Sao José Dos Campos, Feb. 1997

Brazilian Workshop on Mathematical Morphology

THE TIME DIMENSION IN MATHEMATICAL MORPHOLOGY

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BIBLIOGRAPHY

- **Connected Filters :**
  - J. Serra, Ph. Salembier ;
- **Marked and/or Recursive Watersheds :**
  - S. Beucher, F. Meyer ;
- **Filering for Sequences :**
  - E. Decencière, J. Serra, M. Pardas.
- **Region merging :**
  - M. Pardas, Ph. Salembier, F. Marques, F. Meyer
- **Region merging under markers :**
  - B. Marcotegui,

(See in particular the proceedings of ISMM symposia, Kluwer 94, 96)

PLAN

- **Introduction**
  - sequences
- **Watershed Based Segmentation** :
  - still images
  - motion (image sequences)
  - Discussion
- **"Bottom-up" Approach by Regions Merging**:
  - still images
  - image sequences
- **Results**

IMAGE SEQUENCES

- **What is a sequence?**
  - a time succession of 2D images.
- **Main feature of a sequence :**
  - a strong time redundancy
- **How to use it ?**
  - by designing time robust segmentations.

PURPUSES FOR SEQUENCE ANALYSIS

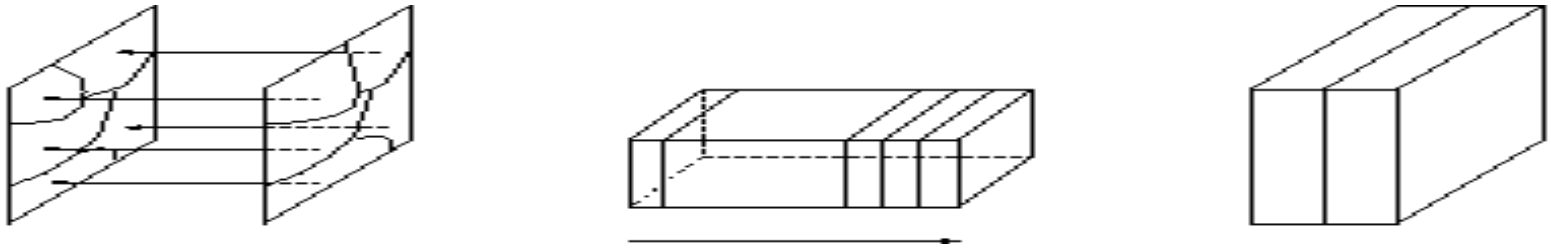
- **Movies and Video:**
  - restoration of old movies ;
  - image compression and/or coding ;
- **Robotics :**
  - automatic control and tracking of persons or objects ;
  - automatic car driving ;
- **Physico-Chemistry :**
  - quality control by vision may concern sequences : chemical reactions, deformations under constraints, etc...
- **Challenge : try and extract significant features from the variation along the time.**

PROCESSINGS UNDER TIME DIMENSION

Is it preferable :

- to process each plane independently,
- or to consider the product Space ⊗ time as a whole,
- or to condition the processing of plane t by the content of plane t-1 ?

2D approach ***3D approach*** ***Recursive approach***



2D APPROACH

Independent segmentations of the successive images

Image n° i

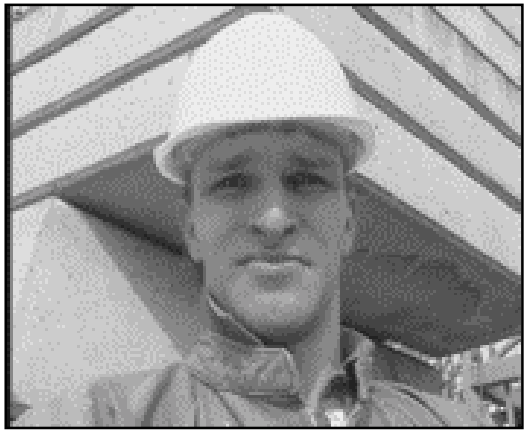


Image n° i + 1

3D APPROACH

Principle : The stack of images is considered as a **unique** image of three dimensions. However, the processing may be preferential in time direction

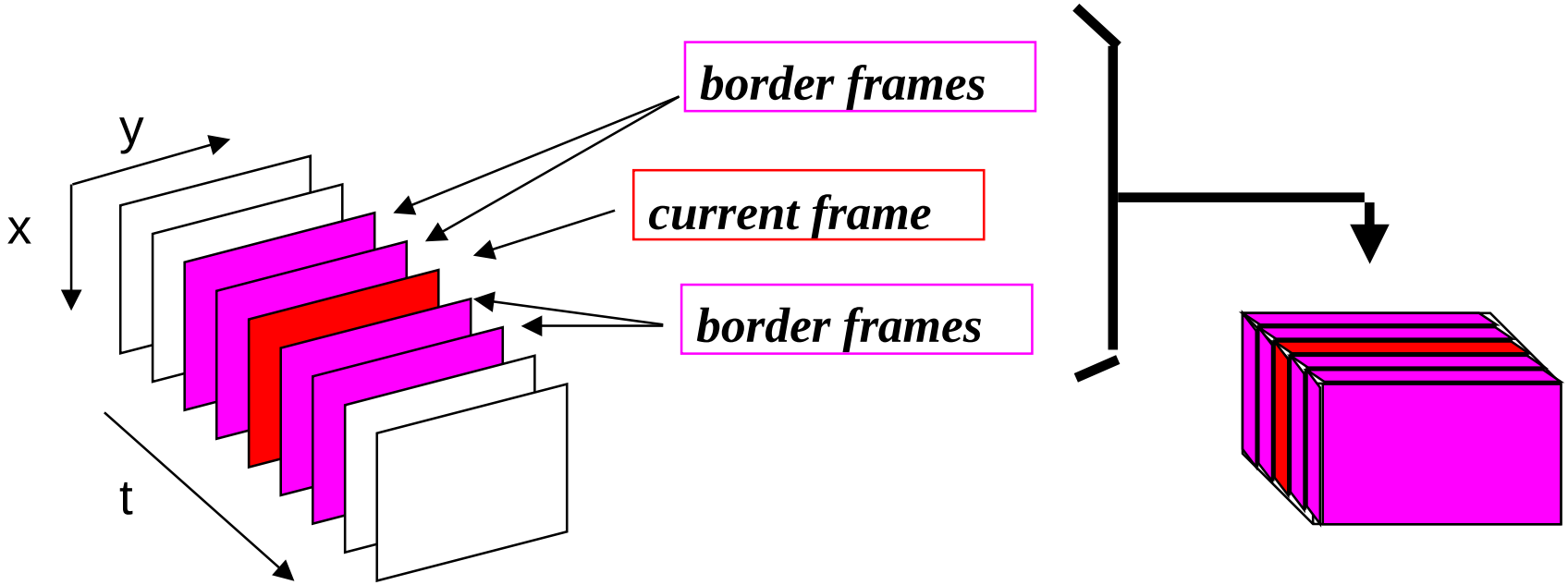
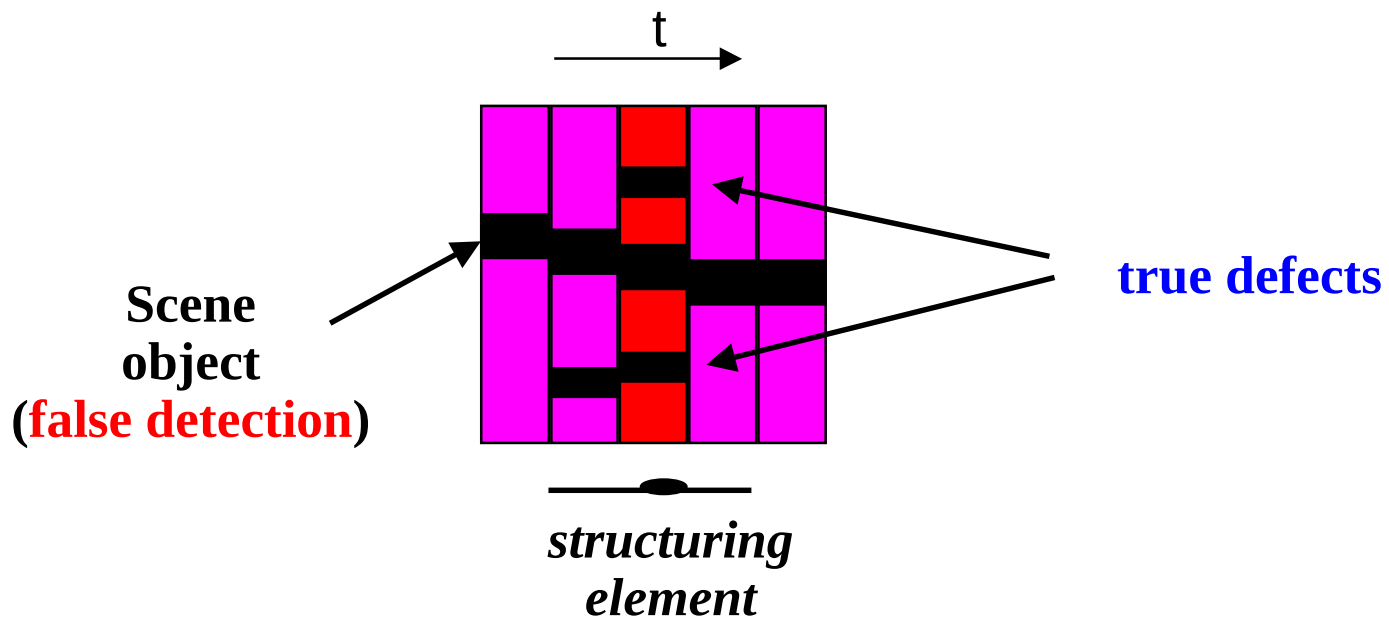


Image Sequence **Working Image**

3D APPROACH : RESTORATION OF OLD MOVIES

Detection along the time axis ⇒ **sorting between false detections and true defects**



METHOD: top-hat by reconstruction along the time axis

EXAMPLE OF 3D CONNECTED FILTERING

Louis Lumière's movie intitled "Arrival at Sydney Station", 1898 .

Initial image,
extracted from the sequence

filtered image

REMINDER : MORPHOLOGICAL SEGMENTATION

The classical morphological segmentation paradigm comprises the three following steps :

– **1 Simplification**: removes non pertinent features of the image

→ **CONNECTED FILTERS**

– **2 Marking** : places a marker inside every homogeneous region

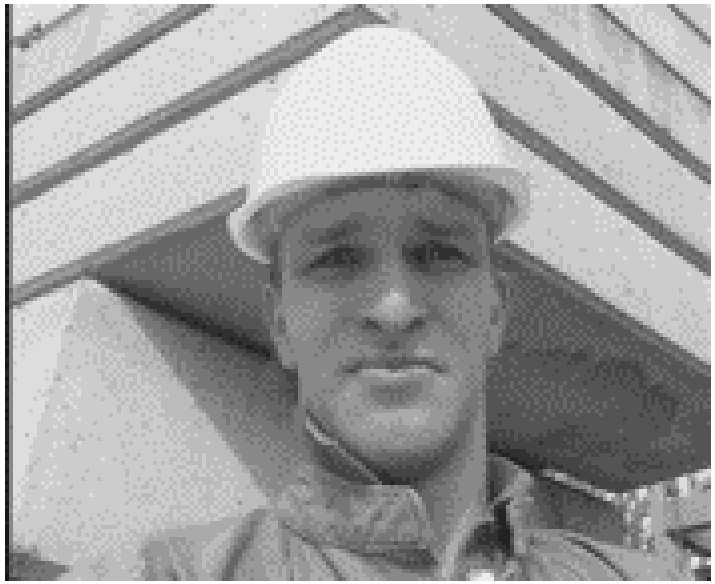
→ **DYNAMICS**

– **3 Markers growth** : draws the contours of the marked objects

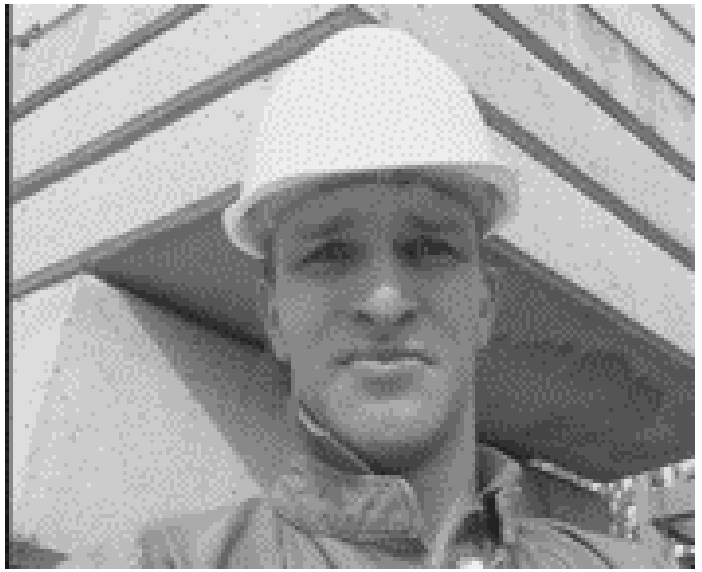
→ **WATERSHEDS**

REMINDER : CONNECTED FILTERING

The connected filter chosen here is a closing∘opening by flat zones areas



- *Original image*
- *16717 regions*



- *Area filter, size 60*
- *9424 regions*

REMINDER : MARKERS EXTRACTION

- *Number of regions versus the dynamics of the gradient*

- *The 75 markers of higher dynamics*

REMINDER : VARIOUS CHOICES OF MARKERS

Markers extraction by dynamics

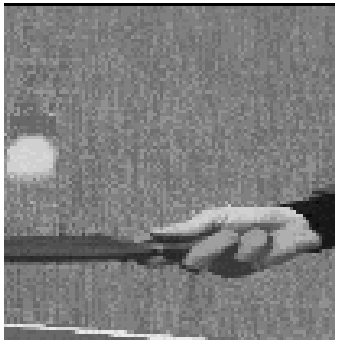
Markers extraction by dynamics and sizes

AN EXAMPLE : ROAD DETECTION

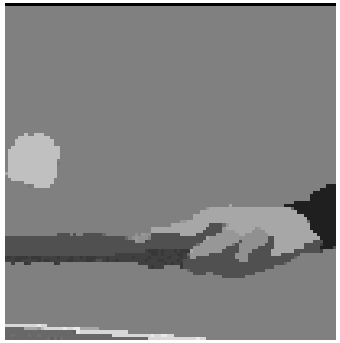
Method : The inside marker is the erosion of segmentation n° t-1, and the outside one is the upper horizontal line of the field (the sky).

Initial image n° t

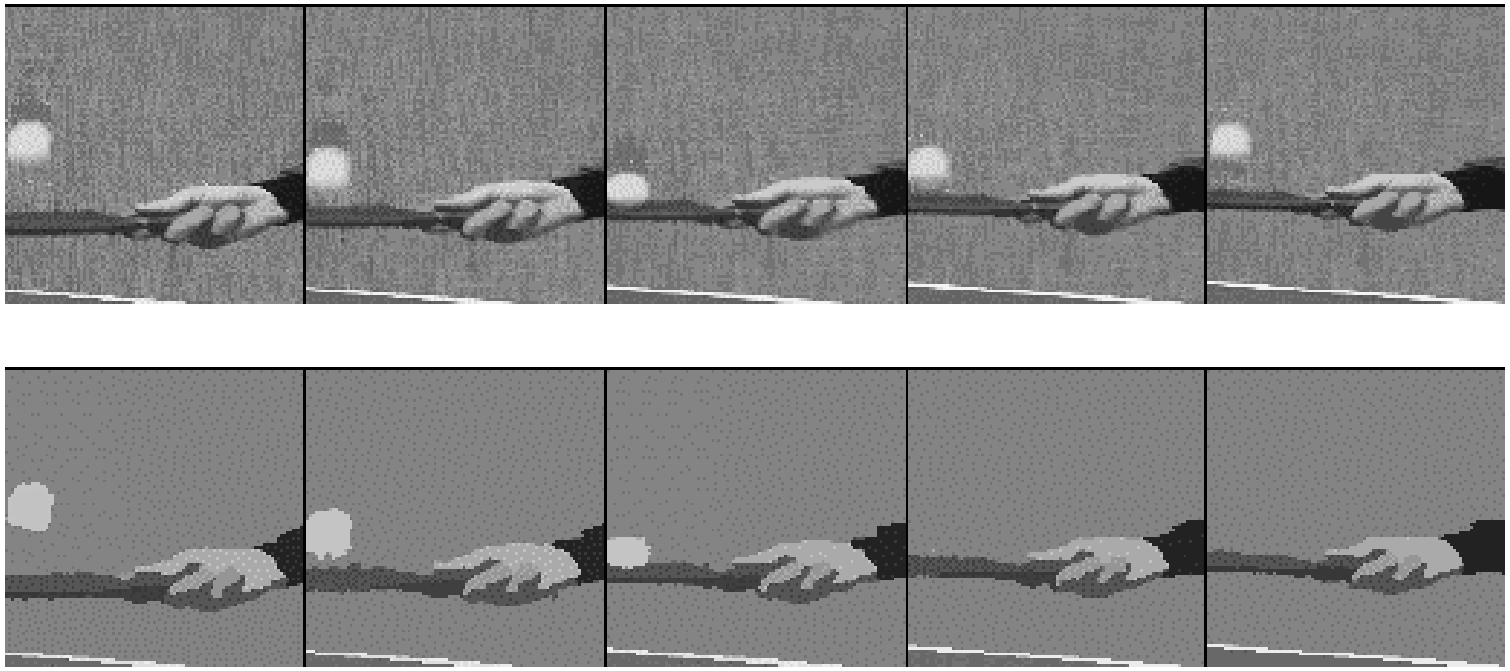
Segmentation of image n° t



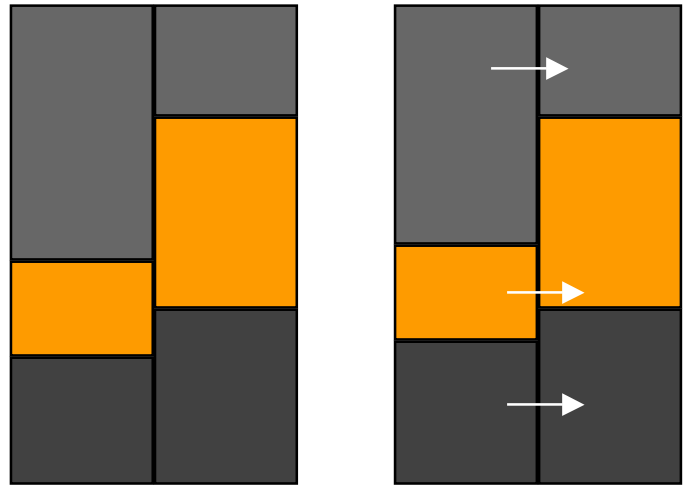
A COUNTER EXAMPLE



What happened to the ping-pong ball ?

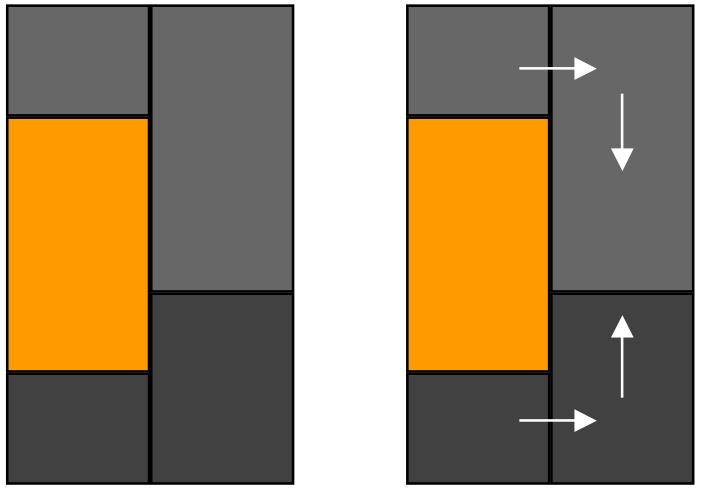


BEHAVIOURS IN RECURSIVE APPROACHES (I)



Motion **without** time disconnection

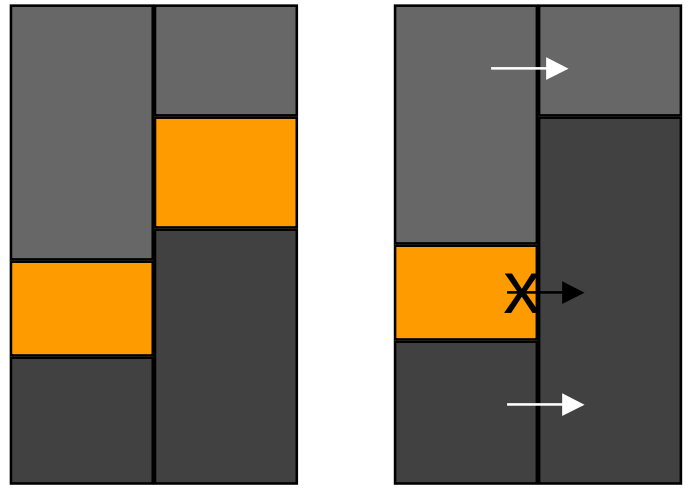
correct result



a region vanishes

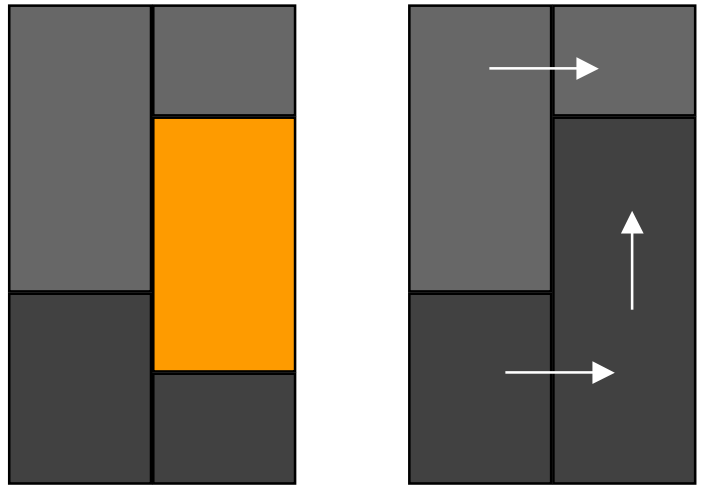
correct result

BEHAVIOURS IN RECURSIVE APPROACHES (II)



Motion **with** time disconnection

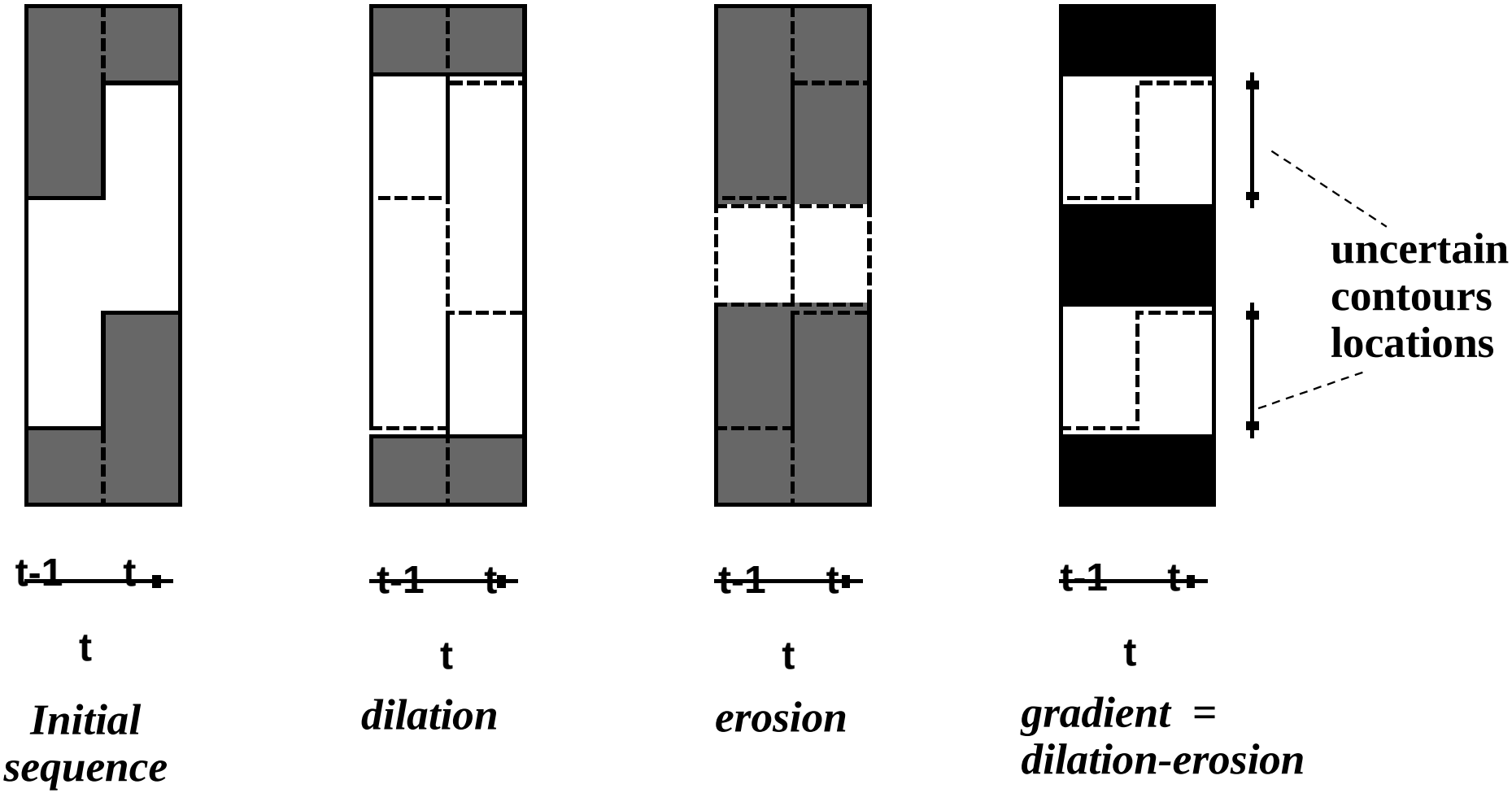
Mistake



a new region appears

Mistake

ANOTHER TROUBLE : THE 3D GRADIENT



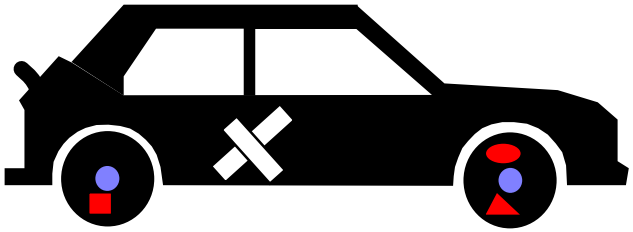
CONCLUSIONS

The usual 2-D morphological segmentation, which is based on the marked watershed of the gradient,

– cannot manage the **arrival of new regions** (note that in some simple cases, the number of regions remains constant: *e.g.* road segmentation);

– in addition, the 3D **gradients are coarser** than the 2D ones, which makes the limits of the regions not precise.

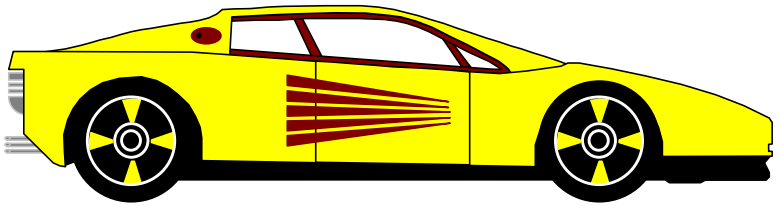
WHAT TO DO ?



To keep using a model which needs band aid ?

¿

?



...or to look for a new paradigm ?

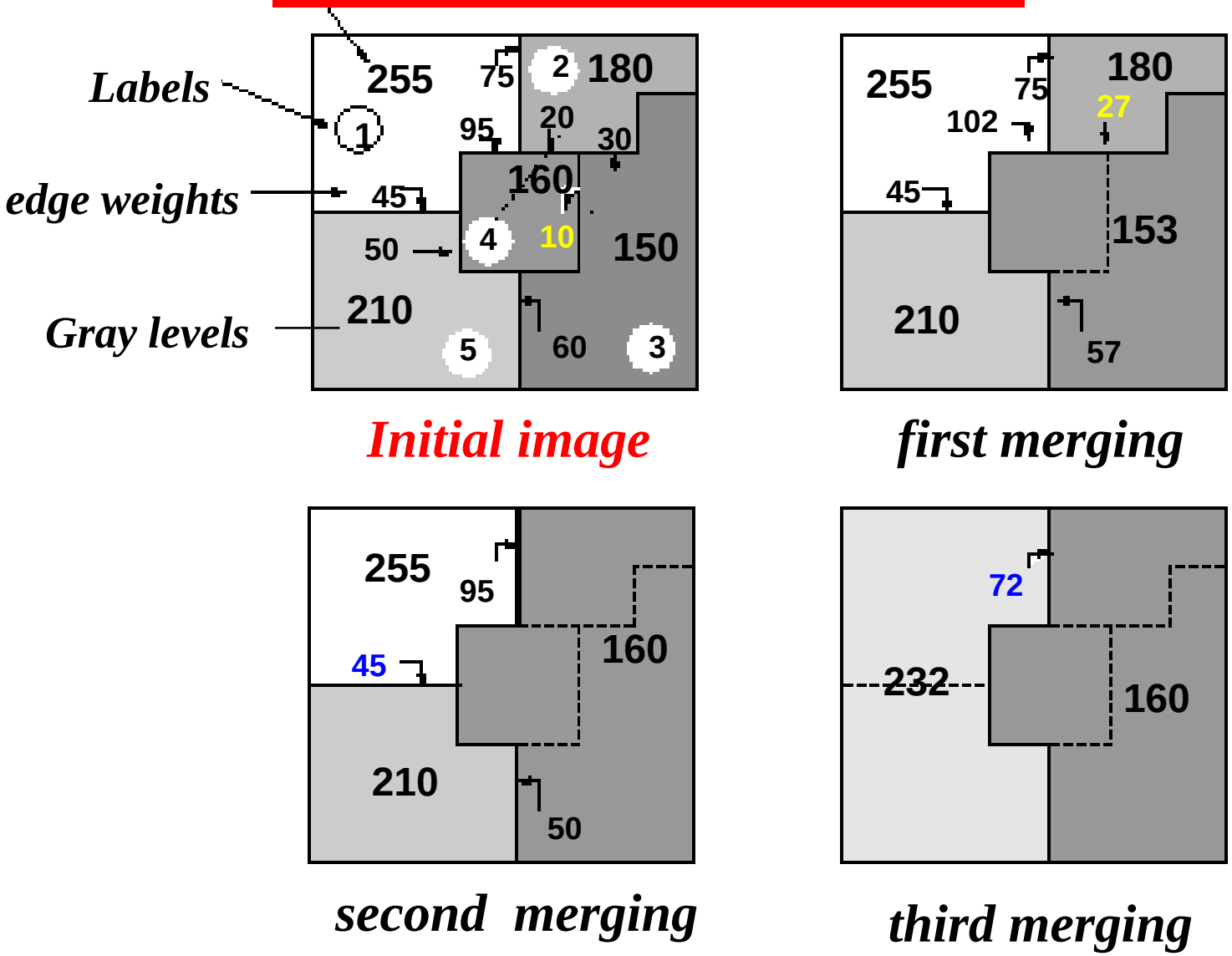
REGION MERGING (I)

- **Definition :**
  - P_i is a partition of the image.The most similar adjacent regions of P_i merge, which generates partition P_{i+1} .
- **Properties :**
  - Iterative process, where each iteration provides a partition coarser than the previous one:

$$\mathbf{P_0 \preceq P_1 \preceq P_2 \preceq \ldots \preceq P_n,}$$

  - where P_{i+1} has exactly one region less than P_i

REGION MERGING (II)



REGION MERGING (III)

- **Advantages**
  - solves the resolution problem;
  - works at the level of the flat zone;
  - merges iteratively the two regions which are the more similar, without introducing a priori markers;
  - generates nested partitions on which decision trees may be designed.
- **Drawbacks**
  - demands the re-evaluation of all borders at each step;
  - provokes leak effects (*i.e.* parasite additional lines)

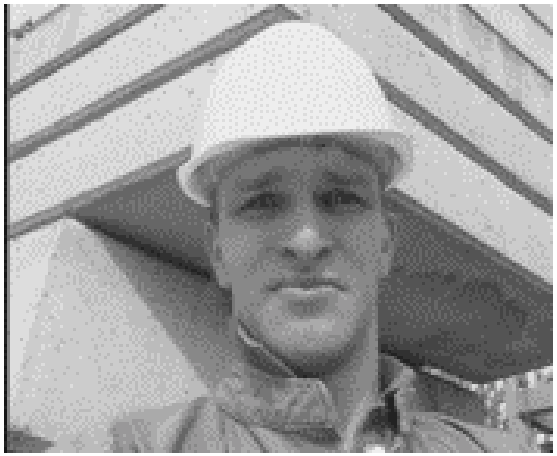
EXHAUSTIVE MERGING ALGORITHM

- **Initialisation:**
  - Introduce a quality criterion κ and a stop criterion σ;
- **Elementary step:**
  - Attempt to merge separately each pair of adjacent regions, and evaluate criterion κ in each case;
  - find out "the" best pair with respect to κ
  - actually merge this pair;
  - re-evaluate the borders around the new region;
- **Iteration:**
  - iterate until the stop criterion σ is reached.

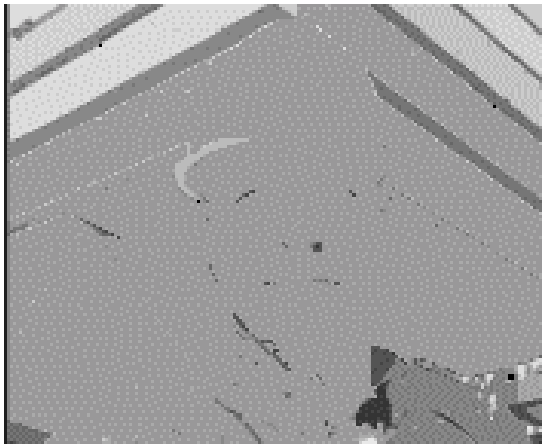
SUB-OPTIMAL MERGING ALGORITHM

- **Initialisation:**
  - Introduce a **local** criterion λ (*e.g.* local contrast), a quality criterion κ and a stop criterion σ;
- **Elementary step:**
  - Evaluate λ for each border of adjacent regions, and keep "the" lower one;
  - check whether the merging preserves criterion κ. If so, merge the two regions ; if not take the second smaller λ , etc..
  - re-evaluate the borders around the new region;
- **Iteration:**
  - iterate until the stop criterion σ is reached. Note that the pairs that don't preserve κ will stay disjoint in the final segmentation

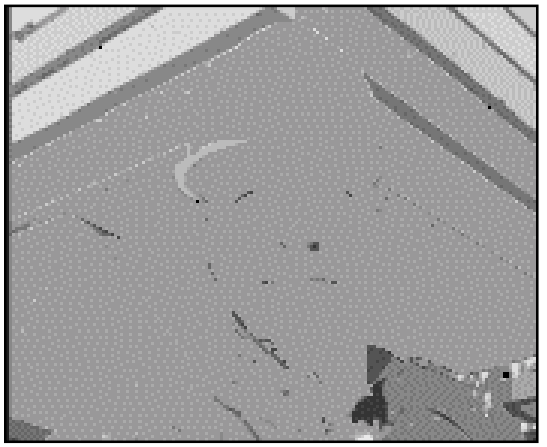
RAW APPLICATION OF THE ALGORITHM



original image



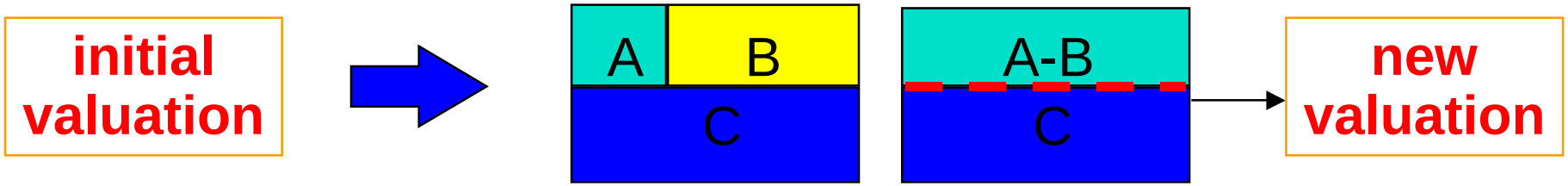
segmentation into 1262 regions,...



...among which, 1080 isolated pixels

Here, "raw" means without re-actualisation of the borders, and without pre-filtering. Note the considerable amount of regions reduced to one pixel.

1rst IMPROVMENT : RE-EVALUATIONS



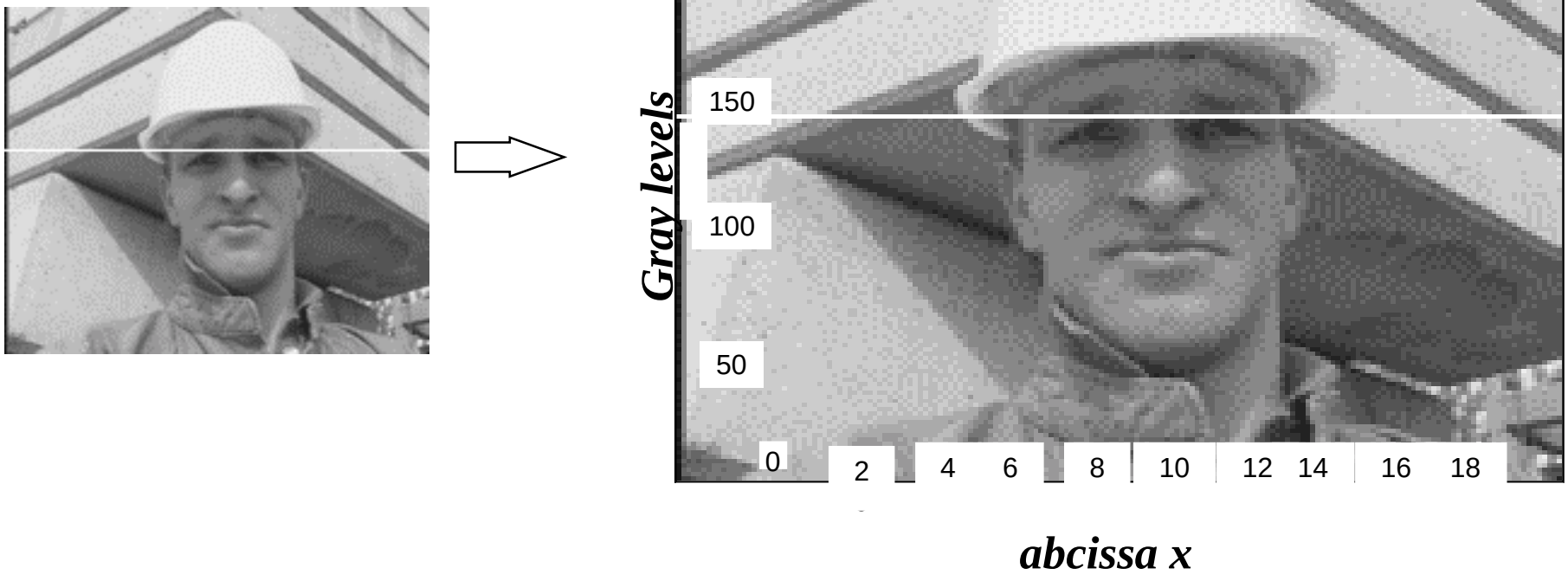
initial image

segmentation into 550 regions

including 422 isolated pixels

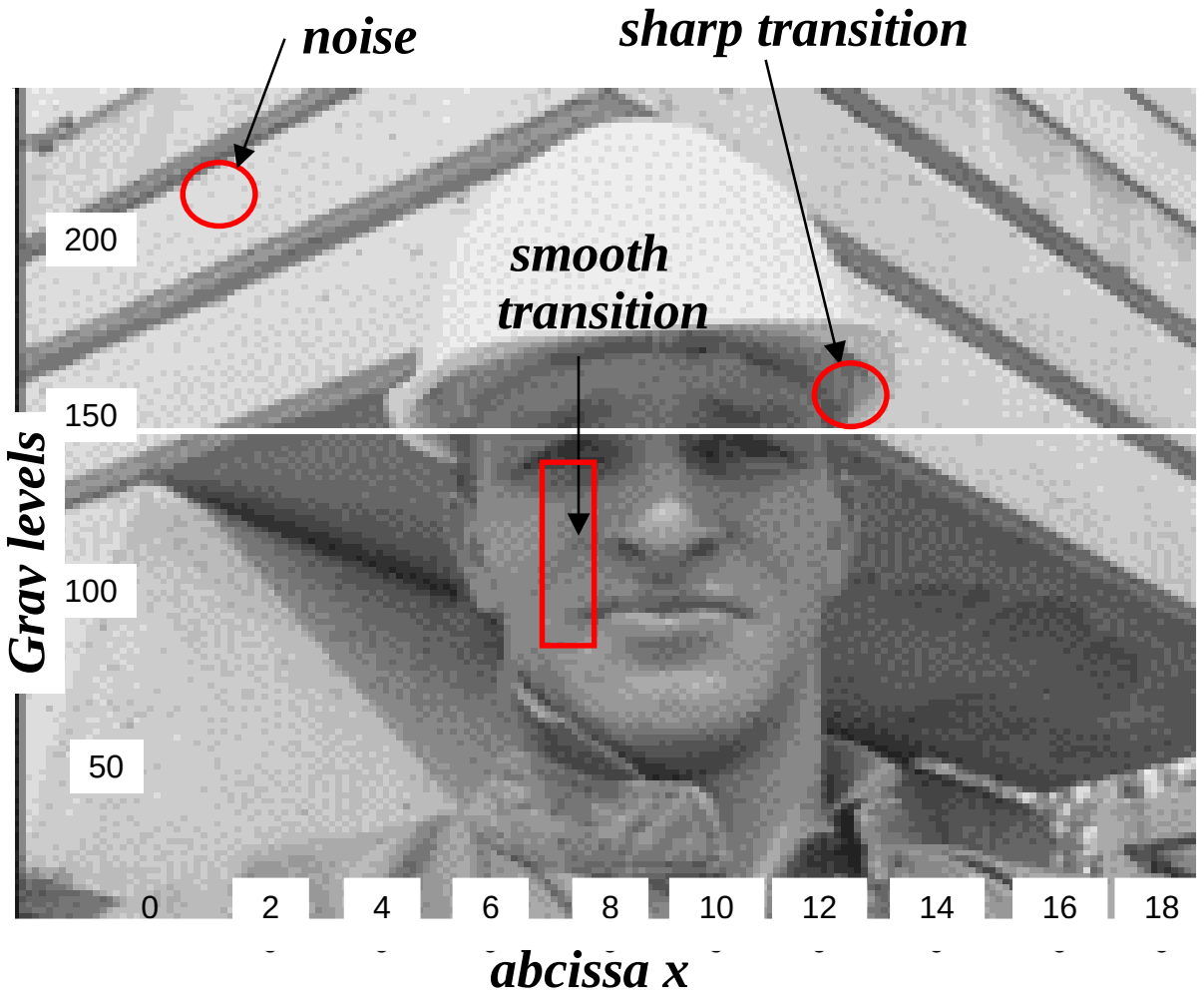
The re-evaluations return correct greys, but isolated pixels are still there.

GRAY PROFILE ALONG LINE 59



ANALYSIS OF THE PROFILE

Conclusion: neccessity of a pre-processing



PRE-PROCESSING

- **Goal :**
  - The goal of the pre-processing is to suppress non significant features in the image, which disturb the segmentation.
- **Means :**
  - Treat separately the small peaks (and sinks), and the small or narrow steps :

{ small peaks and sinks ⇨ 2D or 3D connected filtering,

small or narrow steps ⇨ region growing algorithm, based on a size criterion

EXAMPLE OF PRE-PROCESSING

Initial image

Filtered image

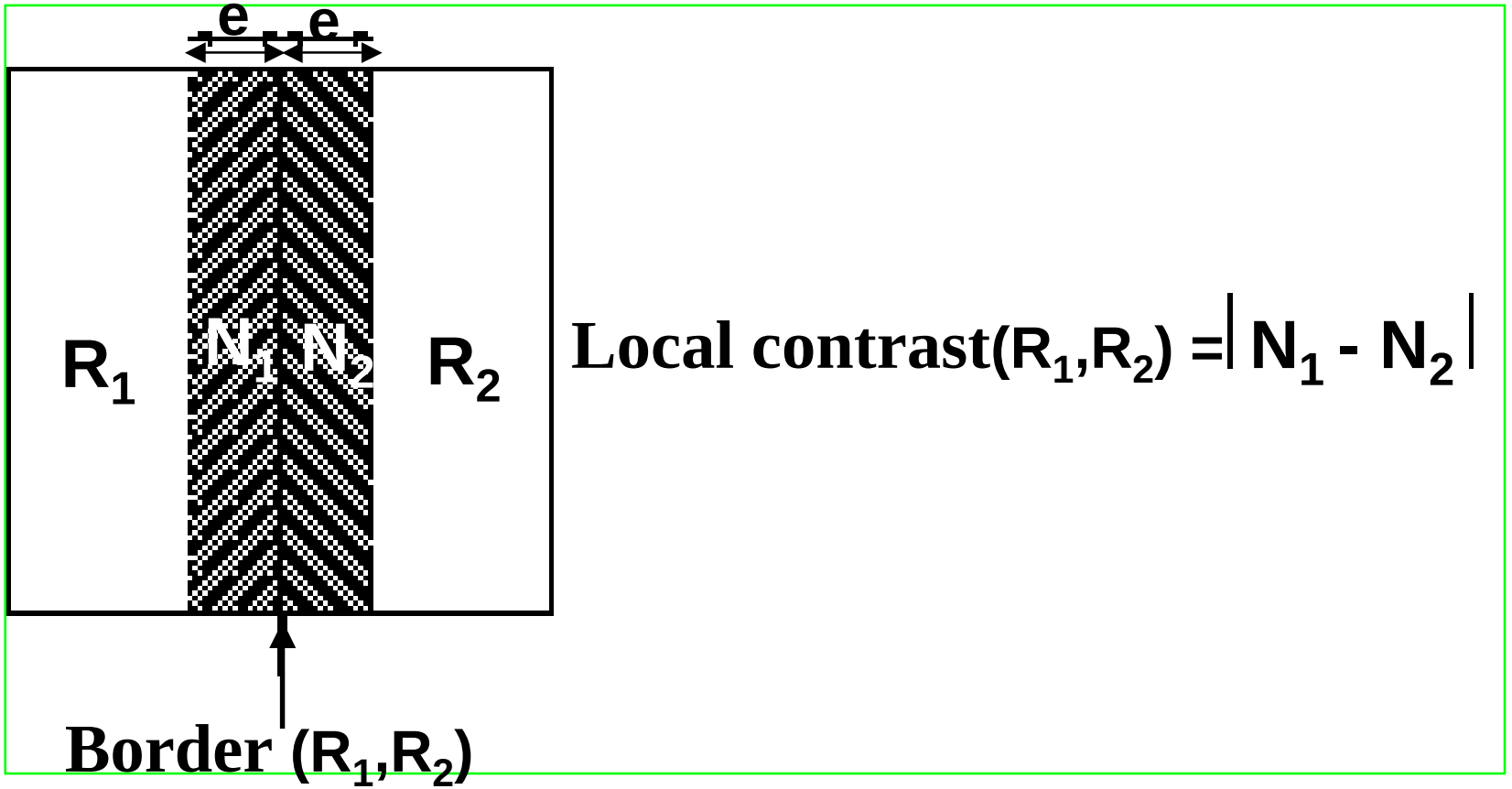
Small steps (in black)

Result of the pre-processing (735 regions)

CRITERIA FOR FUSION

- **Contrast:**
  - difference between the mean gray values of of two adjacent regions;
- **Local contrast :**
  - contrast in a stripe centred along the border;
- **Texture :**
  - similitude with respect to a given model of texture.

LOCAL CONTRAST



$$\text{Local contrast}(R_1,R_2) = |N_1 - N_2|$$

LOCAL CONTRAST: AN EXAMPLE

averaged gray levels

99 regions
4966 contour points

FUSION BY TEXTURE

Ovoids splitting regions relevant on a same texture model

99 regions
4966 contour points

⇩

13920 bits
(previous result)

32.15 dB

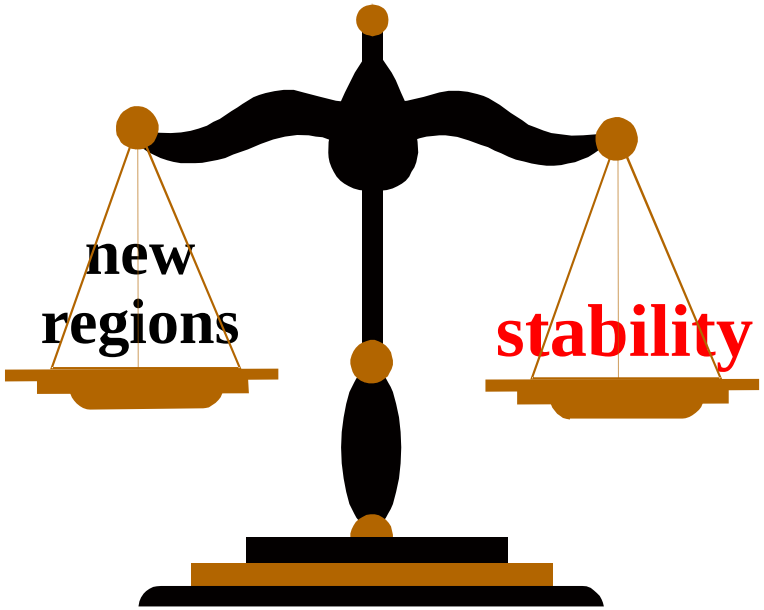
71 regions
4379 contour points

⇩

11352 bits

31.83 dB

SEGMENTATION OF SEQUENCES



- Merging of regions ⇨ avoids a choice of markers
- Markers ⇨ ensures stability

REGION MERGING UNDER MARKERS

Cross criterion: Any pair of neighbour regions may merge, unless both are marked.

	markers growth	*region merging under markers*
marker / non marker	merging allowed	merging allowed
non marker / non marker	merging forbidden	merging allowed
marker / marker	merging forbidden	merging forbidden

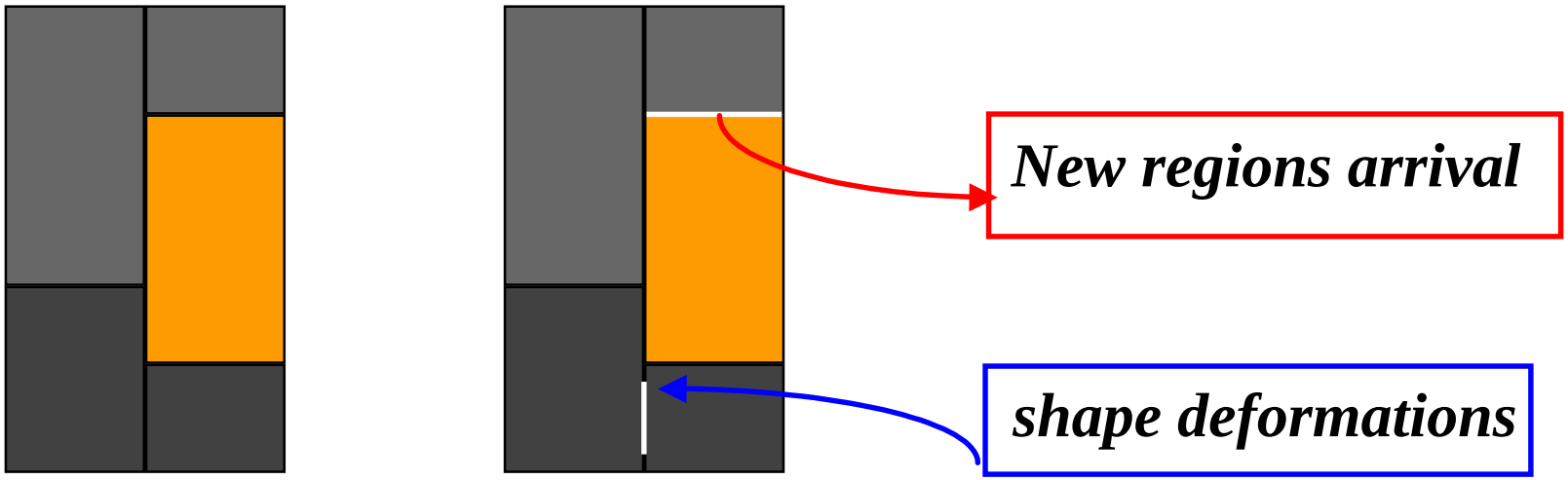
By comparison with pure marker growth, the above cross criterion is more flexible, and allows generation of new regions.

TIME PRIORITARY MERGING

- **Sequences case :**
  - Merging under markers is a general approach.In case of sequences, it is implemented **recursively.**
  - The regions of segmentation t-1 serve as markers at step t ;
  - Image t is then processed by merging under markers.
- **Priority merging :**
  - One merges in priority the t-regions that are included in an already segmented region of time t-1. This ensures **stability;**
  - New regions (with respect to segmentation t-1) are then generated by pure merging process at time t : **versatility.**

GEOMETRICAL INTERPRETATION

The recursive procedure leads to two types of mergings :



In **prioritary merging** , the shape deformations are processed first.

3-D PRE-PROCCESSING (I)

The sequence is filtered by ***closing∘opening*** with respect to the volume of the "flat" zones in 3D

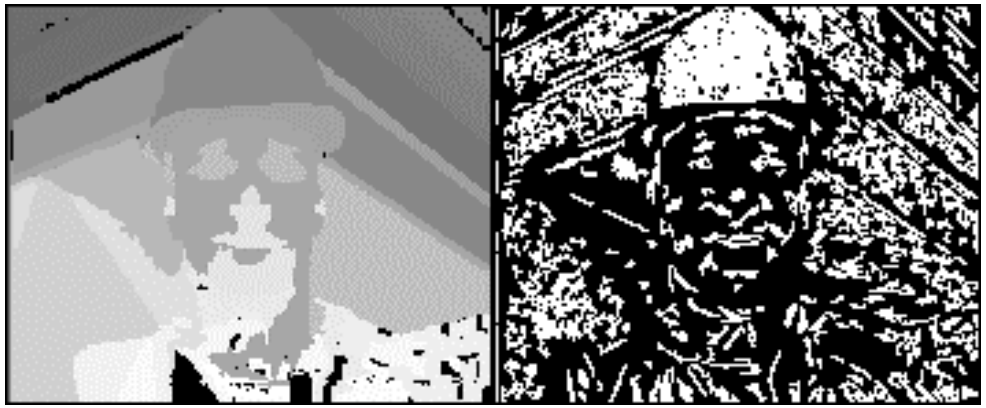
Two successive initial images

The two filtered versions

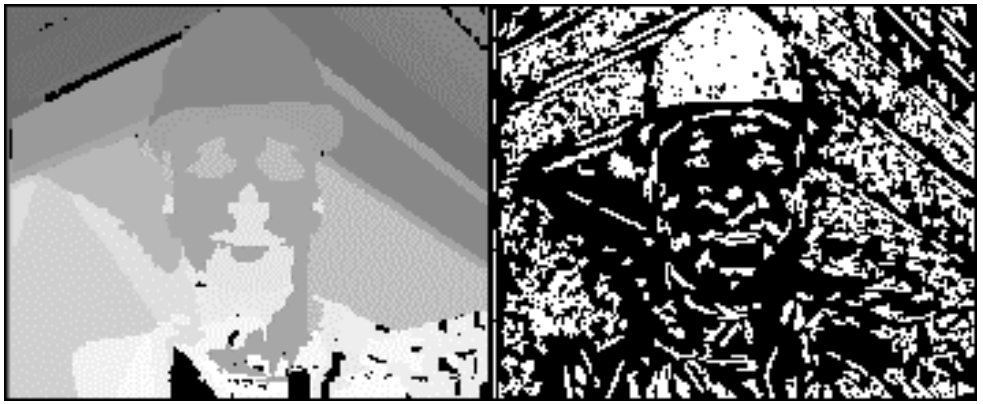
3-D PRE-PROCCESSING (II)

The small transitions are stuck together by 2D marker growing, *i.e.* image by image.

markers



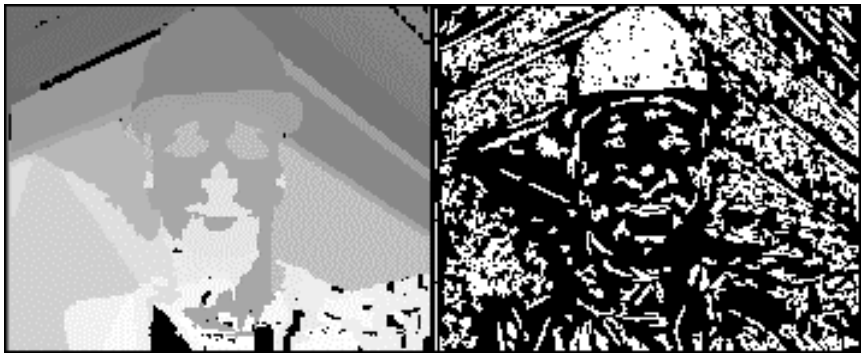
Small transitions (in black)



results

TIME PRIORITARY MERGINGS

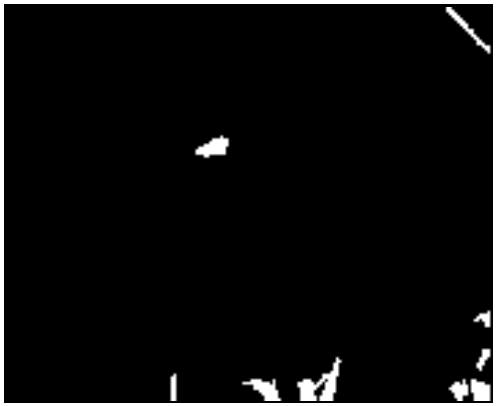
Result of the pre-processing



Priority merging

Time prioritary mergings

Segmentation by contrast merging



Candidates for new regions

RESULTS FOR "FOREMAN" SEQUENCE

Outflow 48.64 kbits/sec Compression rate 62.52

ANOTHER EXAMPLE : "NEWS"

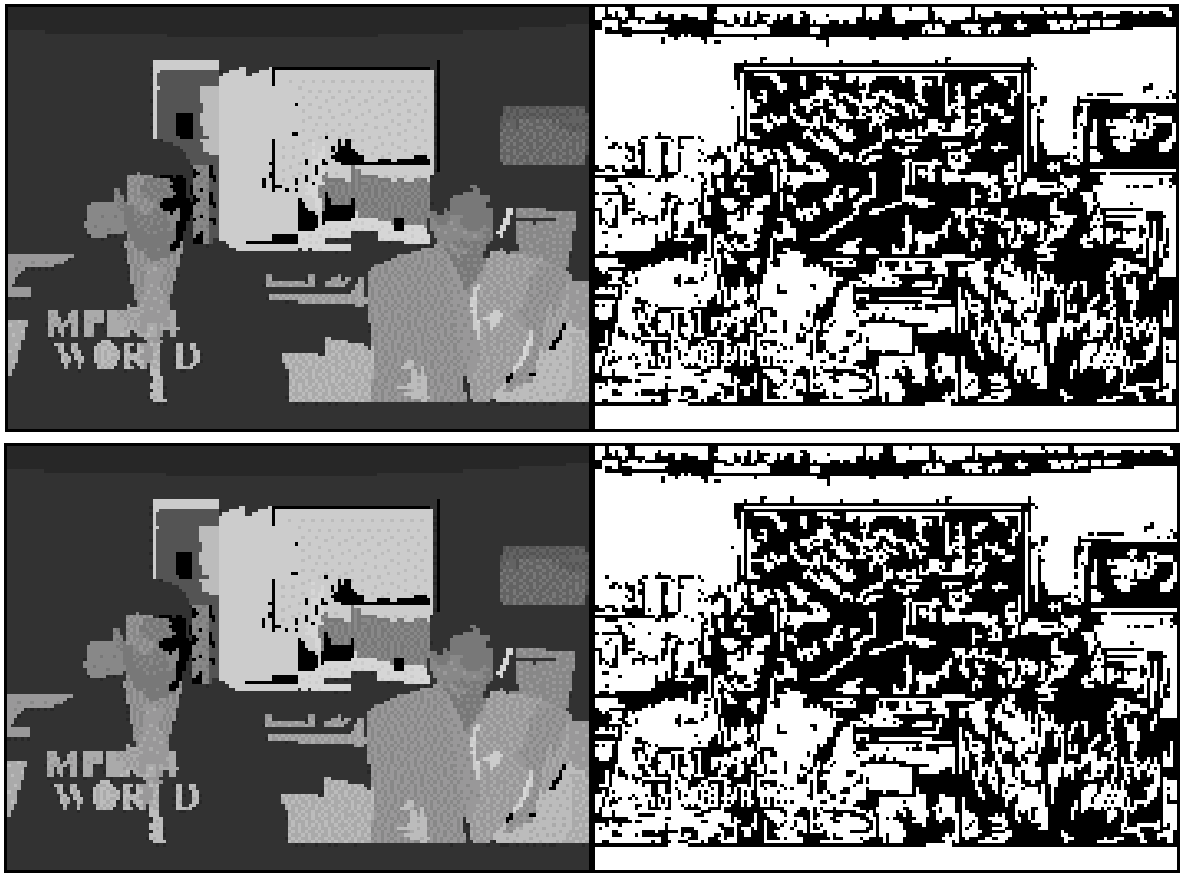
image n° t-5

image n° t

PRE-PROCESSING

N.B. The 3D filtering step, already performed, is not presented .

Markers

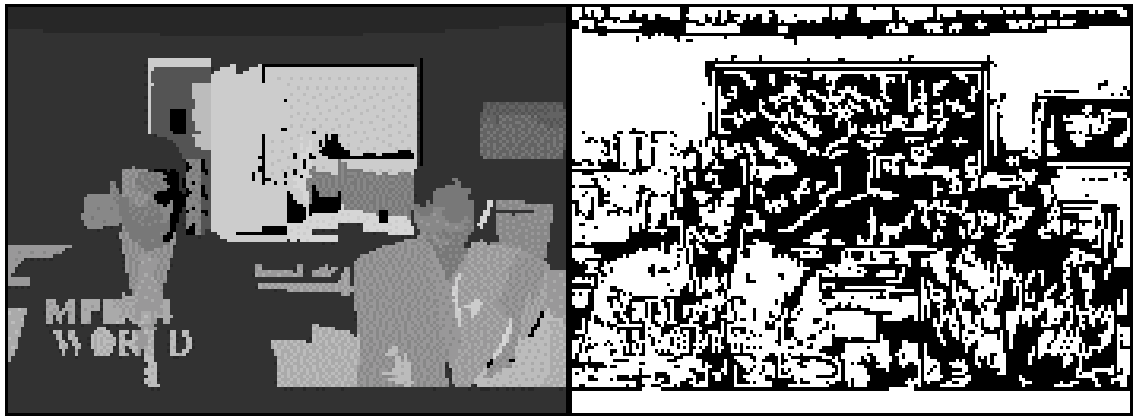


Small transitions (in black)

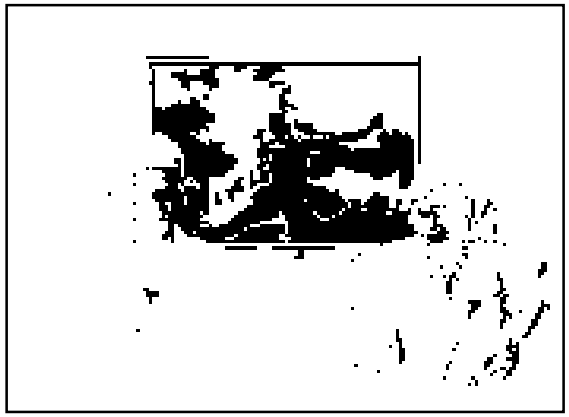
Results

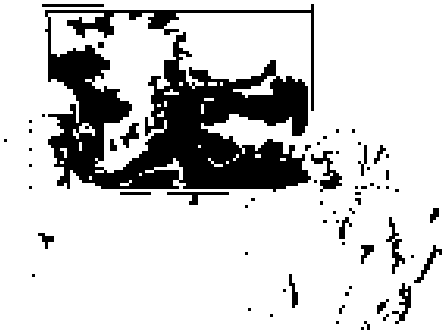
TIME PRIORITY MERGING

Result of the pre-processing



Priority merging





Segmentation by priority merging

MERGING BY CONTRAST

Average gray levels

Candidates for
new regions

RESULTS FOR "NEWS" SEQUENCE

Click here to download this video clip at the CMM website

Outflow 29.50 kbits/sec Compression rate 91.64