REGARDING THE WATERSHED...

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THE WATERSHED TRANSFORMATION in SEGMENTATION

The Watershed transformation has proven to be an efficient segmentation tool:

- **Its mechanism is easy to understand**

- **It comes with a "user guide" ("segmentation paradigm" and markers)**

- **It works in 3D spaces, in sequences, etc… ("nice property")**

- **It can be adapted to various segmentation criteria: contrast, shape, colour, texture, etc...**

But..

WATERSHED for SEGMENTATION

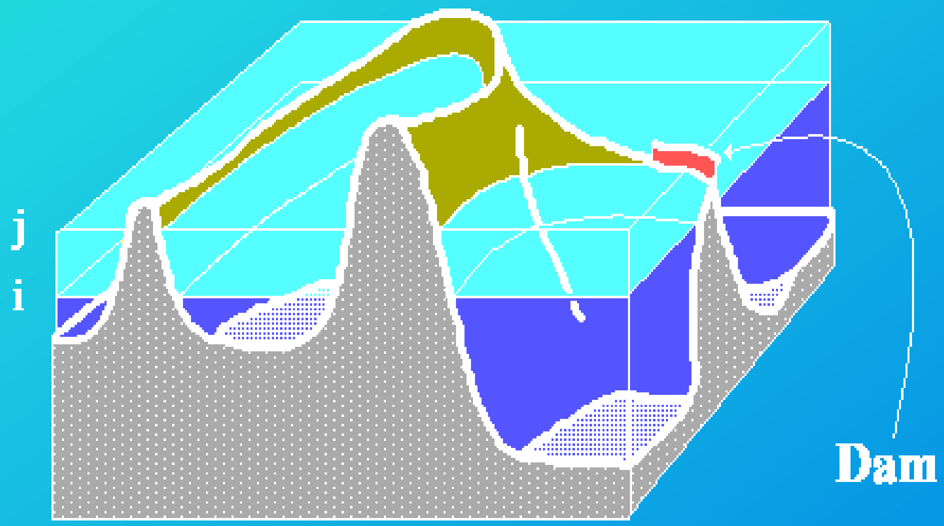
But it has some drawbacks…

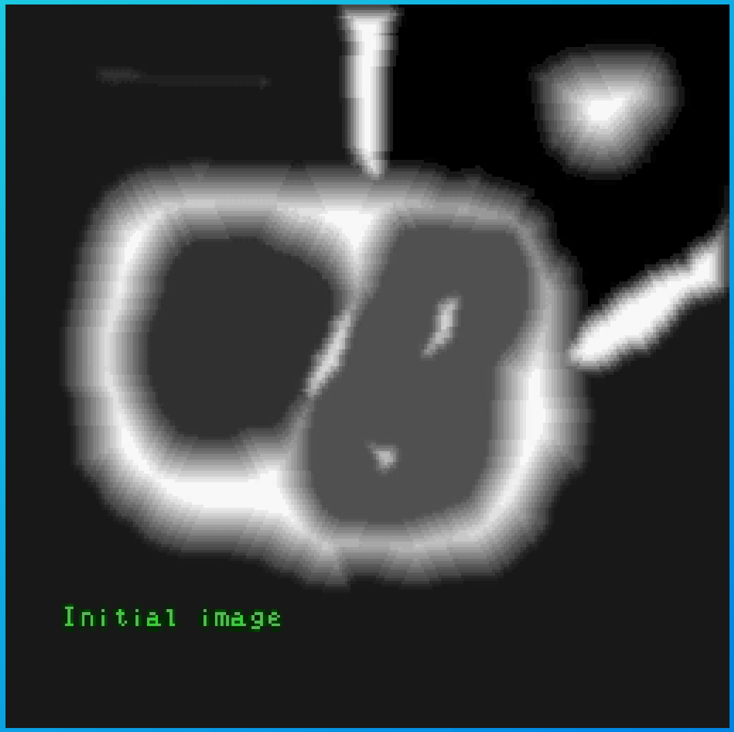
- **The transformation is slow (or, at least, has this bad reputation…)**
- **The transformation is not robust**
- **Most of the algorithms are not exact and the results are often deeply biased (and most of the time, users are not aware of that…)**
- **It's (to some extend) a dead end: it's often the final step of a long process. Afterwards, one must use other tools...**

BRIEF REVIEW OF THE WATERSHED TRANSFORM

Definition

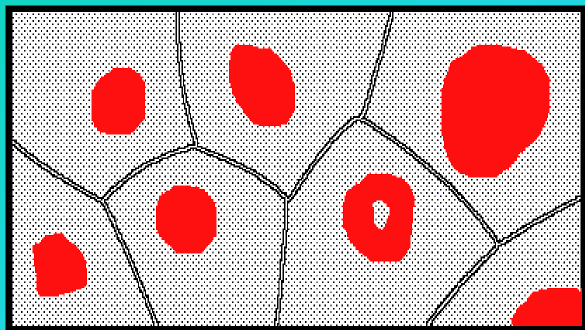
Flooding a topographic surface from its minima...





DEFINITION OF THE WATERSHED (continued)

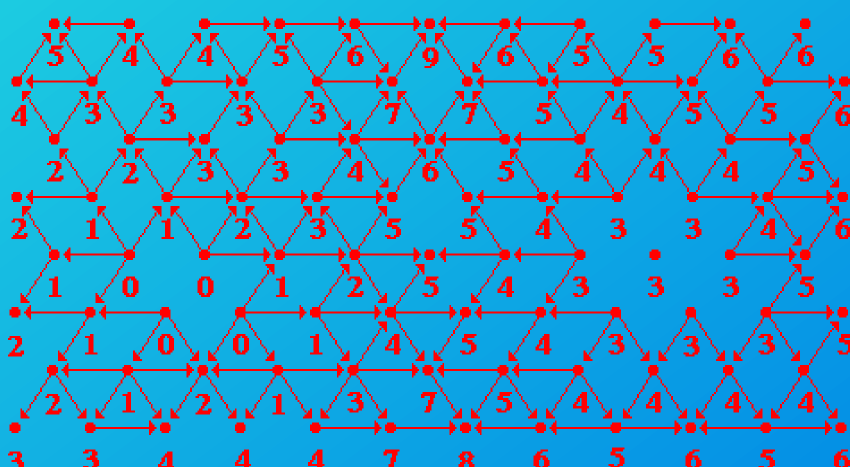
Extension of the SKIZ (skeleton by zones of influence)



$$IZ(X_i) = \{x : d(x, X_i) < d(x, X_j) ; j \neq i \}$$

The watershed transform is simply a generalisation of the SKIZ. The underlying distance function can be depicted by means of an arrowing.

f



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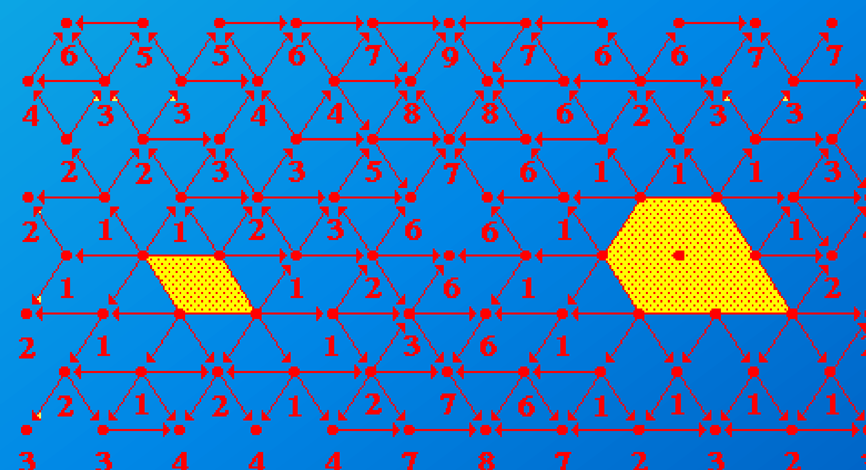
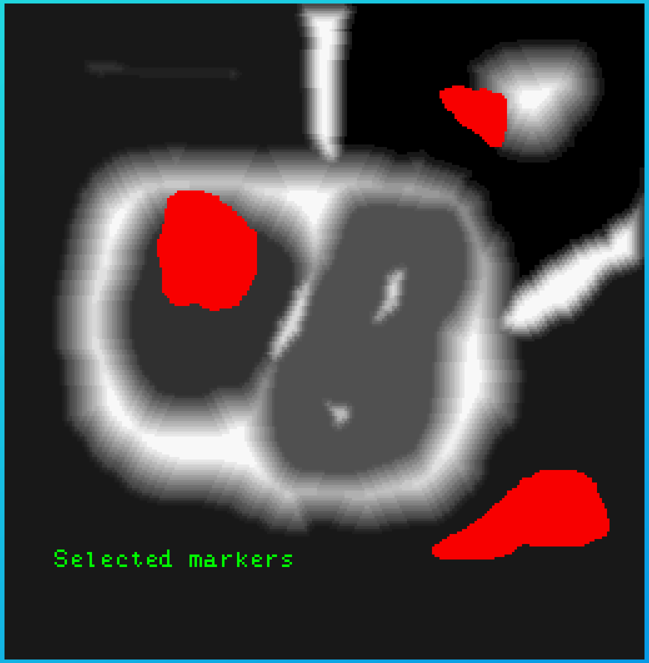


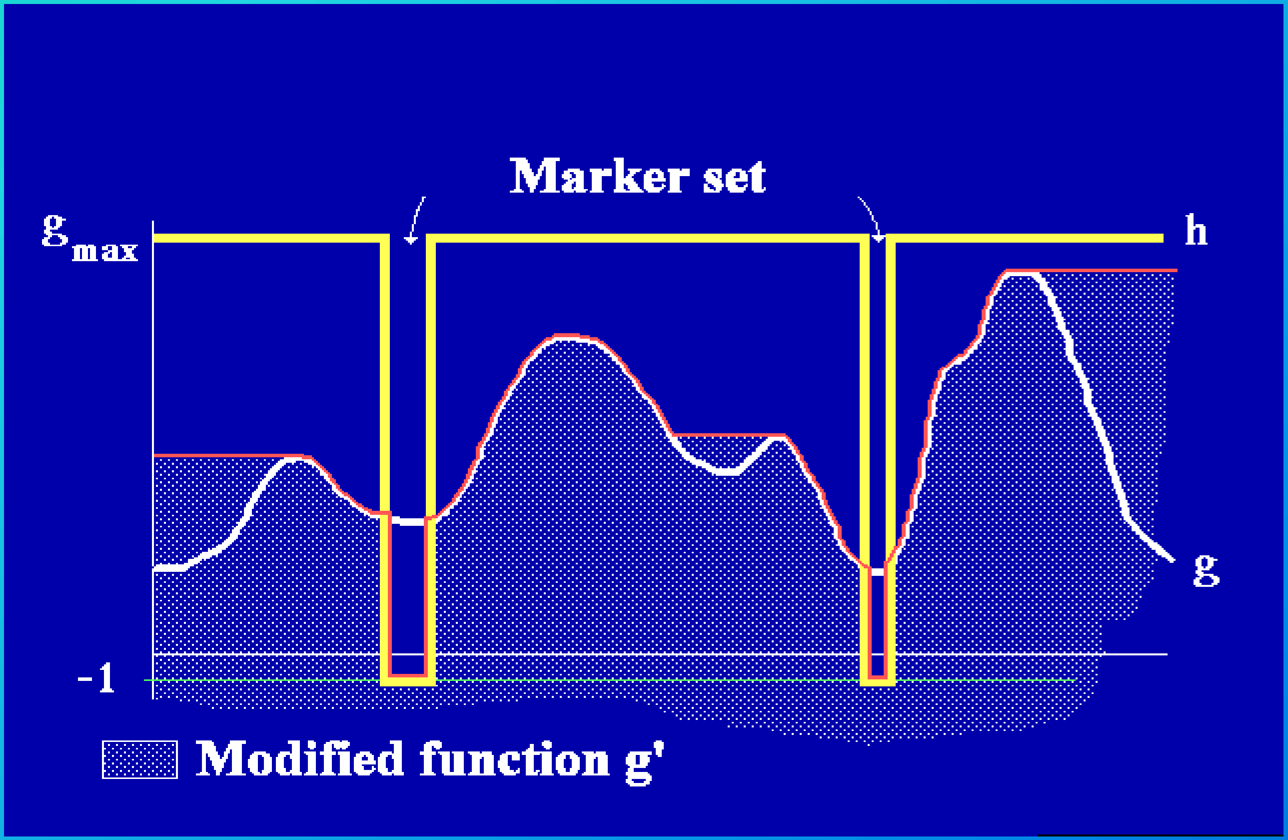
MARKER-CONTROLLED WATERSHED

The initial definition can be modified if we consider a set of markers which are the source of the flooding...



HOMOTOPY MODIFICATION

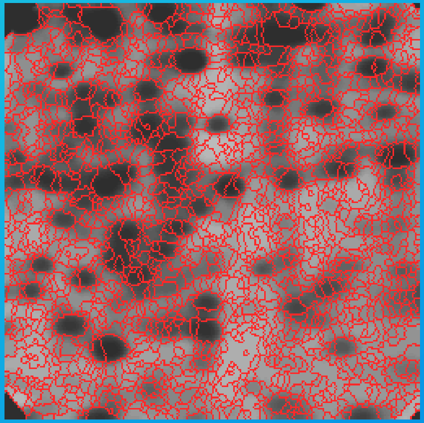
A marker-controlled watershed can be viewed as a "classical" watershed applied on a modified function.



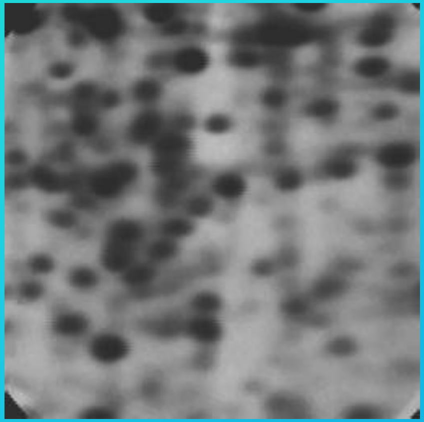
The most visible characteristic of this transformation is the appearence of flat zones (plateaus)

USE OF THE WATERSHED

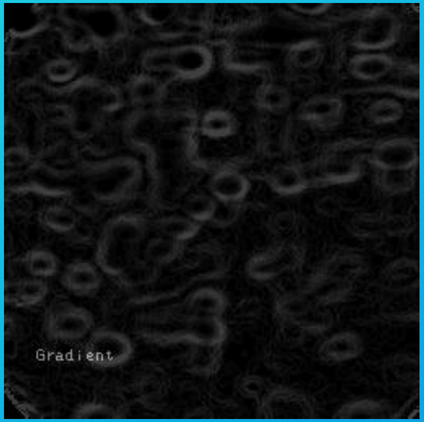
A classical use of the watershed consists in computing the watershed of a gradient modulus function in combination with a set of markers (to prevent over-segmentation).



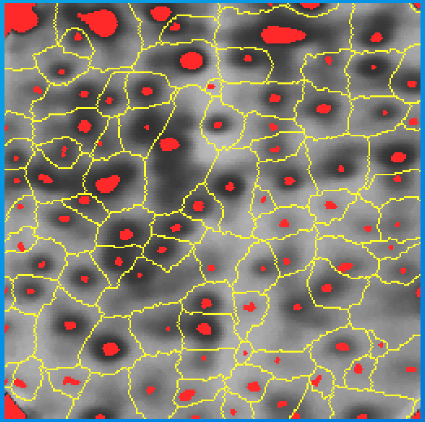
Over-segmentation



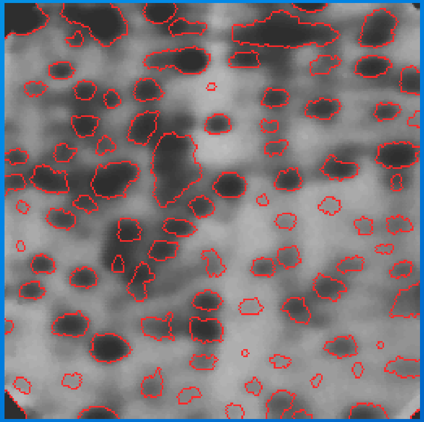
Original



Gradient modulus



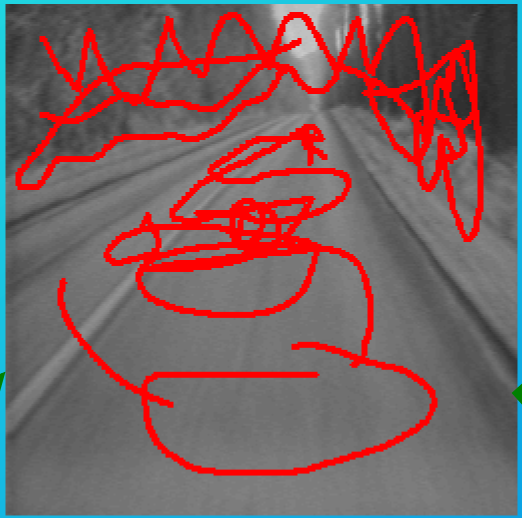
Markers



Blobs

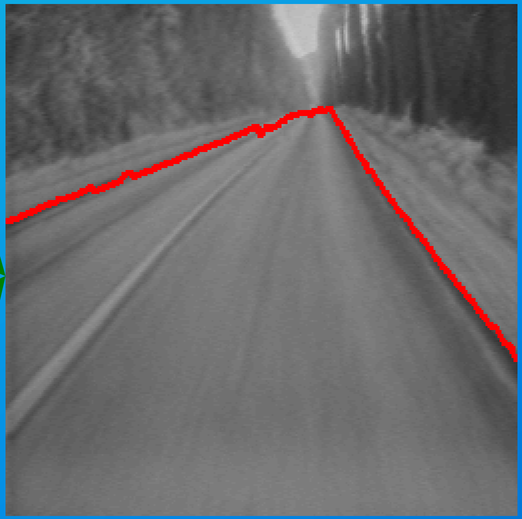
EXAMPLES

Road segmentation



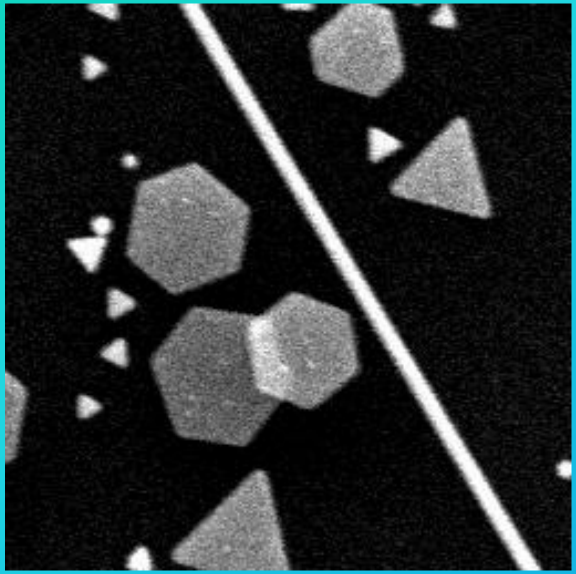
Hand-defined marker

Automatically-defined marker

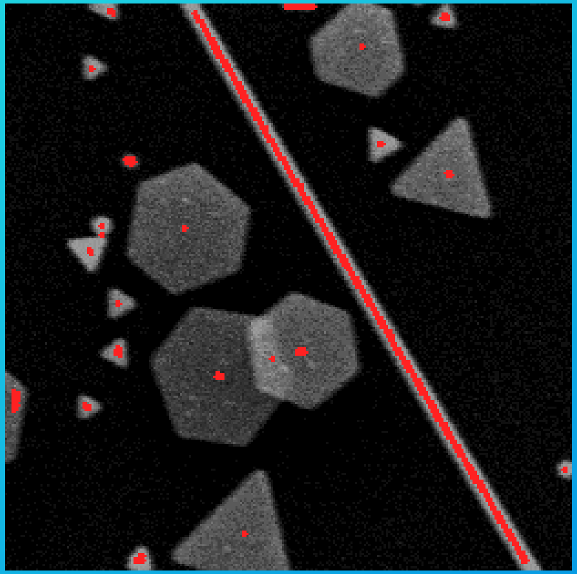


EXAMPLES (continued)

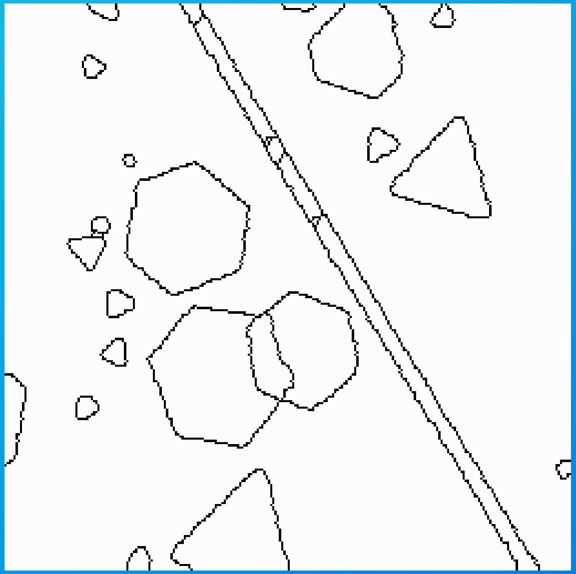
Grains segmentation



Silver nitrate grains in a photographic plate



Marking of the grains and of the overlapping zones



Watershed of the modified gradient image

TRAPS & FALSE IDEAS regarding the WATERSHED

- **Conceptual traps**

The original concept has been diverted. The "classical" notion of watersheds (the geological one) is often used: the watershed lines correspond to the spots where rain drops falling on the topographic surface are splitted and stream down towards different catchment basins (rain fall concept).

These different definitions lead to different algorithmic implementations:

- based on flooding
- based (partly) on water sprinkling
- "exotic" approaches (arrowing)

- **Algorithmic issues**

The watershed transformation is biased and not robust.

ERRORS & FALSITIES relating to the WATERSHED

Crest lines and watersheds

It is not true that the watersheds are superimposed to crest lines or other characteristic features of the topographic surface.

The flat zones (plateaus)

The flooding on the plateaus is based on a MODEL (constant speed). It has mainly two advantages: it is simple and it has a physical meaning.

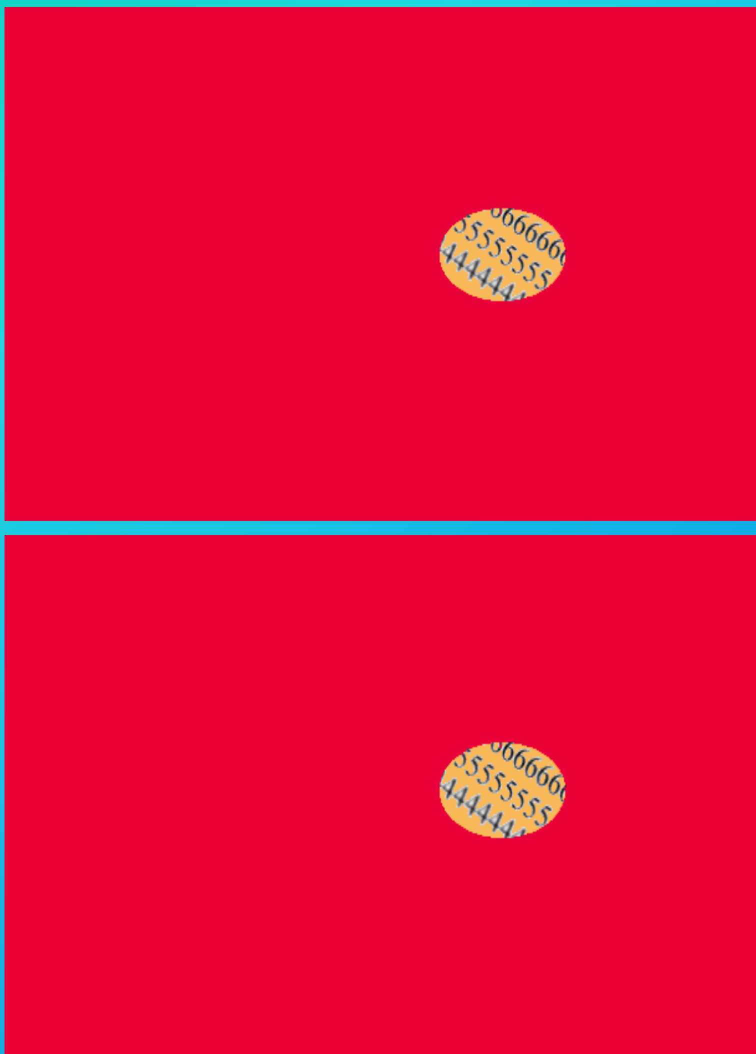
The watershed is not a local operator!

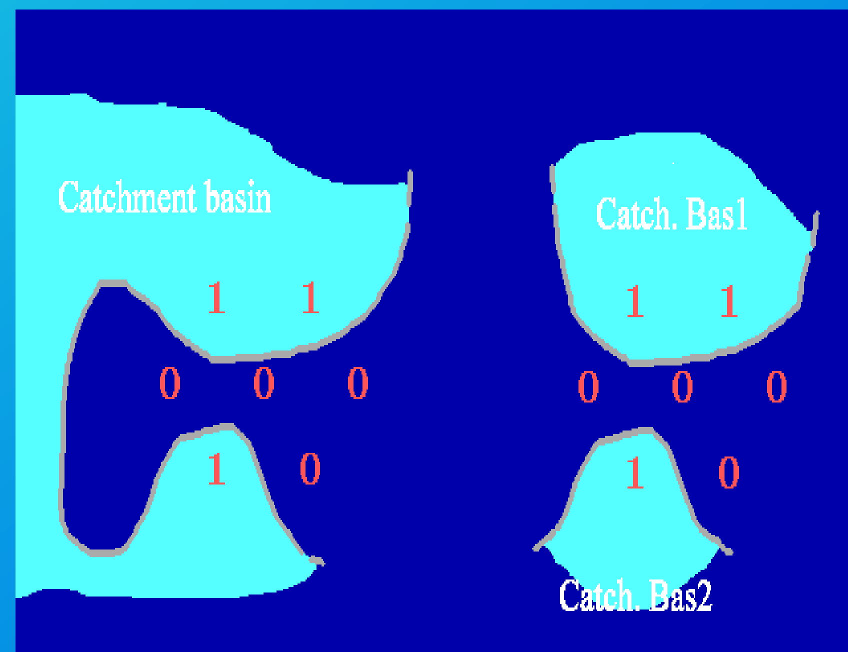
Various trials have been made to give a “mathematical status” to the watershed transformation (“smooth” functions, Morse functions, etc…).

NON-LOCALITY OF THE WATERSHED

You cannot, having only a local knowledge of the neighbourhood of a point, answer the question:

Does this point belong to a watershed line?





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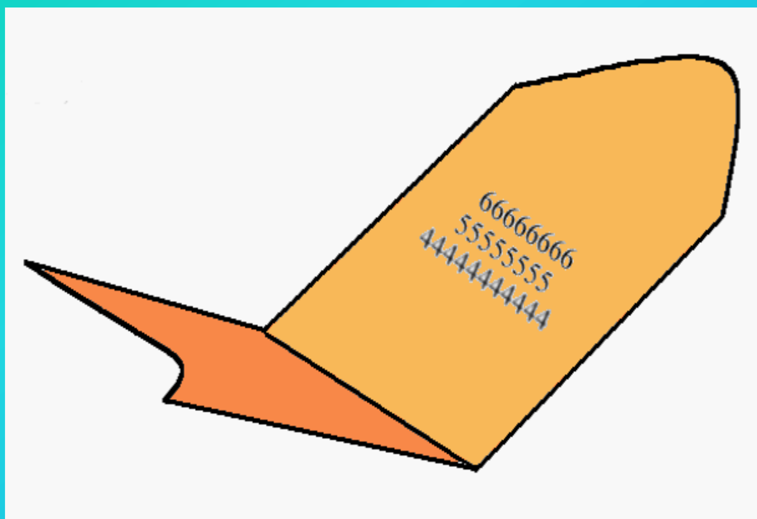
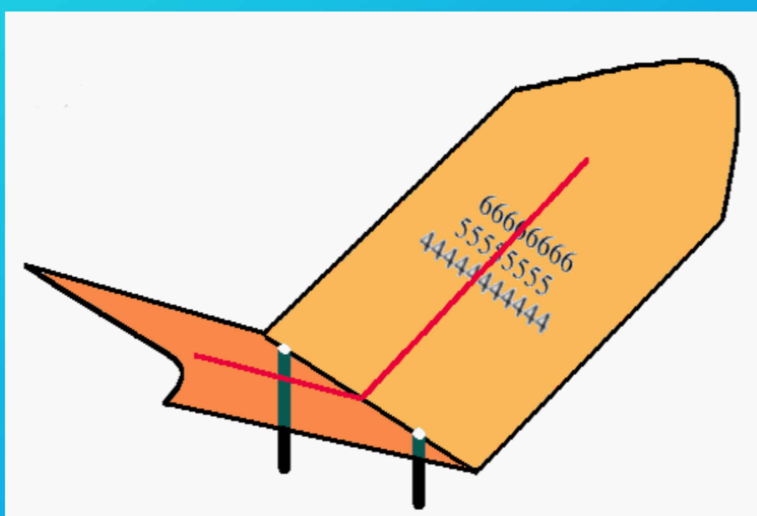
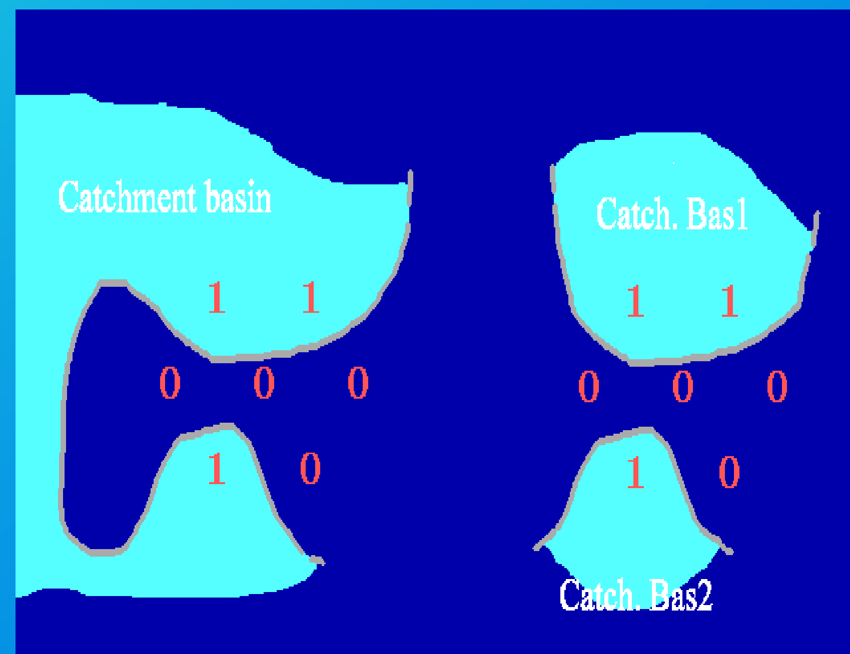






WATERSHED BY FLOODING VERSUS WATERSHED BY SPRINKLING (where intuition leads to misconceptions)

What streaming model is used for the rain drops running on the surface? Constant speed, steepest descent?

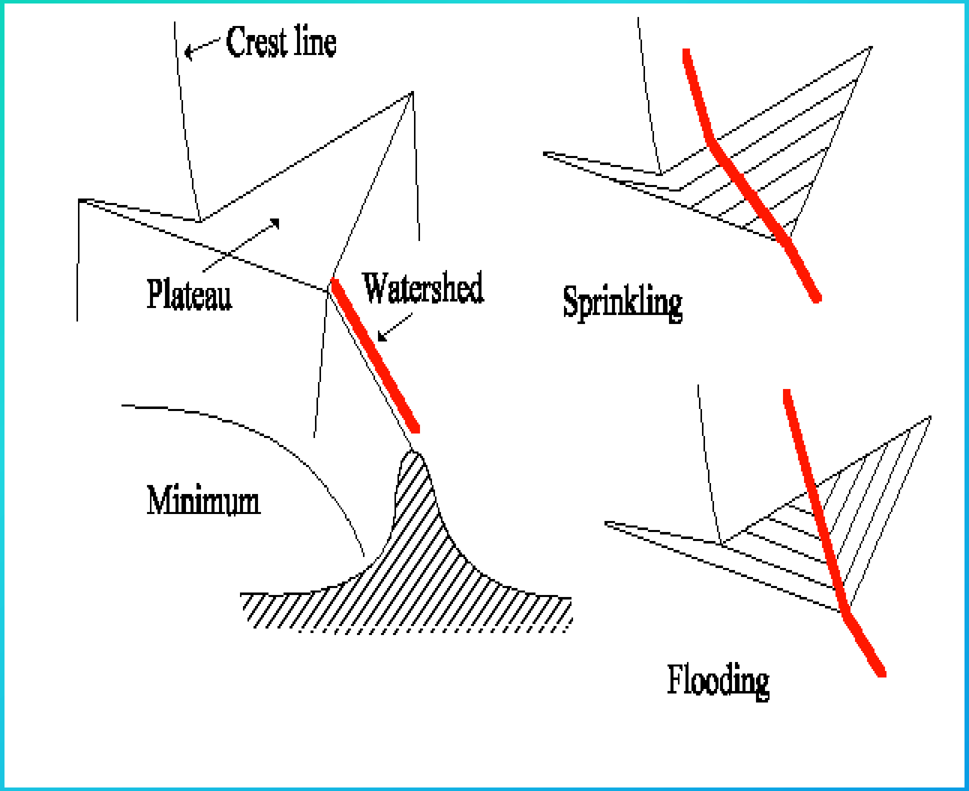
During flooding, all the points at the same height are flooded at the same time.

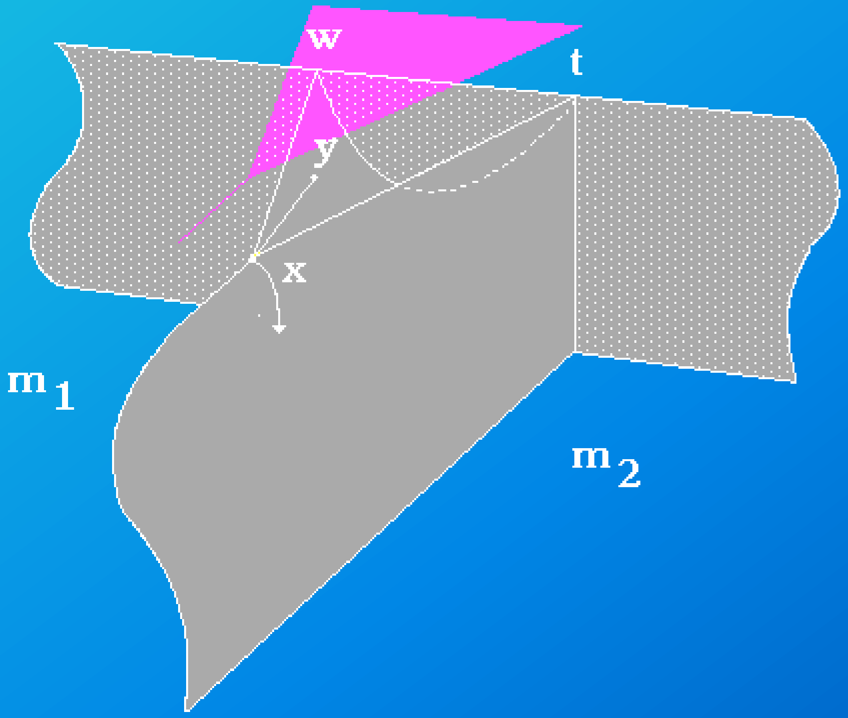
How do the drops behave on the plateaus? Constant speed?

The watershed by flooding produces a partition of the image (catchment basins). Is it also the case when we use a sprinkling model?

STREAMING and FLOODING

Plateaus



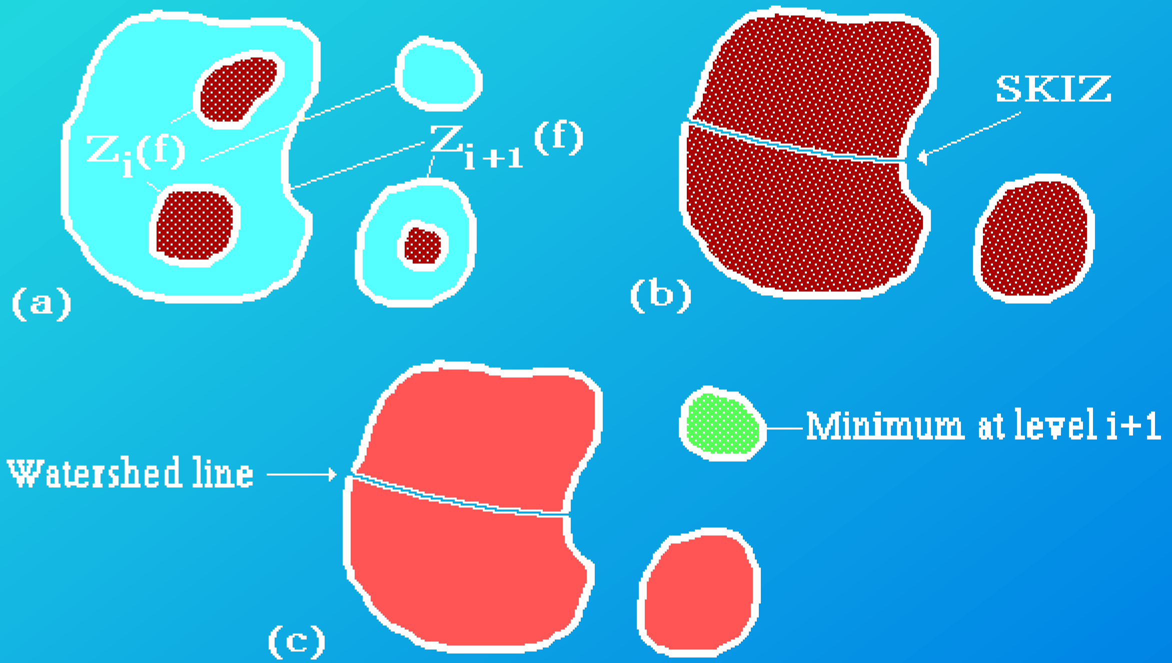


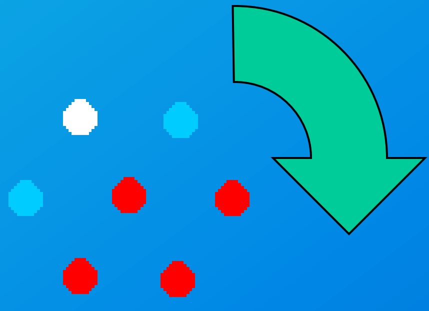
Button-hole structures

WATERSHED: ALGORITHMS & BIAS

Flooding level by level

- The flood propagation is performed by geodesic SKIZs
- Very simple
- Very slow
- Bias due to the use of homotopic thickenings

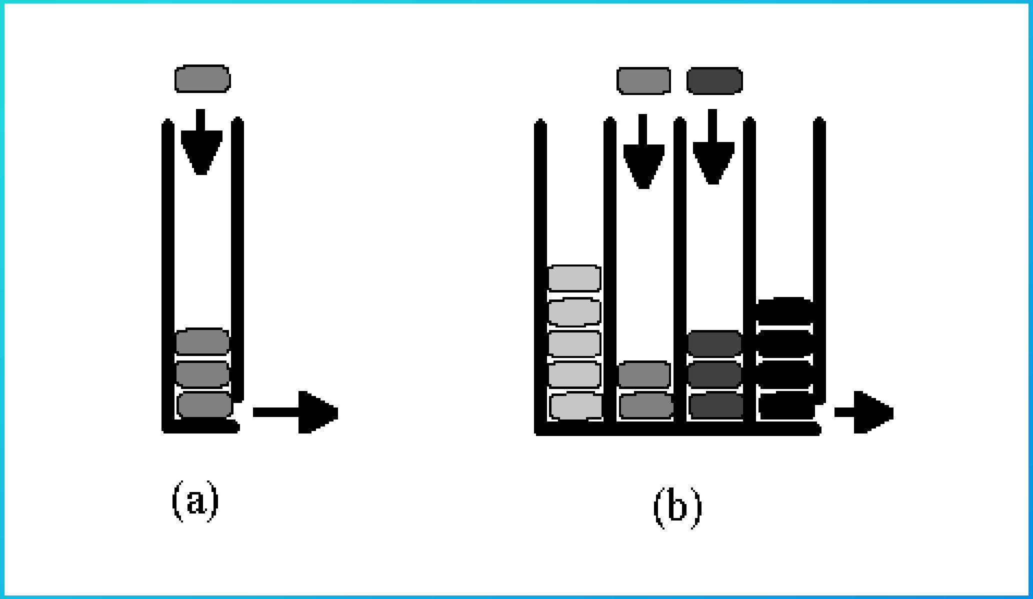




The skiz is performed by successive thickenings with rotated structuring elements

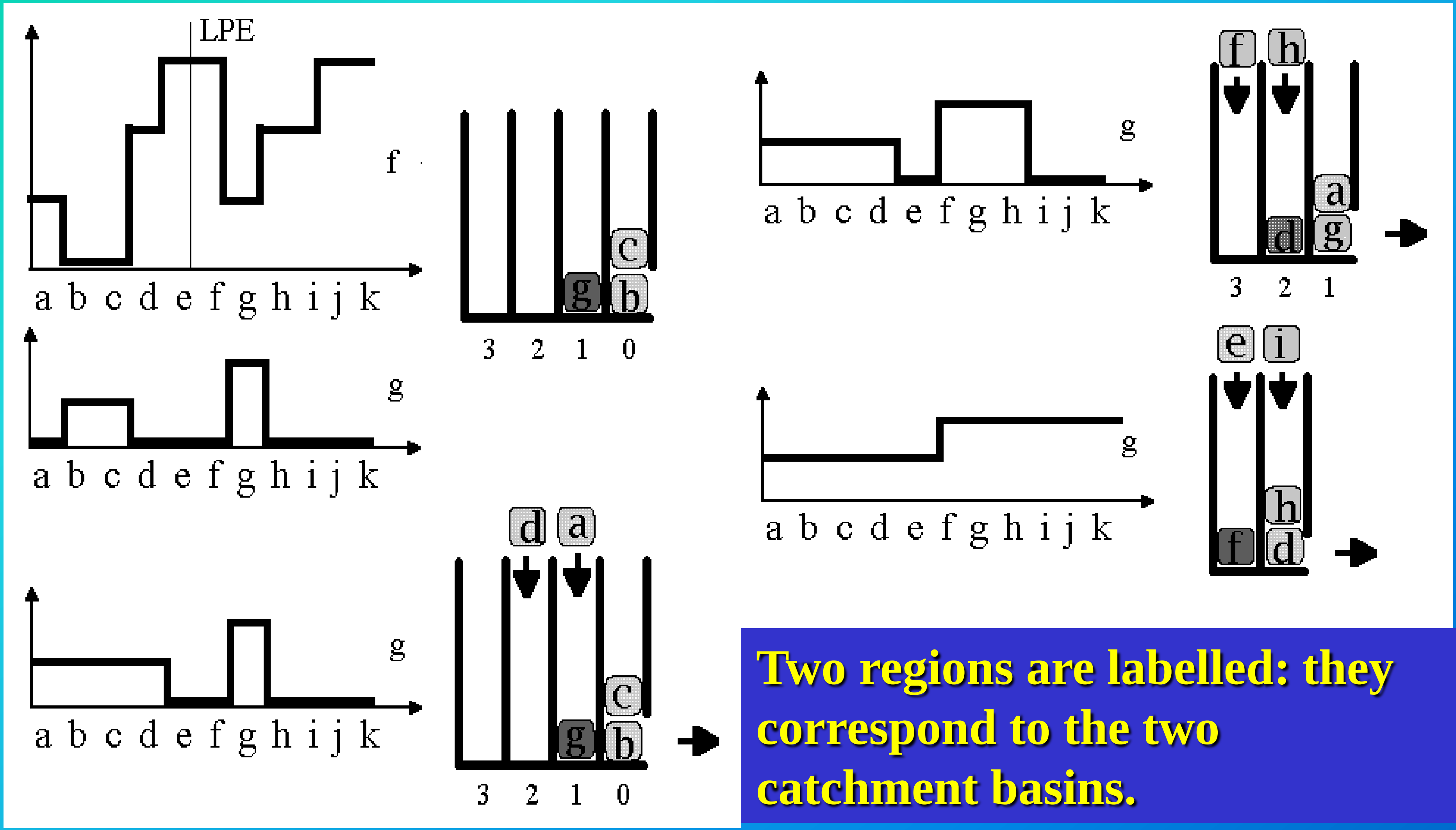
HIERARCHICAL QUEUES

- Flooding algorithm based on hierarchical queues
- Very fast (each pixel is processed once)
- Can also handle easily marker-controlled watersheds
- The result is unfortunately biased



The tokens correspond to the image pixels. A label memory stores the result of the labelling. Each token is put in the queue whose priority corresponds to the pixel value.

HIERARCHICAL QUEUES (Continued)



Two regions are labelled: they correspond to the two catchment basins.

THE MAJOR ISSUES IN THE WATERSHED ALGORITHM

The flooding process and the watershed construction is, *at the same time*, a sequential and a parallel process:

<u>Sequential</u>

- **You cannot process a point if there remain a point at a lower altitude which has not yet be processed.**
- **The flood propagation on the plateau is a sequential process (from the descending border to the ascending border of the plateau).**

<u>Parallel</u>

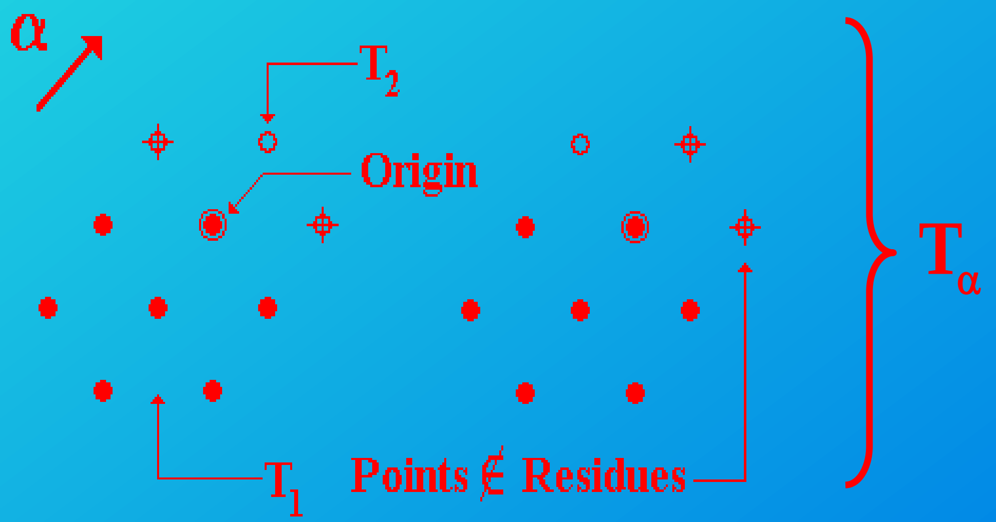
- **All the points at the same altitude or at the same distance from descending borders must be processed at the same time.**

BIASED AND UNBIASED WATERSHED

Watershed processing using union thickenings

Because the usual watershed uses directional thickenings, it does not fulfil the 2nd sequential requirement and the parallel requirement.

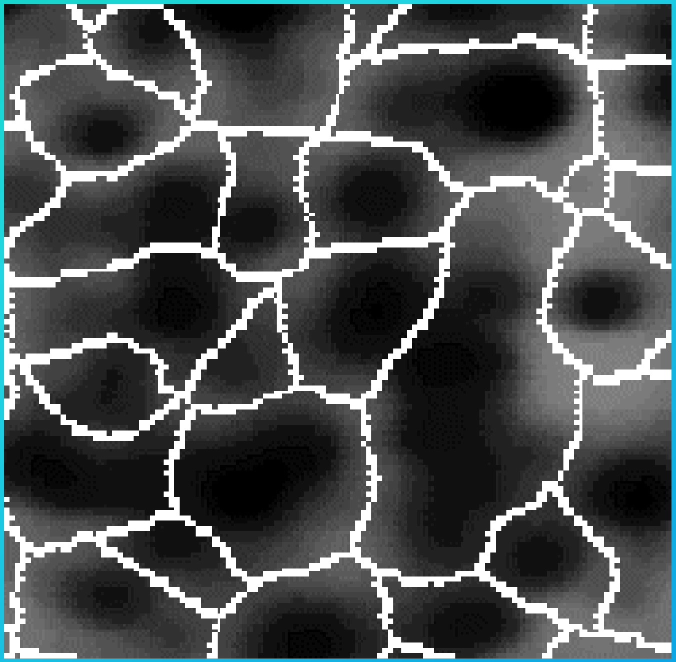
By using union thickenings, we can design an unbiased watershed algorithm (watershed lines are 1 or 2 pixels wide).



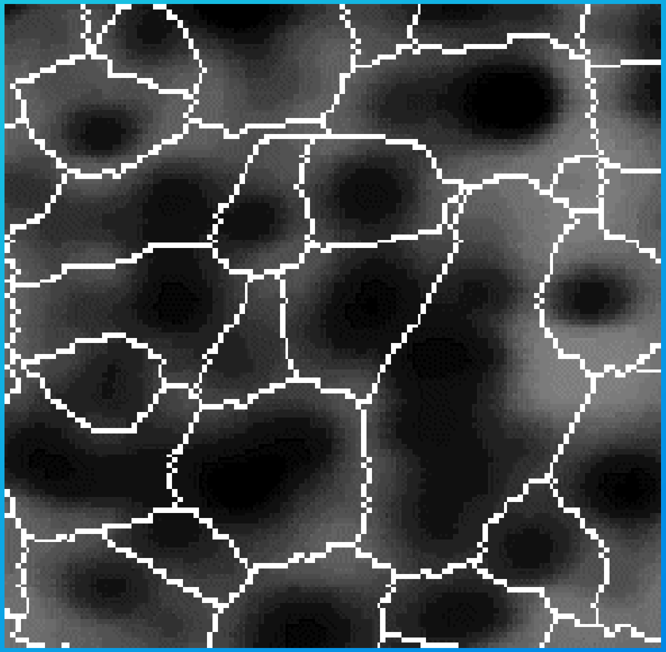
$$\text{Thick}(X) = \bigcup_{\alpha} (X \bullet T_{\alpha})$$

(homotopic thickening)

COMPARISON OF THE TWO ALGORITHMS



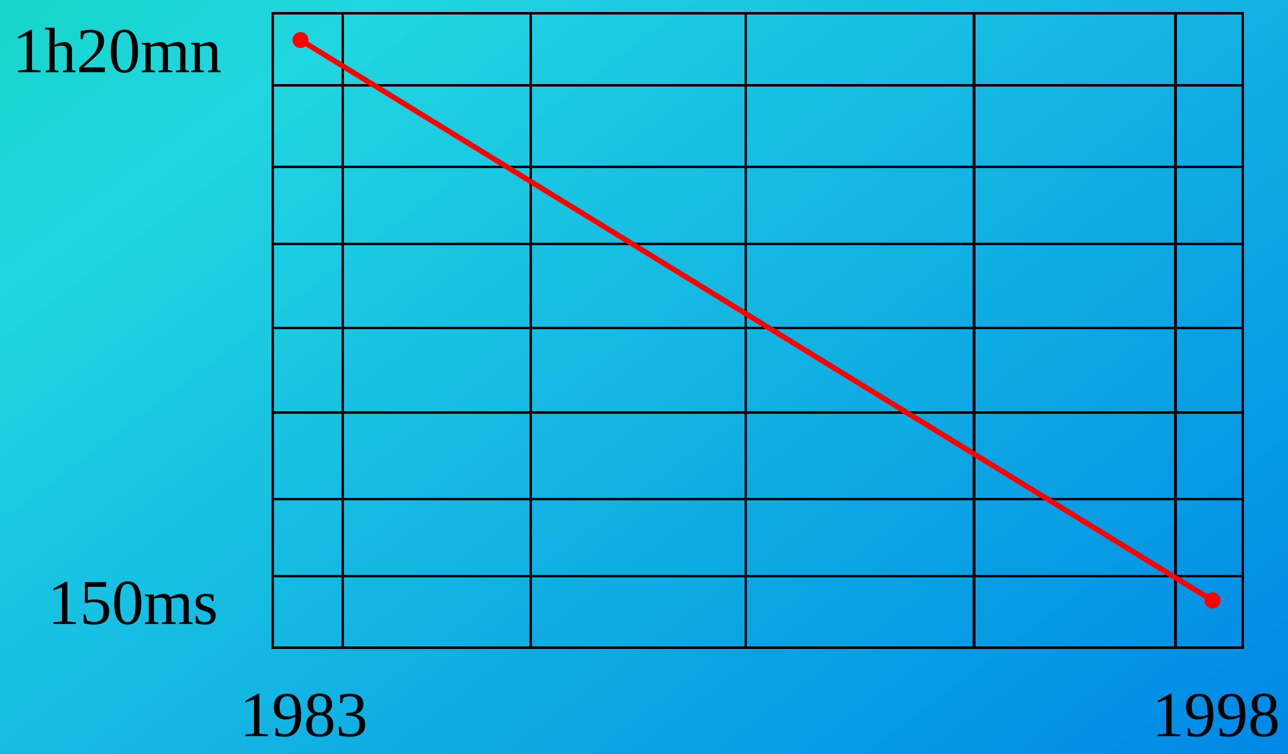
Unbiased watershed



Biased watershed

The bias may be very important!

SPEED OF THE WATERSHED



This leads to the following law:

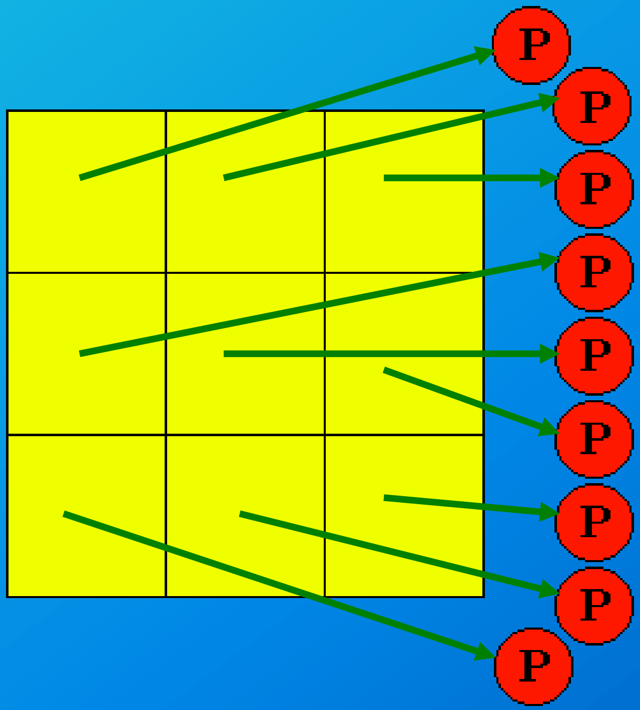
The speed of the watershed transformation doubles every year.

PARALLELISATION OF THE WATERSHED

The parallelisation of the watershed is a solution to increase its speed. But the algorithm must fulfil the requirements depicted above. So, the obvious approach consists in parallelising the parallel part of the flooding while preserving the sequential part.

Various approaches

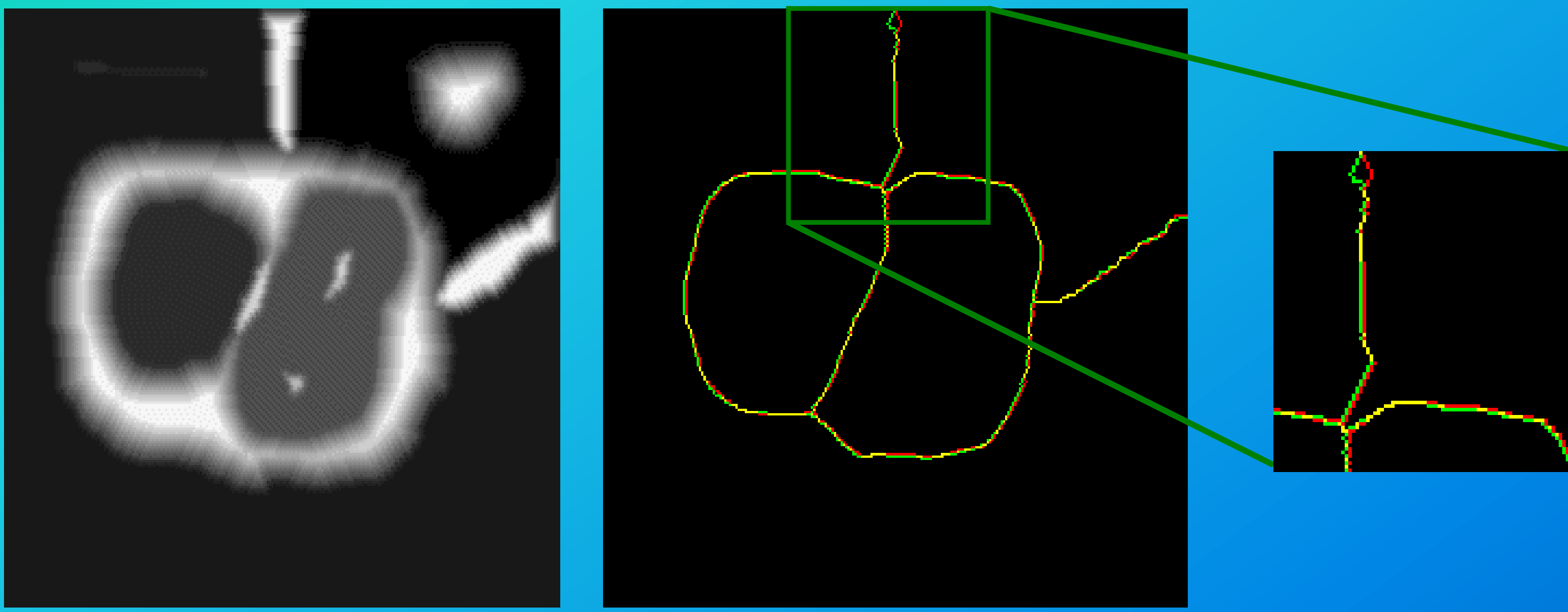
- sub-images
- multiple processors



The process must be supervised!

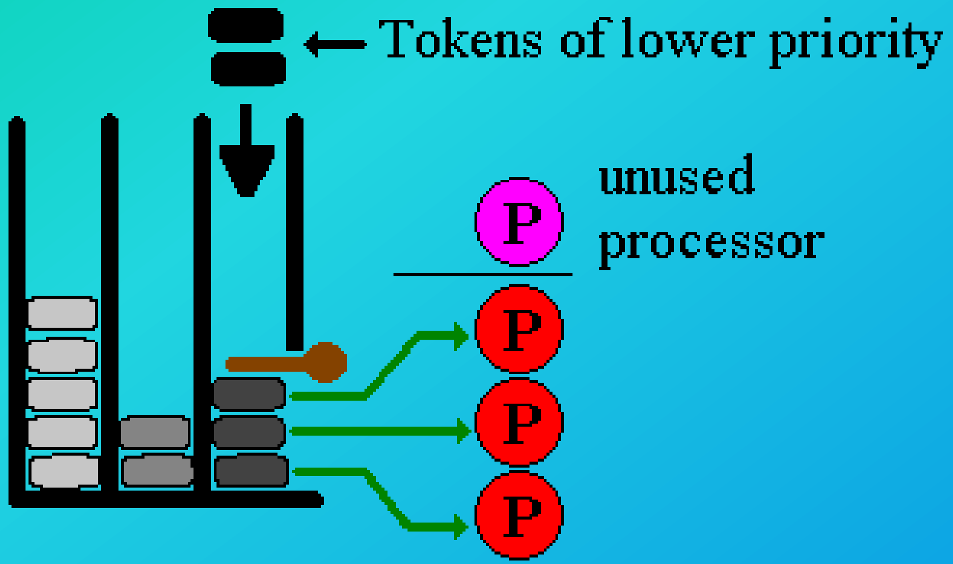
HIERARCHICAL QUEUES AND PARALLELISATION

The HQ algorithm is biased.



The two watersheds are different because the pixels are not processed in the same order inside the queues.

PARALLEL PROCESSING AND HQ



Another problem to be solved is the collision avoidance. The processors cannot write in the same location of the label memory at the same time.
This scheme shows the limits of the parallelisation. If you have more processors than pixels to process, many of these processors are idle.
Is it possible to increase the speed further? The problem is open.

WHY DO WE NEED UNBIASED WATERSHEDS?

The status of the watershed transformation has changed as its speed was increasing. It was considered as the final step of a long and tidious segmentation process. Now, it is viewed as the initial and basic step which allows to enter more and more complex image analysis processes. It is in particular the case for:

- **Multi-criteria segmentations**
- **Segmentation of sequences**
- **Hierarchical segmentation**

MULTI-CRITERIA SEGMENTATION

Return to the segmentation paradigm

One segmentation criterion is used. When multiple criteria are needed, the classical approach consists in defining a simple criterion function.

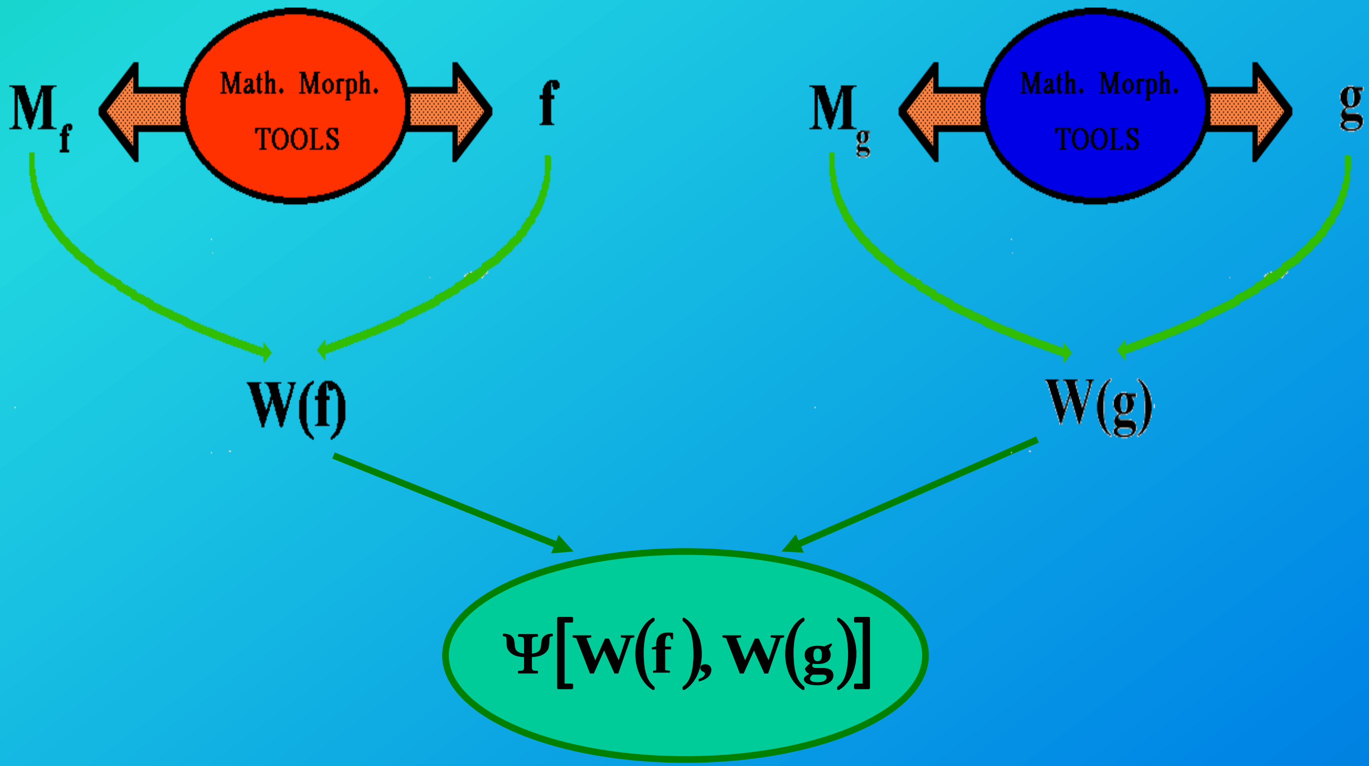
Example: *color segmentation*

$$\left.\begin{array}{l}\text{Hue H}\\ \text{Luminance L}\\ \text{Saturation S}\end{array}\right\} \quad g = \text{grad}(H) + \text{grad}(L) + \text{grad}(S)$$

The color image segmentation is obtained by the watershed of g.

MULTI-CRITERIA SEGMENTATION (continued)

Would it be possible to use different segmentation criteria to produce different watersheds and compare them afterwards?



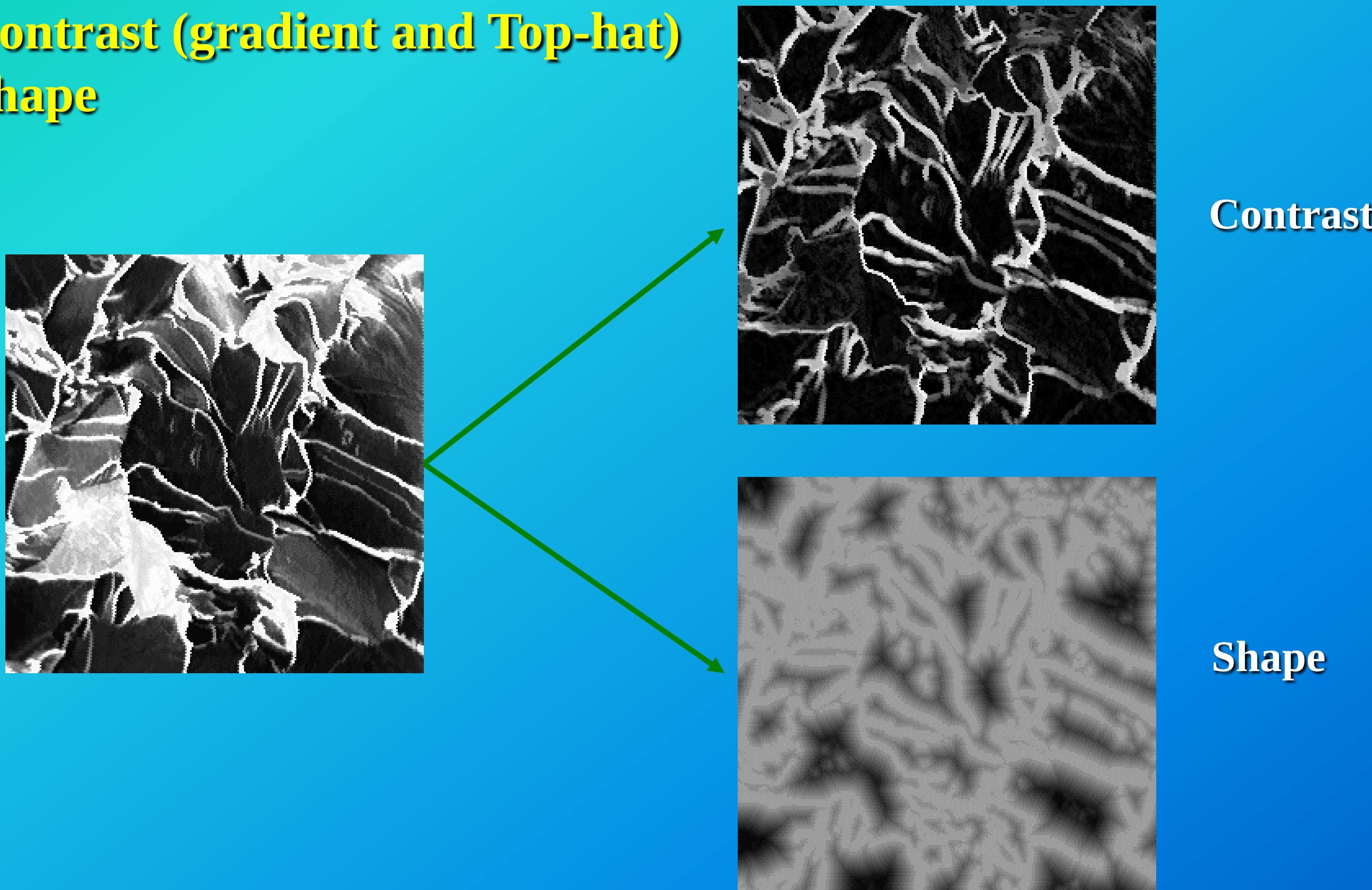
To do this, the watersheds must be unbiased.

Example: ***fracture in steel***

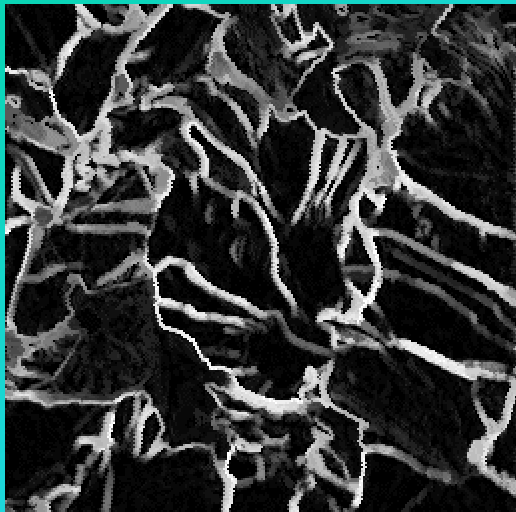
FRACTURE FACETS IN STEEL

Two criteria are used:

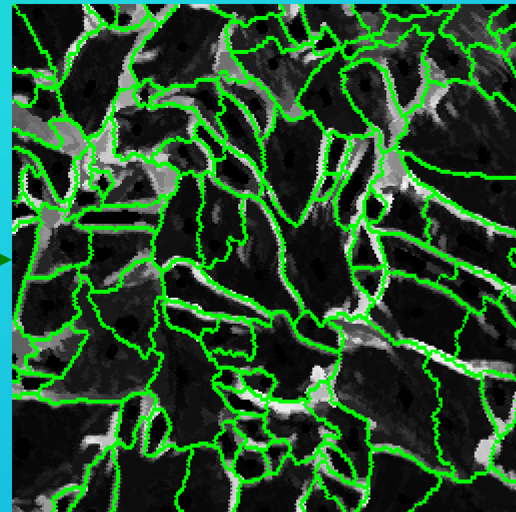
- **Contrast (gradient and Top-hat)**
- **Shape**



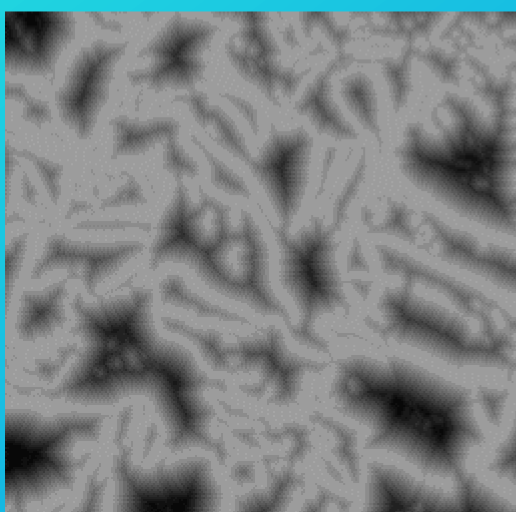
FRACTURE IN STEEL (continued)



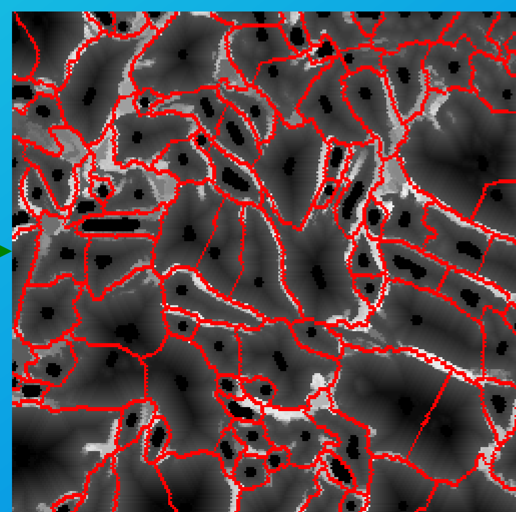
Contrast criterion



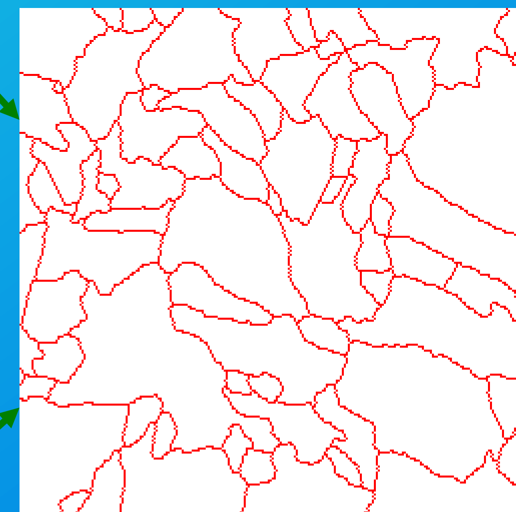
Contrast watershed



Shape criterion



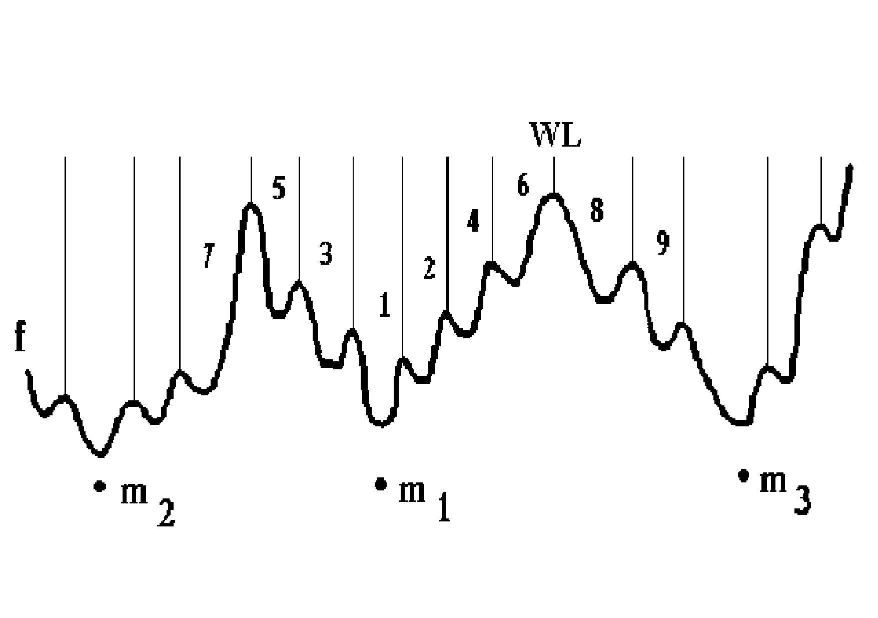
Shape watershed

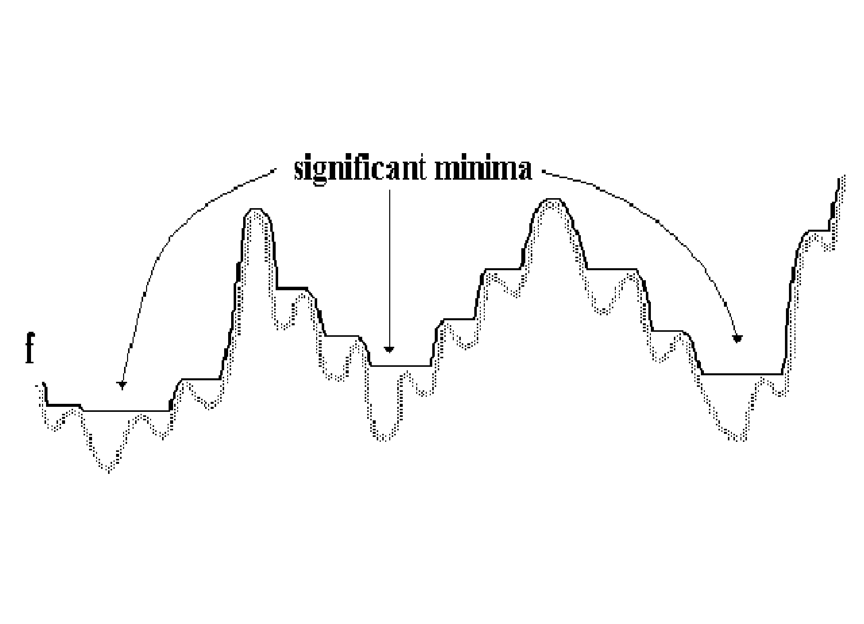


Segmentation based on the two criteria

HIERARCHICAL SEGMENTATION

Example of hierarchy: the waterfall transformation





The initial watershed of the image is used in a geodesic reconstruction. The watershed of the reconstructed image produces a higher level of hierarchy.

HIERARCHICAL SEGMENTATION

Original image

First level of hierarchy

Second level of hierarchy

CONCLUSION

Speed and accuracy of the watershed

The watershed transformation must be fast and accurate. These two requirements are not incompatible. They are the key to future developments (algorithms and applications).

Future developpements

- New watershed algorithms and parallel processes
- New hierarchisation algorithms
- Multi-criteria segmentation
- Multimedia applications
- Real-time image analysis