Digital Image Processing Lecture 7

- Segmentation and labeling
  - Region growing
  - Region splitting and merging
  - Labeling
  - Watersheds
- More smart morphological algorithms from G&W
- Gonzales & Woods:
  - Chapter 10 pp. 763-778
  - Chapter 9 pp. 642-664

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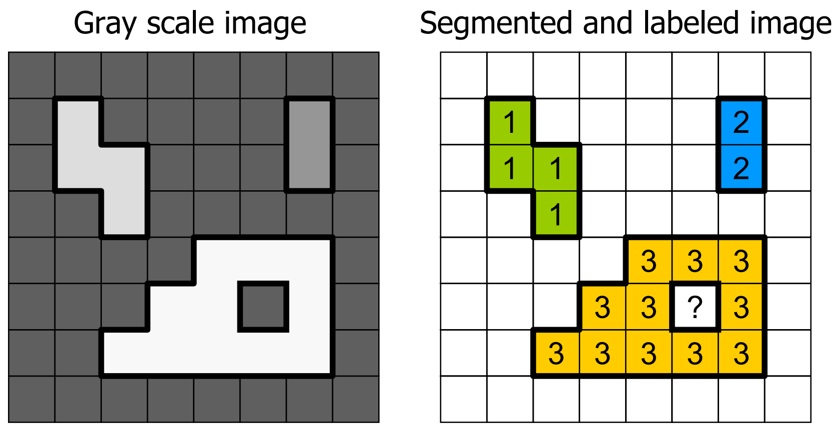
Segmentation and labeling of objects



Segmentation subdivides an image into its constituent regions or objects.

Methods for segmentation

- Point, line and edge detection
- Thresholding
- Region-based segmentation
  - Region growing
  - Region splitting and merging
- Watershed segmentation
- Labeling
  - The RT-algorithm (Run-track) Lab 3
  - The RB-algorithm (Raster-scan Border-follow)

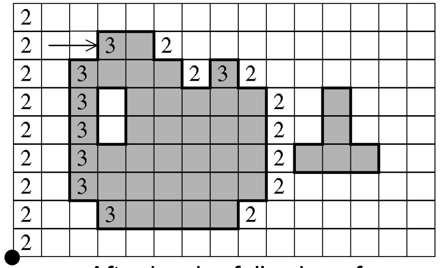
know already | today | later

Labeling, 2 different algorithms

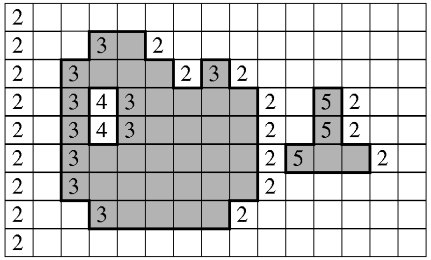
- The RT-algorithm (Run-track)
  - Fast
- The RB-algorithm (Raster-scan Border-follow)
  - Not as fast as the RT-algorithm
  - Gives more information
- There are also other methods, for example:
  - Flood fill from computer graphics…
  - Gonzalez & Woods: Extraction of connected components, see figure 9.17 and 9.18.

The RB-algorithm (Raster-scan Border-follow)

- Raster-scan the image from left to right and from top to bottom.
- When the scanning reach a border (0->1 or 1->0), stop the scanning and start border-follow instead.
- During the border-following process, labels are set to the right of the border.
- Finally all labels are expanded to the right, see next slide.

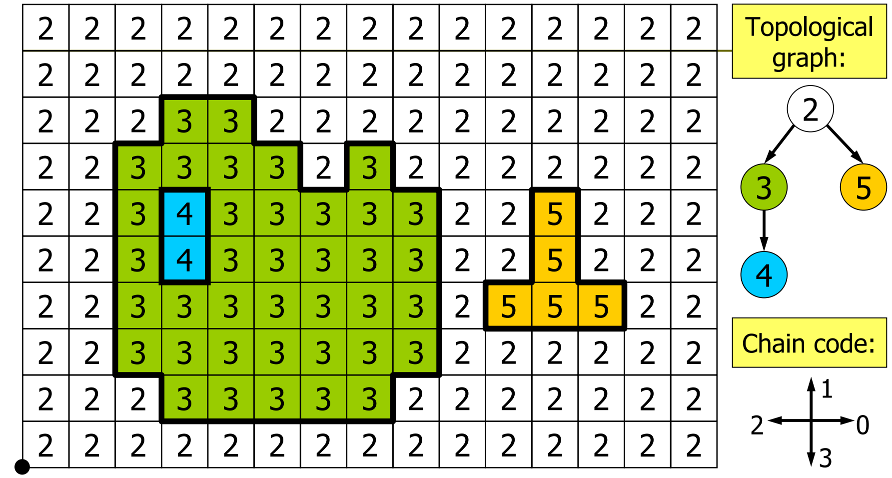


After border-following of the first object



After border-following of both objects and one hole

The RB-algorithm, final result



(3,8) 0 0 3 0 3 0 1 0 3 0 3 3 3 3 2 3 2 2 2 2 2 1 2 1 1 1 1 1 0 1
(3,6) 0 3 3 2 1 1
(11,6) 0 3 3 0 3 2 2 2 1 0 1 1

more about chain code later

Region growing

- Start with a set of seed points and expand them to neighboring pixels if they satisfy a certain criterion.
- Examples of criteria are:
  - Right intensity
  - Right color
  - Right texture
- For a simple example see next slide. It is from G&W 2:nd edition, in the 3:rd edition they have made it a bit too complicated, I think.
  - a) Original X-ray image of a defective weld with cracks. The challenge is to determine the size and location of the cracks.
  - b) The seed points are obtained using a high threshold, T1.
  - c) Result of region growing to intensity pixels >T2. (T2<T1.)
  - d) Boundaries of segmented defective weld (black) overlaid on original image.
  - There is a similarity with thresholding with hysteres!

Lab 6

Region growing, cont.

≈ Fig. 10.51

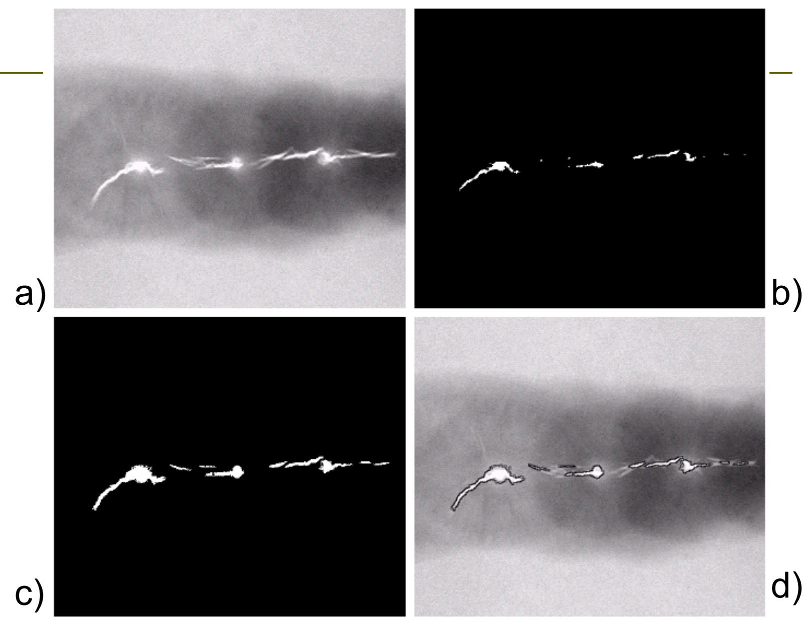
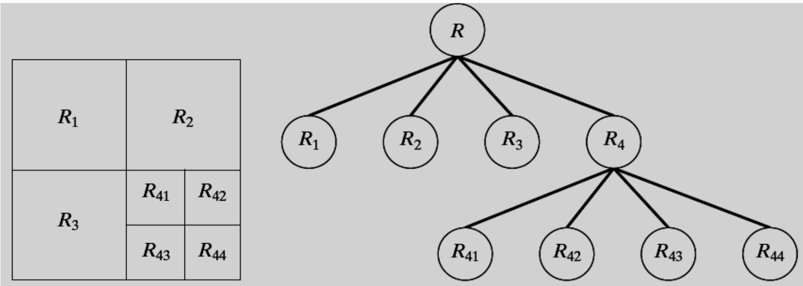


Fig. 10.52

Region splitting and merging

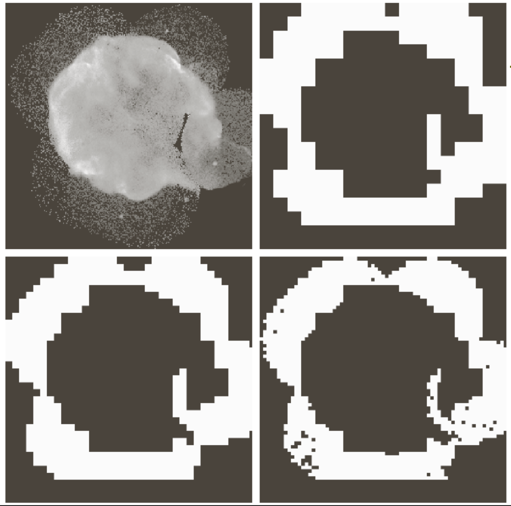
- 1) Split into four disjoint quadrants any region R_i for which $Q(R_i)$=FALSE.
- 2) When no further splitting is possible, merge any adjacent region R_j and R_i for which $Q(R_j \cup R_k)$=TRUE. (Alternative simplification: $Q(R_j)$=TRUE and $Q(R_k)$=TRUE)
- 3)Stop when no further merging is possible



Region splitting and merging

Fig. 10.53

Original image of the Cygnus Loop supernova



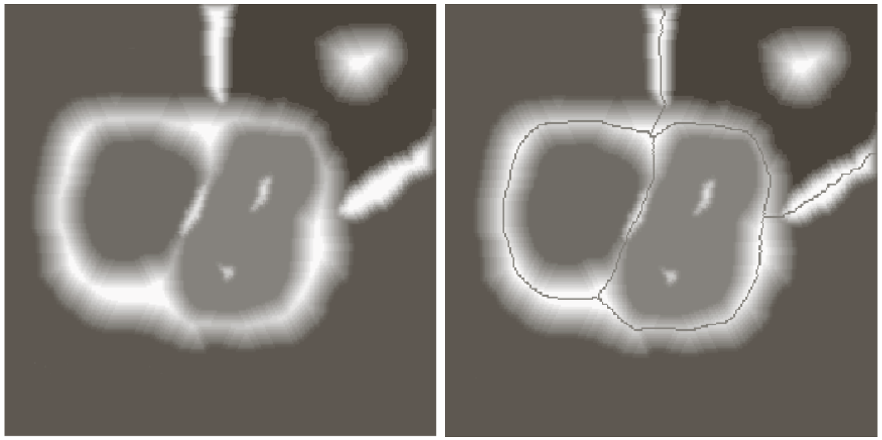
Smallest Quad-Region: 32x32

Smallest Quad-Region: 16x16

Smallest Quad-Region: 8x8

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

Watershed segmentation, introduction



a) h)

Fig. 10.54

Watershed segmentation, introduction

- Fig. 10.54 a) The watershed algorithm regards a gray scale image as a landscape, where the lakes are preferably dark pixels and the ridges and mountains are preferably bright pixels.
- A watershed = a ridge between individual lakes and rivers.
- A catchments basin = a geographic area whose water flows to a certain lake.
- Fig. 10.54 h) The watershed algorithm can find the watersheds in the image. They form closed curves and the area inside each closed curve, the catchments basin, can be regarded as a segmented, individual object.

Watershed segmentation, description

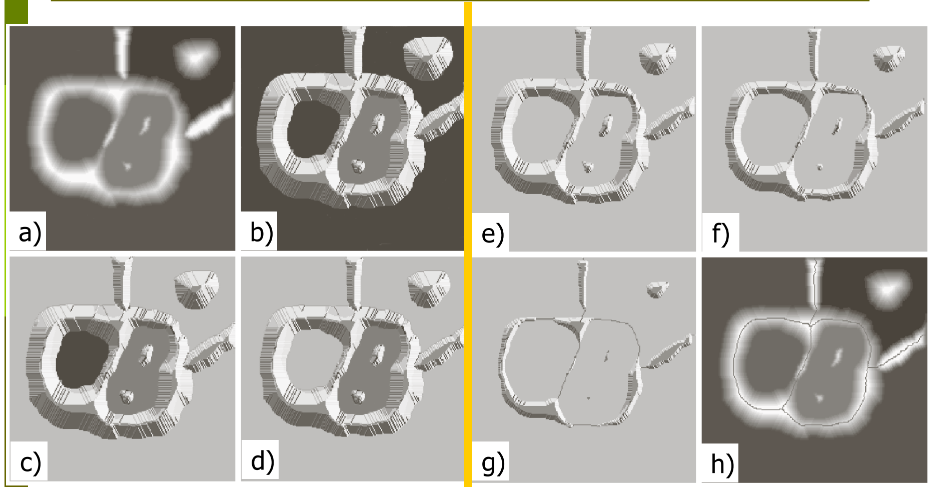


Fig. 10.54

Watershed segmentation, description

- Fig. 10.54 b) is a topographic view of 10.54 a). It is intended to give a 3D-feeling.
- In the beginning, the landscape in a) and b) is totally dry. Local minima are detected and holes are punched in each of them.
- Then the entire landscape is flooded from below by letting water rise through the holes at a uniform rate.
- In c), there is water (light gray) in the background.
- In d), there is also water in the left lake.
- In e), there is water in both lakes.
- In f), there is the first sign on overflow between two catchments basins. Therefore, a short dam has been built between them.
- In g), there are rather long dams.
- Finally, the whole landscape is over flooded with water, separated by high dams, watersheds.
- In h), these watersheds are shown overlaid on the original image.

Watershed segmentation, dam construction

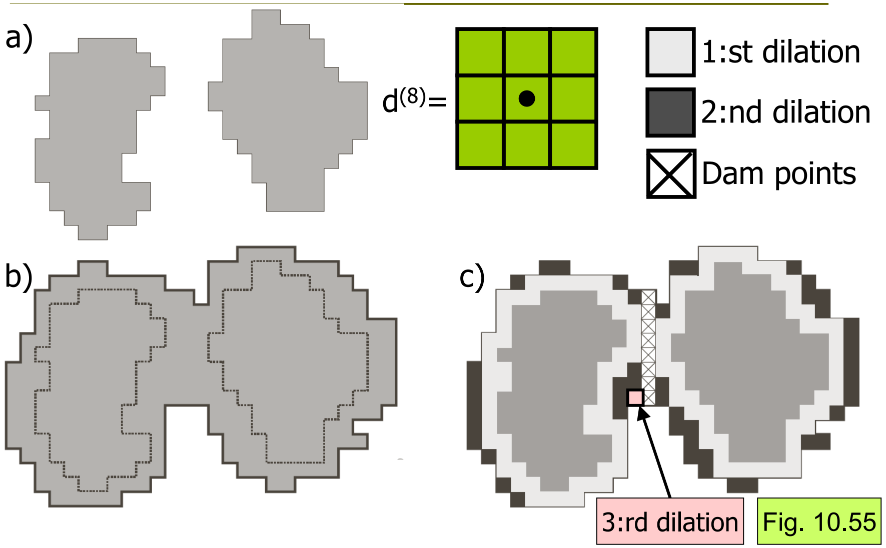


Fig. 10.55

Watershed segmentation, dam construction

- Let $C_{n-1}(M_1)$ denote the pixels in lake M_1 at flooding step n-1. These are shown to the left in a).
- Let $C_{n-1}(M2)$ denote the pixels in lake M_2 at flooding step n-1. These are shown to the right in a).
- Flooding step n is shown in b).
- Let C(n-1) denote the union of $C_{n-1}(M_1)$ and $C_{n-1}(M_2)$. There are 2 objects in C(n-1) in a) and 1 object i C(n) in b). This indicates that something have happened in step n and that some action must be performed.
- Dilate the pixels in a) with the $d^{(8)}$-structuring element considering the following constraints:
  - Dilation is not allowed outside b).
  - Dilation is not allowed so that the pixels in M_1 and M_2 are united.
  - Instead, if the pixels in M_1 and M_2 are going to be united, denote: dam pixel.
- The first dilation in c) gives the light gray pixels.
- The second dilation in c) gives the dark gray pixels and the X-marked dam pixels.

Watershed segmentation, Ex 1)

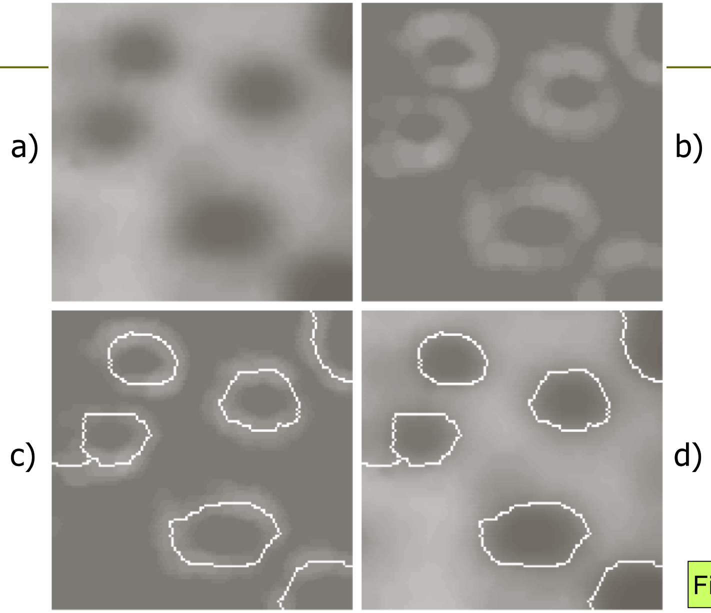


Fig. 10.56

Watershed segmentation, Ex 1)

- a) Original image with dark objects that are going to be segmented.
- b) A usual pre-processing step is to calculate the magnitude of the gradient.
- c) The result of the watershed algorithm overlaid on the gradient image.
- d) The result of the watershed algorithm overlaid on the original image.

Watershed segmentation, Ex 2) oversegmentation

Advanced topic!

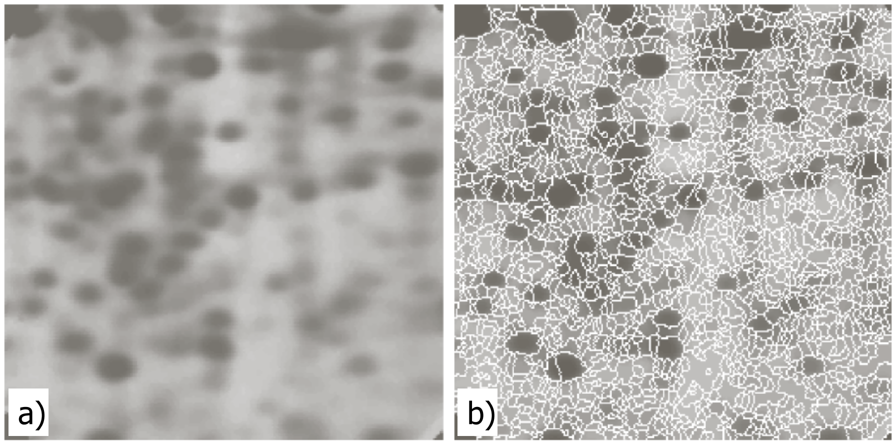


Fig. 10.57

Watershed segmentation, Ex 2) oversegmentation

Advanced topic!

- a) Original image with dark object to be segmented.
- Pre-processing by computation of the magnitude of the gradient.
- Result from the watershed algorithm overlaid on the original image. Oversegmentation!
- The oversegmentation was probably caused by too many local minima.

Watershed segmentation, Ex 2) oversegmentation cured

Advanced topic!

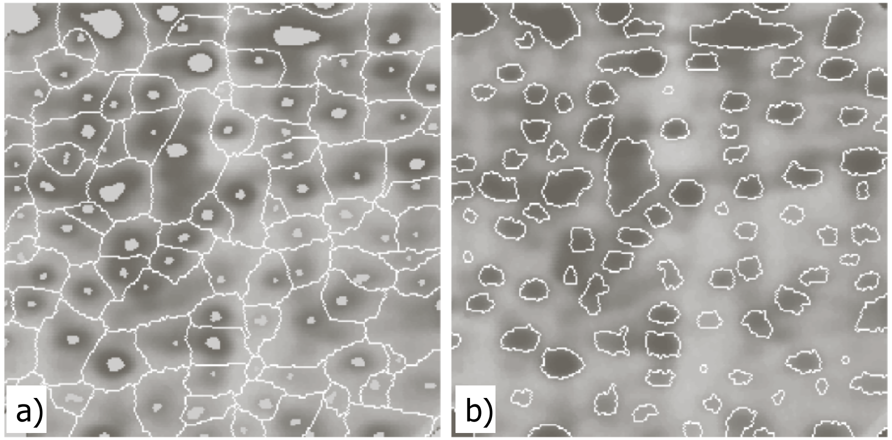


Fig. 10.58

Watershed segmentation, Ex 2) oversegmentation cured

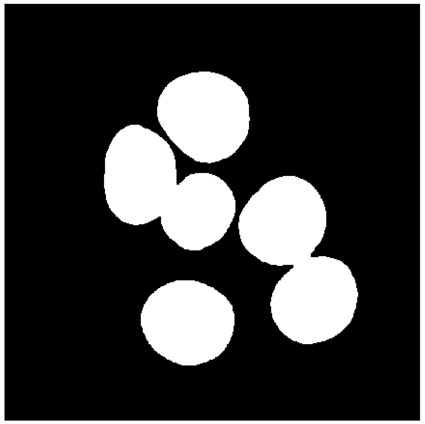
Advanced topic!

- Fig. 10.58 a) The light gray internal markers are regions received by applying a low-pass filter on the original image followed by consideration of the following criteria:
  - The region must be surrounded by pixels of higher values.
  - The region must consist of a number of connected pixels.
  - The points in the region must have approximately the same gray scale value.
- The external markers are the watersheds received when the watershed-algorithm was applied to the low-pass filtered image. The internal markers where then used as local minima.
- The external markers in a) divides the original image into regions. Each region is processed individually. The magnitude-of-the-gradient image was calculated, the internal marker was used as local minimum and the watershed-algorithm was applied. The result is shown in Fig. 10.58 b)!

Watershed segmentation, Ex 3) for overlapping binary objects

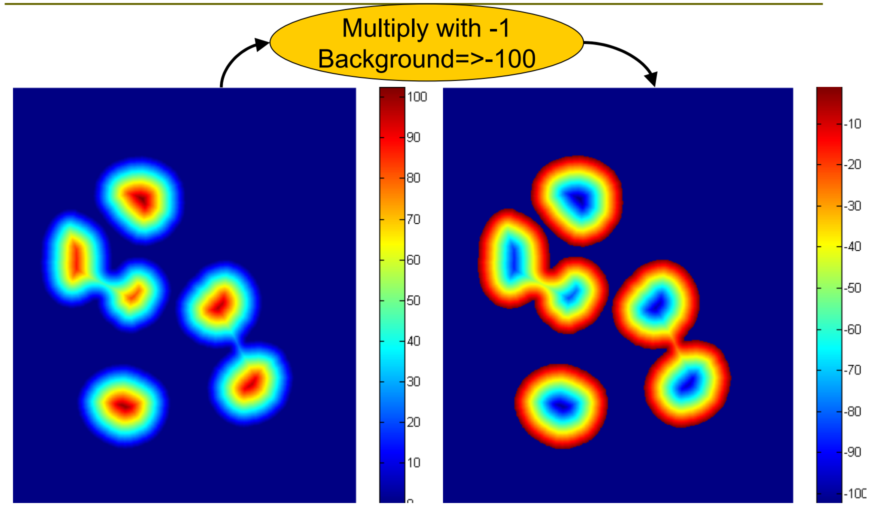
- The watershed algorithm can also be used to segment overlapping binary objects.
- Distance mapping is used to construct a landscape with lakes.
- Computation: See this and the following 2 slides.

Lab 5!



Binary input image

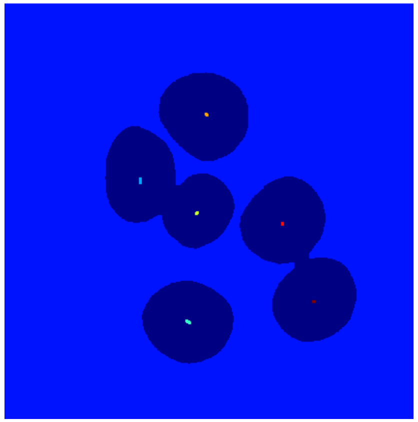
Ex3) Generate a distance map of the objects and "invert" it



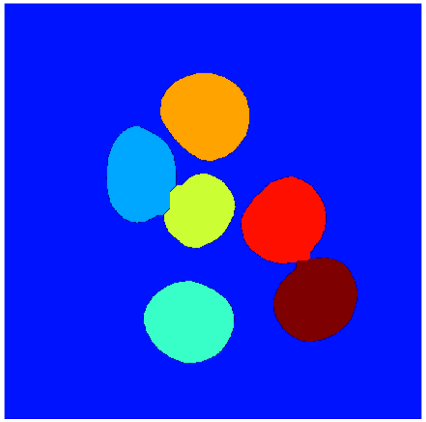
Distance map

"Inverted" distance map

Ex3) Detect local min & apply the watershed algorithm on the ”inverted” distance map



Labeled local min



Result of the watershed algorithm

Some basic morphological algorithms: 1) Boundary extraction

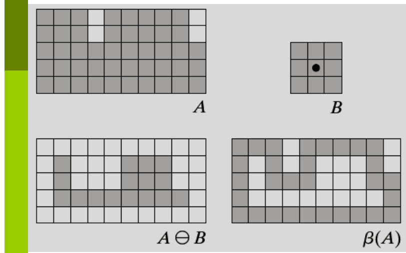


Fig. 9.13

Fig. 9.14

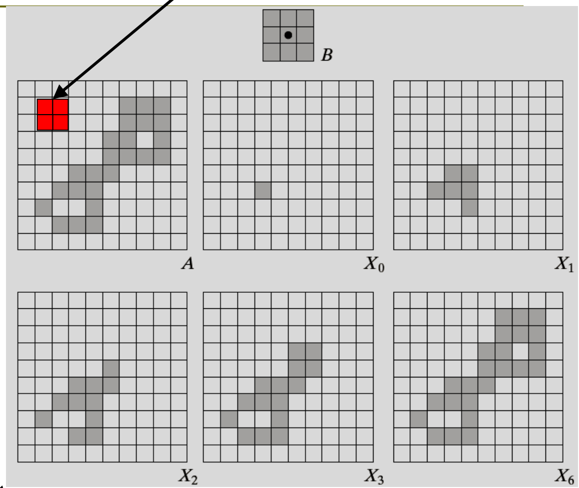
$$\beta(A) = A - (A \Theta B) \quad (9.5\text{-}1)$$

The object A eroded by B

2) Finding connected components

The image X_0 contains the initial seed, which is iteratively dilated by B and multiplied by A.

Extra object does not matter



Binary multiplication

The object X_{k-1} dilated by B

$$X_k = (X_{k-1} \oplus B) \cap A, \quad k = 1,2,3,... \quad (9.5\text{-}3)$$

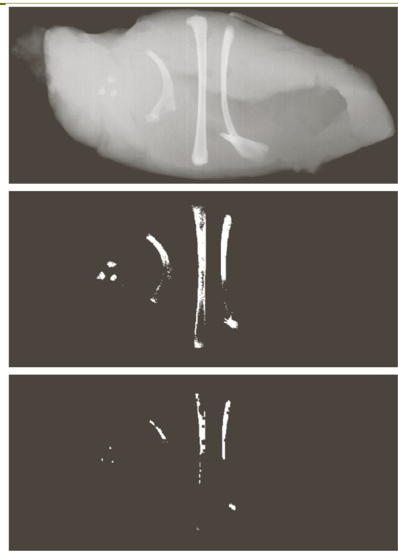
Fig. 9.17

2) Finding connected components

Original image

Thres-holded image

Eroded image



The eroded image can be raster-scanned until a pixel is found. This pixel is labeled by i and the connected component is reconstructed. Its area (number of pixels) is noted. Then the image is scanned again until the next unlabeled pixel is found and labeled by i+1, etc.

Connected component	No. of pixels in connected comp
01	11
02	9
03	9
04	39
05	133
06	1
07	1
08	743
09	7
10	11
11	11
12	9
13	9
14	674
15	85

Fig. 9.18

3) Convex hull

- An set A is said to be convex if the straight line segment joining any two point in A lies entirely within A.
- The convex hull of S is the smallest convex set containing S.

The element B^i found a match in the image X_{k-1}

union by A

$$X_0^i = A$$

$$X_k^i = \left(X_{k-1} \circledast B^i\right) \cup A, \quad i = 1,2,3,\ldots \quad k = 1,2,3,\ldots \qquad (9.5\text{-}4)$$

$$C(A) = \bigcup_{i=1}^{4} D^i, \text{ where } D^i = X_k^i \text{ for } k \text{ converging} \qquad (9.5\text{-}5)$$

3) Convex hull

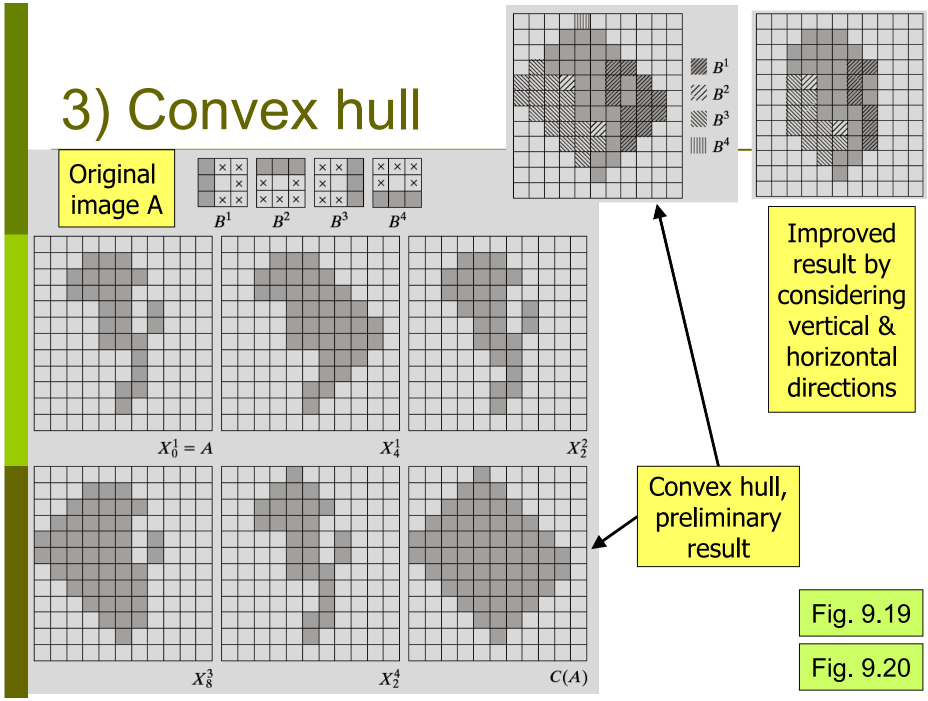
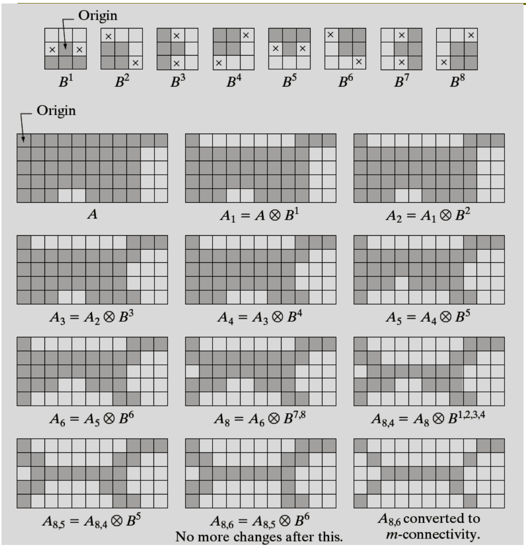


Fig. 9.19

Fig. 9.20

4) G&W:s thinning, connectivity preserving shrinking (to 8-connective skeleton)



$$A \otimes B = A - \left(A \circledast B\right) \qquad (9.5\text{-}6)$$

Thinning of A by B

B found a match in A

$$\{B\} = \{B^1, B^2, B^3, \ldots, B^n\} \qquad (9.5\text{-}7)$$

$$A \otimes \{B\} = \left(\left(\ldots\left(A \otimes B^1\right)\ldots\right) \otimes B^n\right) \qquad (9.5\text{-}8)$$

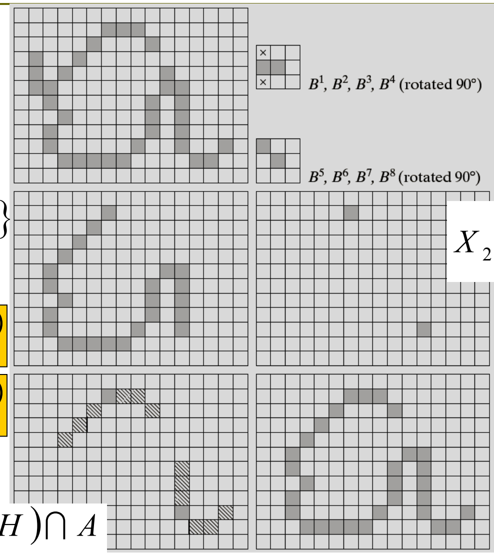
Repeat (9.5-8)!

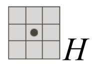
Fig. 9.21

5) Pruning

Something similar in Lab 3?

Original image A





$$X_1 = A \otimes \{B\} \qquad (9.5\text{-}17)$$

$$X_2 = \bigcup_{k=1}^{8} \left(X_1 \circledast B^k\right) \qquad (9.5\text{-}18)$$

Repeat (9.5-17) 3 times

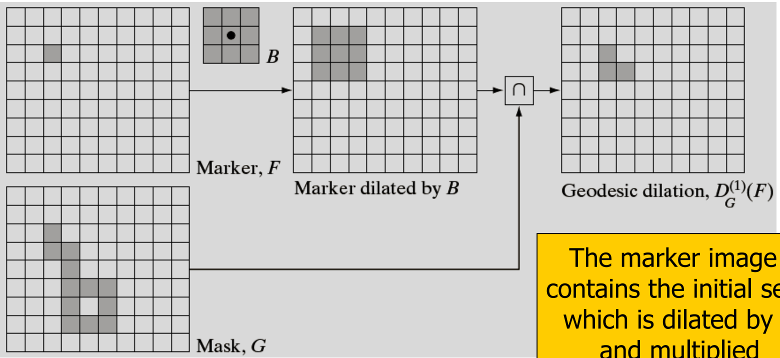
Repeat (9.5-19) 3 times

$$X_3 = \left(X_2 \oplus H\right) \cap A \qquad (9.5\text{-}19)$$

$$X_3 = X_1 \cup X_3 \qquad (9.5\text{-}20)$$

Fig. 9.25

6a) Geodesic dilation of size 1



The marker image F contains the initial seed, which is dilated by B and multiplied by the mask G. The mask G limit the growth of marker F

The marker image F dilated by B

multiplied by G

$$D_G^{(1)}(F) = (F \oplus B) \cap G \quad (9.5\text{-}21)$$

Fig. 9.26

6b) Morphological reconstruction by geodesic dilation iterated until stability

Similar to (9.5-3)

$$\text{when } D_G^{(k)}(F) = D_G^{(k+1)}(F):\ R_G^D(F) = D_G^{(k)}(F) \quad (9.5\text{-}25)$$

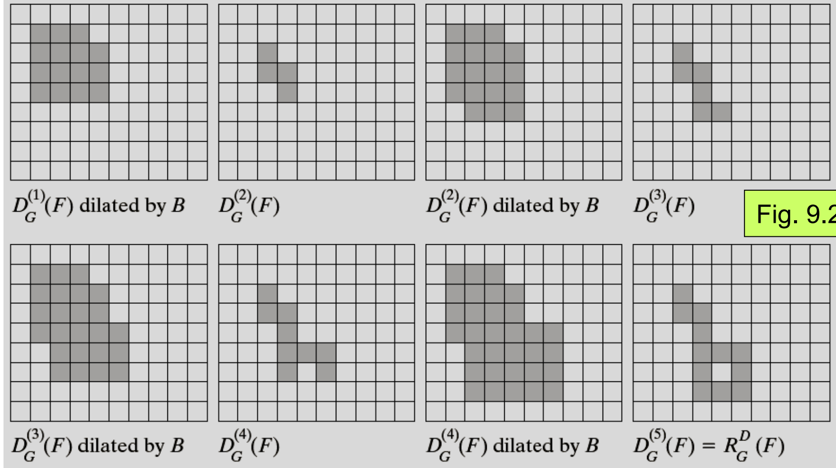


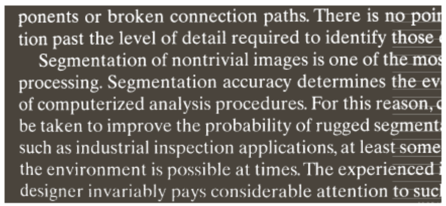
Fig. 9.28

7) Opening by reconstruction

Ex) Extracting characters with long vertical strokes

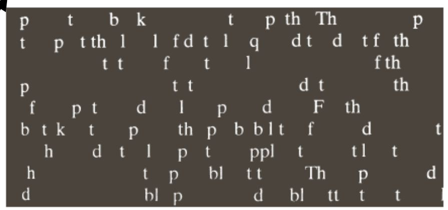
$$O_R^{(n)}(F) = R_F^D[F \ominus nB] \quad (9.5\text{-}27)$$

n erosions by B



Original image F

1 erosion by a 51X1 element



Resulted image

Fig. 9.29

8) Filling holes

$$F(x,y) = \begin{cases} 1 - I(x,y), & \text{if } (x,y) \text{ is on the border of } I \\ 0, & \text{otherwise} \end{cases} \quad (9.5\text{-}28)$$

$$H = \left[R_{I^c}^D(F)\right]^c \quad (9.5\text{-}29)$$

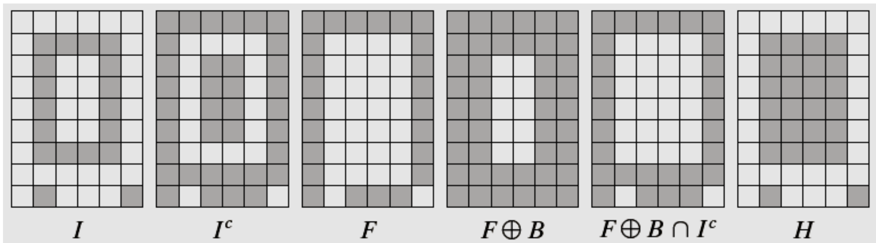
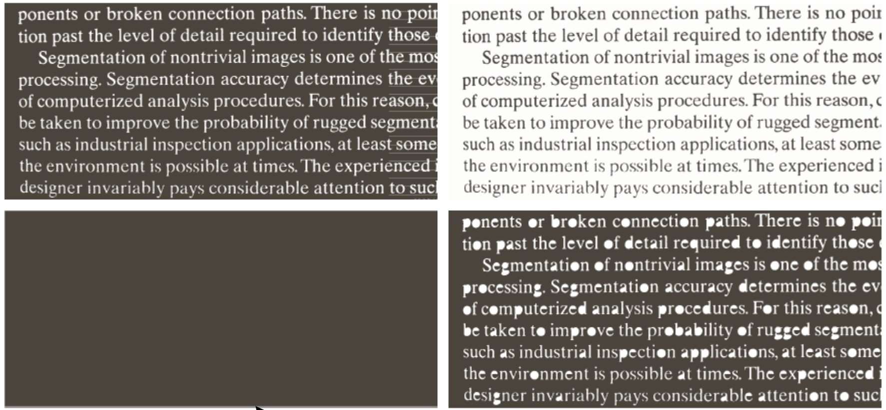


Fig. 9.30

8) Filling holes

Original image I

Complement image I^C used as a mask



Marker image, F

white frame

Resulted image

Fig. 9.31

9) Border clearing

$$F(x,y)=\begin{cases} I(x,y), & \text{if } (x,y) \text{ is on the border of } I \\ 0, & \text{otherwise} \end{cases} \quad (9.5\text{-}30)$$

$$X = I - R_I^D(F) \quad (9.5\text{-}31)$$

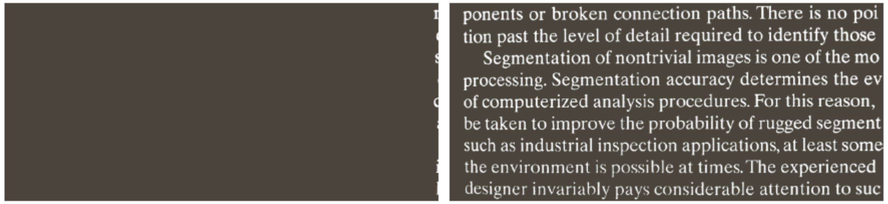


Image with objects touching the the border $R_I^D(F)$

Resulted image, X

error in G&W

Fig. 9.32