INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Ariana

Inverse Problems in Earth Observation and Cartography

Sophia Antipolis

THEME COG

Activity Report

2004

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2. Overall Objectives

Ariana is a joint project of INRIA, CNRS, and the University of Nice-Sophia Antipolis, via the Computer Science, Signals and Systems Laboratory (I3S) in Sophia Antipolis (UMR 6070). The project web site can be found at http://www.inria.fr/ariana.

The Ariana project is engaged in two distinct but strongly synergistic endeavours, one applicative and one methodological. The project aims to provide image processing tools to aid in the solution of problems arising in a wide range of concrete applications in Earth observation and cartography, for example cartographic updating, land management, and agriculture, while at the same time advancing the state of the art in the image processing methods used to construct those tools.

The problems treated by the project run the gamut of image processing, applied to satellite and aerial images. Examples include image restoration and denoising, multicamera reconstruction and superresolution, the extraction of various complex structures in the scene, and retrieval from remote sensing image databases. One thing all the problems have in common is that they are ill-posed inverse problems. Even in those rare cases for which the existence and uniqueness of the solution is guaranteed, the solution is unstable to the perturbing effects of observation noise. It is therefore necessary to introduce prior knowledge concerning the solution, both in order to limit the set of possible solutions and to stabilize the solution against perturbations. Similar problems occur in the processing of other imagery types, with the consequence that the techniques developed in the project have also found application to astrophysical and biological images.

Methodologically speaking, the project uses two broad classes of techniques to attack these problems: probabilistic models combined with stochastic algorithms, and variational models combined with deterministic algorithms. In addition to applying these techniques to specific cases, the project advances these techniques more generally, through innovative modelling and theoretical analysis, and a comparative study of the two classes. An important recent theme, for example, is the incorporation of geometric information into both classes of techniques, in the probabilistic case via the use of stochastic geometry, and in the variational case via the use of higher-order active contours.

The project also concerns itself with a number of important, related problems, in particular the development of the parameter estimation procedures necessary to render the above methods automatic or semi-automatic, and the study of the optimization algorithms used to solve the problems (for example, reversible jump Markov chain Monte Carlo (RJMCMC)).

3. Scientific Foundations

3.1. Probabilistic approaches

Following a Bayesian methodology as far as possible, probabilistic models are used within the Ariana project, as elsewhere, for two purposes: to describe the class of images to be expected from any given scene, and to describe prior knowledge about the scene in the absence of the current data. The models used fall into the following three classes.

3.1.1. Markov random fields

Markov random fields were introduced to image processing in the Eighties, and were quickly applied to the full range of inverse problems in computer vision. They owe their popularity to their flexible and intuitive nature, which makes them an ideal modelling tool, and to the existence of standard and easy-to-implement algorithms for their solution. In the Ariana project, attention is focused on their use in image modelling, in particular of textures; on the development of improved prior models for segmentation; and on the lightening of the heavy computational load traditionally associated with these techniques, in particular via the study of varieties of hierarchical random field.

3.1.2. Wavelets

The development of wavelets as an alternative to the pixel and Fourier bases has had a big impact on image processing due to their spatial and frequency localization, and the sparse nature of many types of image data when expressed in these bases. In particular, wavelet bases have opened up many possibilities for probabilistic modelling due to the existence of not one but two natural correlation structures, intra- and inter-scale, leading to adaptive wavelet packet models and tree models respectively. In Ariana, attention is focused on the use of tree models for denoising and deconvolution; adaptive wavelet packet models for texture description; and on the use of complex wavelets for their improved translation invariance and directional selectivity.

3.1.3. Stochastic geometry

One of the grand challenges of computer vision and image processing is the expression and use of prior geometric information. For satellite and aerial imagery, this problem has become increasingly important as the increasing resolution of the data results in the necessity to model geometric structures hitherto invisible. One of the most promising approaches to the inclusion of this type of information is stochastic geometry, which is a new and important line of research in the Ariana project. Instead of defining probabilities for different types of image, probabilities are defined for configurations of an indeterminate number of interacting, parameterized objects located in the image. Such probability distribution are called ‘marked point processes’. For instance, two examples that have been developed in Ariana use interacting cuboids of varying length, width, height and orientation for modelling buildings; and interacting line segments of varying length and orientation for modelling road and other networks.

3.2. Variational approaches

3.2.1. Regularization and functional analysis

The use of variational models for the regularization of inverse problems in image processing is long-established. Attention in Ariana is focused on the theoretical study of these models and their associated algorithms, and in particular on the Γ-convergence of sequences of functionals and on projection algorithms. Recent research concerns the definition of and computation in a function space containing oscillatory patterns, a sort of dual space to BV space, which captures the geometry of the image. These variational methods are applied to a variety of problems, for example image decomposition.

3.2.2. Contours and regions

In addition to the regularization of inverse problems, variational methods are much used in the modelling of boundaries in images using contours. In Ariana, attention is focused on the use of such models for image segmentation, in particular texture segmentation; on the theoretical study of the models and their associated algorithms, in particular level set methods; and on the incorporation of prior geometric information concerning the regions sought using higher-order active contour energies.

3.2.3. Wavelets

Wavelets are important to variational approaches in two ways. They enter theoretically, through the study of Besov spaces, and they enter practically, in models of texture for segmentation, and in the denoising of the oscillatory parts of images.

3.3. Parameter estimation

One of the most important problems studied in the Ariana project is how to estimate the parameters that appear in the models. For probabilistic models, the problem is easily framed, but is not necessarily easy to solve, particularly in the case when it is necessary to extract simultaneously from the data both the information of interest and the parameters. For variational models, there are few methods available, and the problem is consequently more difficult.

4. Application Domains

4.1. Denoising and deconvolution

These are perhaps the most basic of the applications with which Ariana is concerned, and two of the most studied problems in image processing. Yet progress can still be made in these problems by improving the prior image models used, for example, by using hidden Markov trees of complex wavelets or by decomposing the image into several components. Ariana is also interested in blind deconvolution.

Figure 1. Left: denoising; middle: a degraded (blurred and noisy) image; right: its restoration.

4.2. Segmentation and classification

Many applications call for the image domain to be split into pieces, each piece corresponding to some entity in the scene, for example, forest or urban area, and in many cases for these pieces to be assigned the appropriate label. These problems too are long-studied, but there is much progress to be made, in particular in the use of prior geometric information.

Figure 2. Left: a satellite image; right: its classification.

4.3. Extraction of structures

As the resolution of remote sensing imagery increases, so the full complexity of the scene comes to the fore. What was once a texture is now revealed to be, for example, an arrangement of individual houses, a road

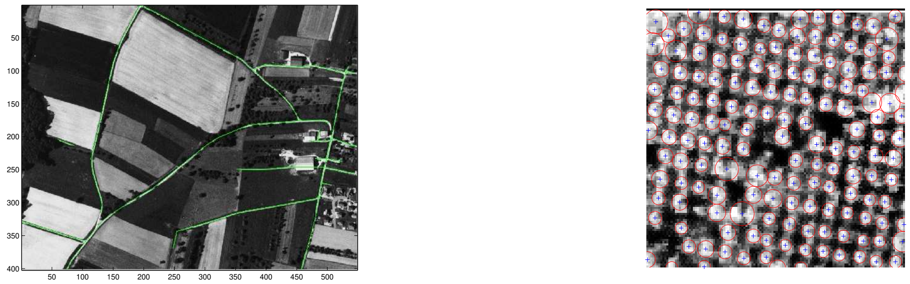


Figure 3. Left: road network extraction; right: tree extraction.

network, or a number of separate trees. Many new applications are created by the availability of this data, but efficient harvesting of the information requires new techniques.

4.4. 3D modelling

Earth observation and cartography is not solely concerned with 2D images. One important problem is the construction of 3D digital elevation models (DEMs) from high-resolution stereo images produced by satellites or aerial surveys. Synthetic aperture radar (SAR) imagery also carries elevation information, and allows the production of more accurate DEMs thanks to interferometry techniques, for example.

Figure 4. Left: DEM; right: interferometry.

4.5. Information mining and database retrieval

Every day, vast quantities of data are accumulated in remote sensing data repositories, and intelligent access to this data is becoming increasingly problematic. Recently, the problem of retrieval from large unstructured remote sensing image databases has begun to be studied within the project.

5. Software

5.1. DEMITRI

Keywords: *Richardson Lucy*, *confocal microscopy*, *image deconvolution*, *total variation*, *wide field microscopy*.

Participants: Nicolas Dey, Laure Blanc-Féraud, Josiane Zerubia [contact].

Figure 5. Image registration for the evaluation of retrieval systems. Left: mosaicked aerial image data; right: registered ground truth classification.

Software for biological image deconvolution (confocal and wide field microscopy) using a Richardson Lucy algorithm regularized by total variation. Deposited with the APP. Transferred to the Pasteur Institute in Paris and the Weizmann Institute in Israel.

5.2. DEFFASER

Keywords: *Gaussian field*, *forest fire*, *peak intensity*, *rare event*.

Participants: Florent Lafarge, Xavier Descombes, Josiane Zerubia [contact].

Software for forest fire detection by statistical analysis of rare events. Deposited with the APP. Transferred to Alcatel Space, Cannes.

5.3. Exaubatibaqua

Keywords: *building detection*, *low quality digital elevation model (DEM)*, *point process*.

Participants: Mathias Ortner, Xavier Descombes, Josiane Zerubia [contact].

Discontinuity detection in low quality DEMs using a marked point process based on rectangles. Deposited with the APP. Transferred to the French National Geographic Institute (IGN), Saint Mandé.

5.4. Exaubatitridi

Keywords: *3D building detection*, *Bayesian approach*, *DEM*, *point process*.

Participants: Mathias Ortner, Xavier Descombes, Josiane Zerubia [contact].

3D reconstruction of buildings from a rectangular initialization using a Bayesian model. Deposited with the APP.

5.5. Exaubatidis

Keywords: *DEM*, *building detection*, *point process*.

Participants: Mathias Ortner, Xavier Descombes, Josiane Zerubia [contact].

Discontinuity detection in optical DEMs using a marked point process based on rectangles. Deposited with the APP. Transferred to the French National Geographic Institute (IGN), Saint Mandé.

5.6. Exaubatilas

Keywords: *building detection*, *laser data*, *point process*.

Participants: Mathias Ortner, Xavier Descombes, Josiane Zerubia [contact].

Discontinuity detection in laser data using a marked point process based on rectangles. Deposited with the APP.

5.7. Exaubaticoope

Keywords: *DEM*, *building detection*, *point process*.

Participants: Mathias Ortner, Xavier Descombes, Josiane Zerubia [contact].

Building detection in DEMs using a marked point process based on rectangles cooperating with segments. The rectangles focus on homogeneous areas and the segments are mapped to discontinuities. Deposited with the APP. Transferred to the French National Geographic Institute (IGN), Saint Mandé.

6. New Results

6.1. Probabilistic Models

6.1.1. A diffusion process for image denoising

Keywords: *diffusion process*, *generalized Gaussian*, *image denoising*, *stochastic differential equation*.

Participants: Xavier Descombes, Elena Zhizhina.

This work is supported by Lyapunov Institute Grant 98-02 and NATO/Russia CLG 980107.

Last year, we began to study the stochastic differential equation (SDE) approach for solving optimization problems [8]. We considered the problem of image denoising and showed that the CPU time taken to reach the optimal solution in the SDE approach was comparable to that in the classical MCMC approach. More interestingly, we showed that we could reach sub-optimal solutions faster with the new approach. Moreover, the sub-optimal solution obtained via the SDE approach could be improved by a standard median filter, which is not the case for the MCMC approach. This year, we have proved that the Brownian motion included in the SDE can be approximated, in the discretization step, by a generalized Gaussian random variable. This permits big jumps in the configuration space, with no increase in the variance of the perturbation law. We are currently studying the impact of this result in practice. In addition, we have studied the new Langevin dynamics associated with the SDE.

6.1.2. Shape from shading using a stochastic differential equation

Keywords: *diffusion process*, *shape from shading*, *stochastic differential equation*.

Participants: Francois Swarzentruber, Xavier Descombes.

This work is part of a PAI Galilee project in collaboration with IRIT (Toulouse) and the Sapienza University of Rome.

In previous work, we showed that stochastic approaches are well adapted to solving the shape from shading (SFS) problem. SFS is an ill-posed problem for which the associated functional to be minimized contains deep local minima. Traditional methods based on deterministic optimization require good initialization to reach the solution. More precisely, they disambiguate the concave/convex ambiguity with difficulty, even when a smoothing prior is added. We have shown that a simulated annealing algorithm based on an MCMC approach solves the problem. However, this approach has a heavy computational cost which makes it inadequate in practical applications. In this work, we embedded the SFS problem into a stochastic differential equation (SDE) framework [8]. The SDE is discretized by an Euler scheme embedded in a simulated annealing framework. The experiments made on synthetic data, shown in Fig. 6, demonstrate that the SDE approach, compared with the MCMC approach, provides results of comparable quality but with a computational time reduced by a factor of 8.

6.1.3. Line network extraction from remotely sensed images using a Bayesian geometric model

Keywords: *RJMCMC*, *line network extraction*, *marked point process*, *simulated annealing*, *stochastic geometry*.

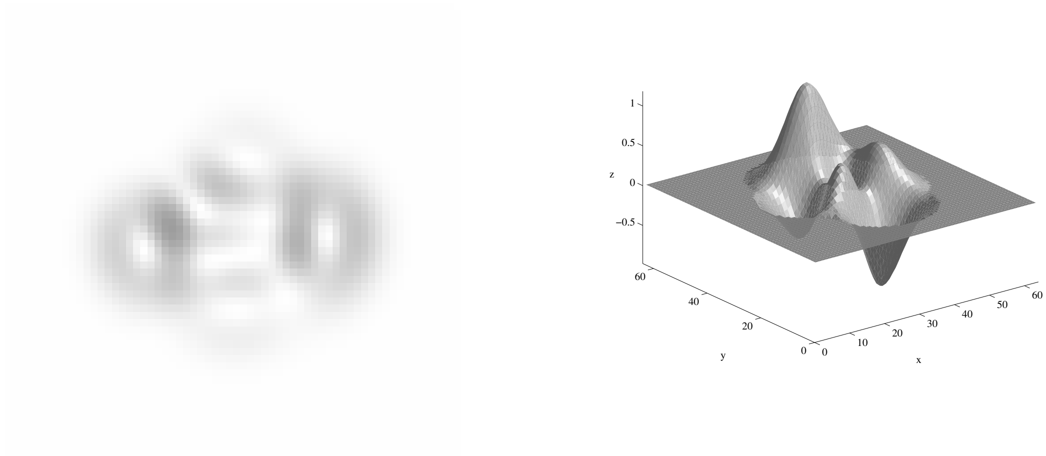


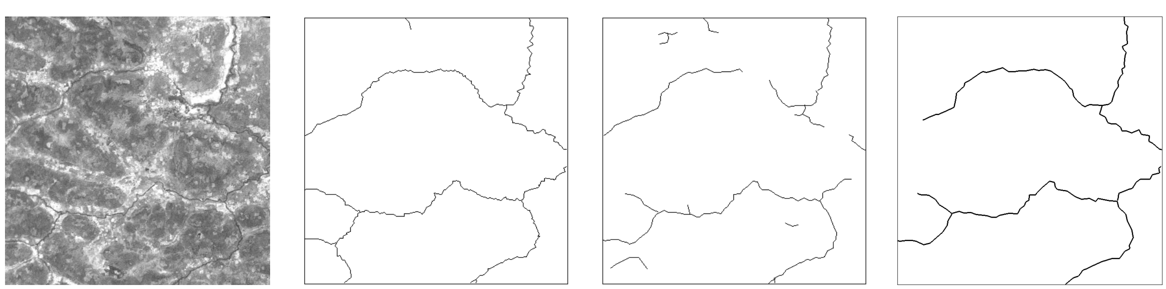
Figure 6. Left: image of a synthetic landscape. Right: 3D reconstruction.

Participants: Caroline Lacoste, Xavier Descombes, Josiane Zerubia.

In collaboration with the French Geographical Survey (BRGM) (N. Bagdhadi).

The context of this work is the unsupervised extraction of line networks from satellite and aerial images. The final application is the production or update of geographical data. We use object processes, or marked point processes, as prior models.

We first proposed modelling line networks by a process whose objects are interacting line segments. The prior model is designed to exploit as fully as possible the topological properties of the network under consideration through potentials based on the quality of each interaction. In previous work, the radiometric properties of the network were modelled using a data term based on statistical measures of the contrast with the nearby background and the homogeneity of the network. In [22], we consider a Bayesian approach. The data term is then the likelihood of the observations, where the observations correspond to the output of a line detector. A parameter tuning rule is defined from geometrical constraints allowing the parameters of the density to be fixed easily. MAP estimation—obtained by simulated annealing using an RJMCMC algorithm—provides a continuous extracted line network with low omission and overdetection ratios, improving the results obtained using previous models, as illustrated in Fig. 7.



Satellite image | Manual extraction | Previous model | Bayesian model

Figure 7. Line network extraction from a satellite image (SPOT XS2) of size 682×674 *pixels.*

6.1.4. Line network extraction from remotely sensed images using a polyline process

Keywords: *RJMCMC*, *line network extraction*, *marked point process*, *simulated annealing*, *stochastic geometry*.

Participants: Caroline Lacoste, Xavier Descombes, Josiane Zerubia.

In collaboration with the French Geographical Survey (BRGM) (N. Bagdhadi).

We extended the models proposed in [19][22] to more complex objects. More precisely, our new model, called CARtographic Oriented LIne Network Extraction (CAROLINE), is a spatial process where the objects are interacting polylines composed of an unknown number of segments. The use of polylines improves the detection of network junctions and increases the accuracy of the extracted network [23]. For example, Fig. 8 shows that the line network extracted using a polyline process is very close to the real network despite the high local curvatures in this network.

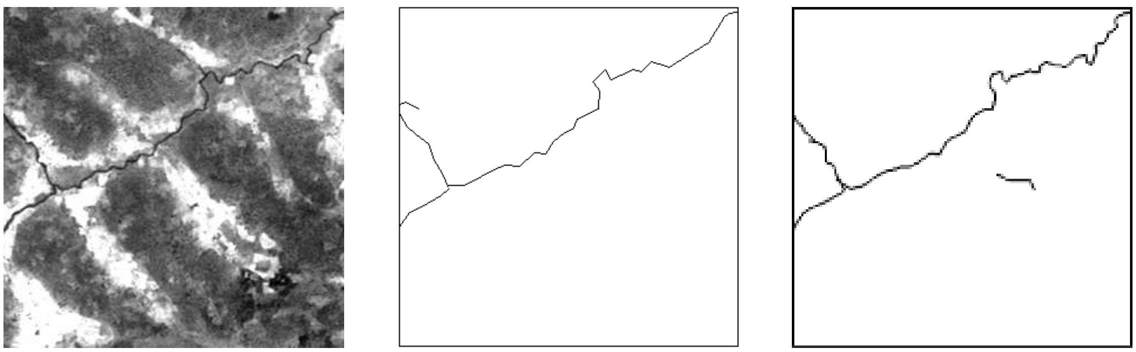


Figure 8. Left: a satellite image (SPOT XS2) of a river network. Centre: the result of river extraction using a segment process. Right: the result of river extraction using a polyline process.

6.1.5. Extraction of hydrographic networks using a hierarchical model

Keywords: *Markov random field*, *RJMCMC*, *hydrographic network extraction*, *marked point process*, *simulated annealing*, *stochastic geometry*.

Participants: Caroline Lacoste, Xavier Descombes, Josiane Zerubia.

In collaboration with the French Geographical Survey (BRGM) (N. Bagdhadi).

In a third piece of work, we proposed a two-step algorithm to extract hierarchical networks, such as hydrographic networks, that are composed of rivers and their tributaries. First, the thick branches of the network (larger than 3 pixels) are detected by an efficient algorithm based on a Markov random field. Second, the line branches of the network—which are much more difficult to extract—are extracted using a recursive algorithm based on a hierarchical model of hydrographic networks, in which the tributaries of a given river are modelled by a polyline process in the neighbourhood of this river. Fig. 9 presents the result of network extraction from a radar image. This is a very encouraging result, as there are no omissions and only two small overdetections with respect to the manual extraction provided by an expert from the French Geographical Survey (BRGM).

6.1.6. Automatic segmentation of digital elevation models using point processes

Keywords: *RJMCMC*, *automatic feature extraction*, *building detection*, *dense urban area*, *digital elevation model*, *inhomogeneous Poisson point process*, *land register*, *laser data*, *simulated annealing*.

Participants: Mathias Ortner, Xavier Descombes, Josiane Zerubia.

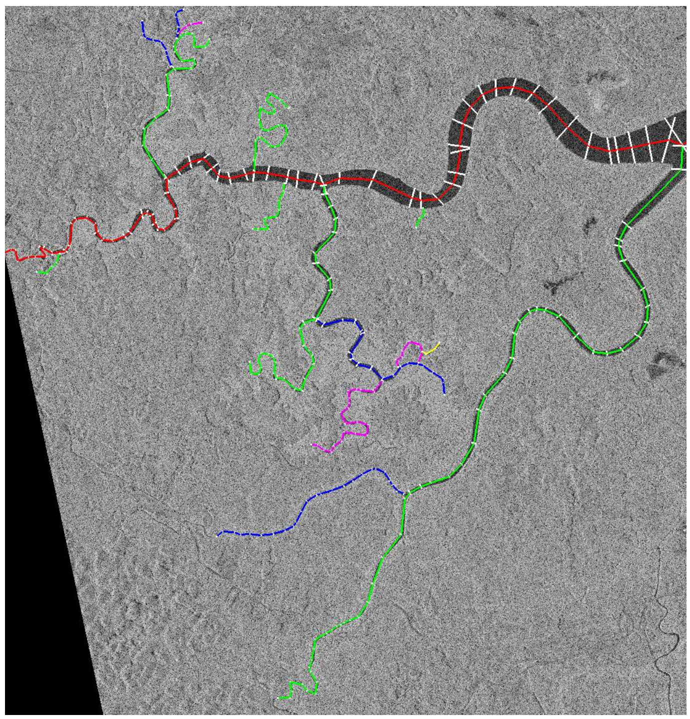


Figure 9. Unsupervised extraction of a hydrographic network from a radar satellite image (ERS) using a hierarchical model. The red line corresponds to the main river; the green lines correspond to the tributaries of this river; the blues ones to the tributaries of these tributaries; and so on. The white lines refer to the successive widths of the extracted objects.

This work was partially funded by the French Defence Agency (DGA).

The context of this work is the reconstruction of urban areas from images. We propose a set of algorithms for extracting simple shapes from digital elevation models (DEMs). DEMs describe the altimetry of an urban area by a grid of points, each of which has a height associated to it (see Figs. 10 and 11).

The proposed models are based on marked point processes. These mathematical objects are random variables whose realizations are configurations of geometrical shapes. Using these processes, we can introduce constraints on the shape of the objects to be detected in an image, and a regularizing term incorporating geometrical interactions between objects. An energy can be associated to each object configuration, and the global minima of this energy can then be found by applying simulated annealing to a Reversible Jump Monte Carlo Markov Chain sampler (RJMCMC).

6.1.6.1. Extension of former results

We have extended and refined three previously developed models to deal with more general data. In particular we obtain results on noisy data. The first two models extract simple shapes (rectangles) using, respectively, an homogeneity constraint and discontinuity detection while the third model looks for three-dimensional polyhedral buildings. We presented an overview of the different models in [11]. The model based on discontinuities was detailed in [26].

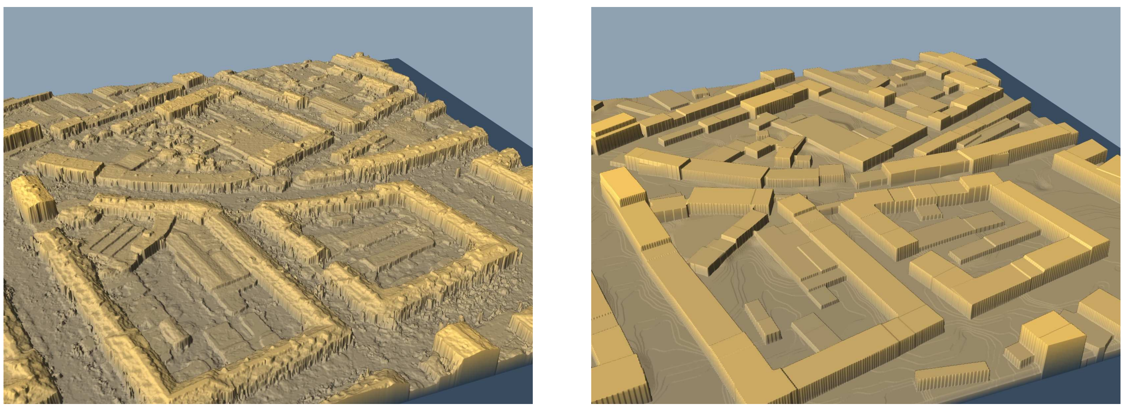


Figure 10. Left: original DEM (Amiens), provided by the French National Geographic Institute (IGN) (20cm,20cm,10cm). Right: simple shapes automatically extracted.

6.1.6.2. Improvement of former algorithms

We have developed some techniques to increase the speed of the algorithm in different cases, especially when using complex building models. We have also proposed an adaptive simulated annealing cooling scheme that proved to perform well: results are improved while the algorithm needs fewer iterations than before.

6.1.6.3. Cooperation

We developed a new kind of model that proved to be powerful on low quality data. This model consists of a superposition of two spatial point processes. The first one is a segment process. The data term corresponds to a discontinuity detector, while the prior term favours connectivity of the network. The second process consists of rectangles: the data term is based on a homogeneity hypothesis while the prior term favours a tiling behaviour. An interaction term then makes the two processes cooperate. Experimental results show the efficiency of the approach (see Fig. 12).

6.1.7. Automatic building extraction from digital elevation models

Keywords: *RJMCMC*, *automatic feature extraction*, *building detection*, *dense urban area*, *digital elevation model*, *inhomogeneous Poisson point process*, *land register*, *laser data*, *simulated annealing*.

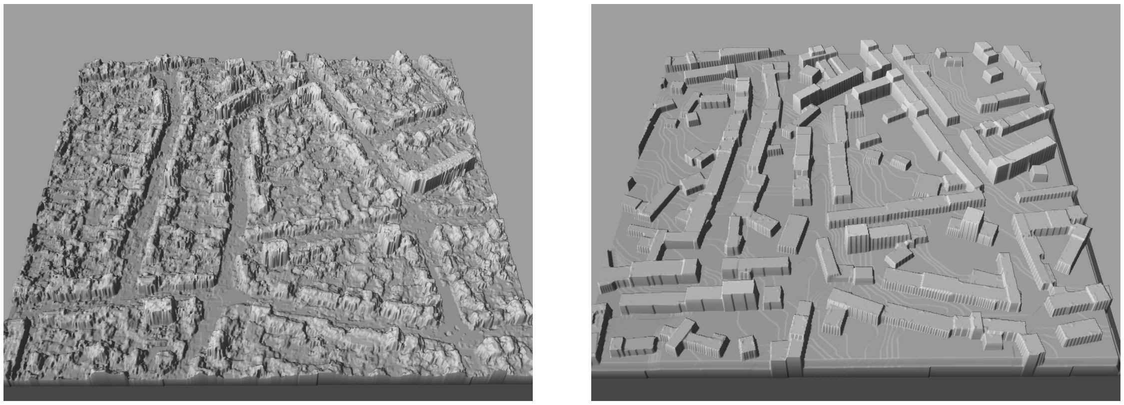


Figure 11. Left: original DEM (Rennes), provided by the French National Geographic Institute (IGN) (40cm,40cm,10cm). Right: simple shapes automatically extracted.

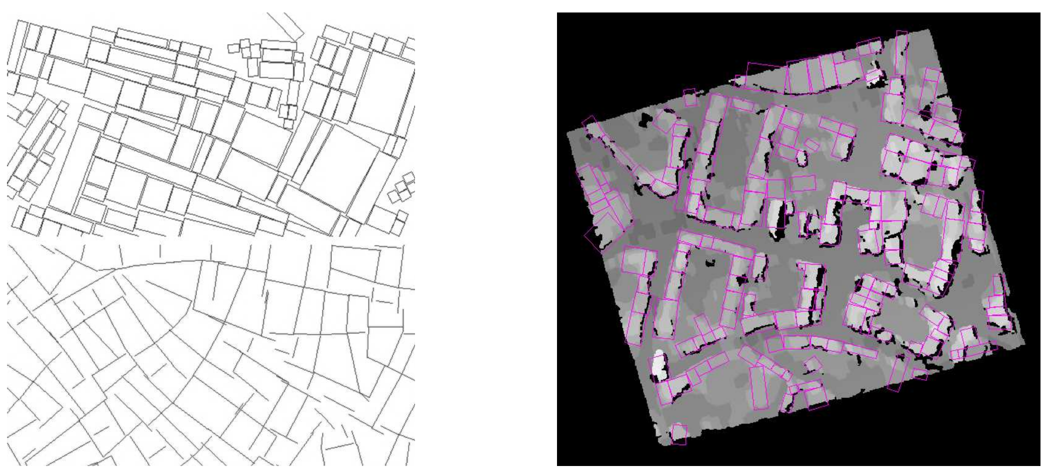


Figure 12. Left: rectangle and segment processes used in cooperation. Right: result of detection on a Pleiades simulation provided by the French Space Agency (CNES) (1m,1m,5m).

Participants: Florent Lafarge, Xavier Descombes, Josiane Zerubia.

This Ph.D. is co-directed by Marc Pierrot-Deseiligny and Didier Boldo, both from the French National Geographic Institute (IGN).

This work concerns the 3D reconstruction of buildings in dense urban areas from DEMs and high resolution satellite images. In particular, we are studying the complementarity of recent work in this area. The work of M. Ortner (section 6.1.6) provides an automatic vectorial description of the 2D silhouette of buildings from a DEM. This approach is based on marked point process. The work of H. Jibrini provides a precise 3D description of roofs based on stereoscopic high resolution data, and a cadastral description of the corresponding buildings. The first piece of work we propose consists of the fusion of these two approaches by considering the feedback of information. In the future, we will also study the synergy of these two approaches in a global stochastic model.

6.1.8. Tree crown extraction using marked point processes

Keywords: *Bayesian image modelling*, *marked point process*, *object-based model*, *parameter estimation*, *tree crown extraction*.

Participants: Guillaume Perrin, Xavier Descombes, Josiane Zerubia.

This Ph.D. is co-supervised by Christian Saguez, director of the Applied Mathematics Laboratory of École Centrale Paris (http://www.mas.ecp.fr), and by Paul-Henry Cournède from the same laboratory. The data (aerial images of French forests) were provided by the French National Forest Inventory (IFN) (http://www.ifn.fr).

In forestry management, high-level parameters such as tree crown diameters, stem density, and low-level parameters such as species classification, are currently assessed by human interpretation and studies on the ground. High spatial resolution images could help forestry managers obtain these parameters automatically.

Using marked point processes, we can describe the distribution of trees in plantation images. The geometrical objects can be either disks or ellipses, while the density of the process contains both prior knowledge about the trees we are detecting (overlap and alignment rules), and a data term which fits our objects to the image (Bayesian image modelling using a mixture of Gaussians). We estimate the distribution of trees by simulating our point process with an RJMCMC algorithm and simulated annealing. The results are obtained on stands of poplars [27] (see Fig. 13). The parameters of the model can be estimated using an importance sampling technique.

6.1.9. Forest fire detection by statistical analysis of the radiometry of satellite images

Keywords: *DT-characteristic*, *Gaussian field*, *cluster*, *forest fire detection*, *peak intensity*, *rare event*.

Participants: Florent Lafarge, Xavier Descombes, Josiane Zerubia.

In collaboration with Alcatel Space (S. Mathieu-Marni). BIRD images provided by the German Space Agency (DLR).

We present a method for forest fire detection in satellite images based on random field theory. The TIR (Thermal InfraRed) channel has a wavelength sensitive to the emission of heat: the higher the heat of an area, the higher the intensity of the corresponding pixel of the image. A forest fire can then be characterized by peak intensities in TIR images. We have developed a fully automatic unsupervised classification method based on Gaussian field theory [36]. We model the image as a realization of a Gaussian field. The fire areas, which have high intensity and are assumed to be a minority, are treated as foreign elements of that field: they are rare events. We determine by a statistical analysis a set of probabilities which characterizes the degree of belonging to the Gaussian field of a small area of the image. Thus, we estimate the probability that the area is a fire (see Fig. 14).

6.1.10. Texture kernels for SVM classification applied to remote sensing problems

Keywords: *classification*, *forest fire detection*, *kernel*, *support vector machines*, *texture*, *training set*, *urban area extraction*.

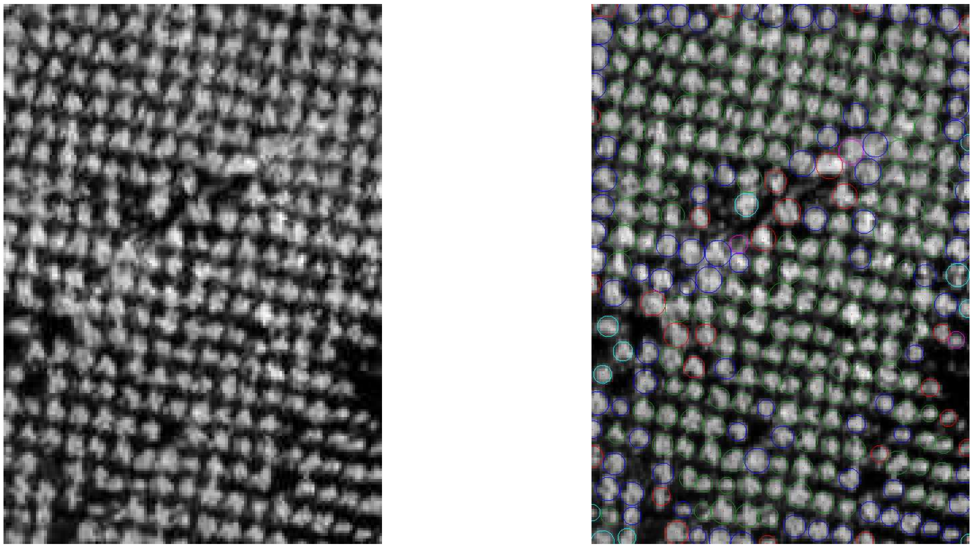


Figure 13. Left: an aerial image of a forest. Right: the result of tree crown extraction.

Figure 14. Left: the result of forest fire detection. Right: ground truth.

Participants: Florent Lafarge, Xavier Descombes, Josiane Zerubia.

In collaboration with Alcatel Space (S. Mathieu-Marni). SPOT5 images courtesy of the ISIS programme of the French Space Agency (CNES).

We present two texture kernels for Support Vector Machine classification applied to remote sensing problems[37]. SVMs constitute a method of supervised classification well adapted to deal with data of high dimension, such as images. We would like to learn parameters that differentiate between two sets of connected pixels. We also introduce kernel functions which characterize a notion of similarity between two pieces of data. In our case this similarity is based on a radiometric characteristic and a texture characteristic. The main difficulty consists in finding texture parameters that are relevant and characterize as well as possible the homogeneity of a set of connected pixels. We apply this method to two remote sensing problems: the detection of forest fires and the extraction of urban areas from high resolution satellite images (see Fig. 15).

Figure 15. Left: the result of forest fire detection. Right: the result of the extraction of an urban area.

6.1.11. Speckle noise removal via alpha-stable distributions

Keywords: *Mellin transform*, *alpha-stable*, *multiplicative noise*, *speckle removal*, *synthetic aperture radar*.

Participants: Alin Achim, Josiane Zerubia.

This work was done in collaboration with Ercan Kuruoglu of CNR Pisa, and was partially supported by ERCIM via a postdoctoral fellowship.

This work concerns the development of novel image processing techniques based on alpha-stable statistics and their applications to the case of synthetic aperture radar (SAR) image data. Specifically, it addresses problems related to the exploitation of alpha-stable and related heavy-tailed models in speckle noise mitigation and segmentation/classification of SAR images with the ultimate goal of detecting the areas of dense urbanization and sparse urbanization with a high resolution.

In particular, a new Bayesian-based algorithm has been developed that reduces speckle in SAR images while preserving the structural features and textural information of the scene. The algorithm is based on modelling the radar cross section using a novel statistical model, the heavy-tailed Rayleigh distribution, recently introduced in [10]. The model was developed based on the observation that the real and imaginary parts of the received complex signal can be accurately modelled using the symmetric alpha-stable family of distributions. Under the assumption of a multiplicative speckle noise model, we first employed a logarithmic transformation in order to transform the noise from multiplicative to additive, and to differentiate its characteristics from the signal characteristics. Then, a maximum a posteriori processor was implemented numerically and the corresponding nonlinearities were applied to the observed data. A novel parameter estimation method was developed for the case of generalized Rayleigh signal mixed with Gamma/Nakagami distributed speckle noise. The estimation method is based on the second-kind statistic theory employing the Mellin transform. We have applied the filter to a number of simulated as well as real speckle images and have compared the results with those obtained by means of classical speckle filters. Our simulations results show that the homomorphic MAP filter based on the heavy-tailed Rayleigh model is among the best for speckle removal.

6.2. Variational Models

6.2.1. Image disocclusion

Keywords: *PDE*, *disocclusion*, *level line*, *orientation*, *probability field*.

Participants: Emmanuel Villéger, Laure Blanc-Féraud, Gilles Aubert.

Disocclusion means to fill a hole in an image ('inpainting'). Occlusions occur, for example, when one object is in front of another one or when there are scratches in old photographs. We focus in this work on non-textured images. A common approach is to extend data inside the hole by taking into account information around the boundary of the hole through level lines. The information is propagated inside the hole along the level lines by solving a transport PDE. We propose to take into account the uncertainty due to the computation of the propagation direction by a gradient [30]. We introduce a field of probabilities for the orientation of the level lines. The method then consists of alternately solving two PDEs, one for the probabilities and one for the intensity. Both PDEs are stabilized by using diffusion terms.

6.2.2. Using ratio costs to extract regions from satellite images

Keywords: *active contour*, *graph algorithm*, *level set*, *minimum ratio cycle*, *nonlocal force*, *ratio energy*, *region extraction*, *segmentation*, *segmentation*, *urban area*.

Participants: Igor Rosenberg, Ian Jermyn, Josiane Zerubia.

Energies defined on closed curves ('active contours') are much used in the modelling and extraction of regions from images. Typically such energies consist of linear combinations of single integrals over the contour. An alternative form of energy consists of the ratio of two integrals. Such energies have several advantages: they eliminate a parameter, which is set automatically by the ratio, and there exists a graph algorithm ('minimum ratio cost cycle') that can be used to find the global minimum of such energies in polynomial time. The forms of energy that can be solved with this algorithm are, however, limited. The purpose of this work was thus to apply the gradient descent algorithms more usually used for active contours to such ratio energies, and to compare the results obtained using graph methods on synthetic and real data (see Fig. 16).

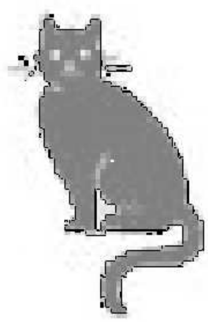
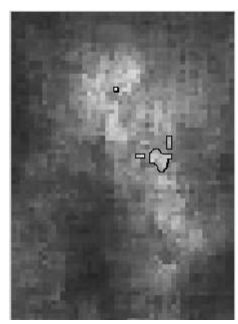



Figure 16. Left: correct segmentation of a cat, with the tail correctly taken as part of the main shape. Right: extraction of regions in an urban area.

6.3. EU Project MUSCLE

6.3.1. Gap closure in line networks using higher-order active contours

Keywords: *active contour*, *gap closure*, *higher-order*, *level set*, *line network*, *nonlocal force*, *shape prior*.

Participants: Marie Rochery, Ian Jermyn, Josiane Zerubia.

This work is a contribution to FP6 Network of Excellence MUSCLE (http://www.muscle-noe.org).

The automatic extraction of line networks from satellite and aerial images is a subject of great current interest due to the large number of such images that are generated but that remain unprocessed due to the sheer volume of data. The extraction of networks is a difficult problem, however, and necessitates the use of significant prior information, in particular concerning the shape of the regions in images occupied by such networks. To incorporate such information, in previous work we introduced a new class of active contour models, 'higher-order active contours', defined by polynomial functionals on the space of contours, and expressible as multiple integrals over the contour. These models are capable of incorporating prior information about the geometry of the region to be extracted, and we developed a specific model for the description of reticulated structures such as line networks. However, occlusions due to the presence of trees or other 'geometric noise' close to the network meant that the networks extracted using this model were often interrupted by 'gaps'. To deal with this problem, in this work we augment our previous model with a term that specifically concentrates on the closure of gaps by making pairs of nearby network extremities extend towards one another and join [29]. The new force term uses our knowledge of the geometry of gaps in networks: if both of a pair of points have high positive curvature, if they lie outside the contour with respect to one another, and if they are closer than a certain distance, they attract, forcing the two extremities composed of such points to move towards one another and eventually merge. The new force significantly improves the results obtained, as shown in Fig. 17.

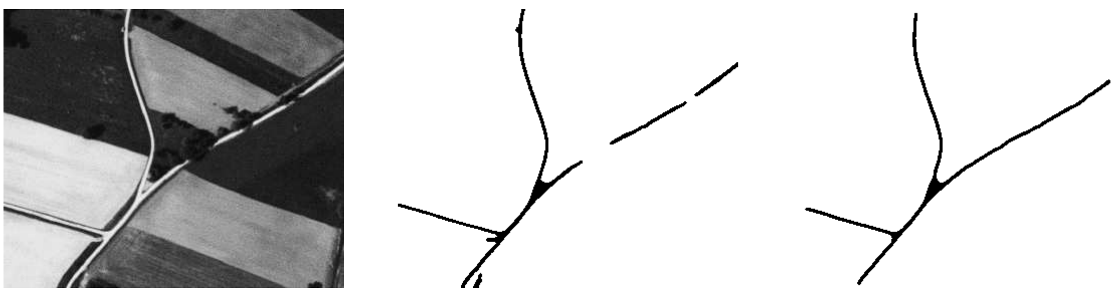


Figure 17. Left: aerial image. Middle: result of extraction without the gap closure force. Right: result of extraction with the gap closure force.

The new term was introduced at the level of the evolution equation, which, aside from its artificiality with respect to the variational formulation, makes analysis more difficult. Current work is focused on the development of an energy term that will produce the same behaviour. The difficulties here are primarily numerical, since the resulting force involves second derivatives of the contour curvature, and thus fourth derivatives of the level set function.

6.4. EU Project MOUMIR

6.4.1. Multimodal statistics of adaptive wavelet packet coefficients

Keywords: *adaptive basis*, *multimodal distribution*, *texture*, *wavelet packet*.

Participants: Roberto Cossu, Ian Jermyn, Josiane Zerubia.

This work was done as part of FP5 Research Training Network MOUMIR (http://www.moumir.org).

In [40], it was noted that although the subband histograms for standard wavelet coefficients take on a generalized Gaussian form, this is no longer true for wavelet packet bases adapted to a given texture, and in particular it is not true for the adaptive Gaussian models developed in [40]. Instead, three types of subband statistics are observed: Gaussian, generalized Gaussian, and interestingly, in some subbands, bi- and tri-modal histograms. These multimodal subbands are closely linked to the structure of the texture, capturing the presence of significant periodicities.

Motivated by these observations, in [34], [17], and [18] such an approach to texture analysis was extended to model these subbands. In this work, we provided theoretical and empirical evidence for the existence of multimodality, using a variety of simple but significant texture models constructed in the Fourier domain. For example, Fig. 18 shows the histograms of wavelet coefficients for a signal whose Fourier coefficient amplitudes at neighbouring frequencies take on a Gaussian shape plotted against the signal bandwidth. These confirm intuition, and also show that multimodality is inextricably linked to the characteristic structures in a texture. We also demonstrate empirically the effect on the wavelet packet coefficient histograms of adding a periodicity to an image. We then demonstrate the discriminatory power of multimodality using both Brodatz textures and textures taken from remote sensing imagery.

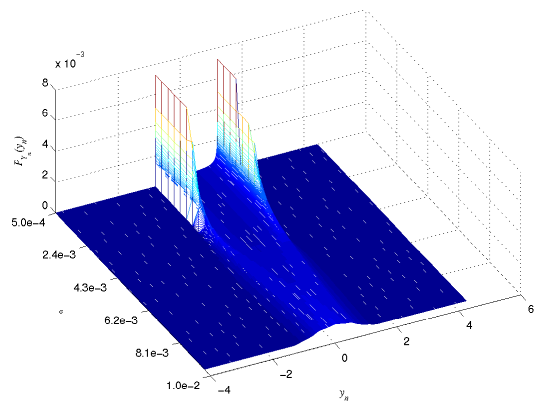


Figure 18. Histograms of wavelet coefficients for a signal whose Fourier coefficient amplitudes at neighbouring frequencies take on a Gaussian shape. The plot is given against the signal bandwidth.

6.4.2. Shape from texture via conformal embeddings

Keywords: *conformal*, *constraint*, *diffeomorphism*, *embedding*, *shape from texture*, *surface*.

Participants: Rami Hagege, Ian Jermyn.

This work was done as part of FP5 Research Training Network MOUMIR (http://www.moumir.org), in collaboration with Professor Joseph Francos of Ben-Gurion University, Israel.

The goal in the shape from texture problem is to recover a surface from its image, which is supposed to be ‘textured’. The regularities in the texture are distorted by the curvature of the surface, and therefore contain information about the shape of the surface.

In previous work, we showed that by estimating a 2D diffeomorphism between the flat texture and its image distorted by the surface, and by assuming that a ‘flat’ texture is mapped to a surface by a conformal embedding, we can complete the estimated 2D diffeomorphism to a conformal embedding, thus estimating the surface, providing the 2D diffeomorphism satisfies certain constraints. Unfortunately, unconstrained estimates typically do not satisfy these constraints. This can happen because of noise in the imaging process or errors in the estimation processes, or because the conformal model of textures on surfaces is only approximately correct. In order to guarantee the existence of a surface, we thus need to find the optimal 2D diffeomorphism that lies in the projectively conformal class, by minimizing a suitably defined energy functional subject to the appropriate constraints. In general, these constraints are hard to implement, but by approximating the 2D diffeomorphism by a polynomial we can impose the constraints using Tarski's theorem. The calculation and implementation of these constraints is the current subject of this work.

6.5. EU Project IMAVIS

6.5.1. Probability density function estimation techniques for synthetic aperture radar data analysis

Keywords: *estimation*, *log-cumulant*, *probability density*, *stochastic EM*, *synthetic aperture radar*.

Participants: Gabriele Moser, Josiane Zerubia.

This work was done as part of EU project IMAVIS, in collaboration with Professor S. Serpico of the University of Genova.

This work focused on the development of probability density function estimation techniques for synthetic aperture radar (SAR) data analysis [25][39]. The problem of modelling accurately the pdf of SAR amplitude imagery was addressed by generalizing the usual circular Gaussian model of the complex SAR signal through the introduction of Generalized Gaussian distributions. A parameter estimation algorithm was developed for the resulting amplitude model based on the recently proposed Method of Log-Cumulants (MoLC), and proved theoretically to be consistent. On the other hand, the selection of a parametric model for the different land-cover types present in a given SAR image was addressed using a pdf estimation technique based on a finite mixture model, together with the assumption that each mixture component belongs to a given dictionary of SAR-specific distributions. The parameter-estimation stage, the selection of the optimal model in the dictionary, and the optimization of the number of mixture components are integrated and automated by combining MoLC with the Stochastic Expectation-Maximization (SEM) methodology [24][38]. The proposed algorithms were validated experimentally on real SAR images acquired by several sensors (ERS-1, XSAR, E-SAR, and the NASA/JPL airborne SAR sensor) and proved to provide accurate PDF estimates and to outperform several previously proposed PDF models.

6.5.2. Satellite image segmentation and classification through the use of a tree-structured MRF

Keywords: *Bayesian estimation*, *Markov random field*, *classification*, *hierarchical model*, *segmentation*.

Participants: Giuseppe Scarpa, Josiane Zerubia.

This work was done as part of EU project IMAVIS, in collaboration with Professor G. Poggi of the University Federico II of Naples.

Several methods have been proposed for the classification of SPOT images in a supervised context where ground truth is available for training, *e.g.* the H-MRF model-based algorithm presented in [42]. Although the overall accuracy of these methods is quite satisfying compared to other algorithms, a few classes were poorly classified, as highlighted by class-wise accuracy indicators. In addition, an undesirable blocking-effect was revealed for the H-MRF algorithm, as shown in Fig. 19 (left).

In order to overcome these problems, in this work, we adapted to the supervised case [28] an unsupervised segmentation algorithm based on a tree-structured MRF model (TS-MRF) recently proposed in [41]. This model is based on the observation that many real images possess a distinctly hierarchical structure. In fact, given a binary tree which represents the hidden class hierarchy, the TS-MRF model uses this structure as a constraint on the parameter space, in order to reduce complexity and to fit better the local structures and parameters of the image. Experimental results on the SPOT image of Lannion Bay show the superior performance of the proposed algorithm with respect to the reference method cited above, both in terms of classification accuracy, and in terms of subjective visual quality, since the blocking-effect has disappeared (see Fig. 19 (right)).

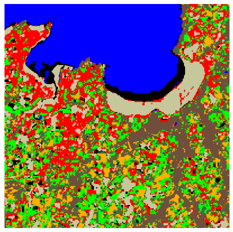
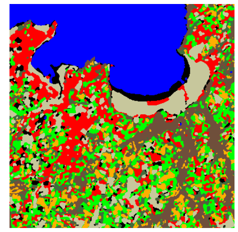



Figure 19. Left: classification by H-MRF. Right: classification by TS-MRF.

6.6. ARC DeMiTri

6.6.1. *Denoising of 3D biological confocal microscopy imagery using a complex wavelet transform*

Keywords: *3D complex wavelet transform*, *confocal microscopy*, *direction selectivity*, *image denoising*, *translation invariance*.

Participants: Gemma Pons, Laure Blanc-Féraud, Josiane Zerubia.

This work is being done as part of INRIA ARC DeMiTri (http://www-sop.inria.fr/ariana/personnel/Nicolas.Dey/DeMiTri/arc.php).

Confocal laser scanning microscopy is a powerful technique for the 3D imaging of biological specimens. However, the images thus acquired are degraded by blur from out-of-focus light, and by Poisson noise due to photon-limited detection. In this work, we focused on the denoising problem. We have proposed a wavelet based thresholding algorithm for 3D confocal image denoising. We have developed a 3D complex wavelet transform. This decomposition is nearly translation and rotation invariant. We have shown that the gain in quality using complex wavelet thresholding is +2dB comparing to standard real wavelet thresholding. Fig. 20 shows the result of denoising real data.

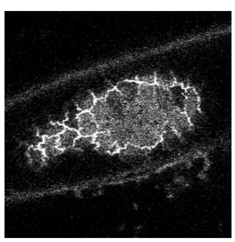
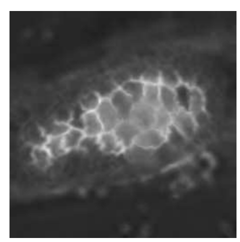



Figure 20. Left: image of drosophile embryon, provided by the Institut de Signalisation, Biologie du Développement et Cancer (CNRS/UNSA). Right: image denoised by 3D complex wavelet coefficient thresholding.

6.6.2. *Deconvolution of 3D biological confocal microscopy imagery using the Richardson-Lucy algorithm with TV regularization*

Keywords: *Richardsdon Lucy algorithm*, *confocal microscopy*, *image deconvolution*, *regularization*, *total variation*.

Participants: Nicolas Dey, Laure Blanc-Féraud, Josiane Zerubia.

This work is being done as part of INRIA ARC DeMiTri *(http://www-sop.inria.fr/ariana/personnel/Nicolas.Dey/DeMiTri/arc.php), in collaboration with J. C. Olivo-Marin, C. Zimmer, and P. Roux from the Pasteur Institute, and Z. Kam from the Weizmann Institute, Israel.*

Several deconvolution algorithms have been proposed to reduce the degradations inherent to confocal microscopy (*i.e.* blur from out-of-focus light and Poisson noise), including the Richardson-Lucy iterative algorithm, which computes a maximum likelihood estimate adapted to Poisson statistics. However, this algorithm tends to amplify noise and must be regularized. In this work, we proposed using the total variation of the 3D image [20][21][35] in conjunction with the Richardson Lucy algorithm. In this way, the image is smoothed while the edges of objects are preserved. Figs. 21 and 22 compare the performance of the proposed algorithm with the more standard quadratic regularization, on simulated and real data respectively.

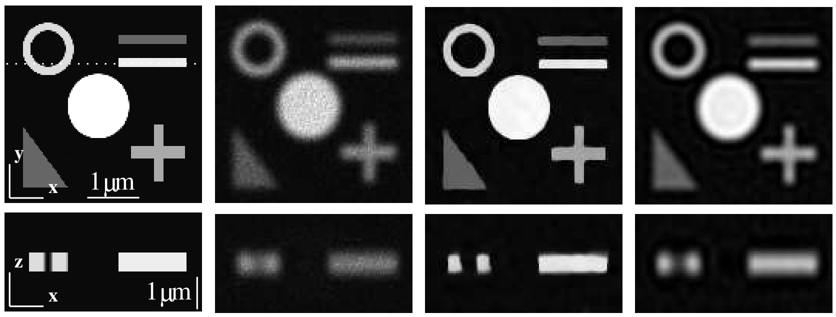


Figure 21. Left: synthetic 3D image (xy and xz slides). Middle-left: blurred and noisy image. Middle-right: image deconvolved by the Richardson-Lucy algorithm and TV regularization. Right: image deconvolved by the Richardson-Lucy algorithm and quadratic regularization.

Figure 22. Left: image of drosophile embryon, provided by the Institut de Signalisation, Biologie du Développement et Cancer (CNRS/UNSA). Right: image deconvolved by the Richardson-Lucy algorithm and TV regularization.

7. Contracts and Grants with Industry

7.1. Industrial

7.1.1. Alcatel Space Cannes

Participants: Florent Lafarge, Xavier Descombes, Josiane Zerubia [PI].

Forest fire detection in TIR (BIRD) and visible (SPOT5) satellite images. Contract # 104E10930041624.

7.1.2. BRGM Orléans

Participants: Caroline Lacoste, Xavier Descombes, Josiane Zerubia [PI].

Updating of line networks in cartography using data fusion and Markov object processes. Contract # 102E03800041624.01.2.

7.1.3. DGA/CTA Arcueil

Participants: Mathias Ortner, Xavier Descombes, Josiane Zerubia [PI].

Analysis of urban areas using Markov object processes and digital elevation models. Grant under DGA/CNRS agreement.

7.1.4. CNES Toulouse

Participants: Avik Bhattacharya, Xavier Descombes, Ian Jermyn, Josiane Zerubia [PI].

Extraction and characterization of line networks in satellite images for retrieval from image databases. Contract signed but number not yet assigned.

7.1.5. IGN Saint Mandé

Participants: Florent Lafarge, Xavier Descombes, Josiane Zerubia [PI].

Automatic building extraction from digital elevation models. Grant under IGN/CNES agreement.

8. Other Grants and Activities

8.1. Regional

8.1.1. INRIA COLORS project 'Arbres'

Participants: Guillaume Perrin, Xavier Descombes [PI], Josiane Zerubia.

In collaboration with the Agricultural and Environmental Engineering Research Centre (CEMAGREF), Montpellier (M. Deshayes), and the French National Forest Inventory (IFN), Montpellier (J. G. Boureau) and Nogent-sur-Vernisson (J. Wolsack).

8.2. National

8.2.1. CNRS MATH/STIC grant 'Détection de structures fines en imagerie 3D'

Participant: Laure Blanc-Féraud [PI].

In collaboration with the Jean-Alexandre Dieudonné Laboratory, CNRS/UNSA (G. Aubert).

8.2.2. ACI Masses de Données 'QuerySat: Heterogeneous and multi-scale descriptors for retrieval from remote sensing image databases'

Participants: Avik Bhattacharya, Xavier Descombes [Ariana PI], Ian Jermyn, Josiane Zerubia.

In collaboration with ENST (H. Maître, M. Roux) and INRIA project Imedia (N. Boujemaa, M. Crucianu).

8.2.3. ACI NIM 'MULTIM: Nouvelles methodes mathematiques pour la restauration d'images multi-canaux'

Participants: Laure Blanc-Féraud [Ariana PI], Xavier Descombes, Josiane Zerubia.

In collaboration with the J-L Lions Laboratory (P. L. Combettes, A. Cohen); J.-A. Dieudonné Laboratory, CNRS/UNSA (G. Aubert); CMAP, École Polytechnique (A. Chambolle); Applied Maths Laboratory, Univ. Paris V (L. Moisan); INFO-IGM Laboratory, Univ. Marne La Vallée (J.-C. Pesquet); Observatoire Midi Pyrennees, Univ. Paul Sabatier Toulouse (S. Rocques).

8.2.4. Action PNTS 'Extraction/mise à jour cartographique des réseaux linéiques à partir de données radar et optique hautes résolutions'

Participants: Caroline Lacoste, Xavier Descombes, Josiane Zerubia [PI].

In collaboration with BRGM (N. Bagdhadi).

8.2.5. Action PNTS 'Extraction de bâti à partir de MNE'

Participants: Mathias Ortner, Xavier Descombes [Ariana PI], Josiane Zerubia.

In collaboration with ENST (H. Maître, M. Roux, S. Amami).

8.3. European

8.3.1. EU project IMAVIS

Participant: Josiane Zerubia [Ariana PI].

The Ariana project is a participant in European Union project IMAVIS (Theory and Practice of Image Processing and Computer Vision), contract IHP-MCHT-99-1, in collaboration with the INRIA Odyssée and Epidaure projects. Web site: http://www-sop.inria.fr/robotvis/projects/Imavis/imavis.html

8.3.2. EU project MOUMIR

Participants: Roberto Cossu, Ian Jermyn, Josiane Zerubia [Ariana PI].

The Ariana project is a participant in European Union Fifth Framework Research Training Network MOUMIR (Models for Unified Multimedia Information Retrieval), contract HPRN-CT-1999-00108/RTN-1999-0177, in collaboration with Trinity College Dublin, University of Cambridge, INESC Porto, University of Thessaloniki, Ben-Gurion University, Radio-Televisaõ Portuguesa, and Bridgeman Art Library. Web site: http://www.moumir.org

8.3.3. EU project MUSCLE

Participants: Marie Rochery, Ian Jermyn [Ariana PI], Josiane Zerubia.

The Ariana project is a participant in the European Union Sixth Framework Network of Excellence MUSCLE (Multimedia Understanding through Semantics, Computation and Learning), contract FP6-507752, in collaboration with 41 other participants around Europe, including four other INRIA projects. Web site: http://www.muscle-noe.org

8.3.4. PAI Procope 'Non-local information extraction within a Bayesian data mining framework for remote sensing images'

Participants: Caroline Lacoste, Mathias Ortner, Marie Rochery, Ian Jermyn [Ariana PI], Josiane Zerubia.

In collaboration with the German Space Agency (DLR) (M. Datcu).

8.3.5. PAI Galilée 'PLATONOV: photocopies de livres anciens par techniques d'optimisation numériques et solutions de viscosité'

Participant: Xavier Descombes [Ariana PI].

In collaboration with IRIT Toulouse (JD Durou, A. Crouzil, P. Gurdjos, F. Courteille) and Università La Sapienza, Rome (M. Falcone, E. Cristiani, A. Seghini).

8.4. International

8.4.1. INRIA ARC DeMiTri

Participants: Gemma Pons, Nicolas Dey, Laure Blanc-Féraud, Josiane Zerubia [PI].

In collaboration with the Pasteur Institute (J. C. Olivo-Marin, C. Zimmer) and the Weizmann Institute (Z. Kam). Web site: http://www-sop.inria.fr/ariana/personnel/Nicolas.Dey/DeMiTri/arc.php

8.4.2. Lyapunov Institute grant 98-02

Participants: Xavier Descombes, Josiane Zerubia [PI].

In collaboration with the IITP of the Russian Academy of Science (E. Pechersky, E. Zhizhina).

8.4.3. NATO/Russia Collaborative Linkage Grant 980107 'Prior shape information for image segmentation in environmental and disaster detection and monitoring'

Participants: Marie Rochery, Ian Jermyn, Xavier Descombes, Josiane Zerubia [PI].

In collaboration with North Carolina State University (H. Krim) and the IITP of the Russian Academy of Science (R. Minlos, E. Pechersky, E. Zhizhina).

8.4.4. INRIA-LIAMA

Participants: Guillaume Perrin, Xavier Descombes, Ian Jermyn, Josiane Zerubia [PI].

In collaboration with V. Prinet, T. Bailloeul, and M. Jaeger.

9. Dissemination

9.1. Conferences, Seminars, Meetings

- Jean-François Aujol gave a talk at the 'Partial Differential Equations Day' organized by GDR-ISIS in Paris in January. He presented his work at CANUM, and attended the 'Haim Brezis' workshop in June.
- Caroline Lacoste visited the German Space Agency (DLR) in Oberpfaffenhofen for the second DLR/INRIA workshop within the framework of the PAI Procope project, at which she presented her work. She gave a talk at the conference 'Spatial Point Process Modelling and its Applications' in April in Castellon, Spain, and at the conference EUSIPCO in Vienna, Austria, in September.
- Florent Lafarge presented his work at Alcatel Space, Cannes, as part of 'Forest Fire Detection Day' in September. He gave a talk at the CNES/DLR workshop at the German Space Agency (DLR), Oberpfaffenhofen, in November.
- Mathias Ortner gave seminars at the French National Geographic Institute (IGN) (MATIS Research Lab), Saint Mandé, in January, and at Alcatel Space, Cannes, in February. He gave talks at the conference 'Spatial Point Process Modelling and its Applications' in April in Castellon, Spain; at the conference 'Monte Carlo and Quasi Monte Carlo Methods' in Juan Les Pins, France in June; and at the conference EUSIPCO in Vienna, Austria, in September. M. Ortner received a Young Author Best Paper Award for his paper at this conference.
- Guillaume Perrin participated in a Ph.D. advancement meeting at École Centrale Paris (Applied Mathematics Laboratory), Chatenay-Malabry, in March. He attended the French National Geographic Institute (IGN) 'Research Days' in Saint Mandé, also in March. In April, he participated in meetings with the French National Forest Inventory (IFN) and CIRAD in Montpellier as part of the COLORS collaboration. He participated in another Ph.D. advancement meeting at École Centrale Paris, Chatenay-Malabry, in May. He gave a talk at EUSIPCO, Vienna in September. In October, he participated in the GreenLab Workshop as a member of the GreenLab Team (modelling of plant growth) of the Applied Mathematics Laboratory of École Centrale Paris, where he gave a talk, and he gave a seminar on his Ph.D. work at LIAMA, Academy of Sciences of China, Beijing. He again visited École Centrale Paris, Chatenay-Malabry, in December for a Ph.D. advancement meeting.

- Marie Rochery visited the German Space Agency (DLR) in Oberpfaffenhofen, in August, for the third DLR/INRIA workshop within the framework of the PAI Procope project, at which she gave a talk. Also in August, she visited North Carolina State University for one week as part of the NATO/Russia CLG project. She gave a talk at the conference ICIP in Singapore in October. Also in October, she made presentations as part of the INRIA Open Doors weekend for the ’Fête de la Science’. She organized and gave a talk at a ‘Séminaire croisé’ between the projects Opale and Ariana at INRIA Sophia Antipolis in November.
- Emmanuel Villéger visited Professor L. Moisan of Université Paris V in August, and presented his work at the conference ICPR in Cambridge, UK, also in August.
- Roberto Cossu attended a meeting of FP5 Research Training Network MOUMIR in London, UK, in March, and presented his work.
- Nicolas Dey visited the LAIQ team at the Institut Pasteur in Paris in January and February. In April, he presented an invited paper at the International Symposium on Biomedical Imaging (ISBI) in Alingham, USA. In May, he participated in the 5^{th} French-Danish workshop on ‘Spatial Statistics and Image Analysis in Biology’ (SSIAB), in Saint-Pierre de Chartreuse. In July, he visited the Weizmann Institute of Science, Israel, for a week, and gave a seminar.
- Ian Jermyn gave an invited talk at the European Space Agency EUSC conference in Madrid in March. Also in March, he attended a meeting of FP5 Research Training Network MOUMIR in London, UK, and made a presentation. In May, he attended a meeting of FP6 Network of Excellence MUSCLE in Heraklion, Greece, and made a presentation. In August, he visited the German Space Agency (DLR) in Oberpfaffenhofen for the third DLR/INRIA workshop within the framework of the PAI Procope project, and gave a talk. Also in August, he visited North Carolina State University for one week, as part of the NATO/Russia CLG project; the University of Wisconsin-Madison; and Rice University, Texas. He gave seminars during each of these visits. He was an invited speaker at the ‘Mathematics in Image Analysis’ (MIA) conference in Paris in September. He attended a meeting at ENST in Paris in September as part of the ACI Masses de Données ‘QuerySat’. In November, he attended a meeting of FP6 Network of Excellence MUSCLE in Malaga, Spain, and made a presentation. He lectured at the Autumn School ‘Image analysis: from theory to applications’ in Tunisia in November.
- Xavier Descombes gave an invited seminar on Classification at IRIT, Paul Sabatier University, Toulouse, in January. He gave an invited talk at the conference ‘Spatial Point Process Modelling and its Applications’ in April in Castellon, Spain. He attended two meetings, one in Toulouse and one in Rome, and organized a third in Sophia Antipolis, in the framework of the PAI Galilee project. He visited the Dobrushin Laboratory at IPIT, Moscow in July as part of the project supported by the Lyapunov Institute and NATO. He attended a meeting at ENST in Paris in September as part of the ACI Masses de Données ‘QuerySat’. He attended a Ph.D. advancement meeting at École Centrale Paris, Chatenay-Malabry, in December. Also in December, he presented the work of Ariana on 3D reconstruction from high-resolution images at the CNES/IGN/ONERA/INRIA meeting.
- Laure Blanc-Féraud visited CNR in Rome in January. She taught at the CNRS/SFO Spring School ‘Information et Imagerie’ in Les Houches in May. She presented Ariana’s research work at POPSUD in June. She attended the workshop "Contenu informatif des images numeriques" at ENS Cachan in November and gave a seminar.

- Josiane Zerubia visited the French National Geographic Institute (IGN) (MATIS Research Laboratory), Saint Mandé, in January. She attended a meeting of FP5 Research Training Network MOUMIR in London, UK, in March. She participated in two meetings on forest fire detection at Alcatel Space, Cannes, in April and September. She attended a Ph.D. advancement meeting at École Centrale Paris in May. Also in May, she presented two pieces of Ariana's work at IEEE ICASSP; was chair of a session at ICASSP; attended meetings of the Publication Board and the Board of Governors of the IEEE Signal Processing Society (SPS), and participated in a long-range planning meeting of the IEEE SPS, all in Montreal, Canada. She organized and was chair of a special session on 'MCMC in Signal and Image Processing' at the MC2QMC conference in Juan Les Pins in June. She gave presentations as part of the INRIA Open Doors weekend in October for the 'Fête de la Science'. Also in October, she attended the IEEE SPS Board of Governors meeting in San Francisco; participated in IEEE ICIP in Singapore, where she was chair of a session, and co-chaired the Editorial Board meeting of IEEE Transactions on Image Processing with P. Moulin from Urbana Champagne; and visited LIAMA in Beijing, where she gave a two-hour tutorial at the Academy of Sciences of China (joint seminar of the Institute of Automation and the Department of Computer Science). In November, she organized the first meeting of the ACI NIM 'Multim' at INRIA Sophia Antipolis. In December, she attended the evaluation meeting of the ARC DeMiTri at the Pasteur Institute, and gave a presentation.

9.2. Refereeing

- Caroline Lacoste was a referee for IEEE TKDE and IEEE TPAMI.
- Mathias Ortner was a referee for the 'Revue de la SFTP' (Journal of the French Society of Remote Sensing and Photogrammetry).
- Roberto Cossu was a referee for IEEE TGRS, Pattern Recognition Letters, and for the conference ICIP.
- Ian Jermyn was a referee for Data and Knowledge Engineering, EURASIP JASP, JMLR, and IEEE TIP, and for the conferences CVPR, ICIP, and ICPR.
- Xavier Descombes was a referee for IEEE TIP, IEEE TPAMI, IEEE TMI, IJCV and Traitement du Signal, and for the conferences ICASSP, ICIP and EUSIPCO.
- Laure Blanc-Féraud was a referee for IEEE TIP, and Traitment du Signal, and for the conferences ICIP and ECCV.
- Josiane Zerubia was a referee for IJCV, IEEE TIP, IEEE TPAMI, and the conferences ICASSP, ICIP, ICPR, and SPIE Signal and Image Processing for Remote Sensing.

9.3. Organization

- As in previous years, members of the Ariana project participated in the visits to INRIA Sophia Antipolis of the Grandes Écoles (X, ENS Cachan, ENPC, Sup'Aéro), and helped students of the 'Classes Préparatoires' with TIPE.
- Ian Jermyn is a member of the Comité de Suivi Doctoral at INRIA Sophia Antipolis. He is the coordinator of a PAI Procope collaboration with the German Space Agency (DLR), and coordinator of Ariana'a efforts within the FP6 Network of Excellence MUSCLE.
- Xavier Descombes is coordinator of the Ariana group for the INRIA ACI 'QuerySat'. He is member of the ORFEO group (CNES). He is member of the thesis guidance committee for a Ph.D. at Cemagref-ENGREF in Montpellier. He was a member of three Ph.D. committees. He was an expert evaluator for the ACI Masses de Données, of a research proposal for NWO, the Netherlands, and of an industrial proposal for ANVAR, France.

- Laure Blanc-Féraud is adjoint director of the CNRS/UNSA I3S Laboratory. She is a member of the managing committee for GDR-ISIS. She is a member of the Admissions Committee for Research Engineers at CNRS. She is a member of the thesis guidance committee of A. Foulonneau, Ph.D. student at the regional Laboratoire des Ponts et Chaussées in Strasbourg. She was a reviewer in five Ph.D. committees, and a member of another. She is a member of the COLORS committee at INRIA Sophia Antipolis. She was an expert evaluator for a research proposal submitted to the Austrian government.
- Josiane Zerubia is an IEEE Fellow, and she is member at large of the Board of Governors of the IEEE SPS. She was elected a member of the Biological Image and Signal Processing Technical Committee of the IEEE SPS. She is Area Editor of the IEEE Transactions on Image Processing, co-Guest Editor of a special section on 'Energy minimization methods in computer vision and pattern recognition' in the IEEE TPAMI February issue, and she is a member of the Editorial Boards of IJCV and the Revue de la SFPT. She was president of sessions at ICASSP in Montreal, MC2QMC in Juan Les Pins, and ICIP in Singapore. She was a Program Committee member for ICASSP, ICIP, CARI, ICPR, and the SPIE Conference on Signal and Image Processing for Remote Sensing. She organized a one-day workshop involving the Pasteur Institute, the Weizmann Institute, and the Ariana project in Sophia Antipolis in May, funded by the ARC DeMiTri. She represented INRIA at the Direction Technique du Ministère de la Recherche for high resolution imagery and remote sensing. She was nominated for three years by the President of the French Space Agency (CNES) as one of 30 experts, to evaluate CNES' research and development for the future within the CERT. She was a reviewer for two Ph.D. committees, at ENST, Paris and ENSEEIHT, Toulouse, and a member of two Ph.D. committees at the University of Nice-Sophia Antipolis. She was president of one HdR committee at the University of Bourgogne, a reviewer for another at the University of Cergy Pontoise, and a member of a third at the University of Nice-Sophia Antipolis. She was a member of the evaluation boards for the Swiss National Science Foundation; the Israel Science Foundation; and the Science Foundation, Ireland. She was an expert evaluator for the the ACI Masses de Données, the ERCIM 'Cor Baayen' prize; and the 'Science and Defence' prize.

9.4. Teaching

- Caroline Lacoste was lab instructor for 'Image processing' (21h) at ESINSA.
- Mathias Ortner was course instructor for 'Algorithms in image processing' (20h) at the University of Nice-Sophia Antipolis.
- Marie Rochery was lab instructor for 'Signal processing' (30h), 'Numerical signal processing' (60 h), and 'Image processing' (21h) at ESINSA.
- Emmanuel Villéger was a teaching assistant for 'Mathematics in computer science' and 'Probability' (64h) at the IUT of Nice.
- Nicolas Dey was lab instructor for 'Unix and systems' (36h) at UNSA. He also taught 'Internet and web sites' (12h) at UNSA.
- Ian Jermyn taught 'Image analysis' (6h) at ESINSA, and 'Filtering and segmentation of space imagery' (2.5h) at Sup'Aéro.
- Xavier Descombes taught 'Image analysis' (15h) at ESINSA, 'Remote sensing' (9h) at UNSA, 'Filtering and segmentation of space imagery' (17h) at Sup'Aéro, and 'Image analysis' (15h) at Paul Sabatier University.
- Josiane Zerubia was director of the module 'Markov Random Fields in Image Processing' in the DEA SIC-IV at the University of Nice-Sophia Antipolis (15h taught), and director of the module 'Remote Sensing' in the DEA in Astrophysics and Sciences of the Universe at the University of Nice-Sophia Antipolis (15h, of which 6h teaching), for which she also taught 'Classification' (3h). She was director of the course 'Filtering and segmentation of space imagery' (40h, of which 20h teaching) at Sup'Aéro, where she also taught 'Variational Methods for Image Processing' (2.5h).

9.5. Ph.D.'s

9.5.1. In progress

- Florent Lafarge: 'Reconstruction 3D de zones urbaines denses à partir de simulations PLEIADE', École Nationale Supérieure des Mines, Paris. Defence expected in 2007.
- Avik Bhattacharyya: 'Indexation d'images satellitaires par des informations structurelles', École Nationale Supérieure de Télécommunications, Paris. Defence expected in 2007.
- Guillaume Perrin: 'Etude du couvert forestier', École Centrale Paris. Defence expected in 2006.
- Marie Rochery: 'Contours actifs d'ordre supérieur et leur application à la détection de linéiques sur des images de télédétection', University of Nice-Sophia Antipolis. Defence expected in 2005.
- Emmanuel Villéger: 'Évolution de sous-variétés de $\mathbb{R}^n$ à l'aide de la fonction distance vectorielle', University of Nice-Sophia Antipolis. Defence expected in 2005.

9.5.2. Defended in 2004

1. Jean-François Aujol: 'Contribution à l'analyse de textures en traitement d'images par méthodes variationnelles et équations aux dérivées partielles', University of Nice-Sophia Antipolis. Defended June 17.
2. Caroline Lacoste: 'Extraction de réseaux linéiques à partir d'images satellitaires et aériennes par processus ponctuels marqués', University of Nice-Sophia Antipolis. Defended September 30.
3. Mathias Ortner: 'Processus ponctuels marqués pour l'extraction automatique de caricatures de bâtiments à partir de modèles numériques d'élévation', University of Nice-Sophia Antipolis. Defended October 5.

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