

Digital Image Processing (CSE/ECE 478)

Lecture-18: Image Segmentation (contd.)

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Many slides borrowed from Vineet Gandhi @CVIT!

Image Segmentation

Partitioning an image into a collection of connected sets of pixels.

1. into **regions**, which usually cover the image

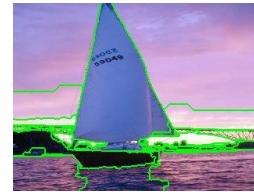


Image Segmentation

Partitioning an image into a collection of connected sets of pixels.

1. into **regions**, which usually cover the image



2. into **linear structures**, such as

- line segments
- curve segments

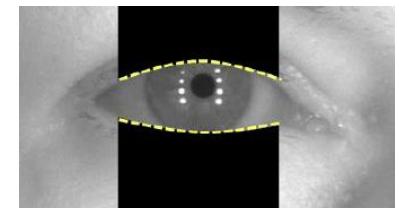


Image Segmentation

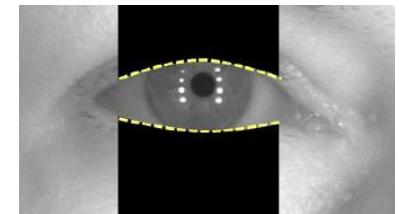
Partitioning an image into a collection of connected sets of pixels.

1. into **regions**, which usually cover the image



2. into **linear structures**, such as

- line segments
- curve segments



3. into **2D shapes**, such as

- circles
- ellipses
- ribbons (long, symmetric regions)

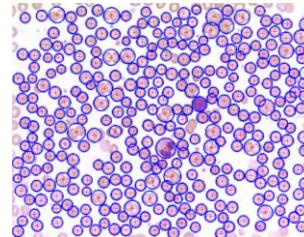


Image Segmentation - Approaches

- Edge-based
- Thresholding
- Region-growing
- Morphological Watersheds
- Motion

Image Segmentation

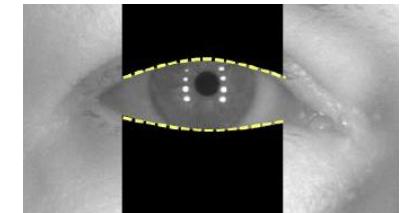
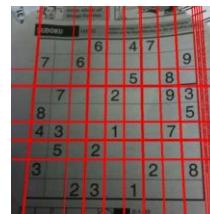
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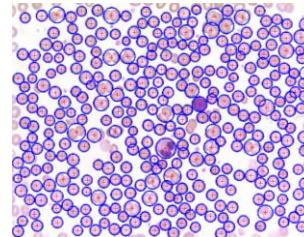
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Region Segmentation: Segmentation Criteria

A segmentation is a partition of an image I into a set of regions S satisfying:

1. $\cup S_i = S$ Partition covers the whole image.
2. $S_i \cap S_j = \emptyset, i \neq j$ No regions intersect.
3. $\forall S_i, P(S_i) = \text{true}$ Homogeneity predicate
4. $P(S_i \cup S_j) = \text{false}, i \neq j, S_i \text{ adjacent } S_j$ Union of adjacent regions does not satisfy homogeneity.



Segmentation: Thresholding based approaches

Two class Segmentation: Motivating example

- Separate pixels associated with object of interest from background

Two damning reports linking the Philippine military to a wave of political killings have left President Gloria Arroyo with a major challenge, analysts say — how to discipline the very people who have ensured her political survival.

The reports, one by a special U.N. envoy and the other by an independent commission of inquiry set up by Arroyo herself, have implicated the country's military in hundreds of political assassina-

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Thresholding

- Separate pixels associated with object of interest from background
- Given a image $f(x,y)$, the segmented image $g(x,y)$ is given by:

$$g(x, y) = \begin{cases} 1 & \text{if } f(x, y) > T \\ 0 & \text{if } f(x, y) \leq T \end{cases}$$

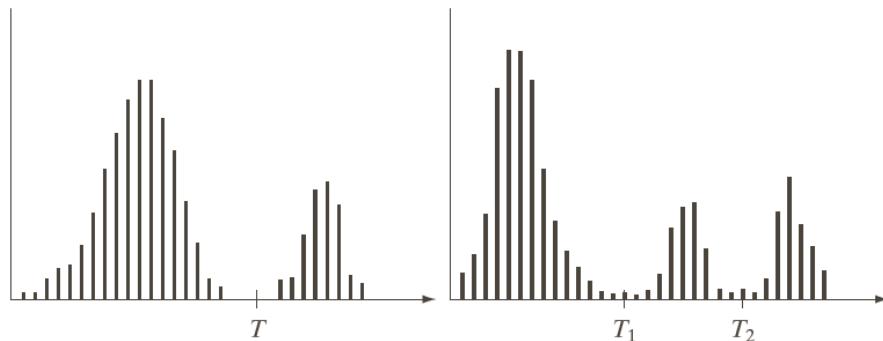
If T is constant over the entire image → Global Thresholding

If T changes over the image → Variable Thresholding

The main question is: **How to find T ?**

Thresholding

- How to find T ?
- One Idea is to explore the intensity histograms (if there is clear separation)



a b

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

Thresholding: Role of Noise

- Clear separation?

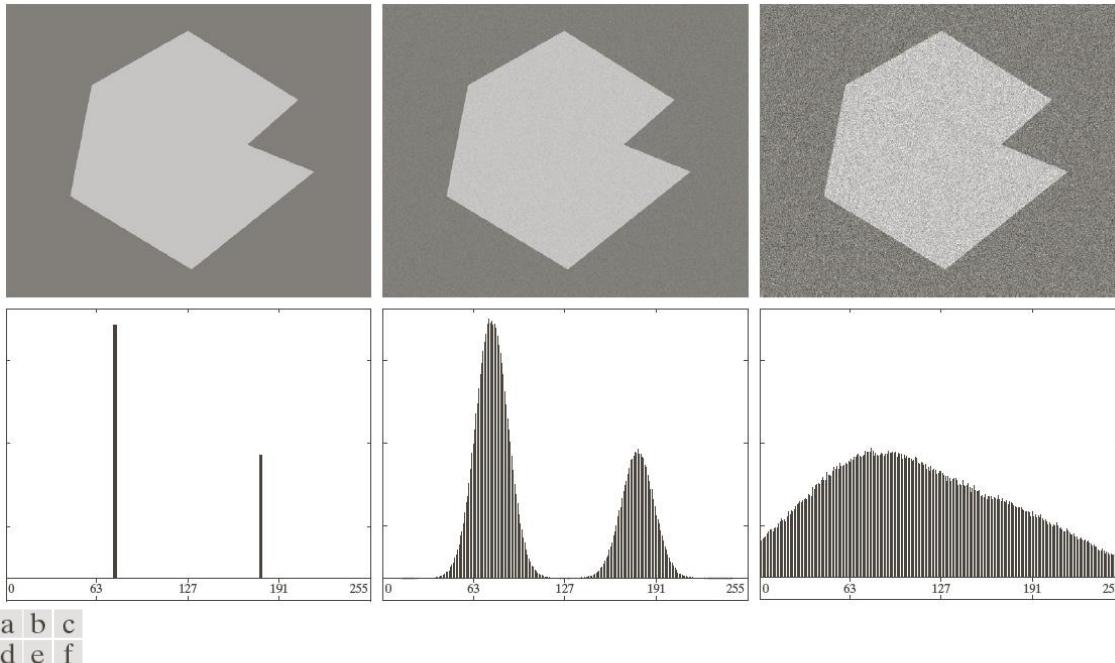


FIGURE 10.36 (a) Noiseless 8-bit image. (b) Image with additive Gaussian noise of mean 0 and standard deviation of 10 intensity levels. (c) Image with additive Gaussian noise of mean 0 and standard deviation of 50 intensity levels. (d)–(f) Corresponding histograms.

Thresholding: Role of Illumination and Reflectance

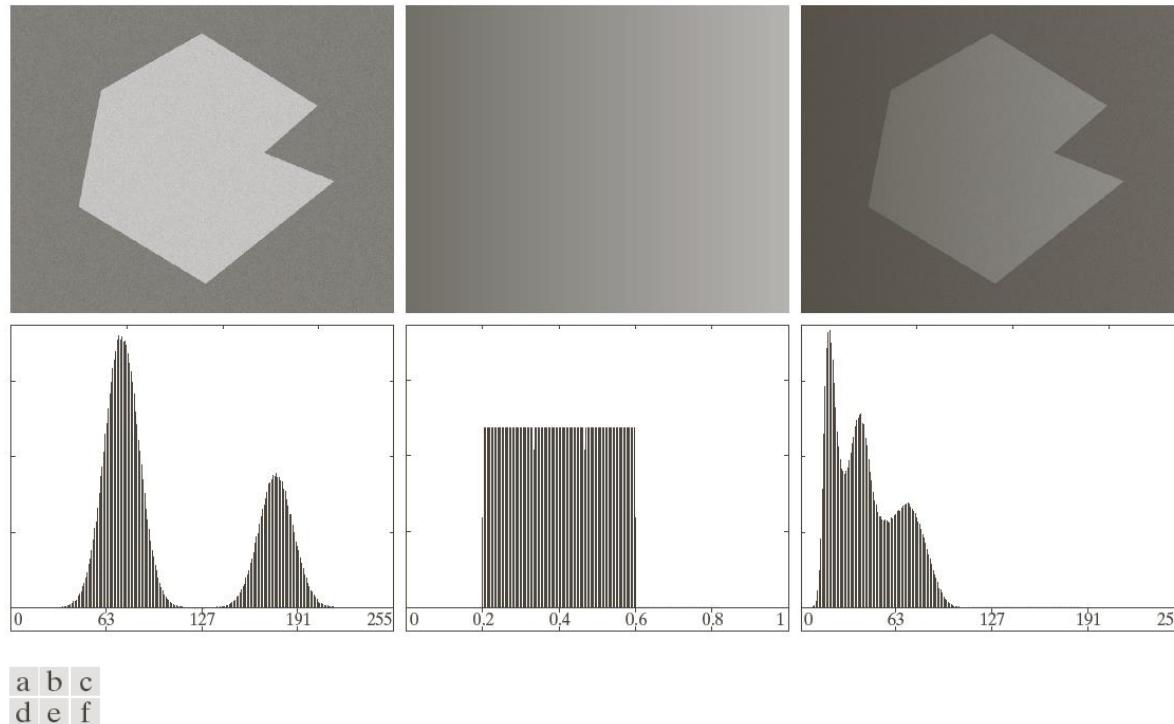
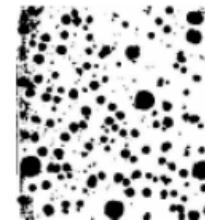
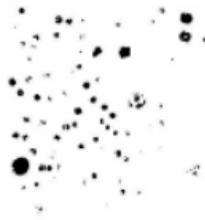
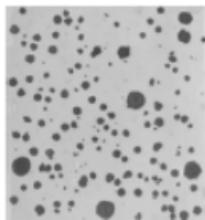


FIGURE 10.37 (a) Noisy image. (b) Intensity ramp in the range [0.2, 0.6]. (c) Product of (a) and (b). (d)–(f) Corresponding histograms.

Choosing a threshold is something of a “black art”:

```
n=imread('nodules1.jpg');
figure(1); imshow(n);
n1=im2bw(n,0.35);
n2=im2bw(n,0.75);
figure(2), imshow(n1);
figure(3), imshow(n2);
```



n: Original image n1: Threshold too low n2: Threshold too high

Finding T: Basic Global Thresholding

Iterative approach

1. Select an initial estimate of global threshold T
2. Segment the image using T
 - This will produce two groups of pixels (G_1 and G_2)
3. Compute the average (mean) intensity values m_1 and m_2 for the pixels in G_1 and G_2 respectively
4. Compute a new threshold value $T_{\text{new}} = (m_1+m_2)/2$
5. If $|T_{\text{new}} - T| < \text{eps}$, stop.
6. Else, set $T = T_{\text{new}}$. Go to Step 2.

Finding T: Basic Global Thresholding

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Matlab function: opthr

Basic Global Thresholding

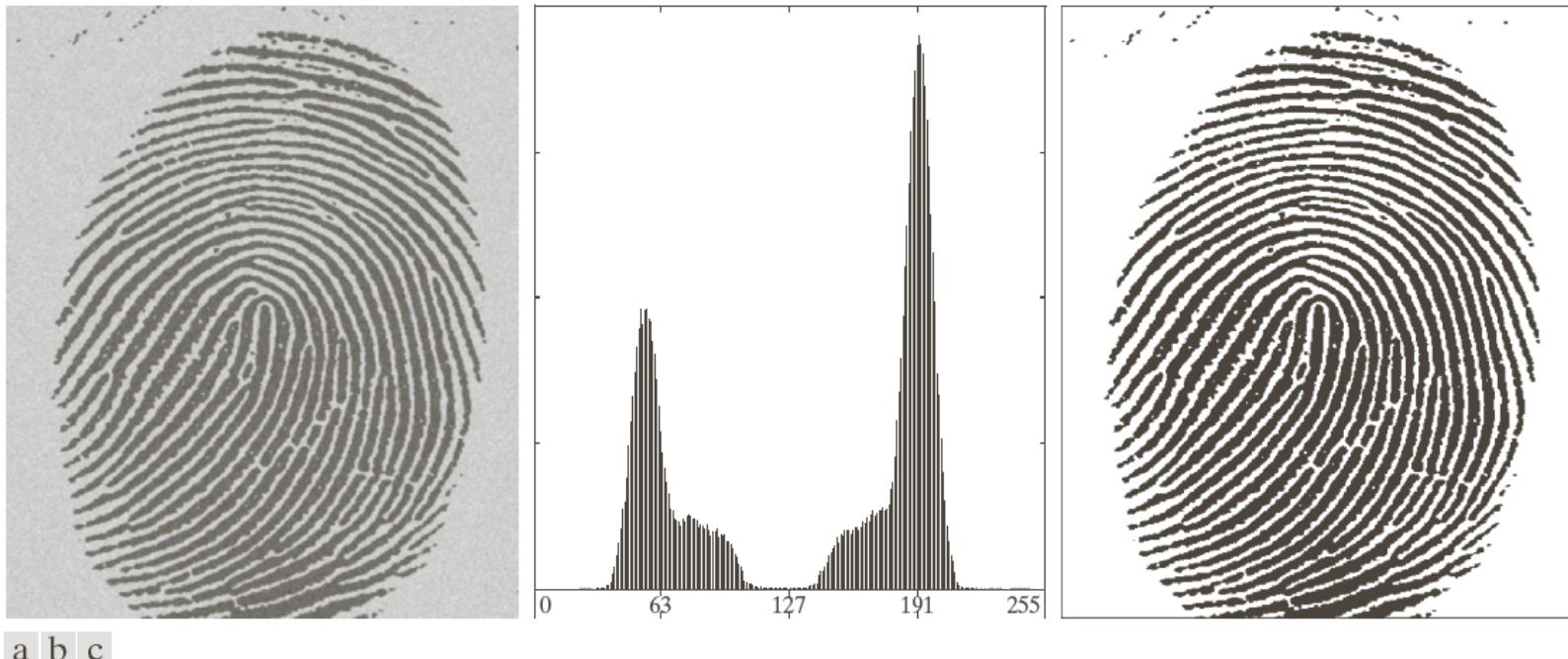
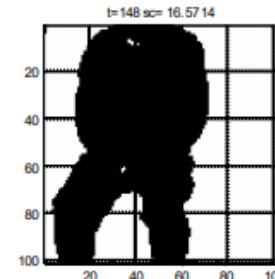
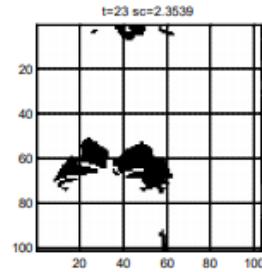
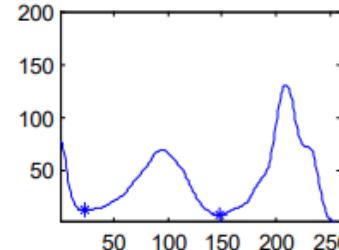
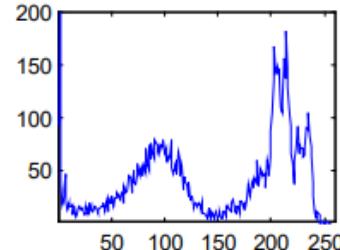


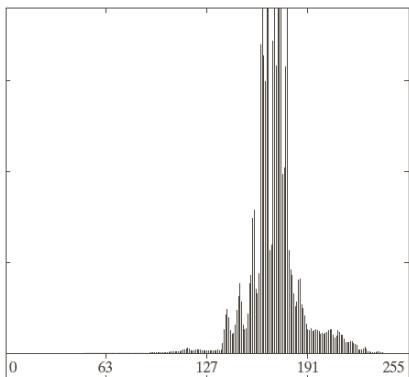
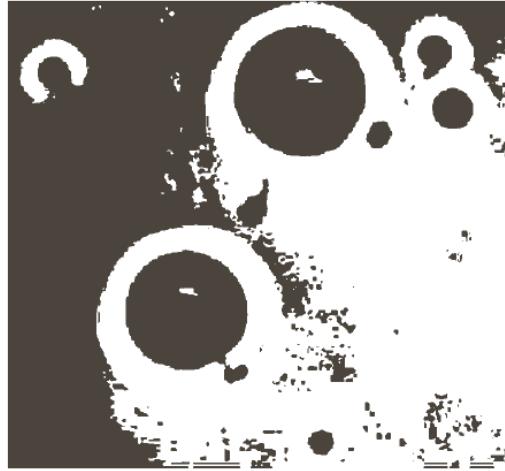
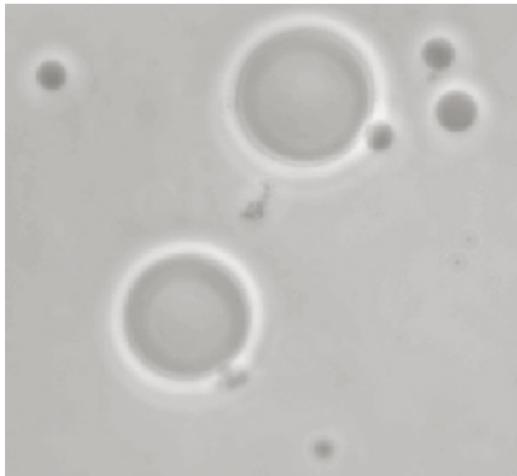
FIGURE 10.38 (a) Noisy fingerprint. (b) Histogram. (c) Segmented result using a global threshold (the border was added for clarity). (Original courtesy of the National Institute of Standards and Technology.)

Global Thresholding

T is usually located at the valley/ one of the valleys

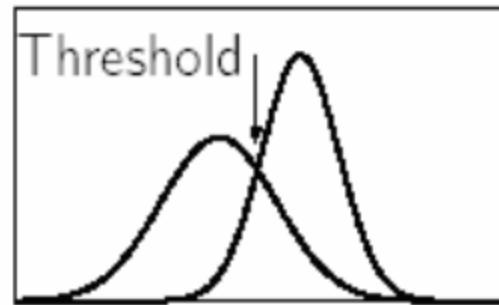
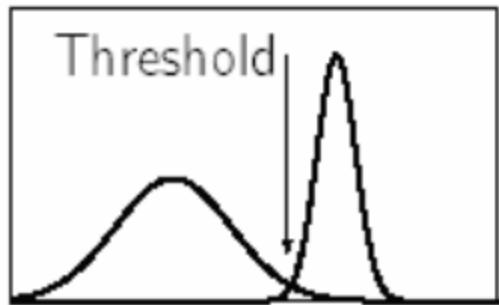


Basic Global Thresholding



- No valleys
- BG intensity close to ROI (region-of-interest) intensity

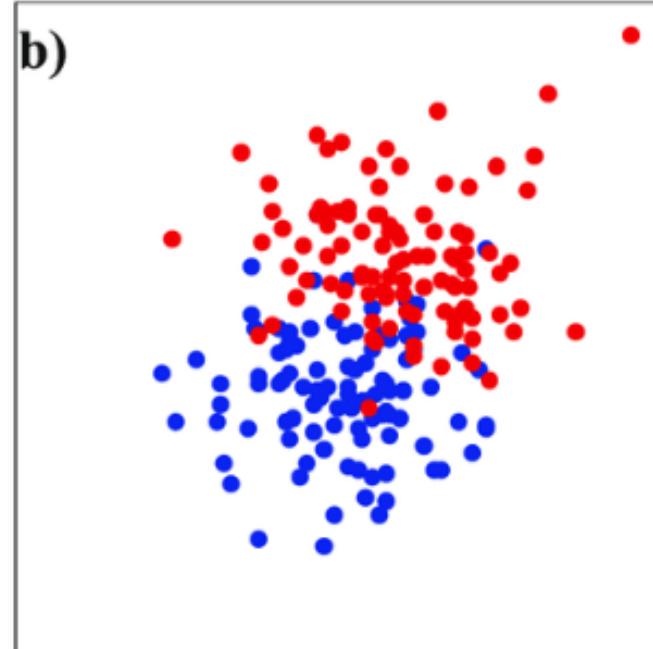
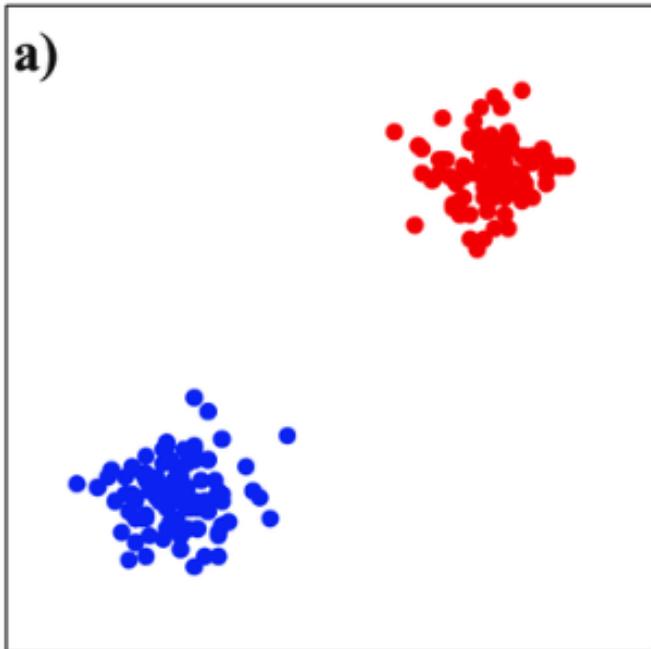
Determining FG/BG separation



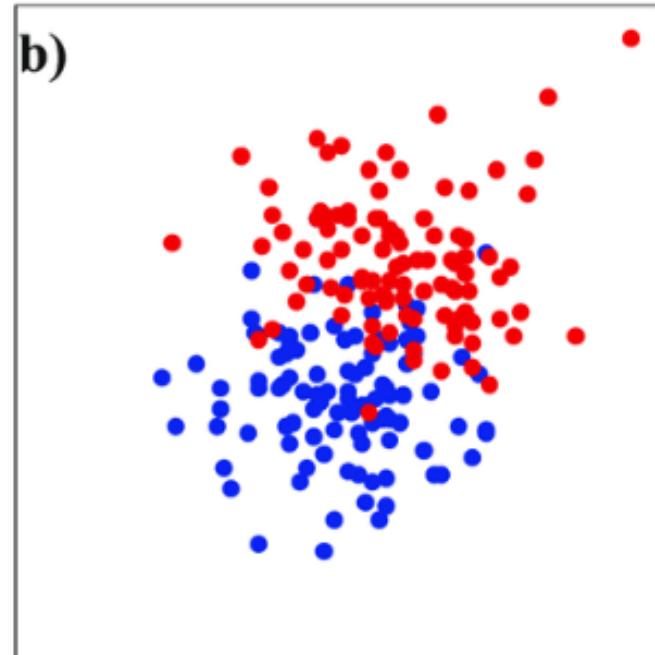
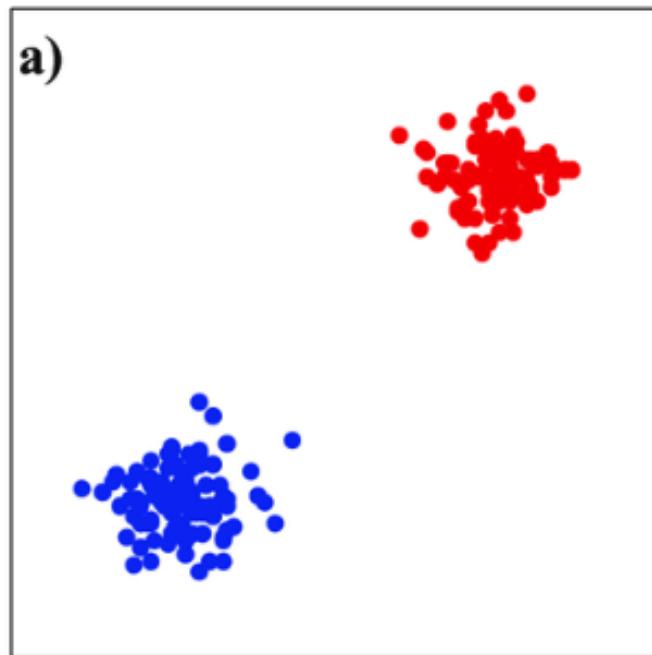
Global Thresholding: Otsu's Method

- Based on histograms
- Automatically finds the optimal threshold maximizing the between class variance
- Proposed in 1975
- Preliminaries:
 - What is the formula for mean and variance of intensities in an image ?
 - What does variance measure ?
 - A probabilistic / normalized-histogram perspective for mean, variance

Inter-class and Intra-class variance



Inter-class and Intra-class variance



2: Inter-class and Intra-class variances concept. a) Low intra-class variance and high inter-class variance: compact well separated clusters. b) High intra-class variance and low inter-class variance: wide clusters without a clear frontier.



Insight

- Variance = A measure of region homogeneity
- Regions with high homogeneity will have a low variance.

Otsu's algorithm: Find the threshold that minimizes intra-class variance.

1. Consider all possible thresholds T
2. For each threshold t in T
 1. Compute the variance for Class-1 pixels (intensities < t)
 2. Compute the variance for Class-2 pixels (intensities $\geq t$)

Intra-class variance \rightarrow

$$\sigma_f^2(t) = \omega_1(t)\sigma_1^2(t) + \omega_2(t)\sigma_2^2(t)$$

Class-1 probability (fraction of pixels
whose intensity $< t$)



Insight

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Intra-class variance $\rightarrow \sigma_f^2(t) = \omega_1(t)\sigma_1^2(t) + \omega_2(t)\sigma_2^2(t)$

Otsu's Method

- Compute the normalized histogram of the input image.
- Denote the components of the histogram by p_i , $i = 0, 1, 2, 3, \dots, L - 1$
- Suppose a threshold is selected k , $0 < k < L - 1$
- C_1 is the set of pixels with levels $[0, 1, 2, 3, \dots, k]$
- C_2 is the set of pixels with levels $[k + 1, k + 2, k + 3, \dots, L - 1]$
- Obtain the value of threshold which **maximizes** the between class variance

$$\sigma_B^2(k) = P_1(k)(m_1(k) - m_G)^2 + P_2(k)(m_2(k) - m_G)^2$$

Otsu's Method

$$\sigma_B^2(k) = P_1(k)(m_1(k) - m_G)^2 + P_2(k)(m_2(k) - m_G)^2$$

- $P_1(k)$ is probability of C_1 occurring

$$P_1(k) = \sum_{i=0}^k p_i, k = 0, 1, 2, \dots, k$$

$$P_2(k) = \sum_{i=k+1}^{L-1} p_i = 1 - P_1(k), k = 0, 1, 2, \dots, k$$

- $m_1(k)$ and $m_2(k)$ are means of C_1 and C_2

$$m_1(k) = \frac{\sum_{i=0}^k i p_i}{P_1(k)} \quad m_2(k) = \frac{\sum_{i=k+1}^{L-1} i p_i}{P_2(k)}$$

Otsu's Method

$$\sigma_B^2(k) = P_1(k)(m_1(k) - m_G)^2 + P_2(k)(m_2(k) - m_G)^2$$

$$\sigma_B^2(k^*) = \max_{0 \leq k \leq L-1} \sigma_B^2(k)$$

In simple words, we evaluate all values of k and select the value of k that yielded the maximum $\sigma_B^2(k)$

This idea can be easily extended to compute multiple thresholds!

Otsu's Method

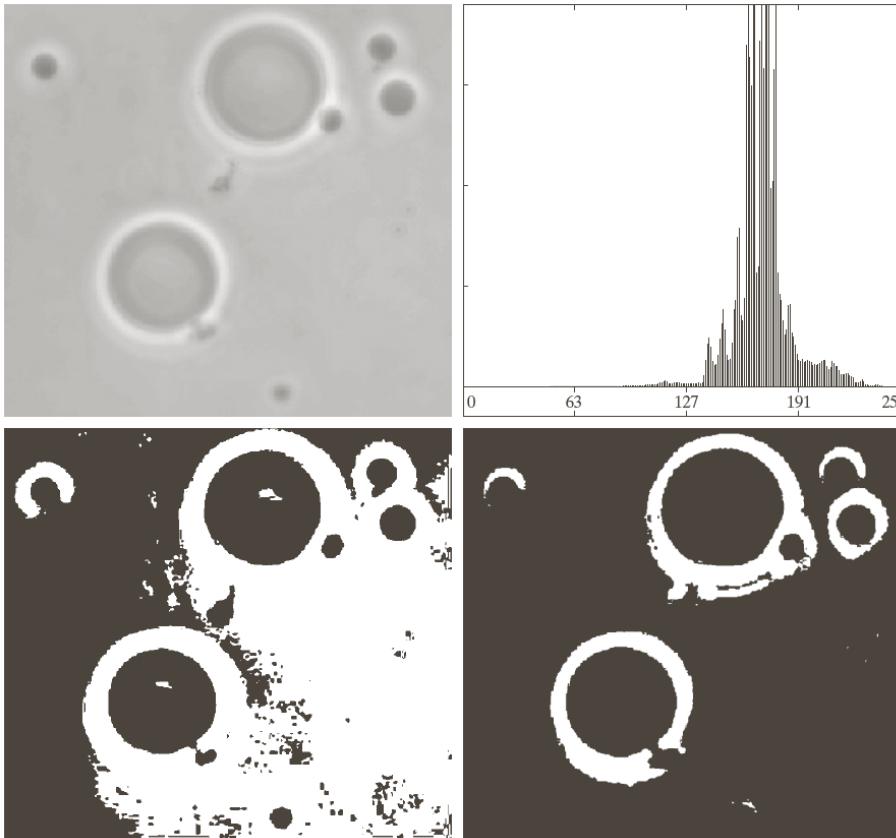
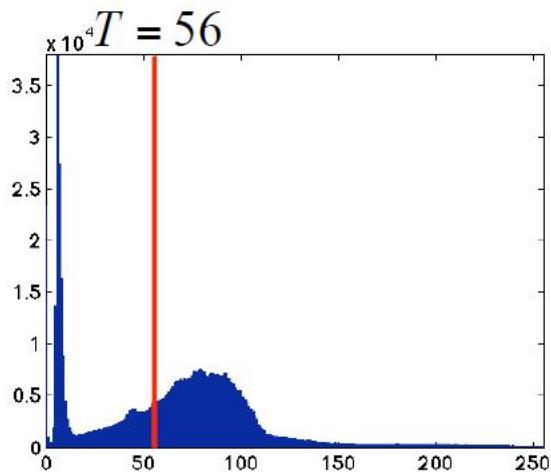


FIGURE 10.39

(a) Original image.
(b) Histogram (high peaks were clipped to highlight details in the lower values).
(c) Segmentation result using the basic global algorithm from Section 10.3.2.
(d) Result obtained using Otsu's method. (Original image courtesy of Professor Daniel A. Hammer, the University of Pennsylvania.)

$$T = 181$$

Otsu's Method



Handling Noise

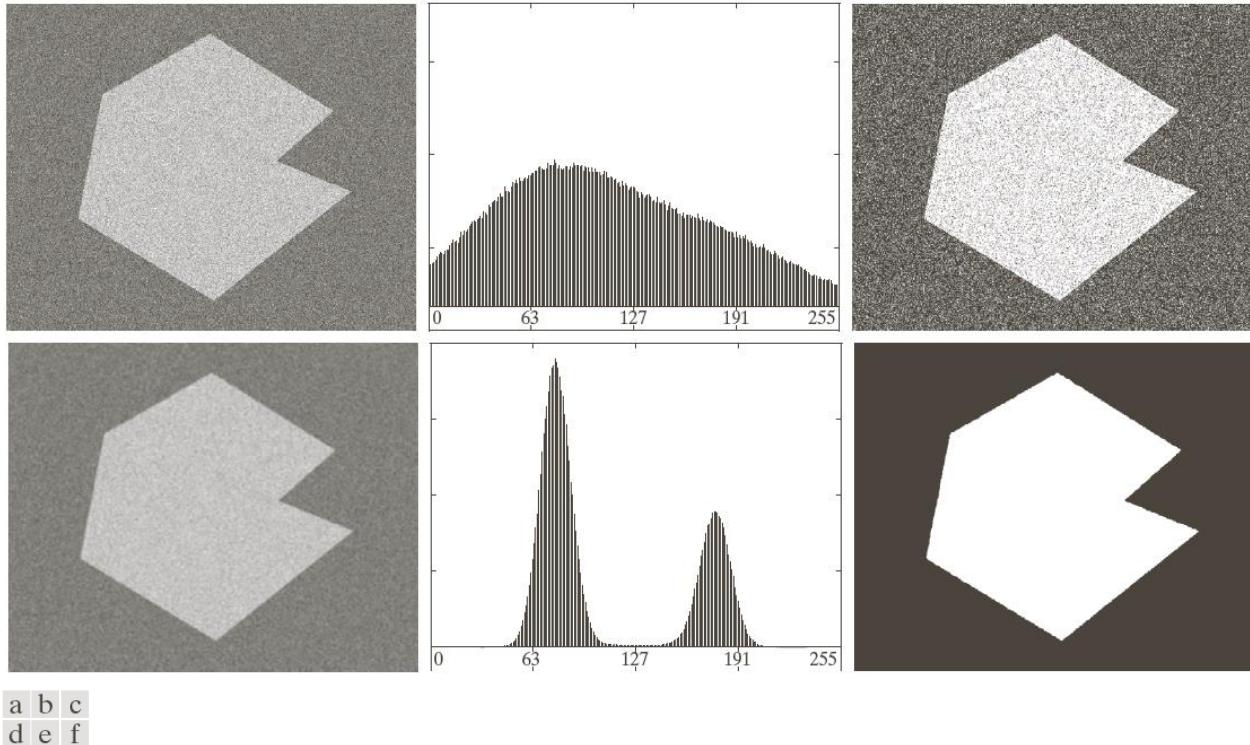


FIGURE 10.40 (a) Noisy image from Fig. 10.36 and (b) its histogram. (c) Result obtained using Otsu's method. (d) Noisy image smoothed using a 5×5 averaging mask and (e) its histogram. (f) Result of thresholding using Otsu's method.

Otsu's method: Main Limitation

Two damning reports linking the Philippine military to a wave of political killings have left President Gloria Arroyo with a major challenge, analysts say — how to discipline the very people who have ensured her political survival.

The reports, one by a special U.N. envoy and the other by an independent commission of inquiry set up by Arroyo herself, have implicated the country's military in hundreds of political assassina-

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Pai et al. PR 2010

No single threshold, may be ideal

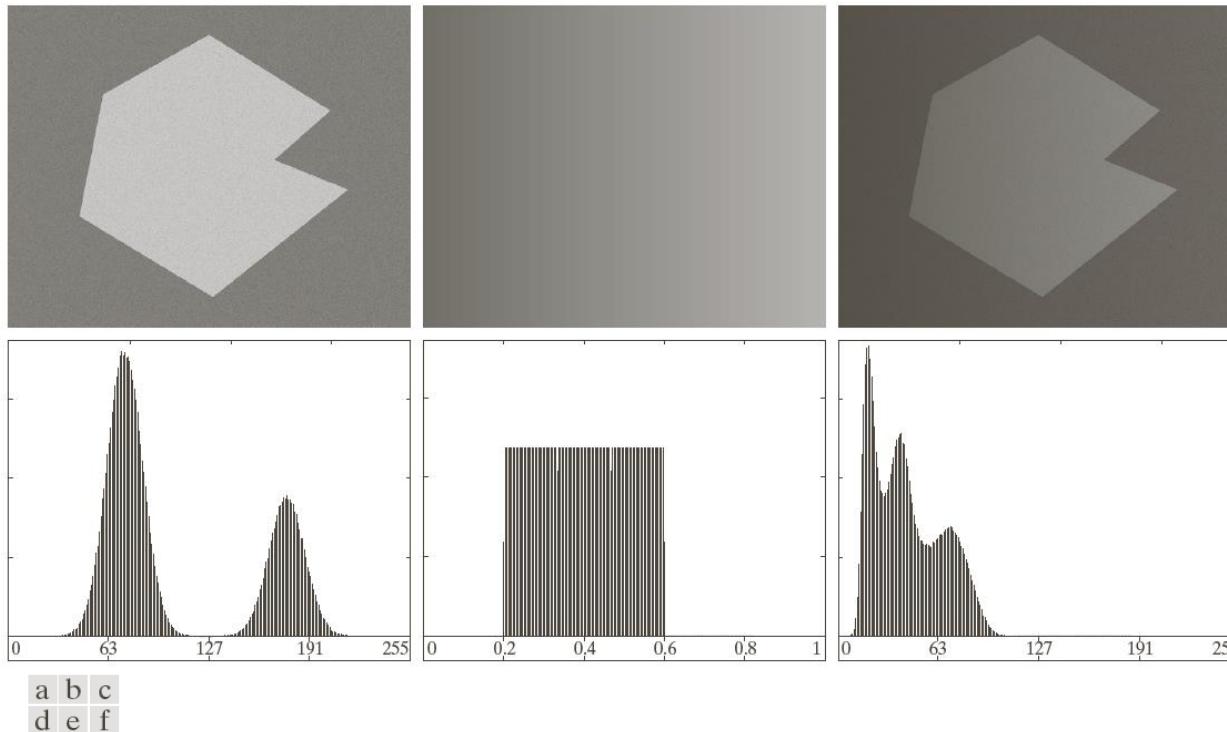


FIGURE 10.37 (a) Noisy image. (b) Intensity ramp in the range [0.2, 0.6]. (c) Product of (a) and (b). (d)–(f) Corresponding histograms.

Global segmentation: main limitation

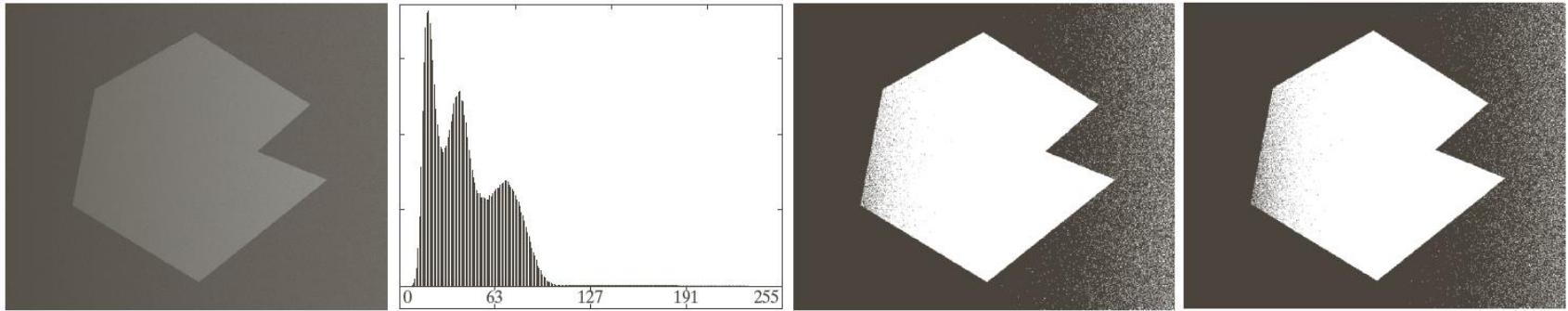
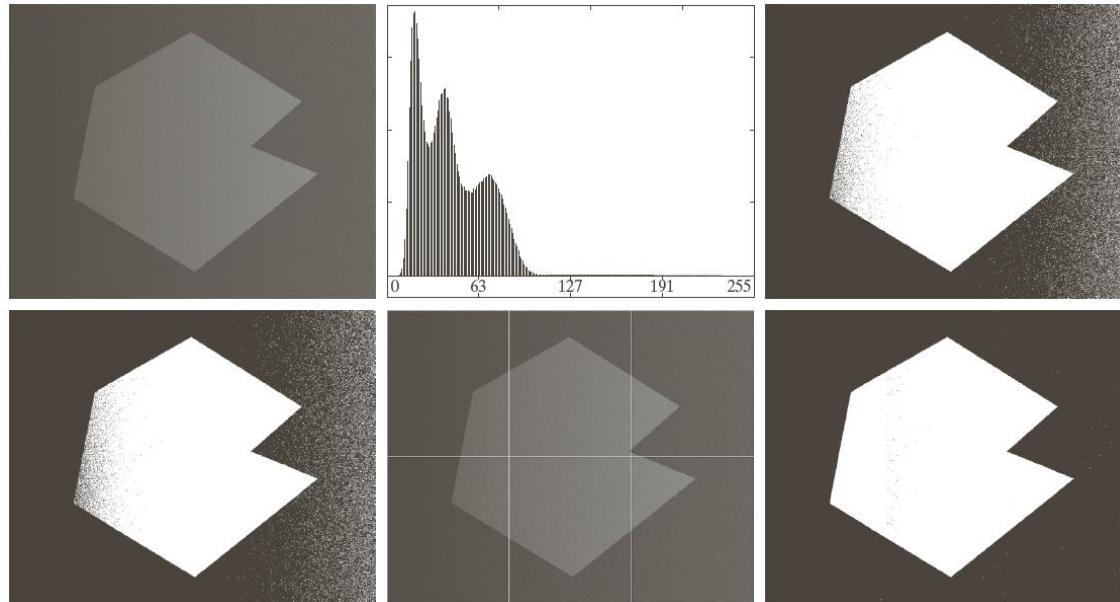


Image subdivision + variable Thresholding



a b c
d e f

FIGURE 10.46 (a) Noisy, shaded image and (b) its histogram. (c) Segmentation of (a) using the iterative global algorithm from Section 10.3.2. (d) Result obtained using Otsu's method. (e) Image subdivided into six subimages. (f) Result of applying Otsu's method to each subimage individually.

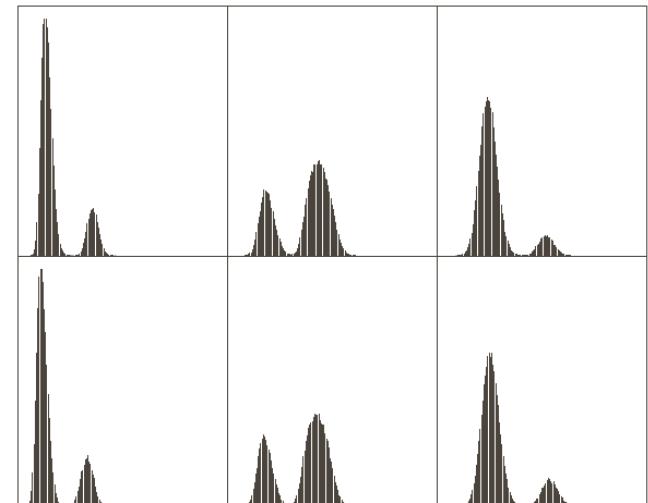


FIGURE 10.47
Histograms of the six subimages in Fig. 10.46(e).

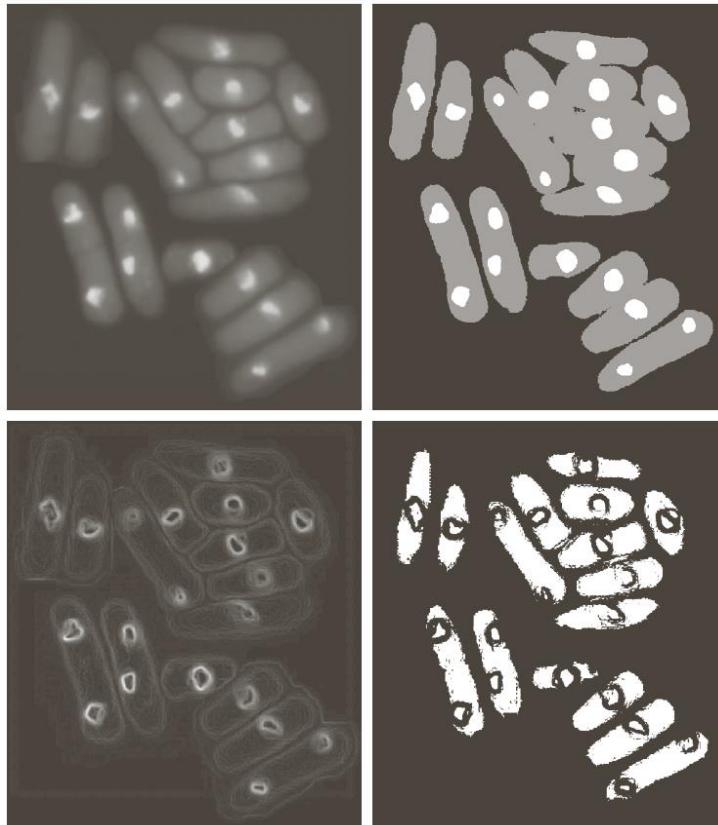
Per pixel variable Thresholding

- Compute standard deviation and mean of each pixel (around local neighborhood)
- Let σ_{xy}, m_{xy} denote the standard deviation and mean value contained in neighborhood S_{xy} centred around (x, y)
- Example threshold function:

$$g(x, y) = \begin{cases} 1 & \text{if } f(x, y) > T_{xy} \\ 0 & \text{if } f(x, y) \leq T_{xy} \end{cases}$$

$$T_{xy} = a\sigma_{xy} + bm_{xy} \quad \text{or} \quad T_{xy} = a\sigma_{xy} + bm_G$$

Per pixel variable Thresholding

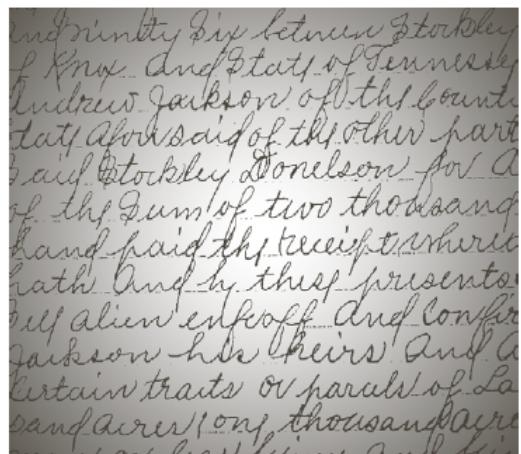


a b
c d

FIGURE 10.48

- (a) Image from Fig. 10.43.
(b) Image segmented using the dual thresholding approach discussed in Section 10.3.6.
(c) Image of local standard deviations.
(d) Result obtained using local thresholding.

Per pixel: moving average



a b c

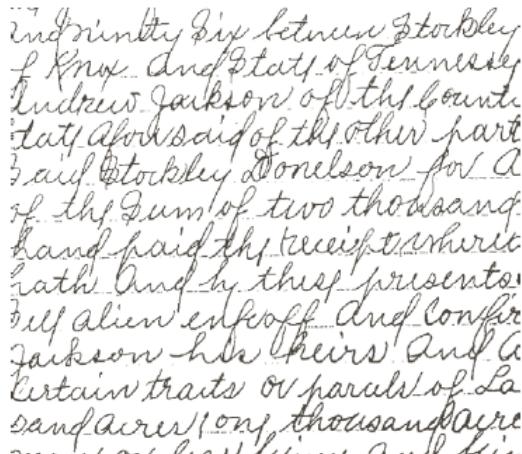
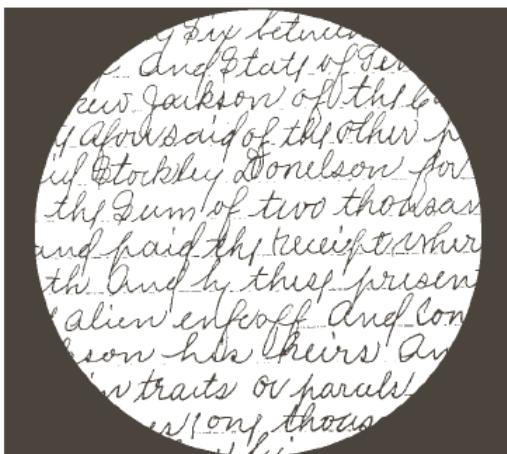
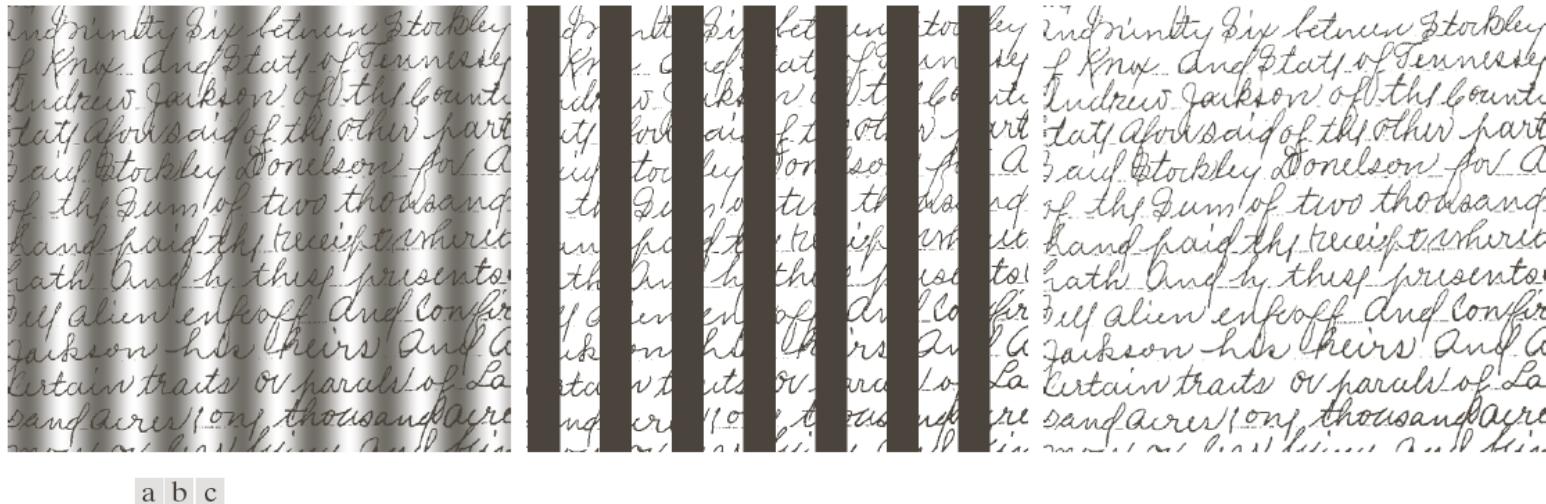


FIGURE 10.49 (a) Text image corrupted by spot shading. (b) Result of global thresholding using Otsu's method. (c) Result of local thresholding using moving averages.

Per pixel: moving average



a b c

FIGURE 10.50 (a) Text image corrupted by sinusoidal shading. (b) Result of global thresholding using Otsu's method. (c) Result of local thresholding using moving averages.

Adaptive thresholding: advanced algorithms

a

Two damning reports linking the Philippine military to a wave of political killings have left President Gloria Arroyo with a major challenge, analysts say — how to discipline the very people who have ensured her political survival.

The reports, one by a special U.N. envoy and the other by an independent commission of inquiry set up by Arroyo herself, have implicated the country's military in hundreds of political assassina-

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b

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d

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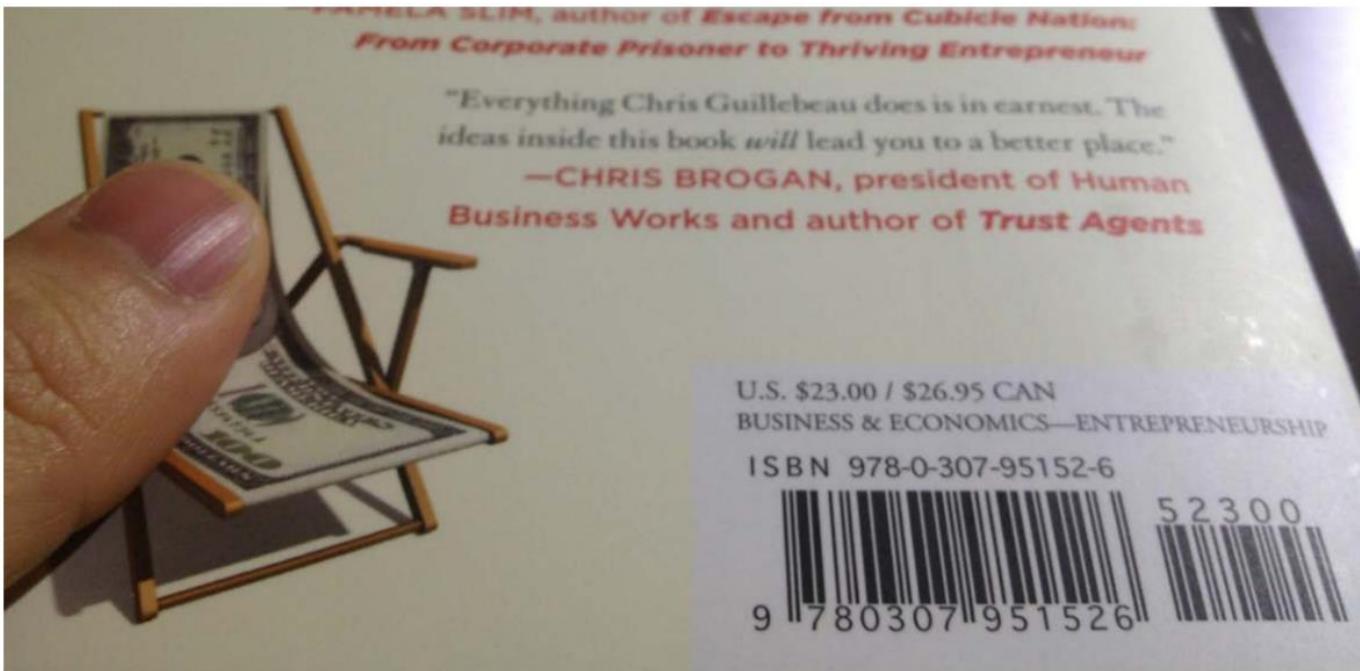
f

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Adaptive thresholding algorithm... Pai et al. PR 2010

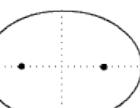
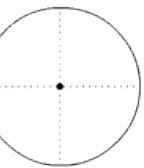
Adaptive thresholding: Use case



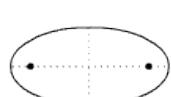
Adaptive thresholding: Use case



$$b^2 = a^2(1 - e^2)$$



$$e = 0$$



$$e = 0.5$$



$$e = 0.75$$

$$e = 0.95$$

Adaptive thresholding: Use case



Adaptive thresholding: Use case



Adaptive thresholding: Use case



Choosing thresholding algorithms

- Based on typical sizes of objects/regions of interest
 - Small → Adaptive/Local
 - Large → Global

Thresholding: Summary

- Many methods
- Survey

Sezgin, M and Sankur, B (2004), "Survey over Image Thresholding Techniques and Quantitative Performance Evaluation", Journal of Electronic Imaging 13(1): 146-165

- Comparison

http://www.fmwconcepts.com/imagemagick/threshold_comparison/index.php

Segmentation: Region based approaches

Region Based Segmentation

- Basic Formulation: Let R represent the entire image region. Segmentation is the process of partitioning R into subregions R_1, R_2, \dots, R_n , such that:

1 $\bigcup_{i=1}^n R_i = R$

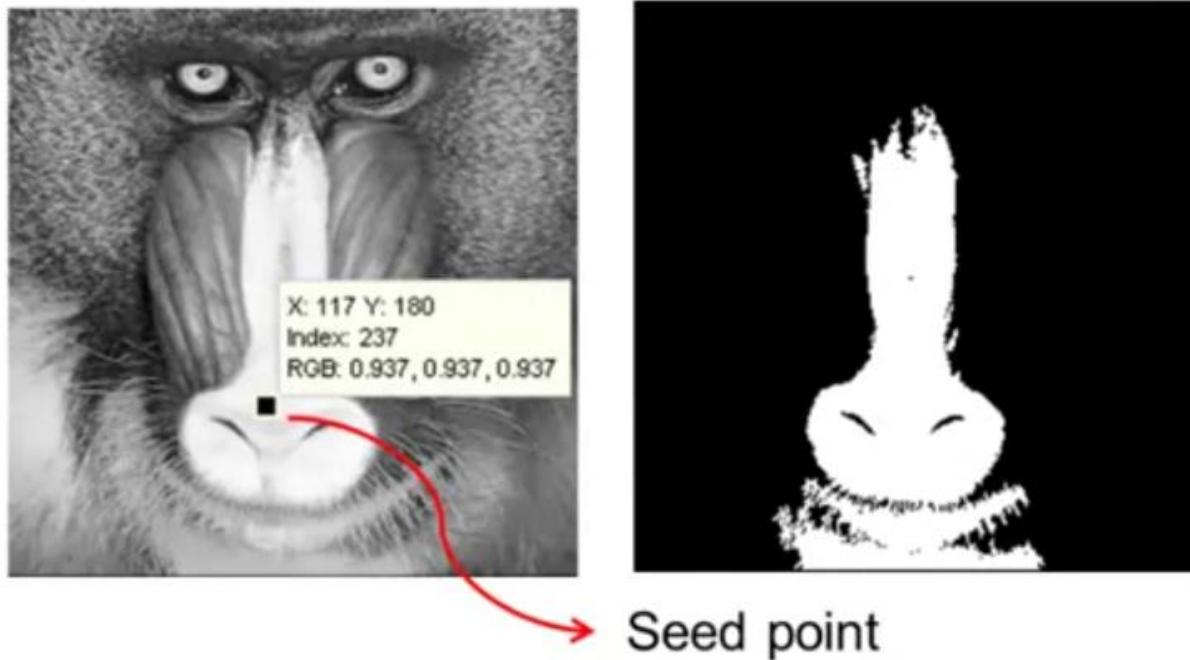
2 R_i is a connected region, for all i

3 $R_i \cap R_j = \emptyset$ for all i and j, $i \neq j$

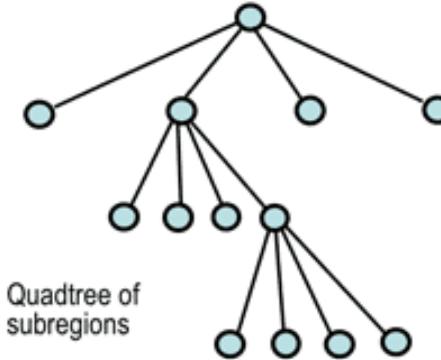
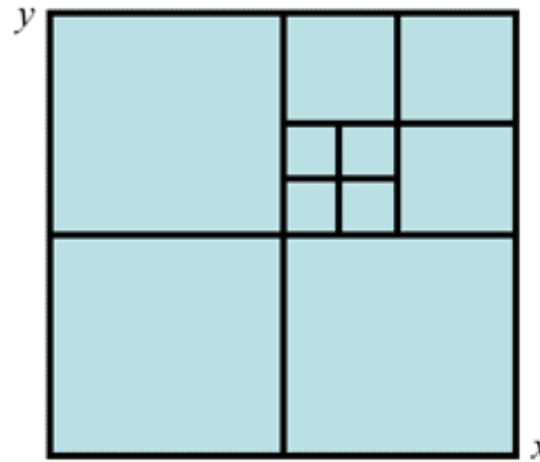
Region Growing

- Start with a set of seed points
 - Based on prior information
 - Based on some properties calculated at each point
- Grow regions based on a predefined criteria
 - Similarities in color, texture etc.

Region Growing: Example

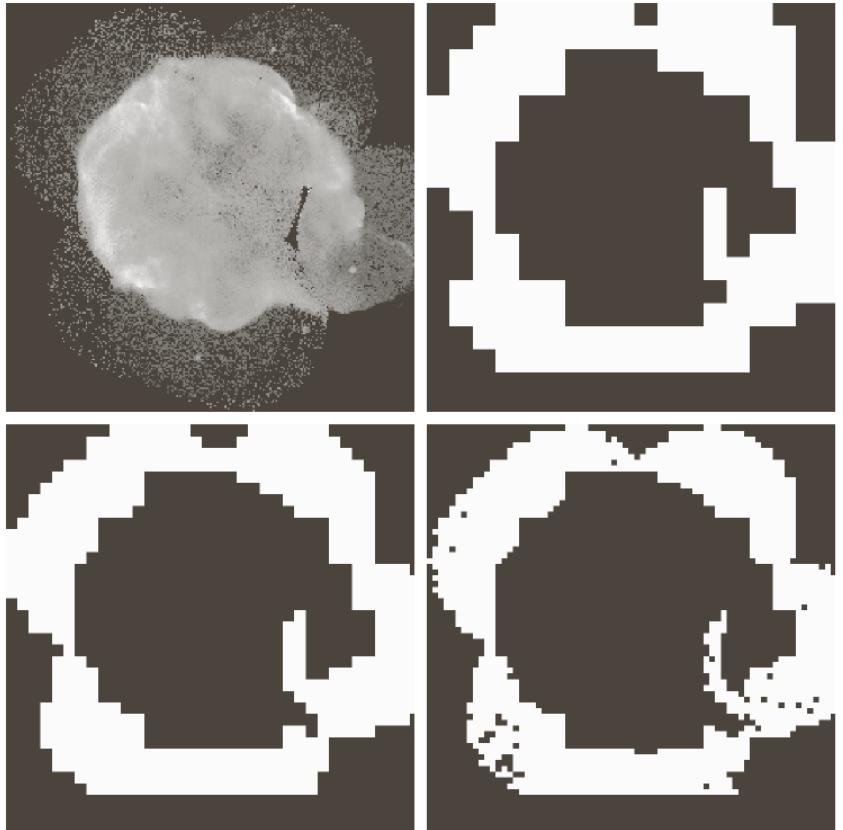


Region Splitting and Merging



Need to define a splitting function and size of the minimum quadrant

Region Splitting and Merging

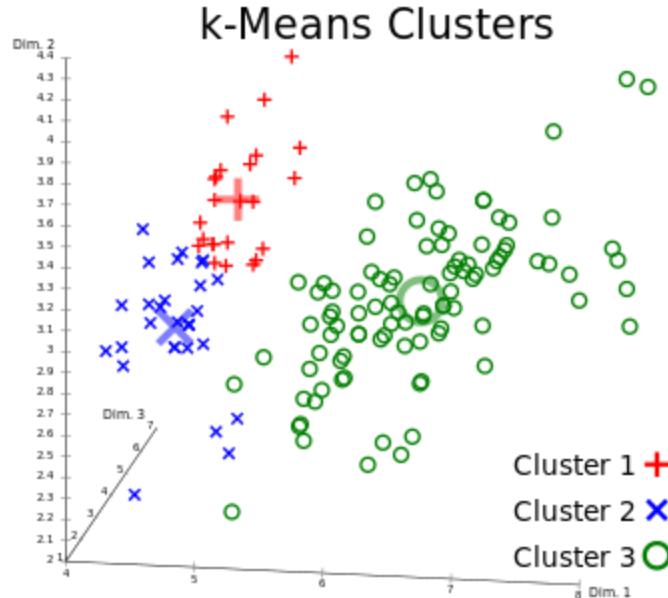


$$Q = \begin{cases} \text{TRUE} & \text{if } \sigma > a \text{ AND } 0 < m < b \\ \text{FALSE} & \text{otherwise} \end{cases}$$

FIGURE 10.53
(a) Image of the Cygnus Loop supernova, taken in the X-ray band by NASA's Hubble Telescope.
(b)–(d) Results of limiting the smallest allowed quadregion to sizes of 32×32 , 16×16 , and 8×8 pixels, respectively.
(Original image courtesy of NASA.)

Clustering

- Clustering using extracted features + spatial coordinates
 - Features like color, texture etc.
 - Algorithms like k-means, agglomerative clustering, spectral clustering etc.

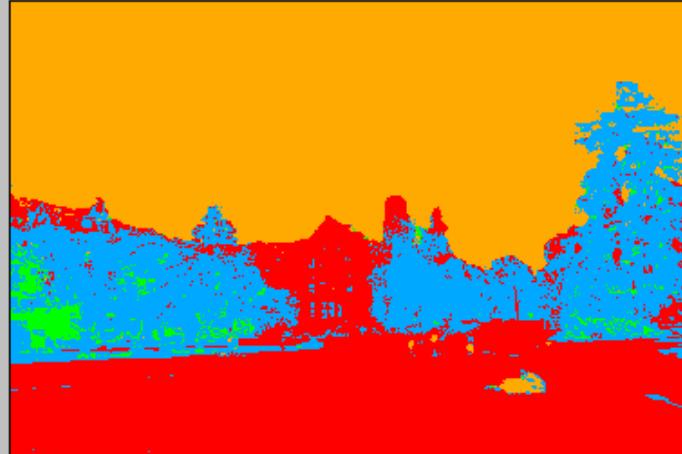


K-Means Example 1

1. Select an image: 2. Select a processor: 3. Click

Options:

Init Method



640*480 (607,118): RGB(20,22,1) Process done! (228,26): RGB(255,170,0)

K-Means Example 2

1. Select an image: imgs/P1010021.JPG

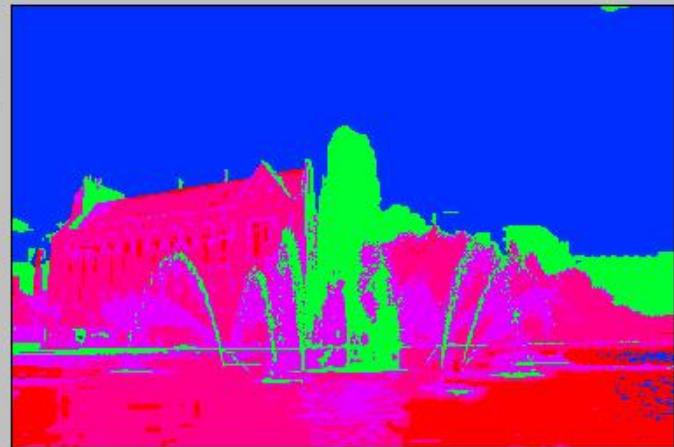


2. Select a processor: KMCluster

Options:

Init Method 0

3. Click process>>



640*480

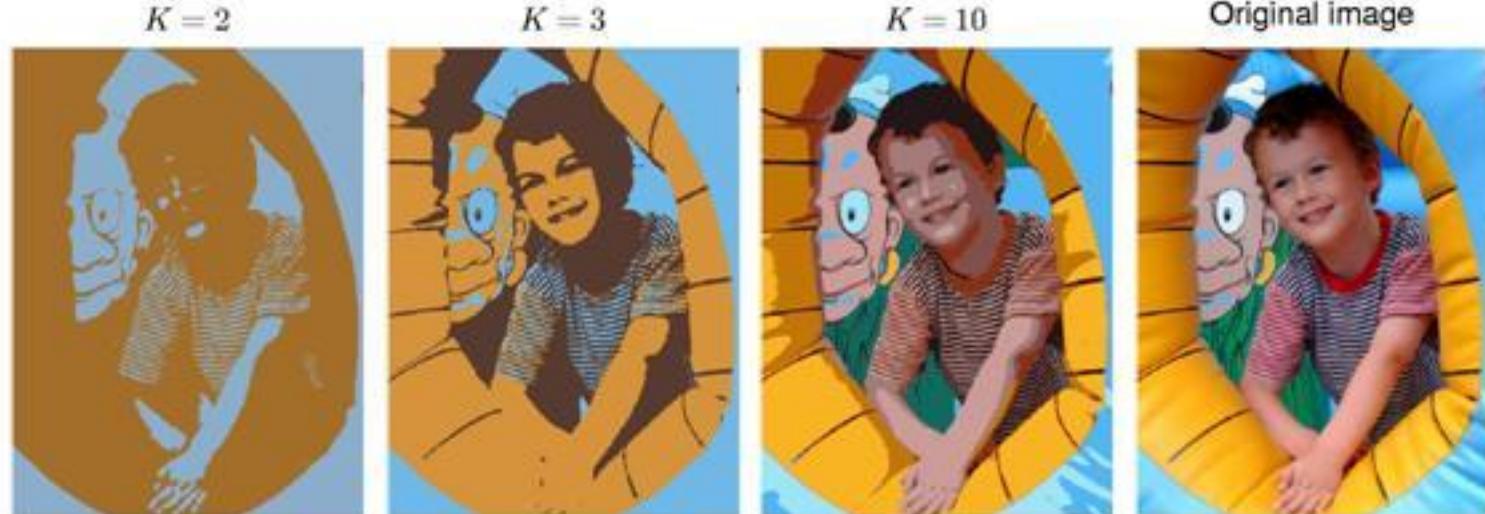
(636,95): RGB(102,130,151)

Process done!

(590,209): RGB(0,46,255)

Clustering

- Clustering using extracted features + spatial coordinates
 - Features : color, texture etc.
 - Algorithms : k-means, agglomerative clustering, spectral clustering etc.

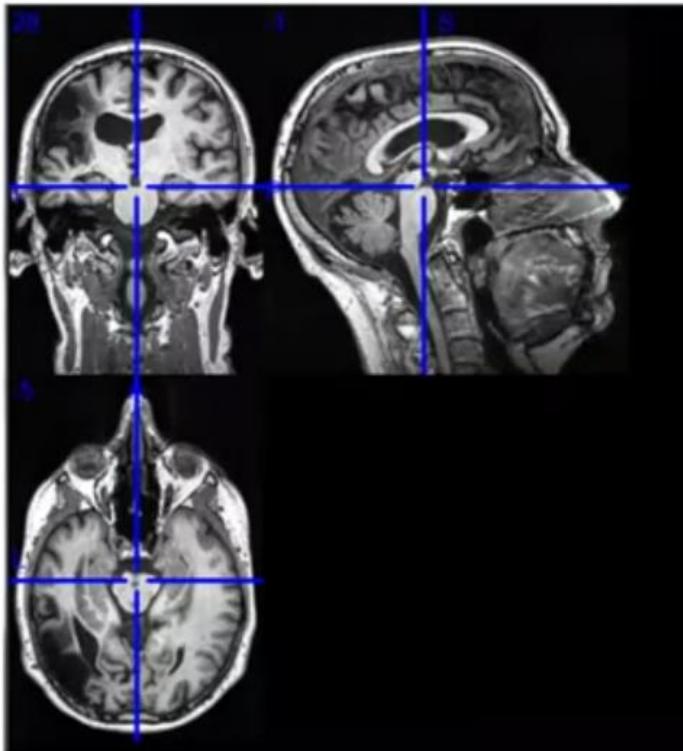


Clustering

- Clustering using extracted features + spatial coordinates
 - Features : color, texture etc.
 - Algorithms : k-means, agglomerative clustering, spectral clustering etc.



Clustering-Medical Images

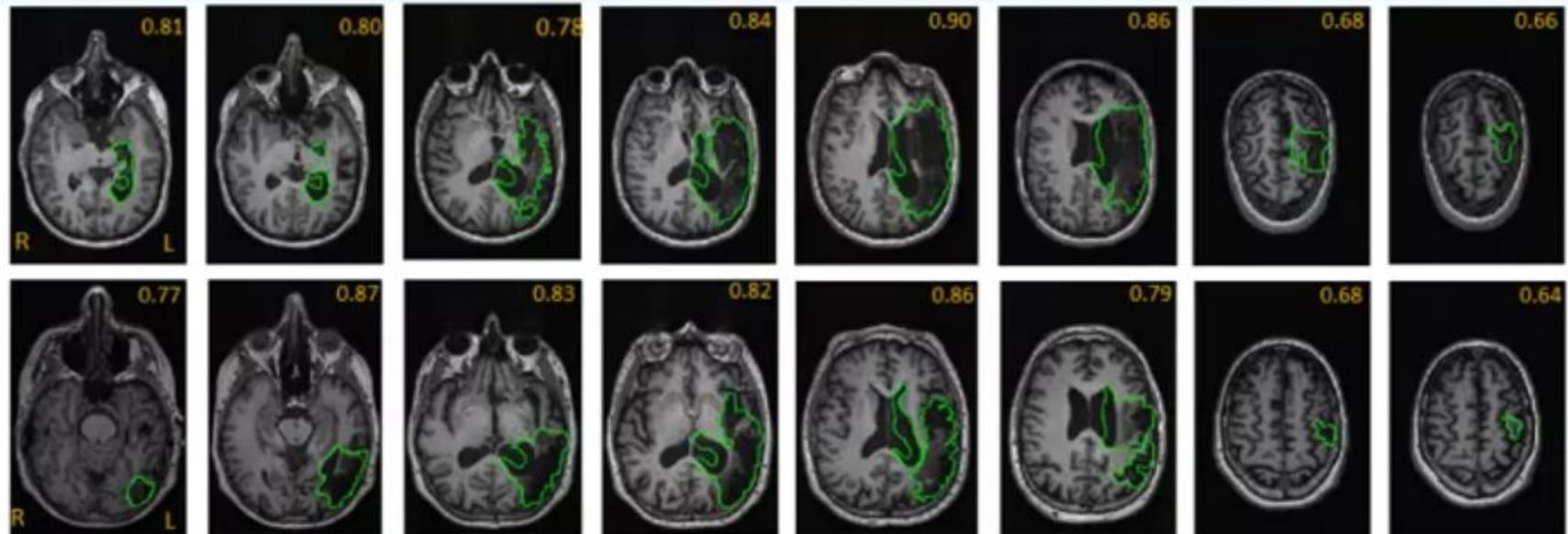


Voxels i.e 3D pixels

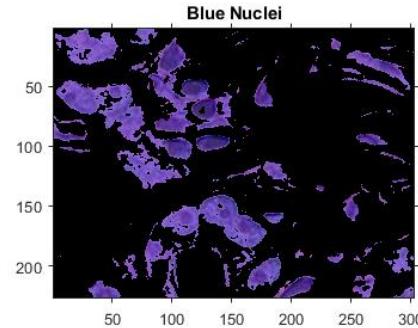
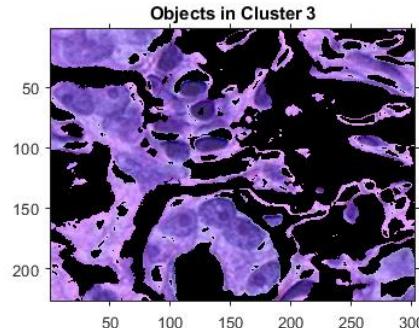
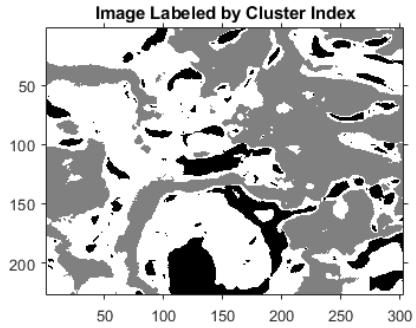
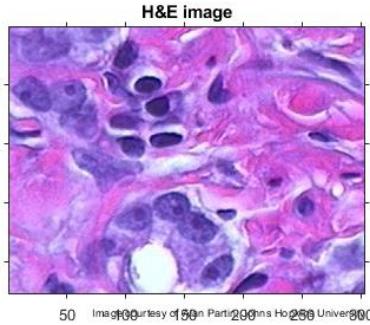
Clustering in 4 dimensional space i.e
 $[x, y, z, I(x,y,z)]$

There are three groups: White matter, Gray matter and CSF

Clustering-Medical Images



Important both for diagnosis + analysis of recovery



RGB -> L^*a^*b

Clustering on a,b

Get intensity

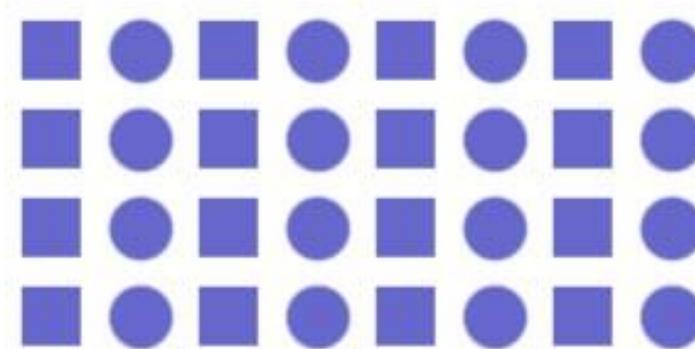
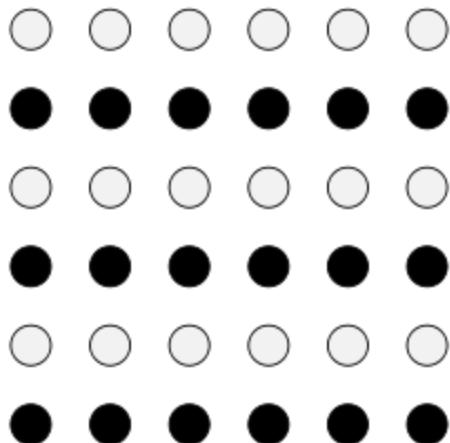
Threshold L

Advanced algorithms

- Mean Shift, Graph cut etc.
- Will be covered in computer vision course

Image Segmentation: How humans do it?

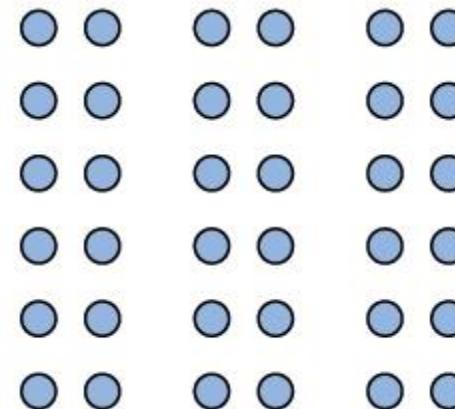
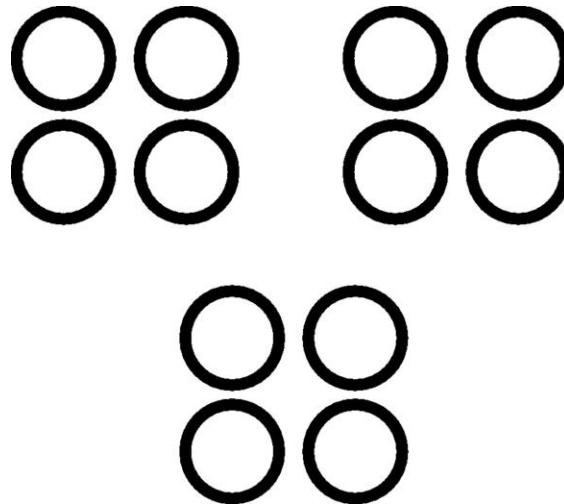
- Gestalt Principles of grouping



1. Similarity

Image Segmentation: How humans do it?

- Gestalt Principles of grouping



2. Proximity

Image Segmentation: How humans do it?

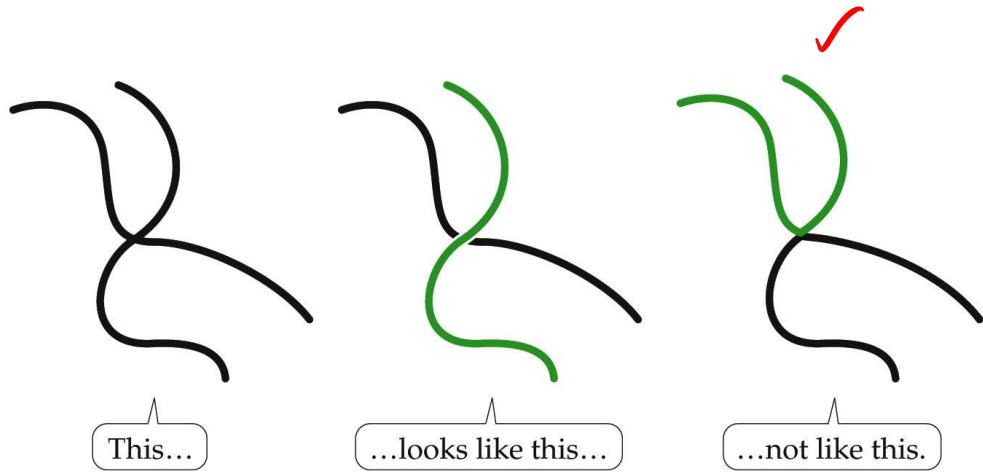
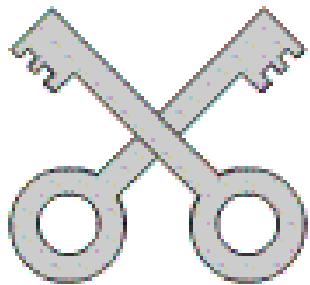
- Gestalt Principles of grouping



3. Closure

Image Segmentation: How humans do it?

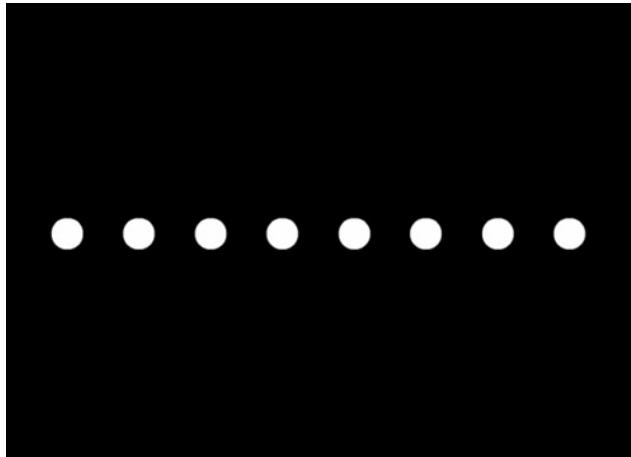
- Gestalt Principles of grouping



4. Good Continuation

Image Segmentation: How humans do it?

- Gestalt Principles of grouping



5. Common Fate

Image Segmentation: How humans do it?

- Gestalt Principles of grouping

[]{ }[]

6. Symmetry

Image Segmentation: How humans do it?

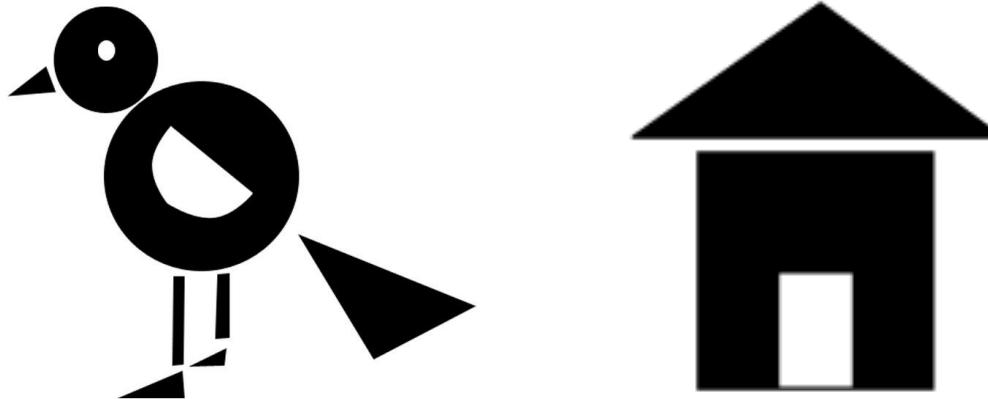
- Gestalt Principles of grouping



7. Parallelism

Image Segmentation: How humans do it?

- Gestalt Principles of grouping



8. Familiarity

Image Segmentation: How humans do it?

- Gestalt Principles of grouping

1. Similarity
2. Proximity
3. Good continuity
4. Closure
5. Common Fate
6. Symmetry
7. Parallelism
8. Familiarity



Additional References

- G&W textbook
 - 10.3, 10.4

Scribe List

2019122001
2019201001
2019201016
2019201017
2019201018
2019201019