Segmentation

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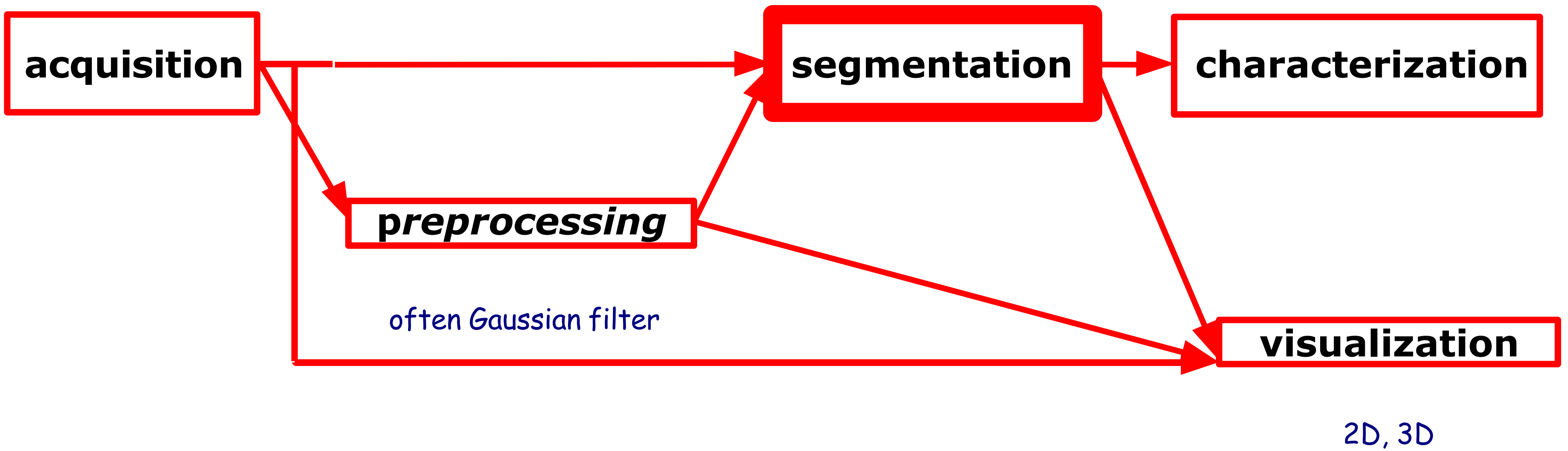
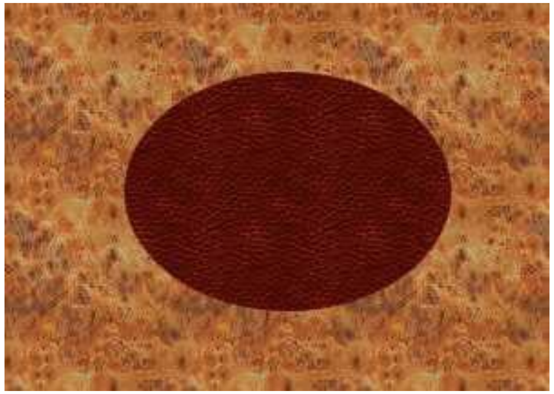
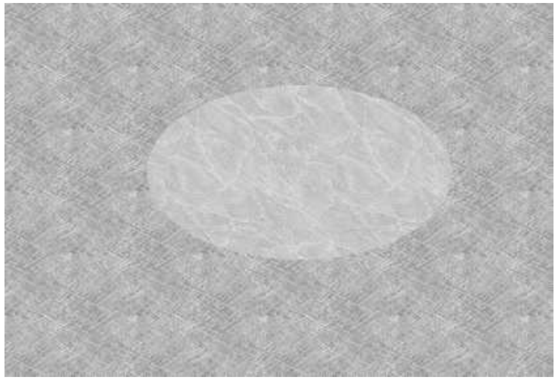
Cycle of digital image processing



Segmentation

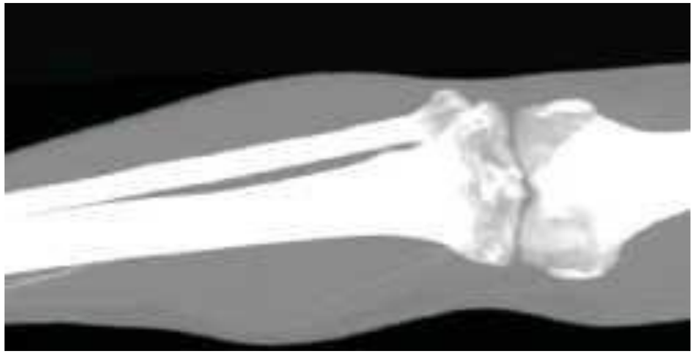
Segmentation - division of the image into **coherent** parts which differ in some way to each other; sometimes also: extract interesting objects from the background





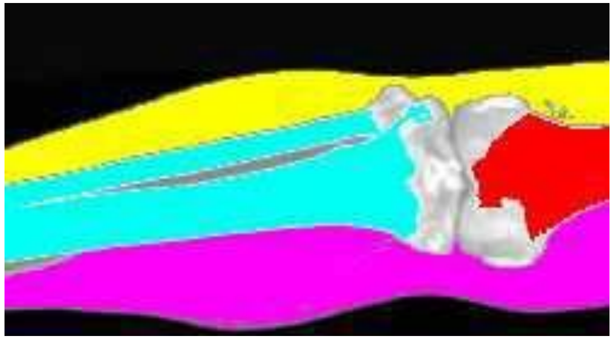
What does it mean coherent?

- withthe same color, brightness
- with similar texture
- no clear boundary
- criterion sometimes difficult to determine (subjective)



Segmentation

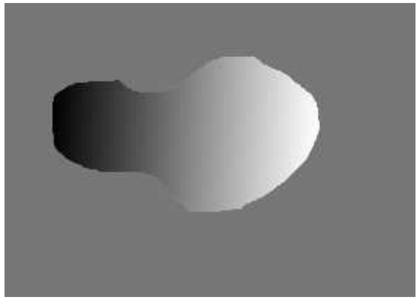
- often divided into two areas - the background and the object(s)
- there is no single method of segmentation - is determined only goal, it is many ways: compete with each other or are complementary
- universal and specialized methods (often using knowledge based on model, such like linear structure)
- two-dimensional and three-dimensional
- automatic, semi-automatic, (manual) not everywhere automatic methods are accepted (medicine)
- methods often multistep, multihybrid
- methods of self-learning
- global and localm methods
- **result:** image where each pixels is assigned to labeled area

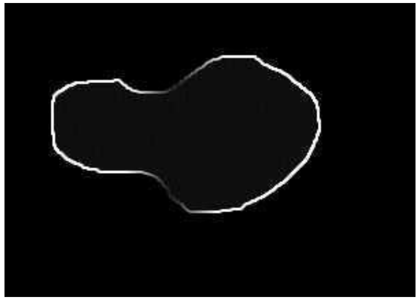


Area and edge segmentation

- can be divided into 2 main groups of segmentation methods:
  - based on the similarities within **areas**
    the result is a set of pixels which (locally) does not differ
  - based on the **borders** between areas
    the result is a set of edges, in which across pixels are very different (edge detectors)

- Results of the methods in both groups are usually similar, but not always





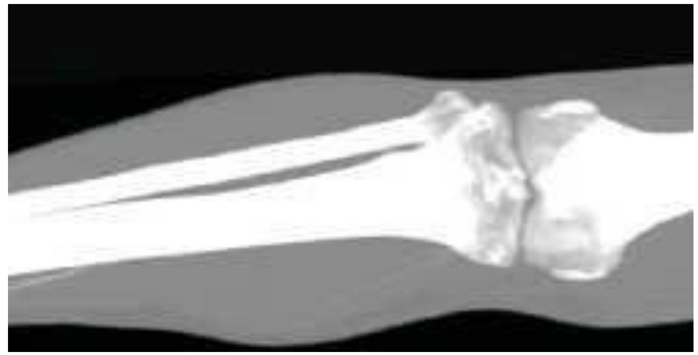
- family of methods, which seems to flee this division - **thresholding** (context-free method, it does not count here surrounding pixels): are you sure?

Segmentation by thresholding

$$I(x,y) \geq T \Rightarrow (x,y) \in \text{„object”}$$
$$I(x,y) < T \Rightarrow (x,y) \in \text{„backgound”}$$

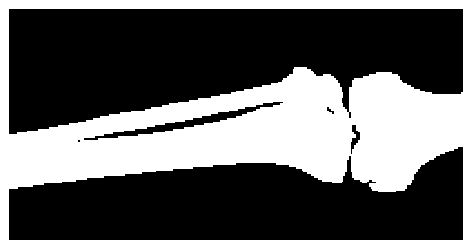
- taken into account only the pixel intensity
- a necessary condition for the application of thresholding:
  the pixels of the object must have a unique range of intensity (eg. the object lighter or darker than the background)
- even when it is assured, it remains an important issue: the choice of threshold **T**
  - automatic selection
  - choice of manual (interactive)
- the same algorithm with different thresholds distinguishes different structure

Thresholding with a single threshold

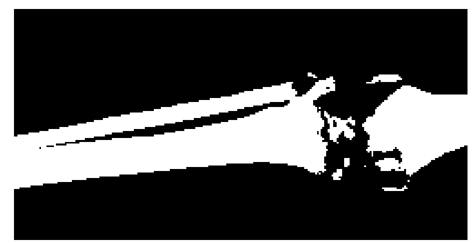


T = 67
whole leg

T = 176
bone structure



T = 230
bone without cartilage

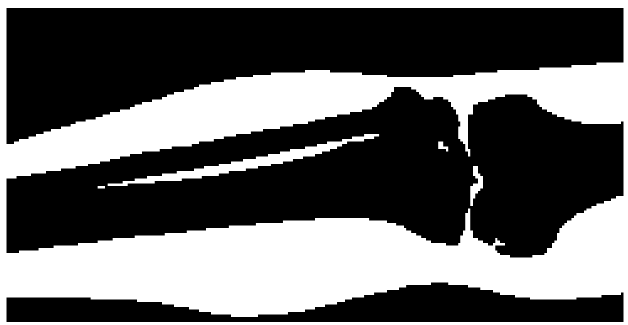


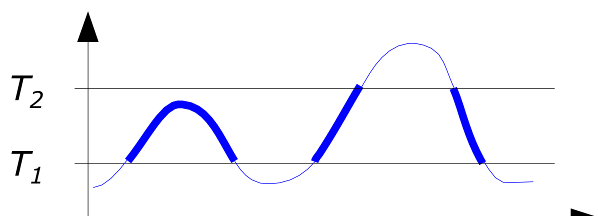
Thresholding with a double threshold

$$T_1 \leq I(x,y) \leq T_2 \quad \Rightarrow \quad (x,y) \in \text{„object”}$$

$$I(x,y) > T_1 \text{ or } I(x,y) < T_2 \Rightarrow (x,y) \in \text{„backgound”}$$

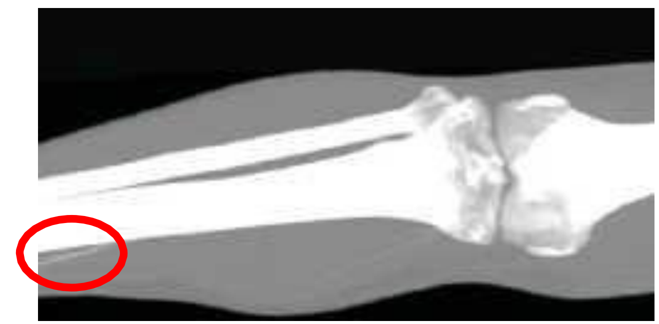
T1 = 67, T2 = 176
boneless leg

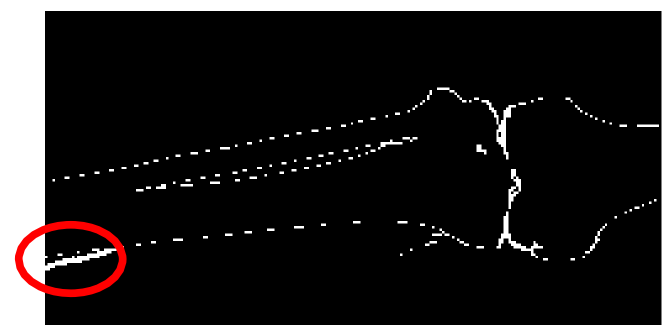




transition zone lighter structures interfere result

T1 = 150, T2 = 176
blood vessel

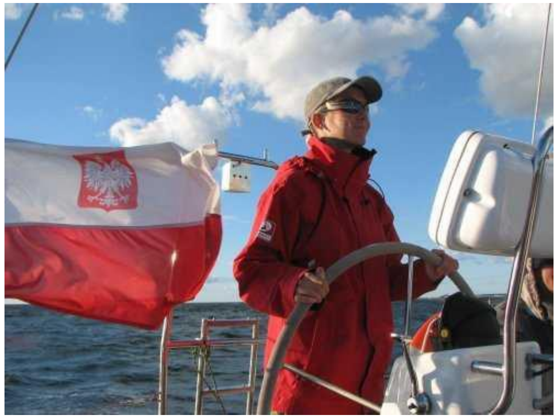




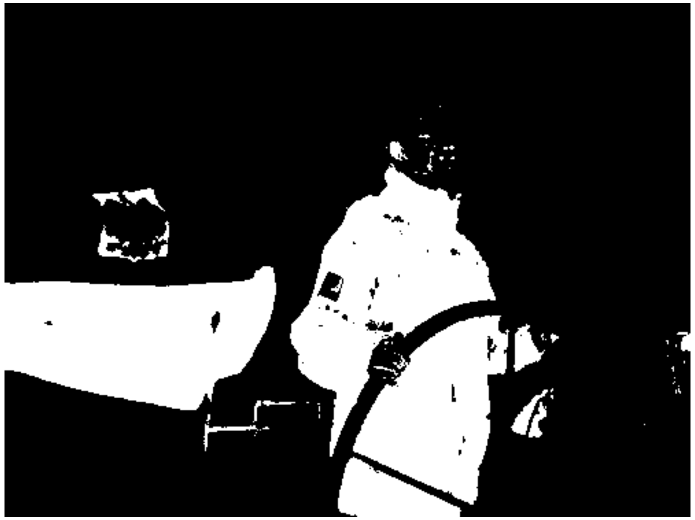
Thresholding color images

- to select a color from the RGB model better idea is to use HSV

thresholding Hue



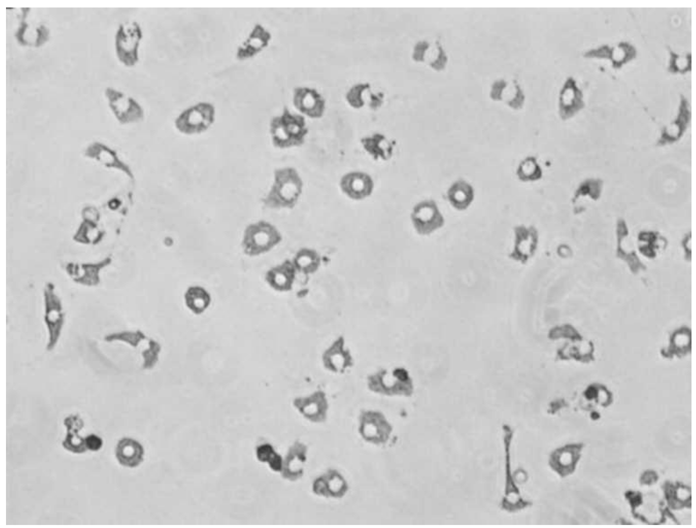
thresholding Hue and saturation (the product of the resulting images)

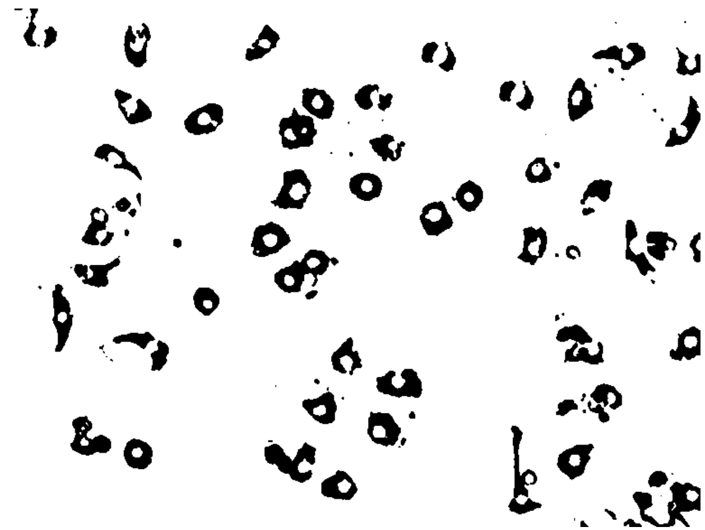


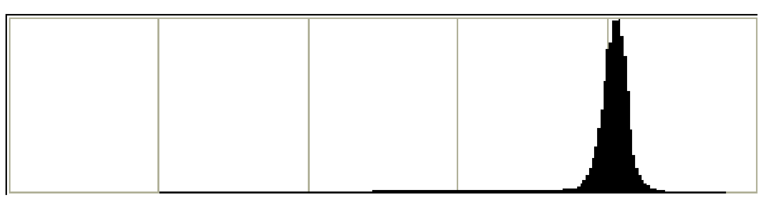
- to better bring out the color can be treshold more channels simultaneously

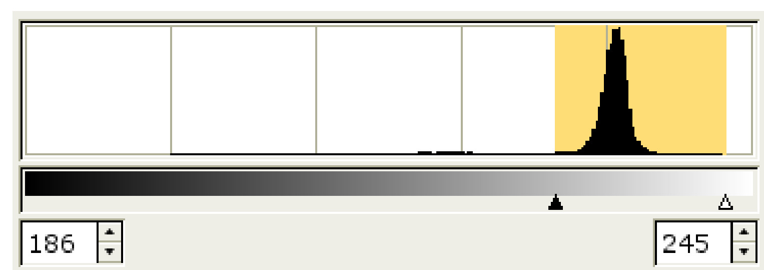
Determination the threshold based on the histogram

- often histogram shows peaks in the frequency of certain intensity
- the boundaries of these peaks can be used as thresholds:





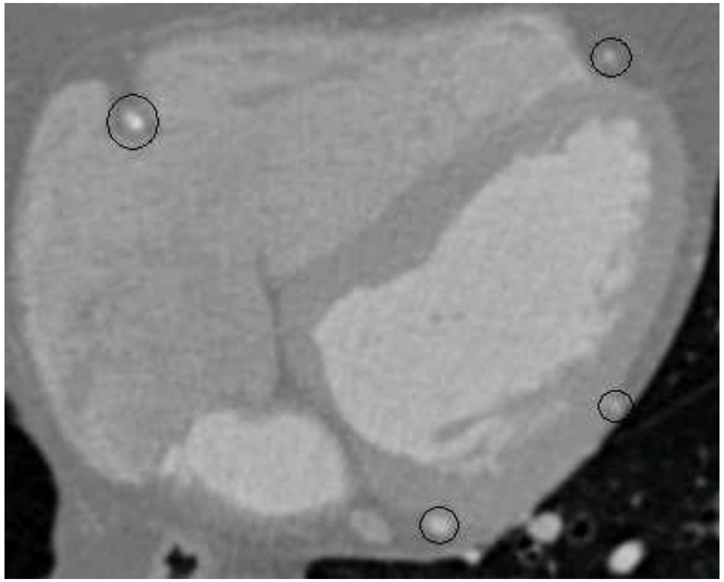


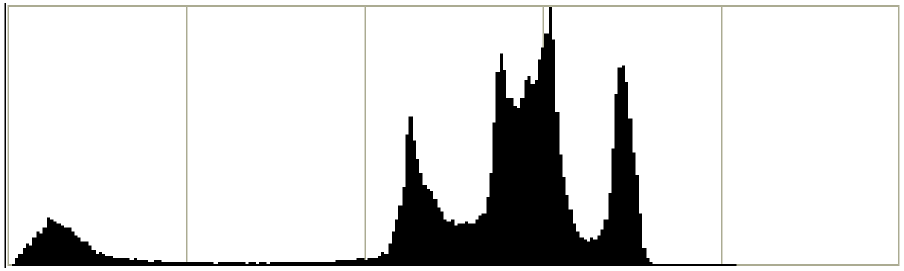


interactive thresholding (GIMP)

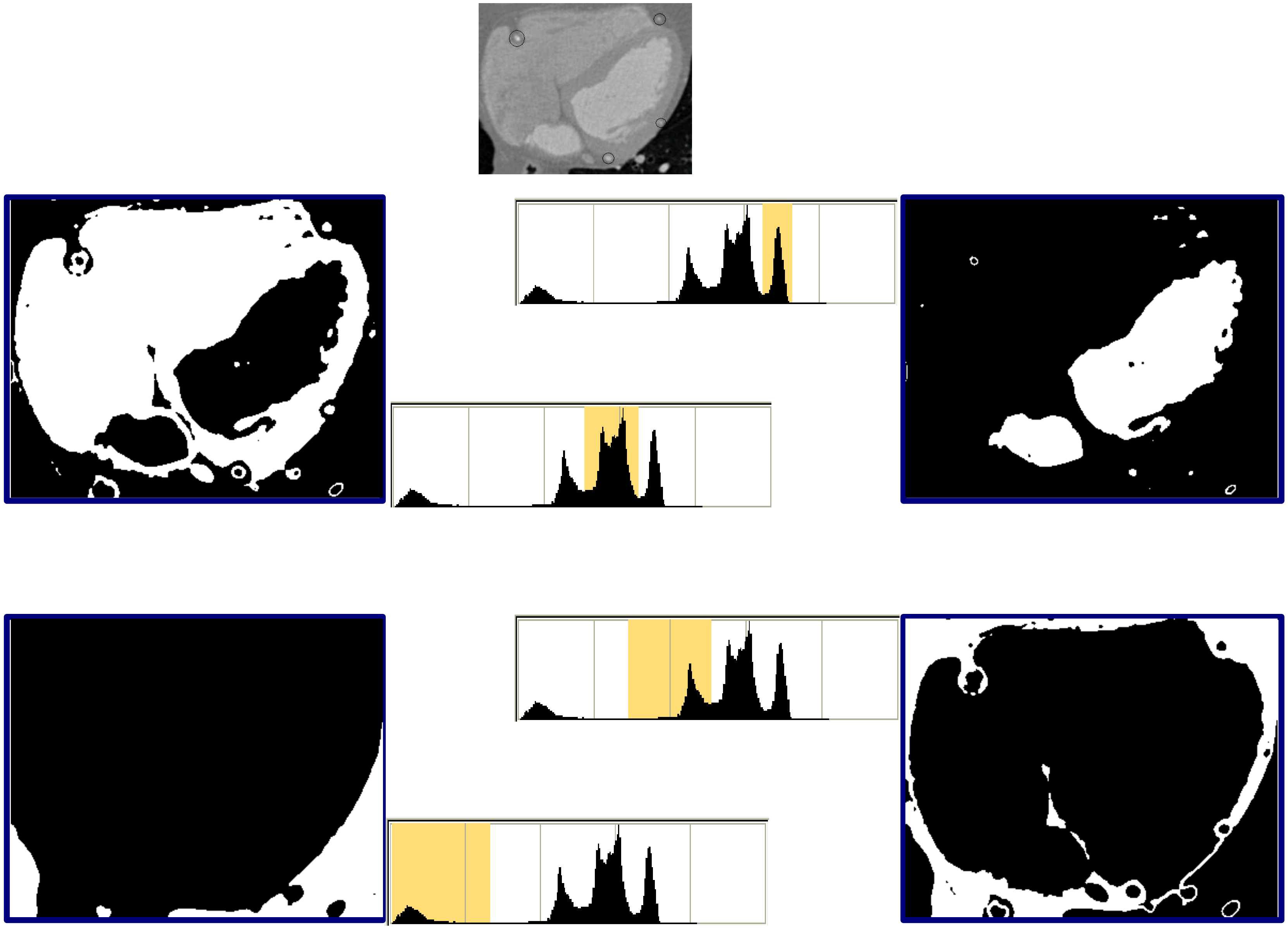
Image with several objects

- objects - various cardiac tissue tomography (cross-transverse)
- Clear can see maximum of frequency peaks in the histogram
- it is possible to interactively isolate these tissues





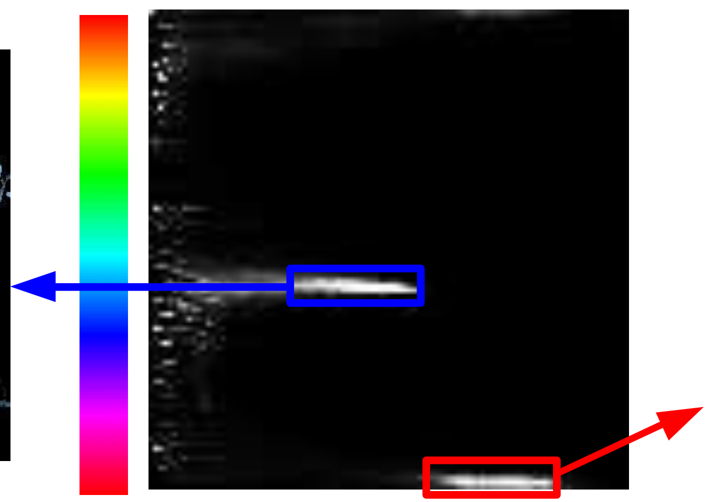
Determination the thresholds based on the histogram



Use of the 2D histogram to threshold

- thresholding in the space HS (hue, saturation)
- two-dimensional histogram shows the maximum frequency peaks
- manualy determination them allows to designation objects with the same color
- you can also use 3D histograms or more (eg. satellite photo in different frequencies)

0.54 <Hue <0.6
0.25 <Saturation <0.6

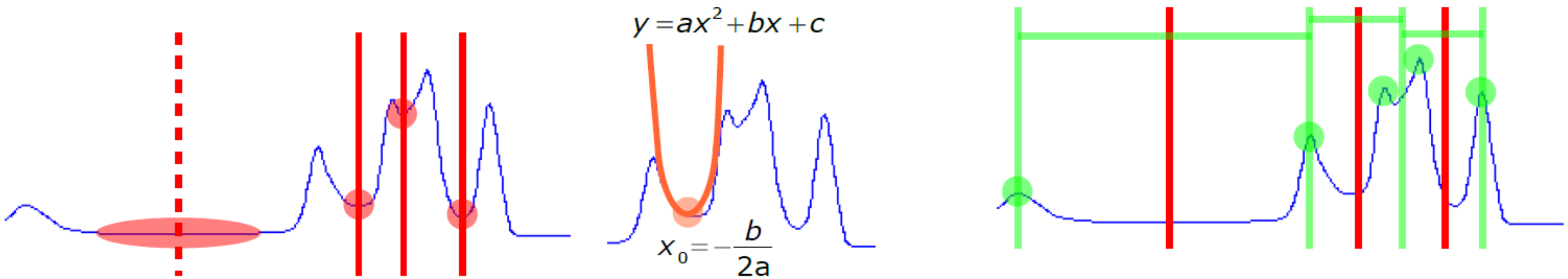


0.95 <Hue
0.55 <Saturation <0.85

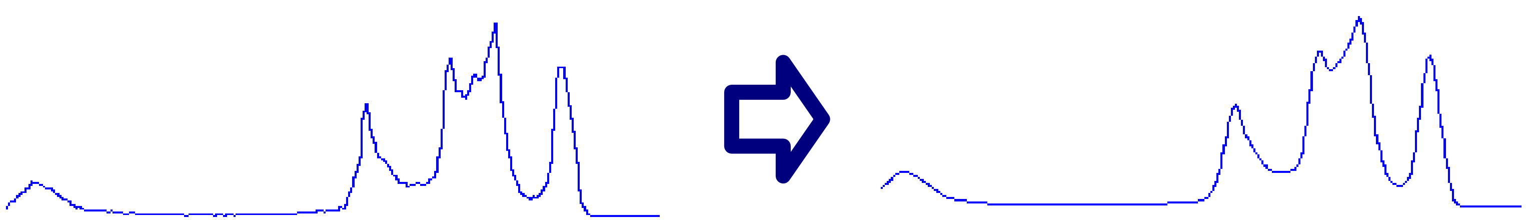
Automatic determination thresholds from the histogram

Geometric approach:

- determination center of the **valleys**: local minima of the histogram;
  - sometimes flat valleys complicate the task
  - center of valleys can be approximated by ellipses (minimizing the square error)
- determination of **peaks**: the local maxima of the histogram and acceptance as a geometric threshold centers between them
  - too close maxima may be replaced by a single maxima



- not to fall into the extremes resulting from noise should be smoothed histogram:



Automatic determination of thresholds from the histogram

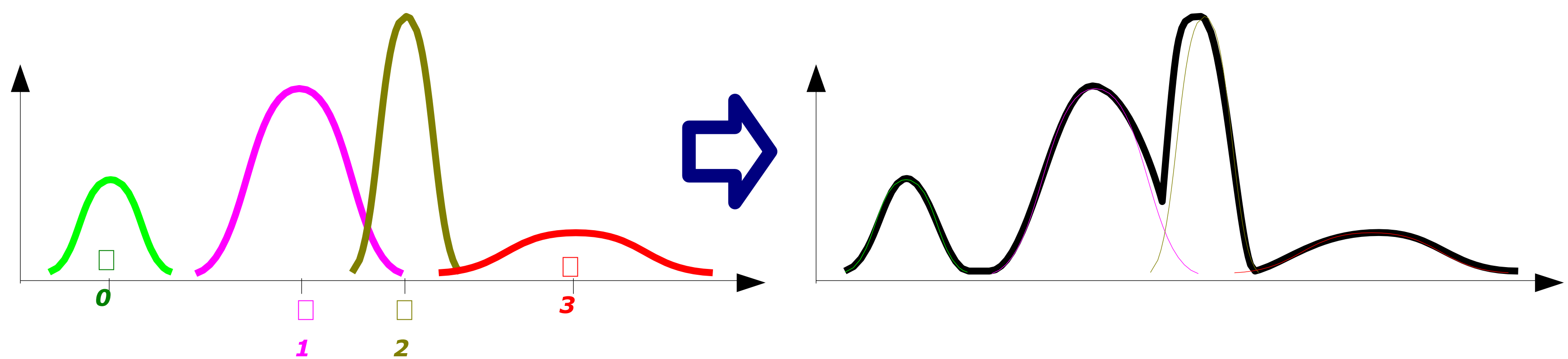
An approach with a specific model intensity distribution of pixels.

- it is assumed here that each of the objects $\mathbf{O_i}$ occur in the image has the intensity eg. a normal distribution N (μ_i, σ_i)
  where: μ_i - represents the mean intensity of the object
  σ_i - standard deviation

- the cumulative probability distribution of the intensity of the pixels in the image is the sum of probability weighted conditional probabilities of the object:

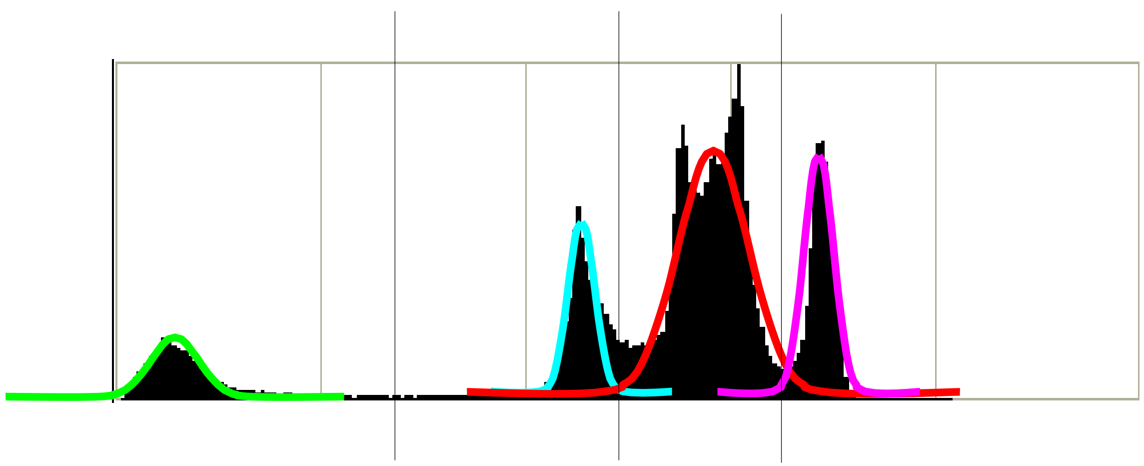
$$P(Image(x,y)=I)=\sum_i P(O_i)\cdot P(Image(x,y)=I|(x,y)\in O_i)$$

- Assuming that each of the conditional probabilities have normal distribution and the probability of the occuring object $\mathbf{O_i}$ acts as a scaling factor, we have:



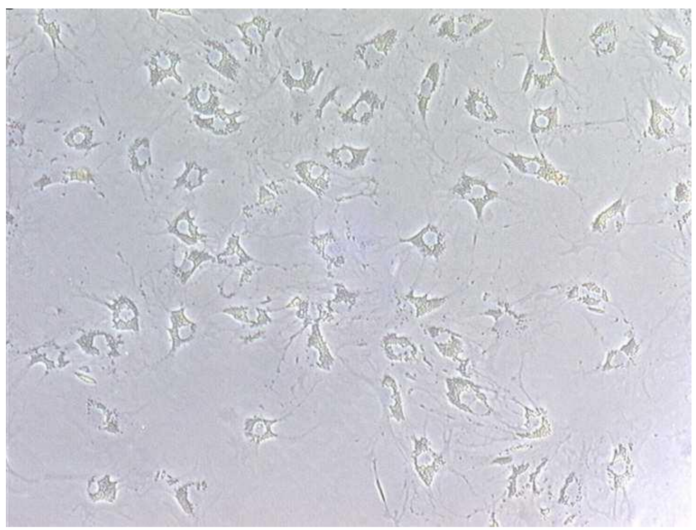
Automatic determination of thresholds from the histogram

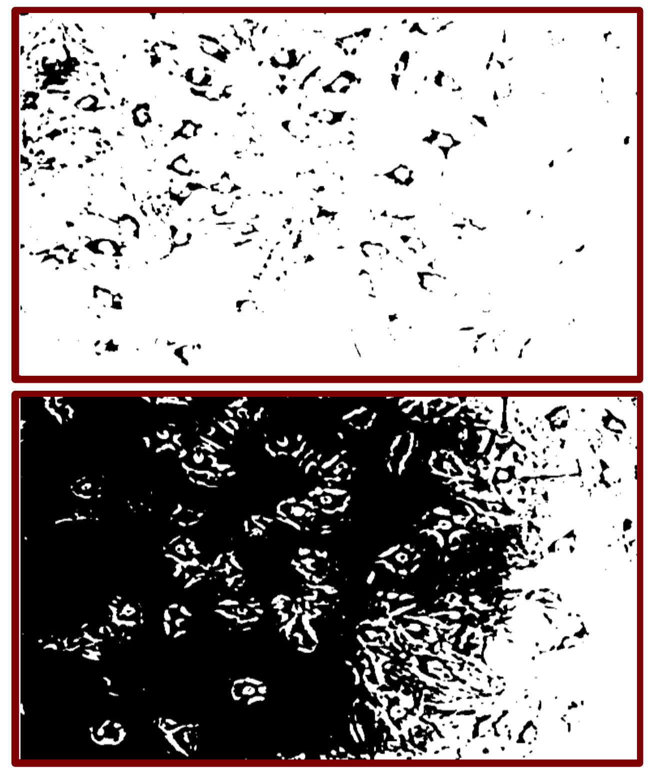
- with histogram and information on the number of objects can be approximated distributions parameters
- estimation of the distribution parameters can be set using one of the existing methods, eg. EM algorithm (expectation-maximization)
- with the parameters of distributions can be assumed thresholds (eg. using Bayes classification rule)



Local thresholds

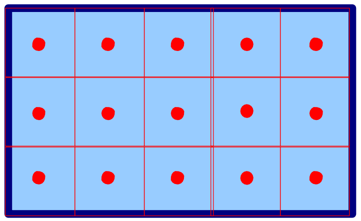
- sometimes the brightness of the objects and background change in the image (eg. due to uneven lighting)
- you can not then designate one global set of thresholds
- thresholds must be local, calculated for parts of the image
- interactive procedure becomes burdensome - the need for automation





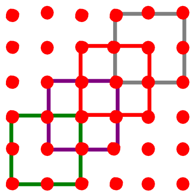
use global thresholds

Adaptive thresholding



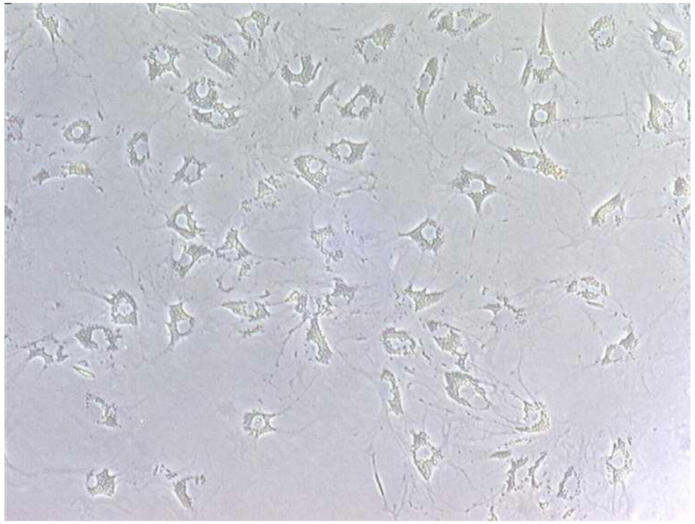
- image is divided into **areas** (size matched to the size of objects, dynamic changes in the environment)

- in each fragment counts local characteristics:
  - the average intensity value
  - minimum and maximum intensity
- On this basis of a **local threshold** is calculated for this fragment
  - the average intensity value
  - the average of the minimum and maximum

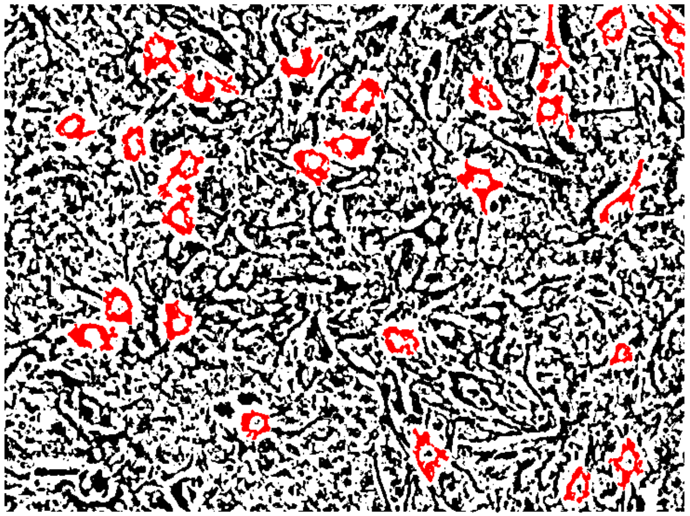


- to avoid abrupt changes in the value of the local threshold at the border areas:
  - counts local thresholds for **each pixel** using its local environment (long-time calculations)
  - shall be calculated threshold values for center of the **disjoint areas** and for the remaining pixels values of the threshold are interpolated

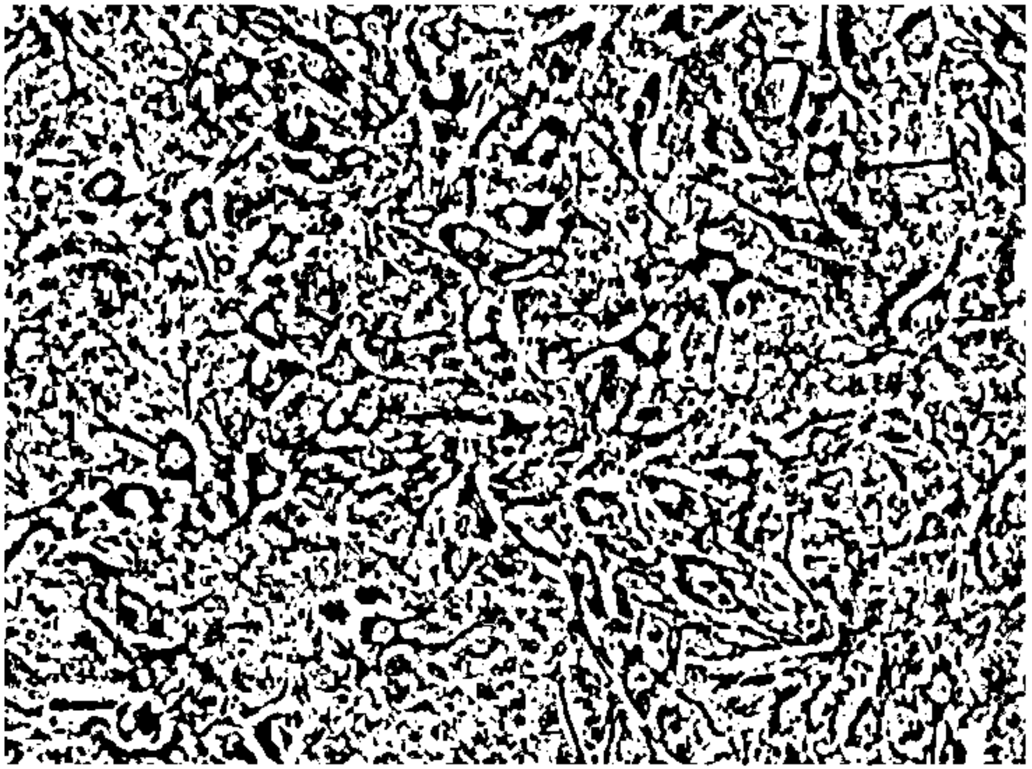
Adaptive thresholding



- local thresholds as mean
- thresholding correctly detects the edges of the cell
- fails in areas without cells



some cells manually highlighted



Adaptive thresholding - additional threshold

- to reject the background pixels where there is no variation of intensity, introduces an **additional global threshold C** of little value (to raise the bar - it is harder to turn the pixel to the object):

$$I(x,y) > local\_treshold + \mathbf{C} \Rightarrow (x,y) \in \text{„object”}$$
$$\text{otherwise} \Rightarrow (x,y) \in \text{„background”}$$

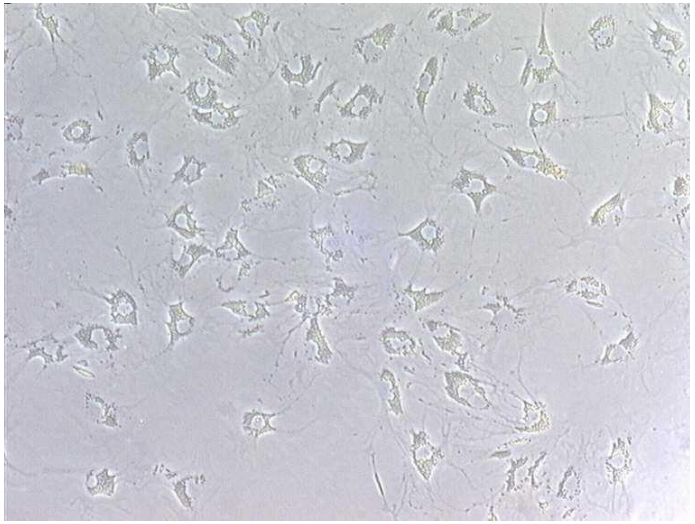
- in uniform areas all pixels has intensity close to average - increased by **C** threshold total reject them

- in the case of presence of the brighter object it will be less than the brightness of the object and more from the background - a relatively small value of **C** will not affect the segmentation of the object

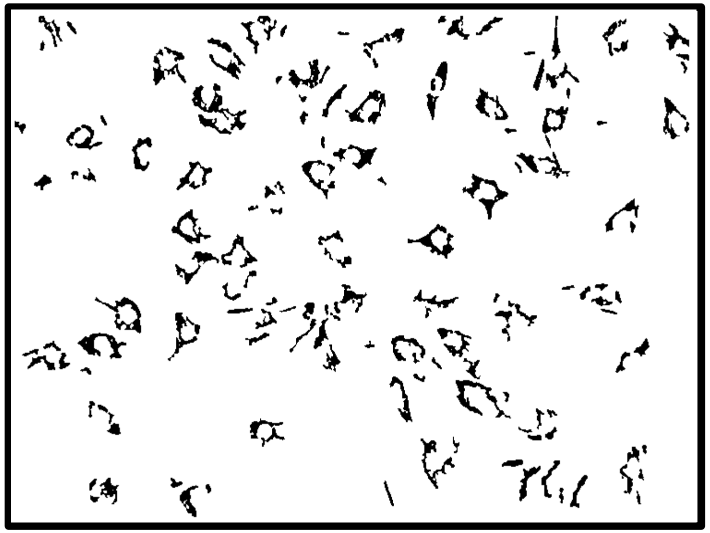
- application: one type of object with a unique intensity (method will not work for multiple objects in the image)

- size of the counting area the local threshold and object must ensure that no areas will be completely contained inside the object

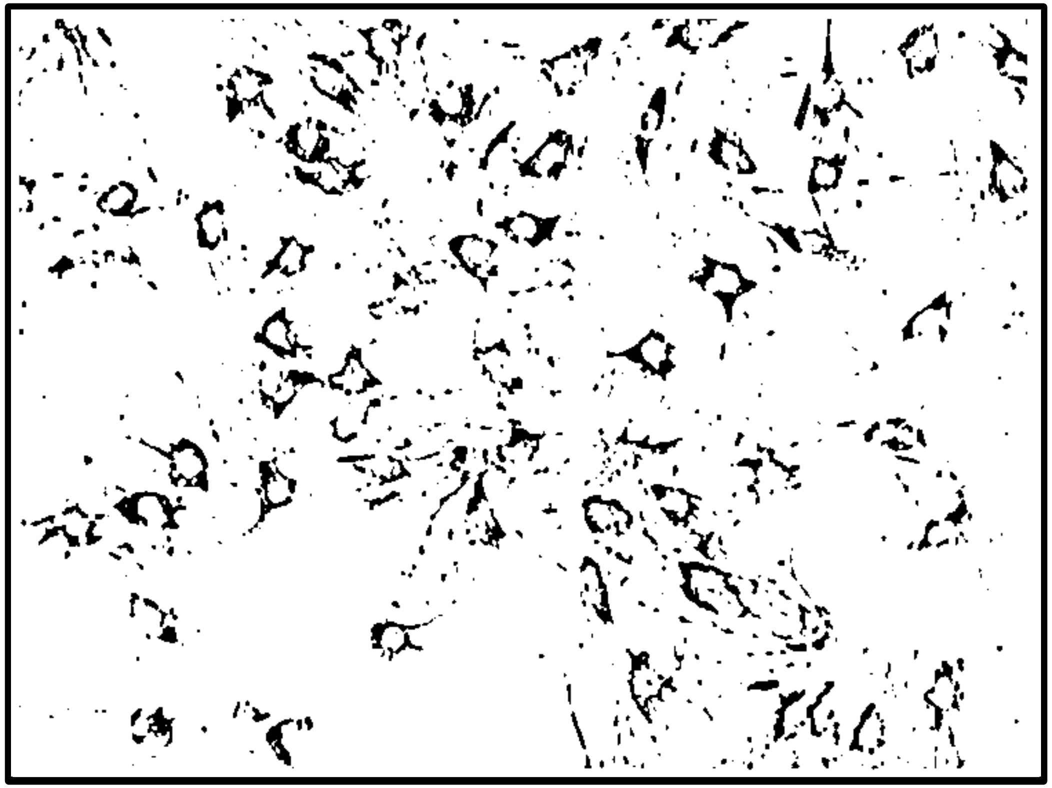
Adaptive thresholding



- local thresholds as mean
- introduced additional threshold **C** will reject background
- choice **C** is interactive



after the removal of the smallest groups



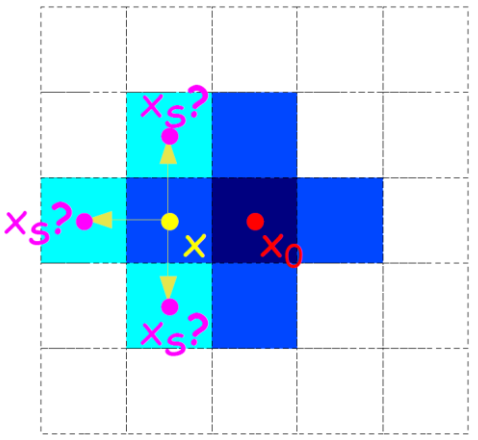
Region growing

- thresholding does not use information about the location of pixels
- **region growing** can be regarded as the addition of an analysis location **(neighborhood)** to **thresholding** technique
- in addition to the criterion of adequate intensity of a pixel belongs to the object must be adjacent to the corresponding pixels - already counted to object
- method requiring a two input parameters:
    - initial object (*which successively grows*), usually in the form of the starting point (seed point): the manual choice, interactive or other analysis stage
    - criterion for adding new points
- local method - not all the pixels are analyzed! (disadvantage and advantage)
- similar to the techniques of computer graphics: *flood fill*

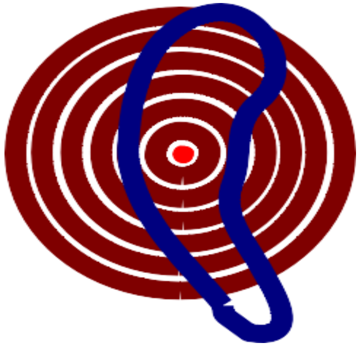
Procedure growth area

- input parameter: the starting point $\mathbf{x_0}$
- auxiliary data structure: a stack **S** pixels

```
S.push (x0);
mark_as_visited (x0); object.add (x0);
while (! S.empty ()) {
        x = S.top (); S.pop ();
        foreach (xs: unvisited_neighbor (x) {
                mark_as_visited (xs);
                if (inclusion_criteria (object, xs)) {
                    object.add (xs);
                        S.push (xs);
                }
        }
}
```

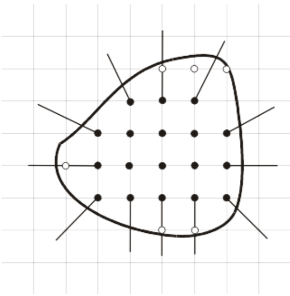


- can use software stack (recursion), but this is inefficient
- instead of the stack (FILO, LIFO), you can use a FIFO queue - the end result is usually the same (exception: changed dynamically inclusion criterion) but different sequence of inclusion pixels (from the inside)
- different defining the neighborhood: 4, 8, hexagonal grid



Criteria for inclusion of pixels

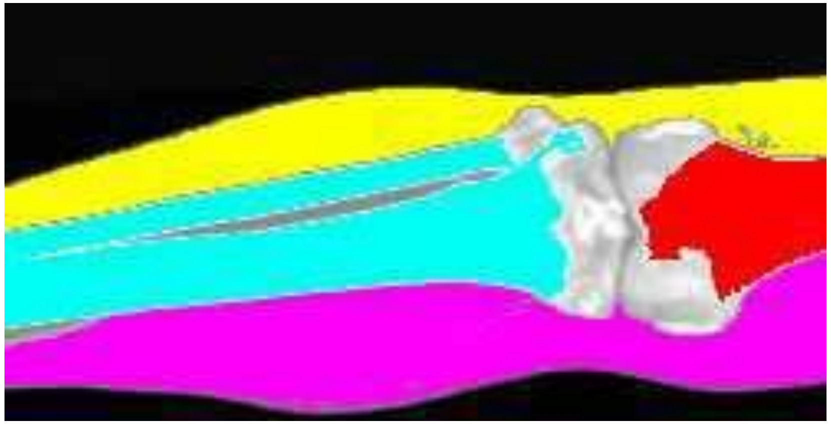
- static criteria:
  - thresholding with a fixed threshold
  - including pixels with low value of amplitude gradient
  - including pixels with a small value of the gradient direction (eg. the direction perpendicular to the current surface of the object)



- dynamic criteria:
  - comparing the intensity of the including pixel with the average intensity of the region (average intensity is calculated after each step / after a fixed number of steps)
  - check whether the inclusion does not change the homogeneity of the area (eg. the excess of the variance of a certain threshold)
    - dependence of the scale - a different weighting of the pixel in the small and large area
  - threshold selection range based on the variance and the average intensity of the initial area (no point)
- the use of other image features than intensity (eg. textural features)

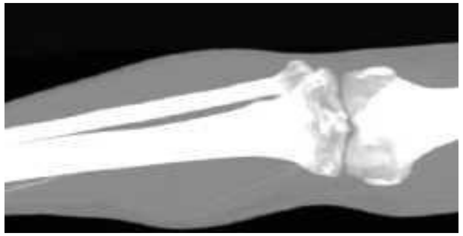
- handing 2 points: the start, and not part of the area

The results of region growing

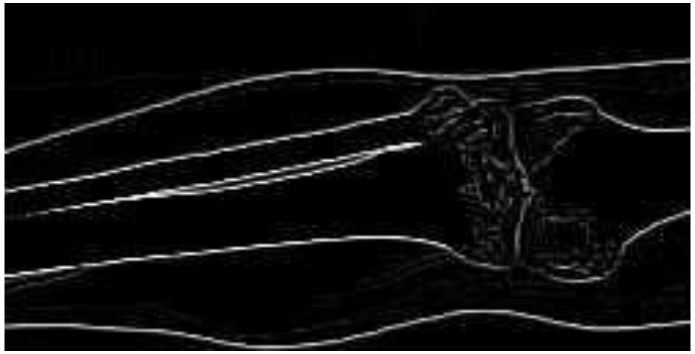


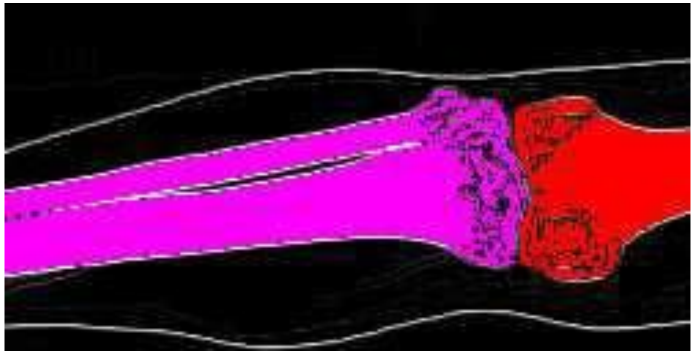
- each color represents a different starting point
- criterion:
  difference intensity of the inculded and the starting pixel below the threshold (sensitivity to the choice of starting point)
- the same objects (tissue) dostomcted as separate if they are not connected on the image
- areas of diffrent intensity (cartilage) dose not distinncted

The results of region growing



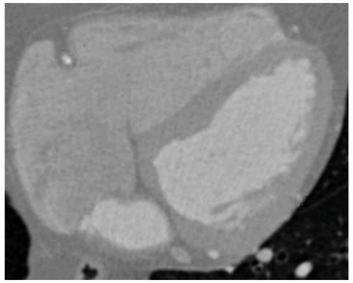
the amplitude of the gradient of the image



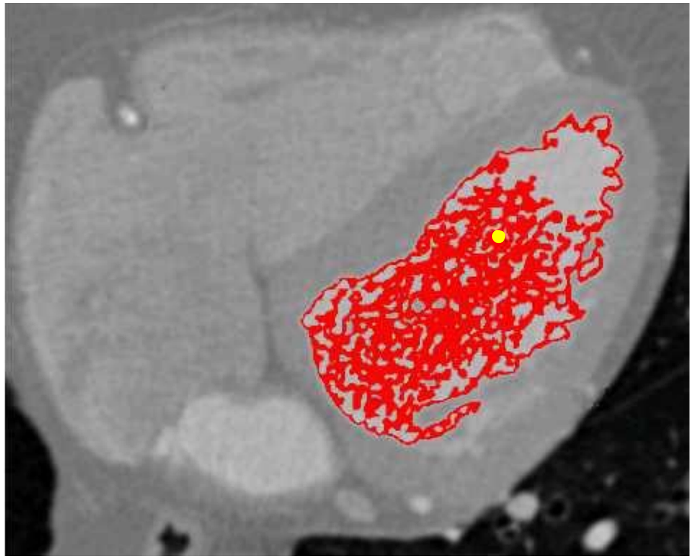


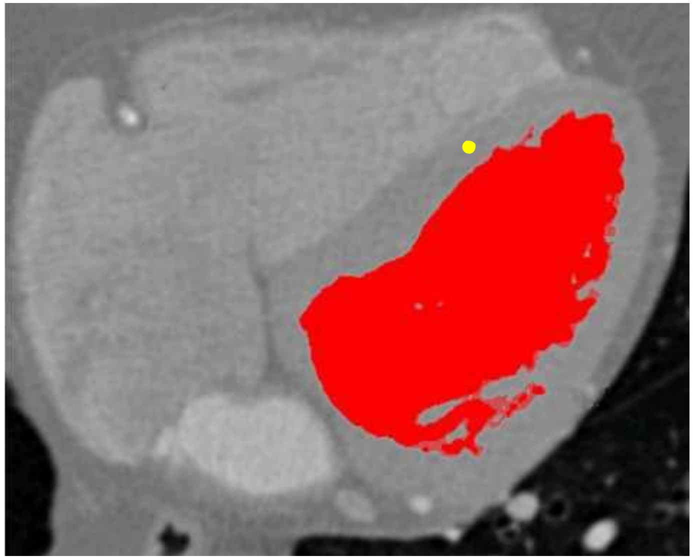
- criterion:
  including pixels with low gradient values
- areas of variable intensity (cartilage) partially included
- need a clear boundary to the algorithm "has not excape"

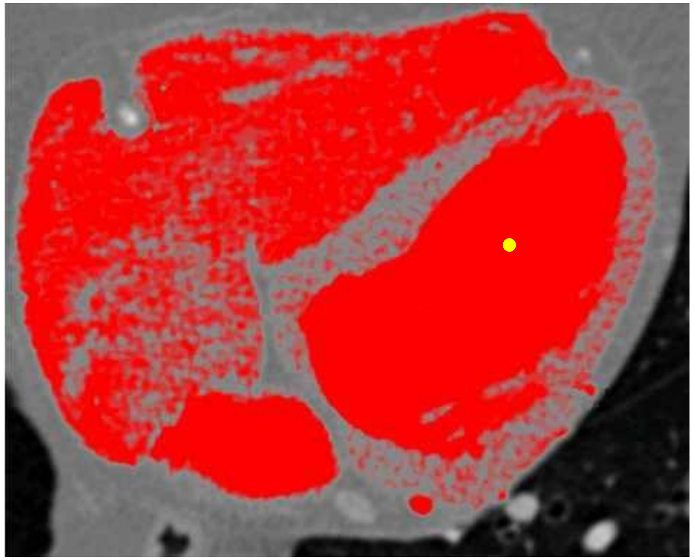
The results of region growing



criterion (thresholding) too selective

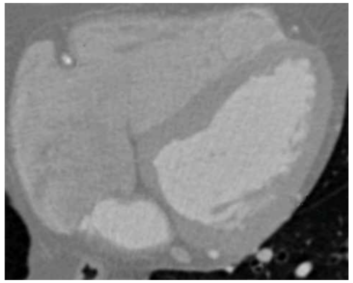




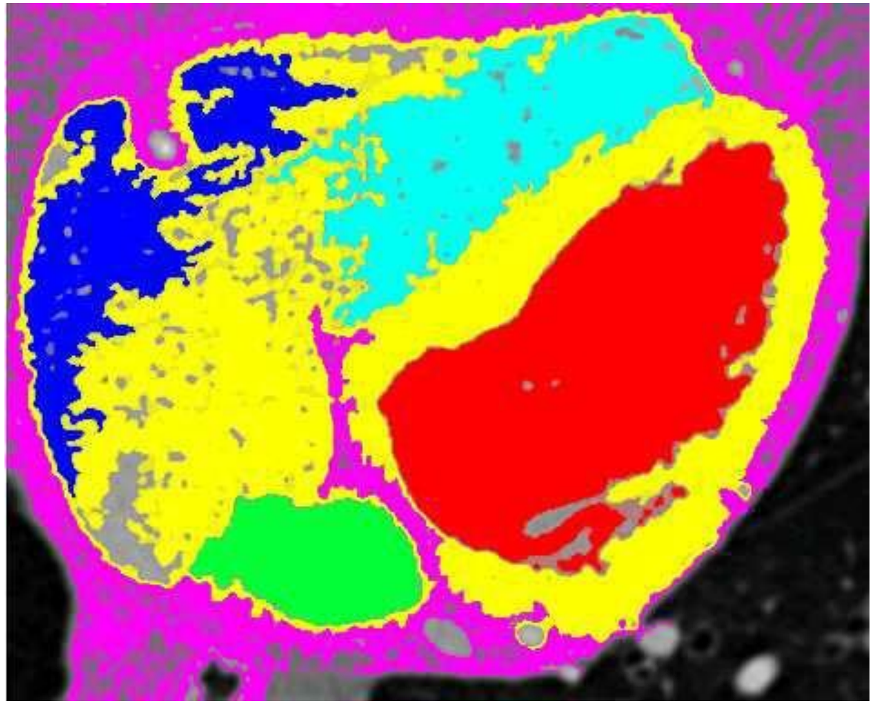


criterion (thresholding) too liberal

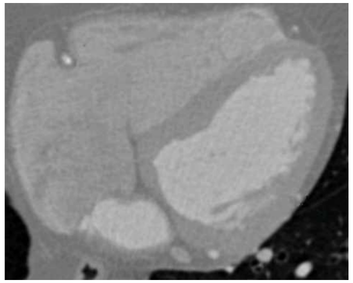
The results of region growing



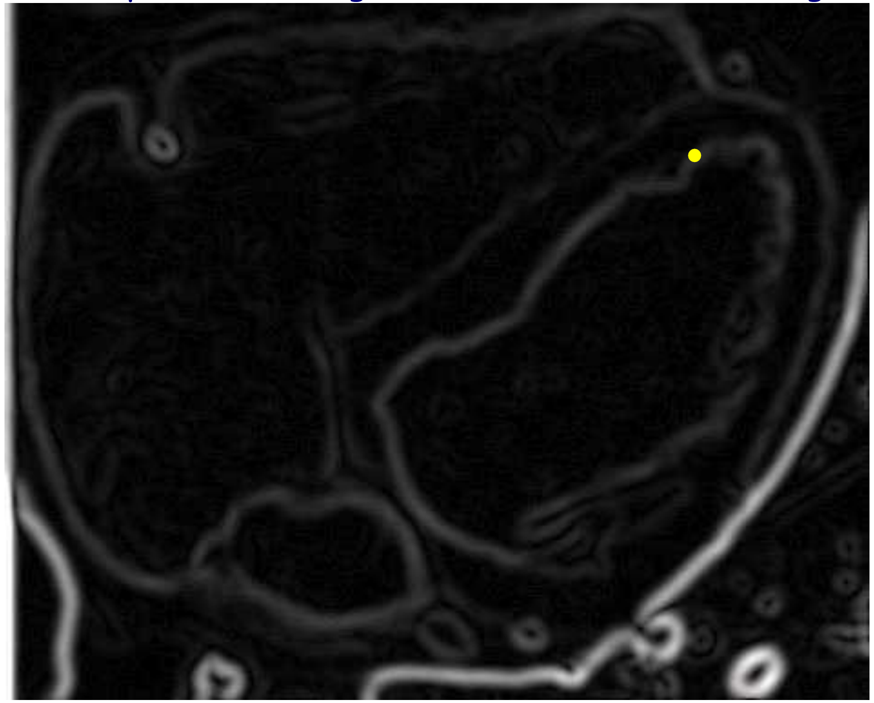
- each color represents a different starting point
- criterion:
  difference of included pixel and starting pixel below the threshold (sensitivity to the choice of starting point)
- high level of noise causes „jagged" boundaries

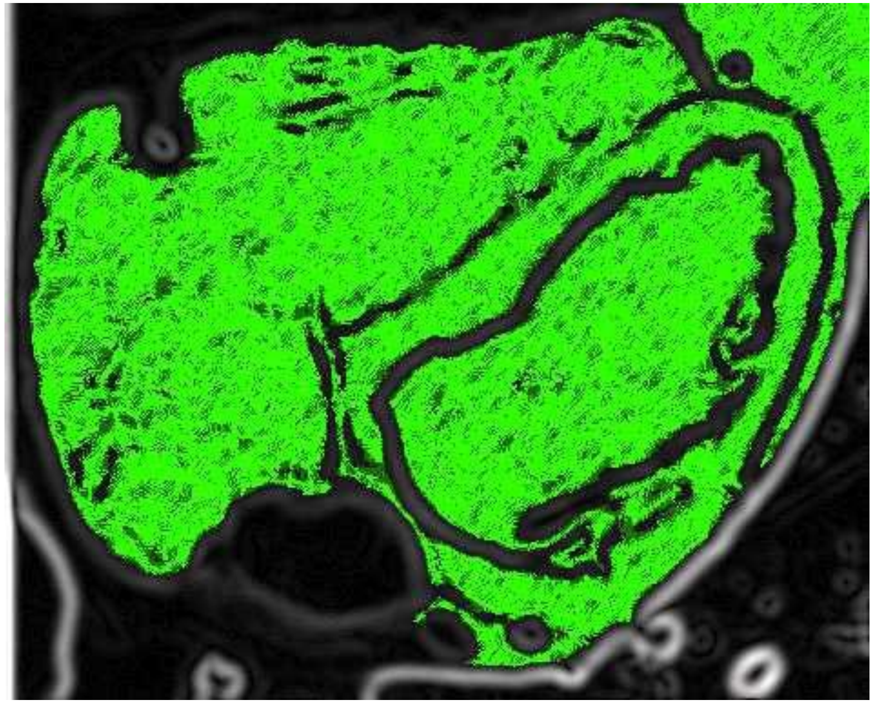


The results of region growing



the amplitude of the gradient of the smoothed image





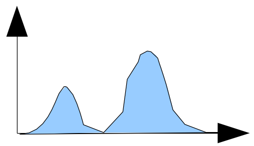
- inclusion criteria: low amplitude gradient
- „spill" algorithm as a result of the weak edge

Split & merge

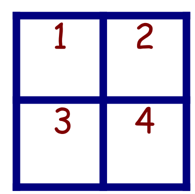
- **growth area** is the interactive algorithm - requires the administration of the starting points - you can do it successively until full coverage of the image with distinncted areas
- **split and merge** algorithm does this automatically - after using each pixel is assigned the label area
- an algorithm based on a similarity of areas
- global algorithm - the whole image is processed
- 2 phase of the algorithm:
    - recursive division of the coherent (uniform) areas
    - grouping of similar areas

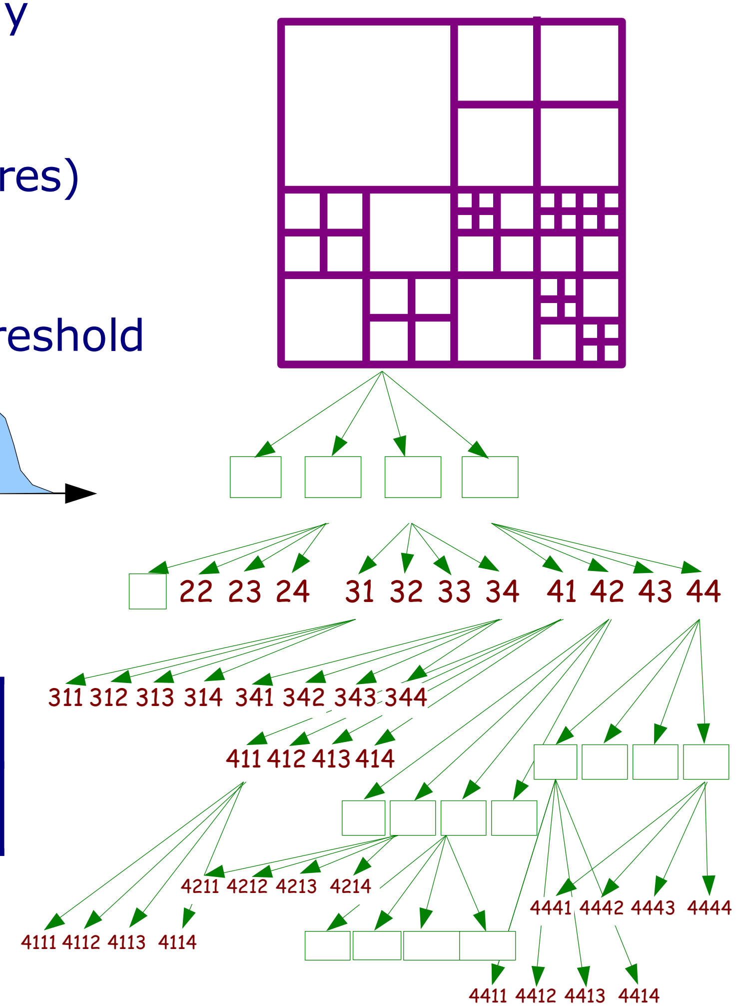
Division phase

- picture, initially treated as one area is recursively divided into smaller and smaller areas
- frequently divided into 4 equal rectangles (squares)
- division criteria:
  - the variance of the area above a certain threshold
  - histogram area is multimodal



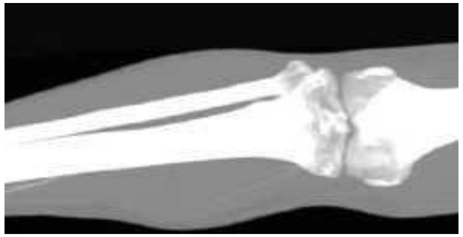
- you can allow the division to the size of the area = 1 piksel or establish minimum area not already subject to division
- crucial for the performance of the algorithm representation of the divided areas
  - Numbering areas numbers on the following decimal positions
  - quad trees

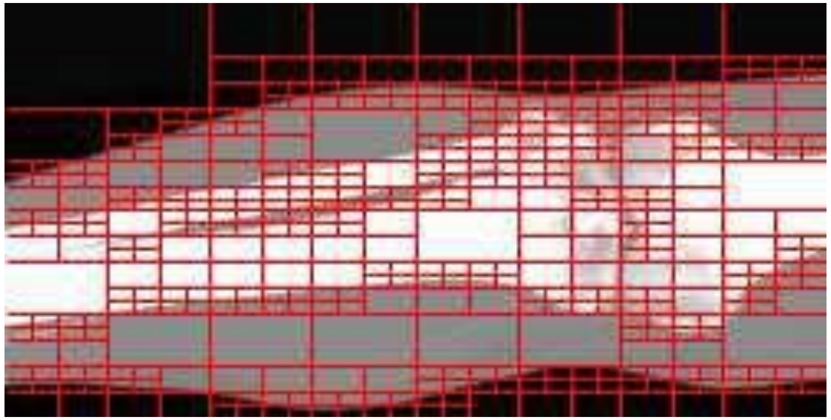




Examples of division

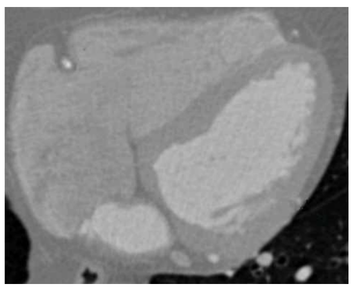
- area is divided into four parts if the variance exceeds the threshold
- the minimum height of the area - 5 pixels
- uniform areas shall not be divisible
- many small areas formed at the borders of objects
- better divided into too many areas than too little areas

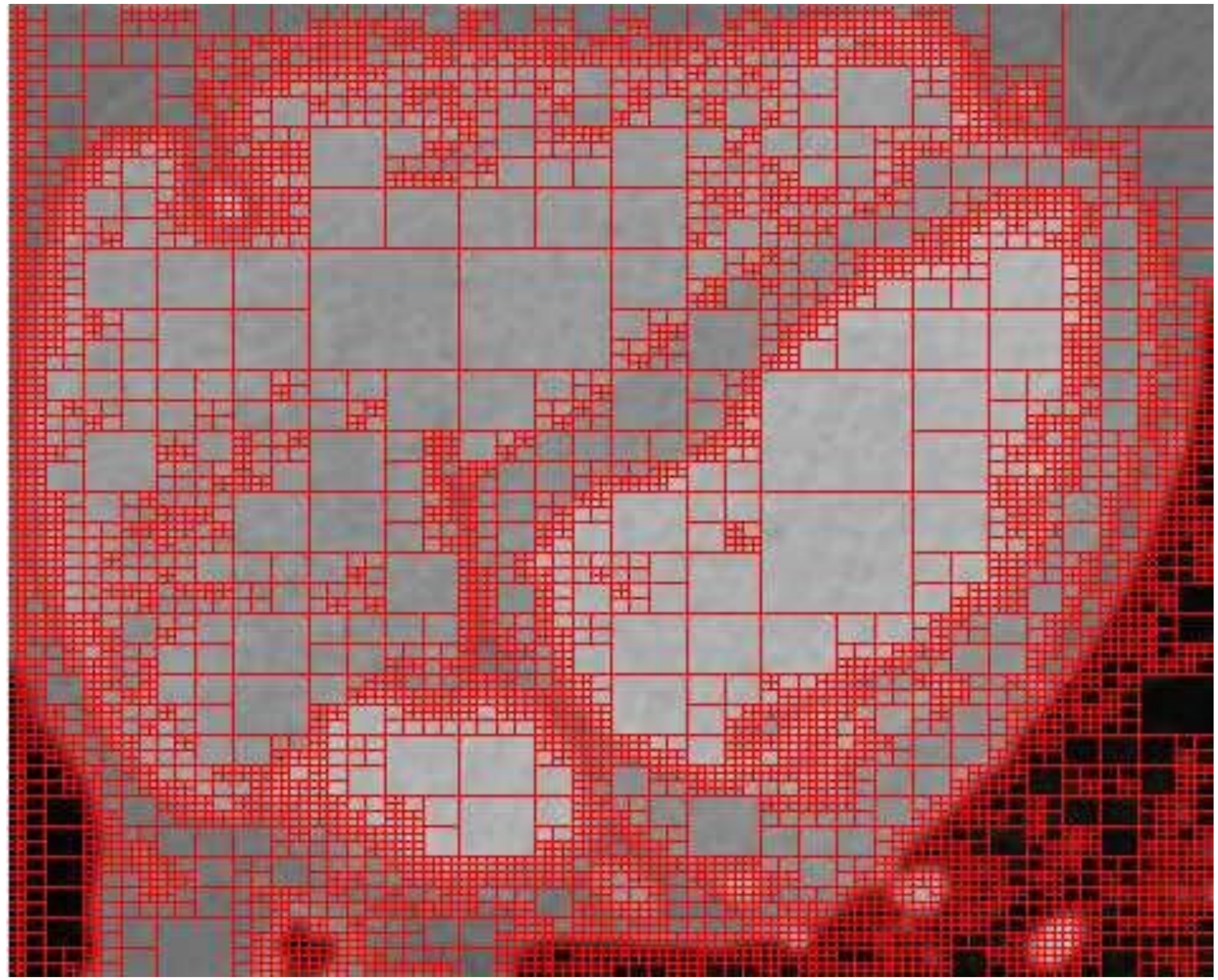




variance threshold of 0.005, the intensity of pixels in the range of <0,1>

Examples of division



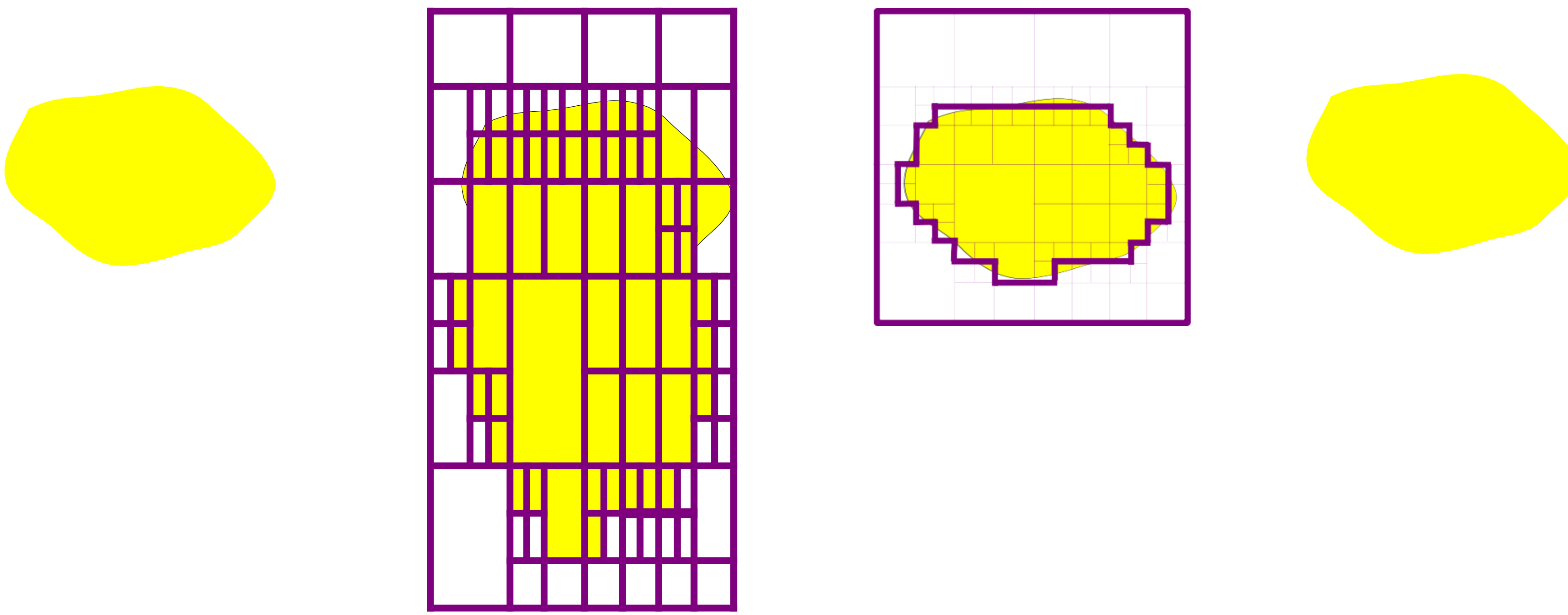


variance threshold: 0.00025, the minimum size of the area: 3 pixels

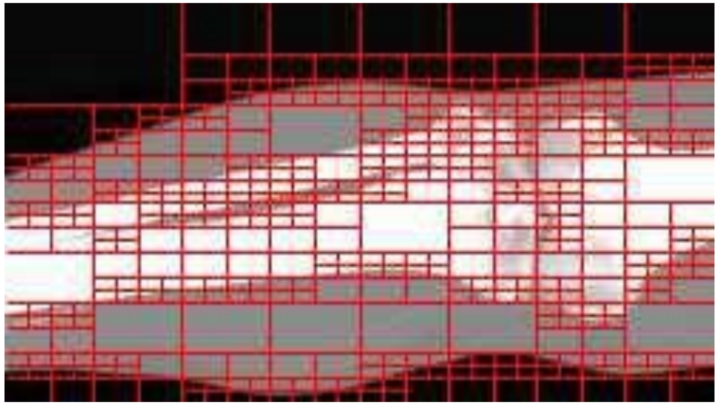
Phase merger

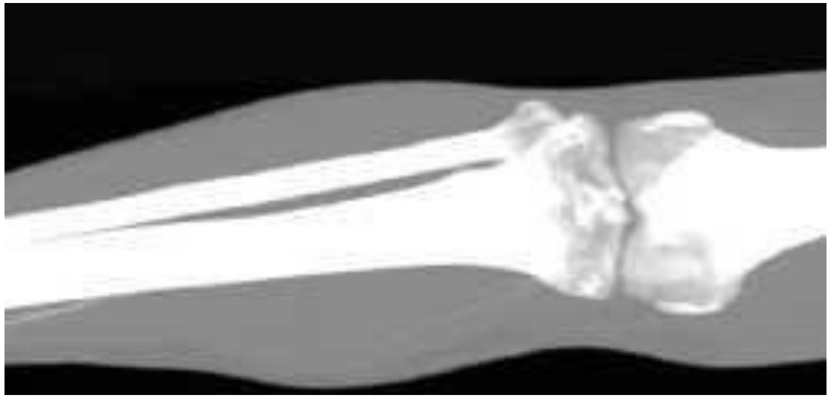
- areas are already (relatively) uniform
- some neighbouring areas are similar to each other (eg. 2 subareas one or two neighbouring are uniform)
- **neighbouring** subareas combined, if they qualify the **criterion of merger:**
  - approximates the average intensity
  - area after junction does not exceed qualify of the criterion of division:
    - histogram is unimodal
    - variancy does not exceed the threshold
  - edge between areas has not high gradient (criterion very resistant to noise)
  - procedure for finding neighboring areas can be complex

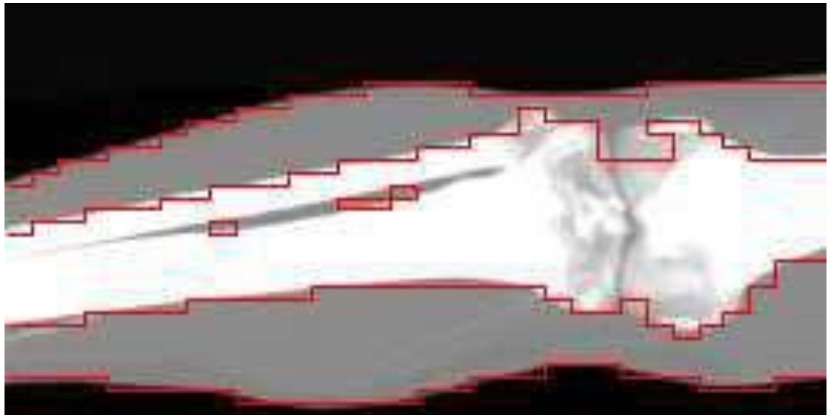
Phase merger



Examples of merging



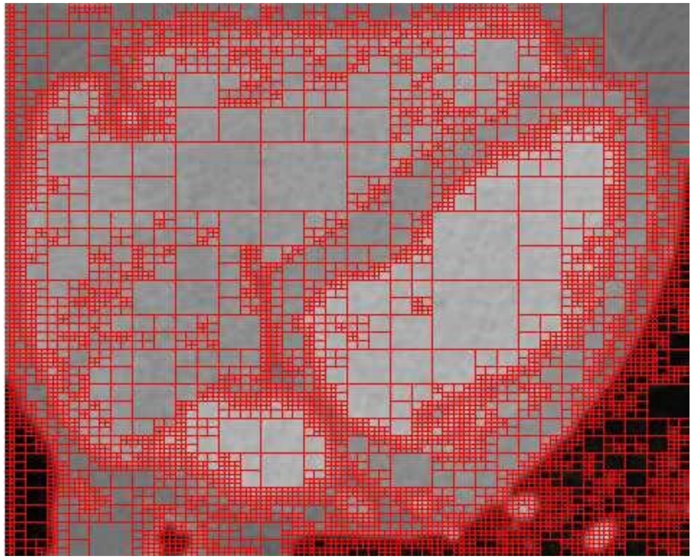




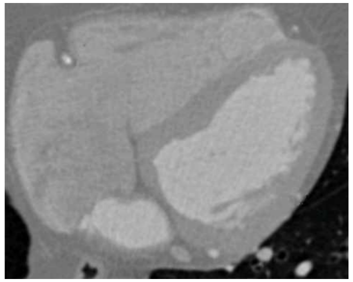
- areas of one tissue combined
- due to the limited spatial resolution (minimum size of areas)
  - edge is broken
  - small sub areas are not identified

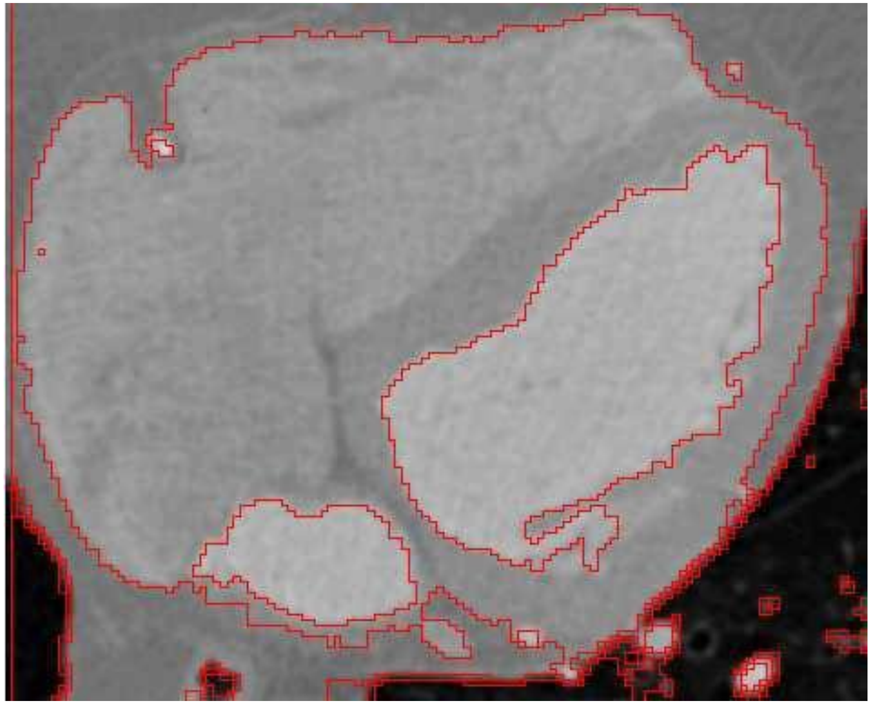
merging criterion: the difference medium brightness below 0.25

Examples of merging



- correctly localized tissue boundaries
- smaller area of the minimum division results in less "broken" boundaries
- much longer phase merging due to a number of areas
- sensitivity to merging parameter
- on the border of unconnected areas





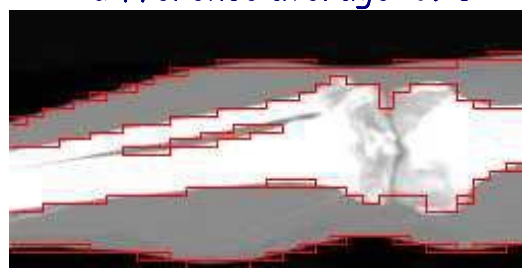
connecting criterion: the difference medium brightness below 0.07

The sensitivity of the phase to connect to the parameter

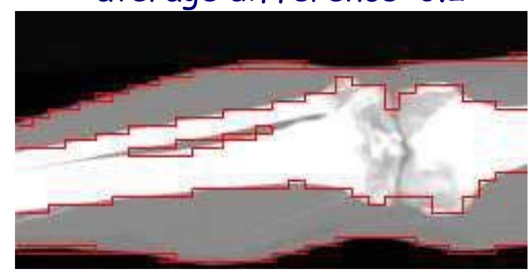
- unsuitable criterion of marging results in too many or too few resulting images
- but sometimes there is no clear answer: what is already another area and what is still the same area (the area of the knee)

average difference: 0.1

difference average: 0.15



average difference: 0.2

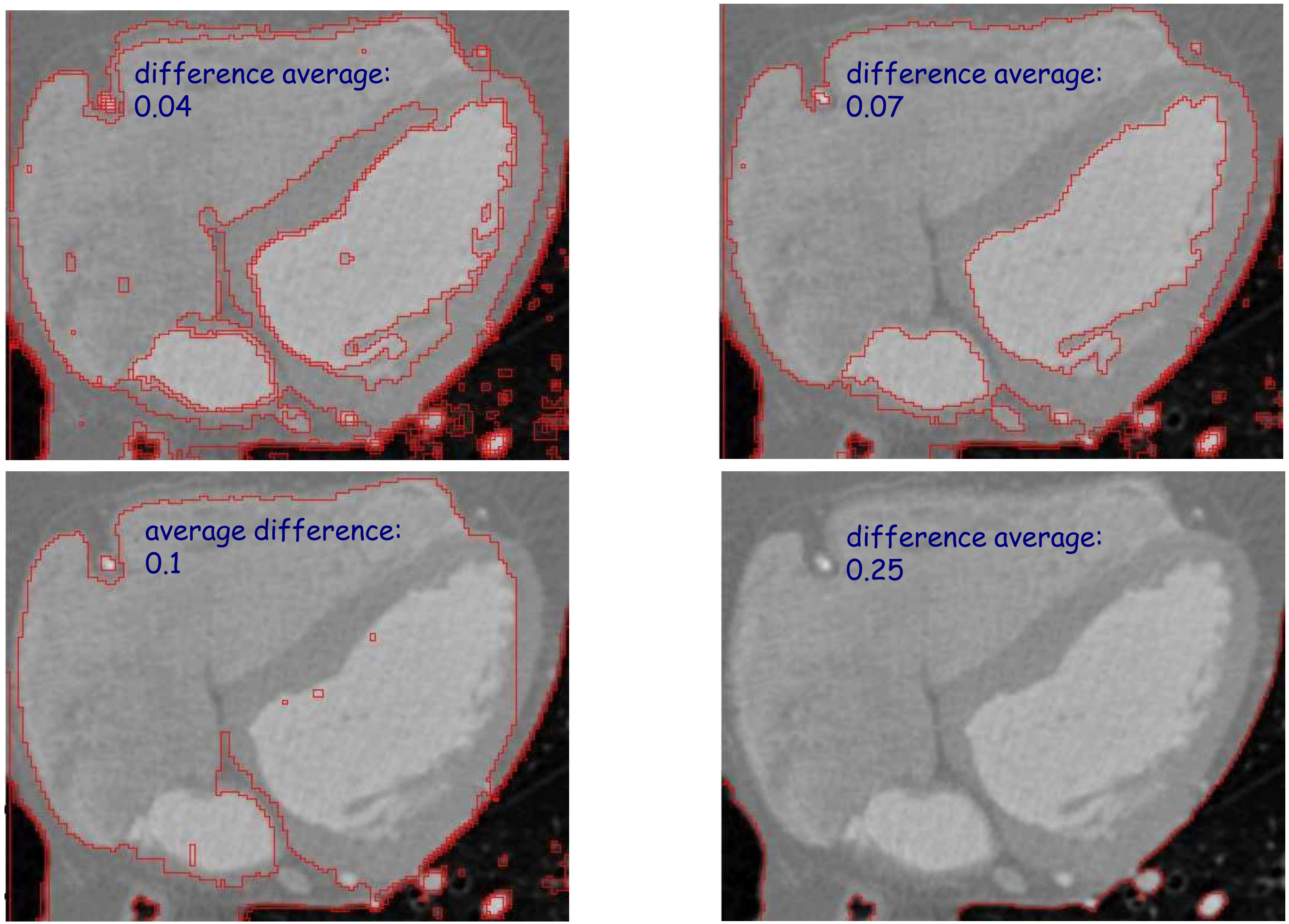


difference average: 0.25

average difference: 0.3

difference average: 0.35

The sensitivity of the phase to connect to the parameter



Summary split and merge algorithm

- you can define a different strategy division:
  - to areas close to a square: independence from the rectangeness image
  - 2 sub areas resulting thresholding, for example adaptation
    - Accurate mapping of shape of the object, without blocks
    - difficult areas such representation

- automatic determination of the number of objects

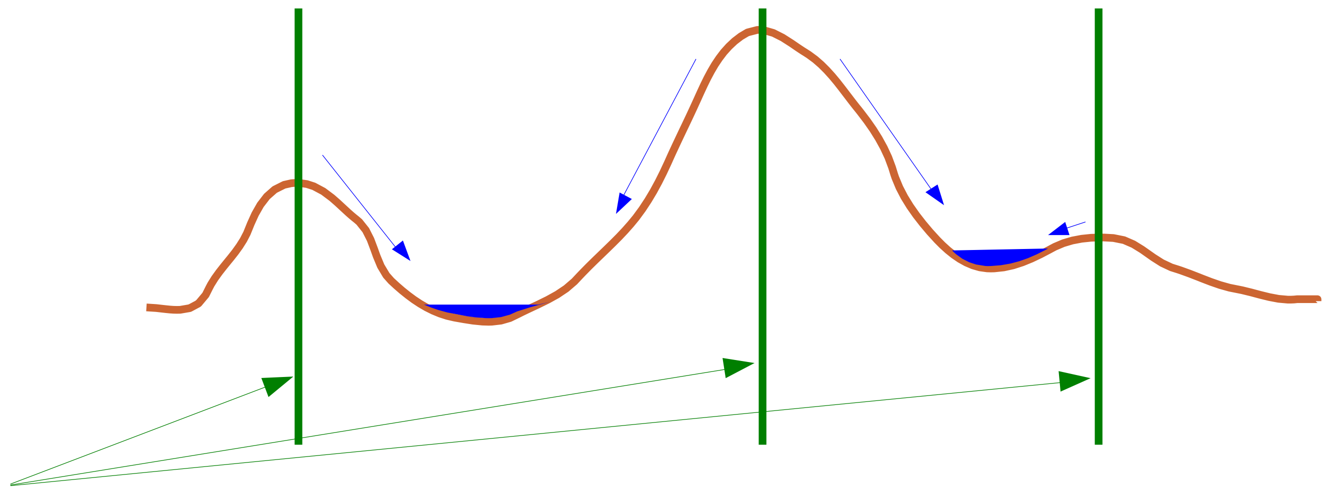
- sensitivity to the selection of parameters

- high computational complexity and time (especially connections connections)

Watershed segmentation

- Method edge segmentation (if based on the gradient)
- derived from mathematical morphology
- draws from geography - the theory of river watershed
- can automatically choose the number of separate objects or allow you to specify the number of the operator
- segmentation process is the same with the water watershed higher regions

Watershed, catchment basin

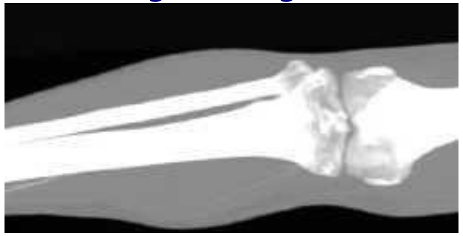


- **watershed** is the line of separation between the catchment basin areas - the areas from which rainwater flows into a common river or a water reservoir
- watersheds lie on the **ridges** function of altitude of area
- ridge is a point which is not full maximum but a peak in at least one direction (in N-1 dimensions)
    - are the points of maximum in the case of 1D functions (local maxima)
    - are lines for 2D functions (actual shape of terrain)
    - are surfaces for 3D functions
- areas (point) where the waters flow from the catchment basin lie at **minima** function of altitude

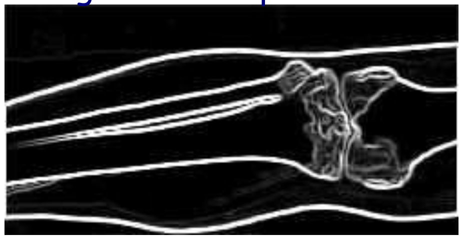
The concept of watershed segmentation

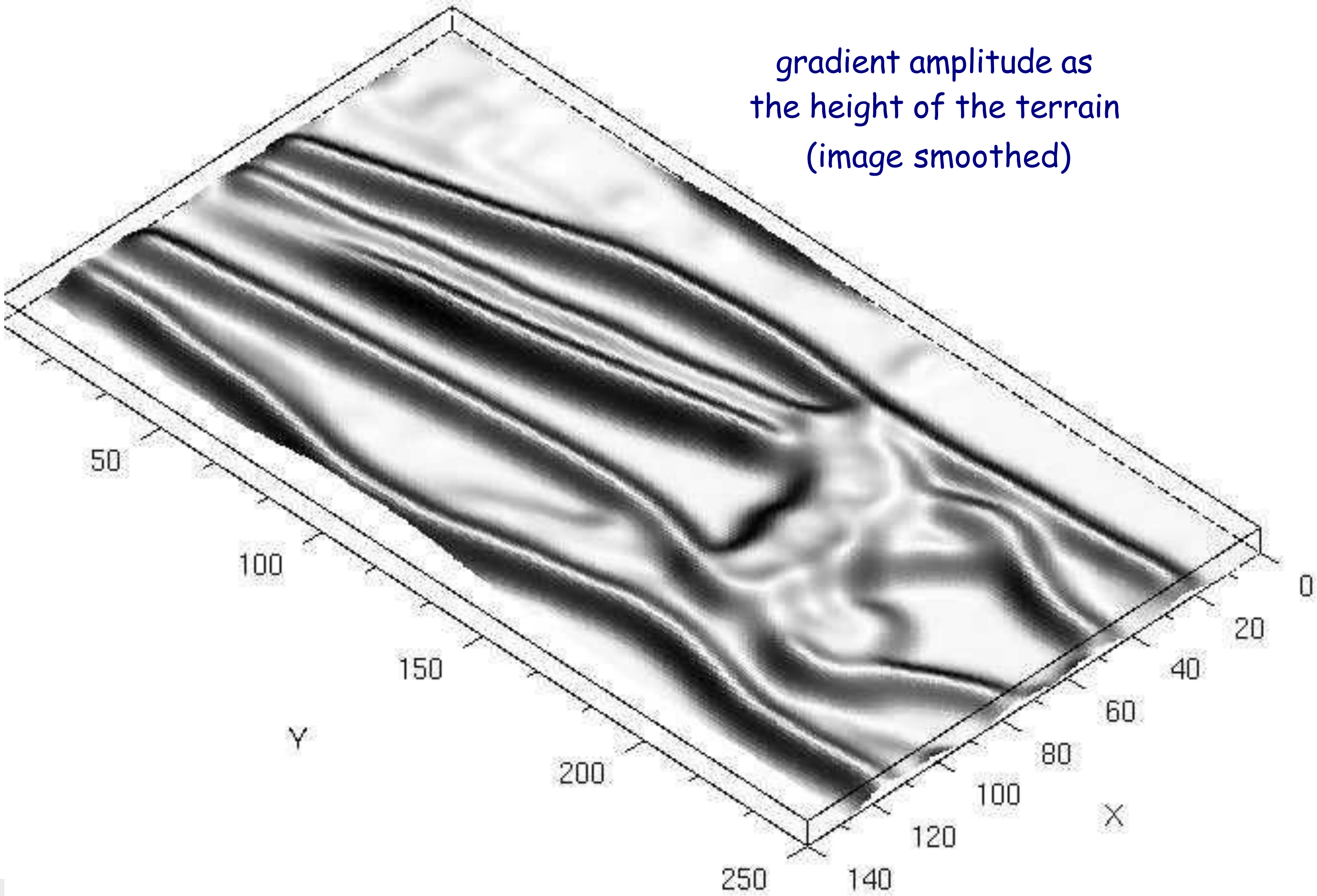
- as the height of the terrain in image segmentation is most assume **gradient amplitude** of image or (rarely) only image **intensity**
- the watershed and the **ridges** of these functions

original image



gradient amplitude



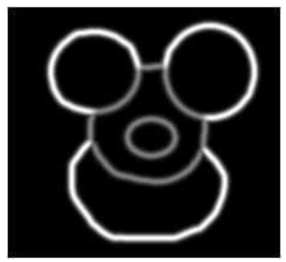


gradient amplitude as the height of the terrain (image smoothed)

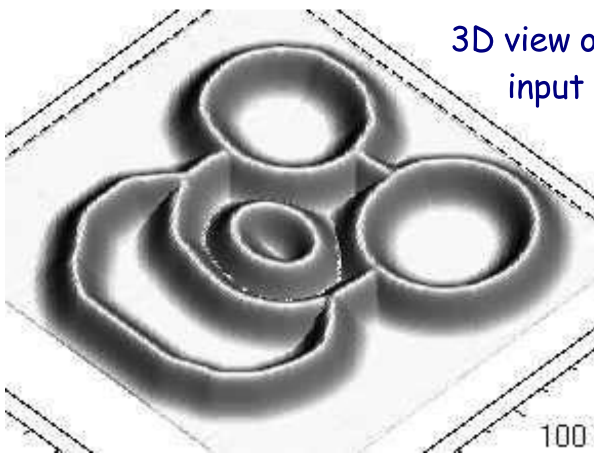
Watershed segmentation, approach based on rainfall

- on the input image is calculated gradient
- because the input image is mostly already processed by calculating the gradient amplitude, the original image, it is a gradient of the gradient

original image



the input image (gradient amplitude)



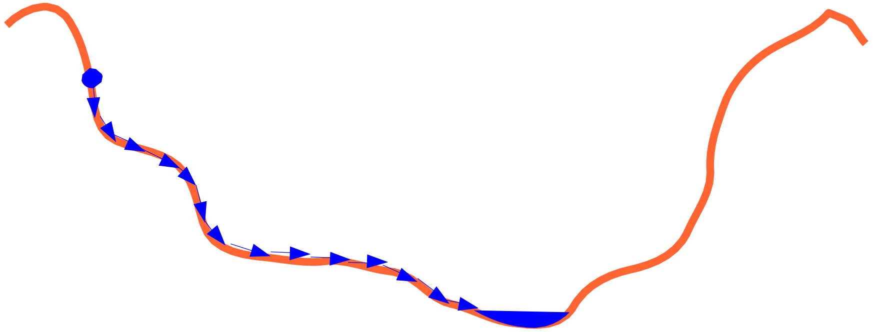
3D view of the input image

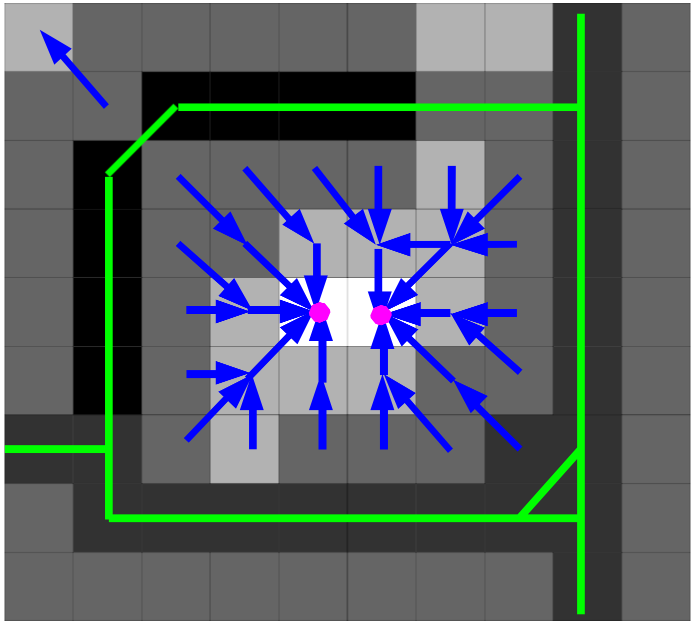
gradient amplitude of the gradient of the original image

Watershed segmentation, approach based on rainfall

- from each pixel is calculated route to a local minimum
- this road runs contrary to the directions of the local gradient
- all the pixels of which the road goes to the same local minimum are included in one catchment basin

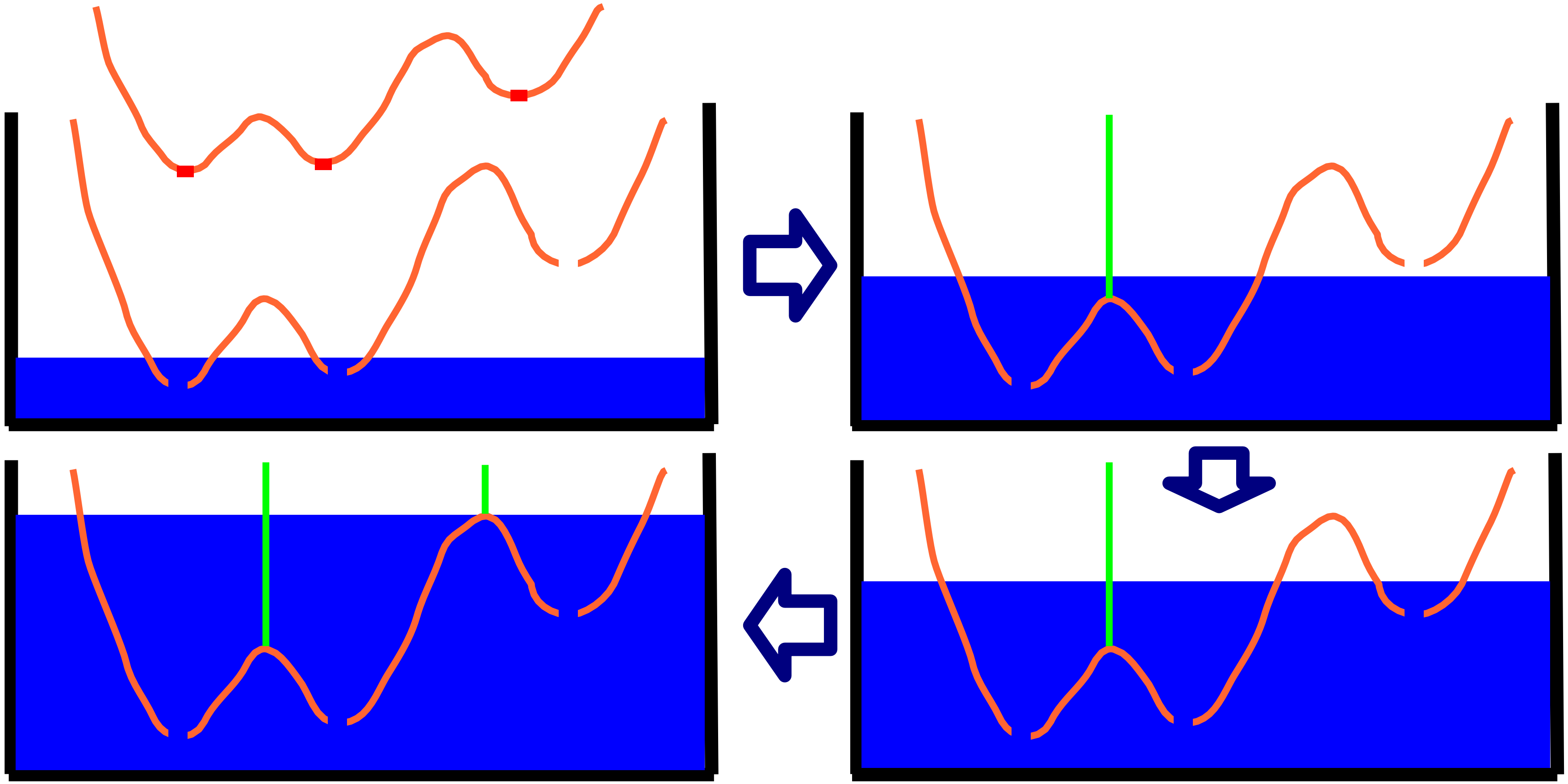
- define the boundaries between catchment basin and watershed - the result of segmentation (segmented contours of the object)





- minima areas may be flat, it may hinder their identification
- in the case of 2D discrete (digital image) direction of the gradient determines which of the 8 (4) of neighboring pixels „flowing rainwater"

Watershed segmentation, approach based on sinking



- in the area are found local minima
- "Drilled" in this place the hole insurface of the „terrain"
- whole "area" gradually immersed in water
- in places where the water from the two holes comes into contact, puts a "dam" defining watershed

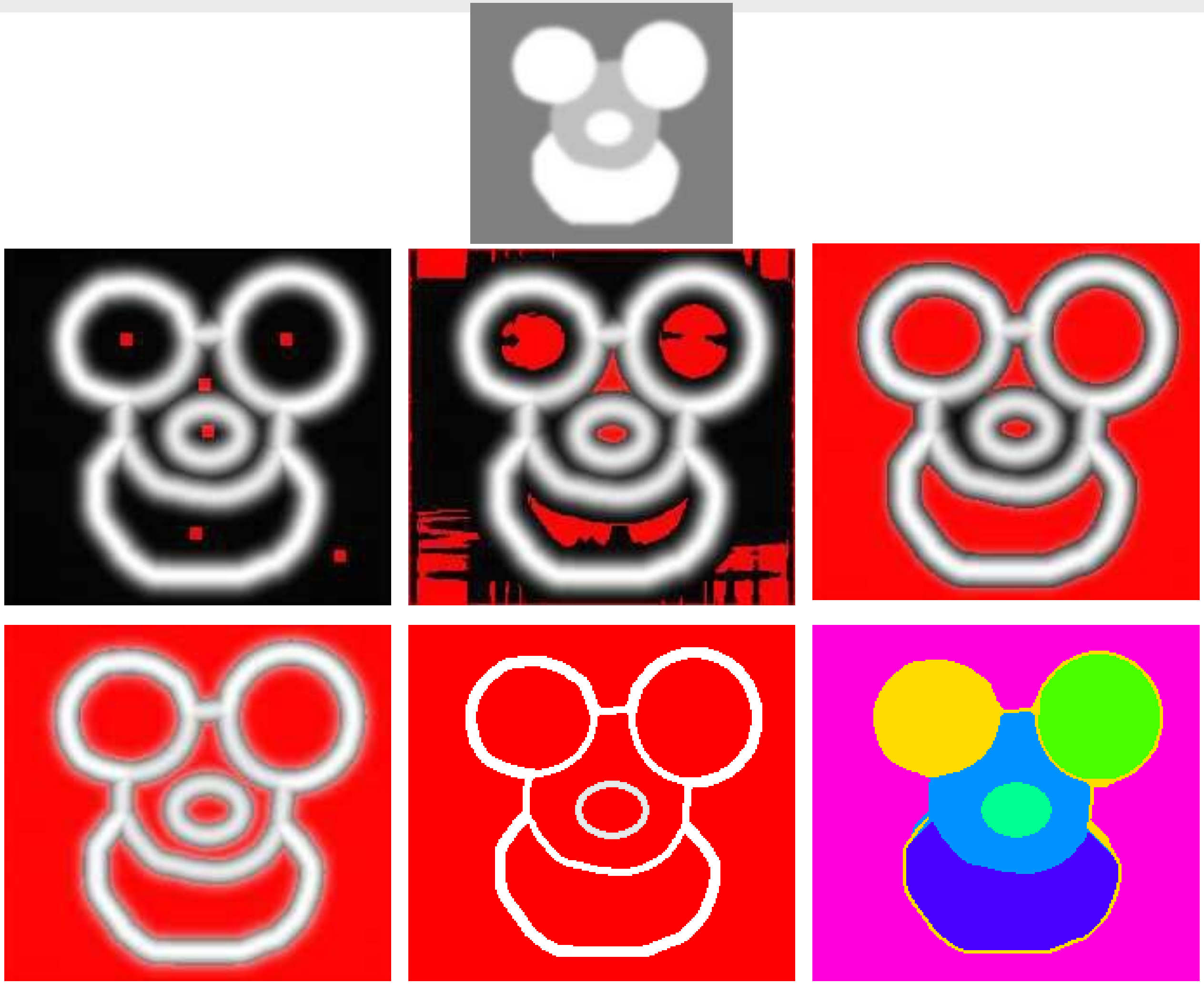
Watershed segmentation algorithm (flooding)

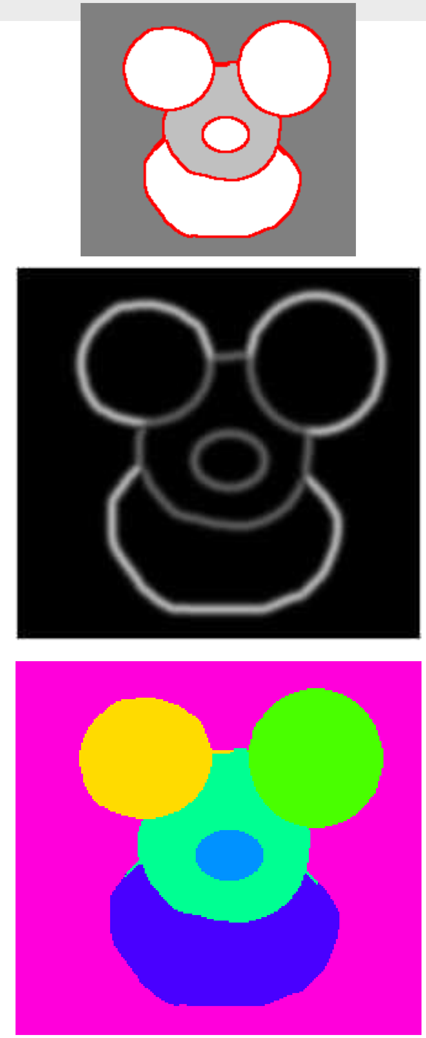
- based on region growing algorithm
- high complexity (but the ability to optimize)

```
1. designate local minima as the initial catchment basin Z
2. organize them by increasing levels of intensity: Z0, Z1, .., ZN
3. for (i = 0; i <N; ++i) // *** equalizing levels catchment basin
    while (not reach the level of water Zi+1)
     // *** All catchment basins Z0, .., Zi, have already the same
     level of water
     for (j = 0; j <= i; ++j)
        - raise the water level Zj by 1
          ie., perform region growing algorithm starting from the area Zj;
            switching criterion: the intensity of the pixels == max
            (I(Zj))+1; including only the pixels not yet included from other
            catchment basins
4. while (not all the pixels included in the catchment basin)
    // *** Even raising the water level in all catchment basins
    for (i = 0; i<N; ++i)
        - Raise the water level Zi 1
          ie., perform region growing algorithm ......
```

- each of the catchment basin receives a different color
- boundaries between colors define watershed (the result of segmentation)

Segmentation by sinking

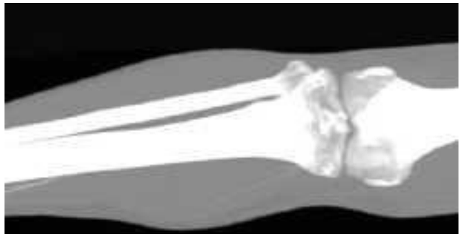


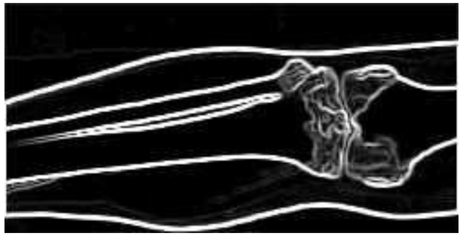


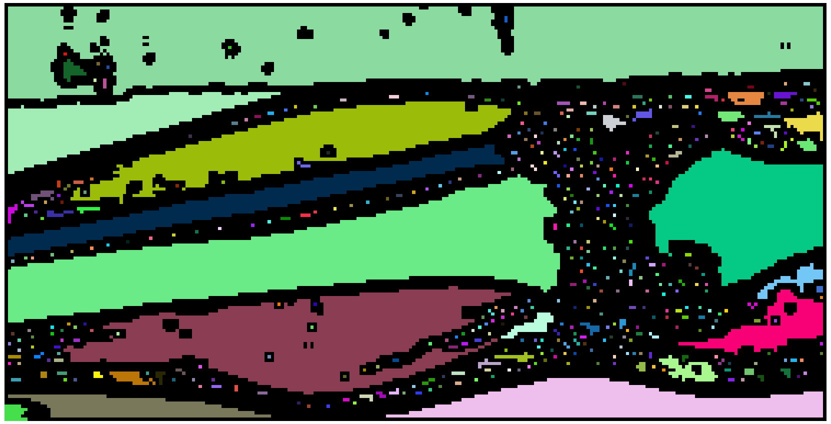
Next phases of watershed segmentation,
image edges (amplitude gradient) has been flattened - are the result of the areola area by another area;
The last image shows the extracted areas

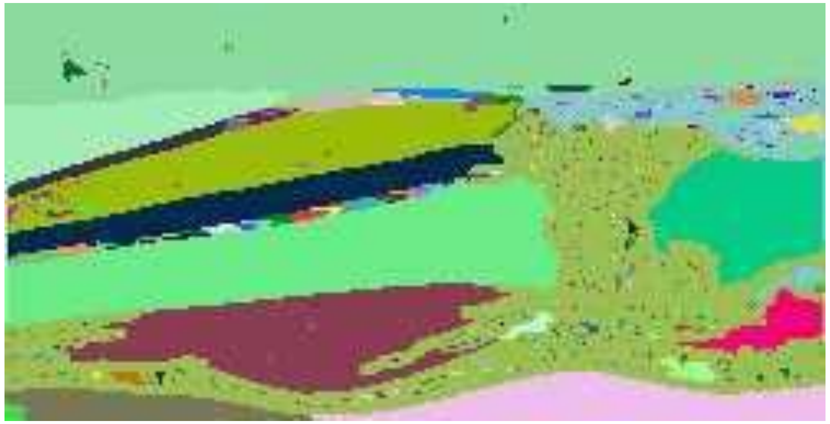
segmentation result using the original amplitude of the gradient

Watershed segmentation of real image


original image

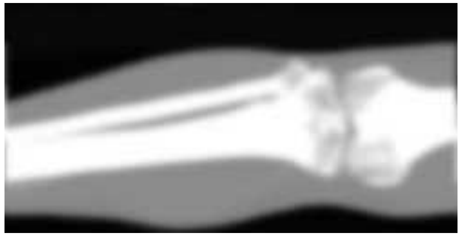

gradient amplitude


calculated local minima (478 minima)

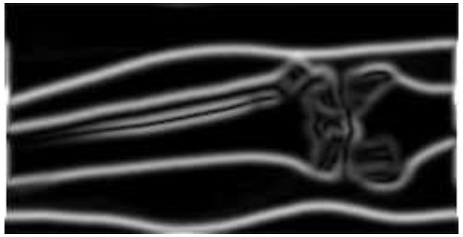

watershed segmentation: 478 areas

- gig numer of local minima lead to fragmented results (oversegmentation)
- segmentation is very long
- areas could be combined, for example by spliting and merging algorithm

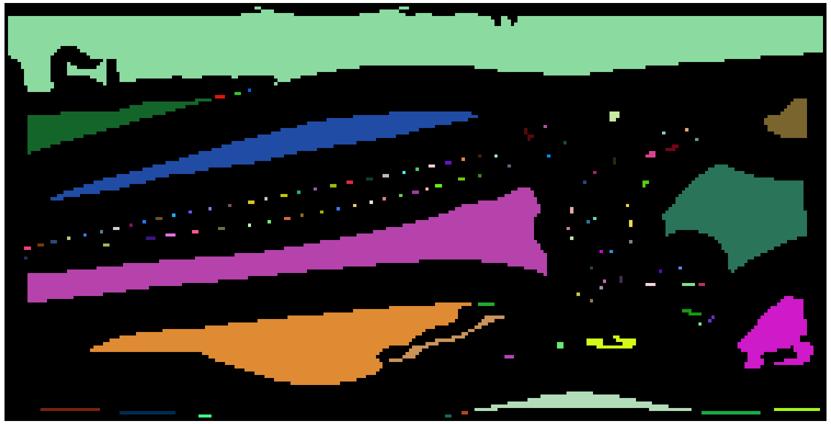
Limiting the number of minima by smoothing



original image after smoothing



gradient amplitude



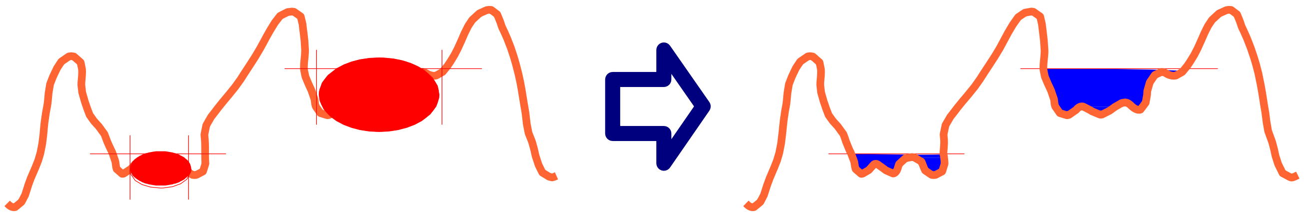
calculated local minima (115 minima)

watershed segmentation 115 areas

- image smoothing reduces the number of local minima
- although it is too much of them (115)
- further smoothing has fallout
  - weakening the edge - the ability to "leak"
  - removing details

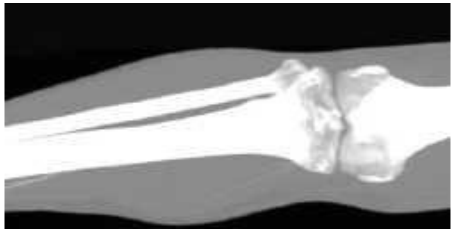
Technique markers

- if you know the number and approximate location of the segmented objects, you can improve the efficiency of watershed segmentation
- on the image are selected markers: areas that lie within the segmented objects
- they replace many local minima
- selection is usually interactive or higher order process

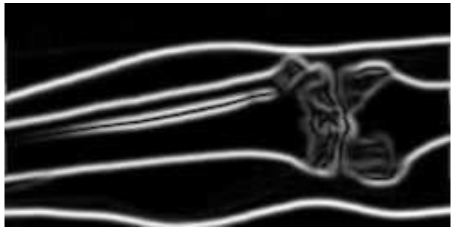


- markers are imidelty "filled with water" to the maximum atlitiud in their area
- further sinking procedure is working normaly
- no longer appear new catchment basin

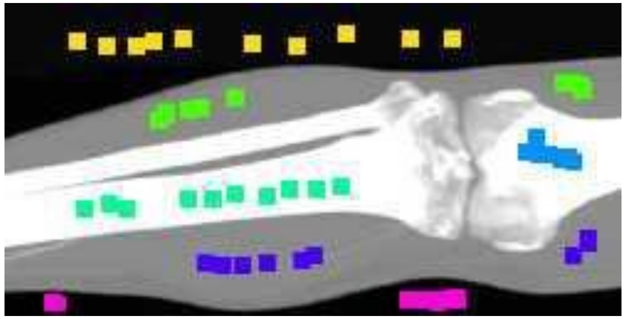
Segmentation using markers



original image



gradient amplitude

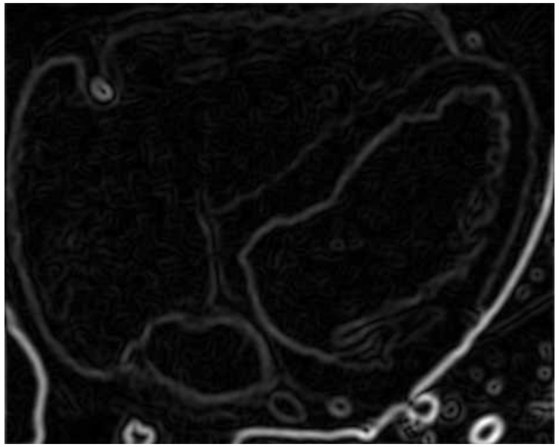


interactively selected markers

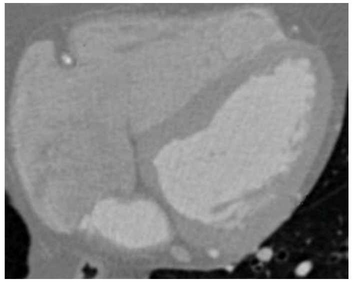
the result of watershed segmentation

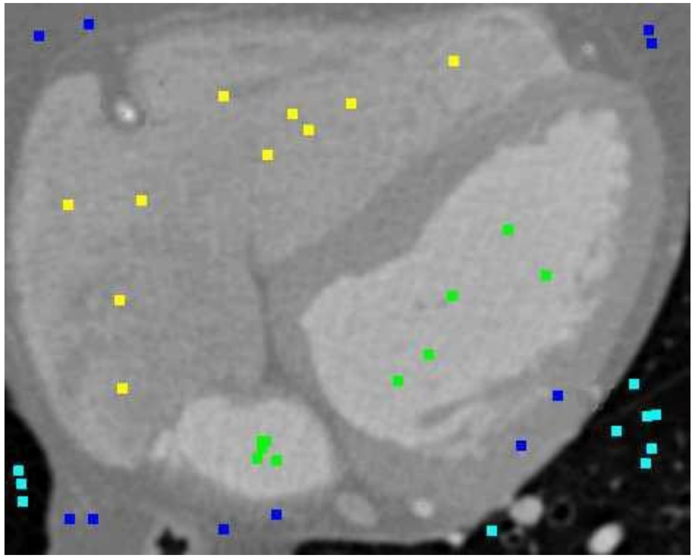
- correct detection of areas with distinct edges
- problems in areas where the edge is blurred
- unselected areas remain undetected

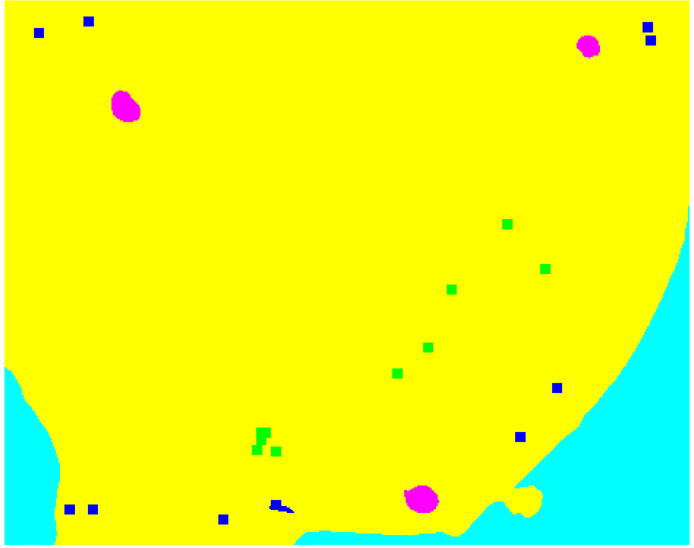
Segmentation using markers


gradient amplitude

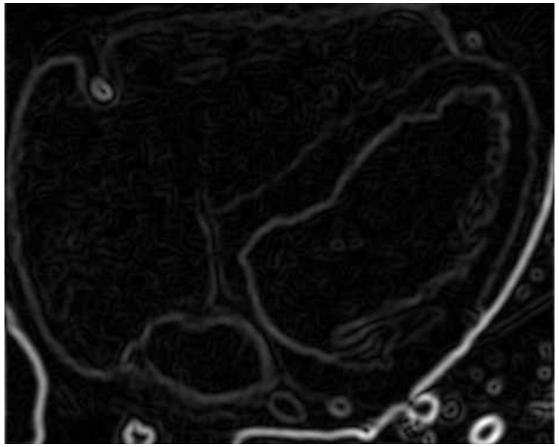
- weak edges cause „sinking" areas of varying intensity
- long time of segmentation


original image


interactively selected markers

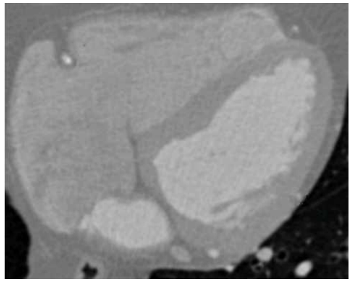

the result of watershed segmentation

Segmentation using markers

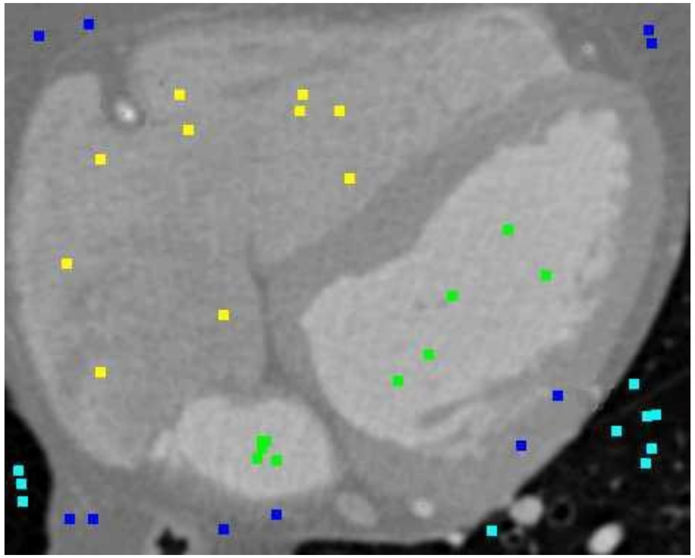


gradient amplitude

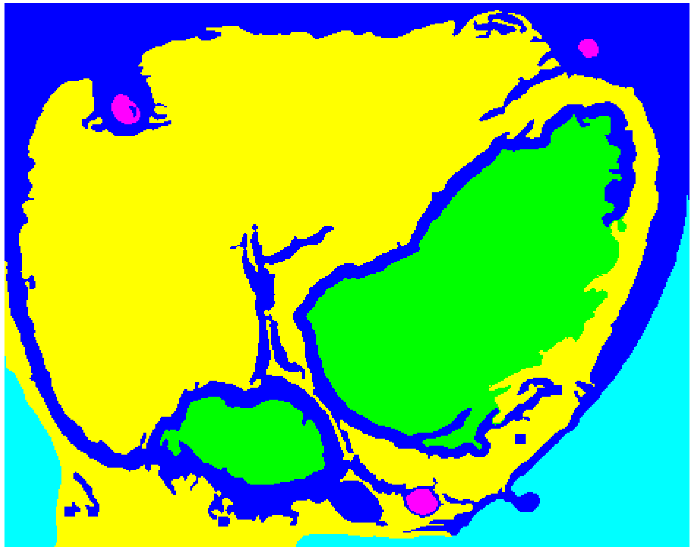
- choice of markers that do not lie on the edges of the limited "spilling" of these markers
- **very sensitive method for the continuity of the boundaries!**



original image



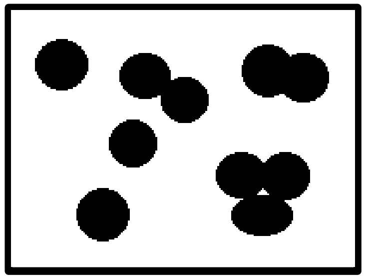
other positions of the yellow markers



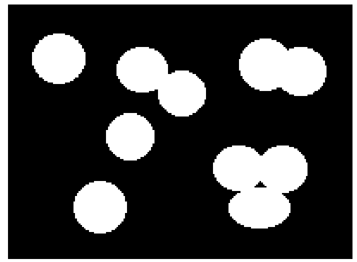
the result of watershed segmentation

The use watershed segmentation to separate overlapping objects

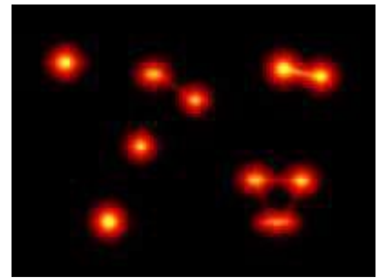
(example with Scilab)



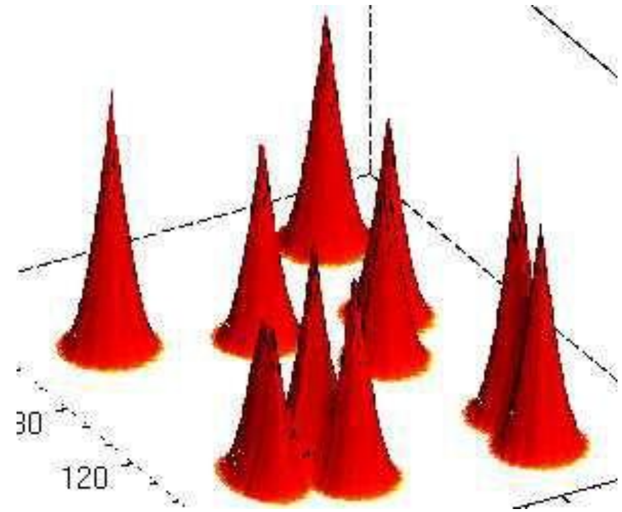
original image
`a`

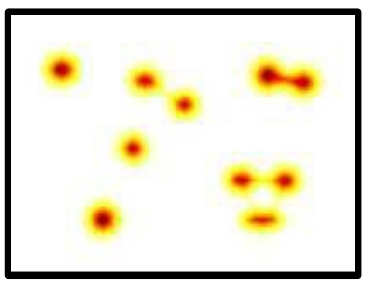


color inversion
`a = 1-a;`

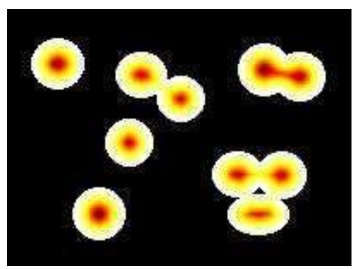


transform spacer
d = normal (bwdist (a), 255);

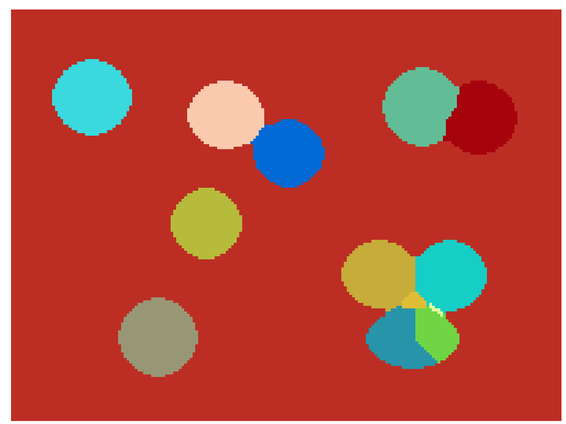




conversion maximów on minima
`d = 255-d;`



reset background
`d = d. * a;`



tsegmentation watershed
`w = watershed (d / 255);`

- the problem of detection of local minima
- there are better methods