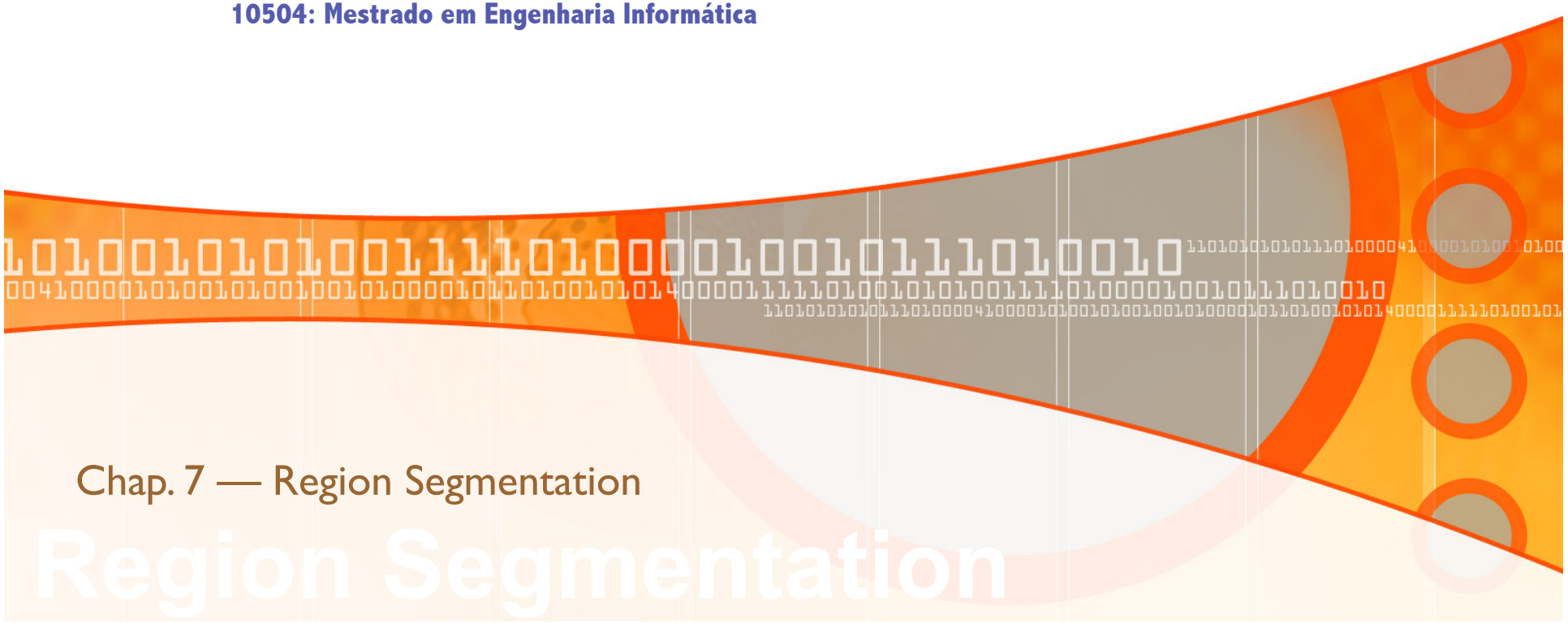
Computação Visual e Multimédia

10504: Mestrado em Engenharia Informática



Chap. 7 — Region Segmentation

Region Segmentation

Outline

...:

- Image segmentation: a reminder.
- Region-based segmentation versus edge-based segmentation.
- Region-based segmentation: definitions and formulation.
- Seed-based region growing segmentation.
- Fast marching-based region growing segmentation.
- Region segmentation by splitting and merging.
- Water flooding-based watershed segmentation.
- Marker-controlled watershed segmentation.
- Inter-pixel watershed segmentation.
- Other more complex region segmentation approaches.

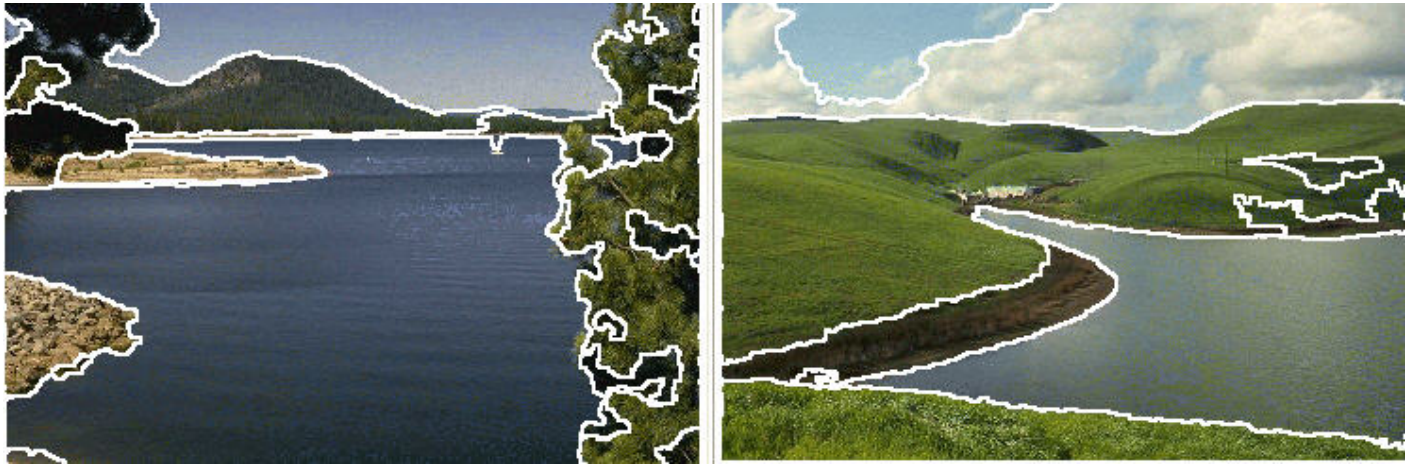
Image segmentation: a reminder

Techniques:

- Segmentation algorithms for monochrome images generally are based on one of *two basic properties* of gray-scale values.
- **Discontinuity**:
  - The approach is to partition an image based on abrupt changes in gray-scale levels.
  - The principal approaches are detection of isolated points, lines, and edges in an image.
  - ***Boundary estimation using edge detection***
    - Boundaries produced are not necessarily closed.
    - Computation of regions is based on differences (discontinuities).
- **Similarity**:
  - The principal approaches are based on thresholding, region growing, and region splitting/merging.
  - ***Region-based segmentation***
    - Closed boundaries.
    - Computation of regions is based on similarity.

Image segmentation: … in pictures

Edge segmentation:



Region segmentation:

http://robots.stanford.edu/cs223b/index.html

Mean Shift: A Robust Approach toward Feature Space Analysis, by D. Comaniciu and P. Meer
http://www.caip.rutgers.edu/~comanici/MSPAMI/msPamiResults.html

REGION-BASED IMAGE SEGMENTATION

What is a region?

Definition:

- A group of connected pixels with similar properties.

Image interpretation:

- ´Region` is an important concept in interpreting an image because regions *may* correspond to objects in a scene.
- Consequently, for a correct interpretation of an image, we need to partition an image into regions that correspond to objects or parts of an object.
- Partitioning into regions done often by using gray values of the image pixels.

Region-based approach

Idea:

- Those pixels that correspond to an object are grouped together and marked.

Principles:

- Similarity:
  - Gray value differences
  - Gray value variance
- Spatial proximity:
  - Euclidean distance
  - Compactness of a region

Assumption:

- Points on same object map to nearby pixels on the image with similar gray values.
- The assumption does not hold true in all cases. Consequently, the solution is to group pixels using principles above and use domain-dependent knowledge.

Region-based segmentation

Definition:

- As any other type of image segmentation, its main goal is to partition an image *I* into regions R_i.
- Unlike edge-based segmentation, which returns boundaries between regions, region-based segmentation is a technique that allows us to determine the regions directly.

Formulation:

- *Completeness*. The segmentation must be complete, i.e., every pixel must be in a region: $\bigcup_{i=1}^{n} R_i = I$
- *Connectedness*. The points of a region must be connected in some sense.
- *Disjointness*. Regions must be disjoint: $R_i \bigcap R_j = \varnothing \quad \forall i = 1,2,\ldots n$
- *Satisfiability*. Pixels of a region must satisfy one common property *P* at least, i.e., any region must satisfy a homogeneity predicate P. $P(R_i) = TRUE, \quad \forall i$
- *Segmentability*. Different regions satisfy different properties, i.e., any two adjacent regions cannot be merged into a single region. $P\left(R_i \bigcup R_j\right) = FALSE$

Comparison of histogram, region growing and deformable contour segmentations

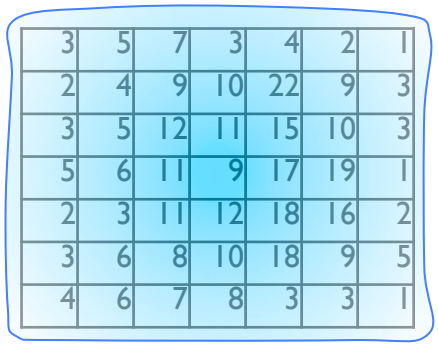
3	5	7	3	4	2	1
2	4	9	10	22	9	3
3	5	12	11	15	10	3
5	6	11	9	17	19	1
2	3	11	12	18	16	2
3	6	8	10	18	9	5
4	6	7	8	3	3	1

threshold $T \geq 10$

threshold $T \geq 11$

threshold $T \geq 12$

region growing with variance of 2 in respect to value 11 with reference to threshold $T \geq 11$



deformable contour to meet threshold $T \geq 11$

Region growing segmentation

Principle/Idea:

- Region growing is the simplest region-based segmentation that groups pixels or sub-regions into larger regions based on pre-defined criteria.
- The pixel aggregation starts with a set of "seed" points in a way that the corresponding regions grow by appending to each seed points those neighboring pixels that have ***similar*** properties (such as gray level, texture, color, shape).

Comparison:

- Region growing based techniques are better than the edge-based techniques in noisy images where edges are difficult to detect.

seed *growing* *final region*

Seed-based region growing segmentation: *pixel aggregation*

The seed point can be selected either by a human or automatically by avoiding areas of high contrast (large gradient) => seed-based method.

Algorithm (for a single region):

- Let R be the region to extract.
  - Initially, the region R only contains its seed point p.
- Let F be a FIFO (First In, First Out) that contains the boundary points of R.
  - Initially, F contains the 8-neighborhood of the seed point p.
- **while** F is not empty
  - **for** each neighbor pixel p* of p in F
    - **if** p* is similar to p
      - p* is added to R
      - neighbor pixels of p* (not in R) are added to F
    - **else**
      - Set p* as non-similar

Seed-based region growing segmentation: *example*

Problem: To isolate the strongest lightning region of the image on the right hand side without splitting it apart.
Solution: To choose the points having the highest gray-scale value which is 255 as the seed points shown in the image immediately below.

original image

http://en.wikipedia.org/wiki/Region_growing

threshold = 255 returns multiple seeds

threshold: 225~255

threshold: 190~225

threshold: 155~255

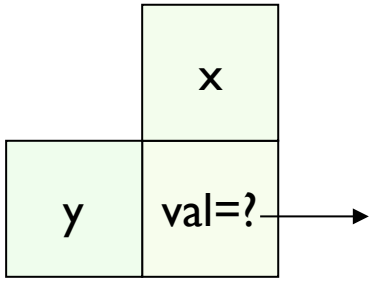
Fast scanning algorithm: a kind of unseeded region segmentation

*If the **criterion of homogeneity** is **local** (compared to the value of the candidate pixel and the pixel of the border) => linear method.*

Fast scanning algorithm:

- The fast scanning algorithm somewhat resembles an unseeded region growing.
- The number of clusters of both two algorithm would not be decided before image passing through them.

Threshold T: $P_1 == P_2$ *iff* $Diff(Col(P_1), Col(P_2)) < T$



x==y: val = x
x<>y: *boundary*(x)→y if |x-y|≤T
new region index if |x-y|>T

1	1	2	2	3	
1	1	1	1	1	

Region growing segmentation: advantages & disadvantages

Advantages:

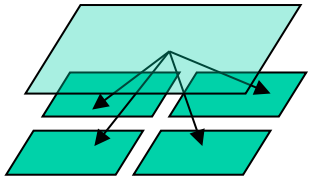
- It is a fast method.
- It is conceptually simple.

Disadvantages:

- Local method: no global view of the problem.
- Gradient problem: in practice, there is almost always a continuous path of points related to color close that connects two points of an image. Thus, unless we use a pre-defined variance (threshold), this will lead to the gradient problem:

- Algorithm very sensitive to noise.

Region splitting and merging segmentation



Region splitting:

- Unlike region growing which starts from a set of seed points, region splitting starts with the whole image as a single region and subdivides it into subsidiary regions recursively while a condition of homogeneity is not satisfied.

Region merging:

- Region merging is the opposite of region splitting, and works as a way of avoiding over-segmentation.
- Start with small regions (e.g. 2x2 or 4x4 regions) and merge the regions that have similar characteristics (such as gray level, variance).

original image *splitting & merging* *thresholding seg.*

Region splitting: *example*

In this example, the ***criterion of homogeneity*** *is the variance of I.*

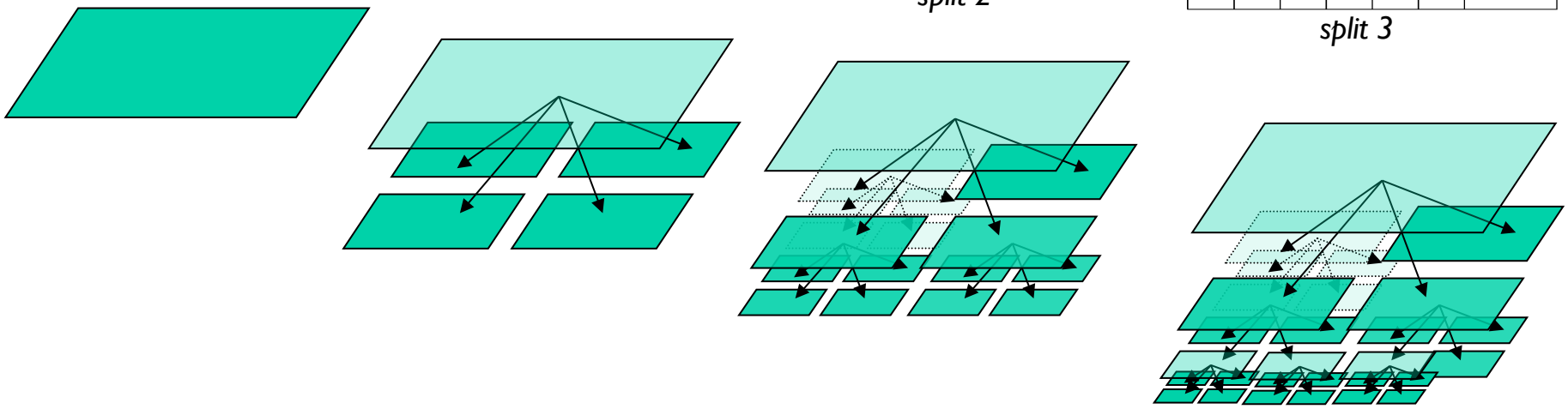
0	1	0	0	7	7	7	7
1	0	2	2	7	7	7	7
0	2	2	2	7	7	7	7
4	4	2	2	7	7	7	7
0	0	1	1	3	3	7	7
1	1	2	2	3	7	7	7
2	4	3	0	5	7	7	7
2	3	3	5	5	0	7	7

original image

split 1

split 2

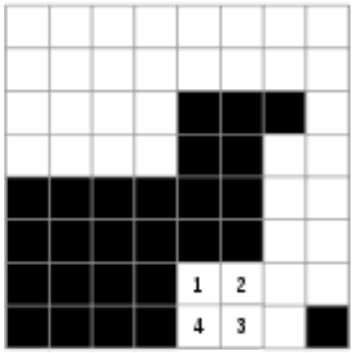
split 3

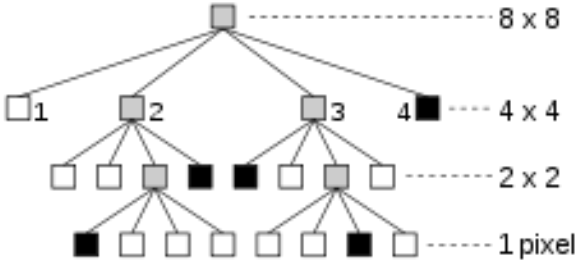


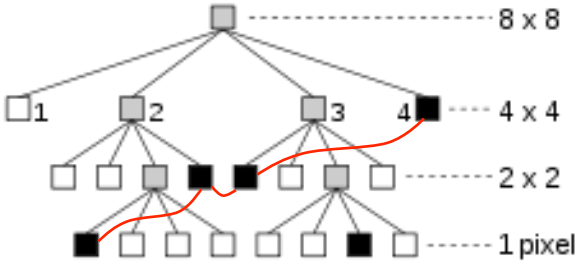
Splitting & merging: data structures

Two data structures:

- ***Quadtree*** for splitting.
  - Splitting is a top-down procedure that creates regions that may be adjacent and homogeneous, but not merged.
- ***RAG*** (region adjacency graph) for splitting and merging.
  - Splitting and merging work together iteratively, i.e., at each iteration of quadtree partitioning.
  - RAG has an embedded quadtree for splitting that represents 4 containment relations.
  - RAG also represents 4 adjacency relations (one per square side).





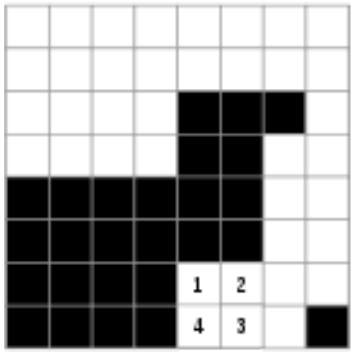


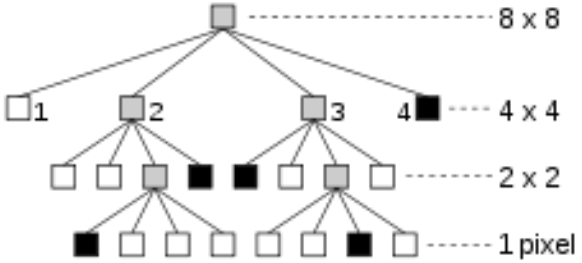
RAG with adjacency relations (in red) for big black region.

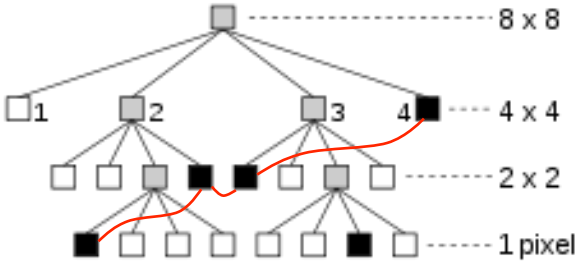
Splitting & merging segmentation algorithm

Algorithm:

- If a region R is inhomogeneous (P (R)=FALSE), then R is split into four sub-regions.
- If two adjacent regions R_i,R_j are homogeneous (P(R_iUR_j)=TRUE), they are then merged.
- The algorithm stops when no further splitting or merging is possible.

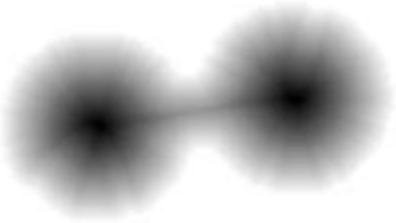


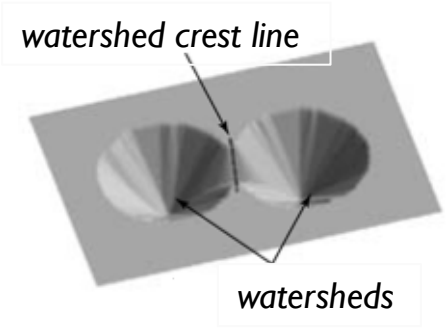




RAG with adjacency relations (in red) for big black region.

Watershed segmentation





Topographic principle:

- An image is considered as a 3D topographic surface with valleys and mountains where each pixel (x,y) is encoded as a surface point (x,y,h), with h standing for its gray level.

Idea proposal (by flooding):

- S. Beucher and C. Lantuéjoul (1979). "Use of watersheds in contour detection". In Proceedings of the *International Workshop on Image Processing, Real-time Edge and Motion Detection (1979)*. http://cmm.ensmp.fr/~beucher/publi/watershed.pdf

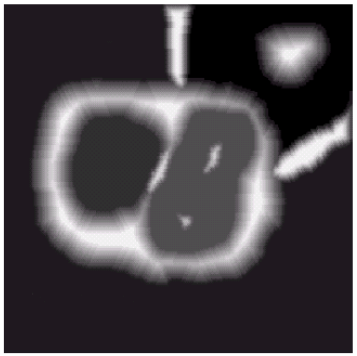
Variants:

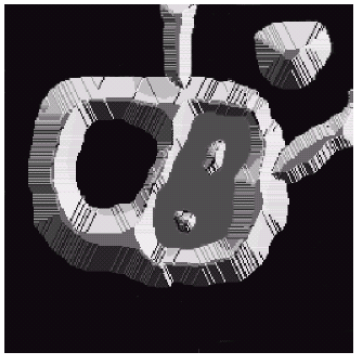
- Watershed by flooding
- Inter-pixel watershed
- Watershed by topographic distance (not taught in this course)
- Topological watershed (not taught in this course)
- etc.

http://en.wikipedia.org/wiki/Watershed_(image_processing)#cite_note-1

Watershed segmentation by flooding

original image





3D topographic surface

3D topographic surface of an image:

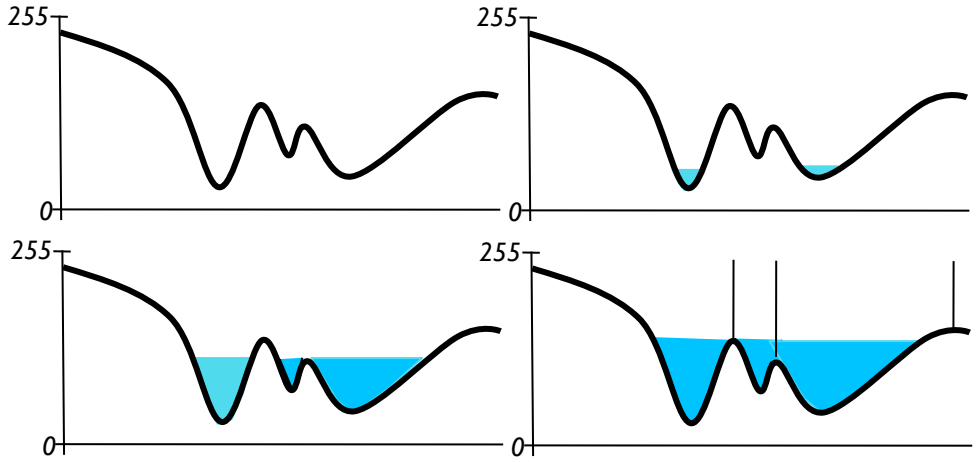
- Visualize an image in 3D using spatial coordinates and gray levels.
  - That is, each pixel is identified by a triple of coordinates (x,y,g), where x,y denote its spatial coordinates and g stands for its gray level.

3 types of points:

- Points that belong to a regional *minimum*.
- Points that belong to a *catchment basin* or *watershed* of that minimum. These points are those at which a drop of water would fall towards a single minimum.
- Points that belong to *crest lines* or *watershed lines*. Each crest point is a point at which at which a drop of water would be equally likely to fall to more than one minimum.

This technique aims at identifying all the third type of points (i.e., points of watershed lines) for segmentation

Watershed segmentation by flooding

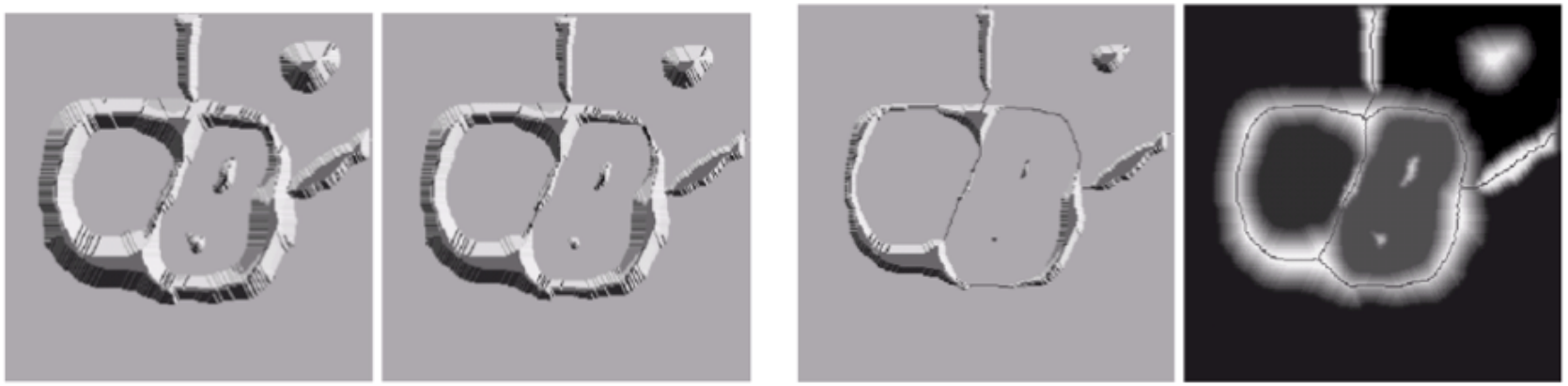


Objective:

- To find watershed lines.

The underlying idea:

- The idea is simple:
  - Imagine that a hole is done through each local minimum so that the entire topography is flooded with water rising through the holes at a uniform rate.
  - When rising water in adjacent catchment basins is about the merge, a dam is built up to prevent merging. *These dam boundaries correspond to the watershed lines*.

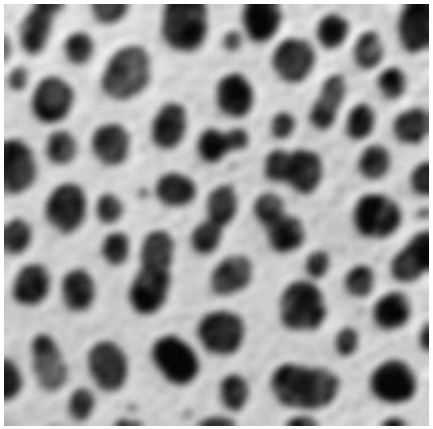


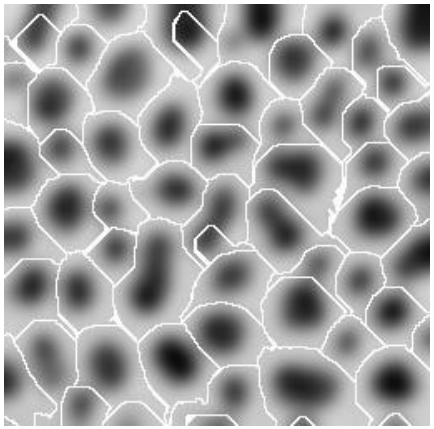
http://euclid.ii.metu.edu.tr/~ion528/demo/lectures/6/4/index.html

Watershed segmentation algorithm

Basic steps:

- Start with all pixels with the lowest possible value.
  - These form the basis for initial watersheds
- For each intensity level k:
  - For each group of pixels of intensity k
    - **If** adjacent to exactly one existing region, add these pixels to that region
    - **Else if** adjacent to more than one existing regions, mark as boundary
      - **Else** start a new region





Watershed segmentation algorithm: *dam construction*

Principle:

- To prevent the merging of water from two catchment basins.

Underlying operation:

- Binary morphological dilation.

Dam construction sub-algorithm:

- Initially, the set of pixels with minimum gray level are 1, others 0.
- In each subsequent step, we flood the 3D topography from below and the pixels covered by the rising water are 1s and others 0s.
- At flooding step n-1, there are two connected components. At flooding step n, there is only one connected component.
  - This indicates that the water between the two catchment basins has merged at flooding step n.
  - Starts the building of a dam (barrier of pixels) in such a single connected component. The barrier increases in altitude using the dilation at each step.

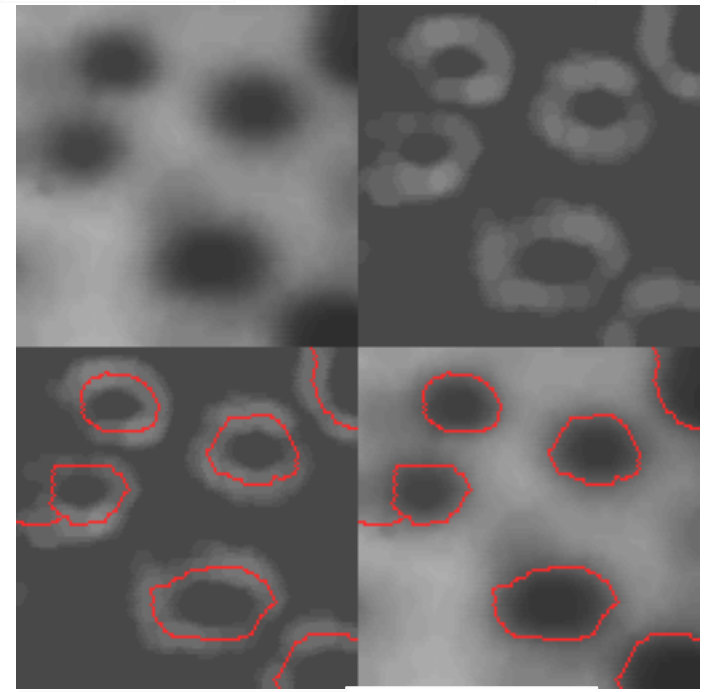
Flooding-based watershed segmentation applied to gradient image

Context:

- Sometimes, the flooding-based watershed segmentation is applied to gradient image instead of being applied to the image itself directly.

Application:

- Applying this transformation to the gradient image, the catchment basins should correspond to, at least theoretically, the homogeneous grey level regions of the image.



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

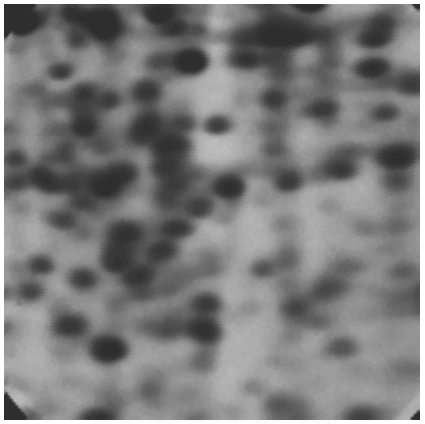
Marker-controlled watershed segmentation (*gradient image*)

Problem:

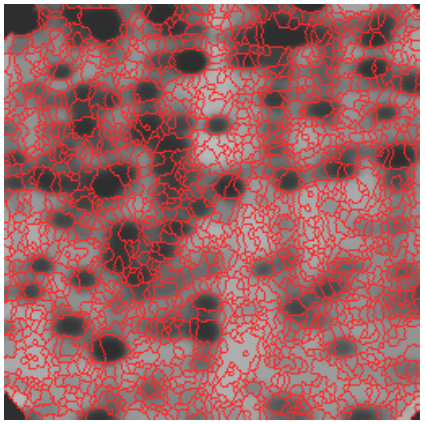
- Due to noise and other local irregularities of the gradient, over-segmentation may occur.

Solution:

- Marker-controlled watershed segmentation:
  - Exclude a number of non-significant minima.
  - The exclusion is done implicitly using markers on the blobs to specify the only allowed regional minima.
  - For example, gray-level values might be used as a markers.

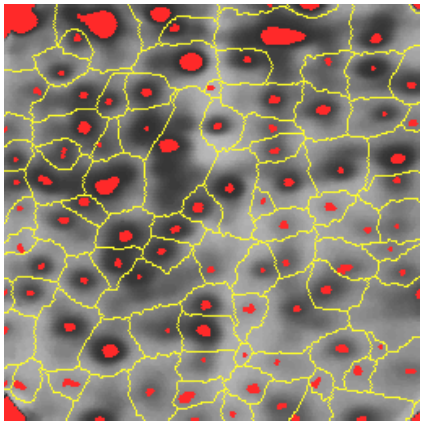


original image

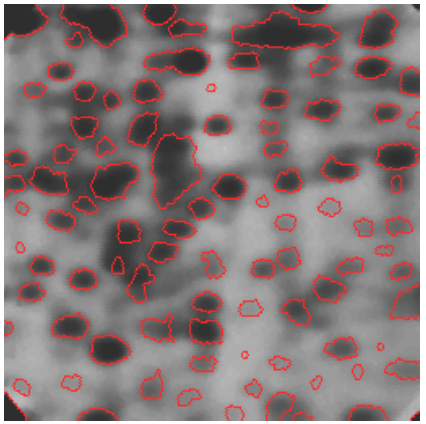


over-segmented image

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



markers of the blobs and of the background



marker-controlled watershed of the gradient image

Inter-pixel watershed segmentation

Idea proposal:

- S. Beucher and F. Meyer (*1993*). The morphological approach to segmentation: the watershed transformation. In *Mathematical Morphology in Image Processing (Ed. E.R. Dougherty), pages 433-481*.

Algorithm:

- *Step 1*. Label each minimum with a distinct label. Initialize a set S with the labeled nodes.
- *Step 2*. Extract from S a node x of minimal altitude *f* or

$$f(x) = \min\{f(y) | y \text{ in } S\}.$$

- *Step 3*. Attribute the label of x to each non-labeled node y adjacent to x, and insert y in S
- *Step 4*. Repeat Step 2 and 3 until S is empty.

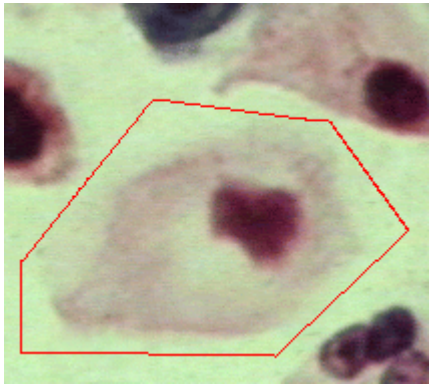
http://en.wikipedia.org/wiki/Watershed_(image_processing)#cite_note-2

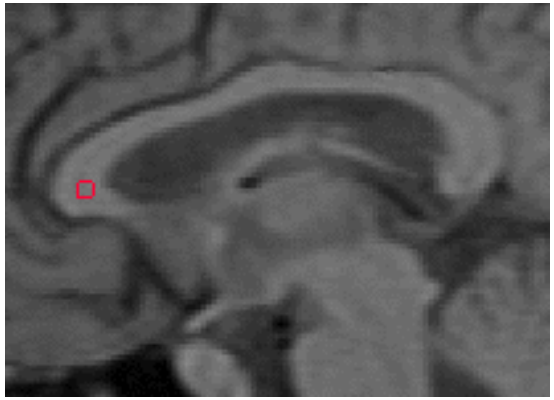
More complex segmentation methods

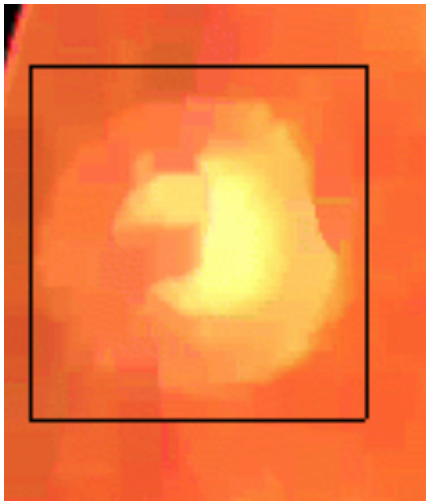
Taxonomy:

- Snakes (or active contours)
  - http://www.markschulze.net/snakes/
- Level sets
  - https://computation.llnl.gov/casc/sapphire/levelsets/levelsets.html
- Graph cuts
  - http://en.wikipedia.org/wiki/Graph_cuts_in_computer_vision
- Generalized PCA (principal component analysis)
  - http://www.cs.otago.ac.nz/cosc453/student_tutorials/principal_components.pdf

Snakes

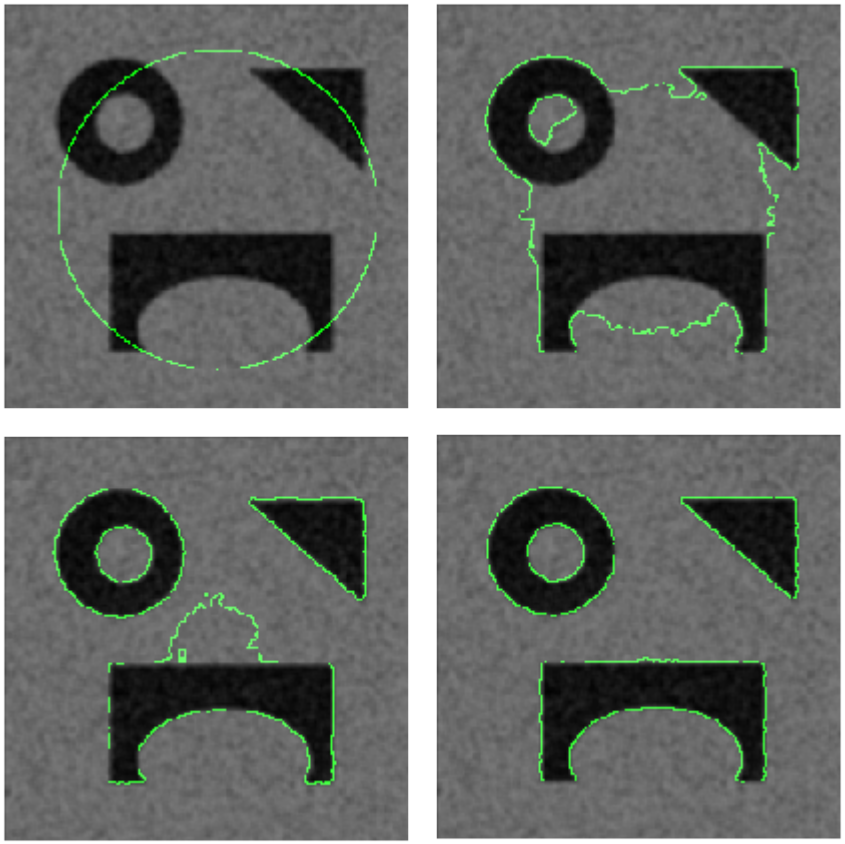


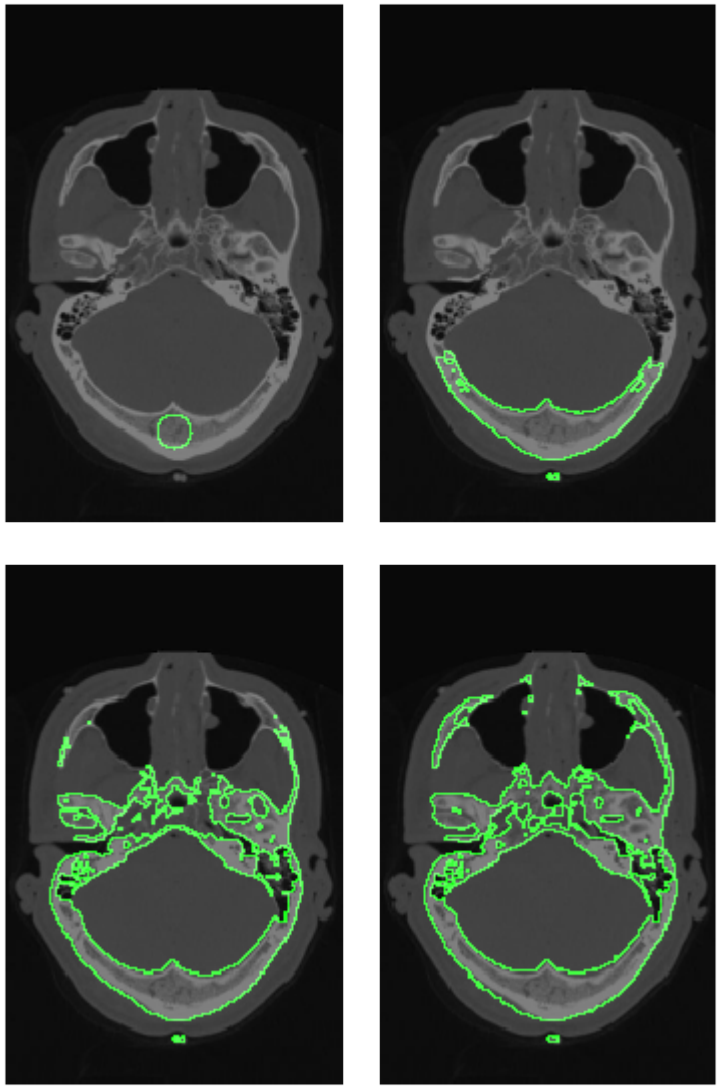




Images taken from http://www.cs.bris.ac.uk/home/xie/content.htm

Level sets





Images taken from http://www.cgl.uwaterloo.ca/~mmwasile/cs870/

Graph cuts

Images taken from efficient graph-based segmentation paper

Generalized PCA (Rene Vidal)

Human

GPCA

Summary:

...:

- Segmentation – essential preliminary step in most scene analysis and automatic pictorial pattern recognition problems.
- Classification of image segmentation methods:
  - Intensity-based segmentation: Thresholding
  - Edge-based segmentation
  - Region-based segmentation
  - Clustering-based segmentation (not taught in this course)
- Choice of technique depends on peculiar characteristics of individual problems.
- A universal algorithm of segmentation doesn't exist, as each type of image corresponds to a specific approach
- Applications:
  - Finding tumors, veins, etc. in medical images, finding targets in satellite/aerial images, finding people in surveillance images, summarizing video, etc.