Indian Statistical Institute
System Science and Informatics Unit

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Five decades of Images Analysis and Mathematical Morphology

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ESIEE,
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France

An oververiew

- *years 60's* : - Europ: microscopical imagery
  - U.S.A. : remote sensing
- *years 70's* : - video sensors, automated microscopy
- *years 80's* : - industrial Control
  - medical macroscopical imagery (*tomography, échography*)
- *years 90's* : - Multimédia, I.C.T.
  - image compression and retrieval
- *years 00's* : - Remote sensing (New sensors), G.I.S
  - colour processing

Plan

- What do «*Image Analysis*» and « *Mathematical Morphology* » mean ?
- the seventies ,
- the seventies ,
- the eighties ;
- the nineties ;
- the recent years ;
- conclusion.

Image processing

Image processing addresses four types of questions :

- ***Codification ,***
- ***Filtering ,***
- ***Segmentation ,***
- ***Feature Extraction.***

Image processing

1- *Codification :*

Comprises all modes of representation. In particular

Acquisition:
analog => digital

Compression:
change in the representation.

Synthesis:
new image from numbers.

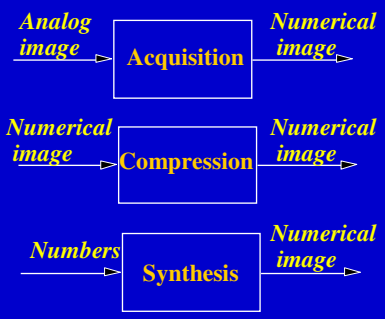
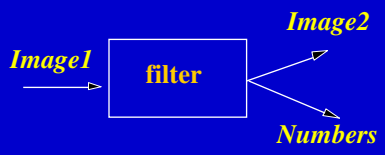


Image Analysis

2 - *Feature Extraction* :

- quality improvment,
- filtering;
- parameters extraction



3 - *Segmentation :*

i.e. partitioning the image into homogeneous regions (for some criterion)

Image processing

1- *Codification :* *Acquisition:* analog => digital

Image processing

1- *Codification :* *Compression (color reduction)*

H, L, S = 83

Image processing

1- *Codification :* *Compression (size reduction)*

Image Analysis

2 - *Filtering* : *noise amending,*

Image Analysis

2 - Filtering : noise amending,

Image Analysis

2 - Filtering : noise amending

(detail)

Image Analysis

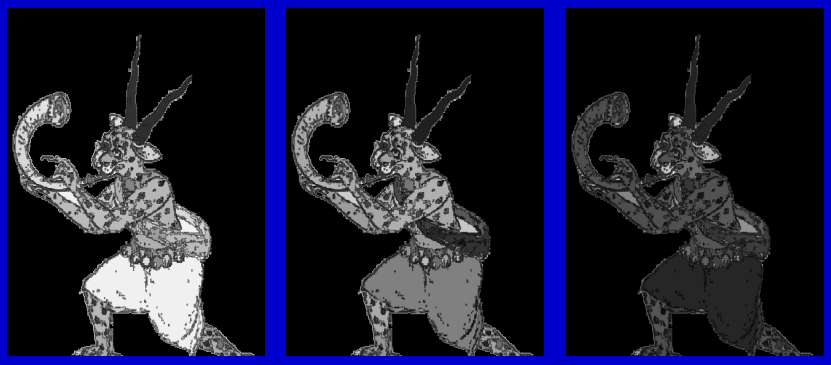
3 - Segmentation : partitioning

Image Analysis

3 - Segmentation : partitioning

Image Analysis

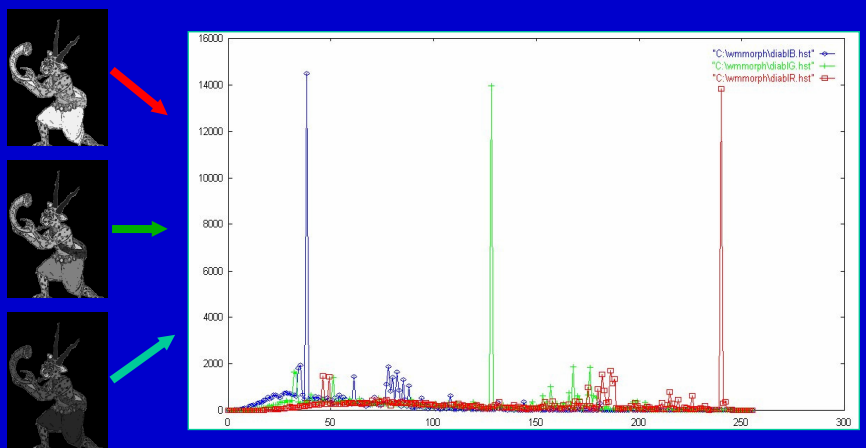
4 - Feature extraction : e.g. color histograms



Red Green Blue

Image Analysis

4 - Feature extraction : e.g. histograms



What is mathematical morphology?

For mathematics

Lattice theory for objects or operators in continuous or discrete spaces;

For image processing

Nonlinear signal and image processing approach based on minimum and maximum operations.

For physics

Set approach for the relations between physical and structural properties.

The basic morphological structure

The basic structure is a ***complete lattice*** *i.e.* a set $\mathcal{L}$

1) provided with a ***partial ordering***, *i.e.* a relation $\leq$ with

$$A \leq A$$
$$A \leq B,\ B \leq A \Rightarrow A = B$$
$$A \leq B,\ B \leq C \Rightarrow A \leq C$$

2) For each family of elements $\{Xi\} \in \mathcal{L}$, there exists in $\mathcal{L}$:

a greatest lower bound $\wedge\{Xi\}$, called ***infimum*** (or inf.) and a smallest upper bound $\vee\{Xi\}$, called ***supremum*** (or sup.)

Examples :

The subsets of a set; and again the numerical functions.

Basic morphological operations

Since the lattice structure rests on ***supremum*** and ***infimum***, the basic operations are those which ***preserve*** these fundamental laws, namely

- ordering Preserving :

$$\{ X \leq Y \Rightarrow \Psi(X) \leq \Psi(Y) \} \quad \Leftrightarrow \quad \textbf{\textit{increasingness}}$$

- commuting under supremum :

$$\Psi (\vee X_i) = \vee \Psi (X_i) \quad \Leftrightarrow \quad \textbf{\textit{Dilation}}$$

- commuting under infimum :

$$\Psi (\wedge X_i) = \wedge \Psi (X_i) \quad \Leftrightarrow \quad \textbf{\textit{Erosion}}$$

The sixties …

The sixties …

- The birth ,
- Physical problems in earth sciences :
  - Milling of rocks
  - Errors in mining drillings
  - Permeability in oil reservoirs
- Two persons
  - First steps of a theory
  - Invention of a device

The sixties …

Main ideas :

- Binary hit-or-miss transform* :
  - Translation invariant structuring element
  - Erosion an dilation
  - Opening and closing
- Random sets**:
  - Boolean model
  - Basic measurements

** G. Matheron, J. Serra* *** G. Matheron*

Petrography

300 mm

- *in brown, olites of limonite (Φ : 100µm to 300µm) ;*
- *in green, chlorite cement with (poor) iron ;*
- *in white, quartz and calcite.*

Calcite migration

50 cm

Calcite migration provokes a bias in the drillings grades which had to be quantified.

Texture Analyser Patent

United States Patent Office 3,449,586 Patented June 10, 1969

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3,449,586

AUTOMATIC SCANNING DEVICE FOR ANALYZING TEXTURES

Jean Serra, Stations d'Essais-Irsid, Maizieres-les-Metz, Moselle, France

Filed June 30, 1966, Ser. No. 561,932
Claims priority, application France, July 2, 1965, 23,273
Int. Cl. G01n *21/30, 21/00;* G01b *11/28*
U.S. Cl. 250—219 10 Claims

ABSTRACT OF THE DISCLOSURE

An automatic scanning device analyzes the texture of a heterogeneous medium with means which detects a quality in one zone of the medium and converts the detected quality into an electric signal, means for displacing the zone within the medium and for taking uniformly spaced measurements throughout the medium, a memory system wherein each signal is stored, logical selection means for comparing the stored signals, and counting means for integrating separately the number of concordances and discordances of the stored signals.

This invention relates to a device for the automatic statistical analysis of the geometrical distribution of distinct qualities which are distributed in a heterogeneous

2

sively the oldest value contained in the said storage means; logical selection means for comparing the stored values k by k after each measurement; and counting means for integrating throughout the course of the analysis the total number of concordances or discordances of the values contained in the storage means and corresponding to an arrangement of k zones which are located with respect to each other at constant multiple distances of the order 1 to n of the analysis pitch.

In a preferred embodiment which is applicable to the analysis of texture of the images of a heterogeneous medium, the invention is more especially characterized by the combination of the following elements: at least one photoelectric receiver having a spectral sensitivity which is adapted to the color which is sought on the image and fitted with a suitable optical device which delivers an electric signal representing one zone of the image; scanning means for displacing the measurement zone over the surface of the image to be analyzed along successive lines; at least one storage shift register corresponding to each photoelectric receiver, each register comprising n binary storage elements; at least one digital counter associated with a logic circuit which determines the concordance or discordance between the signals contained in k storage elements to which it is connected; a selection matrix for connecting the said logic circuit to the selected storage elements; and a control circuit which is synchronized with the image-scanning means so as to produce at regular intervals the displacement by one element of the data con-

The seventies …

The seventies …

- Use of TV camera ,
- Improvements in optical microscopy :
  - Uniform illumination
  - Pecise moving stages
  - beginning of automated microscopy
- Use of this improved micropsopy in
  - Material sciences
  - Cytology
  - petrography

The seventies …

Main ideas :

- Iterated operations* :
  - Individual analysis
  - Thinning and thickening
  - Skeletons and Voronoi
- Extension to grey tone images**:
  - Opening and top-hat **
  - Watershed***

** J.C Klein, , J. Serra* *** F. Meyer, J. Serra, S.R. Sternberg*
****C.Lantuejoul, S. Beucher*

The seventies …in material sciences

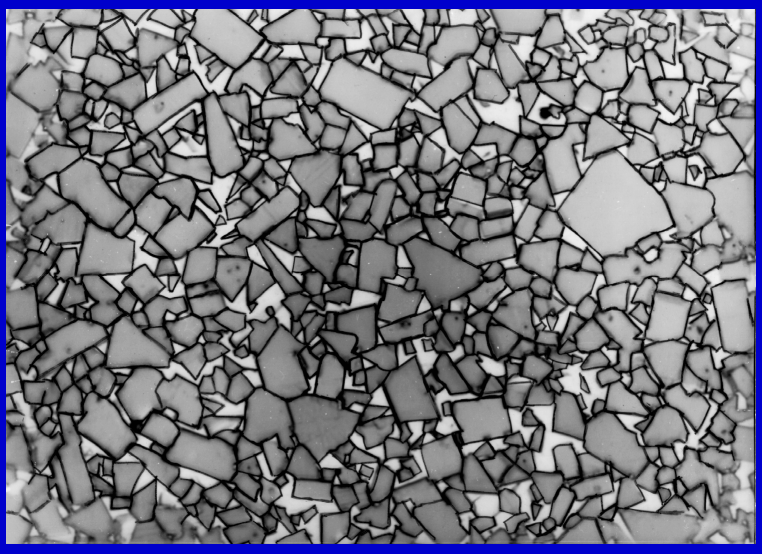
A three side approach :

- manufacture ;
- Micro-structures ;
- Physical properties ;

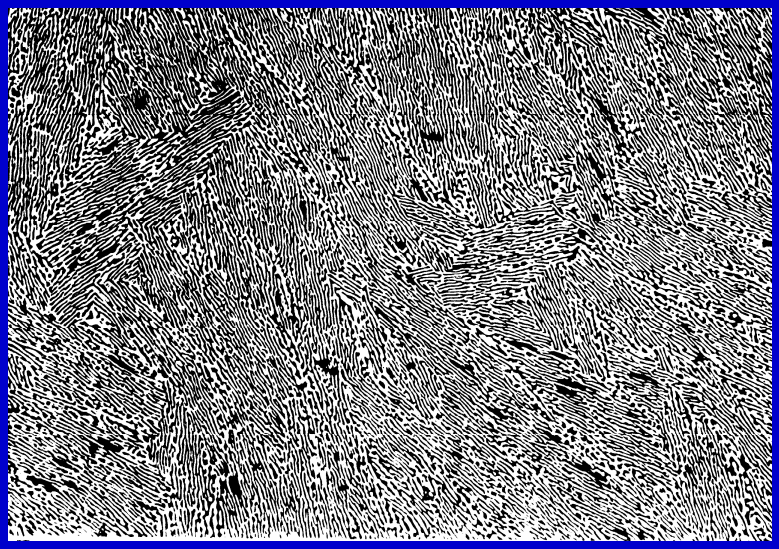
Thee basic features :

- Textures (i.e. infinite shapes) ;
- 2D → 3D (stereology)
- Random sets
  (Boolean model and Poisson tesselations)

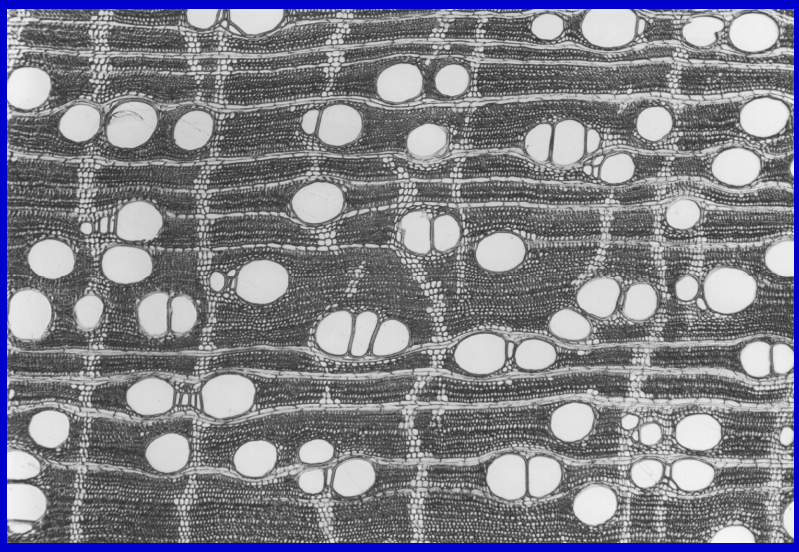
WcCo (carbide of wolfram)



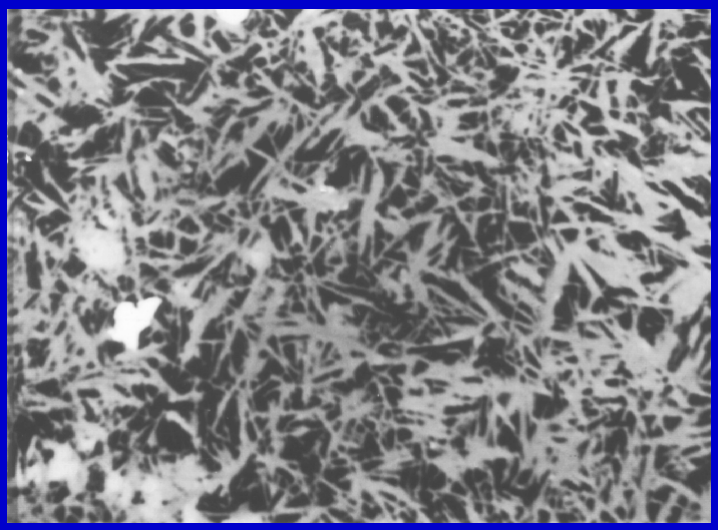
Lamellar eutectic



Tropical woods



Iron ore sinters (black furnace)

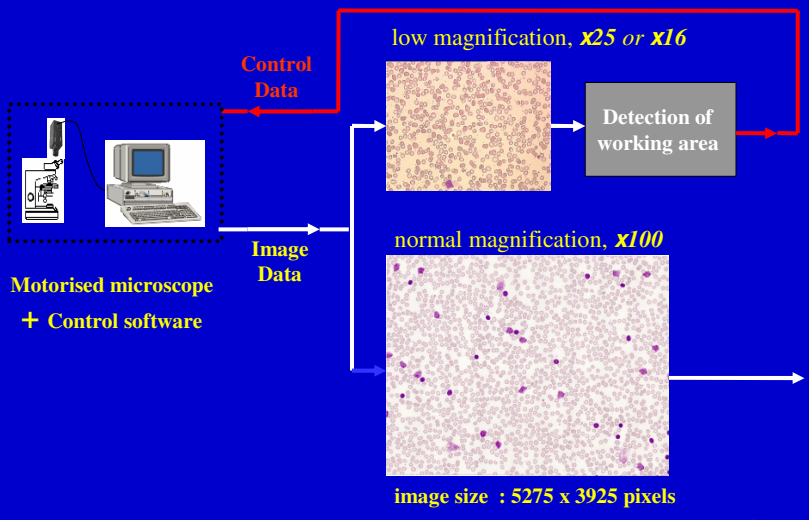


The seventies …in biology

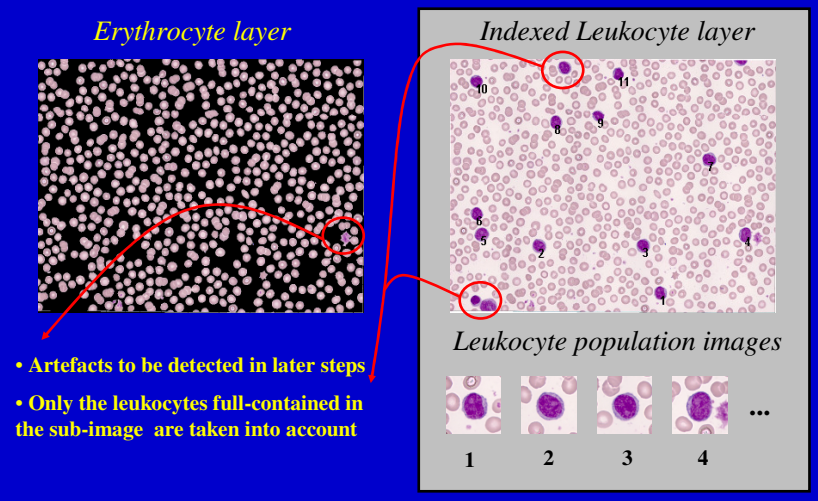
- An example drawn from cytology* :
  - Automated morphological analysis of peripheral blood smears cells in large fields images
  - Tele-haemetology
- Basic features :
  - Standardization of the staining ;
  - Uniform illumination
  - Approach on both individuals and populations

** J. Angulo, J. Serra , G. Flandrin*

Image acquisition station

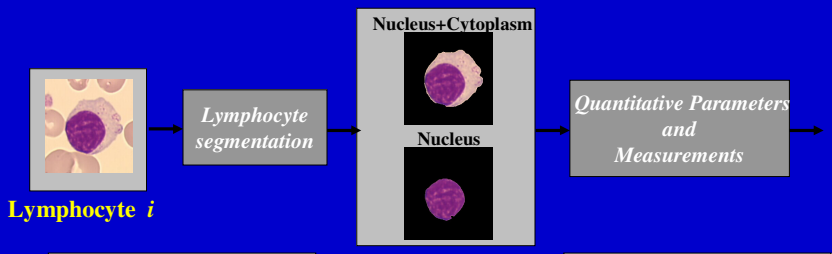


Blood Segmentation



feature extraction and quantification

- **For each lymphocyte,**



Set of values for quantitative parameters and measurements:

sizes and shape parameters, form factors and coefficients, color parameters, morphological texture measurements, etc.

Morphological Feature Classification

Set of values for morphological features:

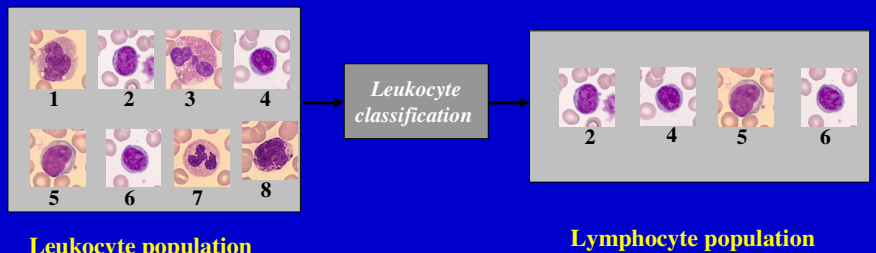
- Nuclear Size = medium
- Cell Size = medium
- N/C Ratio = high
- Chromatin Density = dense
- ...

Lymphocyte Descriptor

Leukocyte classification

- The population of the ***leukocytes*** is classified in order to identify the ***lymphocytes***
- Leukocyte statistics,

1 → Mono, 2 → Ly, 3 → Eosi, 4 → Ly,
5 → Ly, 6 → Ly, 7→ Neut, 8 → Baso

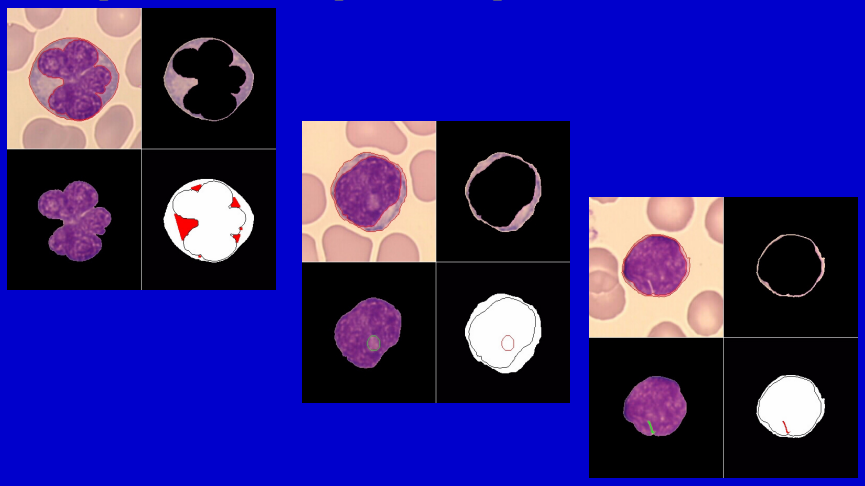


Leukocyte population

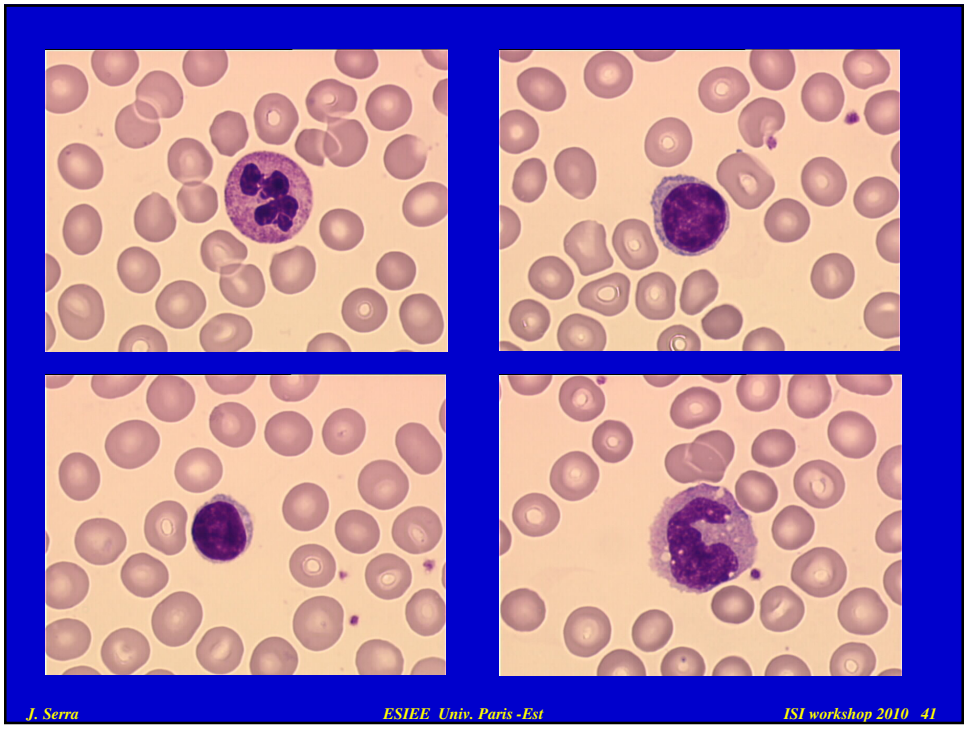
Lymphocyte population

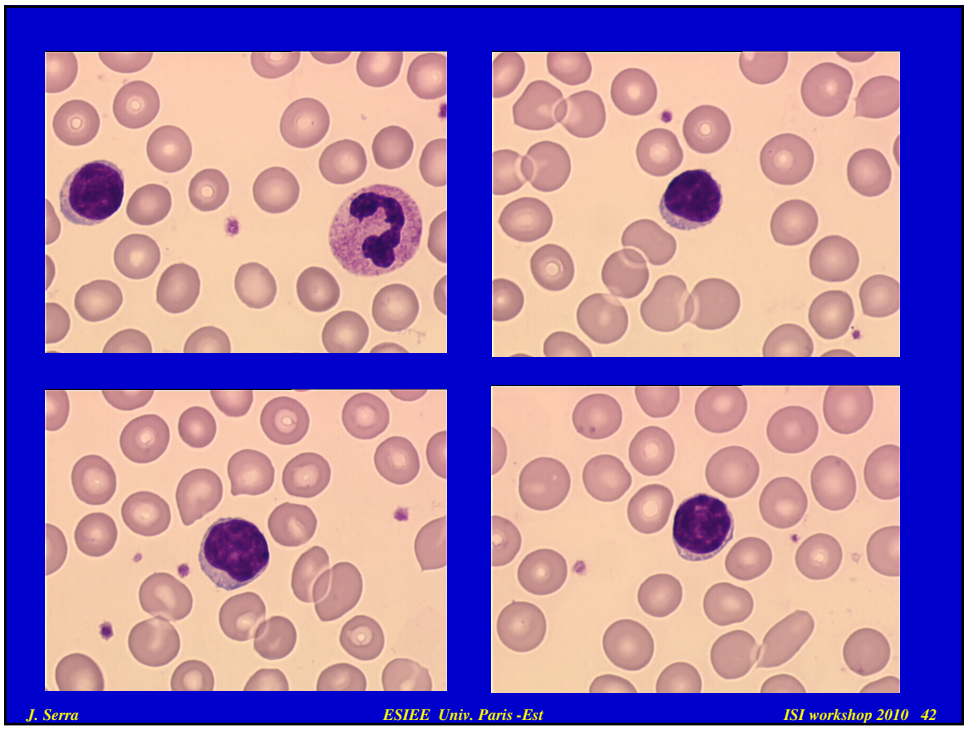
Lymphocyte feature extraction and quantification

Examples of measured quantitative parameters,

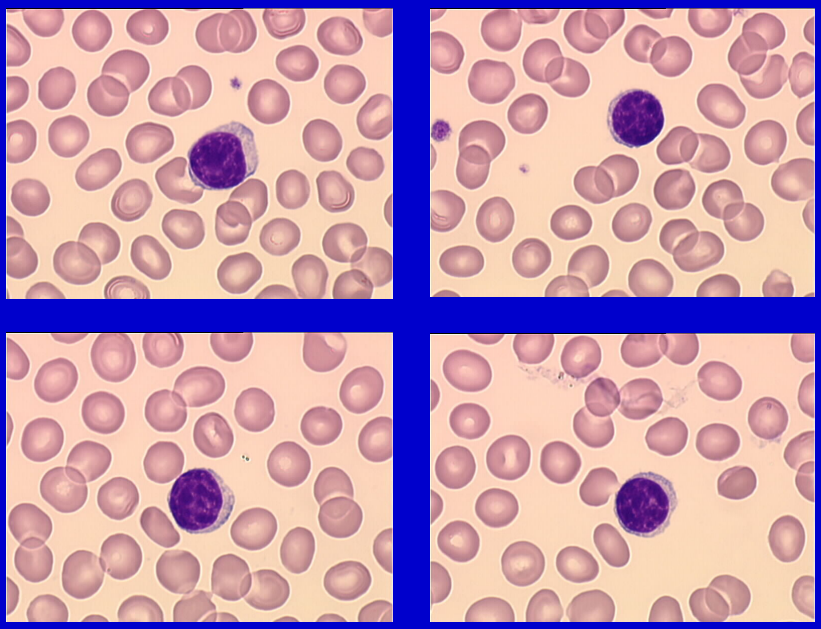


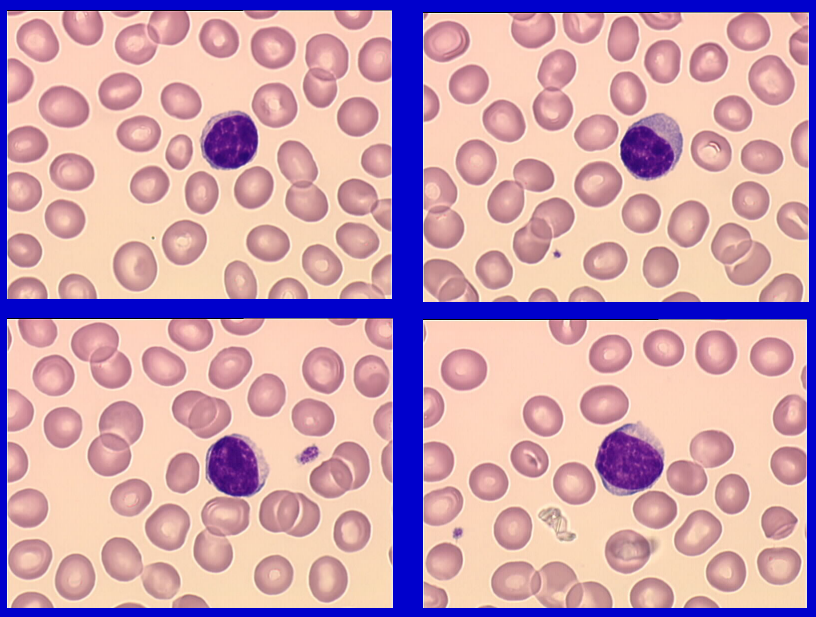
A series of Healthy lymphocytes





Pathological lymphocytes





The eighties …

The eighties …

Main ideas :

- Extension to complete lattices* :
  - Morphological filtering
- Set connection*
- Opening by reconstruction**
  - Geodesy
- Boolean Random functions***:

** G. Matheron, J. Serra **B. Beucher, F. Meyer, S.R. Sternberg, R. Haralick*
**** D. Jeulin, J. Serra, M. schmitt*

The eighties …

- Two major new domains :
  - industrial Control
  - medical macroscopical imagery
- Basic features :
  - New medical sensors (*tomography, échography, retinography*)
  - apparition of motion

The eighties … in India

- ***Prof. S. V. L. N. Rao*** (1928-1998) worked at the Indian Institute of Technology (IIT) Kharagpur, since 1971.
- In 1984, I invited him to the Centre of Mathematical Morphology, Paris School of Mines, for 10 weeks.
- Coming back home, he introduced Mathematical Morphology in India ;
- And developed it in the area of earth sciences:

  - dilational similarity

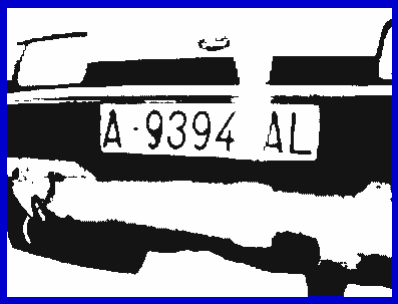
  - neighborhood images

  - soft morphology

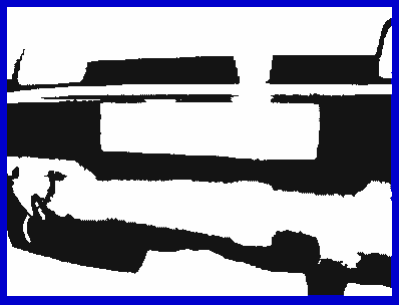
The eighties … in industrial control

- Non destructive control
  - on line control ;
  - particles, powders;
  - welding;
- automatic reading
  - Automatic reading;
  - Car registration number;
  - Tracking ;

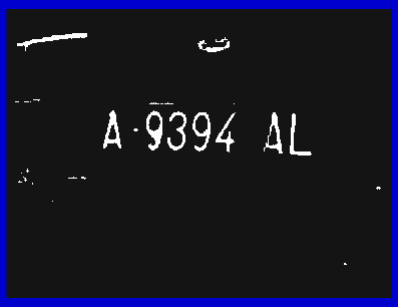
Car registration reading

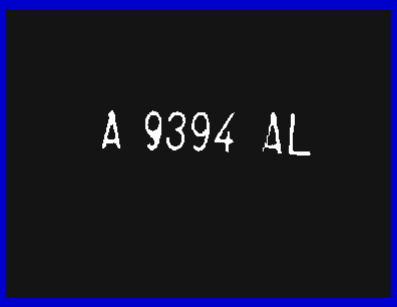


Car registration reading



Car registration reading





Car registration reading

The eighties …in medecine

Automatic recognition of two retinopathies:

- aneurisms due to diabetes
- macula degeneration under aging

(INSERM / CMM)

Vessels Detection for Image Registration

The eighties …in material sciences

- ***Steel and car industries;***
- ***Morphology of the rough surfaces ;***
- ***Stochastic model:***

Interaction Light \ Surface → **NDC**
(IRSID)

Roughness and Friction → **MOTORS**
(PREDIT: PSA, RENAULT, EXXON, JPX)

The nineties …

The nineties …

Main ideas :

- Connected filters and motion* :
  - Hierarchies ans semi-groups
  - Sapce variability
  - Time x space operators
- Fast algorithms**:
  - Grey tone opening (volume, etc..)
  - Geodesic information

** Ph. Slambier, J. Serra* *** L. Vincent P. Soille*

The eighties … in India

- ***Prof. B.S. Daya Sagar***

  - Mathematical morphology for geomorphology

- ***Prof. Bhabatosh Chanda***

  - Morpholoy in computer science

The nineties …

- **Information technologies :**
  - Content based indexation;
  - image compression and retrieval;
  - Tracking ;
  - Restoration of old movies .
- **Basic features:**
  - Motion (video coding);
  - Segmentation theories;
  - Use of connectivity.

Image analysis and multimedia

In vision, the questions are ***semantic*** *(What do we see?)* Hence their answers require some ***understanding*** of the scenes.

Now, the tools for Image Processing are ***syntactic***, and their level of sophistication rather low.

However syntactic tools can be developed for

- ***automation*** of teedious tasks ;
- ***treating*** audiovisual objects ;
- ***associating*** image and context .

An example of generic segmentation

Method: jump connection

Original : from San Cugat, (Barcelona) , 22.650 tiles

δ= 5

324 tiles

δ= 15

73 tiles

A few Multimedia Studies

- Images Orientation (Kodak)

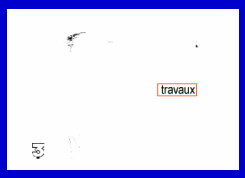
- Lights and Shadows Detection (Kodak - CIFRE grant)

- Old Movies Restoration (EU consortium “Noblesse”)

Content Based Indexation

- ***Segmentation of Color Images***

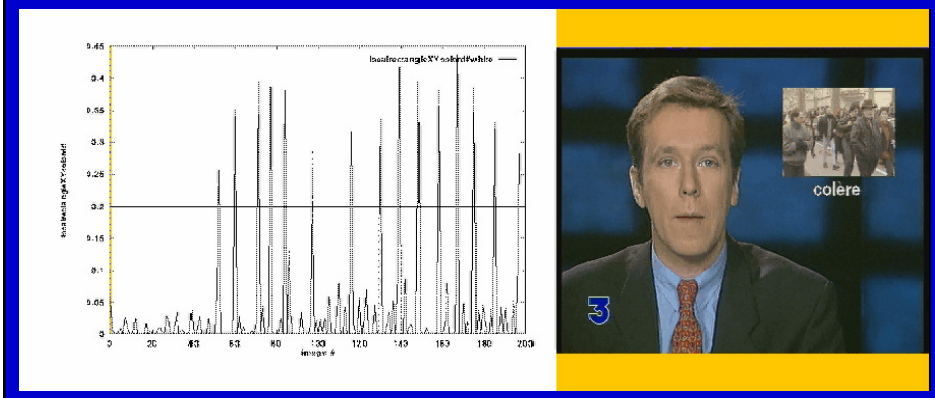
- ***Text Automatic Extraction***



- ***Face Recognition***

Content Based Indexation

- source : T.V. News
  - *Cuts Automatic Detection*



Content Based Indexation

- *Key Images Extraction*

©CMM/ENSMP/ARMINES

Real Time Coding

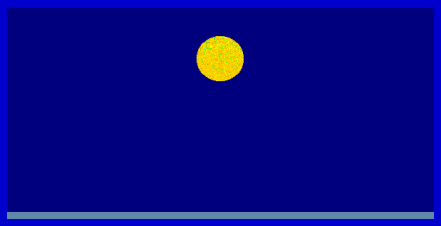
"Real Time" coding unit (EU program MEDEA):

- **foreground / background segmentation ;**
- **Color Sequences.**

Physics of Heterogeneous Media

Flows and Lattice Gaz :

- Hydrodynamics
- Transport in porous media (CEA)
- Random Aggregates



Drops in fusion :

- Simulation of thin layers deposits by plasma
- Action on the process (DGA, MATRA)

The last ten years…

The last ten years …

Main ideas :

- Extension of connection* :
  - (hyper) Connection in lattices
  - Connective segmentation
- Digital morphology**:
  - Graph approach
  - Topological watersh, and exact algorithms
- Digital watershed and segmentation**:
  - Saliency and hierarchies
  - Simplicial graphs

C. Ronse, J. Serra ** G. Bertrand, M. Couprie * L. Najman, J. Cousty*

The last ten years

- ***Earth observation :***

  At the beginning of the years 00's *:*

  – the resolution of some satellites images jumped from 10m to 60 cm;

  – New sensors appeared for remote sensing (lasers, interferometers, etc.);

  – The geographical information systems, (G.I.S) were considerably developed.

- ***Basic features :***

  – Multispectral, including colour, processing;

  – Attention paid to environment;

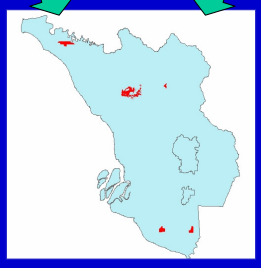
  – Internet access.

Peninsular Malaysia

- Usual maps symbolize objects that ***actually exist*** ,
- e.g. the Malaysian peninsula is ***prior*** to any geographer, and independent of him.

A missing link

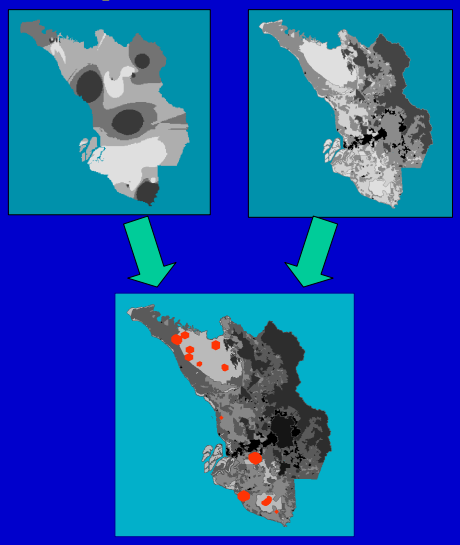
Fire spread ***Fuel amount***



- How to go from these two maps to the burnt regions?
- and derive the size distribution of the burnt regions ?
- ***A stochastic model is required***

A missing link

Fire spread *Fuel amount*



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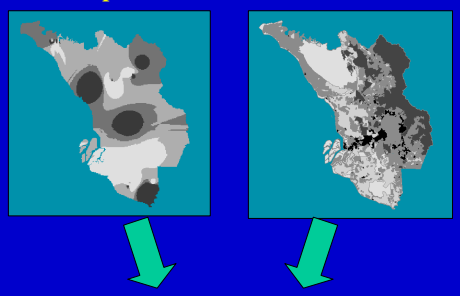

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Fonctional of the iterated spread

Functionals $\mathbf{Q_1}\ldots\ \mathbf{Q_n}$ that $\mathbf{X_1}\ \ldots\ \mathbf{X_n}$ miss the compact set **K :**

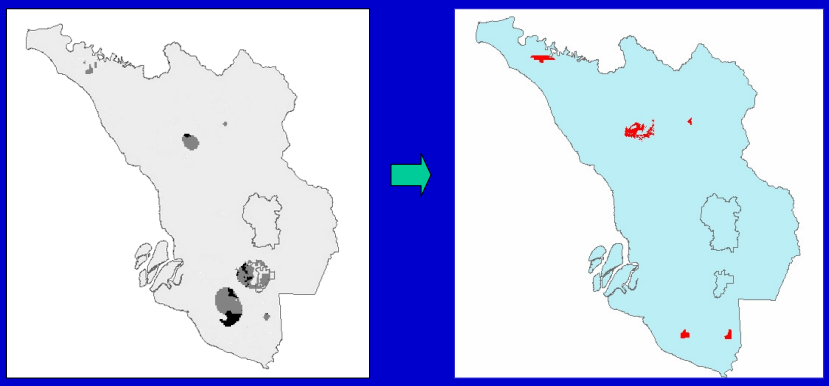
- The first step is just boolean, so that the Choquet characteristic

$$\mathbf{Q_1(K)} = \exp\{ - \theta[\zeta(\mathbf{K}) \cap \zeta(\mathbf{x})] \}$$

- More generally we have the induction relation

$$\mathbf{Q_n\,(K)} = \exp\left[\ \mathbf{1} - \int_{\zeta(\mathbf{x})}\ \theta(\mathbf{dy})\ \mathbf{Q_{n-1}\,(K \mid y)}\ \right]$$

Results



Scars From model prediction

Scars from satellite detection

Period 2001-2004

The next ten years…

The next ten years…

Who knows?…

Conclusions

- *Themes*
- New themes, but the former ones remain active;
- increasing role of earth sciences:
  water resources, climatology, ecology
- *Data*
- microscopy ⇒ macroscopy ⇒ megascopy
- more mixed data (e.g. GIS) with large data sets

Conclusions

Users

- Final users:
  labs ⇒ industry, hospital ⇒ individuals
- from Specific tasks (ind. control) to open ones
  (data mining)

Thank you for your attention !

Questions ?