

Morphological Image Segmentation: A User's Guide

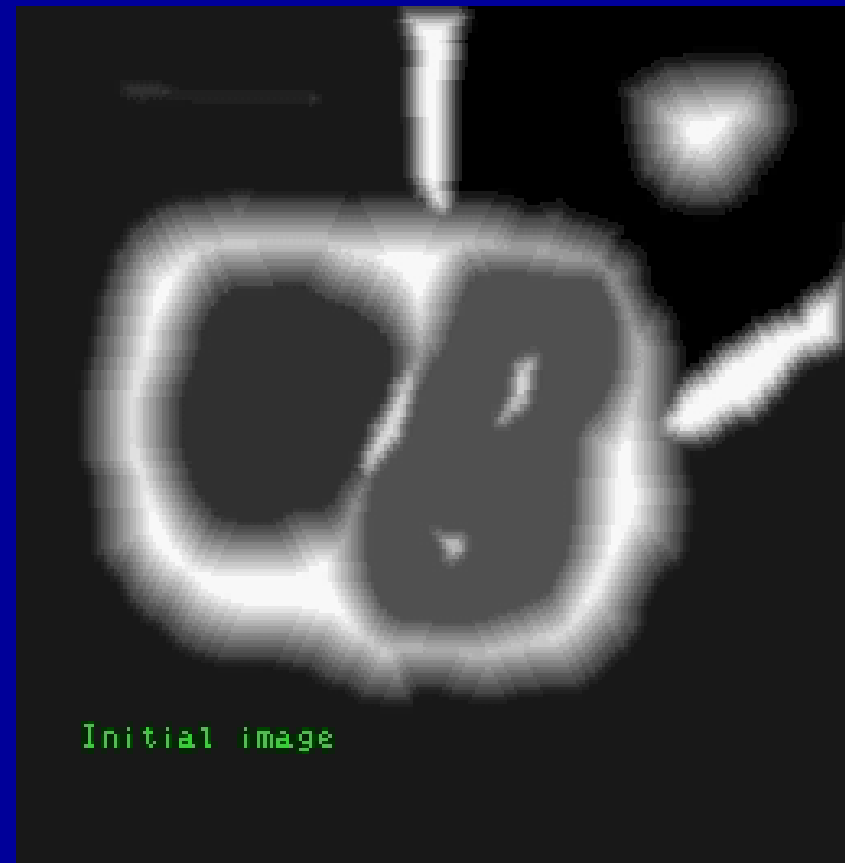
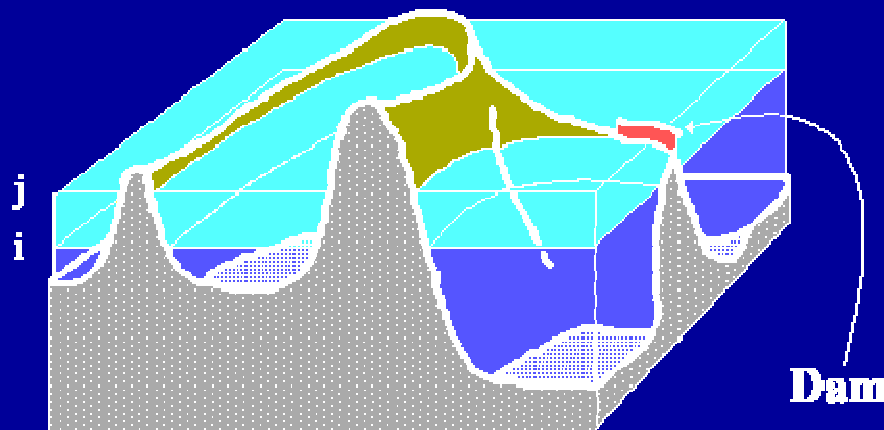
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Watershed Transformation

- It's a flooding process
- Flooding sources are the minima of the function

The result is a partition of the image into catchment basins and watershed lines (dams).

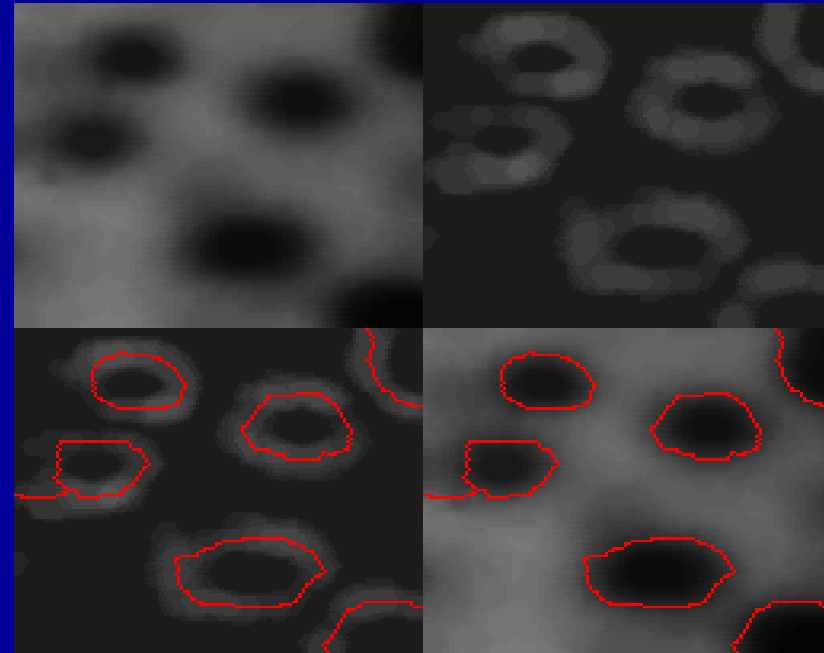
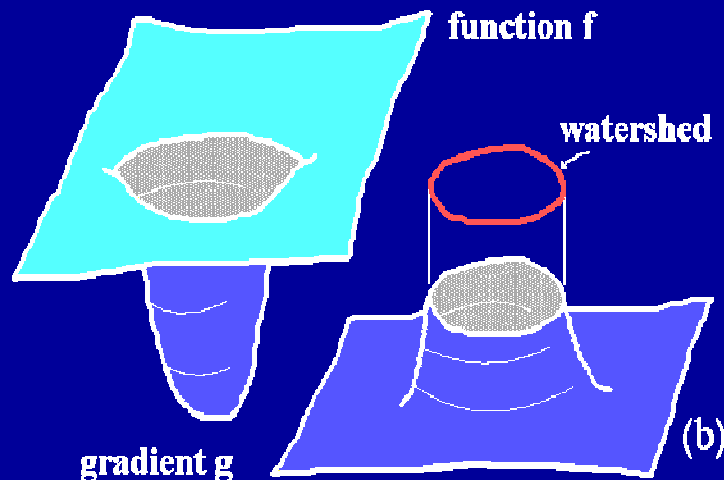


Efficient algorithms exist to realise rapidly this operator.

Using the Watershed Transformation

Use of the watershed transform for greyscale image segmentation:
the initial idea...

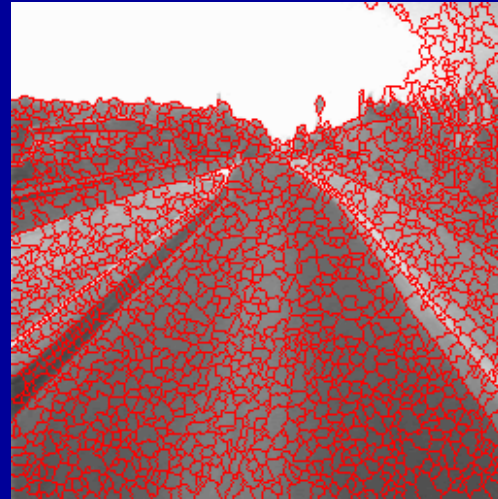
The watershed lines of the
gradient corresponds to
the contour lines



Catchment basins correspond to
homogeneous grey regions in the
image.

Coping with Over-Segmentation

The gradient watershed is over-segmented.



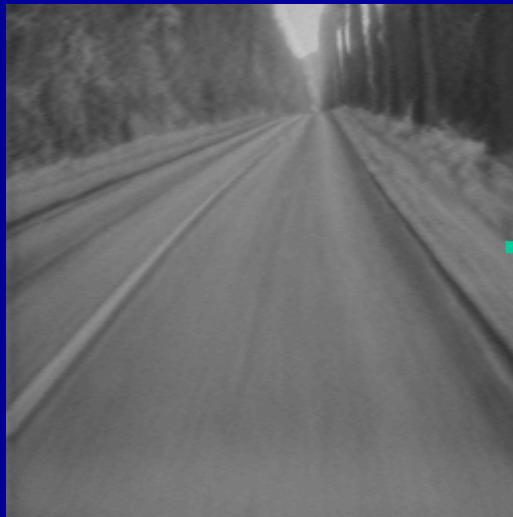
Gradient images are noisy and contain many minima. Each minimum generates a catchment basin in the WTS.

To avoid this over-segmentation due to numerous sources of flooding, one can select some of them (the markers) and perform a *marker-controlled watershed transform*.

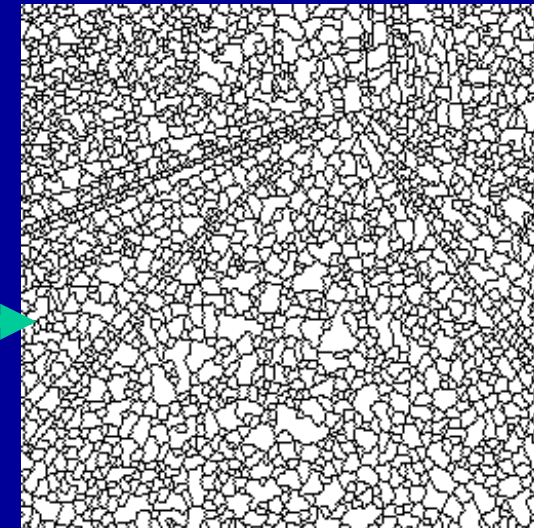
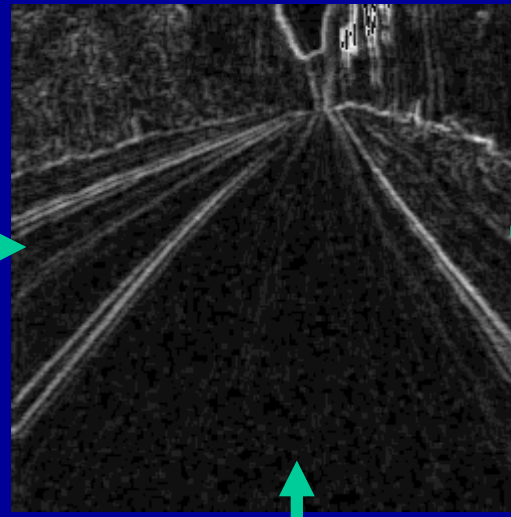


Advantages of the Marker-Controlled Watershed

original image



gradient

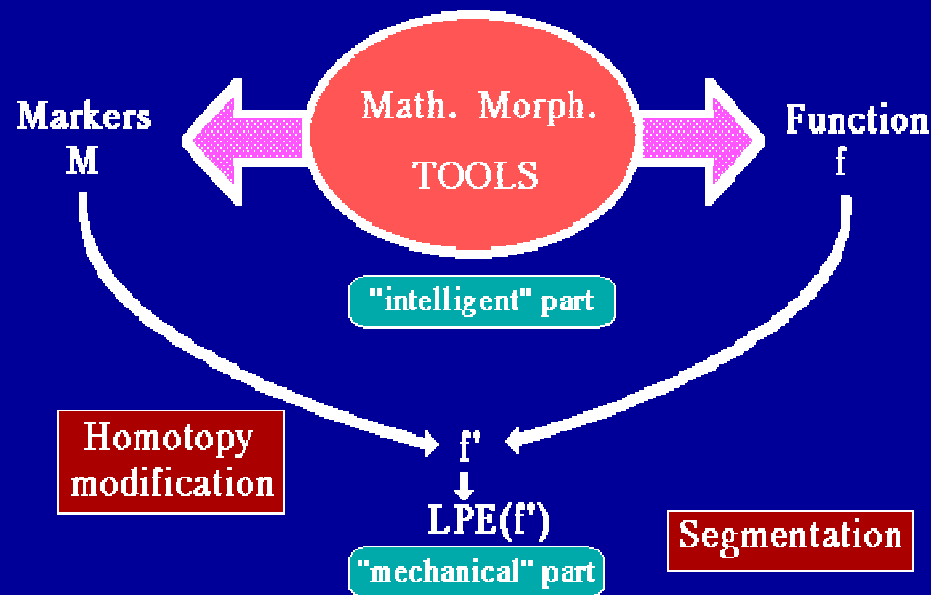


gradient watersheds

Markers corresponding to the two regions to be segmented (drawn by hand actually)



A Simple User's Guide



A morphological segmentation process is performed in two steps

- **The function f quantifies the criterion which is used by the segmentation**
- **The markers indicate the regions/objects to be extracted**

This scheme (segmentation paradigm) has the advantage to be generic and to be applicable to many segmentation problems (2D, 3D, greytone, color, multi-spectral, interactive segmentation, etc.).

It's, however, a simplistic user's guide...

Which Criteria? Which Markers?

- Regarding greyscale (or color) images, contrast criteria are used and therefore functions quantifying differences between adjacent pixels and/or regions:

Gradient

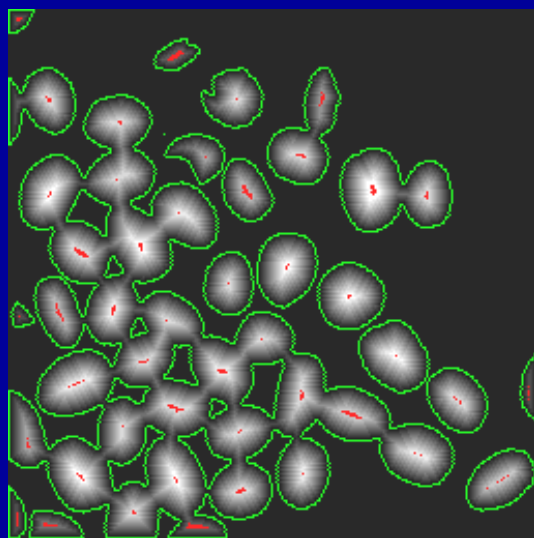
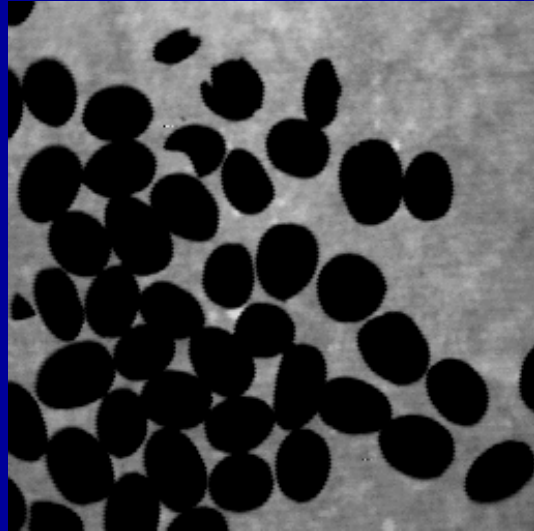
Top-hat transform

Various combinations

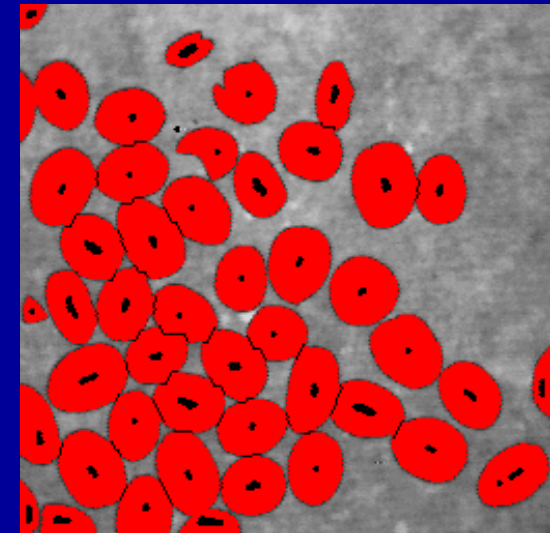
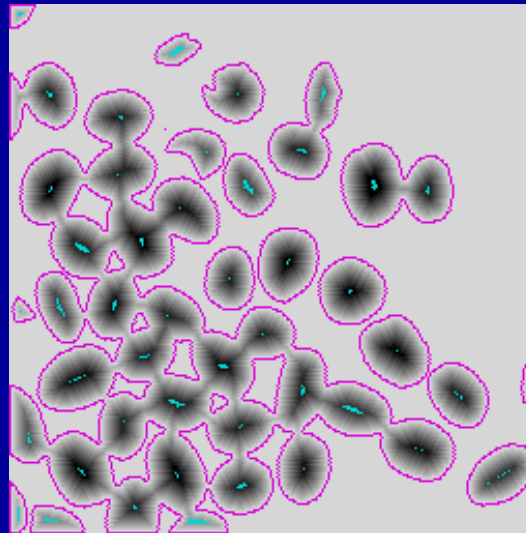
- The watershed approach can also be used to segment sets according to their shapes and sizes. In this case, the *Distance function* is widely used.
- Markers are built by various means. They are often obtained from extrema (minima or maxima) of the criteria functions or by more sophisticated approaches using a wide range of morphological tools (filters, geodesic operators).

Set Segmentation, an Example

Coffee grains

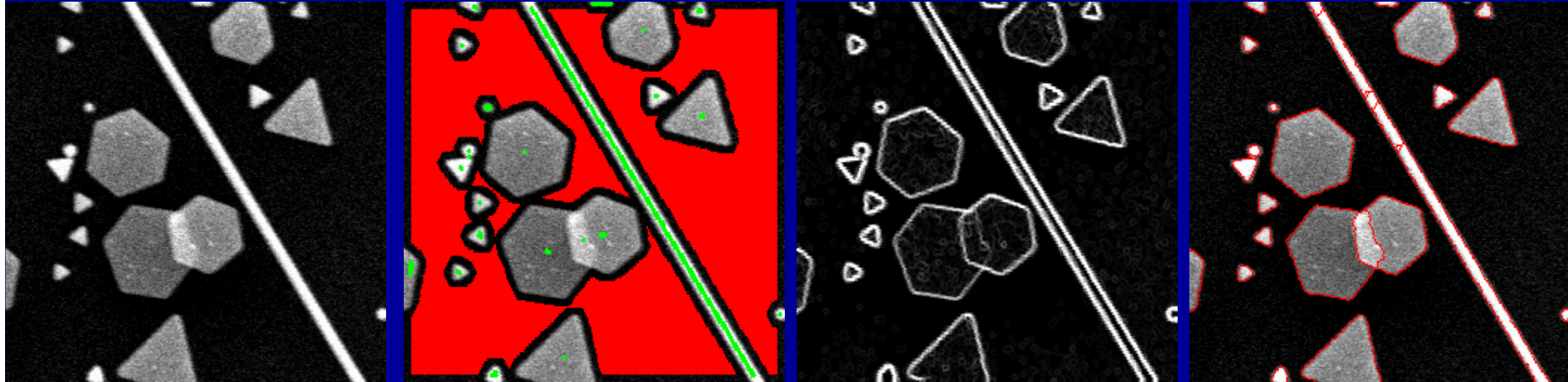


The *distance function* of the set is computed. This distance function is inverted and its watershed is performed. The marker set is made of the maxima of the distance function.

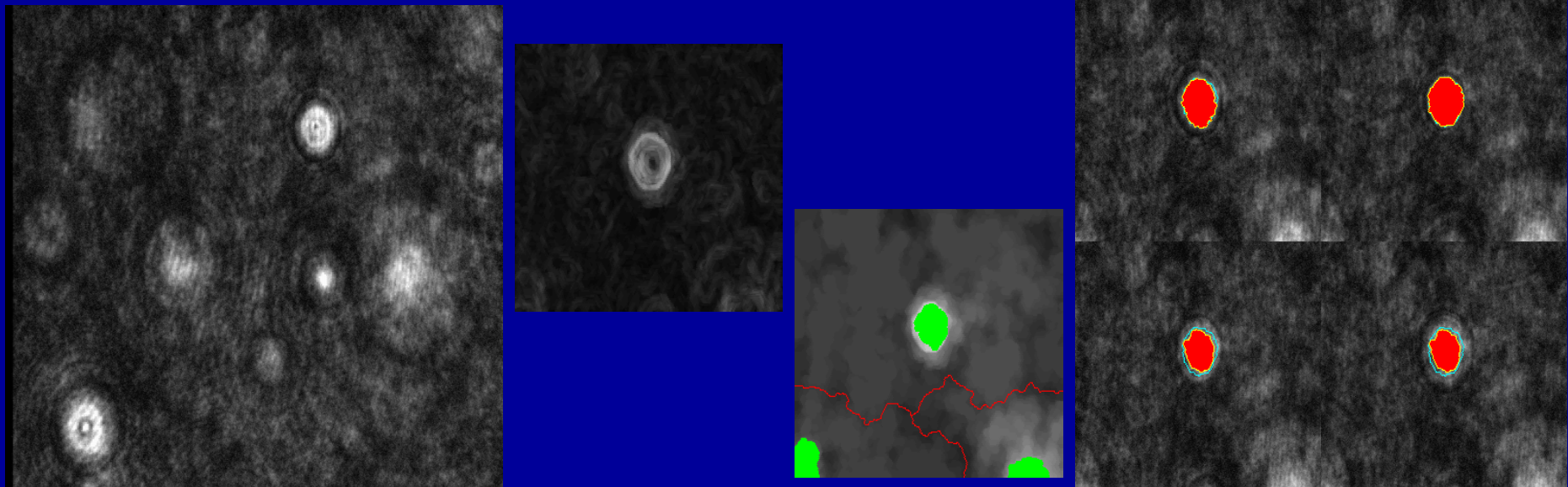


Short Anthology of Applications...

Silver nitrate grains on a film

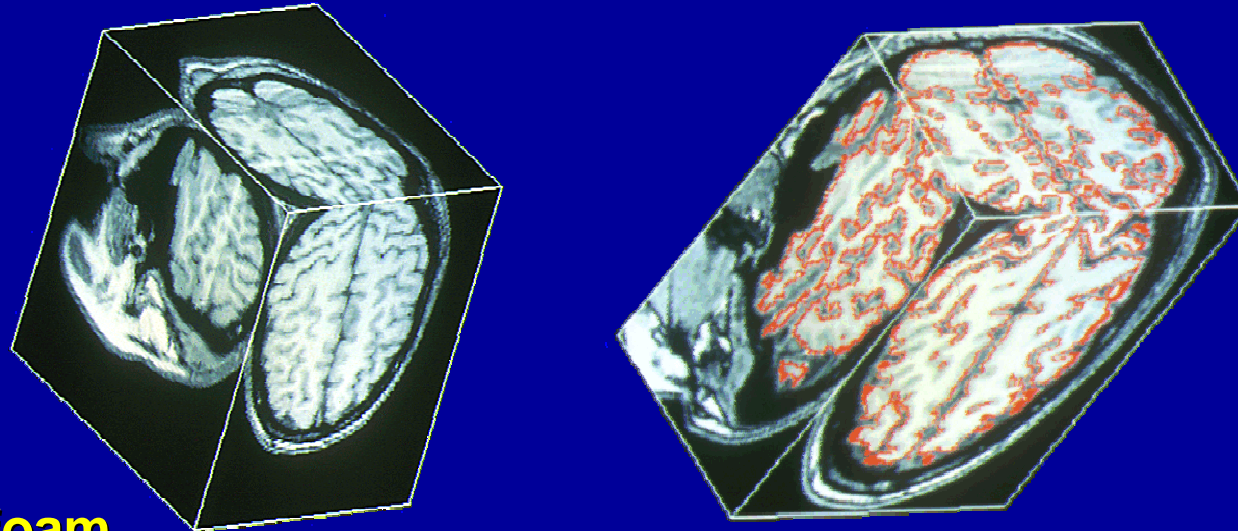


3D restitution of water drops from an hologram

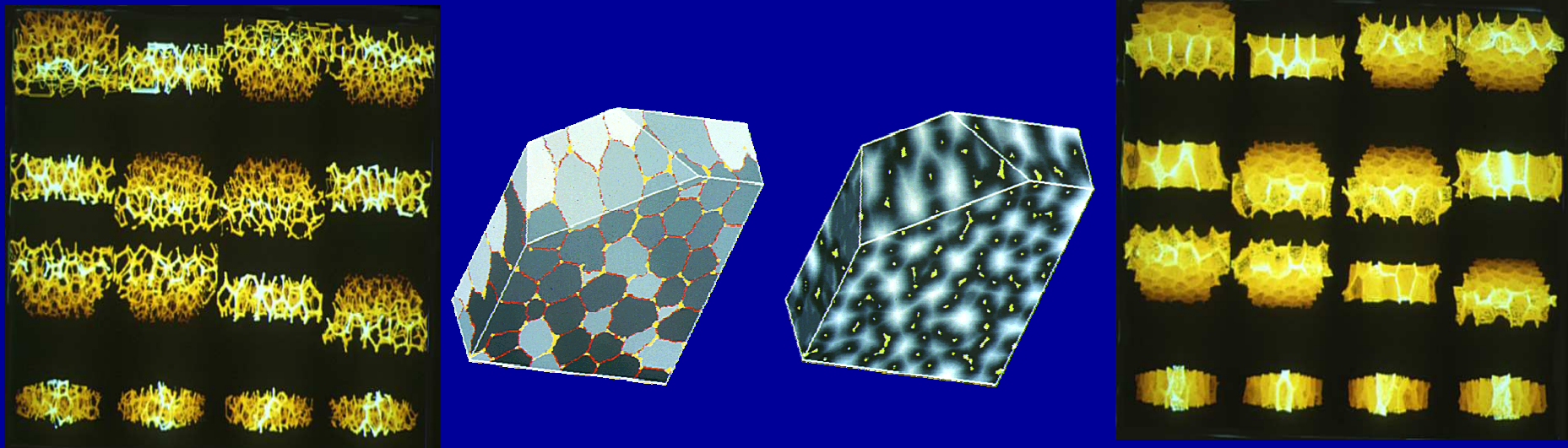


... With 3D Images

3D brain NMR image



Polyester foam

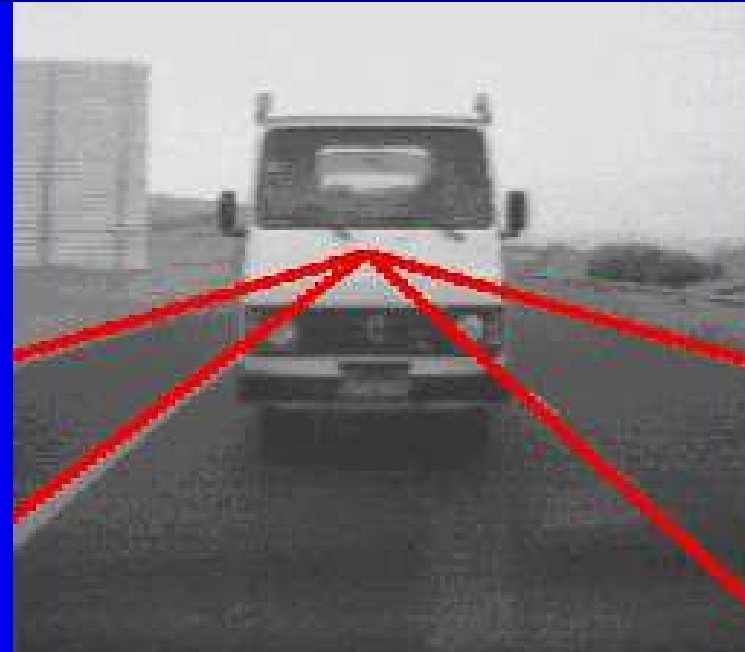


... And With Animated Images

The PROMETHEUS project: road segmentation and obstacle detection



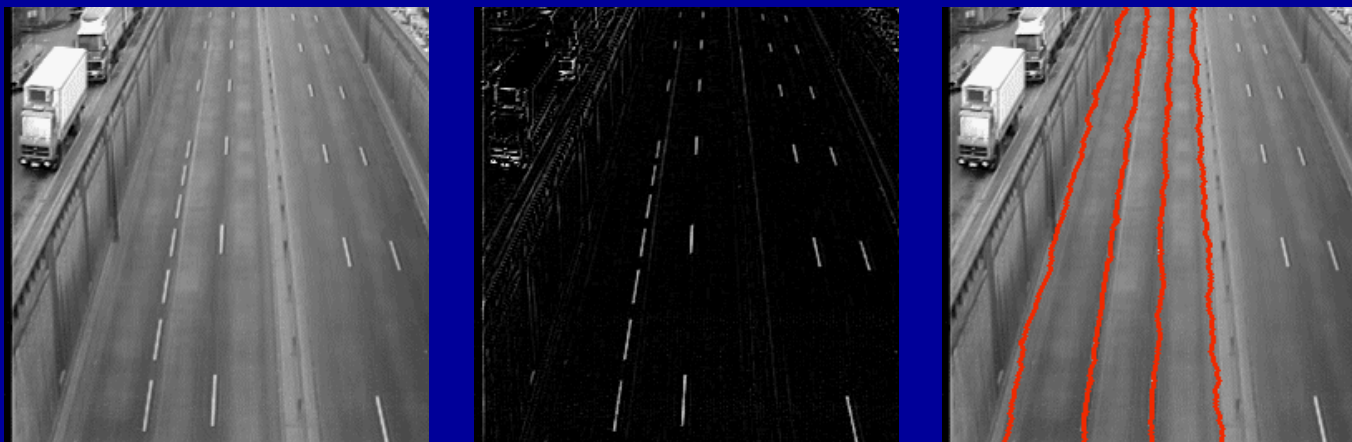
Lane detection based on a watershed segmentation applied on each image of the sequence



Lanes detection with re-use of the previous result as markers in the current image

Extending Shape Criteria to Greyscale Images, Is It Possible?

Until recently, it was difficult to apply shape and size criteria to greyscale image segmentation.



Example of traffic lanes segmentation: the lanes are not separated by a significant difference in grey levels. Therefore, using contrast criteria is irrelevant. Conversely, to use shape or size criteria, we need to work on the set corresponding to the road, which must be obtained by a... segmentation.

New operators allow to bridge the gap between these two kinds of criteria.

Numerical Residues, Short Introduction

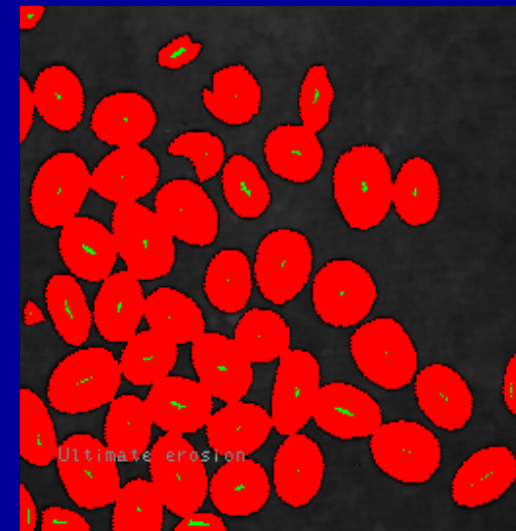
An elementary residual operator is defined by the difference of two operators.

General definition

Starting from two sequences of transformations ψ_i and ζ_i with $\psi_i \geq \zeta_i$, we define a doublet of operators:

- The residual transformation $\theta = \sup_{i \in I} (\psi_i - \zeta_i)$
- Its associated function $q = \arg \max (\psi_i - \zeta_i) + 1$

Many residual operators exist. Many of them are used as criteria functions in segmentation: morphological gradient, top-hat for numerical images, ultimate erosion and distance for sets



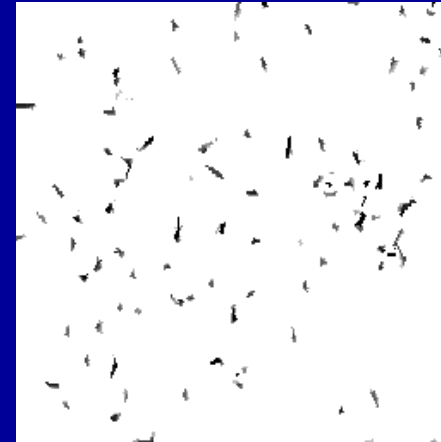
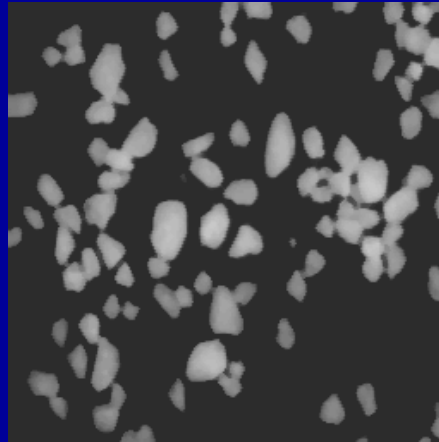
New Residues

Thanks to this general definition of a residual transform, it is possible to extend to functions residues defined for sets:

$$\Psi_i = \varepsilon_i$$

$$\zeta_i = \gamma_{\text{rec}}(\varepsilon_i)$$

Ultimate Erosion



It is also possible to define new transformations:

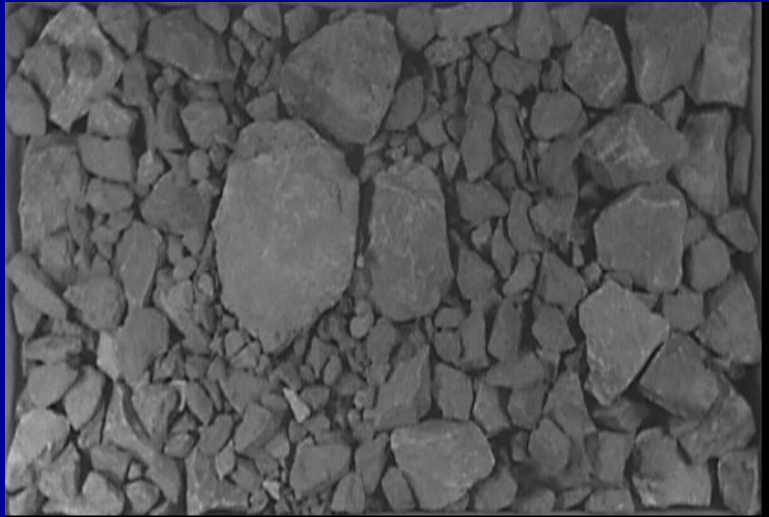
$$\left. \begin{array}{l} \Psi_i = \gamma_i \\ \zeta_i = \gamma_{i+1} \end{array} \right\}$$

θ is named *Ultimate Opening*
 q is the *Granulometric function*

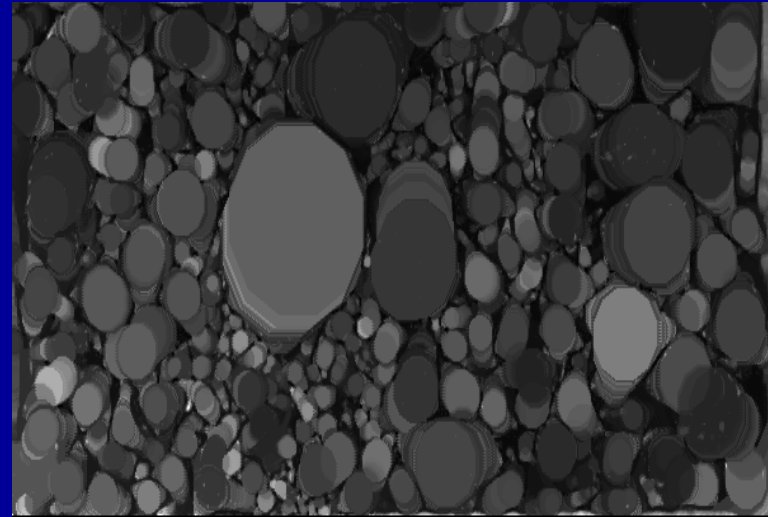
$$\left. \begin{array}{l} \Psi_i = \varepsilon_i \\ \zeta_i = \varepsilon_{i+1} \end{array} \right\}$$

q is called *Quasi-Distance*.

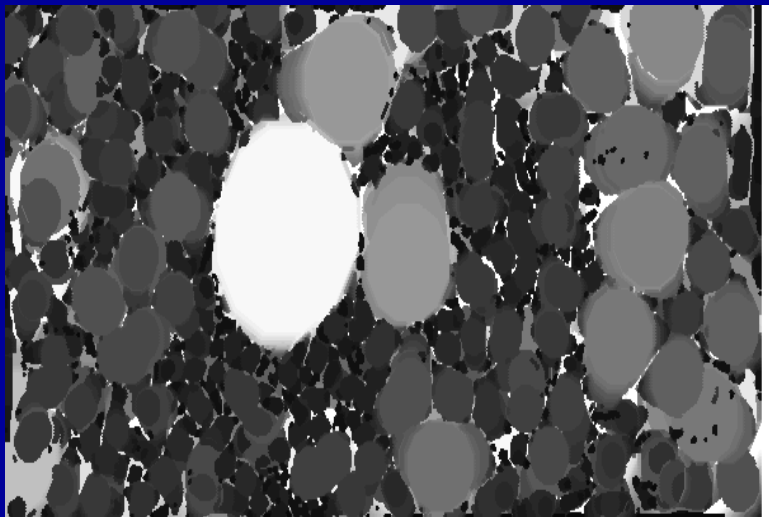
Ultimate Opening Granulometric Function



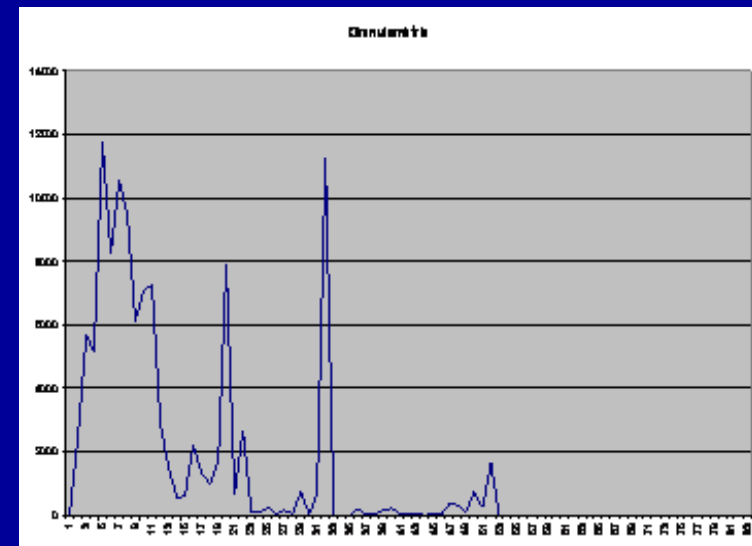
Heap of rocks



Ultimate Opening



Granulometric function

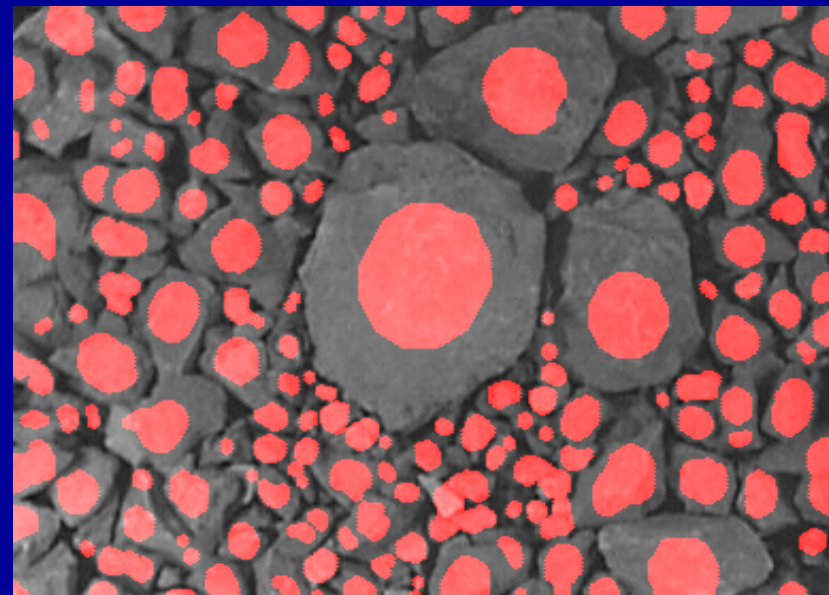
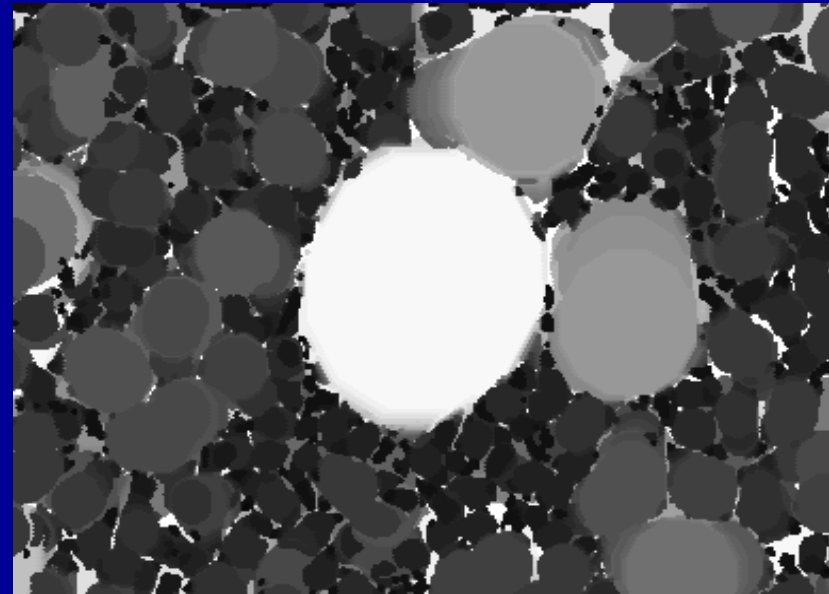


Markers Generation

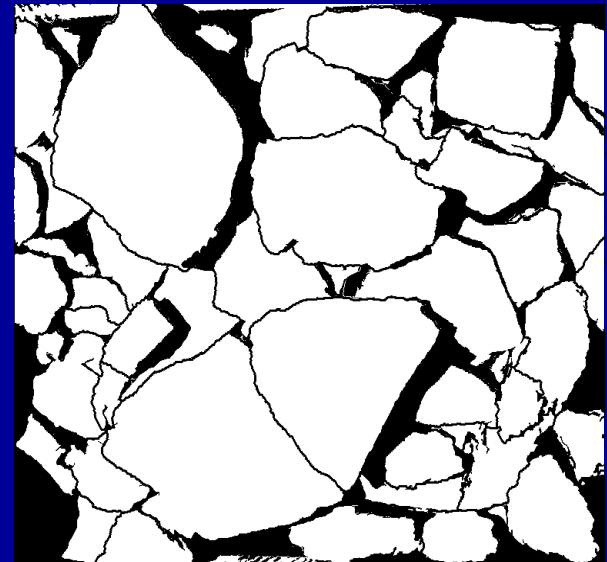
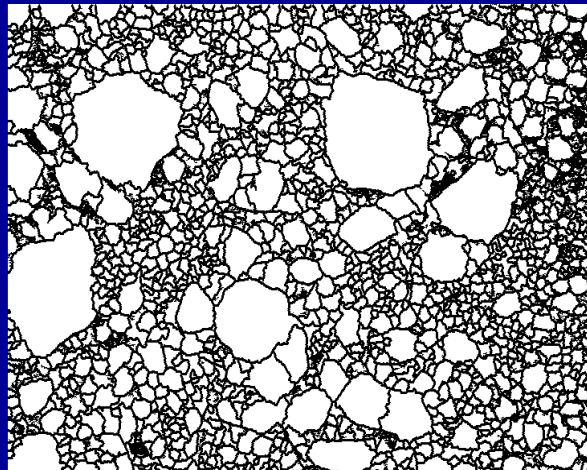
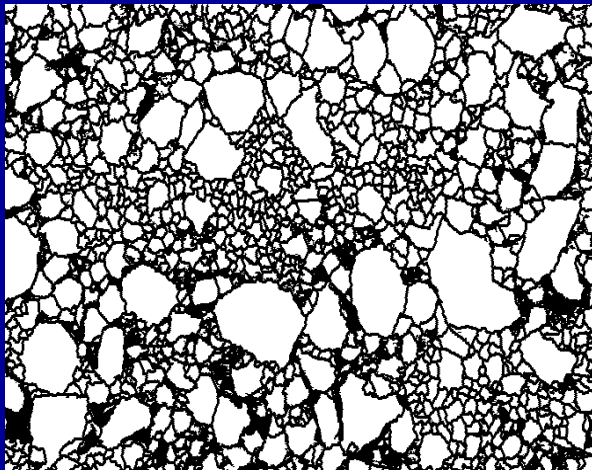
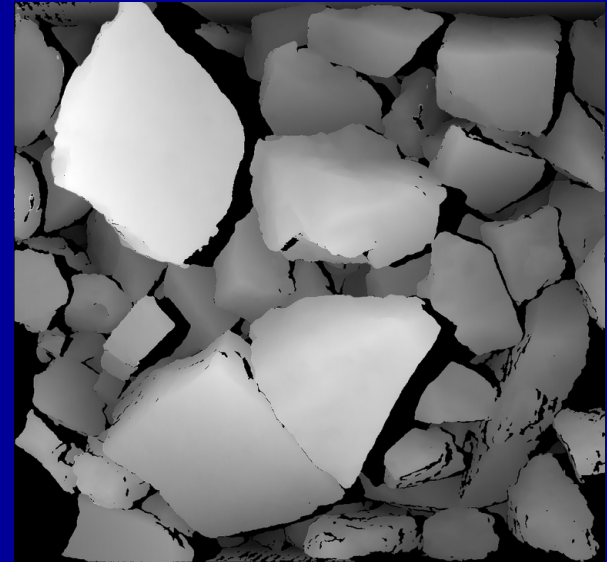
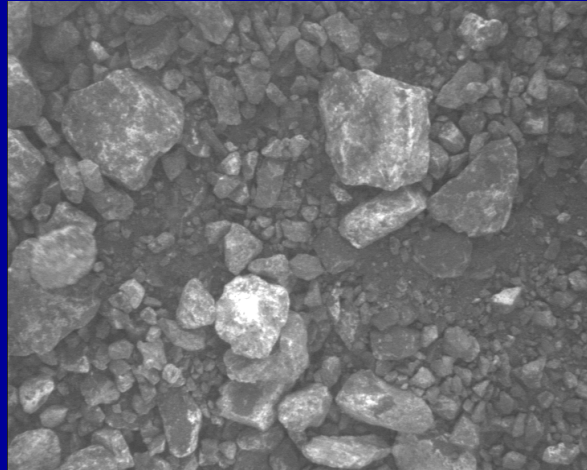
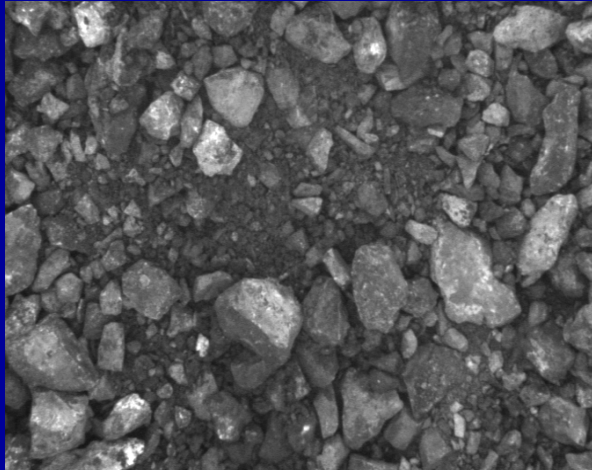
The granulometric function can be used to produce efficient markers for the watershed segmentation

Each threshold λ of the granulometric function q is eroded by a disk of size $k\lambda$ ($k < 1$)

This operation produces markers of blocks whose size is proportional to the size of the block. As a result, markers are better centered, even small particles are well marked and the watershed segmentation is of better quality.

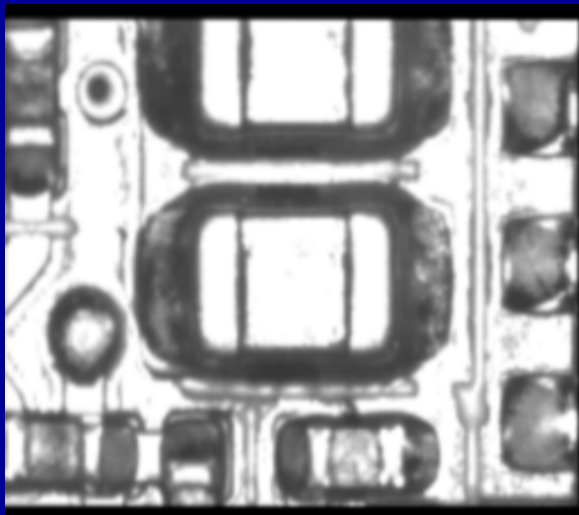


Some Results of Segmentation

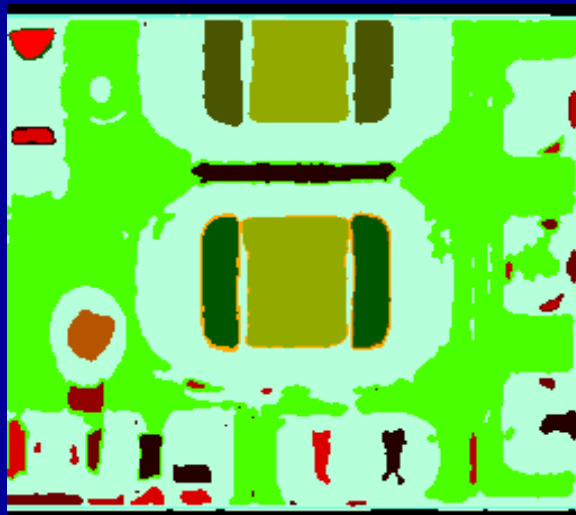


Ultimate Opening Can Be Defined From Any Opening Operator

For instance, with opening by geodesic reconstruction...
This operator emphasizes the size criterion .



Initial image



Ultimate Opening
by reconstruction

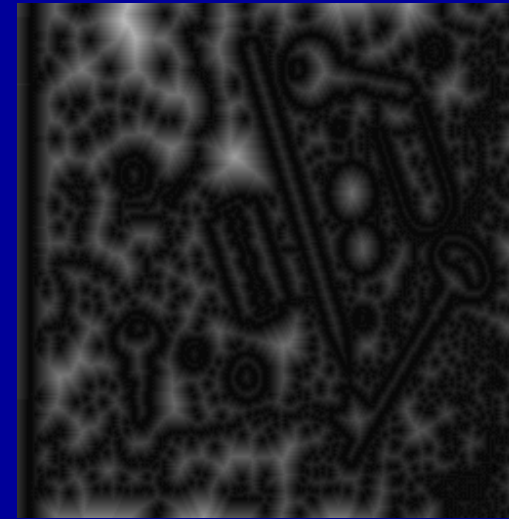
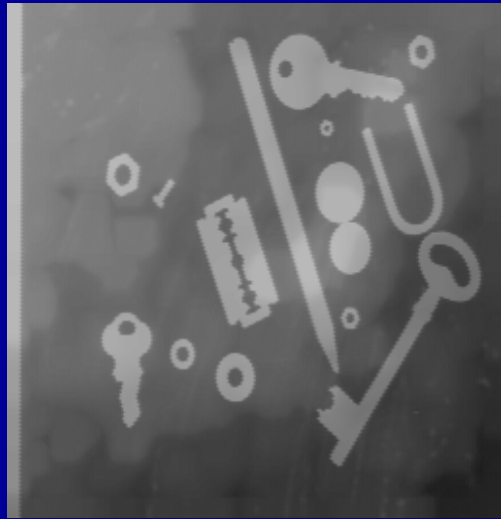


Granulometric
function

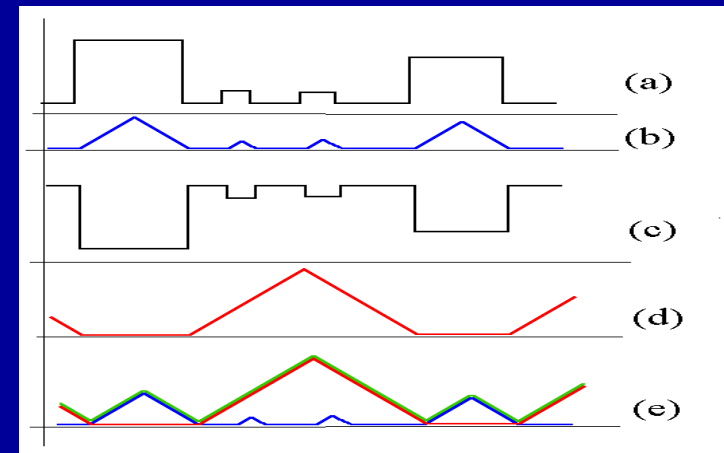
Residual operators provide efficient non parametric filters. The Ultimate Opening is a remarkable tool for marking and extracting salient features from an image.

Quasi-Distance and Segmentation

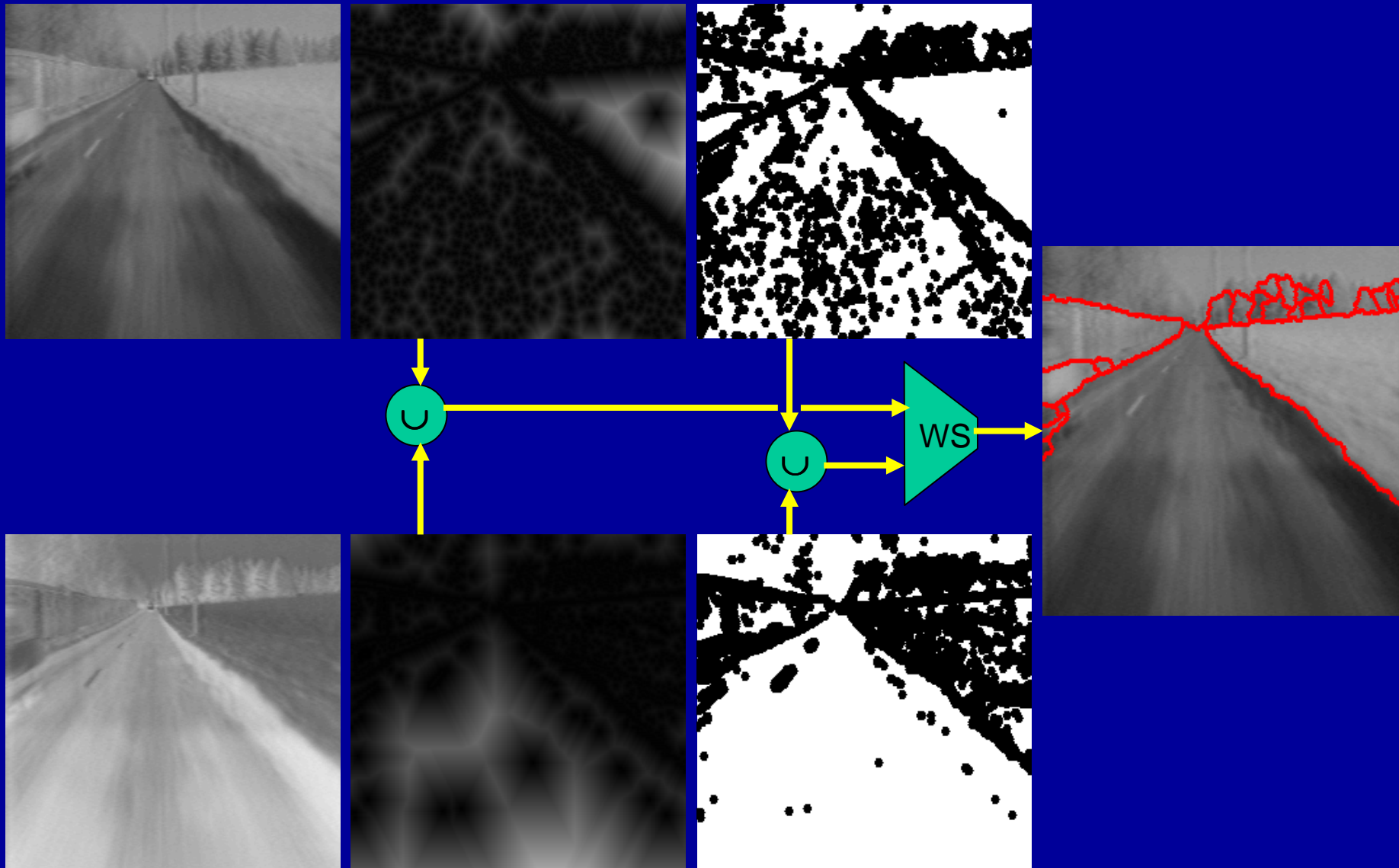
A quasi-distance computed on a greyscale image provides the sizes of the flat (homogeneous) regions \rightarrow Markers for a segmentation based on size and geometry (convexity).



- Quasi-distances performed both on the image and the complementary one $\rightarrow d, d'$
- Sup of the results $\rightarrow h = \sup(d, d')$
- Markers extraction (maxima or threshold)
- Watershed of h



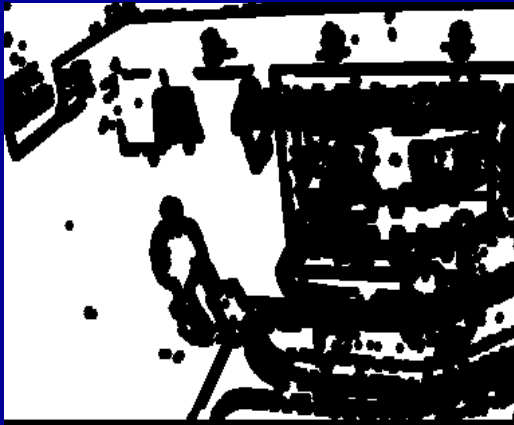
Segmentation With Quasi-Distances



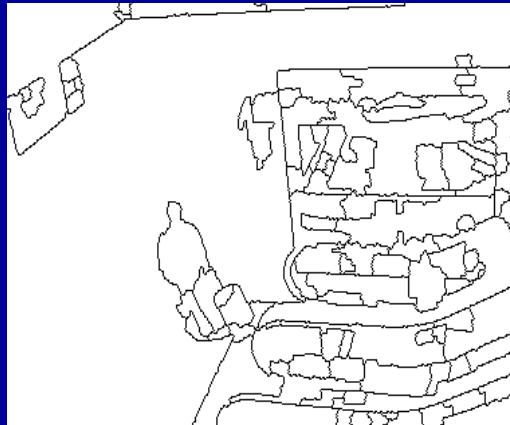
Another Example



Quasi-Distances



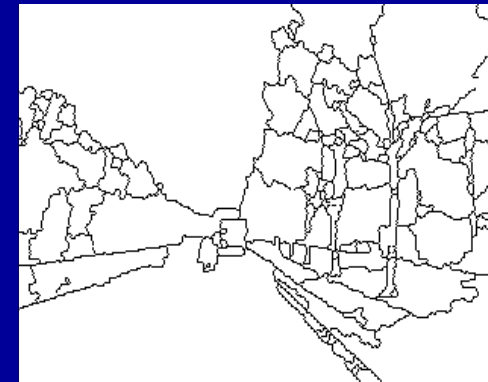
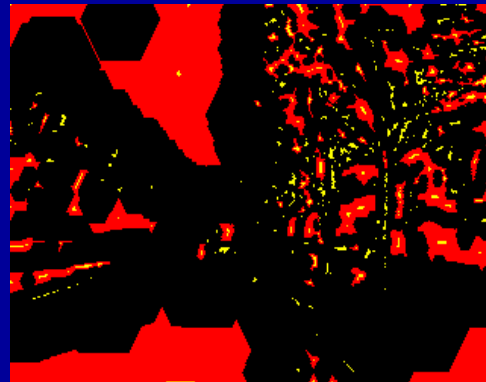
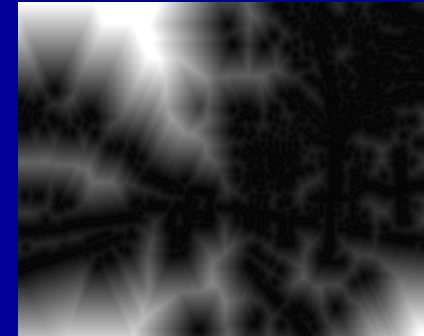
Markers



Segmentation

Video surveillance scene

Gradient and Quasi-Distance



Quasi-distance can be computed on the inverted gradient function

- **Only one quasi-distance is calculated**
- **Hierarchy of regions based on their relative contrast**
- **The shape of regions is taken into account (closure of imperfectly closed regions)**

Conclusions and Perspectives

In the initial user's guide, no clue was given about the morphological operators which could be used for segmentation.

We have shown that criteria functions belong to the residual transforms class and that markers are linked to extrema of these functions.

Residual transformations are built in such a way that they, not only, emphasize variations of some features (contrast, size, shape, etc.) but also, they indicate where the greatest variations occur, what are their amplitudes and which index value produces them.

New residual transforms have been introduced. They bridge the gap between the numerical and binary images regarding shape and size criteria.

Other residues (which have not been presented here) are also very efficient: regularised gradients, spatial-temporal gradients, critical balls, pilings (in hierarchical segmentations), etc.