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Project-Team Ariana

Inverse Problems in Earth Observation and Cartography

Sophia Antipolis

THEME 3B

Activity Report

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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 endeavors, 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.

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 modeling 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 modeling 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 modeling, 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 modeling 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 modeling buildings; and interacting line segments of varying length and orientation for modeling 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 and computation of a function space containing oscillatory patterns, a sort of dual space to the BV space that captures the geometry of the image. Variational methods are also applied to a variety of problems, including phase unwrapping and image decomposition.

3.2.2. Contours and regions

In addition to the regularization of inverse problems, variational methods are much used in the modeling 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.

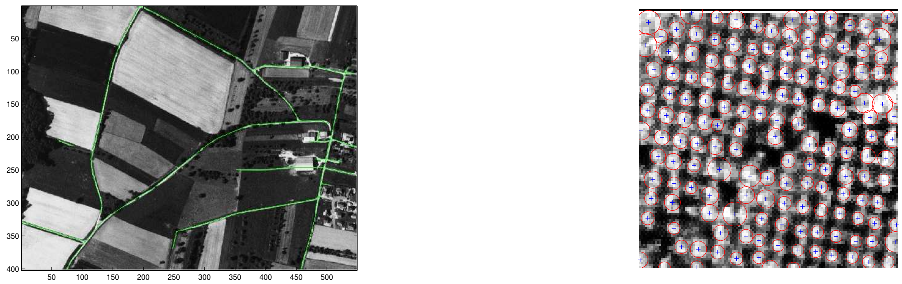


Figure 3. Left: road network extraction; right: tree extraction.

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 an arrangement of individual houses for example, 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 modeling

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

This year the Ariana project did not depose any software at the APP, or apply for any patents. Nevertheless, a great deal of software is under development, including software for the extraction of road and water networks,

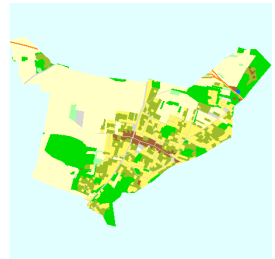


Figure 5. Image registration for the evaluation of retrieval systems. Left: mosaicked aerial image data; right: registered ground truth classification.

trees, and buildings, from optical, SAR, and DEM images, as well as several pieces of software for the segmentation of images based on texture. Software for the deconvolution of confocal microscopy images is also being developed.

6. New Results

6.1. Probabilistic Models

6.1.1. Comparison of the Ising and Chien models

Participants: Xavier Descombes, Eugene Pechersky.

Key words: *Gibbs fields*, *Ising model*, *Chien model*.

This work is supported by Lyapunov Institute grant 98-02.

The goal of this work is to understand and compare the behavior of two Gibbs models, both of which have applications in image processing. One is the well-known Ising model, while the other is a relatively new model constructed to be particularly well suited to segmentation problems.

The application of the models in image processing demonstrated the considerable advantages of the Chien model over the Ising model, and this led to the present comparative study. When a model is studied with image processing in mind, it is the low-temperature behavior that is of most importance. In this study, simulations of configurations for both models at the critical temperatures were undertaken. The differences in the shapes of the configurations obtained were rather unexpected. Typical Ising model configurations at the critical temperature are very similar to noisy configurations. In contrast, the typical configurations of the Chien model have a mosaic shape composed of small patches. Graphs of the number of connected components against connected component sizes are dramatically different for the two models. The Ising configurations have many connected components composed mostly of groups of 1–5 pixels, while for the Chien model, connected groups of approximately 40 pixels constitute a significant proportion of all connected components. Seemingly this distinction is one reason for the above-mentioned success of the Chien model in applications. The relations remain unclear however, and will be the subject of further investigation. Further details can be found in [10].

6.1.2. A diffusion process for image denoising

Participants: Xavier Descombes, Elena Zhizhina.

Key words: *image denoising*, *stochastic diffusion*, *discretization scheme*.

This work is supported by Lyapunov Institute grant 98-02.

We address the problem of image denoising using a Stochastic Differential Equation approach [43]. We consider an interaction diffusion process which is reversible with respect to a Gibbs distribution defined by a given Hamiltonian. The Hamiltonian has an interaction term, ensuring smoothness of the solution, and a data term. The process is called the Langevin dynamics and it can be found as the solution of a stochastic differential equation, which is a stochastic version of a partial differential equation. To derive algorithms for computer simulations, we consider two discrete time approximations of the stochastic differential equation, namely the Euler and the Explicit Strong Taylor approximations. We apply a special procedure to the approximation process (simulated annealing or expectation scheme) to find a denoised image. We compare the convergence properties of the Langevin dynamics algorithms and the Metropolis-Hastings algorithm. Results are shown on synthetic and real data. We observe that the proposed approach provides better results when using a small number of iterations. An example is shown in figure 6. Further details can be found in [43].

Figure 6. Image denoising using the Euler approximation. Noisy image (left), result (right).

6.1.3. Urban area analysis using Markov random fields and data fusion

Participants: Oscar Viveros-Cancino, Xavier Descombes, Josiane Zerubia.

Key words: *urban area classification*, *texture analysis*, *data fusion*, *segmentation*, *Markov random field*.

This work was supported by a SFERE/CONACYT PhD grant (Mexico).

This work is concerned with the analysis and extraction of urban areas in remote sensing images. As radiometric information alone is insufficient for the detection of such areas, we carry out a study of texture analysis techniques for urban scenes. Of the techniques currently available, we choose to describe texture using the conditional variance parameter of a Gaussian Markov model. This parameter, estimated at each point in the image, allows us to extract our initial urban mask. Having noted the complementary nature of radar and optical sensors, we combine the textural information of SPOT and ERS sensors to refine our mask. Finally, we propose and compare different supervised fission-fusion algorithms which allow us to perform an intra-urban classification. From the SPOT and ERS images, we compute different texture and radiometric parameters. A classification is carried out using each of these parameters in turn. The importance of each parameter for each class is given by the corresponding confusion matrix which is computed using training zones. A fusion operator is defined using the different confusion matrices. The site of our study is Mexico City. Further details of this work can be found in [4].

6.1.4. Line network extraction in remote sensing images using Markov object processes

Participants: Caroline Lacoste, Xavier Descombes, Josiane Zerubia.

Key words: *line network extraction*, *marked point process*, *RJMCMC*, *simulated annealing*.

This work is being done in collaboration with Nicolas Baghdadi, French Geological Survey (BRGM).

In this work, we aim to extract line networks, such as roads and waterways, from satellite and aerial images, to assist in the updating of cartography. The line networks in the image are modeled using Markov object processes. These recently developed models provide the same type of stochastic properties as Markov fields, while allowing the incorporation of strong geometric constraints. The models describe interacting, parameterized geometric objects, such as line segments, the interactions allowing the incorporation of constraints on the network topology, such as continuity or small curvature.

The prior model in this work, called “Quality Candy”, is constructed so that the topology of the line network considered is accounted for as fully as possible, through potentials defined with respect to the quality of each interaction. We have shown that this model is particularly suited to the extraction of road networks from satellite or aerial images [31]: the use of quality coefficients for the relation of connection leads to a continuous line network with small curvature. Adaptations of this model also provide promising results in the case of more sinuous networks such as waterways [30].

Radiometric properties of the networks are incorporated using a data term based on statistical tests. This data term can be used for various types of data, including aerial images, and optical and radar satellite images. Two techniques have been proposed in [14] in order to compute this term, the one more accurate, the other more efficient (based on an off-line computation of the data potential).

Optimization of the model is performed using simulated annealing with an RJMCMC algorithm based on a composed proposition kernel designed to accelerate convergence.

In [14][30], we proposed quantitative performance criteria based on a comparison between the extracted line network and a reference line network after a matching between the two networks. Using these criteria, different algorithms and models can be compared.

Figure 7. Results of line network extraction from a satellite image (SPOT XS2) of size 682×674 *pixels. On the left is the data image, in the center the reference line network, manually extracted by an expert (BRGM), and on the right is the extracted line network.*

Figure 7 shows the waterway network extracted from a satellite image. There are trees near the rivers in the network, named riverine forest, and these make the extraction problem more difficult. Results given in [14] confirm the relevance of the off-line computation of the data potential for the computation time.

6.1.5. Automatic segmentation of Digital Elevation Models using point processes

Participants: Mathias Ortner, Xavier Descombes, Josiane Zerubia.

Key words: *building detection*, *land register*, *digital elevation model*, *laser data*, *marked point process*, *RJMCMC*, *simulated annealing*.

Altimetry data for urban areas is now readily available, yet difficult to exploit. Digital Elevation Models (DEMs) may be constructed, for example, from optical data using a correlation algorithm, or from laser measurements. The main objective of this work is the design of an automatic method for building extraction that is able to deal with this kind of data in very dense urban areas.

We thus focus on elementary shape extraction, and propose an algorithm that extracts rectangular buildings. The result provided consists in a kind of vectorial land register map that can be used, for instance, to perform precise roof shape estimation. The proposed algorithm uses our previous work described in [32]. Using a point process framework, we model towns as a configuration of cuboids. An energy is defined that takes into account both the low-level information provided by the altimetry of the scene, and prior geometrical knowledge of the disposition of buildings in towns.

Estimation is performed by minimizing the energy using simulated annealing. We use an MCMC sampler that is a combination of the RJMCMC technique and the Geyer and Möller algorithm for sampling point processes. We proved the convergence of this sampler in [46].

In [45], we present results on real data provided by the French National Geographic Institute (IGN). An example is shown in figure 8. Results were obtained automatically, on areas of size 200m by 200m. These results consist of configurations of around 100 rectangles describing the areas considered, with a classification error of 15%. In [33], we proposed more complex models of buildings.

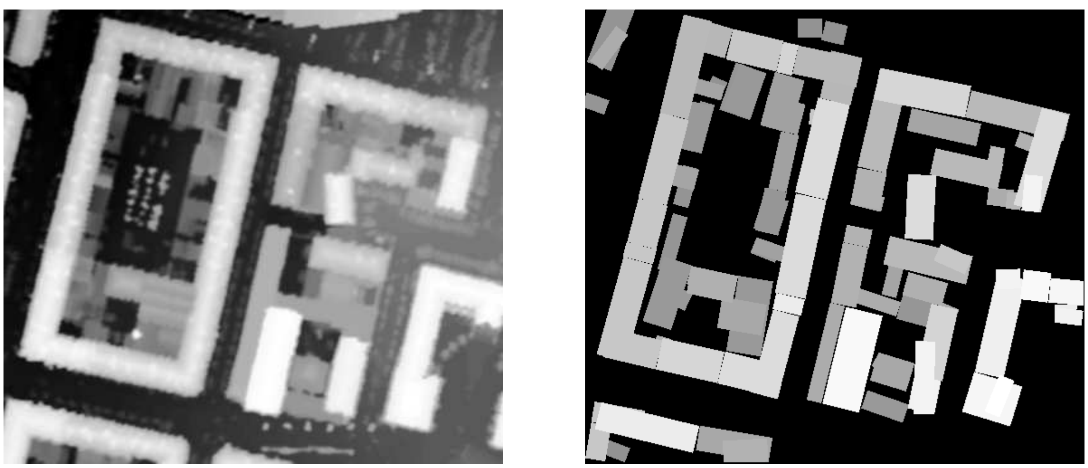


Figure 8. Left: laser DEM, provided by IGN; right: land cover register automatically extracted.

6.1.6. Wavelet-based superresolution

Participants: Rebecca Willett, Ian Jermyn, Rob Nowak, Josiane Zerubia.

Key words: *superresolution*, *wavelet basis*, *multiresolution*, *expectation maximization*.

This work is being done in collaboration with Rice University and the University of Wisconsin, USA. It was partially funded by the NSF, USA.

Superresolution is the process of recovering a high-resolution image from several blurred, and noisy low-resolution images of the same scene. Superresolution is closely related to image deconvolution, except that the low-resolution images are not registered and their relative translations and rotations must be estimated as part of the process. The novelty of the approach to the superresolution problem taken in this work [37] is the use of wavelets and related multiresolution methods within an expectation-maximization reconstruction process. First, the low-resolution images are registered to each other. Then an initial reconstruction is performed using least squares. The low-resolution images are then re-registered to this reconstruction, thereby increasing registration accuracy. In the expectation-maximization algorithm that follows, the expectation step consists of a multi-image deconvolution, while the maximization step consists of a wavelet-based denoising process. Simulations demonstrate the effectiveness of the proposed method, an example being shown in figure 9. On the left is one of 16 low resolution images generated by randomly rotating, translating and downsampling (by a factor of 16) a given high-resolution image. On the right is the superresolved high-resolution image.

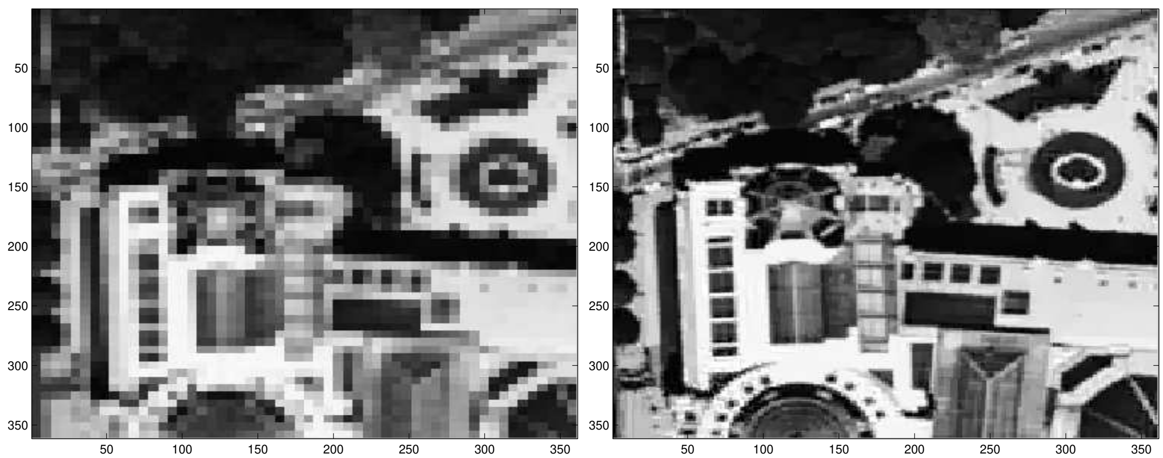


Figure 9. Left: one of 16 low resolution images generated by randomly rotating, translating and downsampling (by a factor of 16) a given high-resolution image; right: the superresolved high-resolution image.

6.1.7. Texture-adaptive mother wavelet selection for texture classification

Participants: Charith Abhayaratne, Ian Jermyn, Josiane Zerubia.

Key words: *texture classification*, *adaptive mother wavelet*, *lifting*, *biorthogonal wavelet*.

This work is supported by an ERCIM postdoctoral fellowship.

Texture is a widely used image attribute in remote sensing image segmentation because it is a distinguishing feature of many land cover types. A probabilistic model for texture based on adaptive wavelet packets has been developed in the Ariana project and applied to texture classification [23][24][41]. During this work, it was observed that classification performance varied with the choice of mother wavelet used in the process. The work described here is concerned with the texture-adaptive selection of a mother wavelet for texture classification using the above model.

As a first step, the mother wavelet is adapted within a standard wavelet basis, with the extension to adaptive wavelet packets to come later. We work with biorthogonal wavelets rather than the more commonly used orthogonal wavelets, due to their linear phase property and easy parameterization, which is based on the lifting framework for wavelet transforms. This required modifying the existing framework to fit the biorthogonal case in which both the primal and dual wavelets appear in the probability model. Work is currently proceeding on the gradient descent optimization procedure that will be used to find the MAP estimate for the mother wavelet.

6.2. Variational Models

6.2.1. Γ-convergence for image restoration

Participants: Laure Blanc-Féraud, Gilles Aubert, Riccardo March.

Key words: *restoration*, *gamma convergence*, *BV space*.

In previous work, a new sequence of functionals was proposed for image restoration. This sequence of functionals showed good results when applied to noisy image restoration and deconvolution. The purpose of this work is to prove mathematically the convergence of this sequence to a limit functional. This limit functional is linked to the Mumford-Shah functional for image segmentation.

6.2.2. Wavelet-based level set evolution for the classification of textured images

Participants: Jean-François Aujol, Gilles Aubert, Laure Blanc-Féraud.

Key words: *texture*, *classification*, *variational approach*, *level set*, *active region*, *active contour*, *multiphase*, *wavelet*, *PDE*, *BV space*, *minimal surface*.

This work, described in [5][19], studies a supervised classification model based on a variational approach. To find a segmentation of the image into classes, we model regions and their interfaces by level set functions. We define a functional on these level sets whose minimizers define the optimal classification into texture classes. An example is shown in figure 10. We have now turned our attention to the theoretical study of this functional, *e.g.* the existence of a solution, its regularity, and so on.

Figure 10. A texture mosaic and the result of the wavelet-based level set classification.

6.2.3. Modeling highly oscillatory signals, with application to image processing

Participants: Jean-François Aujol, Gilles Aubert.

Key words: *image decomposition*, *oscillatory pattern*, *Sobolev space*, *BV space*, *PDE*, *convex analysis*, *optimization*, *calculus of variations*.

This work [39] is a companion paper to the work described in [40], where we reported the numerical analysis of a variational model first introduced by L. Rudin, S. Osher, and E. Fatemi, and revisited by Y. Meyer, for the removal of noise and the capturing of texture in an image. The basic idea in this model is to decompose the image f into two components $u+v$, and then to search for (u,v) as the minimizer of an energy functional. The first component u belongs to BV and contains geometrical information, while the second component v is sought in a space G that contains signals with large oscillations, *i.e.* noise and texture. Y. Meyer carried out his study in R^2, and his approach is built on the tools of harmonic analysis. We carry out our study in a bounded subset Ω of R^2, which is the proper setting for image processing, and our approach is based on functional analysis arguments. We define in this context the space G, give some of its properties, and then study in this continuous setting the energy functional that allows us to recover the components u and v.

6.2.4. Decomposing an image, with an application to textured and SAR images

Participants: Jean-François Aujol, Laure Blanc-Féraud, Gilles Aubert.

Key words: *restoration*, *SAR image*, *texture*, *speckle*, *total variation minimization*, *BV space*.

This work was done in collaboration with Antonin Chambolle, CEREMADE, University Paris Dauphine and École Polytechnique.

We construct an algorithm to split an image into a sum $u + v$ of a bounded variation component and a component containing the textures and noise (see [21][20][40]). This decomposition is inspired by recent work of Y. Meyer. We find this decomposition as the minimum of a convex functional that depends on the two variables u and v, by minimizing alternately in each variable. Each minimization step is based on a projection algorithm for minimizing the total variation. We carry out a mathematical study of our method and present some numerical results (*e.g.* figure 11). In particular, we show how the u component can be used in non-textured SAR image restoration.

Figure 11. f (left) $= u$ (middle) $+ v$ (right).

6.2.5. Image decomposition: a three component model

Participant: Jean-François Aujol.

Key words: *texture*, *restoration*, *total variation minimization*, *BV space*, *Sobolev space*, *wavelet shrinkage*, *convex analysis*.

This work was done in collaboration with Antonin Chambolle, CEREMADE, University Paris Dauphine and École Polytechnique.

We first study the choice of a norm to capture oscillatory patterns in images. Then, based on this study, we construct an algorithm to split an image into a sum $u + v + w$ of a bounded variation component, a component containing the texture, and a third component containing noise. We find this decomposition by minimizing a convex functional which depends on the three variables u, v and w. An example is shown in figure 12.

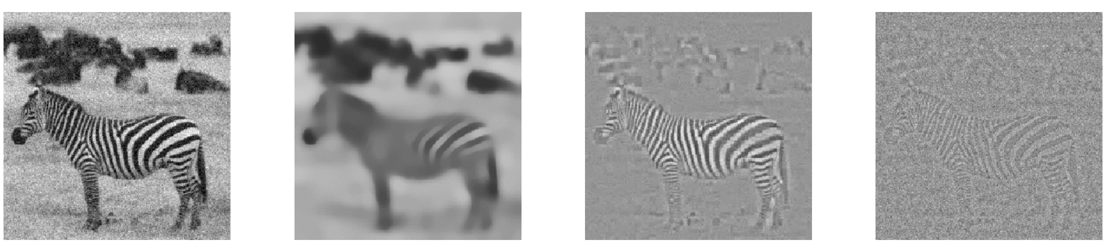


Figure 12. f (left) $= u$ (second to left) $+ v$ (second to right) $+ w$ (right)

6.2.6. Image disocclusion

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

Key words: *interferometry*, *inpainting*, *diffusion*, *transport*, *PDE*.

Interferometry phase images frequently have holes where there is no data. Some methods already exist to fill in the holes in these images. One method is to minimize a functional with respect to two functions, one describing the image grey level and the other the orientation of the level lines. The orientation of the level lines is thus represented as a separate function. These two quantities are linked by constraints on the minimization. Another method is to solve a partial differential equation (PDE). The solution is the grey level of the image. In this case, the PDE contains a term depending on the curvature of the level lines. Thus the PDE is of at least third order.

The novelty of the method being developed in this work is that it uses only second-order PDEs. The orientation of the level lines is represented as the argument of a probabilistic function. This function is a probabilistic gradient of the image depending on the norm of the image gradient. The method consists of solving two coupled second-order PDEs. One equation is for the orientation of the probabilistic gradient, while the second couples the orientation to the grey level of the image.

6.2.7. Higher order active contours and their application to line network detection

Participants: Marie Rochery, Ian Jermyn, Josiane Zerubia.

Key words: *line network extraction*, *shape description*, *quadratic functional*, *higher-order active contour*, *level set*.

In this work, we concern ourselves with active contour models of regions in an image. A topic of great recent interest in this area is the incorporation of prior geometric information into the models. The techniques that have been used to this end thus far all deal with Gaussian fluctuations around particular template shapes. For the application considered here, which is the extraction of road and other networks from remote sensing imagery, this type of model will not do: road networks cannot be described as perturbations of some 'mean' shape. Rather what is needed is a description of a 'family' of shapes that share complex geometric properties, without making reference to any particular shape.

To this end, we have developed a new class of contour energies [36][35][48]. These energies are quadratic on the space of one-chains in the image, as opposed to classical energies, which are linear. They can be expressed as double integrals on the contour, and thus incorporate non-trivial interactions between different contour points. In order to model road networks, we make a particular choice of prior quadratic energy whose minima are reticulated, and use a quadratic data term that links image gradients on either side of a road. To optimize the energies, we use a level set approach. The forces derived from the new energies are non-local however, thus necessitating an extension of standard level set methods. Promising experimental results are obtained using real aerial and satellite images. Some examples are shown in figure 13.

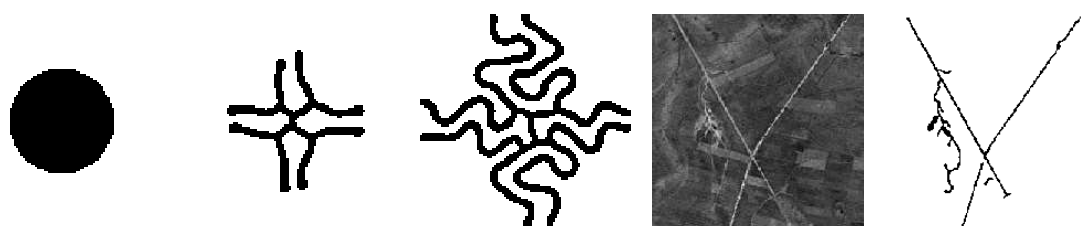


Figure 13. Three leftmost images: the evolution of a circle under non-local forces, showing the development of a reticular structure. Second to right, a satellite image and right, the result of road network extraction.

6.2.8. Interferogram filtering

Participants: Caroline Lacombe, Gilles Aubert, Laure Blanc-Féraud.

Key words: *interferometric filtering*, *adaptive filter*, *phase noise statistic*, *anisotropic diffusion*, *structure tensor*, *diffusion tensor*.

Interferometric radar techniques have been widely used to produce high-resolution ground digital elevation models. In space-borne SAR (Synthetic Aperture Radar) interferometry, two images of the same scene are acquired using two different geometries. The phase difference between the registered images (the so-called interferogram) is related to a desired physical quantity of interest such as the surface topography. The phase difference can be registered only modulo 2π and interferometric techniques consist mainly of recovering the absolute phase (the unwrapped phase) from the registered one (the wrapped phase).

The interferogram has fringes representing the phase within the range of $-\pi$ to π. Any phase values greater than π are wrapped back around to $-\pi$. Due to phase discontinuities the reconstruction of the geometry is ambiguous. But another difficulty comes from the high level of speckle noise, which introduces errors into the reconstruction. Several filters have been applied to this type of image, but they are not adapted to local noise level variations. To preserve phase discontinuities, most of them unwrap the phase in a small filtering window before smoothing, and then wrap it again.

We propose [28][29] an anisotropic diffusion equation designed to restore interferometric images. It has two main purposes. The first is to preserve the structures and discontinuities formed by the fringes. The second is to incorporate noise modeling specific to this type of images. We show that our model formalizes previous related work in interferometry filtering. A result is shown in figure 14.

Figure 14. Left: interferogram data from part of Utah; right: the filtered result after 30 iterations.

6.2.9. Edge detection and phase unwrapping

Participants: Caroline Lacombe, Gilles Aubert, Laure Blanc-Féraud.

Key words: *edge detector*, *phase unwrapping*, *interferometric image*, *level set*, *active contour*, *structure tensor*.

The aim of this work is to find the phase jumps (curves of discontinuities) from a filtered interferogram using a level set approach. Phase interferometric images present typical structures because of fringes. In order to take into account local variations in gradient direction, we propose a new edge-descriptor that uses local information about the principal direction of fringes [3]. Figure 15 shows a numerical result on a part of the filtered interferogram of Utah.

We suppose that the interferogram does not contain terrain discontinuities. In order to add the missing integral cycles to obtain the absolute phase, we propose an automatic method to distinguish each fringe from the image of phase jumps [3]. The algorithm has been tested on both synthetic and real interferograms for which the fringes are all either parallel or concentric. An automatic method is given for interferograms that combine both types of structure.

Figure 15. Left: Initialization. Right: edge detection after 1500 iterations.

6.3. EU Project MOUMIR

6.3.1. Texture analysis using probabilistic models of the unimodal and multimodal statistics of adaptive wavelet packet coefficients

Participants: Roberto Cossu, Karen Brady, Ian Jermyn, Josiane Zerubia.

Key words: *texture*, *multimodal distribution*, *adaptive basis*, *wavelet packet*, *Bayesian*.

This work is being done as part of EU project MOUMIR (http://www.moumir.org).

In [41], 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 [41]. 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 this work we extend the approach to texture analysis proposed in [23][24] to model these subbands. We relax the Gaussian assumption to include generalized Gaussians, and use constrained Gaussian mixtures for the multimodal subbands. We use a Bayesian methodology throughout, finding MAP estimates for the adaptive wavelet packet basis, for subband model selection, and for subband model parameters. Results confirm the effectiveness of the proposed approach, and highlight the importance of multimodal subbands. For example, figure 16 shows the distribution of wavelet packet coefficients from several subbands in two textures. In two of the subbands, one texture has multimodal statistics while the other does not. In the other two subbands, both textures have unimodal statistics. The discriminatory power of the multimodal subbands is clearly visible.

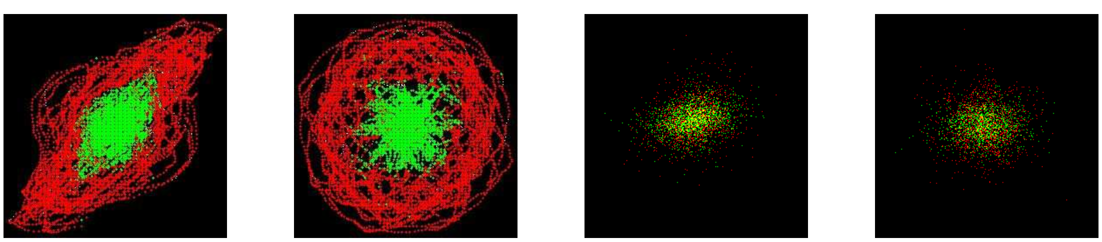


Figure 16. The two leftmost images show wavelet packet coefficient distributions from subbands multimodal for one of two textures. The two textures are shown in different colors. The two rightmost images show distributions from subbands unimodal for both textures. Note the discriminative power of the former.

6.3.2. Evaluation methodology and practice for a database of aerial images equipped with ground truth

Participants: Roberto Cossu, Ian Jermyn, Josiane Zerubia.

Key words: *remote sensing image*, *database retrieval*, *multimodal image registration*, *image mosaicking*, *evaluation methodology*.

This work is being done as part of EU project MOUMIR (http://www.moumir.org).

In collaboration with the University of Cambridge, UK, project Ariana previously conducted a methodological analysis of evaluation procedures for image database retrieval, focusing on two datasets that illustrate the range of image database applications. Work on the first dataset, scanned images of fine art from the Bridgeman Art Library, UK, has finished, and is reported in [44]. The other dataset consists of aerial images of the Ile-de-France Region furnished by IGN. In this case, the analysis led to a search for ground truth for the dataset, which was acquired from the Institute for Urban Planning and Development of the Ile-de-France Region (IAURIF), and which consists of land-use classification maps for the Ile-de-France Region compiled from existing cartography and field studies.

In order to proceed with evaluation using this dataset, the land-use maps first had to be registered with the aerial data. The difficulty lay in the fact that there were several data images overlapping each land-use map, meaning that the required registration was multimodal: the land-use maps were to be registered with the aerial images, and these images were to be registered with each other. The registration process was carried out by a manual procedure, illustrated in figure 17. This first required the selection, by visual inspection, of corresponding points in the ground truth image and the data image. A first degree polynomial transform and nearest neighbor resampling were then used for the warping of the images. In the cases where the geographical area covered by a given land-use map was covered by more (partially overlapping) data images, additional processing steps were required. First of all, such images might have been acquired under different atmospheric conditions. These differences were corrected using a simple histogram matching procedure applied to the overlapping areas. After registration of the data images with land-use maps, they were mosaicked. At the end of the process, composite data images and corresponding land-use maps were obtained for 45 communes in the Ile-de-France Region. A CD-ROM with the results, i.e., the registered data set, was distributed to the MOUMIR partners.

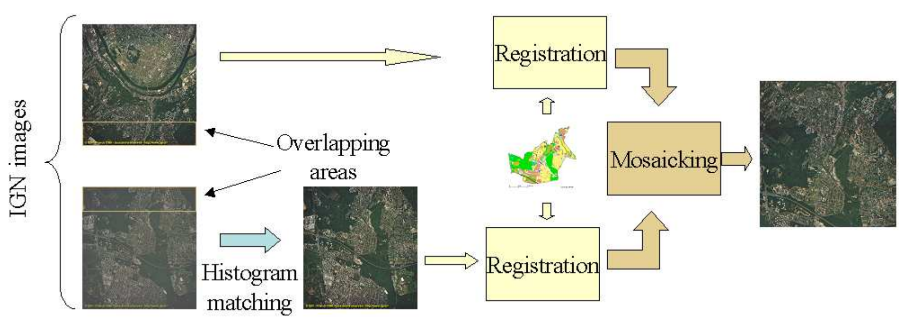


Figure 17. Scheme of the adopted multimodal registration approach

6.3.3. Shape from texture via conformal embeddings

Participants: Rami Haggiag, Ian Jermyn.

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

This work was done as part of EU project MOUMIR, 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 both by the curvature of the surface and by the imaging process, and therefore contain information about the shape of the surface.

One of the key difficulties in the formulation of the problem is how to model a texture on a curved surface. Since the surfaces in which we are interested are equivalence classes of embeddings of (a domain in) R^2 in R^3, we can choose a particular representative of this class, and then push forward the texture, or a probabilistic model of the texture, from R^2 to the surface. In the 1D case, the obvious choice of representative is an isometry, which always exists. In the 2D case under discussion, an isometry does not always exist. However, a conformal embedding does. Conformal embeddings result in a local, isotropic change of scale, and thus preserve angles. They have been used in the computer graphics community for precisely the purpose of moving textures from flat surfaces to curved ones, and thus suit our purposes.

At present we are analyzing the case in which the original 'flat' texture is available, or in other words in which the probabilistic model of the texture is a delta function. This is not unrealistic for image database retrieval applications, in which an exemplar may be used as the query image. In this case, a 2D diffeomorphism taking the flat texture to the distorted image can be estimated. We have developed a method to complete this 2D diffeomorphism to a conformal embedding when such exists, thus estimating the surface. Problems arise, however, if the estimated 2D diffeomorphism is not projectively conformal. This can happen for a number of reasons, errors and noise in the imaging and estimation processes being the most obvious. In addition, the conformal model of textures on surfaces may be only approximately correct in any given scenario. We are currently developing ways to impose the constraint of projective conformality as part of the estimation of the 2D diffeomorphism, in particular in the case that the 2D diffeomorphism is approximated by a polynomial. Subsequent work will use a less restrictive probabilistic model of the texture.

6.4. EU Project IMAVIS

6.4.1. Track detection and classification

Participants: Alexey Teterukovskiy, Josiane Zerubia.

Key words: *track detection*, *classification*, *Gibbs sampler*, *prior distribution*, *Potts model*, *Chien model*, *maximum spacings estimation*.

This work is being done as part of EU project IMAVIS, in collaboration with Professor Bo Ranneby and Jun Yu of the Swedish University of Agricultural Sciences, Sweden.

This research was conducted within the following two connected areas: Bayesian image classification and the estimation of parameters. Within the Bayesian framework, two problems were tackled: the detection of tracks in remote sensing imagery and the classification of multispectral data. For detection of tracks, information about the shape of the tracks was used to construct the prior distribution. The maximization of the posterior distribution was performed using the Gibbs sampler. The effectiveness of the algorithm proposed was compared to that of the algorithm described in [31]. The quality of the image classification can crucially depend on the adequacy of the prior distribution. This fact was reinforced by a simulation study, which demonstrated how the total misclassification rates varied with different priors, such as the well-known Potts model and the Chien model. Work was also done on the estimation of parameters by a maximum spacings (MSP) method, which is an alternative to maximum likelihood (ML) estimation. Contrary to ML, which is known to fail in many situations (notably, with mixtures of Gaussian distributions), the MSP estimate in such cases is consistent. Moreover, it retains the useful properties of the ML estimator, such as asymptotic normality and efficiency. Introduced in 1984 for univariate variables, the MSP estimator is only now being used in higher dimensions, making it an interesting alternative to ML estimation for purposes of image analysis.

6.4.2. *Tree-structured MRFs for noisy image segmentation*

Participants: Giuseppe Scarpa, Josiane Zerubia.

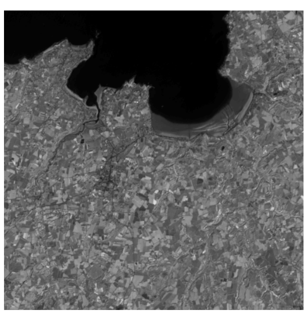
Key words: *segmentation*, *classification*, *hierarchical representation*, *Markov model*, *Bayesian estimation*.

This work is being done as part of EU project IMAVIS, in collaboration with Professor Gianni Poggi of the University Federico II of Naples, Italy.

The goal of this work is the segmentation of multispectral satellite images using Markov random field models as prior probability distributions. In particular, this research focuses on a recent statistical model, an MRF lying on a binary tree structure (TS-MRF). This model has interesting properties both in computational terms and from a modeling point of view.

Computational complexity is reduced thanks to the constrained structure of the TS-MRF, which lies on a binary tree. In the model, the image as a whole is associated with a tree of regions/segments, while each elementary region is associated with a leaf, which is progressively singled out top-down by means of a sequence of binary decisions. Thus a K-class segmentation problem reduces to a sequence of K-1 binary segmentations. Each binary split involves estimating a much smaller number of parameters than a K-ary split, with the result that even the whole sequence of binary steps is much simpler than a single K-ary split. The tree structure also allows the definition of local fields that are well adapted to the local characteristics of the data, thus improving the fidelity of the model. In addition, the proposed method addresses the cluster validation problem in unsupervised segmentation via the definition of a stopping condition for each new node during tree growth.

The performance of the model, in terms of misclassification rate, was assessed on a SPOT image of Lannion Bay in France for which ground truth exists. The assessment showed the improved performance of the method with respect to other MRF-based algorithms, in particular another hierarchical MRF, as well as with respect to non-contextual techniques such as minimum distance, maximum likelihood, and discriminant analysis. An example result is shown in figure 18. Further details can be found in [49].



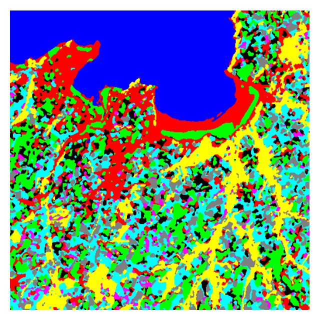


Figure 18. Left: a satellite image; right: the segmentation result.

6.5. COLORS Project Arbres: automatic tree crown detection using marked point processes

Participants: Guillaume Perrin, Xavier Descombes, Josiane Zerubia.

Key words: *tree crown detection*, *marked point process*, *RJMCMC*, *simulated annealing*.

This work was done as part of INRIA COLORS project Arbres , in collaboration with Michel Deshayes, Agricultural and Environmental Engineering Research Center (CEMAGREF), and Jean-Guy Boureau, French National Forest Inventory (IFN).

The availability of digital aerial photographs of high spatial resolution opens up new prospects for the automatic generation of knowledge in the domain of forestry. Parameters such as tree crown diameters, stem density, species classification, and the distribution of non-forested gaps are currently assessed by human interpretation. Algorithms for the automatic extraction of these parameters would greatly aid forestry managers in their work, which is increasingly demanding due to stricter legislation and environmental concerns.

Several tree crown detection techniques already exist, but they all address a specific part of the global problem. Some are suited to dense stands, some handle the detection of trees near the Nadir point, and so on. We propose a new approach to the problem that will enable us to tackle images of forest stands with different species (poplars, conifers, oaks,...), different ground slopes (plains, mountains,...) and different illuminations.

To achieve this goal, we use marked point processes, whose marked points (or objects) represent the trees. The density of this process contains both prior knowledge about the trees we are detecting, and a data term which fits our objects to the image. We estimate the distribution of trees by simulating our point process with an RJMCMC algorithm and simulated annealing. The first results were obtained on stands of poplars, an example being shown in figure 19. Further details can be found in [47]. We are currently broadening our study.

IFN provides us with data, and evaluates our results, in collaboration with CEMAGREF.

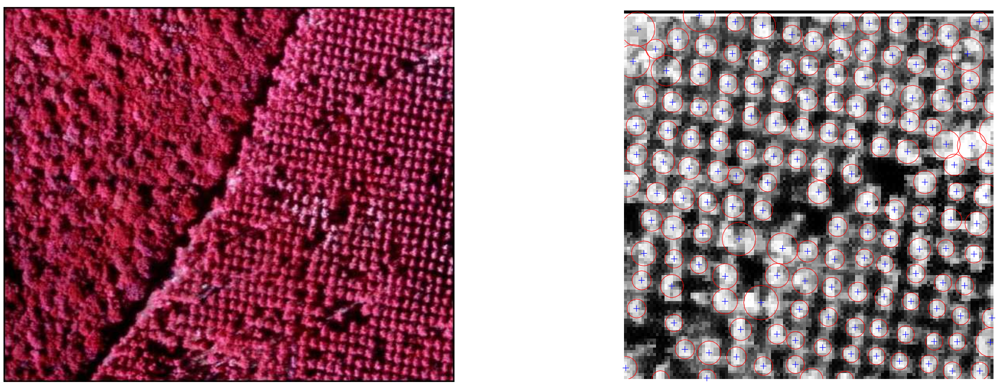


Figure 19. Left: a data image of forest stands (IFN) containing oaks and poplars; right: automatic detection of poplars.

6.6. ARC DeMeTri: blind deconvolution of confocal microscopy

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

Key words: *fluorescence microscopy*, *confocal laser scanning microscopy*, *3D deconvolution*, *PSF*, *image formation*.

This work is being done within the framework of the ARC DeMiTri (http://www-sop.inria.fr/ariana/personnel/Nicolas.Dey/DeMiTri/arc in collaboration with Jean-Christophe Olivo-Marin and Christophe Zimmer, Pasteur Institute, and Zvi Kam, Weizmann Institute of Science, Israel.

The overall goal of this work is to develop a new family of algorithms for the blind deconvolution of three-dimensional microscopic biological images. These algorithms will be based on methods which have previously been developed by the Ariana project. The methods were originally used for satellite image processing and so they currently permit estimation of instrument parameters, such as the PSF and noise variance, for an optical sensor.

The first part of the work consisted in understanding the process of image formation in confocal microscopy, in which the specimen is stained with a fluorescent dye, which is then excited by a laser. The blur due to imprecise focusing is largely removed due to the use of two pinholes. However, the light intensity is very low, with the noise statistics following a Poisson distribution. Even if the laser focusing is accurate and the aperture very small, some blur remains.

We have developed a Richardson-Lucy type algorithm that performs a 3D deconvolution of an image stack. This well-known algorithm is developed in 3D and is regularized with a function that preserves textures and fine structures.

Results have been obtained using simulated data with noise and blur added based on physical models and parameters. We use a physical model of the 3D PSF, provided by the Weizmann Institute, to perform this. The iterations of the algorithm remove the noise and give a precise estimate of the original object.

7. Contracts and Grants with Industry

7.1.1. BRGM Orléans

Updating of line networks in cartography using data fusion and Markov object processes. Contract # 102E03800041624.01.2. Participants: C. Lacoste, X. Descombes, J. Zerubia.

7.1.2. DGA/CTA Arcueil

Analysis of urban areas using Markov object processes and digital elevation models. Grant under DGA/CNRS agreement. Participants: M. Ortner, X. Descombes, Josiane Zerubia.

8. Other Grants and Activities

8.1. Regional

8.1.1. INRIA COLORS project Arbres

In collaboration with CEMAGREF, Montpellier (M. Deshayes), and IFN, Montpellier (J. G. Boureau). Principal investigator: X. Descombes. Participants: G. Perrin, J. Zerubia.

8.2. National

8.2.1. CNRS MATH/STIC grant 'Visual Annotation'

In collaboration with ENS Cachan (L. Younes, D. Geman) and Paris XIII (A. Trouvé). Begun at the end of 2001. Participants: I. Jermyn, J. Zerubia.

8.2.2. CNRS MATH/STIC grant 'Image classification by variational methods and PDEs'

In collaboration with the Jean-Alexandre Dieudonné Laboratory of UNSA (G. Aubert). Begun in mid-2002. Participants: J-F. Aujol, E. Villeger, L. Blanc-Féraud.

8.3. European

8.3.1. EU project MOUMIR

The Ariana project is a participant in European Union 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, Bridgeman Art Library. INRIA principal investigator: J. Zerubia. INRIA participants: K. Brady, R. Cossu, I. Jermyn. Web site: http://www.moumir.org

8.3.2. EU project IMAVIS

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 Odyssée and Epidaure projects. Principal investigator: J. Zerubia. Web site: http://www-sop.inria.fr/robotvis/projects/Imavis/imavis.html

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

In collaboration with the German Space Agency, DLR (M. Datcu). Principal investigator: I. Jermyn. Participants: C. Lacoste, M. Ortner, J. Zerubia.

8.4. International

8.4.1. INRIA ARC DeMiTri

In collaboration with the Pasteur Institute (J. C. Olivo-Marin) and the Weizmann Institute (Z. Kam). Principal investigator: J. Zerubia. Participants: N. Dey, L. Blanc-Féraud. Web site: http://www-sop.inria.fr/ariana/personnel/Nicolas.Dey/DeMiTri/arc.php

8.4.2. Lyapunov Institute grant 98-02

In collaboration with the IITP of the Russian Academy of Science (E. Pechersky, E. Zhizhina). Principal investigator: J. Zerubia. Participants: X. Descombes.

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

In collaboration with North Carolina State University (H. Krim) and the IITP of the Russian Academy of Science (R. Minlos, E. Pechersky, E. Zhizhina). Principal investigator: J. Zerubia. Participants: M. Rochery, I. Jermyn, X. Descombes.

8.4.4. CONACYT grant

In collaboration with the Autonomous National University of Mexico (M. Moctezuma). Principal investigator: X. Descombes. Participants: O. Viveros-Cancino, J. Zerubia.

9. Dissemination

9.1. Conferences, Seminars, Meetings

- The members of the Ariana project participated actively in GDR-PRC ISIS and GDR-MSPCV.
- The members of the Ariana project participated in and presented their work at the first Ariana/DLR (German Space Agency) Collaborative Day in July in Sophia Antipolis, and at the second Collaborative Day in November in Oberpfaffenhofen, Germany, as part of the PAI Procope project.
- The members of the Ariana project participated actively in the INRIA Fête de la Science. In particular, M. Rochery and G. Perrin made presentations at the Special Needs School 'Les Cadrans Solaires', Vence, in October, while J. Zerubia M. Ortner, and N. Dey made presentations as part of the INRIA Open Doors weekend in October.
- As in previous years, the Ariana project participated in the TIPE for the preparatory classes for the Grandes Écoles.
- The Ariana project organized numerous seminars in image processing during 2003. Twenty-two researchers were invited from the following countries: Belgium, Canada, France, Ireland, Israel, Italy, Mexico, Puerto Rico, Sri Lanka, Sweden, Switzerland, the United Kingdom, and the United States. For more information, see the Ariana project web site.
- The Ariana project participated actively in the visits to INRIA Sophia Antipolis of students from the Grandes Écoles (ENS Ulm, ENS Cachan, ENS Lyon, École Polytechnique, Sup'Aéro...)
- J.F. Aujol participated in the workshop CANUM, and he gave a talk as part of the Ariana-Odyssée joint seminar 'The uses of texture in image processing, and associated mathematical problems', at INRIA Sophia Antipolis in March.

- K. Brady participated in the MOUMIR meeting at INESC in Porto, Portugal, in June, where she presented a poster of her work.
- C. Lacoste gave a talk as part of the Ariana/Mistral joint seminar ‘Stochastic state space exploration strategies applied to image processing and network modeling’, at INRIA Sophia Antipolis, in May. She attended the symposium ‘Etats de la recherche: aspects probabilistes en vision’, at ENS Cachan, Paris, in June, and the symposium ‘Modélisation aléatoire et industries aérospatiales’, at the Laboratoire de Statistique et Probabilités, Toulouse, in October.
- M. Ortner gave a talk as part of the Ariana/Mistral joint seminar ‘Stochastic state space exploration strategies applied to image processing and network modeling’, at INRIA Sophia Antipolis, in May, and gave a seminar at DGA/CTA Arcueil, Paris, in May.
- G. Perrin visited IFN and CEMAGREF, both in Montpellier, in July, and IFN in Nogent sur Vermisson in December.
- M. Rochery visited Prof. V. Caselles of Pompeu Fabra University, Spain, for one week in July, supported by GDR-ISIS, and gave a seminar to the VISSTA group of the Electrical and Computer Engineering Department at North Carolina State University, USA, as part of a three week visit to Dr. H. Krim in August.
- E. Villeger participated in the conference AMAM in February, and visited CMLA at ENS Cachan, Paris, for three days in April.
- R. Cossu participated in the meeting of EU project MOUMIR at INESC in Porto, Portugal, in June, and there presented a poster.
- N. Dey visited the Pasteur Institute, Paris, several times throughout the year, spending a total of seven weeks there. During one of these visits, he gave a seminar. He participated in the Scientific Volume Imaging (SVI) User Group Meeting, at the SVI headquarters, Hilversum, the Netherlands.
- I. Jermyn participated in a meeting of the CNRS AS Fouille d’Image at ENST, Paris, in January and attended the IGN Research Days at IGN, Paris, in February. He visited Trinity College, Dublin, as part of EU project MOUMIR, in March and participated in the MOUMIR meeting at INESC in Porto, Portugal, in June. He visited ENS Cachan, Paris, as part of the MATH/STIC project ‘Visual Annotation’, in September.
- X. Descombes participated in the ORFEO meeting at CNES, in May and visited the IITP of the Russian Academy of Science in September in the context of a project supported by the Lyapunov Institute (grant 98-02). He gave two invited talks in the Computational and Information Infrastructure session of the Astronomical Datagrid Workshop held at the Nice Observatory (OCA) in October as part of a collaboration with the OCA, and gave a talk at the Lyapunov workshop for the 10^{th} anniversary of the Lyapunov Institute, Moscow, also in October. He gave a talk in the workshop ‘Pixels et Cités’, Marne la Vallée, organized by SFPT, IGN, IRD, and INRIA, in November, and another at the workshop on Hyperspectral Images organized by Alcatel Space, Cannes, in December.
- L. Blanc-Féraud participated in the CNRS AS Fouille d’Image, and attended several meetings in Paris. She gave an invited talk in the conference VIA Vision, Image and Agriculture, Dijon, and gave another in the Computational and Information Infrastructure session of the Astronomical Datagrid Workshop held at the Nice Observatory (OCA) in October as part of a collaboration with the OCA.
- J. Zerubia gave invited talks at the University of Paris VI, in January, and ETH Zurich and Infoterra Friedrichhaffen, Germany, in February. In May, she participated in the ORFEO meeting at CNES, Paris, and visited Alcatel Space and Silogic, both in Toulouse. She visited the University of Pompeu Fabra, Barcelona, Spain, in September, and Alcatel Space, Cannes, in November.

9.2. Refereeing

- J.F. Aujol was a referee for IEEE TIP.
- C. Lacombe was a referee for IEEE TSP.
- C. Abhayaratne was a referee for IEEE TIP and IEEE Signal Processing Letters.
- R.Cossu was a referee for IEEE TIP, IEEE TGRS, International Journal on Information Fusion, Photogrammetric Engineering and Remote Sensing, and for the conference MultiTemp.
- I. Jermyn was a referee for IEEE TIP, IEEE TPAMI, JMLR, and Traitment du Signal, and for the conferences ICASSP, ICIP,and UIST.
- X. Descombes was a referee for IEEE TIP, TMI, IEEE PAMI, and Traitement du Signal, and for the conferences ICIP, ORASIS, and ICASSP.
- L. Blanc-Féraud was a referee IEEE Signal Processing Letters, IEEE TIP, and the conferences ACIVS, ICIP, and GRETSI.
- J. Zerubia was a referee for IJCV, IEEE TIP and IEEE TPAMI, and for the conferences ICASSP, ICIP, EMMCVPR, ORASIS, Pixels et Cités, GRETSI, TAIMA, and the SPIE Conference on Signal Processing for Remote Sensing.

9.3. Organization

- C. Abhayaratne was chair of the ‘Wavelets and Multirate Filtering’ session at the International Symposium on Image and Signal Processing and Analysis (ISPA).
- R.Cossu served on the organizing committee of the Second International Workshop on the Analysis of Multitemporal Remote Sensing Images (MultiTemp 2003), Ispra, Italy, in July.
- I. Jermyn is a member of the Comité de Suivi Doctoral and the Library Working Group at INRIA. He organized the DLR/Ariana Workshop in July as part of the Procope collaboration with the German space Agency, DLR. He was chair of the ‘Indexing’ session at GRETSI, and was a member of one PhD committee during 2003.
- X. Descombes was a member of one PhD committee in 2003, and was co-chair of the ‘Classification and segmentation II’ session at IGARSS.
- L. Blanc-Féraud is a member of the Scientific Committee of CNRS RTP 25 ‘Imagerie, vision et analyse de scènes’. She was in charge of Communications at the I3S Laboratory (CNRS/UNSA) until August, and Adjoint Director of the I3S Laboratory from September. She is a member of the COLORS Committee at INRIA. She was a member of a PhD pre-defence committee at LCPC in Strasbourg, and was a reviewer for two PhD theses, and a committee member for a third. She attended the General Assembly of the GDR, Dourdan, in March, and organized the GDR-PRC ISIS ‘Texture Day’ meeting in Paris, in June. She organized a meeting of the AS Fouille d’Image and GDR-PRC ISIS on ‘Applications en Fouille d’Image’ at ENST in July. She was chair of the ‘Restoration and reconstruction: multicomponent analysis’ session at GRETSI.
- J. Zerubia was made an IEEE Fellow in January, and she is member at large of the Board of Governors of the IEEE Signal Processing Society. 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 Transactions on Pattern Analysis and Machine Intelligence November issue, and she is a member of the Editorial Board of the Bulletin of the SFPT. She was general co-chair of EMMCVPR in Lisbon, in July, general chair of the "Pixels et Cités" workshop in Marne la Vallée, in November, and president of a session at ICIP in Barcelona, in September. She was a Program Committee member for ICASSP, ICIP, EMMCVPR, ORASIS, Pixels

& Cités, GRETSI, TAIMA, and the SPIE Conf. on Signal and Image Processing for Remote Sensing. She organized a one-day workshop between the Pasteur Institute, the Weizmann Institute, and the Ariana project in Sophia Antipolis in July, 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 a member of three PhD defence committees at UNSA and ENST, a committee member for one HdR at Sup-Aéro, and a reviewer for another at the University of Rennes. She was a nominator for the Kyoto Prize in Information Science given by the Inamori Foundation in Japan, and she was a member of the evaluation boards for the Swiss National Science Foundation and the Israel Science Foundation.

9.4. Teaching

- J.F. Aujol was teaching assistant for 'Mathematics applied to Digital Images' (64h) at the IUT of the University of Nice Sophia-Antipolis.
- C. Lacoste was lab instructor for 'Image' (21 hours) at ESINSA.
- C. Lacombe was a teaching assistant for 'Financial Mathematics' (8h), and in charge of a course in 'Mathematical Harmonization' (10h), both for the DESS in 'Informatique et Mathématiques Appliquées à la Finance et à l'Assurance' at ESSI. She was also teaching assistant for 'Partial Differential Equations' (26h) and 'Numerical Mathematics' (52h) at ESSI.
- M. Rochery was lab instructor for 'Signal Processing' (30 hours), 'Numerical Signal Processing' (30 hours), and 'Practical Electronics' (37 hours) at ESINSA.
- E. Villeger was teaching assistant for 'Mathematical Theory of Computer Science' (42h), and lab instructor for a course on Maple (21h), both at the IUT of the University of Nice Sophia-Antipolis.
- N. Dey was lab instructor of 'Unix Systems' (39h) at the University of Nice-Sophia Antipolis.
- I. Jermyn taught 'Image Analysis' (6h) at ESINSA, and 'Filtering and Segmentation of Space Imagery' (2.5h) at Sup'Aéro.
- X. Descombes taught 'Image Analysis' (15h) at ESINSA, 'Remote Sensing' for the DEA in Astrophysics (9h) at the University of Nice-Sophia Antipolis, and 'Filtering and Segmentation of Space Imagery' (17h) at Sup'Aéro.
- J. Zerubia was director of the module 'Markov Random Fields in Image Processing' in the DEA SIC 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' (40h, of which 20h teaching) at Sup'Aéro, where she also taught 'Variational Methods for Image Processing' (2.5).

9.5. PhDs

9.5.1. In progress

1. Jean-François Aujol, 'Classification d'image couleur texturée par approche variationnelle', University of Nice-Sophia Antipolis, defence expected in 2004.
2. Caroline Lacoste, 'Mise à jour cartographique des réseaux linéiques en fusion de données par processus Markov objet', University of Nice-Sophia Antipolis, defence expected in 2004.
3. Mathias Ortner, 'Analyse urbaine à partir de modèles numériques d'élévation par processus Markov objet', University of Nice-Sophia Antipolis, defence expected in 2004.
4. G. Perrin, 'Étude du couvert forestier à partir d'un processus objet', Centrale Paris, defence expected in 2006.
5. 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.
6. Emmanuel Villéger, 'Evolution de sous-variétés de R^n à l'aide de la fonction vecteur distance', University of Nice-Sophia Antipolis, defence expected in 2004.

9.5.2. Defended in 2003

1. Oscar Viveros-Cancino. 'Analyse des zones urbaines par fusion de données en télédétection', University of Nice-Sophia Antipolis. Defended June 10.
2. Karen Brady. 'A probabilistic framework for adaptive texture description', University of Nice-Sophia Antipolis. Defended December 17.
3. Caroline Lacombe. 'Modèles variationnels et équations aux dérivées partielles pour le déroulement de phase en interféromètrie radar de type RSO', University of Nice-Sophia Antipolis. Defended December 16.

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[4] O. VIVEROS-CANCINO. *Analyse Des Zones Urbaines Par Fusion de Données En Télédétection.* Ph. D. Thesis, , University of Nice-Sophia Antipolis, 2003.

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