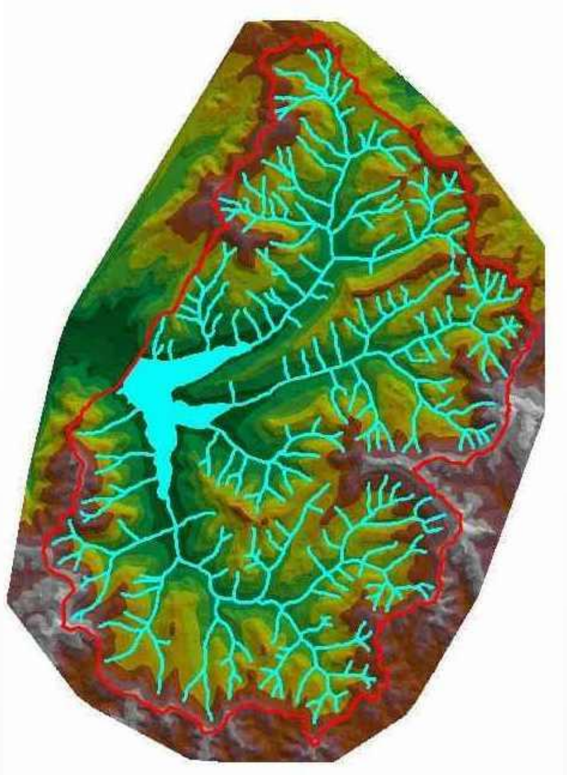
Basic Image Processing Algorithms

PPKE-ITK

Lecture 9.

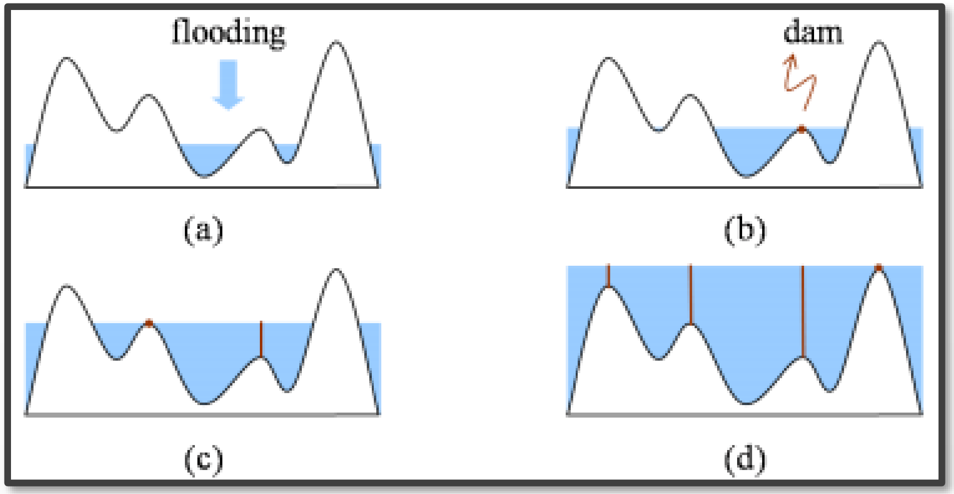
Watershed algorithm

- A mathematical morphology based approach on image segmentation



Watershed Segmentation

- A grey-level image may be seen as a topographic surface, where the grey level of a pixel is interpreted as its altitude in the surface.
- The goal of the algorithm is to find the „watersheds" that are separating the „catchment basins" from each other.

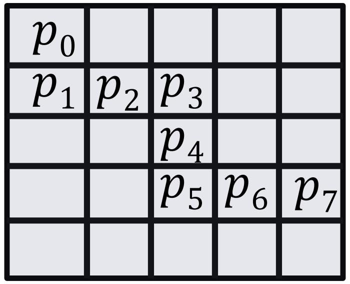


Concept of the watershed algorithm*

*Yu-Hsiang Wang: „Tutorial: Image Segmentation" (http://disp.ee.ntu.edu.tw/meeting/%E6%98%B1%E7%BF%94/Segmentation%20tutorial.pdf)

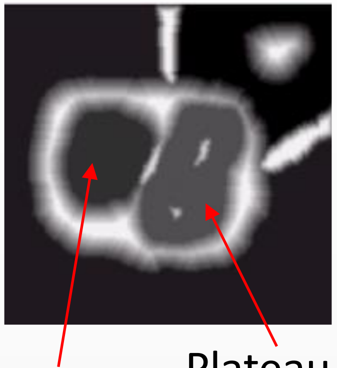
Watershed-Basic Definitions

- I: 2D gray level image
- Path P of length ℓ between p and q in I
  - A $(\ell + 1)$-tuple of pixels $(p_0 = p, p_1, \ldots, p_\ell = q)$ such that p_i, p_{i+1} are adjacent (4 adjacent, 8 adjacent, or m adjacent)
  - $\ell(P)$: the length of a given path P



4-adjacent path P with $\ell(P)$=6

- Minimum
  - A minimum M of I is a connected plateau of pixels from which it is impossible to reach a point of lower altitude without having to climb



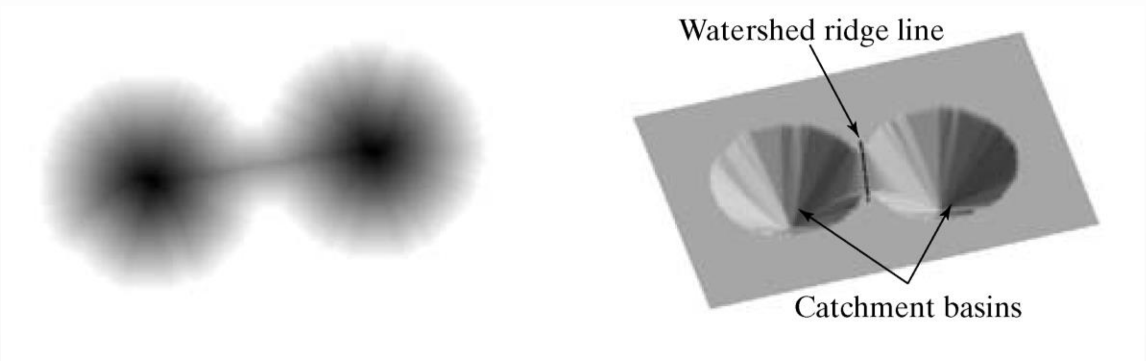
Basic Steps

- Piercing holes in each regional minimum of I
- The 3D topography is flooded from below gradually
- When the rising water in distinct catchment basins is about to merge, a **dam** is built to prevent the merging

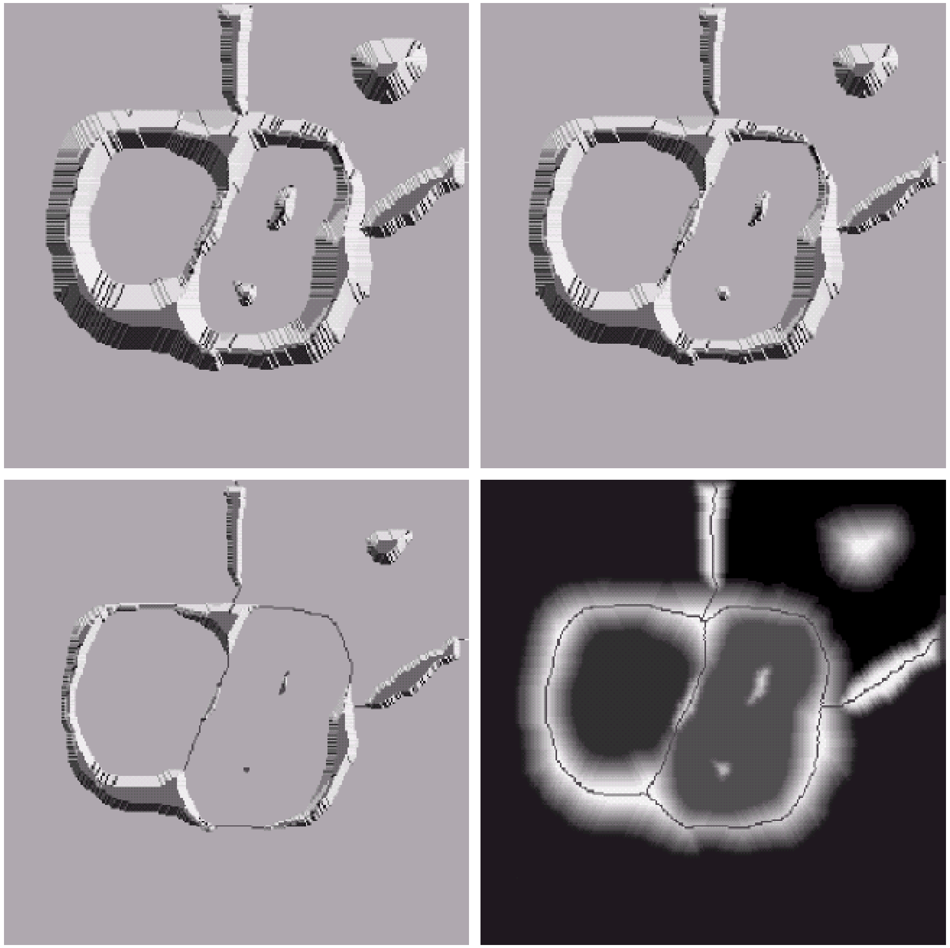
- Instead of working on an image itself, this technique is often applied on its gradient image.

Watershed-Basic Definitions

- Three types of points
  - Points belonging to a regional minimum
  - Catchment basin / watershed of a regional minimum
    - Points at which a drop of water will certainly fall to a single minimum
  - Divide lines / Watershed lines
    - Points at which a drop of water will be equally likely to fall to more than one minimum
    - Crest lines on the topographic surface
- This technique is to identify all the third type of points for segmentation



Basic Steps



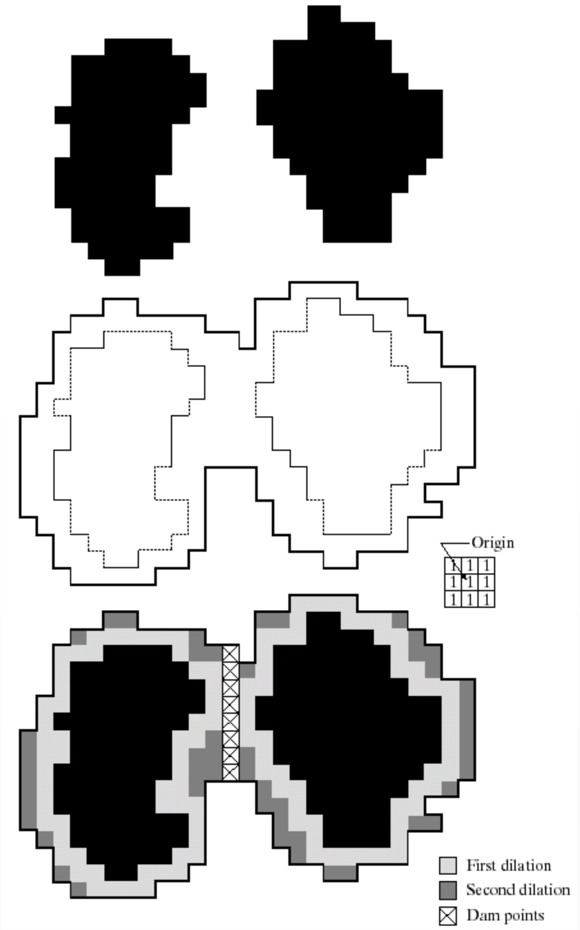
- The dam boundaries correspond to the watershed lines to be extracted by a water-shed segmentation al-gorithm
  - Eventually only const-ructed dams can be seen from above

Dam Construction

- Based on binary morphological dilation
- At each step of the algorithm, the binary image in obtained in the following manner:
  1. Initially, the set of pixels with minimum gray level are 1, others 0.
  2. In each subsequent step, we flood the 3D topography from below and the pixels covered by the rising water are 1s and others 0s. (See previous slides)

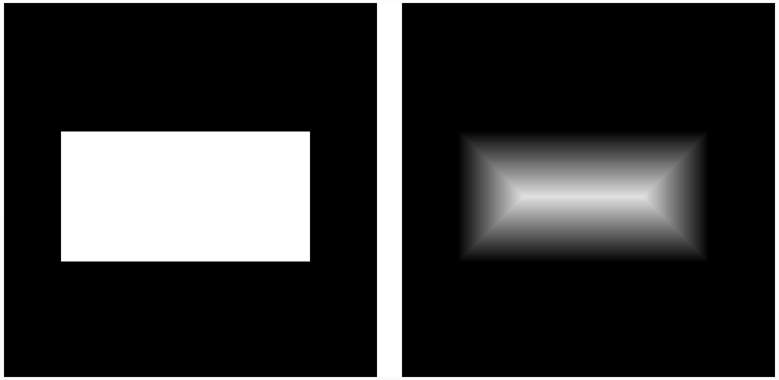
Dam Construction

- The dam is constructed by the points on which the dilation would cause the sets being dilated to merge.
  - Result: one-pixel thick connected path
  - Setting the gray level at each point in the resultant path to a value greater than the maximum gray value of the image. Usually max+1



Distance transform

- Distance transform operator:
  - Input: binary image (showing foreground/background regions)
  - Result: a graylevel image, where the graylevel intensities of points inside foreground regions are show the distance to the closest boundary from each point
  - Implementation: through morphological operations
  - Often used as input of the Watershead transform (instead of the gradient image)



https://homepages.inf.ed.ac.uk/rbf/HIPR2/distance.htm

Example 1 - Watershed Transform of Binary Image Using the Distance transform

A: Original image B: Negative of image A

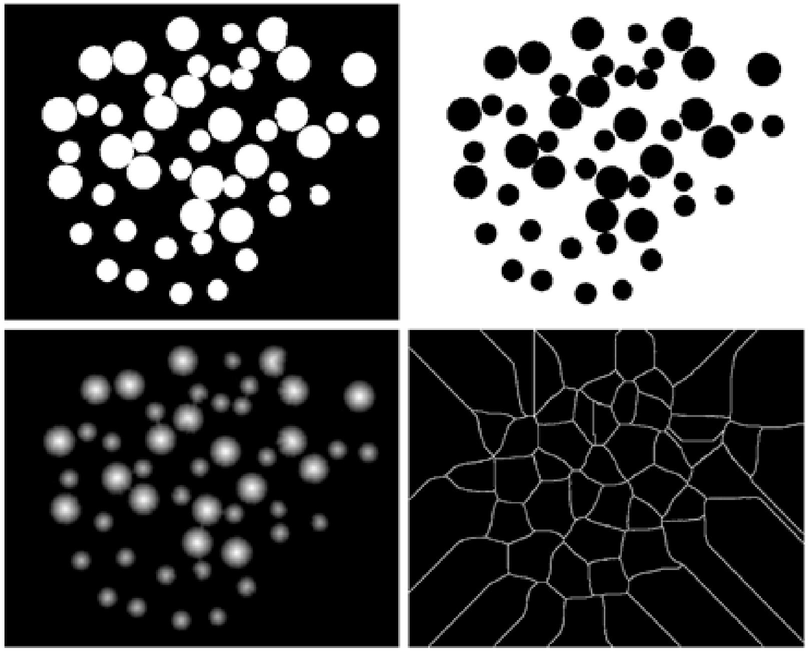
C: Distance transform of B D: Watershed transform of C

A	B
C	D

Distance transform of a binary image is defined by the distance from every pixel to the nearest non-zero valued pixel

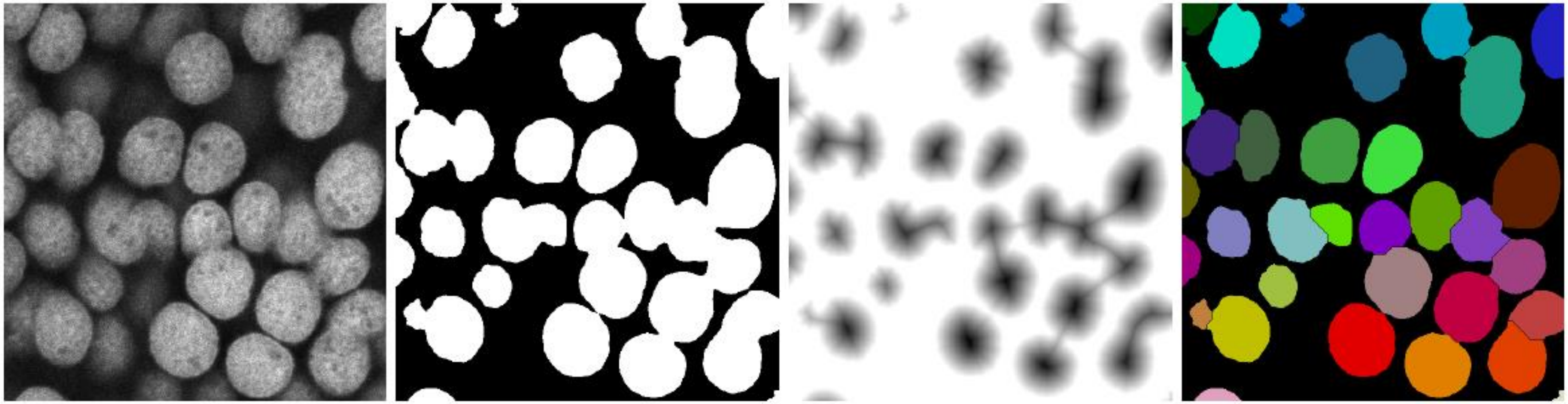
1	1	0	0	0
1	1	0	0	0
0	0	0	0	0
0	0	0	0	0
0	1	1	1	0

0.00	0.00	1.00	2.00	3.00
0.00	0.00	1.00	2.00	3.00
1.00	1.00	1.41	2.00	2.24
1.41	1.00	1.00	1.00	1.41
1.00	0.00	0.00	0.00	1.00



Example 1 - Watershed Transform of Binary Image Using the Distance transform

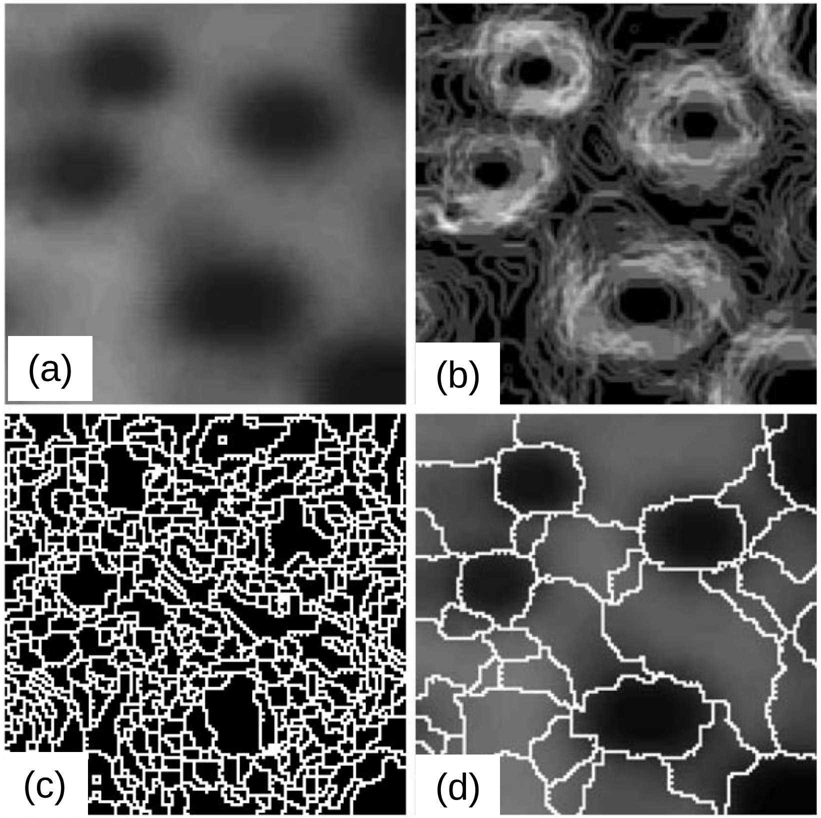
- Segmentation example applying watershed to the inverse distance image using the binary mask



Examples 2 - oversegmentation

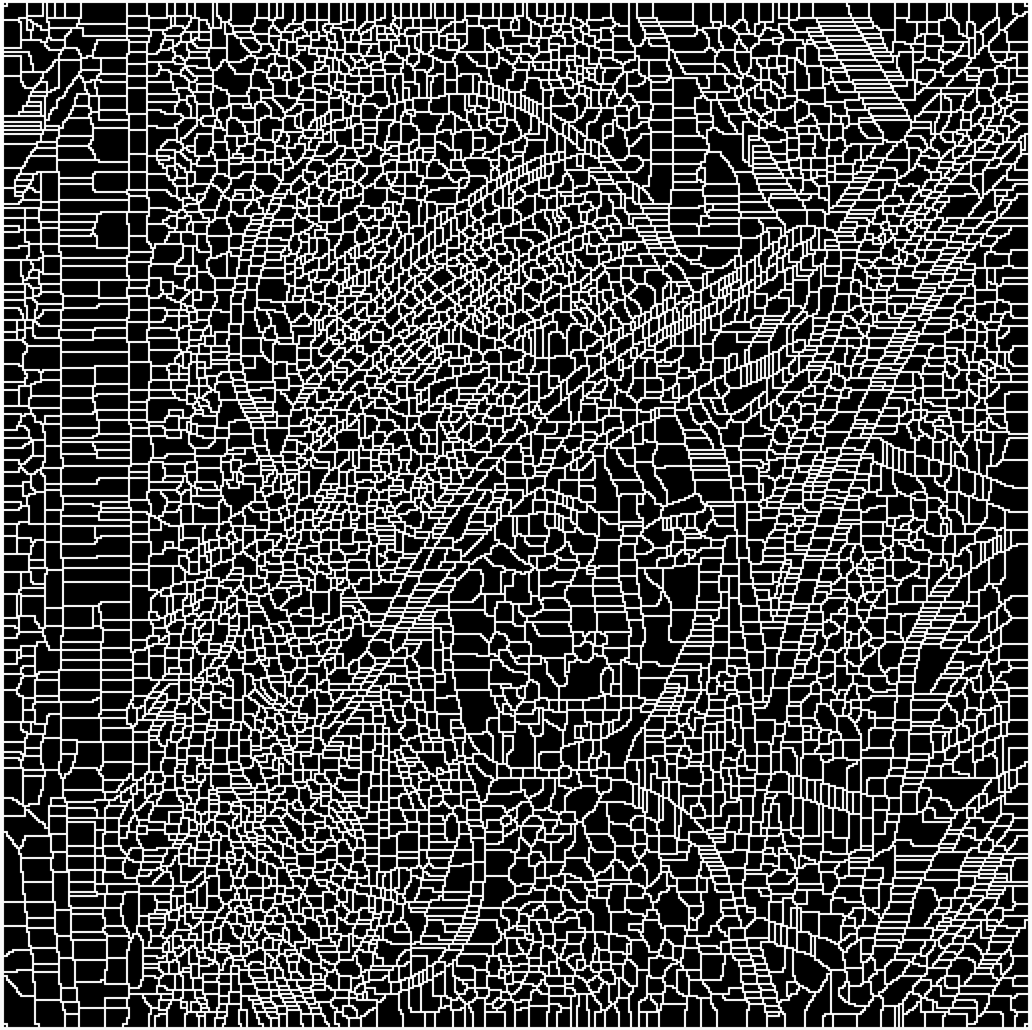
(a) Original image
(b) Gradient image of image (a)
(c) Watershed lines obtained from image b (oversegmentation)
- ➔ Each connected region contains one local minimum in the corresponding gradient image

(d) Watershed lines obtained from smoothed image (b)



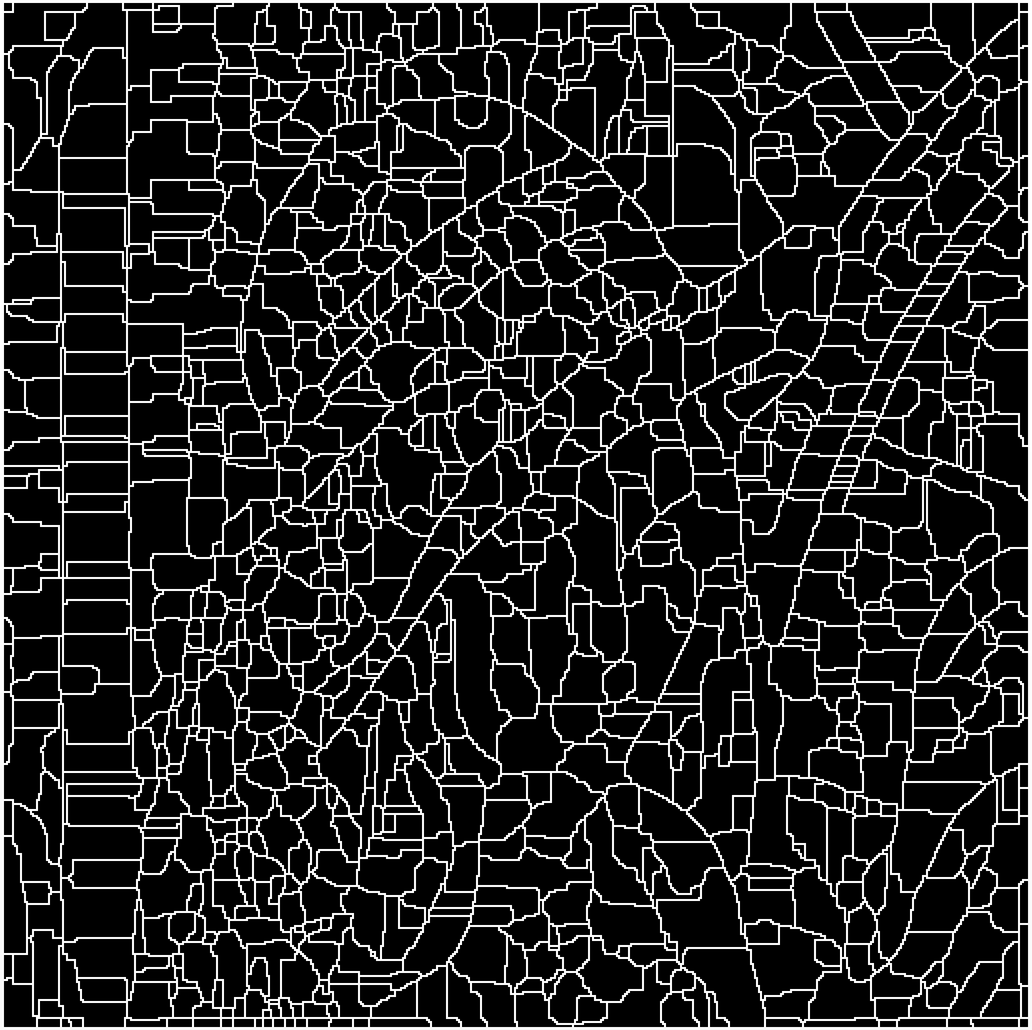
Simple trick

- Use median filter to reduce number of regions



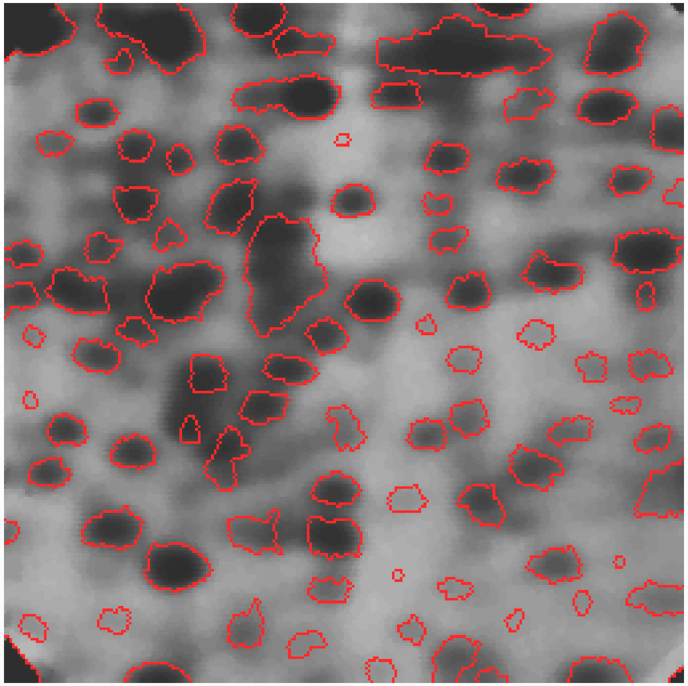
Simple trick

- Use median filter to reduce number of regions



Object segmentation by watershed algorithm

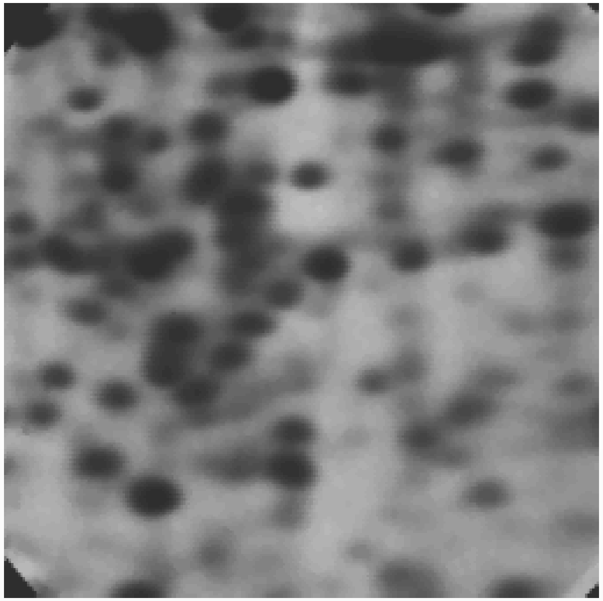
- Task: segmentation of (possibly touching) objects in front of a background



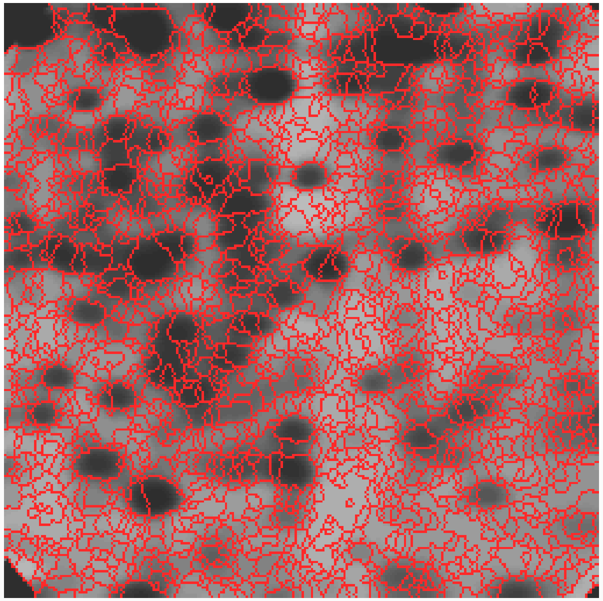
Electrophoresis image

Watershed Segmentation

- Over-segmentation problem:
  - most times the real watershed transform of the gradient present many catchment basins, each one corresponds to a minimum of the gradient that is produced by small variations, mainly due to noise.



Original Image*



Segmentation Result*

*Yu-Hsiang Wang: „Tutorial: Image Segmentation" (http://disp.ee.ntu.edu.tw/meeting/%E6%98%B1%E7%BF%94/Segmentation%20tutorial.pdf)

The Use of Markers

- Over-segmentation problem
  - Usually, we cannot overcome it with simple filtering (like median)
  - Use of markers can be a solution
- Internal markers are used to limit the number of regions by specifying the objects of interest
  - Like seeds in region growing method
  - Can be assigned manually or automatically
  - Regions without markers are allowed to be merged (no dam is to be built)
- External markers: pixels where we are confident to belong to the background
  - Watershed lines are typical external markers and they belong the same (background) region

Watershed Based Image Segmentation

- Use internal markers to obtain watershed lines of the gradient of the image to be segmented.
- Use the obtained watershed lines as external markers
- Each region defined by the external markers contains a single internal marker and part of the background
- The problem is reduced to partitioning each region into two parts: object (containing internal markers) and a single background (containing external markers)

Over-segmentation: solution

- FIRST STEP: we mark each blob of protein of the original image

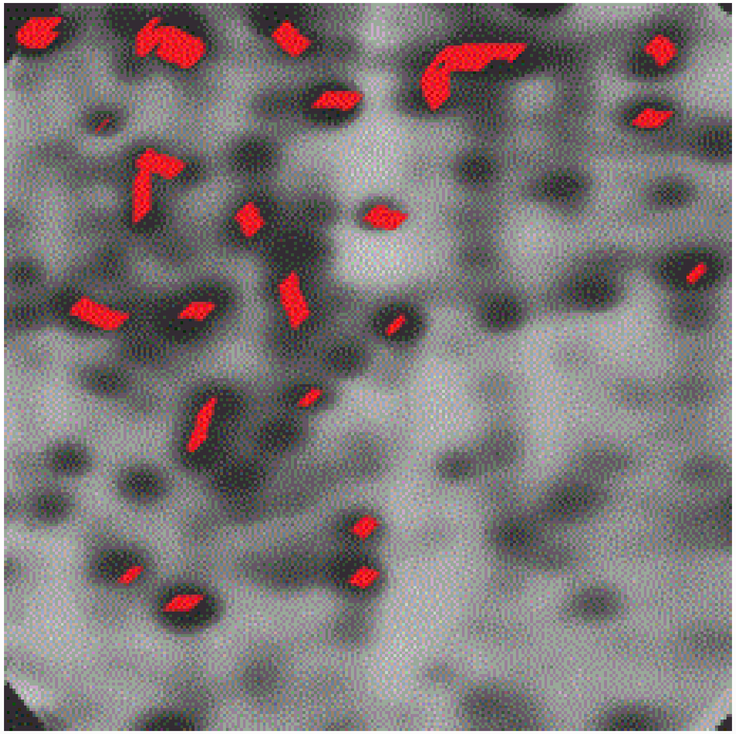
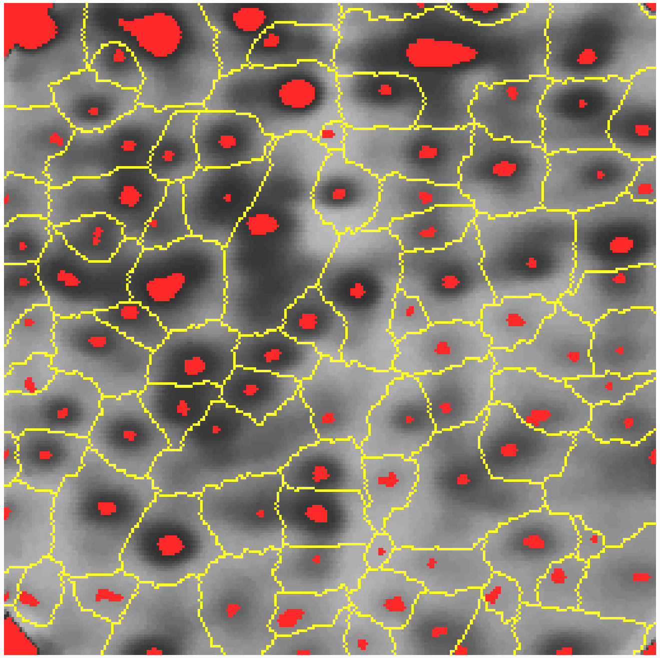


Image with a few markers (not all blobs are marked here)

Usage of internal markers

- Now we look at the final result of the marking as a topographic surface, but in the flooding process instead of piercing the minima, we only make holes through the components of the marker set that we produced

- This way the flooding will produce as many catchment basins as there are markers in M, and the watershed lines of the contours of the objects will be on the crest lines of this topographic surface



Initial image marked with the set M and the resulting watershed lines

Watershed Segmentation

- Partitioning each region into two parts: object (containing internal markers) and a single background (containing external markers)
  - Global thresholding, region growing, region splitting and merging…

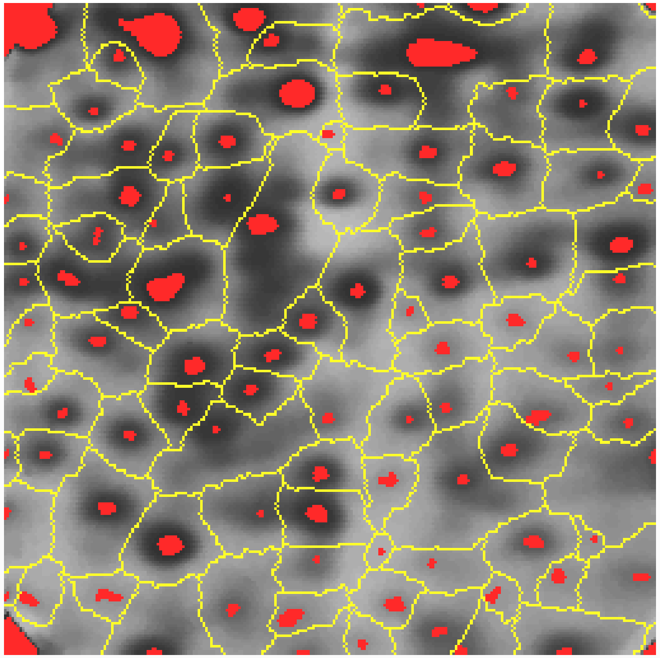
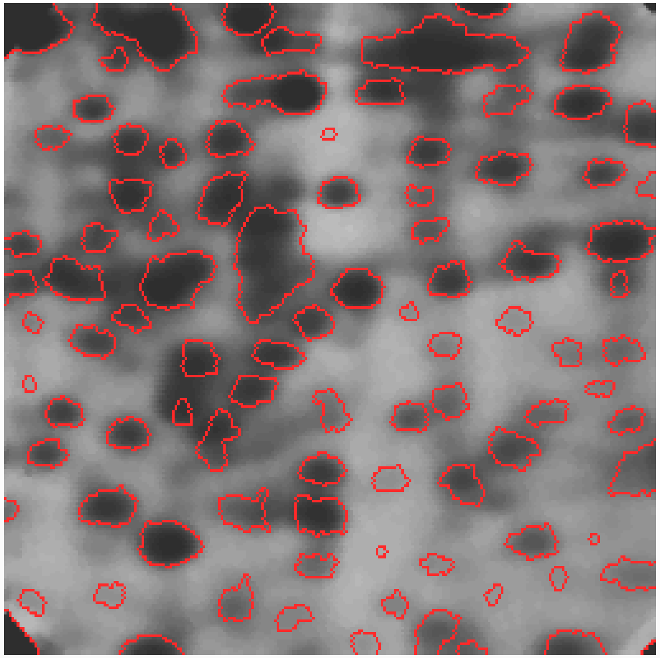


Image with internal and external markers

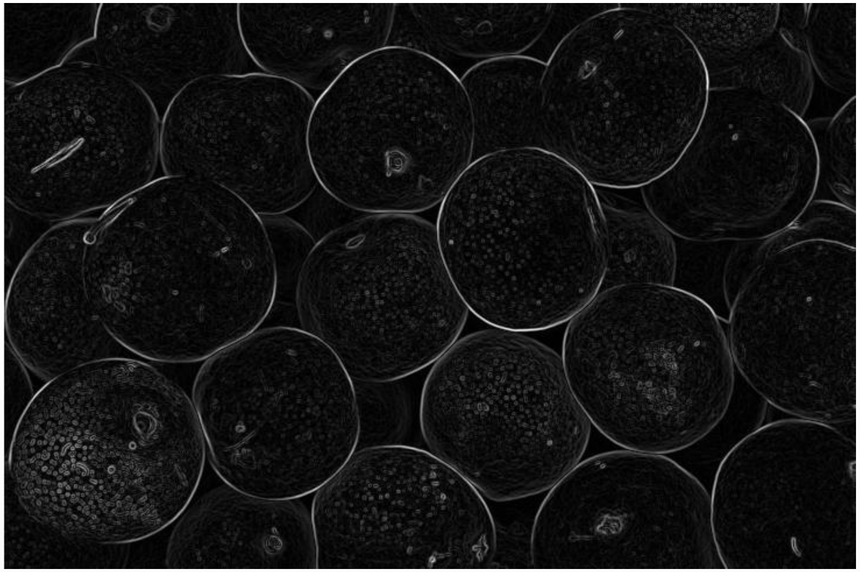


Final segmentation result

Watershed segmentation example

- Use the Gradient Magnitude as the Segmentation Function
  - The gradient is high at the borders of the objects and low (mostly) inside the objects.

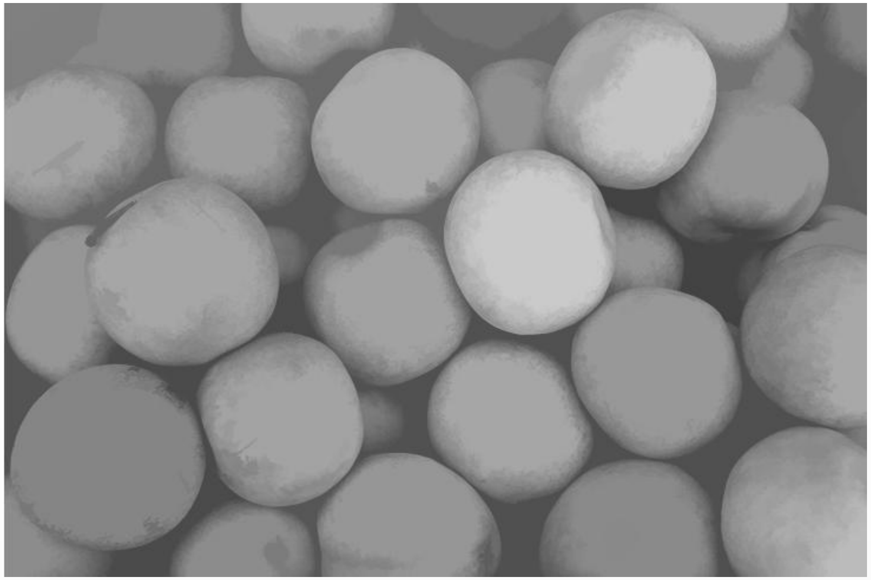
Original image (I)



Gradient magnitude image

Watershed segmentation example

- Obtaining good foreground markers: regional maxima of the morphology enhanced input image

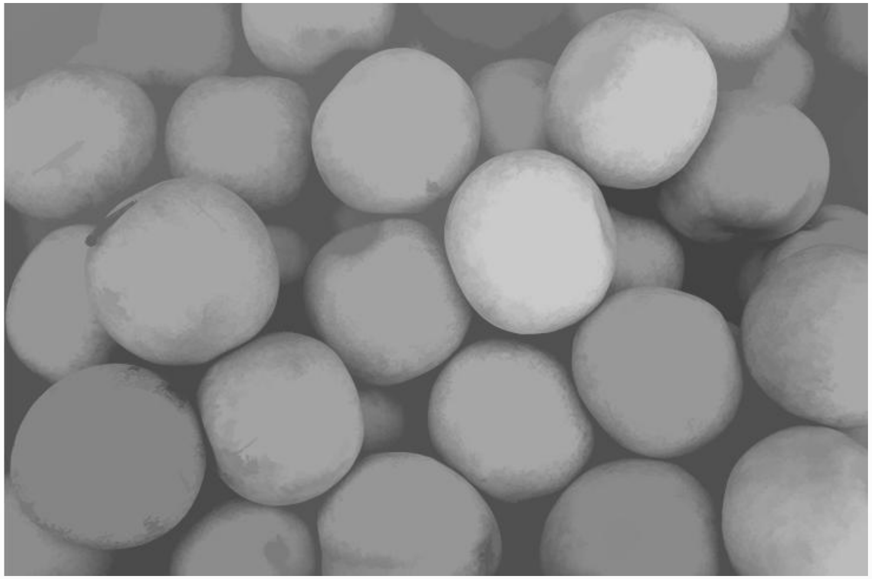


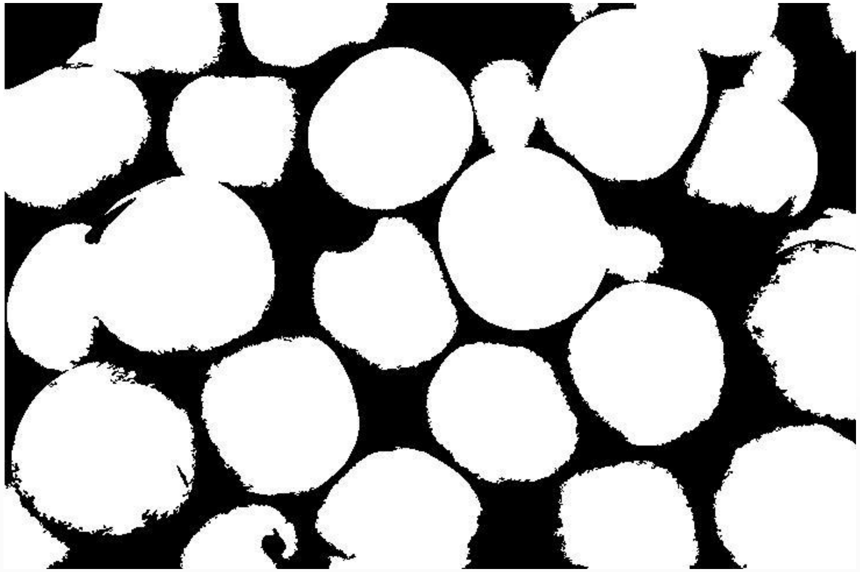
Result of grayscale morhpology (M)

Regional maxima of (M) superimposed on original image (I)

Watershed segmentation example

- Obtaining good background markers
  - Step 1: threshold the morphology enhance image

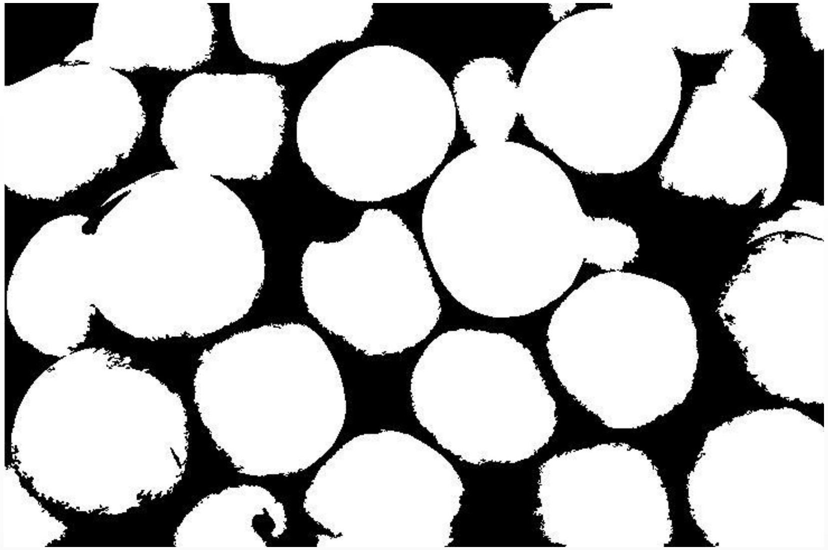


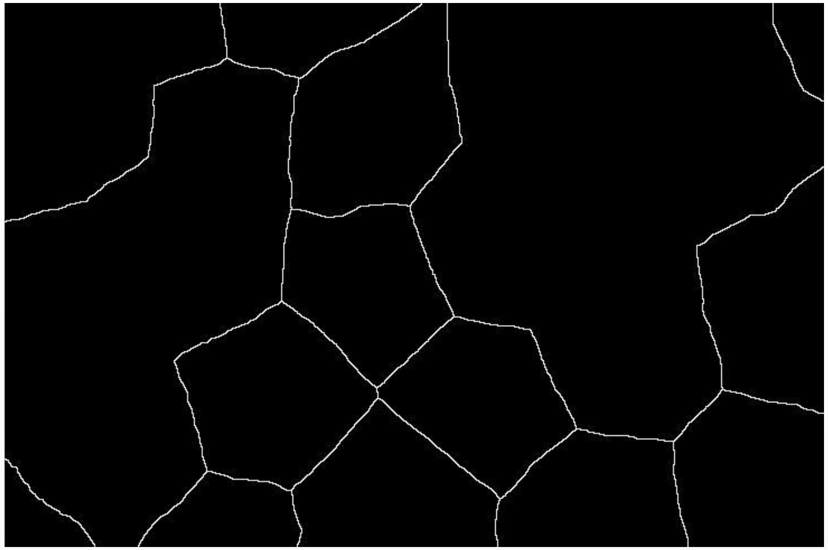


- Result of grayscale morhpology (M)
- T: result of Otsu threshold on M

Watershed segmentation example

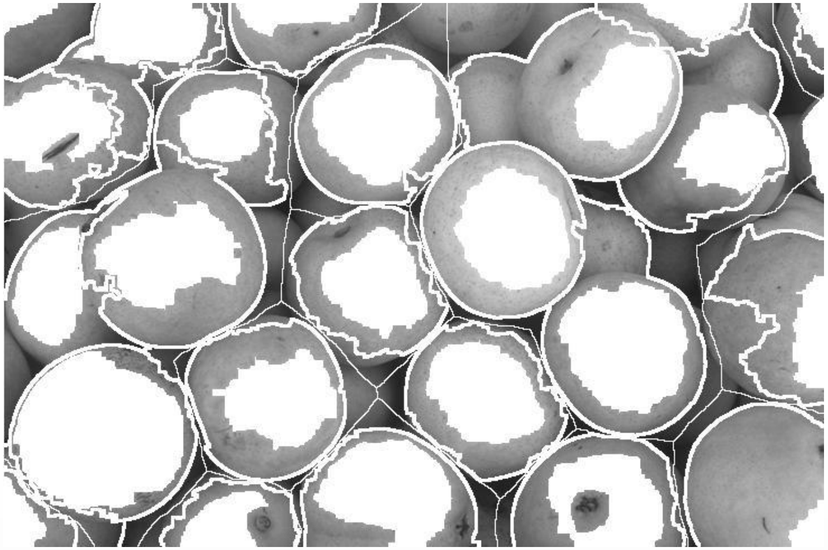
- Obtaining good background markers
  - Step 1: threshold the morphology enhance image
  - Step 2: using the watershed transform of the distance transform of T, and then looking for the watershed ridge lines of the result



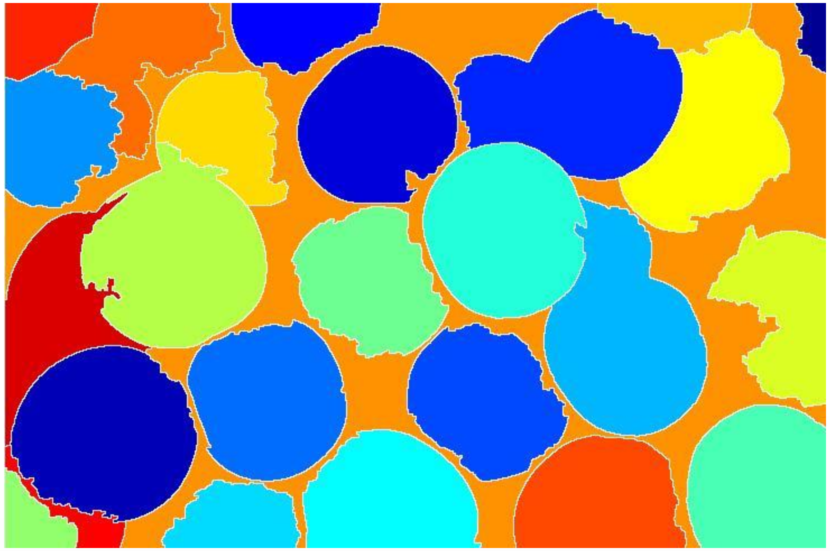


- T: result of Otsu threshold on M
- Watershed lines (background markers)

Watershed segmentation:
Visualization of the results



Superimpose the foreground markers, background markers, and segmented object boundaries.



Segmentation results: display the label matrix as a color image

Matlab tutorial example, with source code:
https://www.mathworks.com/help/images/examples/marker-controlled-watershed-segmentation.html?prodcode=IP&language=en

Watershed application example

- Segmentation of masonry wall images

Input

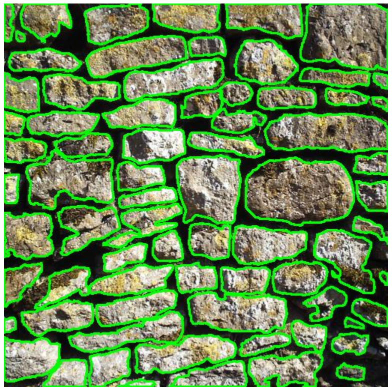
Marker image by Deep Learning

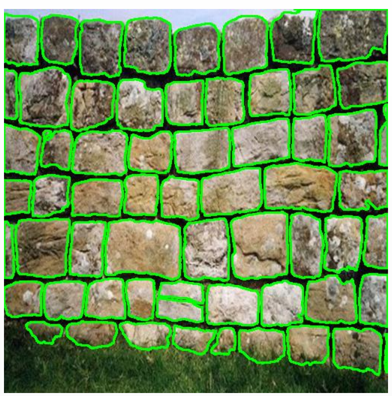
Segmentation result

Ground Truth

Reference: Y. Ibrahim, B. Nagy and *Cs. Benedek*: "CNN-based Watershed Marker Extraction for Brick Segmentation in Masonry Walls", *International Conference on Image Analysis and Recognition (ICIAR)*, Waterloo, Canada, August 27-29, 2019

Further results…





Y. Ibrahim, B. Nagy and *Cs. Benedek*: "CNN-based Watershed Marker Extraction for Brick Segmentation in Masonry Walls", *International Conference on Image Analysis and Recognition (ICIAR)*, Waterloo, Canada, August 27-29, 2019

Summary: Watershed Segmentation

- There are 3 types of pixels:
  - Points belonging to a regional minimum
  - Point belonging to the catchment basin of a regional minimum
  - Points belonging to a watershed line
- The resulted boundaries of the regions are continuous.
- But it is time consuming and has over-segmentation problems.
- The solution to the over-segmentation is to use markers:
  - Internal markers:
    - Each one correspond to one object
    - Surrounded by points with higher altitude
    - Points in a region form a connected component
    - The points of the connected component has the same intensity
  - External markers:
    - Segment the image into regions with one internal marker object and background points.