The Hessian matrix

$$Hf = \begin{bmatrix} \frac{\partial^2 f}{\partial x^2} & \frac{\partial^2 f}{\partial x \partial y} \\ \frac{\partial^2 f}{\partial y \partial x} & \frac{\partial^2 y}{\partial y^2} \end{bmatrix}$$

- The second directional derivative of a function

$$f''_{\beta} = \begin{bmatrix} \sin\beta & \cos\beta \end{bmatrix} H \begin{bmatrix} \sin\beta \\ \cos\beta \end{bmatrix}$$

$$= \begin{bmatrix} \sin\beta & \cos\beta \end{bmatrix} \begin{bmatrix} v_1 & v_2 \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} \begin{bmatrix} v_1^T \\ v_2^T \end{bmatrix} \begin{bmatrix} \sin\beta \\ \cos\beta \end{bmatrix}$$

Steger's Line Detection Algorithm (I)

- Local intensity model (1D along the maximum curvature direction)

$$p(x) = r + r'x + \frac{1}{2} r'' x^2$$

$$r^* = -\frac{r'}{r''}$$

Declare a center line point if $x^* \in \left[-\frac{1}{2} \quad \frac{1}{2} \right]$

Steger's Line Detection Algorithm (II)

- Step 1: determine the local direction of intensity search from the eigenvector corresponding to the maximum eigenvalue.

$$\begin{pmatrix} n_x & n_y \end{pmatrix}$$

- Step 2: Calculate x*

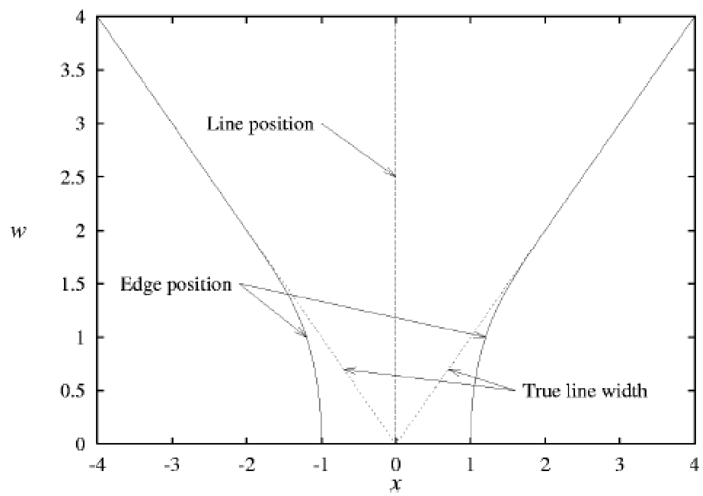
$$r^* = -\frac{r_x n_x + r_y n_y}{r_{xx} n_x^2 + 2 r_{xy} n_x n_y + r_{yy} n_y^2}$$

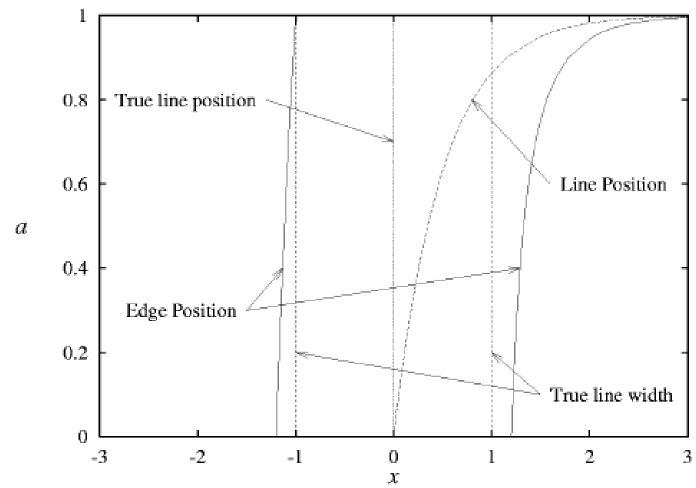
- Step 3: individual points are connected based on a directed search and linking process.

Steger's Line Detection Algorithm (III)

- Edge points can also be calculated by line detection in the gradient image. This is helped by knowledge of the direction of center line.

- Unbalanced intensity profile can be corrected based on a look-up table.





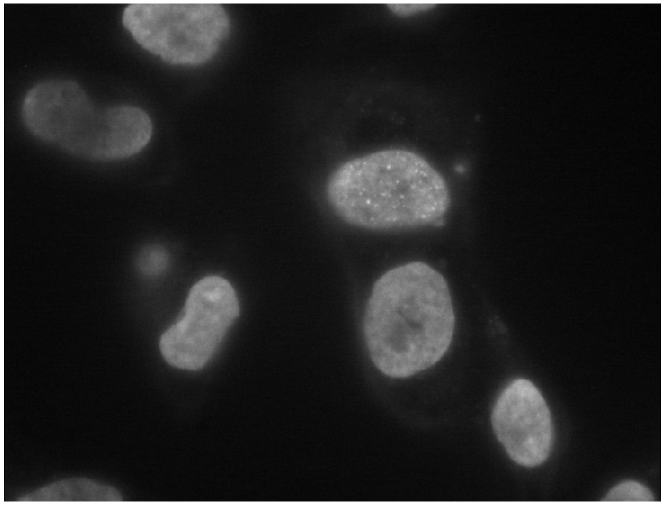
- Review: Line/curve detection using the Hough transform
- Steger's line/curve detection algorithm
- Intensity thresholding-based image segmentation
- A brief introduction to ITK

Overview: Image Segmentation (I)

- Definition

  Segmentation is the process of separating objects from background (Snyder & Qi)

  Segmentation is the partitioning of a dataset into continuous regions (or volumes) whose member elements have common, cohesive properties (Yoo in "Insight into Images").

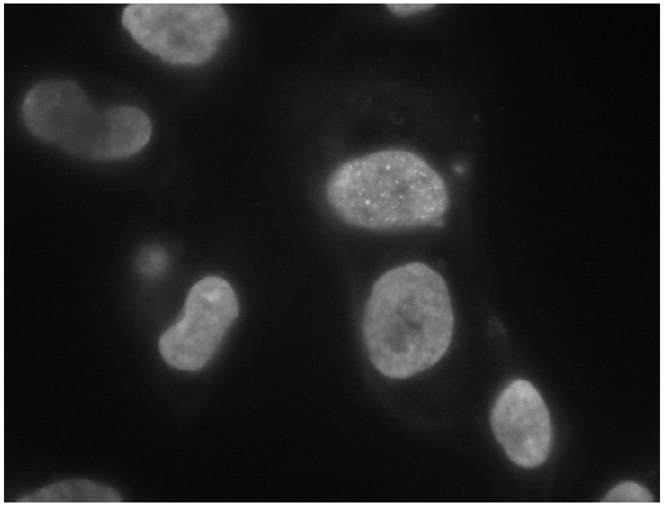


- Segmentation is an essential process in bioimage analysis; It is critical for many subsequent processes such as object recognition and shape analysis.

Overview: Image Segmentation (II)

- There are many types of segmentation techniques:

  - Threshold-based segmentation
  - Region-based segmentation
  - Boundary/surface-based segmentation
  - Motion-based segmentation
  - Color-based segmentation
  - Others…



- It is often very useful to combine multiple techniques for image segmentation.

- For bioimage analysis, accuracy in segmentation is essential.

Thresholding-Based Segmentation (I)

- Revisit the definition

  "Segmentation is the partitioning of a dataset into continous regions (or volumes) whose member elements have common, cohesive properties".

- Intensity is the most frequently used property.

- Multiple continuous regions of cohesive intensities will result in multiple peaks in intensity histogram.

Thresholding-Based Segmentation (II)

- Thresholding-based segmentation is usually among the first options to be considered.
  - Simple; can be quite reliable
  - Easy to implement.

- There are many refinements to the basic idea that work remarkably well.

Basic Ideas of Thresholding-Based Segmentation (I)

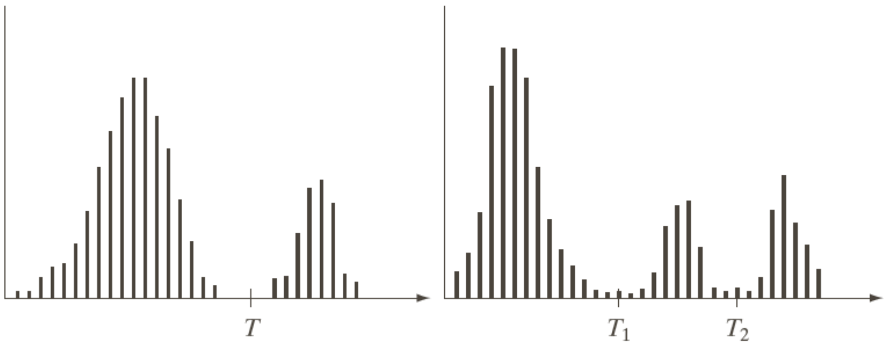


FIGURE 10.35 Intensity histograms that can be partitioned (a) by a single threshold, and (b) by dual thresholds.

$$g(x,y)=\begin{cases}1 & if \quad I(x,y)>T\\ 0 & if \quad I(x,y)\le T\end{cases}$$

$$g(x,y)=\begin{cases}a & if \quad I(x,y)>T_2\\ b & if \quad T_1<I(x,y)\le T_2\\ c & if \quad I(x,y)\le T_1\end{cases}$$

Basic Ideas of Thresholding-Based Segmentation (II)

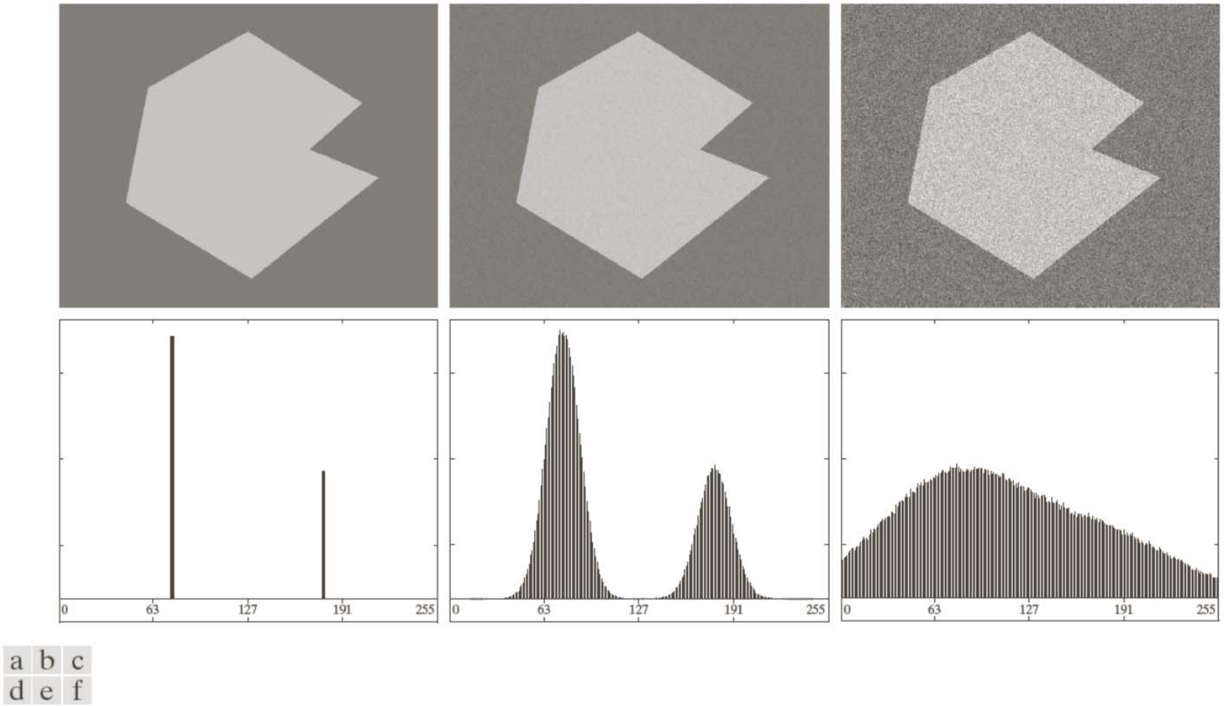
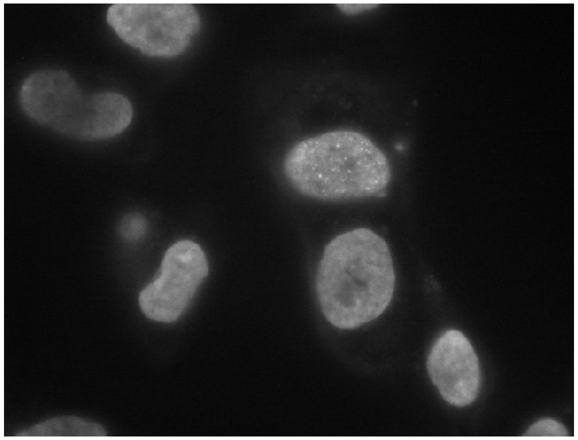


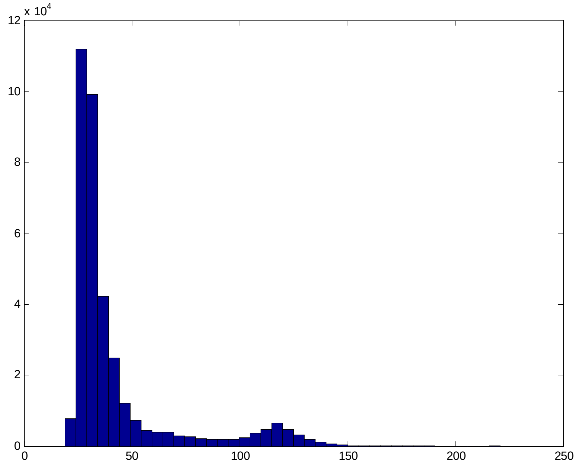
FIGURE 10.36 (a) Noiseless 8-bit image. (b) Image with additive Gaussian noise of mean 0 and standard deviation of 10 intensity levels. (c) Image with additive Gaussian noise of mean 0 and standard deviation of 50 intensity levels. (d)–(f) Corresponding histograms.

How to Set Thresholds (I)

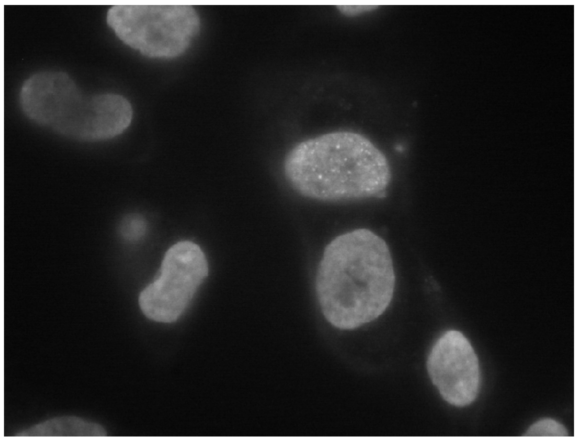
- There are several ways to set the thresholds.
  - Using local minima in the intensity histogram.
  - Use intensity histogram fitting with a mixture of Gaussians.

- Example:

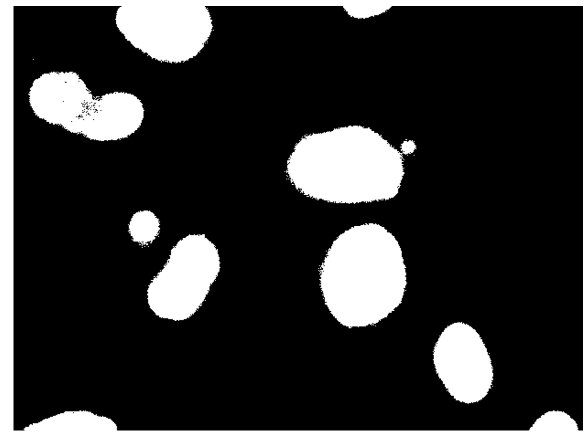




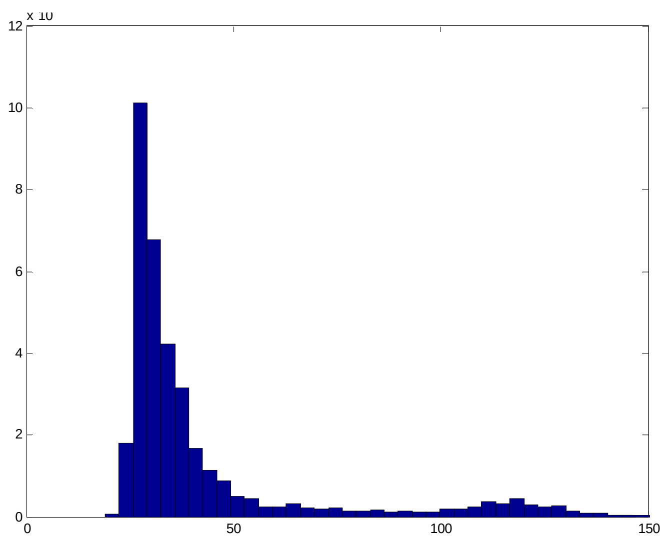
Example Results



Threshold = 70



Threshold = 60



How to Set Thresholds (II)

- One way to fit multiple Gaussians

  Reference: C. Fraley and A. E. Raftery. *Model-based clustering, discriminant analysis and density estimation*. Journal of the American Statistical Association, 97:611–631, 2002.

  Implementation in R : http://www.stat.washington.edu/mclust/

- Determine the number of Gaussians

  - Bayesian information criterion (BIC)

$$\mathrm{BIC} \equiv 2\,\mathrm{loglik}_M\left(x, \theta_k^*\right) - N_M \log\left(n\right)$$

$$\begin{aligned}
&M \rightarrow \text{Model} \\
&\mathrm{loglik}_M\left(x, \theta_k^*\right) \rightarrow \text{maximized likelihood} \\
&N_M \rightarrow \text{Number of parameters in model } M \\
&n \rightarrow \text{Number of measurements}
\end{aligned}$$

How to Set Thresholds (III)

- Determine the threshold between two neighboring Gaussian

$$\frac{w_1}{\sigma_1\sqrt{2\pi}} exp\left(-\frac{\left(x-\mu_1\right)^2}{2\sigma_1^2}\right) = \frac{w_2}{\sigma_2\sqrt{2\pi}} exp\left(-\frac{\left(x-\mu_2\right)^2}{2\sigma_2^2}\right)$$

$$\left(\frac{1}{2\sigma_2^2}-\frac{1}{2\sigma_1^2}\right)x^2+\left(\frac{\mu_1}{\sigma_1^2}-\frac{\mu_2}{\sigma_2^2}\right)x+\left(\frac{\mu_2^2}{2\sigma_2^2}-\frac{\mu_1^1}{2\sigma_1^2}-log\,\frac{w_2\sigma_1}{w_1\sigma_2}\right)=0$$

- Review: Line/curve detection using the Hough transform
- Steger's line/curve detection algorithm
- Intensity thresholding-based image segmentation
- A brief introduction to ITK

Introduction to ITK (I)

- Started in 1999 through funding by the National Library of Medicine to support the Visible Human Project.
- Website: http://www.itk.org/
- ITK: insight toolkit

  - Open source software package for image registration and segmentation
- Language: 55% C++; 25% C; XML 11%; Other 9% (as of Feb-27, 2012)

Introduction to ITK (II)

- Scale
  - Approximately 2.2 million lines of code (as of Feb-27, 2012)
  - Initial cost: 718 person years, $39M (as of Feb-27, 2012)

- Current release 4.0 (as of Feb-27-2012)

Introduction to MAT-ITK

- Website: http://matitk.cs.sfu.ca/

Opcode	Method
SCC	ConfidenceConnectedSegmentation
SCSS	CellularSegmentationSegmentation(Debug)
SCT	ConnectedThresholdSegmentation
SFM	FastMarchSegmentation
SGAC	GeodesicActiveContourLevelSetSegmentation
SIC	IsolatedConnectedSegmentation
SLLS	LaplacianLevelSetLevelSetSegmentation
SNC	NeighbourhoodConnectedSegmentation
SOT	OtsuThresholdSegmentation
SSDLS	ShapeDetectionLevelSetFilter
SWS	WatershedSegmentation

Questions?