Bioimage Informatics

Lecture 14, Spring 2012

Bioimage Data Analysis (IV)

Image Segmentation (part 3)

Outline

- Review: intensity thresholding based image segmentation
- Morphological image processing
- Watershed image segmentation
- Region-based image segmentation

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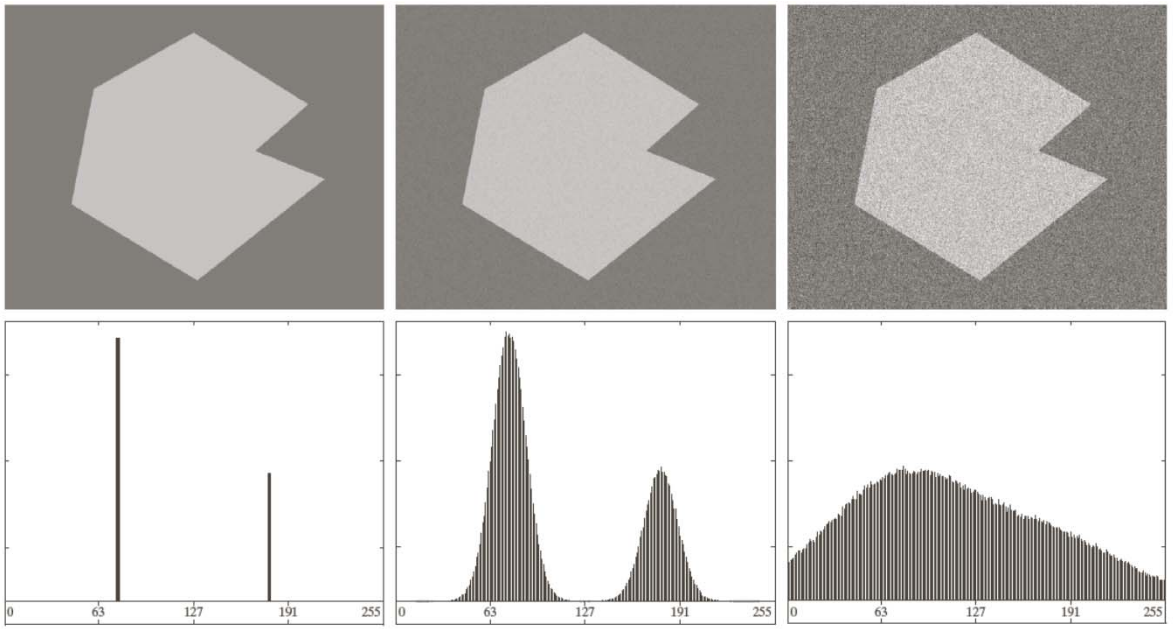
Basic Ideas of Thresholding-Based Segmentation



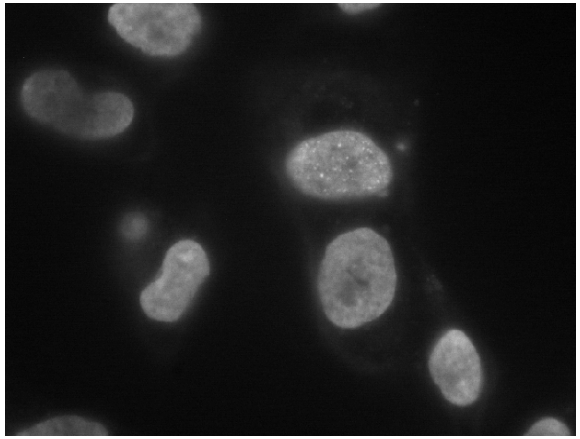
a b c
d e f

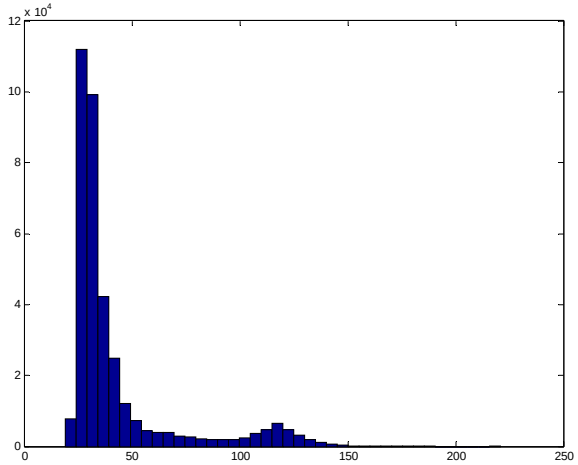
FIGURE 10.36 (a) Noiseless 8-bit image. (b) Image with additive Gaussian noise of mean 0 and standard deviation of 10 intensity levels. (c) Image with additive Gaussian noise of mean 0 and standard deviation of 50 intensity levels. (d)–(f) Corresponding histograms.

How to Set Thresholds (I)

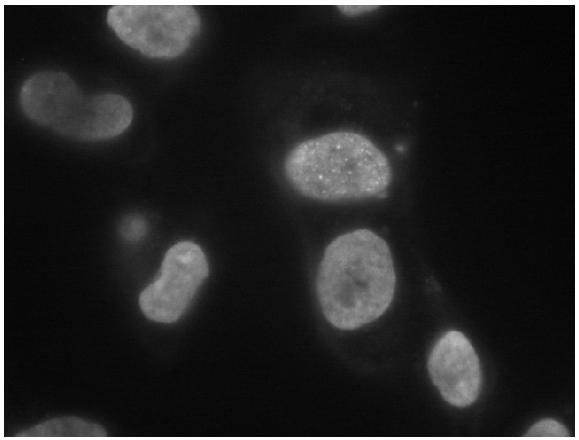
- There are several ways to set the thresholds.
  - Using local minima in the intensity histogram.
  - Use intensity histogram fitting with a mixture of Gaussians.
  - Intensity data clustering: e.g. k-means clustering

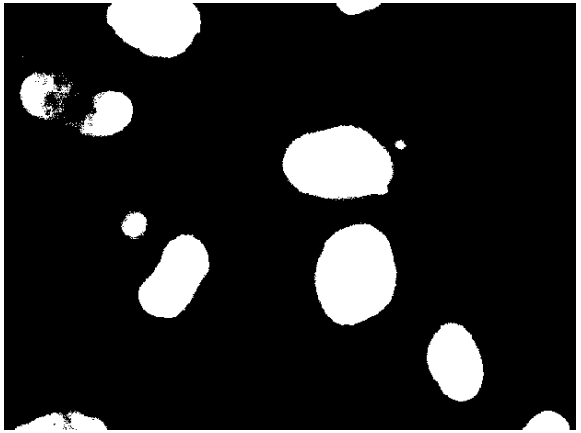
- Example:





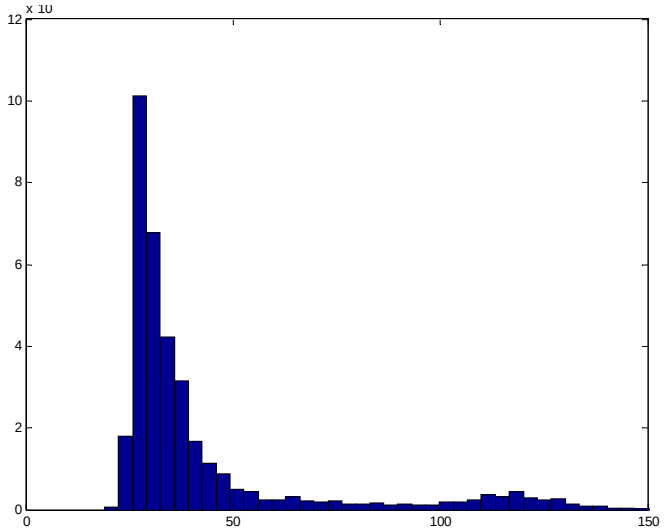
Example Results





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)

$$\mathrm{BIC} \equiv 2\, log\ p_M\left(x \middle| M\right) - N_M \log(n)$$

$M \rightarrow$ Model
$log\ p_M\left(x \middle| M\right) \rightarrow$ maximized likelihood
$N_M \rightarrow$ Number of parameters in model M
$n \rightarrow$ Number of measurements

How to Set Thresholds (III)

- Discriminant analysis (supervised classification)

$$P\left(x \in \text{class } j\right) = \frac{w_j p_j\left(x\right)}{\sum_{k=1}^{M} w_k p_k\left(x\right)}$$

- Determine the threshold between two neighboring Gaussian

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

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

How to Set Thresholds (IV)

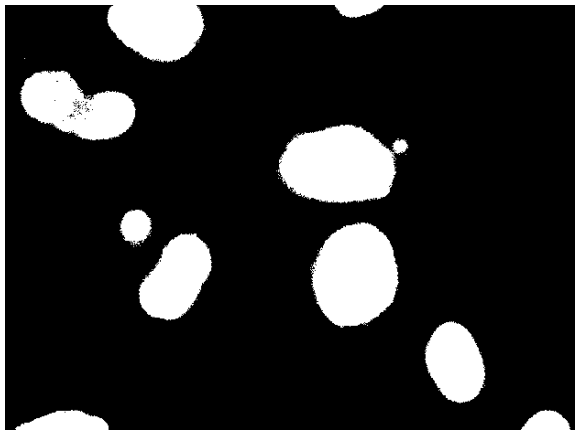
- Many data clustering techniques can be used.
- Example: k-means clustering

$$\arg\min_{S} \sum_{i=1}^{K} \sum_{x_j \in S_i} \left\| x_j - \mu_i \right\|^2$$

Region Connection After Thresholding

- Thresholded pixels need to be connected into regions, often through recursive region growth.

- Morphological image processing is often required to remove noise-related irregularities.



- Review: intensity thresholding based image segmentation
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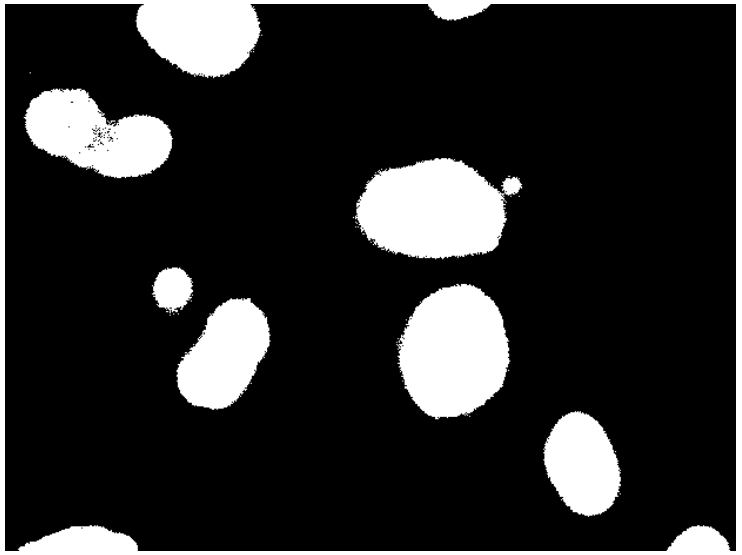
Morphological Image Processing

- Some typical applications:

  - To remove small isolated regions generated by noise

  - Contour smoothing

  - Region filling and connection



Mathematical Background (I)

- Denote the 2D integer space as Z^2, which is the space of image pixel coordinates.

- Basic relations: Let A be a set in Z^2

$$a = (a_1, a_2) \quad a \in A \quad \text{or} \quad a \notin A$$

$$A \subseteq B$$

- Basic operations

$$C = A \bigcup B$$
$$D = A \bigcap B$$
$$A - B = \{ w \mid w \in A, w \notin B \}$$

Mathematical Background (II)

- Two definitions commonly used in morphology

  - Reflection

$$\hat{B} = \left\{ w \middle| w = -b, \quad \forall b \in B \right\}$$

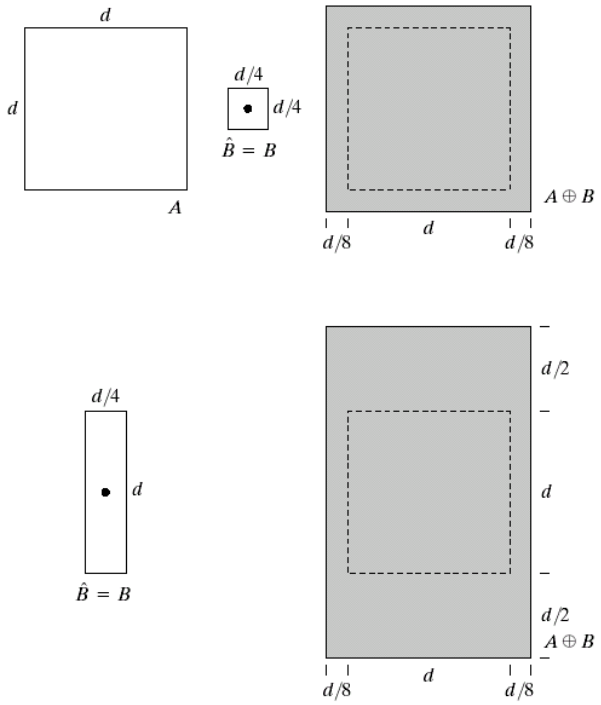
  - Translation

$$(A)_z = \left\{ c \middle| c = a + z, \quad \forall a \in A \right\}$$

Image Morphology: Dilation

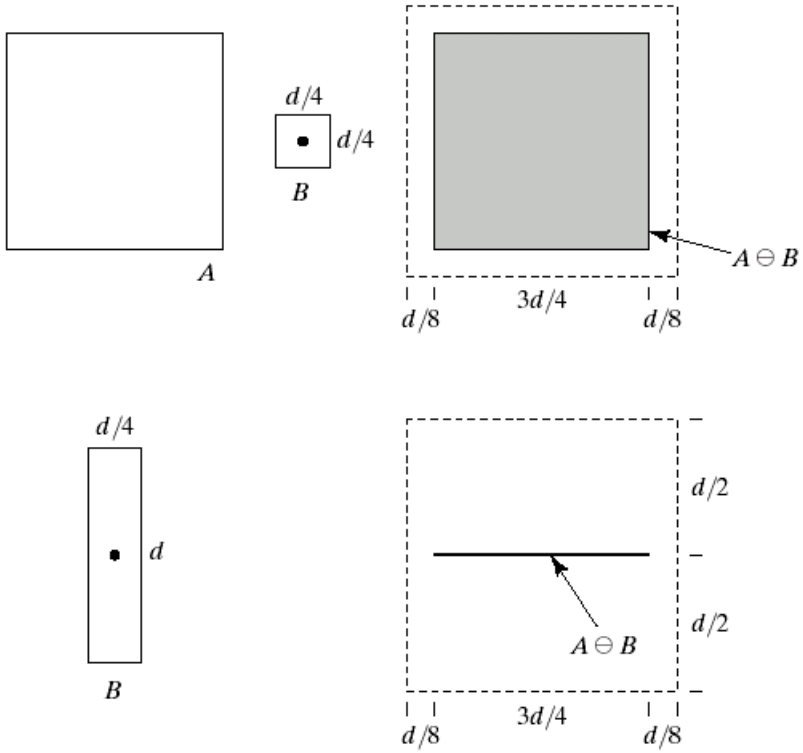
a b c
d e

FIGURE 9.4
(a) Set A.
(b) Square structuring element (dot is the center).
(c) Dilation of A by B, shown shaded.
(d) Elongated structuring element.
(e) Dilation of A using this element.



$$A \oplus B = \left\{ z \middle| \left[\left(\hat{B} \right)_z \cap A \right] \neq \varnothing \right\}$$

Image Morphology: Erosion

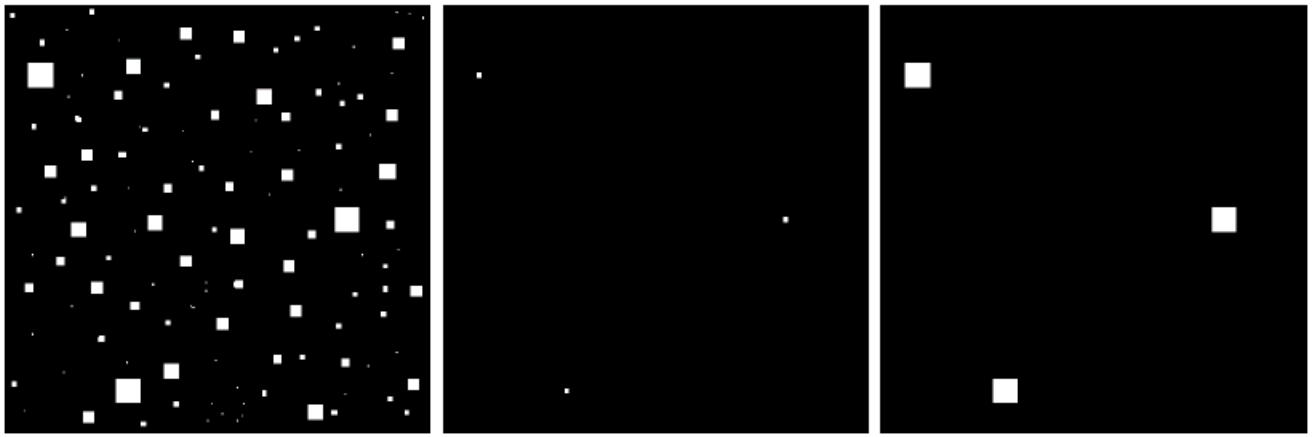


$$A \odot B = \left\{ z \middle| (B)_z \subseteq A \right\}$$

a b c
d e

FIGURE 9.6 (a) Set A. (b) Square structuring element. (c) Erosion of A by B, shown shaded. (d) Elongated structuring element. (e) Erosion of A using this element.

Erosion+Dilation



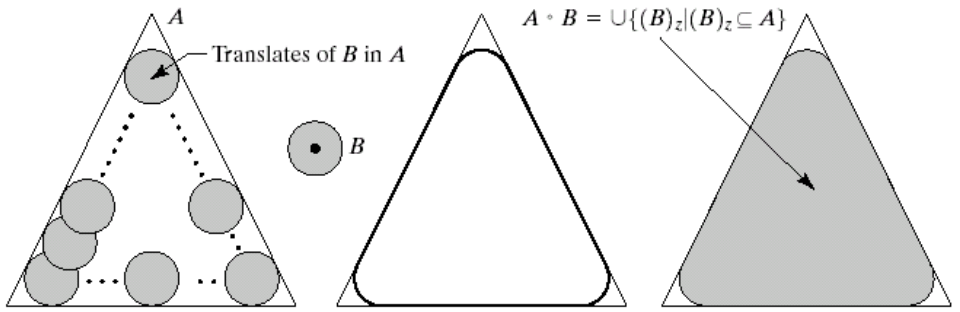
a b c

FIGURE 9.7 (a) Image of squares of size 1, 3, 5, 7, 9, and 15 pixels on the side. (b) Erosion of (a) with a square structuring element of 1's, 13 pixels on the side. (c) Dilation of (b) with the same structuring element.

Image Morphology: Opening

- Erosion followed by dilation

- Functions
  - Smooth contours
  - Break thin connections
  - Remove thin protrusions



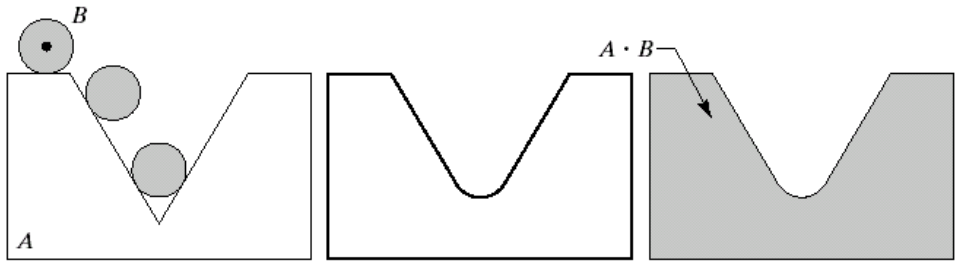
a b c d

FIGURE 9.8 (a) Structuring element B "rolling" along the inner boundary of A (the dot indicates the origin of B). (c) The heavy line is the outer boundary of the opening. (d) Complete opening (shaded).

$$\text{Opening}(A,B) = (A \odot B) \oplus B$$
$$= \cup\left\{(B)_z \,\middle|\, (B)_z \subseteq A\right\}$$

Image Morphology Operation: Closing

- Dilation followed by erosion
- Functions
  - Connects narrow breaks
  - Fills small holes



a b c

FIGURE 9.9 (a) Structuring element B "rolling" on the outer boundary of set A. (b) Heavy line is the outer boundary of the closing. (c) Complete closing (shaded).

$$\text{Closing}(A,B) = (A \oplus B) \odot B$$

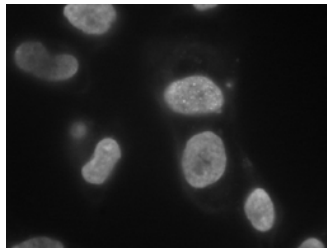
Image Morphology References

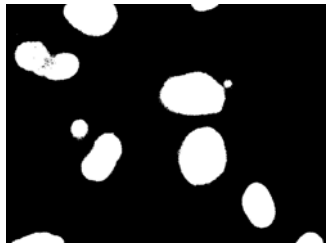
[1] Soille, *Morphological image analysis: principles and applications*, Springer, 2002.

[2] Dougherty & Lotufo, *Hands-on morphological image processing*, SPIE, 2003.

Thresholding-Based Image Segmentation

- Image segmentation using intensity thresholding is based on classification of individual pixels.
- Classified pixels need to be connected into regions, often through recursive region growth.
- Morphological image processing is commonly used to remove noise-related irregularities.





- Review: intensity thresholding based image segmentation
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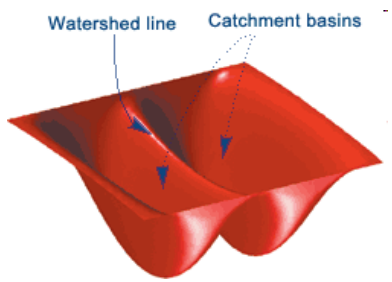
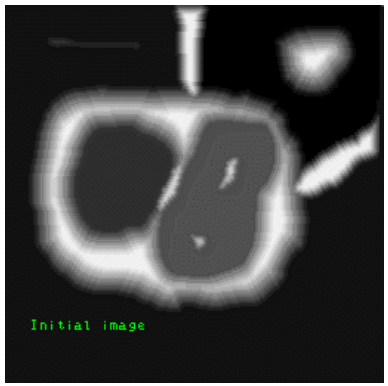
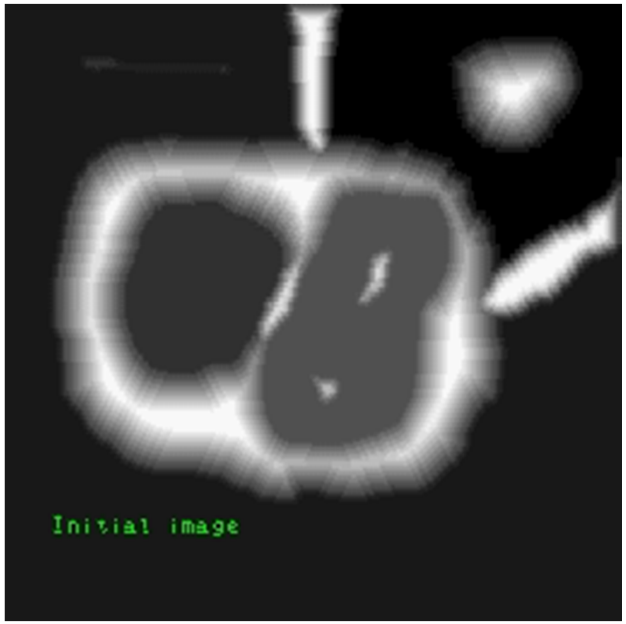
Watershed Segmentation (I)

- Watershed segmentation is based on image morphology operations.





- Basic concepts
  - Watershed lines (divide lines)
  - Catchment basins



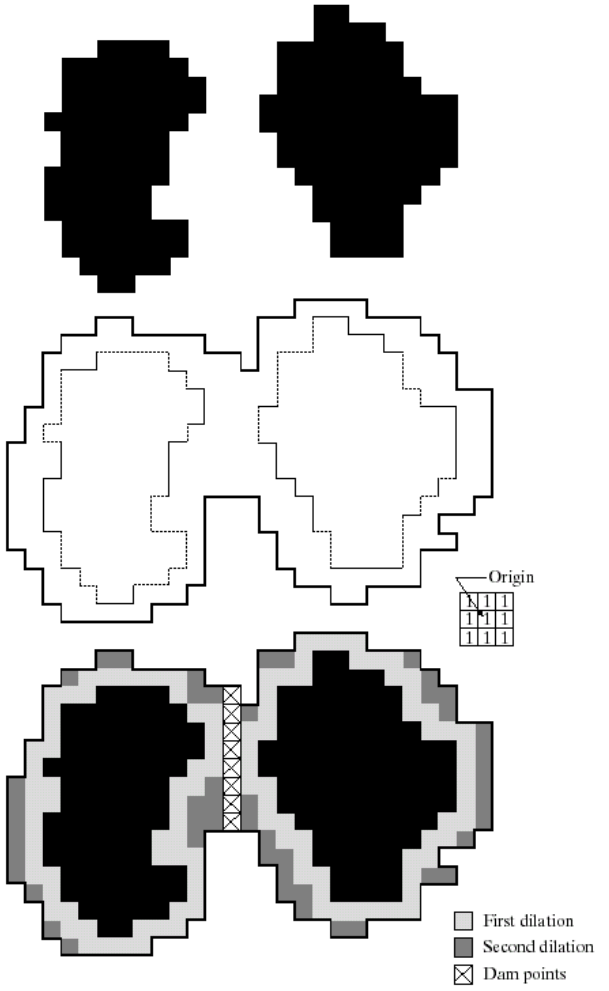
- Classification of points
  - Is a local minimum
  - Is not a local minimum
    - Belonging to a watershed line
    - Belonging to a catchment basin

- Goal: to find the watershed lines

http://cmm.ensmp.fr/~beucher/wtshed.html

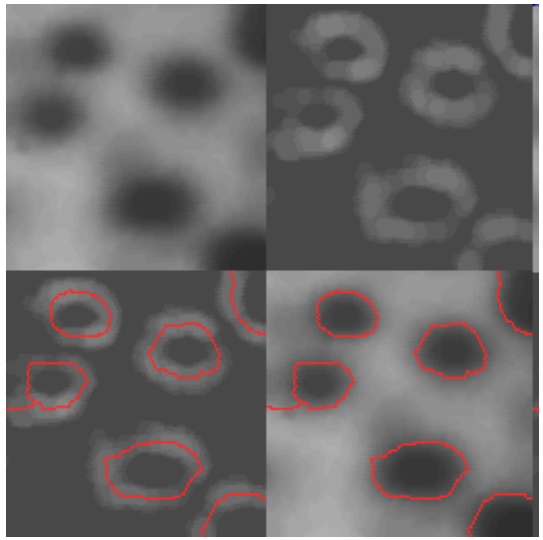
Watershed Segmentation (II)

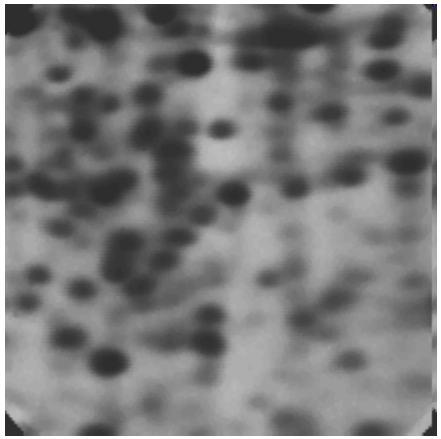
- The key step is to build the watershed lines.
- This is done based on dilation and intersection detection.
- The intensity of each watershed line points is set to be higher than the maximum image intensity.

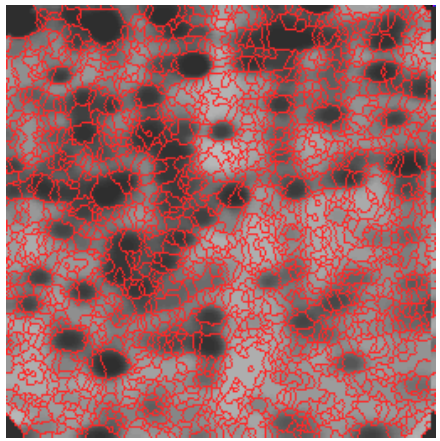


Watershed Segmentation (III)

- Watershed is usually applied to gradient images.
- Image noise often causes oversegmentation because of false local minima caused by noise.

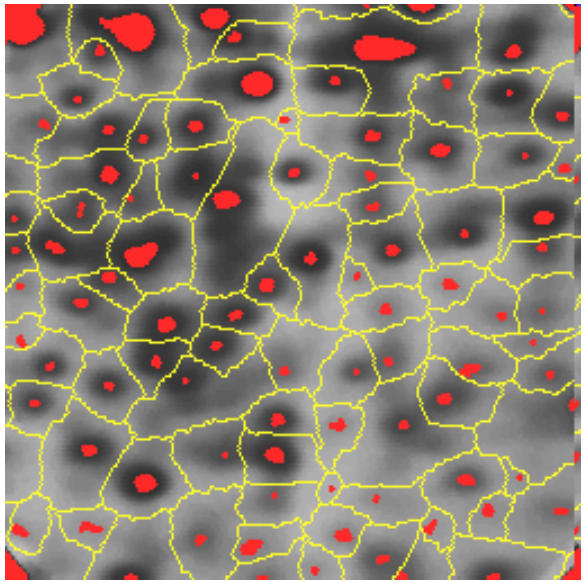


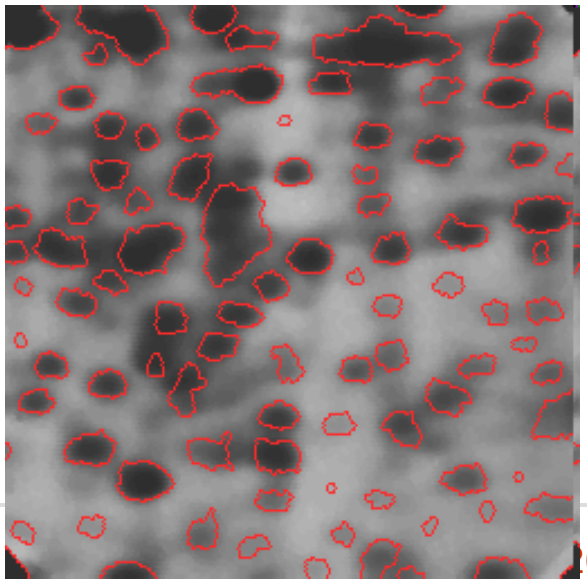




Watershed Segmentation (IV)

- Oversegmentation can be minimized by using markers.
- Markers are the only allowed local minima.
- Construction of markers
  - Low-pass smoothing of the original image
  - Identify connected local minimum regions as markers





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Region-Based Segmentation (I)

- Segmentation based on region growth

  Starting with seeds, recursive grow from the seeds based on

  1) Similarities; 2) Connectivity or adjacency

- Seed selection

  - Strong evidence
  - Random sampling

- Criteria for stopping the iteration

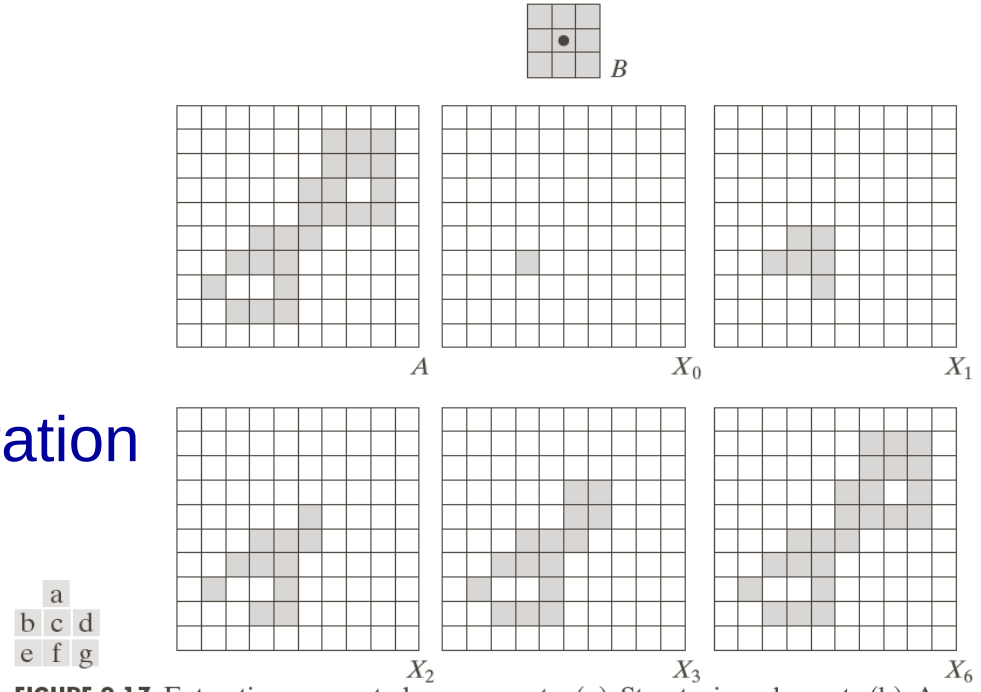
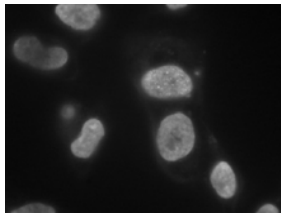
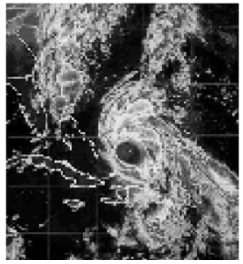


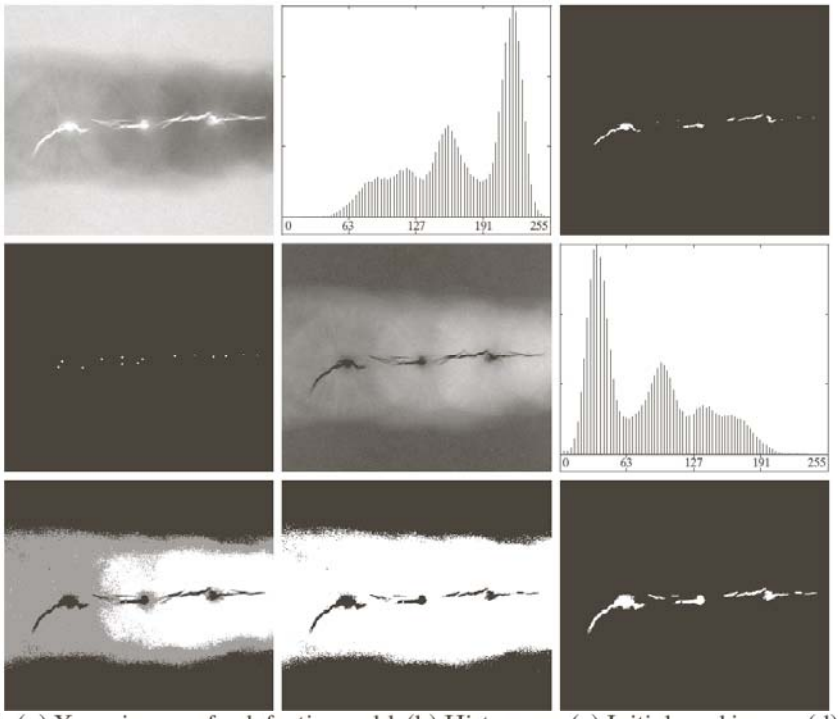
FIGURE 9.17 Extracting connected components. (a) Structuring element. (b) Array containing a set with one connected component. (c) Initial array containing a 1 in the region of the connected component. (d)–(g) Various steps in the iteration of Eq. (9.5-3).

Region-Based Segmentation (II)

- Some generic examples







a b c
d e f
g h i

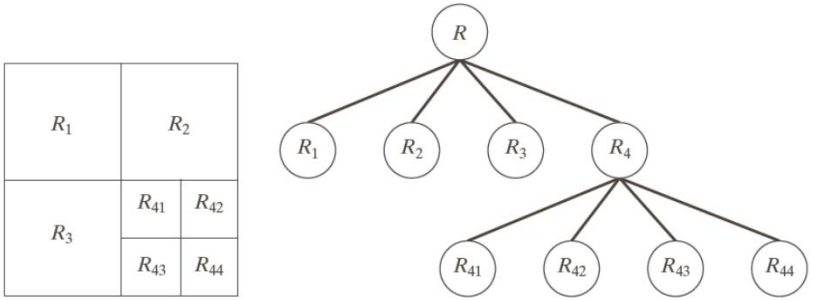
FIGURE 10.51 (a) X-ray image of a defective weld. (b) Histogram. (c) Initial seed image. (d) Final seed image (the points were enlarged for clarity). (e) Absolute value of the difference between (a) and (c). (f) Histogram of (e). (g) Difference image thresholded using dual thresholds. (h) Difference image thresholded with the smallest of the dual thresholds. (i) Segmentation result obtained by region growing. (Original image courtesy of X-TEK Systems, Ltd.)

Region-Based Segmentation (III)

- Segmentation based on splitting/merging

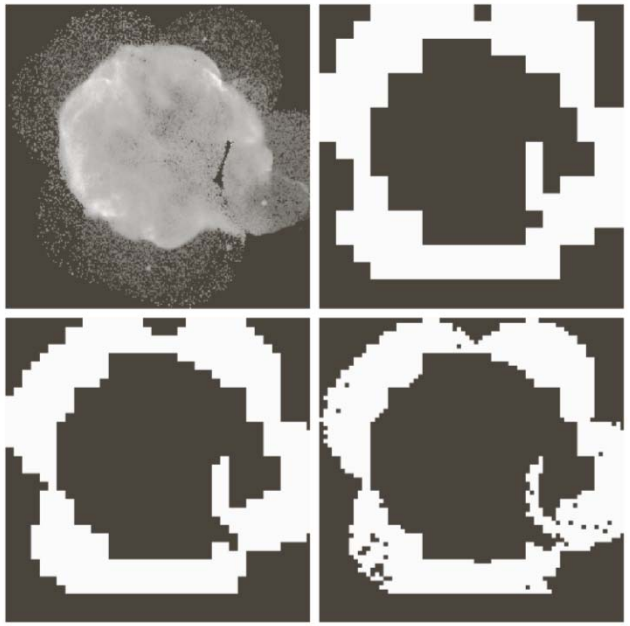
  Starting with subdividing images into several regions, recursive adjust regions through splitting/merging based on

  1) Dissimilarities; 2) Connectivity & adjacency



a b

FIGURE 10.52 (a) Partitioned image. (b) Corresponding quadtree. R represents the entire image region.

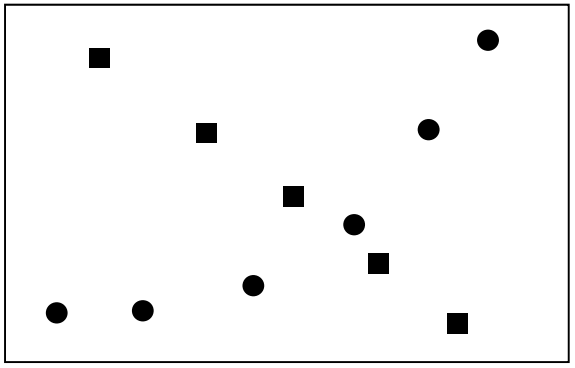


a b
c d

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.)

Region-Based Segmentation (IV)

- Fundamental limitations of region-based segmentation
  - Decision is typically based on local measures; No global information



- Reminder: Related MATLAB functions from DIP are deposited at the Blackboard site for this class.

Questions?