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Inverse Problems in Earth Observation and Cartography

Sophia Antipolis

THEME COG

Activity Report

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1. Team

Team Leader

Josiane Zerubia [Research Director (DR1) INRIA]

Administrative Assistant

Corinne Zuzia [Administrative Assistant (TRN) INRIA (half-time in the project-team)]

Research Scientists (INRIA)

Xavier Descombes [Research Scientist (CR1)]
Ian Jermyn [Research Scientist (CR1)]

Research Scientists (CNRS)

Laure Blanc-Féraud [Research Director (DR2), Team Vice-Leader]

Postdoctoral Fellows

Mats Erikson [Mr. Erikson is funded by the French Ministry of Research (MESR). He arrived in October]
Dan Yu [Ms Yu is funded by the French Ministry of Research (MESR). She arrived in December]

Ph.D. Students

Alexis Baudour [Mr. Baudour is funded by an ENS/AMN grant. He started his Ph.D. in October]
Avik Bhattacharya [Mr. Bhattacharya is funded by a grant from French Space Agency (CNES) and INRIA]
Alexandre Fournier [Mr. Fournier is funded by a grant from the French Defence Agency (DGA) and CNRS. He started his Ph.D. in November]
Peter Horvath [Mr. Horvath is funded by a grant from MAE/EGIDE, INRIA, and the University of Szeged, Hungary. He started his Ph.D. in September]
Florent Lafarge [Mr. Lafarge is funded by a grant from the French Space Agency (CNES) and the French National Geographic Institute (IGN)]
Ting Peng [Ms Peng is funded by a grant from MAE/EGIDE, CASIA/LIAMA, and Alcatel Alenia Space. She started her Ph.D. in September]
Guillaume Perrin [Mr. Perrin is funded by an MESR grant from École Centrale Paris]
Marie Rochery [Mrs Rochery was funded by an MESR grant from the University of Nice-Sophia Antipolis. She defended her Ph.D. in September]
Emmanuel Villeger [Mr. Villeger is an ENS student, funded first by an ENS/AMN grant, and then by teaching as a college Professor during the last year of his Ph.D.. He defended his Ph.D. in December]
Pierre Weiss [Mr. Weiss is funded by an MESR grant from the University of Nice-Sophia Antipolis. He started his Ph.D. in October]
Olivier Zammit [Mr. Zammit is funded by a SILOGIC/INRIA grant. He started his Ph.D. in October]

Student Interns

Vikram Agrawal [Mr. Agrawal (IIT New Delhi, India) was funded by the INRIA Internship programme/ACI QuerySat from May to August]
Johan Aubray [Mr. Aubray was funded by the French Civil Aviation Authority (DGAC) from April to September]
Alexis Baudour [Mr. Baudour was funded by ENS Cachan from April to August]
Aymen El Ghoul [Mr. El Ghoul (Sup'Com Tunis) was funded by an INRIA STIC-Tunisia and ACI QuerySat grant from April to June]
Alexandre Fournier [Mr. Fournier was funded by INRIA and the French Geographical Survey (BRGM) from April to September]
Pierre Gernez [Mr. Gernez was funded by INRIA (COLORS FIGARO) from April to September]
Marion Lebellego [Ms Lebellego was partially funded by ECO-NET from April to September]
Alain Lehman [Mr. Lehman (ETHZ) was funded by Studex (Switzerland) from May to August]
Praveen Pankajakshan [Mr. Pankajakshan (IIT Roorkee, India and Texas A&M University, USA) was funded by the INRIA Internship programme/P2R Franco-Israeli programme from November to December]

Pierre Weiss [Mr. Weiss was funded by I3S (CNRS/UNSA) from April to August]

Visiting Scientists

Alin Achim [Lecturer, University of Bristol, UK. One week in June funded by the University of Bristol]
Fernand Cohen [Professor, Drexel University, USA. Mid-June to mid-September, funded by CNRS]
Joseph Francos [Professor, Ben-Gurion University, Israel. One week in August, funded by Ben-Gurion University]
Peter Horvath [Ph.D. student, University of Szeged, Hungary. January to June, funded by EU project IMAVIS]
Zoltan Kato [Assistant Professor, University of Szeged, Hungary. Two weeks in April, and one week in December, funded by PAI Balaton]
Robert Minlos [Professor, IITP, Russia. Two weeks in October funded by Egide (ECO-NET)]
Boris Nahapetian [Professor, University of Yerevan, Armenia. Two weeks in November/December funded by Egide (ECO-NET)]
Eugene Pechersky [Professor, IITP, Russia. Four weeks in May/June funded by Egide (ECO-NET) and four weeks in November/December funded by CNRS]
Ting Peng [Ph.D. student, LIAMA, Beijing, China. Two weeks in May, funded by CASIA/LIAMA]
Veronique Prinet [Associate Professor, CASIA/LIAMA, Beijing, China. One week in December, funded by ARC Mode de Vie]
Ryad Tebourbi [Assistant Professor, Sup'Com Tunis, Tunisia. One week in January, funded by INRIA STIC-Tunisia]
Rebecca Willett [Assistant Professor, Duke University, USA. One week in June, funded by the INRIA USA Initiative]
Roland Wilson [Professor, University of Warwick, UK. January to March, funded by the Royal Society, UK]
Elena Zhizhina [Professor, IITP, Russia. Four weeks in October funded by Egide (ECO-NET)]

External Collaborators

Gilles Aubert [Professor at the Jean-Alexandre Dieudonné Laboratory, CNRS/UNSA]
Gérard Giraudon [Research Director (DR1) INRIA, Director of Development and Industrial Relations]
Marc Sigelle [Ingénieur en chef du Corps des Télécom, and Associate Professor in the Signal and Image Processing Department, ENST, Paris]

2. Overall Objectives

2.1. Overall Objectives

Ariana is a joint project-team 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-team web site can be found at http://www.inria.fr/ariana.

The Ariana project-team is engaged in two distinct but strongly synergistic endeavours, one applicative and one methodological. The project-team 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-team 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-team have also found application to astrophysical and biological images.

Methodologically speaking, the project-team 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-team 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-team 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-team, 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-team, 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-team. 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-team 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.

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.

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

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

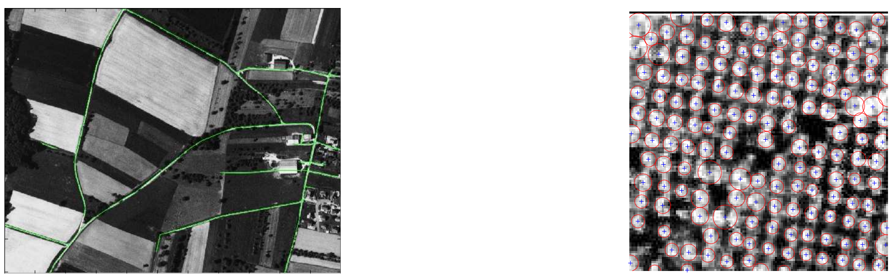
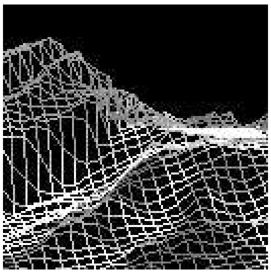


Figure 3. Left: road network extraction; right: tree extraction.

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.



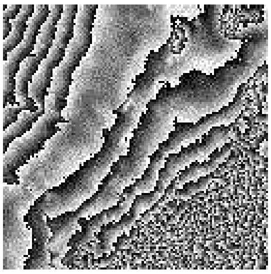


Figure 4. Left: DEM; right: interferometry.

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-team.

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

5. Software

5.1. Quality-Candy

Keywords: *RJMCMC*, *marked point process*, *road network extraction*, *segments*.

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

Software for road network extraction using a Marked Point Process model based on segments. Deposited with the APP. Transferred to the CPE Engineering school in Lyon and the French Geographical Survey (BRGM) Orléans.

5.2. CAROLINE

Keywords: *RJMCMC*, *marked point process*, *polylines*, *road network extraction*.

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

Software for road network extraction using a Marked Point Process model based on polylines. Deposited with the APP. Transferred to the French Geographical Survey (BRGM) Orléans.

5.3. HIMNE

Keywords: *Markov Random Fields*, *RJMCMC*, *hydrographic network extraction*, *marked point process*.

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

Software for hydrographic network extraction using a Markov Random Field and a hierarchical Marked Point Process model. Deposited with the APP. Transferred to the French Geographical Survey (BRGM) Orléans.

5.4. ExtraLine

Keywords: *active contours*, *geometry*, *higher order*, *level sets*, *line network extraction*, *prior*, *road detection*, *shape*.

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

Software for line network extraction from aerial and satellite images using a new generation of active contours, 'higher-order active contours'. Deposited with the APP. Transferred to the University of Szeged in Hungary and to the LIAMA in China.

5.5. ExtraLinePlus

Keywords: *active contours*, *continuation*, *gap closure*, *geometry*, *higher order*, *level sets*, *line network extraction*, *occlusion*, *prior*, *road detection*, *shape*.

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

Software for line network extraction from aerial and satellite images using a new generation of active contours, 'higher-order active contours', and able to tackle the problem of occlusions. Deposited with the APP. Transferred to the University of Szeged in Hungary and to the LIAMA in China.

5.6. PhaseLine

Keywords: *active contours*, *geometry*, *higher order*, *line network extraction*, *phase field*, *prior*, *road detection*, *shape*.

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

Software for line network extraction from aerial and satellite images using phase field models of higher-order active contours. Deposited with the APP.

6. New Results

6.1. Probabilistic models

6.1.1. Image deconvolution using Langevin dynamics

Keywords: *Langevin dynamics*, *blind deconvolution*, *image restoration*.

Participants: Marion Lebellego, Xavier Descombes.

This internship was co-supervised by Elena Zhizhina from the ITTP of RAS, Moscow. It was partly funded by an Egide ECO-NET project [http://www-sop.inria.fr/ariana/personnel/Xavier.Descombes/Xaveconet.html], and partly by NATO/Russia Collaborative Linkage Grant 980107.

In previous work [47], we have shown that the Langevin dynamics associated with a stochastic differential equation represents an advantageous alternative to Metropolis dynamics in the context of image denoising. Here, we generalize this work to the image deconvolution problem. First, we assumed that the convolution kernel is known. Interesting results have been obtained (see figure 6). We then considered the myopic deconvolution problem. In this case, a parametric model of the kernel is given but the associated parameters have to be estimated. Our approach consists in alternately estimating the restored image and the kernel parameters. Finally, we addressed the blind deconvolution problem, in which both the image and the kernel are unknown. In this context, we obtain satisfactory results only if a 'good' initialization of the kernel is given. Avoiding this requirement is still an open issue.

Figure 6. Left: convolved image; right: restored image.

6.1.2. Shape from shading using stochastic dynamics

Keywords: *Langevin dynamics*, *Metropolis Adjusted Langevin Dynamics*, *Metropolis dynamics*, *Shape from Shading*.

Participants: Alain Lehman, Xavier Descombes.

This internship (Master from ETHZ) was funded by Studex (Switzerland).

The shape from shading problem consists in recovering a 3D shape from a single view. Under some specific assumptions, the slope of the 3D surface is linked to the observed image intensity by the Eikonal equation. This ill-posed inverse problem is known to represent a challenge for optimization techniques. We have compared various stochastic schemes in the context of shape from shading. The first idea of this work is to compare a completely random exploration of the configuration space given by Metropolis dynamics with Langevin dynamics, which is driven by the gradient of the Hamiltonian of the problem. Note that these two schemes converge to the global minimum of the energy function, contrary to deterministic methods. As a result, we have shown that in some cases, Langevin dynamics performs better than Metropolis dynamics. However, in some cases the configuration obtained with Langevin dynamics corresponds to a deep local minimum (at least with a reasonable cooling schedule for the temperature). In the context of shape from shading, even a deep local minimum can lead to a solution very far from the optimum. In order to overcome this difficulty, we studied a mixture of Metropolis and Langevin dynamics, referred to as the Metropolis Adjusted Langevin Algorithm (MALA). This algorithm outperforms the two previous dynamics. The result of a 3D reconstruction is given in figure 7.

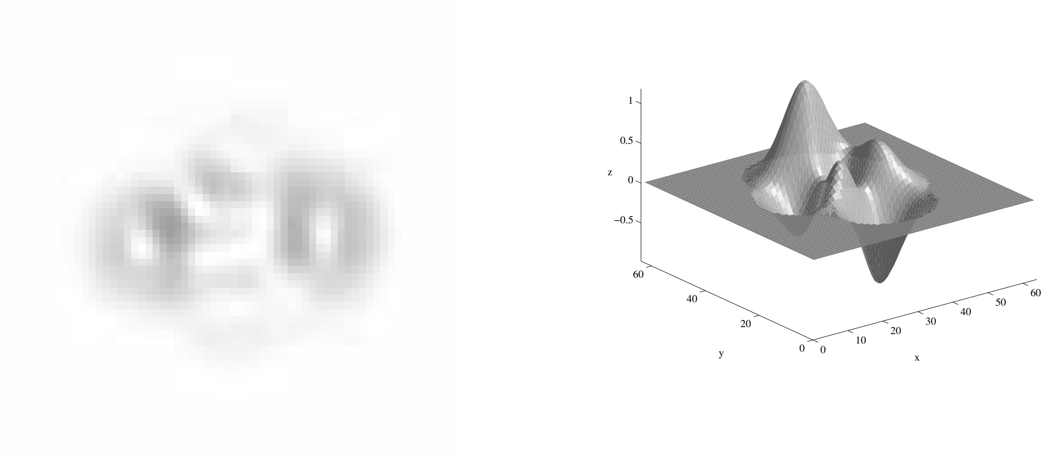


Figure 7. Left: image of a synthetic landscape; right: 3D reconstruction result.

6.1.3. Road extraction using a three-stage approach

Keywords: *Chien model, Gabor filters, Road extraction, mathematical morphology*.

Participant: Xavier Descombes.

In this work, we propose a road detection algorithm consisting of three steps. The first step uses a generalization of Gabor filters which allows the local extraction of road information from the data. This is referred to as the low-level extraction of road networks. The middle level consists of regularizing the previous result using a Markov random field. We use a prior derived from a previous model, called the Chien model [46], which allows the extraction of a line network from the set of pixels detected as road candidates by the bank of generalized Gabor filters in the first step. This model incorporates 3×3 interactions and allows the local prolongation of the line network. Finally, the high level interpretation of the result consists in connecting the network, depending on proximity and curvature criteria. This last stage is performed using mathematical morphology operators. This approach provides results (see figure 8) nearly comparable to those obtained by more sophisticated approaches [11]. Note that this approach has low computational cost and is fully automatic.

Figure 8. Left: aerial image (© French National Geographic Institute (IGN)); right: road extraction result

6.1.4. Tree crown extraction using a Markov random field

Keywords: *Markov random field, long-range interactions, tree crown detection*.

Participants: Guillaume Perrin, Xavier Descombes.

This work is the result of a collaboration with Eugene Pechersky from the ITTP of RAS, Moscow. It was partly funded by an Egide ECO-NET project [http://www-sop.inria.fr/ariana/personnel/Xavier.Descombes/Xaveconet.html].

In this work, we address the problem of tree crown extraction from infra-red remote sensing images. We define a template-based Markov random field that includes short-range interactions to promote regularization inside the tree crowns, medium-range interactions defining the tree borders, and long-range attractive interactions to favour the regular structure of poplar stands. Besides the 'tree' and 'outside tree' labels, a third label defining the centre of the trees is included in the model. The neighbourhood defining the long-range interactions is estimated by analysing the Fourier transform of the data. Finally, from the segmentation results, each individual tree is delineated using the tree centre label. We thus obtain a description of the population which allows the estimation of the number of trees and various statistical descriptors such as the average size (see figure 9).

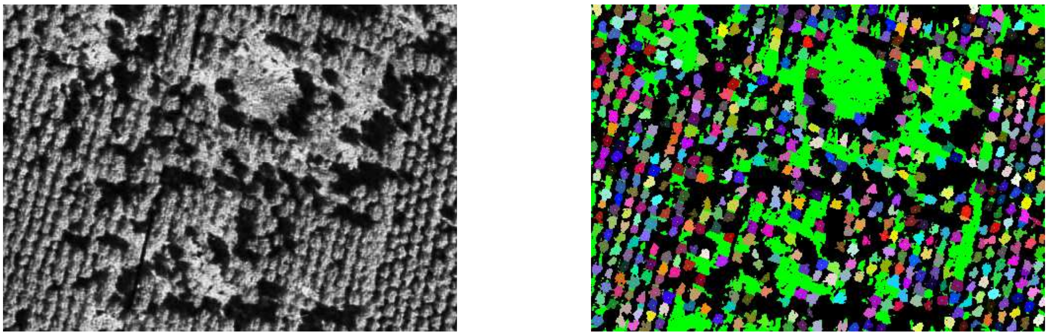


Figure 9. Left: infrared image (© French National Forest Inventory (IFN)); right: tree crown detection result.

6.1.5. Target detection via the analysis of texture perturbations

Keywords: *Markov random field, parameter estimation, target detection, texture*.

Participants: Alexandre Fournier, Xavier Descombes, Josiane Zerubia.

This Ph.D. is funded by the French Defence Agency (DGA) in collaboration with CNRS. The data will be provided by the French Defence Agency (DGA) and EADS.

The goal of this work is to detect specific targets that are hidden in the background. We consider the target detection problem as the perturbation analysis of a texture model. We thus consider the texture analysis framework in a non-stationary context. The models used will be Markov random field models. The target environment will be characterized by model parameters locally estimated from the image, and local variations of these parameters will enable us to detect the target automatically. From the data, different statistical parameter maps will be estimated. Target detection will be based on the analysis of these maps via the detection of local variations. The performance of the detection is linked to the accuracy of the statistical parameter estimation, so we will develop robust estimators for small sample sizes. Following target detection, segmentation based on a region-growing technique will delineate the different targets. Finally, a classification procedure will characterize each target. This classification will be based on a training set for each potential target.

6.1.6. Evaluation of the damage caused by forest fires

Keywords: *Gaussian field, Support Vector Machines, classification, forest fire, texture*.

Participants: Olivier Zammit, Xavier Descombes, Josiane Zerubia.

This work is done in collaboration with Silogic, Toulouse [http://www.silogic.fr].

The aim of this work is to evaluate and quantify the damage caused by forests fires. We will extract radiometric information from the different channels of SPOT 5 satellite images (super-mode and multispectral). We plan to use Gaussian random fields and Support Vector Machines for the classification. A map of the burnt areas will be produced and validated, allowing them to be referenced, placed in their geographic context, and their surface area estimated.

6.1.7. Multiscale road extraction

Keywords: *Bayesian image analysis, Quality Candy model, marked point process, road extraction.*

Participants: Alexandre Fournier, Xavier Descombes, Josiane Zerubia.

This work is funded by the French Geographical Survey (BRGM) and INRIA. It is part of a PNTS initiative. The data are provided by the French Geographical Survey (BRGM).

A road extraction algorithm, called the 'Quality Candy' model, was previously developed in the Ariana project-team [11]. This algorithm takes the road width as a parameter. The goal of this work is to include the road width in the state space, and thereby classify roads according to their scale. Introducing such changes led us to define new transition kernels in the Markov chain that take into account realistic changes in the road model width. Moreover, the resolution of the image is taken into account because each proposal now depends on the object width. This led us to normalize the energy at each scale so that jumps between different resolutions are possible and realistic.

The results are encouraging (see figure 10): we are now able to detect roads with multiple widths in a single image. However, the result has lower precision than the original version of the model [11]. The side effects of energy normalization are now being studied in order to improve the spatial precision. The detection of very thin roads is still troublesome.

Figure 10. Left: synthetic image; middle: detection of lines of width 1–4 pixels; right: detection of lines of width 5–8 pixels.

6.1.8. Automatic building 3D reconstruction from high resolution satellite images

Keywords: *3D building reconstruction, Bayesian approach, Markov chain Monte Carlo, parametric model.*

Participants: Florent Lafarge, Xavier Descombes, Josiane Zerubia.

This Ph.D. is co-supervised by Marc-Pierrot Deseilligny, chief scientist of the technical direction of the French National Geographic Institute (IGN)[http://www.ign.fr]. The data are provided by the French Space Agency (CNES) [http://www.cnes.fr/html/_455_.php] and the French National Geographic Institute (IGN), who also partially fund this work. The work is part of a PNTS initiative.

The automatic 3D reconstruction of urban areas has become a topic of growing interest in the last few years. Models built from connected planar facets have recently been used in various applications such as the computation of electromagnetic wave propagation and the creation of virtual realities. Several automatic methods have been developed using aerial images or laser scanning. Nowadays, this problem can be tackled using another kind of data: satellite images. The most recent satellites possess sensors with sub-metric resolution. The main advantages of satellite data over aerial images are a higher swath width and greater ground coverage.

An automatic building extraction method developed previously in the Ariana project-team [48] is used to provide rectangular building footprints, thus localizing the buildings. 3D parametric methods based on a Bayesian approach are then used to reconstruct the buildings. Parametric methods are preferred since they are less complex, more robust with respect to satellite data, and more adapted to rectangular building footprints. Collections of rectangular base parametric models with rectangular ground footprints are defined. The methods are based on the definition of a density which contains both *a priori* knowledge about the buildings, taking into account the interactions existing between neighbouring models, and a data term which fits the models to the DEM [36]. A Markov Chain Monte Carlo algorithm coupled with simulated annealing is used to optimize this density. Figure 11 presents some results.

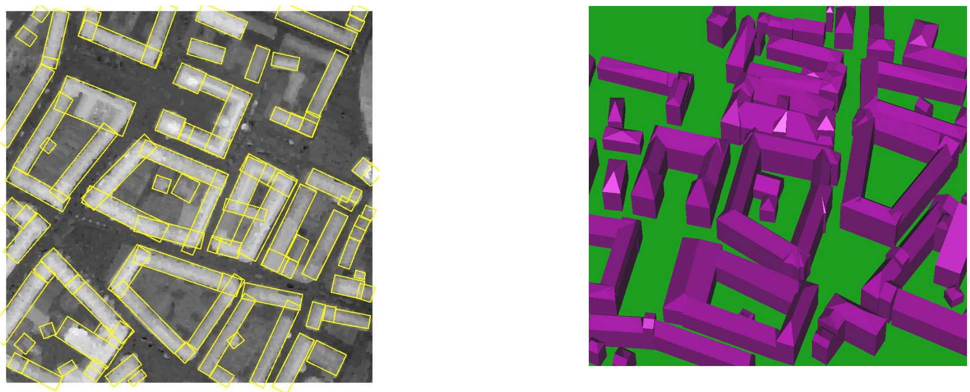


Figure 11. Left: a Digital Elevation Model (© French Space Agency (CNES)) and associated rectangular building footprints (© INRIA); right: the result of 3D reconstruction.

6.2. Variational models

6.2.1. An approximation of the Mumford-Shah energy by a family of discrete edge preserving functionals

Keywords: *Gamma-convergence, finite elements, image segmentation*.

Participants: Gilles Aubert, Laure Blanc-Féraud.

In collaboration with Riccardo March from the Istituto per le Applicazioni del Calcolo (IAC), CNR, Rome [http://www.iac.cnr.it].

The goal of this work is to show the Γ-convergence of a family of discrete functionals to the Mumford-Shah image segmentation functional. The functionals of the family are constructed by modifying the elliptic approximating functionals proposed by Ambrosio and Tortorelli. The quadratic term of the energy related to the edges of the segmentation is replaced by a nonconvex functional. These functionals were proposed in a previous paper [51], which demonstrated the good numerical quality of the proposed approximation. Here, the theoretical proof is completed [6].

6.2.2. Detecting codimension-two objects in an image with Ginzburg-Landau models

Keywords: *Ginzburg-Landau model, PDE, point detection, segmentation.*

Participants: Laure Blanc-Féraud, Gilles Aubert.

This is joint work with Jean-François Aujol, ex-Ph.D. student in the Ariana project-team, now a CNRS permanent researcher at ENS Cachan [http://www.cmla.ens-cachan.fr/~aujol].

In this work, we propose a new mathematical model for detecting singularities of codimension greater than or equal to two in an image. This means we want to detect points in a 2D image or points and curves in a 3D image. Inspiration was drawn from the Ginzburg-Landau models used for modelling many phenomena in physics. We have proposed a model adapted to image processing, we have stated its mathematical properties and have given some experimental results demonstrating its capabilities in image processing [5]. This work was dedicated to 2D images; we are currently working on a 3D model.

6.2.3. Image restoration for bounded noise

Keywords: *L-infinity norm, bounded noise, decomposition, geometry, texture, total variation.*

Participants: Pierre Weiss, Laure Blanc-Féraud, Gilles Aubert.

In this work we focus on the minimization of energies involving an L^∞ norm. Such a norm is difficult to handle, because it is non-differentiable, and approximations lead to unstable algorithms. This norm occurs in many recent applications notably in the denoising of uniform noise or in the decomposition of an image into geometric and textured components.

We have found an original method to minimize such energies. The idea is to replace the non-differentiable energy by a differentiable one that we minimize under some constraints. This result allows us to design new algorithms to solve the above mentioned problems. In particular, we propose a new model using Total Variation to denoise bounded noise, and a simple algorithm without extra parameters to solve the problem of decomposition into textured and geometric components introduced by Y. Meyer.

In figure 12, we show the result of the denoising of an image perturbed by white uniform noise. We see that compared to the Rudin-Osher-Fatemi model, details are better preserved (hair) and the solution is smoother (cheeks).

6.2.4. Variational models for road network updating in dense urban areas from very high resolution optical images

Keywords: *Road network extraction, VHR, data fusion, digital cartography, updating, variational models.*

Participants: Ting Peng, Ian Jermyn, Josiane Zerubia.

This Ph.D. is co-supervised by Professor Baogang Hu, Chinese Director of the Sino-French Laboratory in Informatics, Automation and Applied Mathematics [http://liama.ia.ac.cn], Institute of Automation, Chinese Academy of Sciences, Beijing, China, and by Véronique Prinet, Associate Professor in the same laboratory. The data (Quickbird images and GIS of Beijing urban areas) were respectively provided by DigitalGlobe [http://www.digitalglobe.com] and the Beijing Institute of Survey and Mapping [http://www.bism.cn/english/].

The aim of this work is the automatic extraction of road networks from dense urban areas using very high resolution (VHR) optical satellite images. The final goal is the retrieval and updating of road network databases in urban areas, a task crucial to many Geographic Information System (GIS) applications like intelligent vehicle navigation, urban planning, environment guidance, emergency handling, etc. Because of its significant applicability, the present research work could be part of larger and wider research project, aiming at developing tools for decision support, with one of the applications cited above.

The research will use the higher-order active contour models developed within the Ariana project-team for road network extraction from medium to high resolution images [42], [43], and adapt both the prior and the likelihood terms to the demands of VHR imagery. This will involve developing a multiscale model of the image that can take into account the complex surface features associated with roads in VHR images (cars,

Figure 12. Top-left: original image; top-right: image with additive white uniform noise; bottom-left: restored image using the Rudin-Osher-Fatemi model; bottom-right: restored image with the proposed model.

road markings, etc.), and refining the prior region model to allow for more variation in the width of roads, and to capture the orthogonal structure of many urban road junctions.

6.3. EU project MUSCLE

6.3.1. *New higher-order active contour energies for network extraction*

Keywords: *active contours, continuation, gap closure, geometry, higher order, level sets, line network extraction, occlusions, prior, road detection, shape.*

Participants: Marie Rochery, Ian Jermyn, Josiane Zerubia.

This work is being done as part of EU project MUSCLE [http://www.muscle-noe.org/].

Using the framework of higher-order active contours [42], we define a new quadratic continuation energy for the extraction, in the presence of occlusions, of the 2D regions corresponding to line networks in remote sensing images [30], [43]. Occlusions create interruptions in the data that frequently translate to gaps in the extracted network. The new energy penalizes nearby opposing extremities, and thus favours the closure of gaps. Nearby opposing extremities are identified using long-range interactions between pairs of points on the contour. This new model allows the extraction of fully connected networks. In figure 13, we present an experimental result on a real aerial image that demonstrates the effectiveness of the new model.

6.3.2. *Phase field models and higher-order active contours*

Keywords: *active contours, geometry, higher order, line network extraction, phase field, prior, road detection, shape.*

Participants: Marie Rochery, Ian Jermyn, Josiane Zerubia.

This work is being done as part of EU project MUSCLE [http://www.muscle-noe.org/].

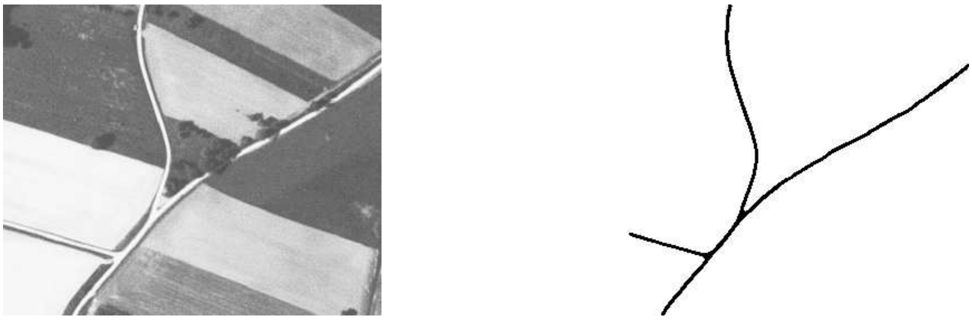


Figure 13. Left: an aerial image of an occluded road network (© French National Geographic Institute (IGN)); right: the result of road network extraction.

We propose to use a new framework in order to model regions: we represent a region via a level set of a 'phase field' function [31], [41]. The function is not constrained, *e.g.* to be a distance function; nevertheless, phase field energies equivalent to classical active contour energies can be defined. They represent an advantageous alternative to other methods: a linear representation space; ease of implementation (a PDE with no reinitialization); neutral initialization; and greater topological freedom. We extend the basic phase field model with terms that reproduce higher-order active contour energies, in order to introduce prior geometric knowledge into the model. In addition to the above advantages, the phase field greatly simplifies the analysis and implementation of the higher-order terms. We define a phase field model that favours regions composed of thin arms meeting at junctions, combine this with image terms, and apply the model to the extraction of the 2D regions corresponding to line networks in remote sensing images. A result using the new framework, which does not yet include the gap closure energy described in section 6.3.1, is shown in figure 14.

Figure 14. Left: an aerial image of a road network (© French National Geographic Institute (IGN)); right: the result of road network extraction with the phase field model.

6.3.3. Quartic models of the nonlinear statistics of adaptive wavelet packet coefficients

Keywords: *Bayesian*, *adaptive basis*, *multimodal*, *nonlinear*, *quartic*, *texture*, *wavelet packet*.

Participants: Johan Aubray, Ian Jermyn, Josiane Zerubia.

This work was done as part of EU project MUSCLE [http://www.muscle-noe.org/].

This work addresses the accurate modelling of textures using probabilistic models. In [44], models were developed based on wavelet packet bases adapted to the structure of the texture being described. The use of adaptive bases allows the model to focus on the important structures in a texture and to capture long-range correlations with little extra computational effort. The initial models were Gaussian, but it was observed that the empirical subband statistics of the resulting adaptive bases in fact assume three forms: Gaussian, generalized Gaussian, and, typically in subbands with narrow frequency support, bimodal. The latter are closely linked to the structure of the texture, since they predict that the most probable image under the distribution is in fact textured, unlike most previous texture models.

An initial attempt to model this variety of behaviour used a choice of models for each subband [21] [45]. To reduce the complexity of the description, to remove the necessity for model selection, and to provide greater flexibility for future models of the joint subband statistics, in this work the subband models are unified using a two-parameter quartic probability distribution. We use a Bayesian methodology throughout, computing MAP estimates for the adaptive wavelet packet basis and for the subband model parameters using depth-first search and a quasi-Newton optimization algorithm.

Results show that the significant structure in the texture is captured by these new models, as shown in figure 15. The joint statistics of the bimodal subbands display complex dependencies, for which extended quartic models are under development.

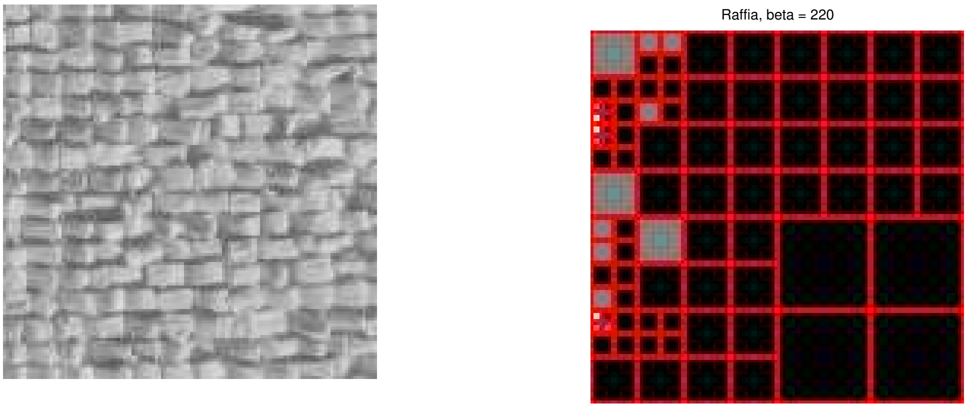


Figure 15. The 'Raffia' Brodatz texture, and its adaptive wavelet decomposition. The black subbands are Gaussian, the gray ones are 'pseudo-Gaussian', while the white subbands are bimodal.

6.3.4. High-level understanding for remote sensing image retrieval

Keywords: *image retrieval, segmentation, semantics.*

Participants: Dan Yu, Ian Jermyn, Josiane Zerubia.

This work is being done as part of EU project MUSCLE [http://www.muscle-noe.org/] and is partly funded by the French Ministry of Research. The aerial data are provided by the French National Geographic Institute (IGN) and the ground truth maps by the Institute for Urban Planning and Development of the Paris Île-de-France Region (IAURIF)[http://www.iaurif.org/].

The volume of data in remote sensing image databases is increasing day by day. Terabytes of data have been collected, and yet no efficient means exists for their analysis and study. Effective retrieval from such databases is therefore a matter of high priority if this mass of data is to be useful. However, accurate, robust and efficient retrieval must in the end be based on accurate, robust and efficient comprehension of the images involved, where comprehension here means a mapping of each image to a semantic space defined, independently of the retrieval process, by the specific application. Thus, this work focuses primarily on the extraction of the image semantics in a specific application and secondarily on its retrieval. The dataset involved is a collection of aerial images of the Île-de-France Region. A useful semantics to associate with this database is built on the predicate: 'The land area corresponding to region R in the image is occupied by land cover type C'. Ground truth for this semantics exists in the form of land use classification maps for the Île-de-France Region. These maps classify the land area into eleven 'regional' classes (such as 'forest'), and several 'linear' classes (such as 'waterways'). The aim of the work is twofold. First, to be able to generate, using techniques (texture and colour-based image classification; extraction of linear networks,...) both existent and under development in project-team Ariana, automatic classifications of the images in the dataset into these classes. Second, to incorporate this image comprehension facility into an image retrieval system, for example, the IKONA system [http://www-rocq.inria.fr/imedia/ikona/], developed by the Imedia project-team at INRIA Rocquencourt.

6.4. EU project IMAVIS

6.4.1. Higher-order active contours for tree detection

Keywords: *active contours, geometry, higher order, level sets, prior, shape, tree detection*.

Participants: Peter Horvath, Ian Jermyn, Josiane Zerubia.

This Ph.D. is co-supervised by Zoltan Kato, Assistant Professor at the University of Szeged, Hungary [http://www.inf.u-szeged.hu/~kato]. The data are provided by the French National Forest Inventory (IFN) [http://www.ifn.fr/spip/sommaire.php3?lang=en]. It is partly supported by EU project IMAVIS [http://www-sop.inria.fr/robotvis/projects/Imavis/imavis.html], by the Egide PAI Balaton programme, and by the French Ministry of Foreign Affairs (MAE).

We present a method for modelling a 'gas of circles', and apply it to the extraction of tree crowns from aerial images [33]. The method is based on the higher-order active contour framework introduced in the Ariana project-team [49], [42]. The framework allows the incorporation of prior geometric knowledge into active contour models via long-range interactions between contour points.

The parameters of the energy described in [42] can be chosen so that circles with a given radius are stable, thus providing a good prior model for the detection of circular structures in images (*e.g.* tree crowns, cells, silos, craters). To choose the parameters, we expand the energy function in a Taylor series up to second order around a circular contour. We set the parameters so that the first derivative is zero and the second derivative is positive definite, thus ensuring stability. The data term is composed of a Chan-Vese Gaussian energy, and a boundary gradient term. Preliminary results are shown in figure 16.

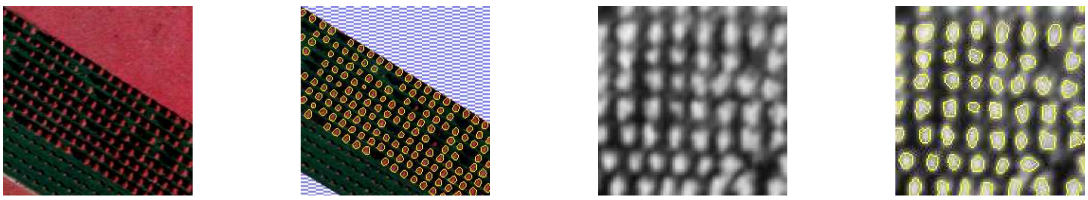


Figure 16. First and third: aerial images of forestry plantations (© French National Forest Inventory (IFN)); second and fourth: segmentation results.

6.5. ARC MODE de VIE

6.5.1. Tree crown extraction using marked point processes

Keywords: *Reversible Jump Markov Chain Monte Carlo, forestry, marked point process, object-based model, simulated annealing, 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 and the Digiplante INRIA project-team [http://www-rocq.inria.fr/Digiplante/]. The data (aerial images of French forests) are provided by the French National Forest Inventory (IFN) [http://www.ifn.fr]. The work forms part of ARC MODE de VIE [http://www-sop.inria.fr/ariana/Projets/ModedeVie/MODEdeVIE.html].

In forestry management, high-level parameters such as the number of stems or the distribution of tree crown diameters are assessed by Forest Inventories using field studies. Nevertheless, these statistics are not precise enough to appear on forestry maps, whose resolution is less than 1 ha. High spatial resolution images could help forestry managers to obtain, using appropriate algorithms, more knowledge at the scale of individual trees.

Using marked point processes, we can describe the distribution of trees in forestry images. We proposed modelling the tree crowns by a process whose objects are interacting ellipses. The prior model exploits the properties of the trees we are detecting (overlap and alignment rules for plantations for instance), while the data term fits our objects to the image. In previous work we defined a Bayesian model [39] which gives good extraction results on plantation images. However, this model has some limits as soon as the initial segmentation of the plantation is not perfect. We also introduced a non-Bayesian model (see Fig. 17) which solves this problem and offers us further prospects in the study of other stand structures such as isolated trees. Finally, we worked on the optimization of the algorithm by comparing different simulated annealing schemes in [28], [38].

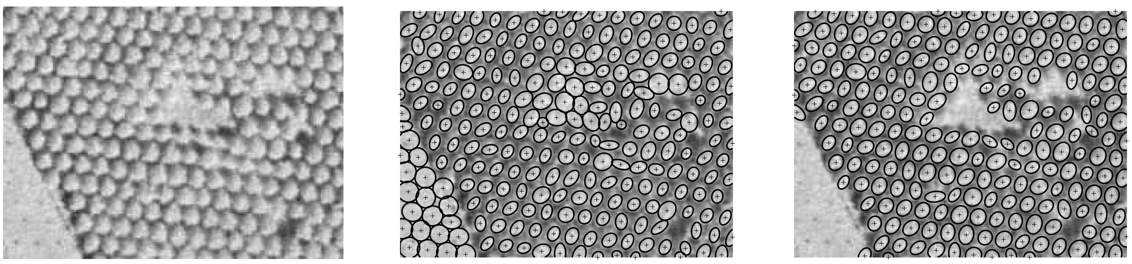


Figure 17. Left: an aerial image of a forest (© French National Forest Inventory (IFN)); middle: extraction result with the Bayesian model; right: extraction result with the non-Bayesian model.

6.5.2. Tree classification and characterization

Keywords: *Tree classification, forestry, shape analysis, texture*.

Participants: Mats Erikson, Xavier Descombes, Josiane Zerubia.

This work is the result of a collaboration through ARC MODE de VIE with Paul Henry Cournède and Philippe de Reffye (Digiplante project-team, INRIA Rocquencourt, the MAS Laboratory, École Centrale Paris, and LIAMA, Beijing, China) [http://www-sop.inria.fr/ariana/Projets/ModedeVie/MODEdeVIE.html].

The key aim of this collaboration is to develop an automatic tool to study forestry populations from remote sensing images. Several work packages have been outlined: tree extraction, texture analysis, shape analysis, and classification from textural and shape parameters. The results will be validated using forestry simulation software based on the growth model GreenLab [http://www-rocq.inria.fr/Digiplante/]. From the application point of view, these tools will enable us to simulate a 3D rendering of a forestry area, to study the evolution of a population between two dates, and to forecast the evolution of forestry, both from an architectural and from a functional point of view.

We will combine the different results obtained by the tree detection procedure and the textural and shape analysis. In particular, we will propose and develop a classification procedure. To achieve this, we will rely on the extraction tools developed within the Ariana project-team. We will develop statistical tools to validate the resulting classification, based on the different tree species, the age of trees, and various biomass parameters.

6.6. ACI Masses de Données QuerySat

6.6.1. Study of the change with resolution of the parameters of adaptive wavelet packet texture models

Keywords: *adaptive basis, change, parameter, resolution, texture, wavelet packet*.

Participants: Vikram Agrawal, Aymen El Ghoul, Ian Jermyn, Josiane Zerubia.

This work was performed as part of ACI QuerySat [http://www.tsi.enst.fr/QuerySat/indexen.html] and partly funded by the INRIA Internship programme (IIT New Delhi) and by the INRIA STIC-Tunisia programme (Sup'Com Tunis).

As the resolution of detectors increases, remote sensing image databases contain images at an ever wider range of resolutions. Current retrieval systems rely heavily on the use of parameters extracted from the data by texture models of various types in order to represent semantics and retrieve images. In this context, the existence of images at different resolutions creates problems because the same semantics will have different parameters at different resolutions. There are two solutions to this problem: one is to find parameters that are resolution-independent. However, this necessarily means that some information is lost, not just about the resolution, but about the texture being described. The alternative, which is the subject of this work, is to understand how the parameters change when the resolution changes, and to adjust the retrieval process accordingly.

Texture models based on wavelets have the advantage that they are naturally multiscale, and hence more easily adaptable to different resolutions. It is advantageous to go beyond standard wavelet bases, and to use wavelet packet bases adapted to the texture being modelled [44], [45], thereby capturing accurately the dependencies that characterize texture structure while maintaining subband independence and the multiscale nature of the model. In this case, in addition to individual subband parameters, the basis itself may change with resolution. The first part of this work consisted of an empirical study of the change in subband parameters and basis when the resolution is reduced using various operators. Some results of this study are shown in figure 18 for the scaling operator (which produces no change in the basis) and the Gaussian operator. The study concluded that the basis was quite stable for several operators of interest, in particular Gaussian, and that an analytical treatment would be feasible in the Gaussian case. The second part of the work consisted of a calculation of the change in the subband parameters and basis for the Gaussian operator. Under reasonable approximations, one result is that the wavelet packet basis becomes more decomposed under a reduction of resolution, thus facilitating the analysis of the change of basis.

6.6.2. Indexing of remote sensing images using road networks

Keywords: *database retrieval, graph matching, remote sensing, road network, skeleton*.

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

This Ph.D. is co-supervised by Henri Maître, deputy director of École Nationale Supérieure des Télécommunications, Paris [http://www.tsi.enst.fr]. This work has been done as part of ACI QuerySat [http://www.tsi.enst.fr/QuerySat/], and is partly funded by the French Space Agency (CNES).

The growing need for semantically accurate retrieval from large remote sensing image archives demands a precise and robust characterization of the semantics of the images in the archive. Road networks can be used

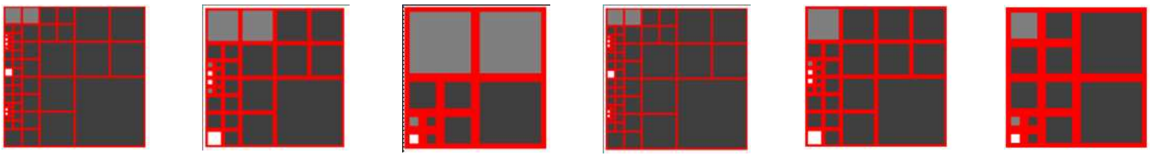


Figure 18. Change of adaptive wavelet packet basis and subband type (Gaussian, grey; generalized Gaussian, black; bimodal, white) with resolution change. Left-hand three images: scaling operator; right-hand three images: Gaussian operator. Resolution decreases by factor of two from one image to its right-hand neighbour, which should be compared to the top-left quadrant of its predecessor.

to characterize certain types of semantics, and consequently can be used to retrieve images. They can be used to position an image geographically in a way that is invariant to detector type and other confounding factors, and to characterize certain types of environment, for example urban areas, via statistics computed from the network. To use road networks in this way has several pre-requisites: the road network must be extracted with adequate precision from the original images [18], [11]; it must be converted into a representation suitable for matching to other road networks or for clustering; and suitable matching and clustering algorithms must be developed. This work studies the latter two elements. The results will be tested using two image retrieval systems available to ACI QuerySat: the IKONA system [http://www-rocq.inria.fr/imedia/ikona/] developed by the INRIA Imedia project-team, and the retrieval system at ENST, which operates in a similar manner to the German Space Agency (DLR) KIM system [http://isis.dlr.de/mining/].

To allow the maximum flexibility, the outputs of the extraction algorithms are converted to a common representation: an undirected graph, with special nodes representing road extremities and junctions, and strings of standard nodes representing roads. The nodes and arcs can be decorated with geometric and image information. The output of [18] is the distance function of the region corresponding to the road network, from which a skeleton graph is computed using [50], but adapted to allow for non-connected and multiply connected regions. The output of [11] is a collection of line segments. After dilation with a small structuring element and computation of the distance function, [50] can again be applied. Some results are shown in figure 19. The computation of appropriate statistics and probabilistic graph matching and graph clustering algorithms based on retrieval scenarios provided by the French National Geographic Institute (IGN) and others is work in progress.

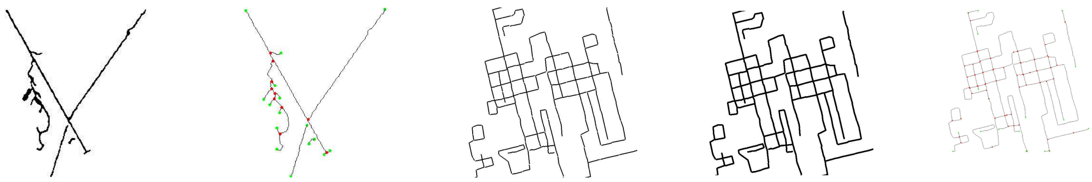


Figure 19. From the left: extracted road network; its graph representation; extracted road network; image dilated with a 3×3 mask; its graph representation.

6.7. ACI NIM Multim

6.7.1. Multi-spectral image restoration and decomposition

Keywords: *correlation, geometry, multi-spectral image, texture, total variation.*

Participants: Pierre Weiss, Laure Blanc-Féraud, Gilles Aubert.

This work is being done as part of ACI Multim [http://www-syscom.univ-mlv.fr/ACI/].

Multi-spectral images appear in a growing number of applications. This is due to the fact that using the radiometric properties of objects permits a more precise analysis. Such images may come from cameras, satellites, or microscopes, to give some examples. These detectors introduce distortions that are detrimental to tasks like segmentation and recognition. The easiest way to restore multi-spectral images is to use classical algorithms designed for gray level images on each channel separately. This approach is clearly not optimal, since the channels are correlated.

The aim of this work is first to discover the relations that exist between the different channels, and then to introduce new energies for restoration and decomposition that will take these relations into account. The first models are based on the hypothesis that the orientations of the level lines of the different channels are the same. Figure 20 shows the difference between a channel-by-channel approach, and an approach that takes into account the relations between the channels.

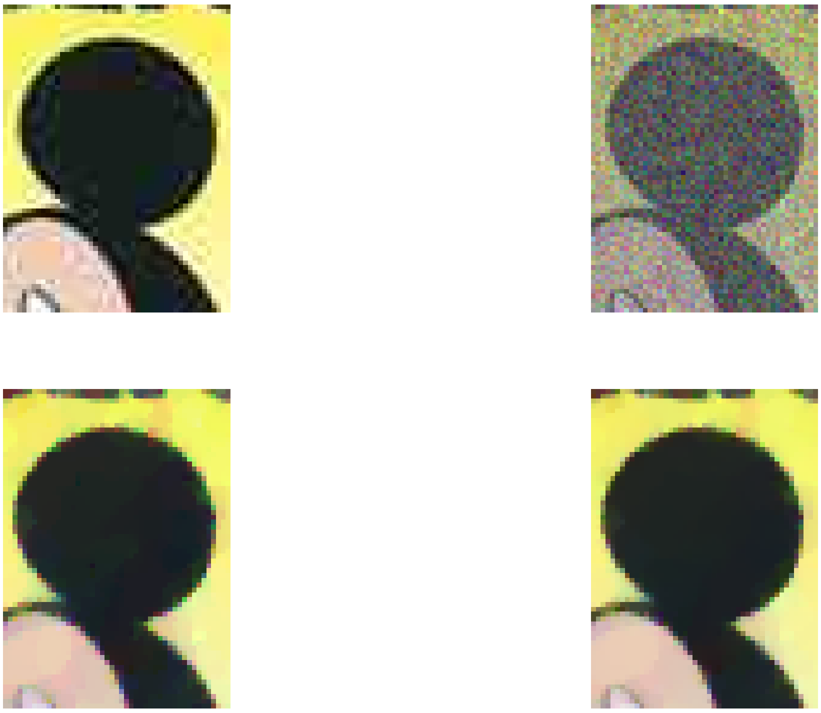


Figure 20. Top-left: original image; top-right: image with additive white Gaussian noise; bottom-left: restored image using the Rudin-Osher-Fatemi model channel by channel; bottom-right: restored image using the Rudin-Osher-Fatemi model with inter-channel correlations.

6.8. Application to astrophysics

6.8.1. Detection of cosmic filaments using the 'Quality Candy' model

Keywords: *'Quality Candy' model, cosmic filaments, marked point process*.

Participants: Pierre Gernez, Xavier Descombes, Josiane Zerubia.

This internship was co-supervised by Eric Slezak and Albert Bijaoui from the Nice Cote d'Azur Observatory [http://www.obs-nice.fr/accueil/english/index.html]. It was funded by INRIA COLORS project FIGARO [http://www-sop.inria.fr/ariana/personnel/Xavier.Descombes/FIGARO.html].

Beyond three hundred billion light-years, the cosmos can be seen as a gas of galaxies, uniformly distributed and isotropically moving. At smaller distances, astronomical observations have shown that the distribution of matter in the Universe is not so homogeneous. Galaxies cluster in long structures, called filaments, with huge voids between them. The filaments, which only represent about 10% of the volume of the Universe, are organized in a complex three-dimensional web-like network. This work concerns the extraction of such networks from astronomical images. To do this, we have adapted a stochastic model initially developed for road extraction from satellite images [11]: the 'Quality Candy' Model. The approach models the filaments by a configuration of connected line segments. This approximation is optimized through a simulated annealing algorithm which minimizes the geometrical and physical constraints corresponding to the filament network we want to detect. A result of filament extraction from a galaxy map is shown in figure 21. The network extracted matches astronomical expectations. This is the first time that filaments have been extracted directly from galaxy maps obtained from astronomical surveys.

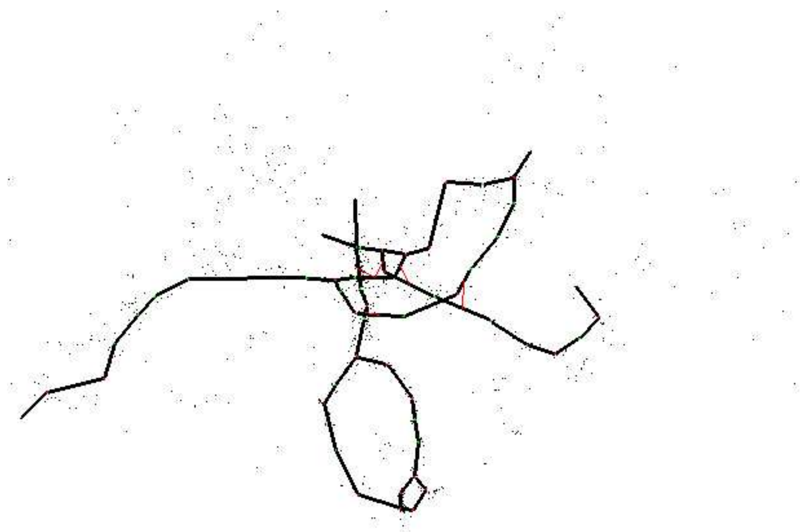


Figure 21. Galactic filaments extracted from a galaxy map provided by the Center for Astrophysics, Harvard.

6.9. Applications to biology

6.9.1. Blind deconvolution of biological images using 3D complex wavelets

Keywords: *3D complex wavelets, biological image, blind deconvolution, confocal microscopy, parameter estimation, wide-field microscopy*.

Participants: Praveen Pankajakshan, Laure Blanc-Feraud, Josiane Zerubia.

This is joint work with the Pasteur Institute, Paris (J.C. Olivo-Marin, B. Zhang) [http://www.pasteur.fr/english.html], the Weizmann Institute (Z. Kam) [http://www.weizmann.ac.il/] and Technion (A. Feuer) [http://www.technion.ac.il/], Israel. It is partly funded by the P2R Franco-Israeli collaborative programme and by the INRIA internship programme (IIT Roorkee).

The confocal laser scanning microscope (CLSM) is an optical fluorescence microscope associated to a laser that scans the specimen in 3D and uses a pinhole to reject most out-of-focus light. The ability of CLSM to image optical sections of thick specimens explains its rapidly increasing use in biological research. Nevertheless, the quality of confocal microscopy images suffers from two basic physical limitations. First, out-of-focus blur due to the diffraction-limited nature of optical microscopy remains substantial, even though it is reduced compared to wide-field microscopy. Second, the confocal pinhole drastically reduces the amount of light detected by the photomultiplier, leading to Poisson noise. The images produced by CLSM can therefore benefit from postprocessing by deconvolution methods designed to reduce blur and noise. The Ariana project-team has worked on these methods [9] in collaboration with the Pasteur Institute in Paris and the Weizmann Institute in Israel for three years.

We recently proposed a restoration method based on a 3D complex wavelet decomposition that gives good results in denoising real biological images [29], [40].

The goals of this work are first to extend this denoising method to deconvolution in the 3D complex wavelet domain, and second to estimate the parameters of the Point Spread Function via impulse response modelling of the blur due to physical phenomenona during the acquisition. Tests will be conducted on confocal microscopy images provided by the Pasteur Institute and wide-field microscopy images provided by the Weizmann Institute.

6.9.2. Segmentation and deconvolution of 3D images

Keywords: *3D image processing, Ginzburg-Landau, filament, segmentation, variational method*.

Participants: Alexis Baudour, Laure Blanc-Feraud, Gilles Aubert.

This work is being done in collaboration with Christophe Zimmer from the Pasteur Institute, Paris [http://www.pasteur.fr/english.html]. It is partly funded by a CNRS Math/STIC grant.

Our work currently deals with filament detection in skeletons of cells. These filaments are detected by locally approximating the 2D or 3D image function by its second order Taylor polynomial. The direction of the filament is determined from the Hessian matrix of the Taylor polynomial. This first method is not robust enough in the presence of noise. Thus we have to complete the missing parts of the filaments.

We start from the complex Ginzburg-Landau model, which comes from physics, and which has been used for inpainting singularities whose codimension is higher than one in an image. The filaments are the zero level set of a complex-valued function defined on the 3D space which minimizes the energy derived from the Ginzburg-Landau model. We use variational methods to find this minimum.

7. Contracts and Grants with Industry

7.1. Industrial

7.1.1. Alcatel Alenia Space Cannes

Participants: Ting Peng, Ian Jermyn, Josiane Zerubia [PI].

Road network updating in dense urban areas from very high resolution optical images. Contract in the process of being signed.

7.1.2. Silogic Toulouse

Participants: Olivier Zammit, Xavier Descombes, Josiane Zerubia [PI].

Evaluation of the damage after a forest fire from high resolution satellite images. Contract #1156.

7.1.3. CNES Toulouse

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

Extraction and characterization of line networks in satellite images for retrieval from image databases. Contract #293

7.1.4. IGN Saint Mande

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

Automatic building extraction from digital elevation models. Grant from the French National Geographic Institute (IGN) and the French Space Agency (CNES).

7.1.5. BRGM Orleans

Participants: Alexandre Fournier, Xavier Descombes, Josiane Zerubia [PI].

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

7.1.6. IFN Nogent sur Vernisson

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

Semi-automatic methods for forestry cartography using aerial and high resolution satellite images. Contract in the process of being signed.

7.1.7. DGA/CTA Arcueil

Participants: Alexandre Fournier, Xavier Descombes, Josiane Zerubia [PI].

Target detection through texture perturbation analysis. Grant from the French Defence Agency (DGA) and CNRS.

8. Other Grants and Activities

8.1. Regional

8.1.1. INRIA COLORS project 'FIGARO'

Participants: Pierre Gernez, Xavier Descombes [PI], Josiane Zerubia.

In collaboration with the Nice Côte d'Azur Observatory (A. Bijaoui, E. Slezak), and INRA, Avignon (R. Stoica).

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

Participants: Alexis Baudour, Laure Blanc-Féraud [PI].

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

8.2. National

8.2.1. INRIA ARC project 'MODE de VIE: MODEling and DEtecting Vegetation in Interaction with their Environment'

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

In collaboration with the Digiplante project-team (INRIA Rocquencourt, MAS, AMAP of CIRAD (O. Chassagneux, P.H. Cournède, P. de Reffye)), the MAS laboratory (C. Saguez), and LIAMA, Beijing, China (C. Cassissa, T. Fourcaud, M. Jaeger, V. Prinet). [http://www-sop.inria.fr/ariana/Projets/ModedeVie/MODEdeVIE.html].

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

Participants: Vikram Agrawal, Avik Bhattacharya, Aymen El Ghoul, Ian Jermyn, Xavier Descombes [Ariana PI], Josiane Zerubia.

In collaboration with the Signal and Image Processing laboratory of ENST (M. Campedel, Y. Kyrgyzov, B. Luo, H. Maître, M. Roux), INRIA project-team IMEDIA (O. Besbes, S. Boughorbel, N. Boujemaa, M. Crucianu, M. Ferecatu, V. Gouet) and URISA of Sup'Com Tunis (Z. Belhadj, A. Ben Azza, R. Tebourbi).

8.2.3. ACI NIM 'Multim: Nouvelles méthodes mathématiques pour la restauration d'images multi-canaux'

Participants: Pierre Weiss, Xavier Descombes, Laure Blanc-Féraud [Ariana PI], 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, University Paris V (L. Moisan); INFO-IGM Laboratory, University Marne La Vallée (J.-C. Pesquet); Observatoire Midi Pyrennées/University Paul Sabatier, Toulouse (S. Rocques).

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

Participants: Alexandre Fournier, Xavier Descombes, Josiane Zerubia [PI].

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

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

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

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

8.3. European

8.3.1. Egide 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 (F. Courteille, A. Crouzil, JD Durou, P. Gurdjos) and University La Sapienza, Rome (E. Cristiani, M. Falcone, A. Seghini).

8.3.2. Egide PAI Balaton 'Efficient shape priors for colour textured image segmentation'

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

In collaboration with the University of Szeged, Hungary (P. Horvath, Z. Kato).

8.3.3. EU project IMAVIS

Participants: Peter Horvath, Ian Jermyn, Josiane Zerubia [Ariana PI].

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

8.3.4. EU project MUSCLE

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

The Ariana project-team 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 project-teams. Web site: http://www.muscle-noe.org

8.4. International

8.4.1. ECO-NET 'Méthodes de la Physique statistique pour l'analyse d'image: application à la gestion forestière'

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

In collaboration with the IITP of the Russian Academy of Science (R. Minlos, E. Pechersky, E. Zhizhina) and the Department of Applied Mathematics and Informatics of the Russian-Armenian-Slavonian University of Yerevan (B. Nahapetyan, P. Solakhyan).

8.4.2. 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).

8.4.3. INRIA/USA Initiative

Participants: Ian Jermyn [PI], Josiane Zerubia.

In collaboration with the University of Wisconsin-Madison (R. Nowak) and Duke University (R. Willett).

8.4.4. INRIA/LIAMA Initiative

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

In collaboration with LIAMA, Institute of Automation, Chinese Academy of Sciences (T. Bailloeul, H. BaoGang, G. Cassissa, T. Fourcaud, M. Jaeger, T. Peng and V. Prinet).

8.4.5. INRIA STIC-Tunisia

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

In collaboration with INRIA project-team Imedia (N. Boujemaa, V. Gouet, N, Grira), and URISA of Sup'Com Tunis (Z. Belhadj, A. Ben Azza, S. Bougharel, A. El Ghoul, R. Tebourbi).

8.4.6. P2R Franco-Israeli collaborative programme 'Blind deconvolution in 3D biological microscopy'

Participants: Praveen Pankajackshan, Laure Blanc-Féraud, Josiane Zerubia [PI].

In collaboration with the Pasteur Institute, Paris (J-C. Olivo-Marin, B. Zhang), the Weizmann Institute (Z. Kam) and Technion (A. Feuer), Israel.

9. Dissemination

9.1. Conferences, Seminars, Meetings

- The members of the Ariana project-team participated actively in GdR ISIS and GdR MSPCV.
- The members of the Ariana project-team participated in the INRIA/UNSA Fête de la Science at Parc Valrose in Nice in October. In particular, G. Perrin and J. Zerubia made presentations.
- The Ariana project-team organized numerous seminars in image processing during 2005. Twenty researchers were invited from the following countries: Australia, Canada, France, Hungary, Italy, Russia, the United Kingdom, and the United States. For more information, see the Ariana project-teamweb site.
- As in previous years, members of the Ariana project-team participated actively in the visits to INRIA Sophia Antipolis of students from the Grandes Écoles (École Polytechnique, ENS Cachan, ENPC, Sup'Aéro), and helped students of the Classes Préparatoires with TIPE in France and in Tunisia (IPEST).

- Avik Bhattacharya gave a talk at the ACI QuerySat meeting in February at INRIA Sophia Antipolis. He gave seminars at ENST (TSI Department), Paris, and at INRIA Rocquencourt (project-team IMEDIA), in April. He visited Sup’Com, Tunisia, in May, and gave a seminar. He gave a seminar at ENST (TSI Department), Paris, and visited the French National Geographic Institute (IGN) MATIS Research lab, Saint Mandé, in July. He attended an International Summer School on Pattern Recognition in Plymouth, U.K., in July, and presented his work at IIT Kharagpur in India in August.
- Peter Horvath presented a paper at the Hungarian-Austrian Conference on Image Processing and Pattern Recognition in May in Veszprem, Hungary.
- Florent Lafarge gave talks at the conference GRETSI in Louvain-la-Neuve, Belgium, and at the conference ICIP in Genoa, Italy in September. He visited the German Space Agency (DLR) in Oberpfaffenhofen for the DLR/CNES workshop in November at which he presented his work. In December, he gave seminars at Sztaki (Hungarian Academy of Sciences) and the Catholic University of Budapest. He also visited the University of Szeged where he gave a seminar.
- Guillaume Perrin attended an advancement meeting of the ARC Mode de Vie at INRIA Sophia Antipolis, in March. In June, he participated in a Ph.D. and ARC Mode de Vie advancement meeting at École Centrale Paris (Applied Mathematics Laboratory), Chatenay-Malabry. In September, he participated in a meeting with the French National Forest Inventory (IFN), Nogent sur Vernisson. He gave a talk at the conference ICIP, Genoa, in September, and presented a poster at the conference EMMCVPR, St-Augustine, Florida, in November. He visited École Centrale Paris, Chatenay-Malabry, in December for a Ph.D. and ARC Mode de Vie advancement meeting.
- Marie Rochery gave a talk at the conference ICIP in September in Genoa, Italy.
- Ian Jermyn participated in January in a presentation of the Ariana project-team to the Projects Committee of the I3S laboratory. He presented a paper at the PSIP workshop in Toulouse in January. In March, he presented the Ariana project-team to an industrial and governmental delegation from Bavaria. In April, he attended a meeting of FP6 Network of Excellence MUSCLE in Paris, and made a presentation. In June, he gave an invited talk at GdR ISIS Workshop on Shape, Models and Deformations, at ENST in Paris, and attended the PNTS Long-Wavelength Radar workshop, also at ENST, Paris. In August, he attended a meeting of ACI QuerySat in Rocquencourt, and gave a presentation. In October, he visited the LIAMA institute in Beijing, China, and gave an invited talk at a workshop. While in China, he also attended the conference ICCV, and presented a paper. In December, he attended a meeting of FP6 Network of Excellence MUSCLE at INRIA Rocquencourt, and made a presentation. In December, he visited the University of Szeged, Hungary, and gave a seminar.
- Xavier Descombes gave a seminar at the Strasburg Observatory in March. He was invited by the American Institute of Mathematics to present his work at a workshop in Palo Alto in May. He gave two seminars in June in the context of the Orfeo group and of the 3D optical R&D group at CNES in Paris. He was an invited speaker in a workshop on 3D image processing organized by the SEE and GdR ISIS in Paris in June. He took part in the EUSIPCO conference in September and presented a paper. He attended a Galilee project meeting at the University La Sapienza in Rome in September. He also took part in several meetings of ACI QuerySat and ARC MODE de VIE. In November, an image of a result of his work was used on the cover of Physics Today magazine.
- Laure Blanc-Féraud presented a poster and chaired a session at the conference ICASSP, Philadelphia, in April, and also participated in the General Assembly of GdR ISIS in Batz-sur-Mer. In June, she co-organized the GdR ISIS/GdR MSPC Workshop on Shape, Models and Deformations, a two-day meeting ’From images to 3D models: automatic and assisted extraction’ with GdR ISIS and the SEE/Club 29, and SFPT, all in Paris. In September, she participated in the conference ICIP in Genoa. Also in September, she presented the work of the Ariana project-team to a delegation from the town of Cannes, at INRIA, in connection with the Technopole Image. She visited the Pasteur Institute in Paris twice as part of a collaboration on biological images.

- Josiane Zerubia visited Silogic in Toulouse, and attended a meeting on orbital systems organized by the French Space Agency (CNES) in Labége, both in February. Also in February, she presented the work of the Ariana project-team on biological images to an American-Israeli delegation of the Hadassah Foundation. In March, she attended the first meeting of the ARC MODE de VIE in Sophia Antipolis. Also in March, she went twice to Toulouse to evaluate the R&T of the French Space Agency (CNES), and to participate, as one of 30 experts of CERT, in the writing of a report on the subject sent to the President of CNES. Still in March, she visited the Pasteur Institute in Paris as part of the P2R Franco-Israeli collaboration. She also attended, in March, the two-day ‘Journées de la Recherche de l’IGN’ in Saint Mandé. In April, she attended a meeting of FP6 Network of Excellence MUSCLE in Paris. In June, she attended an ORFEO meeting at the French Space Agency (CNES) in Paris, and a P2R Franco-Israeli collaborative programme meeting at the Pasteur Institute, Paris. In August, she attended a meeting of ACI QuerySat in Rocquencourt. In September, she attended the conference ICIP in Genoa, Italy, where she had four papers and was chair of a session. Also in Genoa, she co-chaired a meeting of the Editorial Board of the IEEE TIP, and had a meeting with the General Chair of ICASSP06 as part of the ICASSP06 Organizing Committee. In September, she attended a meeting on 3D DEM from high resolution images co-organized by CNES, IGN, ONERA, and INRIA in Toulouse. In October, she attended a meeting on ‘security’ at the College de France in Paris. In November, she attended a meeting with Silogic in Sophia Antipolis. In December, she attended another meeting with Silogic, this time in Toulouse, where she also visited the C-S Remote Sensing Laboratory to do some bench-marking of their research as an expert.

9.2. Refereeing

- G. Perrin was a referee for SFPT (Revue Française de Photogrammétrie et de Télédétection).
- Marie Rochery was a referee for IEEE TIP.
- Ian Jermyn was a referee for CVIU, JMLR, IEEE TIP, and IEEE TPAMI, and for the conferences CVPR05, ICIP05, and SITIS06.
- Xavier Descombes was a referee for IEEE TIP, IEEE PAMI, IEEE TMI, IEEE TGRS, IJCV, Traitement du Signal, and SFPT (Revue Française de Photogrammétrie et de Télédétection), and for the conferences ICIP05 and GRETSI05.
- Laure Blanc-Féraud was a referee for IEEE TIP and Machine Vision and Applications, and for the conferences ICIP05, ACIVS05, and GRETSI05.
- Josiane Zerubia was a referee for IJCV, IEEE TIP, and SFPT (Revue Française de Photogrammétrie et de Télédétection), and for the conferences ICASSP05, ICIP05, EMMCVPR05, SPIE-ISPRS ‘Image and Signal Processing for Remote Sensing’05, GRETSI05, TAIMA05, and for the Special Sessions of ICASSP06.

9.3. Organization

- Ian Jermyn is a member of the Comité de Suivi Doctoral at INRIA Sophia Antipolis. He is the coordinator of an Egide PAI Balaton collaboration with the University of Szeged, Hungary, and coordinator of the Ariana project-team’s efforts within the FP6 Network of Excellence MUSCLE. He is the Ariana coordinator for an INRIA STIC-Tunisia project. He is a member of the Technical Committee for EUSIPCO06. He was a member of the programme committee for SITIS06, and is a member of the programme committees for IFMIP06, IEEE POCV06, and the ECCV06 workshop ‘Computation Intensive Methods for Analysis of Vision Data’. He was a reviewer for the Chinese side of a joint French-Chinese Ph.D. at the LIAMA Institute, Beijing, China, and committee member for the French side.

- Xavier Descombes is the Ariana project-team coordinator for the INRIA ACI QuerySat. He is principal investigator for the COLORS action FIGARO, for ARC MODE de VIE and for an ECO-NET project. He is member of the ORFEO group (CNES) and of the R&T 3D Optique working group of CNES. He was an expert evaluator for ACI Masses de Données, for the Israel Science Foundation and for an industrial proposal for ANVAR, France. He is member of the scientific committee of PopSud and head of the Learning and Statistics group of GdR ISIS. He is a member of the technical committees for SITIS06 and RFIA06. He was nominated as expert 'comité multi' of CNRS. He is member of the thesis guidance committee for a Ph.D. at the Agricultural and Environmental Engineering Research Centre (CEMAGREF) ENGREF in Montpellier. He was a reviewer for three Ph.D.'s, at the University Paul Sabatier, Toulouse, at the University Paris XI, and at LSS (Sup'Elec).
- Laure Blanc-Féraud is the Ariana project-team coordinator for the INRIA ACI MultiNIM and for the CNRS Math/STIC project. She is a member of the managing committee of GdR ISIS, and vice-director of I3S laboratory (CNRS/UNSA). She is a member of the scientific committee of the ED STIC in Sophia Antipolis, a member of Section 61 of the Scientific Council of the University of Nice-Sophia Antipolis, and a member of the COLORS committee at INRIA Sophia Antipolis. She was an expert evaluator for a research proposal for ECOS-Sud, Uruguay. She was a committee member for three Ph.D.'s, one at the University Paris V, and two at the University of Nice-Sophia Antipolis. She was a reviewer for two Ph.D.'s, at the University Orsay (L2S) and at the University La Sapienza in Rome, and a reviewer for two HdR's, at the University Orsay (L2S), and at the INPG (LIS), Grenoble.
- Josiane Zerubia is an IEEE Fellow. She is a member of the Biological Image and Signal Processing Technical Committee of the IEEE Signal Processing Society. She is an Area Editor for IEEE TIP, and she is a member of the Editorial Boards of IJCV and the Revue Française de Photogrammétrie et de Télédétection of SFPT. She was president of a session at ICIP05 in Genoa. She was a programme committee member for ICASSP05, ICIP05, EMMCVPR05, SPIE-ISPRS 'Image and Signal Processing for Remote Sensing'05, and TAIMA05. Together with Patrick Flandrin from ENS Lyon, she is co-organizing the Special Sessions of ICASSP06. She represented INRIA at the Direction Technique du Ministère de la Recherche for high resolution imagery and remote sensing. She was a member of the CERT Committee, as one of 30 experts nominated by the Director of the French Space Agency (CNES) to evaluate the future research and development of CNES. She was a member of the evaluation boards for the Israel Science Foundation and for the Indo-Swiss Research Programme. She is principal investigator for the PNTS initiative with the French Geographical Survey (BRGM). She is the Ariana project-team coordinator for Fifth Framework European Union project IMAVIS. She is principal investigator for the NATO/Russia Collaborative Linkage Grant, for the INRIA/LIAMA initiative, and for the P2R Franco-Israeli collaborative programme. She is also principal investigator for the seven current industrial contracts and grants of the Ariana project-team. She is a member of the ORFEO group (CNES) and of the R&T 3D Optique working group of CNES. She organized the ACI QuerySat meeting at INRIA Sophia Antipolis in February involving ENST, Sup'Com Tunis, and INRIA project-teams Imedia and Ariana. She was a reviewer for a Ph.D. at ENST in Paris, a member of a Ph.D. committee at the University of Nice-Sophia Antipolis, and president of an HdR committee at the University Paul Sabatier/INPT (CESBIO) in Toulouse.

9.4. Teaching

- Alexis Baudour was lab instructor for 'Mathematics for digital images' (45h), at the IUT of Nice Sophia Antipolis.
- Peter Horvath was lab instructor for 'Introduction to programming (tutorial)' (70 h) at the University of Szeged, Hungary.

- Florent Lafarge was lab instructor for ‘Computer science’ (90 h) at the University Paris V, and for ‘Image processing’ (8h) at ENSG, University Marne-La Vallée.
- Marie Rochery was lab instructor for ‘Digital signal processing’ (66 h) at ESINSA.
- Pierre Weiss was a lab instructor for ‘Combinatory logic’ (60h) at ESINSA.
- Ian Jermyn taught ‘Image analysis’ (6h) at ESINSA, and ‘Filtering and segmentation of space imagery’ (2.5h) at Sup’Aéro.
- Xavier Descombes taught a module in ‘Image Processing’ (15h) at ESINSA and ‘Filtering and segmentation of space imagery’ (17.5h) at Sup’Aéro.
- Laure Blanc-Féraud taught ‘Image restoration’ (15h) for the Masters 2 course IGMMV and ‘Mathematics for digital images’ (30h) at the IUT of Nice Sophia Antipolis.
- Josiane Zerubia taught the module ‘Stochastic models in image processing’ for the Masters 2 course IGMMV at the University of Nice-Sophia Antipolis (15h). She was director of the course ‘Filtering and segmentation of space imagery’ at Sup’Aéro (40h, of which 20h taught), where she also taught as part of the course ‘Variational methods for image processing’ (2.5h).

9.5. PhDs

9.5.1. In progress

1. Alexis Baudour: ‘Segmentation et déconvolution d’images 3D’, University of Nice-Sophia Antipolis. Defence expected in 2008.
2. Avik Bhattacharya: ‘Indexation d’images satellitaires par des informations structurelles’, École Nationale Supérieure de Télécommunications, Paris. Defence expected in 2007.
3. Alexandre Fournier: ‘Détection de cibles par une analyse des perturbations de la texure’, École Nationale Supérieure d’Aeronautique et de l’Espace, Toulouse. Defence expected in 2008.
4. Peter Horvath: ‘Image segmentation with shape priors’, University of Nice-Sophia Antipolis and University of Szeged, Hungary. Defence expected in 2007.
5. Florent Lafarge: ‘Reconstruction 3D de zones urbaines denses à partir d’images satellitaires haute résolution’, École Nationale Supérieure des Mines, Paris. Defence expected in 2007.
6. Ting Peng: ‘Variational models for road network updating in dense urban areas from very high resolution optical images’, University of Nice-Sophia Antipolis and the Sino-French Laboratory in Informatics, Automation and Applied Mathematics, Institute of Automation, Chinese Academy of Sciences, Beijing, China. Defence expected in 2008.
7. Guillaume Perrin: ‘Extraction de houppiers par processus ponctuels marqués’, École Centrale Paris. Defence expected in 2006.
8. Pierre Weiss: ‘Décomposition d’images multispectrales’, University of Nice-Sophia Antipolis. Defence expected in 2008.
9. Olivier Zammit: ‘Evaluation des dégats après un feu de forêt à partir d’images satellitaires’, University of Nice-Sophia Antipolis. Defence expected in 2008.

9.5.2. Defended in 2005

1. Marie Rochery: ‘Contours actifs d’ordre supérieur et leur application à la détection de linéiques dans des images de télédétection’, University of Nice-Sophia Antipolis. Defended September 28.
2. Emmanuel Villeger: ‘Constance de largeur et déocclusion dans les images digitales’, University of Nice-Sophia Antipolis. Defended December 6.

9.6. Prizes

- Jean-François Aujol (Ariana Ph.D. student, defended June 2004) was awarded the 2005 Thesis Prize of the club EAA, Signal and Image section, for his thesis entitled 'Contribution à l'analyse de textures en traitement d'images par méthodes variationnelles et équations aux dérivées partielles'.
- For some years, the Ariana project-team has been a member of the Image and Video Understanding ERCIM Working Group. This Working Group gave rise to the European Union Network of Excellence MUSCLE, a projet of 42 partners working on 'Multimedia Understanding through Semantics, Computation, and LEarning'. As a consequence of this and other achievements, the Working Group was awarded the ERCIM Working Group Award in May 2005.

10. Bibliography

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[1] M. ROCHERY. *Contours actifs d'ordre supérieur et leur application à la détection de linéiques dans des images de télédétection*, Ph. D. Thesis, Universite de Nice Sophia Antipolis, September 2005.

[2] E. VILLÉGER. *Constance de largeur et désocclusion dans les images digitales*, Ph. D. Thesis, Universite de Nice Sophia Antipolis, December 2005.

Articles in refereed journals and book chapters

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