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The 'Centre de Morphologie Mathématique' at Fontainebleau

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Abstract: We describe here the 'Centre de Morphologie Mathématique' (CMM) at Fontainebleau and relate its current activities.

I. Structure

The 'Centre de Morphologie Mathématique' (CMM) is a division of the research centre in Fontainebleau of the 'École Nationale Supérieure des Mines de Paris' (ENSMP). It has become famous for developing a discipline in image analysis called mathematical morphology, which has been applied in various fields: mineralogy, petrography, angiography, cytology, etc..

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About 20 people work in the CMM, which is organized into 4 groups: applications in biology, computer vision, materials, and computer implementations.

— *Scientific adviser*: G. Matheron (also with the 'Centre de Géostatistique').
— *Director*: J. Serra.
— *Group of* F. Meyer (applications in biology): S. Laroche (*Ph.D. student*), L. Vincent (*Ph.D. student*), M. Grimaud (*Ph.D. student, employee of a private company*), F. Friedlander.
— *Group of* S. Beucher (computer vision): M. Bilodeau (*Ph.D. student*), Y. Terol.
— *Group of* D. Jeulin (materials): M. Kurdy (*Ph.D. student*), Tang.
— *Group of* J.C. Klein (computer implementations): M. Gauthier, F. Collange, R. Peyrard (*Ph.D. student*).
— *Secretary*: L. Pipault.
— *Librarian*: L. Adriamasinoro.

This year an undergraduate student, Jaumier, worked at the CMM in his training practice for the degree of civil engineer.

II. Research

Papers presenting some theoretical and practical results recently obtained at the CMM can be found in [1] and [2]. We describe here current research. N.B.: The CMM uses the software packages *Visilog* (computer vision) and *Morpholog* (mathematical morphology) developped by B. Lay. Digital images are represented on a hexagonal grid, and all algorithms are written in this framework; for the display of images on a CRT with a square grid, the hexagonal grid is digitized on a square one by a simple interface.

G. Matheron: *Mathematical theory.*

Probabilistic models, and conditional simulation. Complete lattices, and topological structures adapted to morphological operators.

J. Serra: *Mathematical theory.*

Definition and study of the activity lattice, and of toggle mappings. General approach for thinning and thickening. Boolean random functions.

F. Meyer: *Sequential algorithms.*

Although parallel neighbourhood transformations on images are conceptually simpler than sequential ones, the latter can be more efficient. Sequential algorithms are investigated for various operations, such as: Euclidean distance transform on a grid (see Vincent below), connected skeletons from distance skeletons, etc.. This work will be presented in [2].

S. Laroche: *Rare events (biology), and hardware.*

L. Vincent: *Euclidean distance transform, morphology on graphs, and applications in histology.*

Algorithms are investigated for computing the Euclidean distance transform and skeleton of a hexagonal grid image. This should make the grid digitization 'transparent'.

Starting from disjoint cells (connected components in a binary image), one builds the corresponding Voronoi diagram, whose facets are the zones of influences of the original cells, and whose edges form together the locus of points of the exoskeleton which are equidistant from two distinct cells (this locus is also called the *skiz*). The dual Delaunay triangulation gives a graph on which morphological operations (based on neighbourhood relations between vertices) can be applied. This work will be presented in [2].

M. Grimaud: *Digital radiology.*

Contrast-enhancing algorithms are developped, which raise grey-levels of plateaus in images. Texture is analysed with the help of regional minima. A model for colour perception will be investigated, in particular on macroscopic effects of microscopic textures.

F. Friedlander: *Digital cardiology.*

S. Beucher: *Highway traffic monitoring.*

This work aims at automatic detection of traffic disturbances (accidents, congestion, etc.) on a highway by computer analysis of sequences of images taken from a camera. A hardware prototype has been built, and a patent submitted.

A movable camera is posted along (or above) a highway. It produces a sequence of images at a frequency of 4 pictures per second, which is processed on a computer. An initialization stage gives the tracks of the highway (by temporal averaging and filtering). From the variation of the width of these tracks in the image, the local magnification factor (ratio of real and apparent size of objects) can be determined at each location (cfr. perspective).

A simple grammar (made of dark and light zones) is used to characterize individual vehicles. Each one gets a tag indicating its location, and a mask giving its size. Now the following problems arise:

— If vehicles are mutually too close, they will not be correctly separated.

— If the camera is put at a too oblique position w.r.t. the highway, some vehicles will be occluded. On the other hand, the higher the camera, the better the results (by improved perspective).

— The position of the sun should be taken into account, because it induces shadows.

— Some vehicles (3%) are doubly marked (as two distinct ones), especially heavy lorries.

The trajectory of a vehicle in the image sequence is easily determined: to a vehicle in an image corresponds in the next image the closest vehicle in the traffic direction (one reasonably assumes that vehicles are separated by more than 1/4 second). This trajectory allows one to recover in the sequence vehicles which were not detected in a particular image (for example a car occluded by a lorry), and to eliminate aberrant detections.

All vehicle trajectories are centered on highway tracks. When a vehicle changes its track, its trajectory stops, and a new one starts.

A typology of events and accidents (in terms of trajectories) must be done.

The method described above is suited to daylight condition. Work has begun on the analysis of traffic in night condition. Here vehicles are identified by their lights, which must be separated from public lighting and reflections; public lighting does not move, while the motion of reflections is rather incoherent w.r.t. vehicle lights. One must also distinguish between motorcycles, (with one light), cars (with two lights), and cars with only one light functioning; for example motorcycles usually move faster.

The twilight condition combines features of both daylight and night ones. Its analysis should require some form of AI.

M. Bilodeau: *Urban traffic monitoring*.

This is more difficult than highway traffic, because vehicles often change their direction. It is therefore necessary to detect their individual motion. Two particular problems must be investigated:

— Motionless vehicles: they are considered as parked, and they narrow the street.

— Vehicles turning left at a light-controlled crossroad: they are one chief cause of congestion; one must monitor their flow in order to determine the duration of simultaneous red light in both branches of the crossroad.

N.B.: In Belgium, the company Devlonics at Kortrijk builds traffic detection systems based on the ideas of Maes at KUL.

Y. Terol: *The 'tailor algorithm'.*

This is the 2D version of the classic problem of 'bin packing': how to fit a set of surfaces on a rectangular strip of fixed width and minimal length.

D. Jeulin: *Materials.*

Work at the CMM is limited to the supervision of Kurdy and Tang. The rest of the time is spent for one third at the 'Centre des Matériaux' in Corbeil (about 100 people) on the use of mathematical morphology, and for two thirds at the 'Centre de Géostatistique' for research on change of scale in the physics of heterogeneous media.

M. Kurdy: *Anisotropic morphology, and applications in metallography.*

For the detection of metal grains in a cut, a segmentation of the image is necessary. Contours are detected by morphologic operations. However there are gaps in the edges, and these must be filled. An isotropic propagation of edges by cones is investigated.

Tang: *Fluid flow model on a hexagonal grid.*

The flow of a fluid is modelled as a flow of molecules on a hexagonal grid (the model does not work on a square grid). Each molecule has unit velocity in one of the six grid directions. Several basic patterns of collision between molecules, or between a molecule and the wall, can be proposed in accordance with the laws of mechanics (preservation of momentum). These patterns are then selected so as to give a global behaviour consistent with the Navier-Stokes equation and the law of Poiseuille in the Euclidean case.

J.C. Klein: *Computer science and hardware.*

M. Gauthier: *Hardware implementation of traffic monitoring.*

(See Beucher and Bilodeau above.)

F. Collange: *Contract work in hardware.*

Hardware prototypes are built for the private company Cambridge Instruments.

R. Peyrard: *Design of electronic chips.*

III. Student work

Mathematical morphology is one of the 14 options available to students of the ENSMP for the curriculum in mining engineering. During one year the student is taught basic theory and techniques, and familiarized with computing equipment and the *Morpholog* software package. The second year is mainly devoted to training practice in another institution or company. This generally consists in solving a practical problem in image analysis using techniques from mathematical morphology with the help of the *Morpholog* package or any hardware which implements mathematical morphology. Each student is supervised by a member of the CMM, and must present a report at the end of the academic year. This year 4 students completed their training practice in mathematical morphology.

Students at other schools can also make their training practice at the CMM. This year Jaumier, a student in civil engineering, worked there on a problem posed by the Hotel-Dieu hospital: the detection in angiographic images of the eye fundus, of features associated with diabetic retinopathy (e.g., micro-anevrisms, size of the macular zone, hemorrhages, exsudates, macular oedema, etc.).

There is also the possibility for graduate students to work at the CMM for a Ph.D. degree in mathematical morphology.

References

[1] J. Serra, ed: *Image Analysis and Mathematical Morphology, Vol. 2: Theoretical Advances*. Academic Press, New York, NY (1988).

[2] *Signal Processing*: Special issue on mathematical morphology (to appear).