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Project-Team Ariana

Inverse Problems in Earth Observation and Cartography

Sophia Antipolis - Méditerranée

THEME COG

Activity Report

2008

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2. Overall Objectives

2.1. Introduction

Ariana is a joint project-team of INRIA, and of CNRS and the University of Nice-Sophia Antipolis via the Computer Science, Signals and Systems Laboratory (I3S) in Sophia Antipolis (UMR 6070). It was created in 1998.

The Ariana project-team aims to provide image processing tools to aid in the solution of inverse problems arising in a wide range of concrete applications, mainly 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. Certain applications in biological and medical imaging are also considered, using the same tools as in remote sensing.

2.2. Highlights of the year

- Associated Team ODESSA was created on January 1, 2008 [http://www-sop.inria.fr/ariana/Projets/Odessa/index.html]. The project is dedicated to the use of stochastic dynamics such as diffusion and birth and death processes for the detection of objects in aerial and high-resolution satellite images. It will strongly enhance the collaboration between the Ariana project-team and the Dobrushin Laboratory of the Institute for Information Transmission Problems in Moscow and the Pattern Recognition group in Minsk University.
- Josiane Zerubia was part of the Organizing Committee of IEEE ISBI'08 in Paris sponsored by INRIA.

  http://www.biomedicalimaging.org/2008/.
- Xavier Descombes was awarded a prize by the journal 'La Recherche' in the field 'Human Health'. The prize was for work done in collaboration with Franck Plouraboué and Laurent Risser (IMFT Toulouse), Caroline Fonta (Cerco Toulouse) and Peter Cloetens (ESRF Grenoble).

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.

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

4.2. Segmentation and classification

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

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

4.3. Extraction of structures

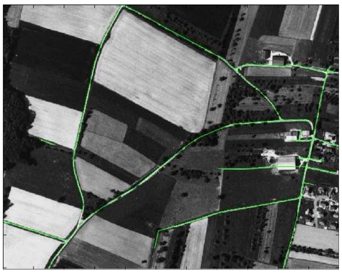
As the resolution of remote sensing imagery increases, so the full complexity of the scene comes to the fore. What was once a texture is now revealed to be, for example, an arrangement of individual houses, a road network, or a number of separate trees. Many new applications are created by the availability 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.

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.



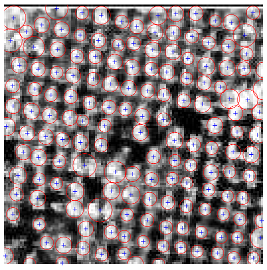
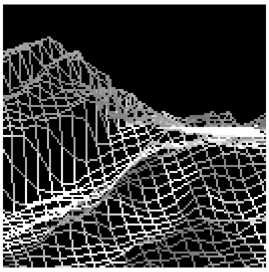


Figure 3. Left: road network extraction; right: tree extraction.



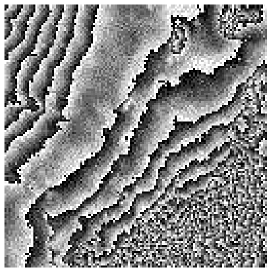


Figure 4. Left: DEM; right: interferometry.

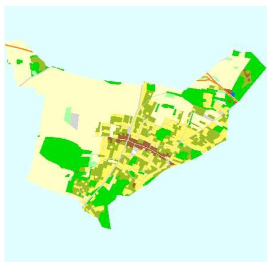


Figure 5. Image registration for the evaluation of retrieval systems. Left: mosaicked aerial image data; right: registered ground truth classification.

5. Software

5.1. Software

5.1.1. Transfers

The software Blinde V2.0 was transferred to the German Space Agency (DLR). The software GRENAT V2.0 was transferred to CURAT (Cocody University of Abidjan).

5.1.2. Deposits

The software MISSAR V2.0 was deposited with the APP in December 2008. It deals with the statistical modelling of high-resolution Synthetic Aperture Radar (SAR) images. It was developed in collaboration with G. Moser and S. Serpico from the University of Genoa in Italy, and V. Krylov from Moscow State University in Russia.

5.1.3. Code library for marked point processes

Keywords: *library*, *marked point process*.

Participants: Bayrem Tounsi, Xavier Descombes [contact].

In this work, we are developing a library in C++ for manipulating marked point processes for image analysis. We have developed routines for models based on discs and ellipses. These models include our previous work on tree detection and flamingo counting. Different kernels for defining an RJMCMC scheme in order to optimize the model have been included in the library. We are currently addressing models based on segments and rectangles.

5.1.4. User interface for tree crown extraction

Keywords: *marked point process*, *tree crown extraction*, *user interface*.

Participants: Neismon Fahé, Xavier Descombes, Josiane Zerubia [contact].

This work is funded by the French National Forest Inventory (IFN) [http://www.ifn.fr/]. It was done in collaboration with Guillaume Perrin, a former Ariana Ph.D. student (see the 2005 and 2006 activity reports).

In this work, we developed a user interface for the software GRENAT, which deals with tree crown extraction using marked point processes (see figure 6). To achieve its goal, the software needs many parameters to be set, so the first aim of the user interface was to provide a user-friendly way to handle these. The second goal was to enable an automatic mode for extraction and data processing in GRENAT. The software still needs to be evaluated on large image sets and for many sets of parameter values; an automatic mode would facilitate this process. Further features are scheduled to be added to the project. The software GRENAT exists as a stand-alone program, and the user interface is a layer interacting with it. The tools involved in the development are for the most part web technologies such as Ajax (Asynchronous javascript and XML), PHP and java.

6. New Results

6.1. Probabilistic models

6.1.1. A new birth and death algorithm for road detection

Keywords: *diffusion*, *marked point process*, *road detection*.

Participant: Xavier Descombes [contact].

This study was partially supported by INRIA Associated Team ODESSA and the Poncelet Laboratory. It was conducted in collaboration with Pierre Cariou and Prof. E. Zhizhina, IIPT Moscow (Russian Academy of Sciences) within the Poncelet Laboratory [http://www.mccme.ru/lifr/].

Figure 6. Some results obtained with the software GRENAT. (© IFN/INRIA)

We have generalized our previous continuous birth and death dynamics to the case of road network extraction. We previously defined a continuous birth and death process which, after discretization, can be interpreted as a multiple birth and death algorithm [5]. Each iteration is divided into three steps. The first step consists of generating a configuration of objects which is added to the current configuration. In the second step, the different objects are sorted into a list according to the value of the data term. Finally, in the death step, each object, taken in list order, is killed with a probability depending on the posterior model. We have applied this framework to the context of road network detection. The road network is defined by interacting points along the roads. An energy which favours network connectivity was defined. Preliminary results have been obtained on aerial and satellite images.

6.1.2. Shape descriptors based on the shape entropy

Keywords: *entropy*, *shape*.

Participant: Xavier Descombes [contact].

This study was supported by INRIA Associated Team ODESSA. It was conducted in collaboration with Serguei Komech, IIPT Moscow (Russian Academy of Sciences).

In this work, we address shape classification. We consider a definition of shape entropy which consists of evaluating the area ratio between a given shape after a dilation and the original shape when the dilation size tends to zero. This parameter can be interpreted as a descriptor of shape smoothness. We have proposed a discretization scheme to estimate this descriptor. This work, still in progress, has provided some preliminary results. We are studying the effect of different diffeomorphisms on the shape entropy and their relevance for defining several shape descriptors for classifying shapes.

6.1.3. 3D building reconstruction by solving the direct problem

Keywords: *3D reconstruction*, *birth and death dynamics*, *buildings*.

Participant: Xavier Descombes [contact].

This study was supported by INRIA Associated Team ODESSA and an ECONET project. It was conducted in collaboration with P. Lukashevich, A. Krauchonak, and B. Zalesky from the UIIP in Minsk, and E. Zhizhina from the IITP in Moscow and J.D. Durou from IRIT in Toulouse.

In this project, we aim at reconstructing buildings in 3D from one or several aerial or satellite images. The main idea is to avoid solving the so-called inverse problem. We will simulate configurations of buildings and test them with respect to the data. The generation of configurations will be done by a multiple birth and death dynamics. A Gibbs point process will be defined including prior information about building configurations. To define the data term, the building configuration will be projected into the data plane(s), using models of shading and shadows. This projection will be performed using OpenGL for a fast 2D rendering of the scene. The first task consisted of modelling the shadows depending on the orientation of the buildings and the position of the sun. Preliminary results have been obtained on synthetic data.

6.1.4. Shape recognition for scene analysis

Keywords: *birth-and-death dynamics*, *colour infrared aerial images*, *differential geometry*, *elastic metric*, *image segmentation*, *point processes*, *shape space*.

Participants: Maria S. Kulikova, Xavier Descombes, Josiane Zerubia [contact].

This Ph.D. is funded by an MESR and also supported by Associated Team SHAPES [http://www-sop.inria.fr/ariana/Projets/Shapes/].

Part of this work was done in collaboration with Dr. E. Zhizhina and Prof. R. Minlos from the Institute of Information Transmission Problems (IITP, Russian Academy of Sciences, Russia) within Associated Team ODESSA.

This research work addresses the problem of image analysis using various geometric shapes represented in the image. To tackle this problem a stochastic approach is considered based on object processes, which are based on marked point processes (MPP). This allows us to take into account geometrical information, *i.e.* the shape of an object. The main point is to define a probability model in the space of shapes in order to generate random samples of different classes of objects.

Figure 7 shows some examples of synthetic tree crowns, generated randomly from a multidimensional normal distribution.

Figure 7. Left: mean shape of the tree crown class. Right: sampled tree crown shapes.

This tool is used to extract a configuration of objects from the image by minimizing an associated energy functional using a birth-and-death dynamics. The density associated with the ‘shapes’ MPP is defined with respect to the Poisson measure. The energy functional has a prior term introducing constraints on the objects and their interactions, and a data term that matches a shape and an object using the image information of the latter.

6.1.5. Parameter estimation for marked point processes

Keywords: *marked point processes*, *parameter estimation*, *pseudo-likelihood*, *remote sensing*, *stochastic EM*.

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

This research was supported by an INRIA postdoc fellowship and by the French Space Agency (CNES).

Marked point processes are useful for image processing problems such as object extraction. Typical applications include the detection and counting of tree crowns or flamingos in remote sensing images. In this work, we propose a strategy for estimating the parameters associated with such a marked point process. This strategy can be divided into two steps:

1. the introduction of a prior on the parameters;
2. estimation using stochastic EM.

The first step consists of analyzing the identifiability of the parameters of marked point processes. It allows us to derive adequate models and then to introduce appropriate priors on the parameters to be estimated. The second step deals with estimation itself: a stochastic EM method based on the pseudo-likelihood of the process. Finally, this work allows us to develop quasi-unsupervised object detection procedures.

6.1.6. Stochastic modelling of 3D objects applied to penguin detection and counting

Keywords: *3D object detection*, *king penguin*, *marked point process*, *multiple birth and death method*.

Participants: Ahmed Gamal-Eldin, Giovanni Gherdovich, Xavier Descombes, Josiane Zerubia [contact].

This work is being performed in collaboration with Dr. Michel Gauthier-Clerc from La Tour du Valat (http://www.tourduvalat.org/) and Prof. Yvon Le Maho from Institut Hubert Curien (http://iphc.in2p3.fr/).

During the last ten years, stochastic geometry based on marked point processes has been developed for the detection of 2D objects in images, starting with roads, buildings [10], and trees, and most recently, flamingos [17]. Imaging of these objects was orthonormal, so that 3D objects could be treated as 2D. These models were developed via various Masters and Ph.D. theses in the Ariana project-team. the results of which demonstrated their efficacity. This success provided the encouragement to go further with these models, to seek cases where the images include perspective, and hence where the objects of interest have to be modelled in 3D, including all the associated effects: object occlusion, shadows, depth, etc.

The applications of such algorithms would be many. As a first step, we concentrate on the detection and counting of King Penguins from images provided by the researchers of La Tour du Valat (see figure 8). We also work on Emperor and Adelie Penguins with the Institut Hubert Curien. We defined an imaging protocol for imaging both the penguins and the landscape, because a digital elevation model is not available for Possession island where the penguins live. We are currently working on modelling a penguin as a simple 3D object such as an ellipsoid, a cylinder, or a half ellipsoid, looking for a good trade-off between the precision of the geometric model and computational complexity. The detection of the objects is based on a marked point process.

6.1.7. Object detection in high resolution radar images

Keywords: *high resolution*, *marked point process*, *radar images*.

Participants: Fatih Arslan, Xavier Descombes, Josiane Zerubia [contact].

This study was partially supported by the COLOR project ODEUR in collaboration with ONERA Salon de Provence http://www.onera.fr/salon-de-provence/index.php.

This project is an application of our previously developed framework for object detection using a marked point process and multiple birth and death dynamics. The originality of this work is the use of high resolution radar images (RAMSES) with a significant level of noise. Using these images, we addressed the problem of the detection of elliptic objects. The mean object size was significantly larger than in our previous applications, demanding huge computation time. To address this problem with a computation time compatible with the application, we developed a multi-scale approach. This multi-scale framework is applied only for computing the birth map, which leads the stochastic search in the configuration space. The optimization itself is performed on the initial scale, to avoid loss of precision. Preliminary results have been obtained on two different problems, namely the detection of oil tanks and the detection of olive trees. The algorithm has been tested on high resolution radar images provided by ONERA Salon de Provence.

Figure 8. This image, provided Tour du Valat, shows part of the penguin colony living on Possession Island.

6.1.8. Optimization of the pupil configuration in an OAS imaging system

Keywords: *numerical integration*, *optical aperture synthesis*, *stochastic optimization*.

Participants: Giovanni Gherdovich, Xavier Descombes [contact].

This research was supported by a contract funded by Thales Alenia Space.

By 'Optical Aperture Synthesis' (OAS), we mean the design of optical systems equipped with more than one pupil. Given an upper bound on the diameter of the pupils due to technological constraints, an OAS system covers Fourier space better than a single pupil system. In this work we consider the problem of minimizing the integral distance from a target Optical Transfer Function (OTF), *i.e.* finding the optimal positioning of an array of pupils, with a Markov Chain Monte Carlo technique. Only the ideal case with no aberrations is considered. The main contribution of this work is to provide empirical evidence that the Adaptive Simpson Quadrature proposed by Gander and Gautschi is well suited to the evaluation of this distance and its derivatives, with respect to both accuracy and computation time.

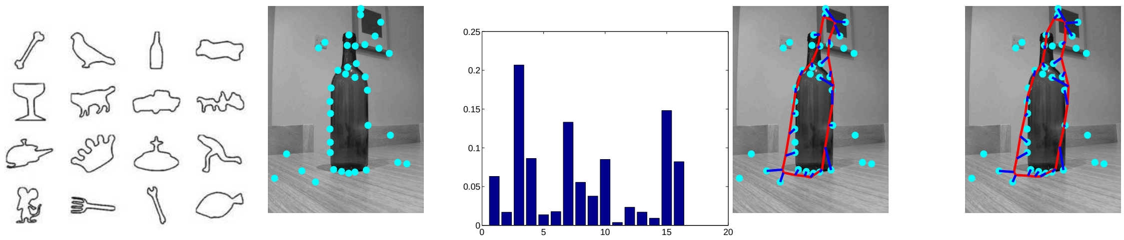
6.1.9. Looking for shapes in two-dimensional point clouds

Keywords: *Bayesian*, *Monte-Carlo*, *classification*, *clutter*, *matching*, *metric*, *point cloud*, *prior*, *registration*, *saddle point*, *sampling*, *shape*.

Participant: Ian Jermyn [contact].

This work was supported by and performed as part of INRIA Associate Team SHAPES in collaboration with Prof. Srivastava of Florida State University [http://www-sop.inria.fr/ariana/Projets/Shapes/].

In this work [13], we study the problem of identifying shape classes in 2D point clouds. These clouds contain sub-sampled contours corrupted by clutter and observation noise. This kind of data can result, for example, from a simple pre-processing of images containing objects with prominent boundaries. Taking an analysis-by-synthesis approach, we simulate high-probability configurations of sampled contours using models learnt from training data in order to evaluate the given test data. We develop statistical models of sources of (nuisance) variability: (i) shape variations of contours within classes; (ii) variability in sampling continuous curves into points; (iii) pose and scale variability; (iv) observation noise; and (v) points introduced by clutter. Sub-samplings of closed curves into a finite number of points are represented by positive diffeomorphisms of the unit circle. We derive probability models on these functions using their square-root forms and the Fisher-Rao metric. Using a Monte Carlo approach, we simulate configurations from a joint prior on the shape-sample space and compare them to the data using a likelihood function. Average likelihoods of simulated configurations lead to estimates of the posterior probabilities of different classes and, hence, to Bayesian classification. An example is shown in figure 9.



(a) (b) (c) (d) (e)

Figure 9. (a): 16 shape classes; (b): original image and detected primitives; (c): estimated posterior probabilities for the 16 shape classes (numbered from left to right then top to bottom); (d) and (e): two examples of high-probability matches.

6.1.10. Detecting and Clustering Changes Due to Human Activity in Optical Aerial Images

Keywords: *aerial images*, *building detection*, *change classification*, *marked point process*.

Participants: Csaba Benedek, Josiane Zerubia [contact].

This research is supported by an INRIA postdoc fellowship and by Associated Team SHAPES [http://www-sop.inria.fr/ariana/Projets/Shapes/].

Aerial image databases contain rich and continuously augmenting content acquired over the few last decades. Automatic image indexing by detecting and clustering the changes in images of the same area taken at different times may be crucial for quick and up-to-date content retrieval in several applications. Although most previous studies have dealt with SAR/infrared imagery, the significance of handling purely optical photos is also increasing. The research goal is the development of advanced stochastic models for the detection of changes related to human activity (new, altered, or vanished roads, buildings, ploughed fields) in aerial images taken with several months or years time difference. The images include both rural and urban areas. Due to seasonal changes, changing illumination, and the results of irrelevant human intervention (such as crop rotation in agricultural fields), the use of RGB sensor information alone renders this a highly challenging task. This research work includes the design, implementation, and testing of advanced Markovian segmentation models for change detection and change classification. We intend to take advantage of the most recent probabilistic techniques, like Mixed Markov models, Conditional and Discriminative Random Fields, and Marked Point Processes. Note that the above models simultaneously take into account the consistency of local features and segmentation labels, spatial feature correlation, spatial smoothness of the cluster map, and a configurable relationship between the different features/processing components. For the above reasons, we expect from the resulting methods notable performance improvement versus previous approaches.

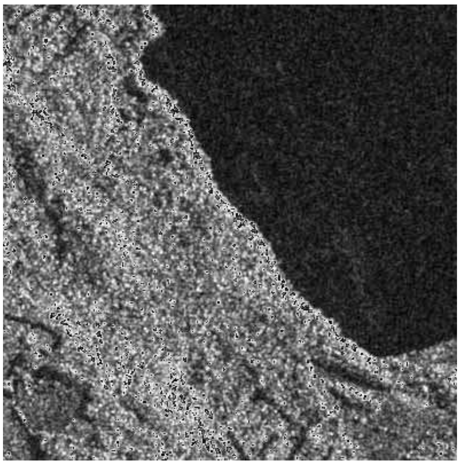
6.1.11. Modelling the statistics of high resolution SAR images

Keywords: *finite mixture models*, *parametric estimation*, *probability density function estimation*, *stochastic expectation maximization (SEM)*, *synthetic aperture radar (SAR)*.

Participants: Vladimir Krylov, Josiane Zerubia [contact].

This research was done in collaboration with G. Moser and S. B. Serpico of the University of Genoa, Italy, with the financial support of the French Space Agency (CNES). The data was provided by ONERA (RAMSES images) and the Italian Space Agency (COSMO-SkyMed images).

In the context of remotely sensed data analysis, a crucial problem is the development of accurate models of the statistics of the pixel intensities. In this work, we develop a parametric finite mixture model for the statistics of intensities in high resolution Synthetic Aperture Radar (SAR) images. Along with the models, we design an efficient parameter estimation scheme by integrating the Stochastic Expectation Maximization (SEM) scheme and the Method of log-cumulants (MoLC) with an automatic technique to select, for each mixture component, an optimal parametric model taken from a predefined dictionary of parametric probability density functions (pdf). In particular, the proposed dictionary consists of the eight most efficient state-of-the-art SAR-specific pdfs: Nakagami, log-normal, generalized Gaussian Rayleigh, SαS generalized Rayleigh, Weibull, K-root, Fisher and generalized Gamma.



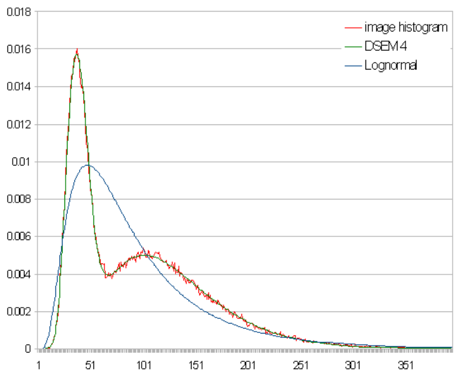


Figure 10. Left: COSMO-SkyMed image of Piemonte, Italy (©Italian Space Agency). Right: image histogram; estimation with the best state-of-the-art method (here Lognormal); and by our method with K=4 components.

The experimental results (see figure 10) with a set of several real COSMO-SkyMed and airborne RAMSES sensor images demonstrate the high accuracy of the designed algorithm, both from the viewpoint of a visual comparison between the estimates and the corresponding image histograms, and from the viewpoint of the quantitative correlation coefficient between them (always above 99.5%). We stress, in particular, that the method is efficient on all the considered images, despite their different statistics (*e.g.* histogram unimodality or multimodality) and high heterogeneity.

6.1.12. Change detection based on polygons

Keywords: *change detection*, *directional statistics*, *polygonal approximation*, *polygonal classification*.

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

This research was partly funded by the French Defence Agency (DGA).

In this work, we analyze the influence of orientation when classifying change 'objects' [20]. The objects are polygons approximating changed zones detected from a pair of images of a remotely sensed scene taken at different times. The approximation algorithm was presented in a 2007 activity report. Here, the polygons are classified using a simple K-means algorithm. However, the feature space is composed of the orientations of the corresponding sides of each polygon. Thus a Euclidean metric cannot be applied and the K-means algorithm relies on the chordal distance between orientations and the corresponding Karcher mean (which is very well known in polygonal statistics). The results (see figure 11) are encouraging and show that orientations can yield information on the underlying changed objects. The classification algorithm is, however, very sensitive to approximation errors (a small error in the polygonal approximation can yield a significant difference in the orientation of the sides). The results might be dramatically improved by using a variable number of sides for each polygon for either approximation or classification.

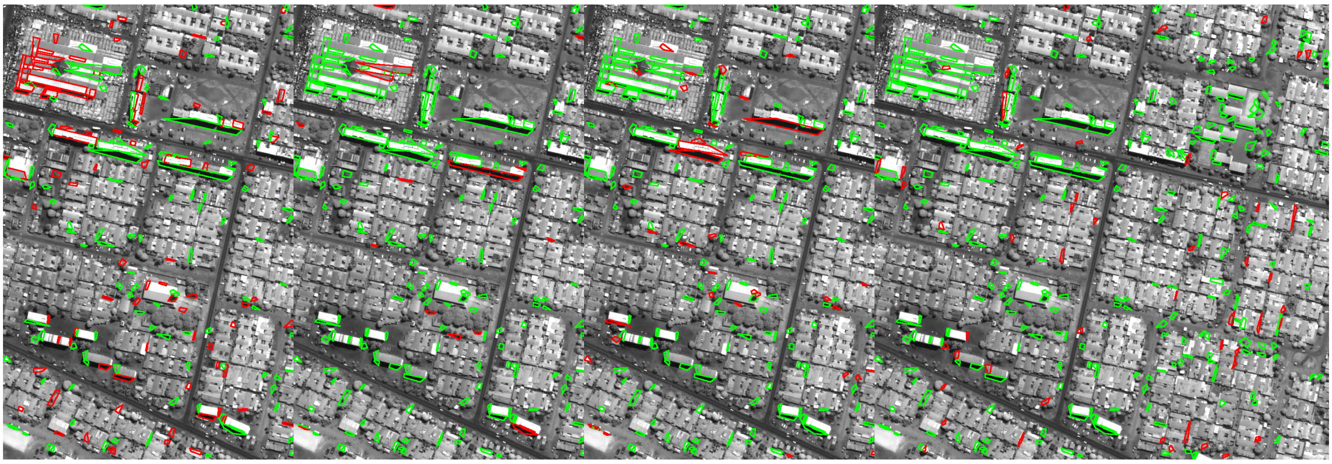


Figure 11. Successive classes (in red) obtained after approximating the 'changed' zones found from a pair of remotely sensed images of Abidjan. Original images: Quickbird, ©DigitalGlobe, distributed by Spot Image, and provided by the French Defence Agency (DGA).

6.1.13. Assessment of damage after forest fires from satellite images

Keywords: *burnt areas*, *classification*, *forest fire*, *learning*, *region growing*, *satellite image*, *support vector machine*.

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

This Ph.D. was partially funded by AKKA Technologies (ex-SILOGIC) and INRIA. We particularly thank Commandant Poppi (Fire brigade member and director of the cartography service, SDIS83 Draguignan) for interesting discussions.

This work investigates the problem of burnt area mapping from high-resolution satellite images. Our approach is based on the use of a single SPOT 5 image, acquired after the fire, to detect automatically the burnt areas. The method is based on Support Vector Machines (SVM), a supervised classification technique that exhibits greater accuracy and better generalization ability than traditional classifiers. Because all burnt pixels have similar spectral characteristics, while unburnt pixels vary greatly since they belong to different classes (forest, water, urban area, road, field,...), we propose to use the One-Class SVM (OC-SVM), an extension of the original two-class SVM that uses only positive examples for the training and classification steps.

In order to take into account the spatial information provided by the image, the OC-SVM algorithm is used as a region-growing technique, thereby decreasing false positives and improving the boundaries of burnt areas [30]. Moreover, the samples of burnt areas required for the training step of the SVM are automatically selected from the image histogram [31]. Finally, the proposed classification approach was tested on several SPOT5 satellite images (see figure 12) to validate its effectiveness with respect to vegetation type and burnt surface area. The burnt areas extracted are compared to reference maps provided by the French Space Agency (CNES), Infoterra France, SERTIT, local fire brigades (SDIS 06, 93 and 2B), and the French Forestry Office (ONF).

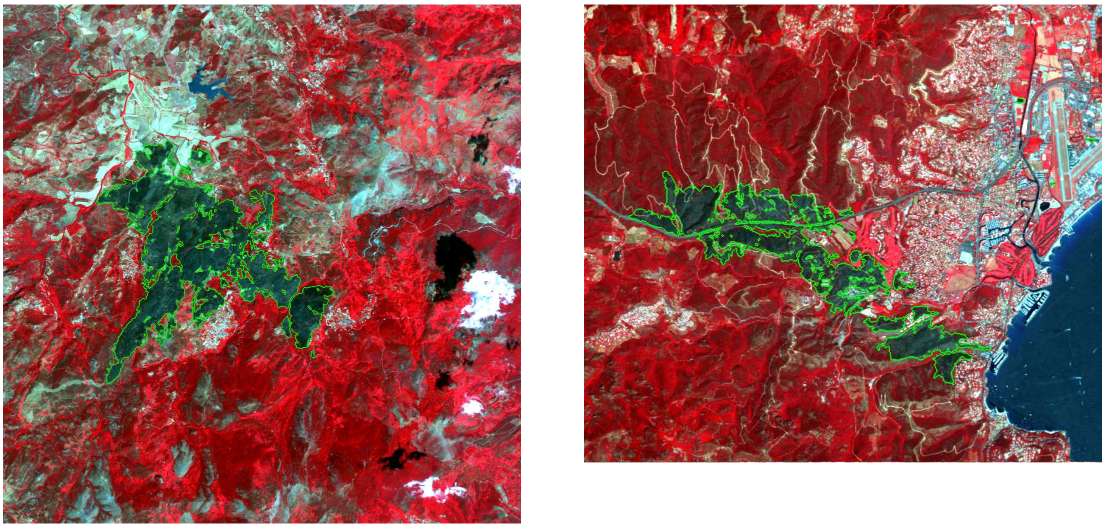


Figure 12. Overlays of the SPOT 5 images (©CNES, Distribution SPOT Image) and the extracted boundaries (©INRIA). Left: Eastern Corsica, 2005 (about 1,000 hectares); right: Alpes-Maritimes, 2007 (about 450 hectares).

6.1.14. SVM classification of vegetation type in one aerial image

Keywords: *Haralick features*, *classification*, *multi-class support vector machine*, *supervised learning*.

Participants: Nabil Hajj-Chehade, Josiane Zerubia [contact].

This research was partially supported by the Center of Embedded Networked Sensing (CENS) at the University of California, Los Angeles (UCLA) [http://research.cens.ucla.edu/] and by INRIA-DRI, and is conducted in collaboration with the French National Forest Inventory (IFN) [http://www.ifn.fr/].

The purpose of this work is to develop a method for classifying the vegetation types in an aerial or a satellite image. Different vegetation types differ not only in colour, but also in texture. We study the use of four Haralick features (energy, contrast, entropy, homogeneity) for texture analysis, and then perform the classification using the One-Against-All (OAA) multi-class Support Vector Machine (SVM), which is a popular supervised learning technique for classification. The choice of features (along with their corresponding parameters), the choice of the training set, and the choice of the SVM kernel highly affect the performance of the classification.

The image that we used (see figure 13), is a colour infrared (CIR) aerial image provided by the French National Forest Inventory (IFN). The image contains two types of vegetation, so the problem is a three-class classification (we refer to the three classes as type1, type2 and other). A preliminary result is shown in figure 13. This result was obtained by classifying on the spectral bands, the normalized difference vegetation index (NDVI) and an entropy feature. We used the Gaussian-kernel SVM.

Work in progress includes enhancing the classification by finding a good feature set (with good parameters), a good training set and a good SVM kernel. We also plan to incorporate a second stage to discriminate between dense and sparse vegetation.

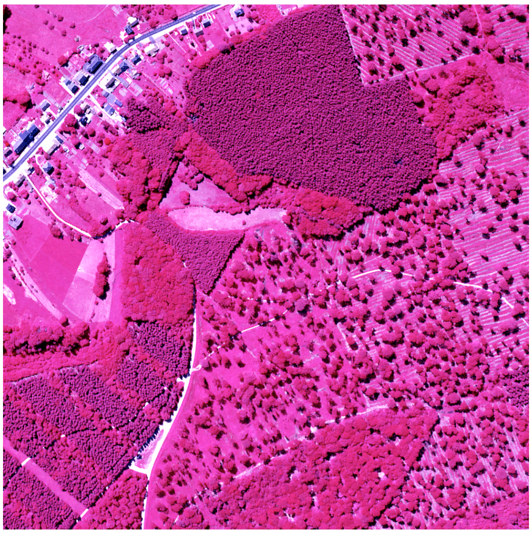
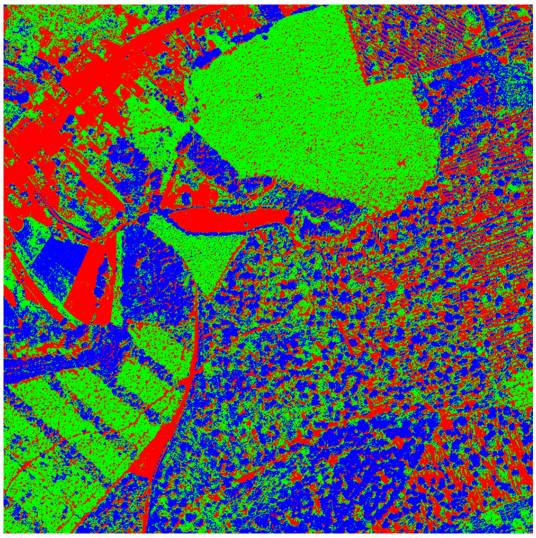



Figure 13. Left: raw image with two types of trees (©French National Forest Inventory (IFN)); right: three-class SVM classification result (green for type1, blue for type2, and red for other).

6.2. Variational models

6.2.1. A Γ-convergence approach for the detection of points in 2D images

Keywords: *curvature-dependent functional*, *divergence-measure field*, *point detection*, Γ-*convergence*.

Participants: Daniele Graziani, Laure Blanc-Féraud [contact].

The research of Daniele Graziani is supported by ANR project Detecfine. This work is done in collaboration with Prof. G. Aubert of the J.-A. Dieudonné Mathematics Laboratory of the University of Nice Sophia Antipolis [http://math1.unice.fr].

Detecting fine structures like points or curves in 2D or 3D images is an important issue in image analysis. For instance, in biological images a point may represent a viral particle whose visibility is compromised by the presence of other structures like cell membranes or noise.

In order to detect the singularities of the image, we have to find a function space whose elements generate, in a suitable sense, a measure concentrated on points. Such a space is $\mathcal{DM}^p(\Omega)$, the space of the fields $U : \Omega \to R^2$ whose distributional divergence is a Radon measure. We want to remove the structures that do not interest us by building up, starting from initial data U_0, a new vector field U whose singularities are given by the points of the image I we want to isolate. To this end, we propose to minimize an energy involving competition between a divergence term and the counting Hausdorff measure $\mathcal{H}^0$. To initialize the minimization process, we need a vector field U_0 linked to the initial image I, belonging to the space $\mathcal{DM}^p(\Omega)$. Such a vector field can be provided by the gradient of a weak solution of the classical Dirichlet problem with measure data I.

Numerically, the energy must be approximated by means of a more tractable functional. We provide such an approximation by using Γ-convergence. This theory is designed to approximate a variational problem by a sequence of different variational problems. This approach leads to an approximating functional, whose discretization can be obtained in a straightforward way. In the example shown in figure 14, the points are caught by the 0-level sets of a suitable function w depending on the small parameter ε and governing the convergence of the approximating functional to the initial energy.

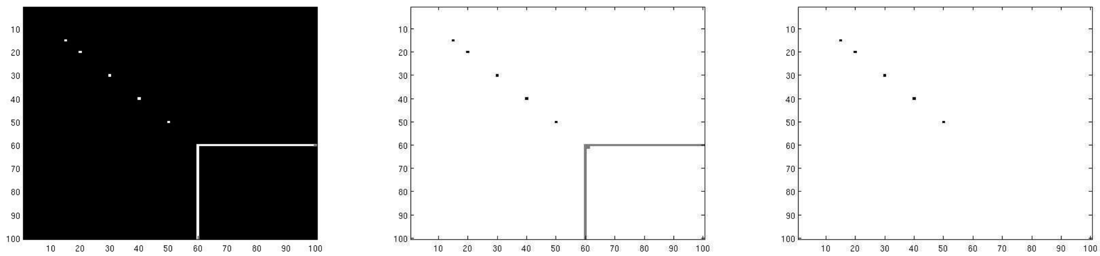


Figure 14. Synthetic image: curve and points are present in the initial image. Our method is capable of removing the curve from the image. Left: initial image; centre: the function w_ε; right: the set $\{w_\varepsilon \simeq 0\}$.

6.2.2. Efficient first-order schemes for convex optimization in image processing

Keywords: *Moreau regularization*, *Nesterov scheme*, *duality*, *l1 norm minimization*, *total variation*.

Participants: Weiss Pierre, Laure Blanc-Féraud [contact].

This Ph.D. is co-supervised by Prof. G. Aubert of the J.-A. Dieudonné Mathematics Laboratory of the University of Nice Sophia Antipolis [http://math1.unice.fr].

In this work, we have developed fast algorithms for convex optimization problems [14]. The problems considered are of the form $\min_x(f_1(x) + f_2(x))$ where f_1 and f_2 are convex functions belonging to one of the following classes:

- Lipschitz differentiable functions;
- strongly convex functions;
- conjugate functions;
- simple functions (functions for which the proximal operator can be obtained explicitly).

We systematically analyse the rate of convergence of the proposed methods. To the best of our knowledge, these theoretical rates are the state of the art for the classes of problems considered. We also compare our algorithms to some other standards and show their practical superiority on many different problems.

The algorithms proposed are helpful in solving many image reconstruction problems. These problems can include (but are not limited to) distortions like perturbed sampling (regular, irregular, compressive), blur, and additive noise (impulsive, uniform, Gaussian). The images and curves illustrate the efficiency of the algorithms. After 100 low complexity iterations, we obtain the results shown in figures 15 and 16.

6.2.3. Change detection based on level lines

Keywords: *change detection*, *illumination*, *invariance*, *level lines*.

Participants: Alexandre Fournier, Pierre Weiss, Laure Blanc-Féraud [contact].

Figure 15. Left to right: original image; noisy image (salt and pepper 40%); image restored with a $BV - L^1$ model.

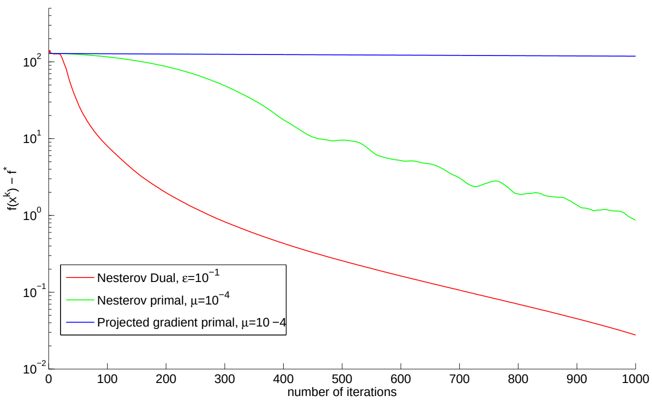


Figure 16. Comparisons of convergence rates. Blue: classical approach; green: Nesterov's approach; red: our approach.

This research was partially funded by the French Defence Agency (DGA), and was conducted in collaboration with Prof. G. Aubert of the J.-A. Dieudonné Mathematics Laboratory of the University of Nice Sophia Antipolis [http://math1.unice.fr].

In this work, we analyze the illumination invariance of the level lines of an image [21]. We show that if the scene surface has Lambertian reflectance and the light is directed, then a necessary condition for the level lines to be illumination invariant is that the 3D scene be developable and that its albedo satisfies some geometrical constraints. We then show that the level lines are 'almost' invariant for piecewise developable surfaces. Such surfaces fit most urban structures. This allows us to devise a very fast algorithm that detects changes between pairs of remotely sensed images of urban areas, independently of the lighting conditions. We show the effectiveness of the algorithm both on synthetic OpenGL scenes and real Quickbird images. We compare the efficiency of the proposed algorithm with other classical approaches and show that it is superior both in practice and in theory. More precisely, we compare it to two methods:

1. monotone projection (similar to a global contrast change) algorithm;
2. comparison of level-set trees yielded by the Fast Level-Set Transform [41].

Different tests were made on synthetic and real images, providing qualitative and quantitative results. Some results were obtained on a synthetic pair of images simulating changes in a city. The results show that our algorithm is far more robust to false positives related to illumination changes. Figure 17 shows ROC curves of the three methods on a real scene (suburbs of Beijing), again showing the superiority of our algorithm.

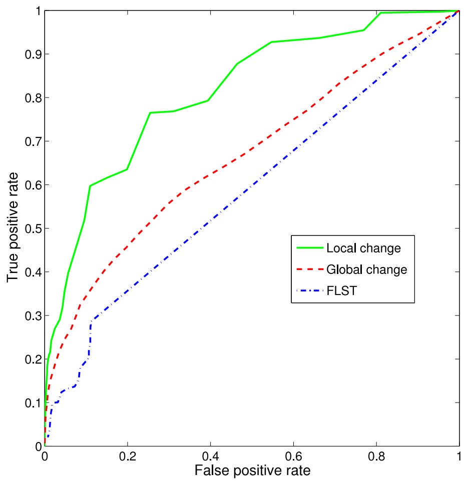


Figure 17. ROC curves for change detection in an image of a Beijing suburb.

6.2.4. Satellite image reconstruction from irregular sampling

Keywords: *convex optimization*, *deconvolution*, *image restoration*, *l1-norm*, *satellite imaging*, *variational method*, *wavelet*.

Participants: Mikael Carlavan, Pierre Weiss, Laure Blanc-Féraud, Josiane Zerubia [contact].

This work was partially funded by a contract with CS-SI [http://www.c-s.fr].

The problem of image reconstruction consists in estimating an image in a continuous setting from discrete observations. Beginning with the pioneering work of Shannon, several methods have been proposed for image reconstruction from regularly or irregularly spaced discrete observations. In this work, we consider the whole restoration problem of satellite images which includes: regular sampling image reconstruction from irregularly spaced samples (we assume that the locations of the samples are known); image deconvolution taking into account the Point Spread Function of the optics (supposed known); removal of noise due to acquisition by the sensors. Based on recent advances in convex optimization from Yurii Nesterov, we propose a new method to solve this image restoration problem using a variational approach regularized with an l^1-norm. This method is very fast, and has a convergence rate in $O\left(\frac{1}{k}\right)$ where k is the iteration number, while most minimization methods converge in $O(\frac{1}{\sqrt{k}})$. To the best of our knowledge, this is the best theoretical rate of convergence using first order methods.

Convergence results are shown in figure 18, which plots the value $f(x_k) - f(x^*)$ against the number of iterations for f an $l^1 - l^1$ energy dedicated to satellite image reconstruction. We can see that our accelerated method dramatically improves the convergence rate. To decrease $f(x_0) - f(x^*)$ by a factor 10^4, classical gradient methods require 2400 iterations while our accelerated method requires only 110 iterations.

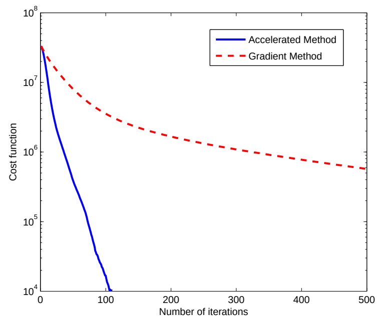


Figure 18. Evolution of $f(x_k) - f(x^*)$ versus iteration number for classical gradient methods and our accelerated method.

6.2.5. Study of a phase field higher-order active contour model for river extraction

Keywords: *higher-order active contour*, *phase diagram*, *phase field*, *river extraction*, *stability analysis*.

Participants: Aymen El Ghoul, Ian Jermyn, Josiane Zerubia [contact].

This work is funded by a PACA regional grant and INRIA, supported by a contract from the French Space Agency (CNES) in collaboration with Thales Alenia Space.

Higher-order active contours (HOACs) and their phase field equivalents have been used with success to extract road networks from medium [43], [42] and very high resolution [28] optical satellite images. River networks constitute another important type of line network in such images. This work uses an existing HOAC model and studies various aspects of its application to river network extraction.

Sensitivity to initial conditions is an important issue when one uses iterative descent algorithms to minimize an energy, as is the case with HOACs. We studied a number of different initial conditions (several based on maximum likelihood, a random initialization, the neutral initialization [42], and several others. The converged solutions agreed to within 0.5% pixel difference. We then studied two different image models, a multivariate Gaussian (MG) and a mixture of two multivariate Gaussians (MMG), with the same HOAC prior. The idea was that the second model would better take into account the heterogeneity in the appearance of the river network produced by occlusions. At the level of maximum likelihood this was not true, as the MMG model allowed some parts of the background to be classified as river. With the addition of the HOAC prior, however, the results using the MMG model were better than those of the MG model on all images tested.

We also concluded the stability analysis of the HOAC model [32], [18] for a long bar configuration by combining the results of a bar and a circle, as shown in figure 19. The colours in this figure correspond to combinations of stable bar and stable circle, with positive or negative energy. This phase diagram enables the selection of parameters to model a particular physical situation. In particular, using parameter values obtained from this diagram, we tested an 'inflection point' model for networks. The idea is to avoid false positives in the background by rendering a network configuration only marginally stable in the absence of supporting image data. The results are shown in figure 19: the false positives are indeed eliminated.

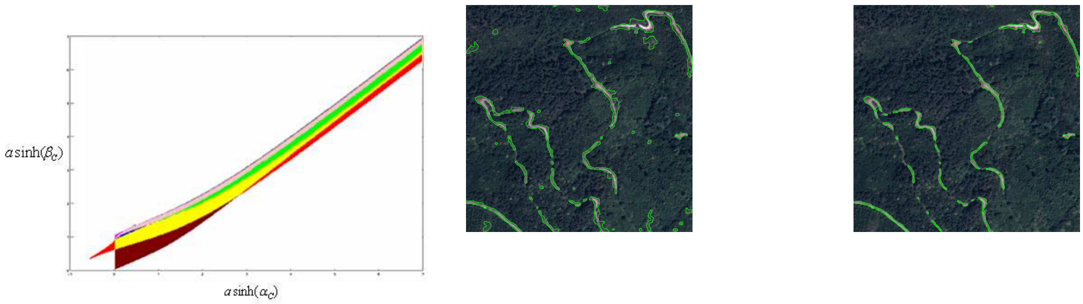


Figure 19. Left: phase diagram. Maroon, red, yellow, green, white, blue, pink, gray, magenta correspond respectively to B+, C+, B+ C+, B+ C-, UB UC, B- C+, B- C-, C- and B-; B, C, U, + and - refer respectively to bar, circle, unstable, positive energy and negative energy. Middle: segmentation result using parameter values selected from the maroon zone. Right: segmentation result using 'inflection point' parameter values. Note that false positives in the background are removed.

6.2.6. Phase field HOAC models for road network extraction in dense urban areas from VHR satellite images

Keywords: *dense urban area*, *higher-order active contour*, *nonlocal*, *phase field*, *prior*, *road network extraction*, *shape*, *very high resolution*.

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

This Ph.D.was co-supervised by Baogang Hu and Véronique Prinet, both of LIAMA/CASIA, Chinese Academy of Sciences [http://liama.ia.ac.cn]. 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]. This work was partially supported by Thales Alenia Space.

The goal of this work was to develop robust approaches for the semi-automatic extraction of road networks in dense urban areas from very high resolution (VHR) optical satellite images. Starting from a previous higher-order active contour (HOAC) model developed for medium resolution images, we first concentrated on updating the road network using the image and out-of-date GIS data. We introduced a multi-resolution statistical data model and a prior energy linking the road network to the GIS data, with good results [11].

We then turned to the direct extraction of secondary roads. In the previous HOAC prior, the interaction between points on the same side of a road has the same range and magnitude as that between points on opposite sides of a road, a limitation that turned out to be serious for smaller roads. We developed two energies to overcome this limitation. The first [28] is a nonlinear nonlocal HOAC term that increases the magnitude of interactions along the road. Although promising results were obtained at reduced resolutions, the computational cost of this term is high. The second [27] is a new Euclidean invariant linear nonlocal HOAC term. This permits separate control of the interactions between points on the same side of a road and between points on opposite sides of a road. Via a stability analysis, we studied the behaviour of the energy as a function of its parameters, thereby establishing constraints on the parameters in terms of network width(s). The linear nonlocal term is also more efficient computationally than the nonlinear term, and can thus be applied to images at full resolution. This allows some narrower network branches to be extracted, and in general the extraction accuracy is improved at full resolution. Some results are shown in figure 20.

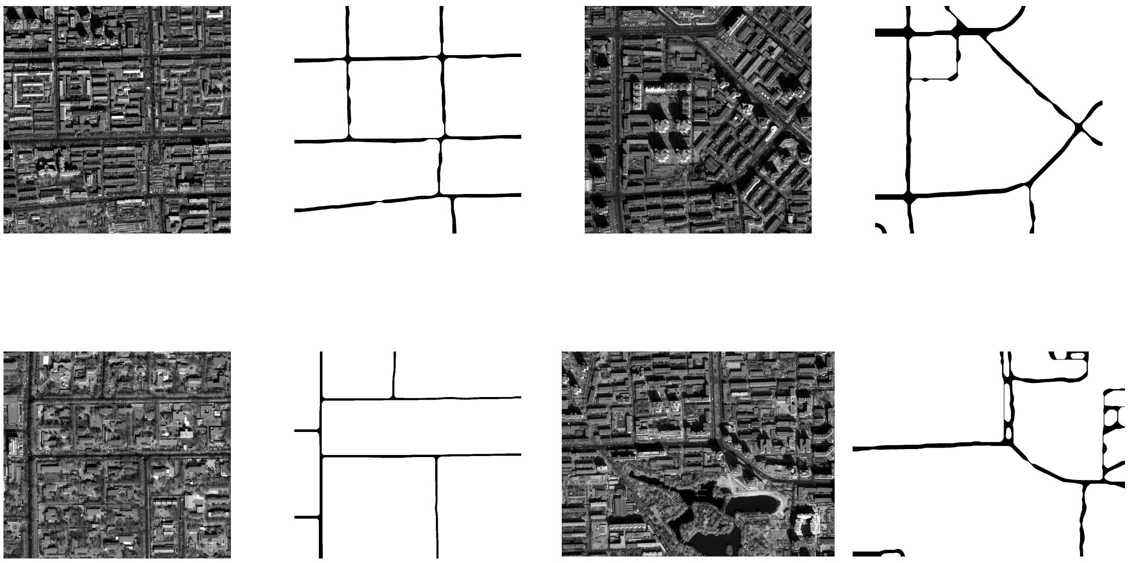


Figure 20. Results using the new linear model on pieces of a QuickBird image at full resolution. Image size, left to right, top to bottom: 1400×1400*;* 1200×1200*;* 880×800*; and* 1600×1200.

6.3. EU Project MUSCLE

6.3.1. *Unsupervised land classification using Tree Structured MRFs and Mean Shift*

Keywords: *image segmentation*, *land classification*, *markov random fields*, *mean shift*.

Participants: Raffaele Gaetano, Josiane Zerubia [contact].

This study is part of a Ph.D. funded by the University Federico II of Naples, Italy, and EU project MUSCLE, and conducted in collaboration with Prof. G. Scarpa (University of Naples).

The work addresses the problem of land classification via pixel-based image segmentation of low- and medium-resolution multispectral satellite images. Unsupervised segmentation is performed using a particular class of Markov random fields, *tree structured MRFs*. These models allow the hierarchical representation of a 2D field by the use of a sequence of nested MRFs, each corresponding to an internal node of the tree. Consequently, the segmentation algorithm can perform optimization of such models by recursively working on a single internal node at a time, from the root to the leaves, with a significant reduction in complexity.

In previous work on TS-MRFs, only binary tree structures were used. This is too constraining when attempting to fit arbitrarily structured data within a hierarchical tree representation. In the first stage of this research, we extended the model to generic tree structures by removing the unnecessary binary constraint, and then devised a new TS-MRF unsupervised segmentation technique which improves upon the original algorithm by selecting a better tree structure and eliminating spurious classes. Results are obtained by using the Mean-Shift procedure to estimate the number of pdf modes at each node, and to obtain a more reliable initial clustering for subsequent MRF optimization.

To this end, we also devised a new, reliable, and fast clustering algorithm based on Mean-Shift. It makes use of a variable kernel size strategy based on the k-Nearest Neighbors (k-NN) technique, aimed at coping with the widely varying density of data points in the space of spectral responses. Its implementation makes use of a speed-up strategy that significantly cuts computational complexity: the proposed solution is based on the idea that, during the kernel-based Mean Shift procedure for mode detection, data points lying 'close' to the trajectory drawn from the starting kernel centre to the detected mode are likely to belong to the same basin of attraction as the mode itself.

Results show that the new algorithm outperforms the old algorithm both on synthetic data and real SPOT satellite images of Lannion Bay (France). In both cases, a more coherent tree structure is created, and segmentation quality is consequently increased. These improvements are confirmed by classification quality assessment (see figure 21), showing lower average error rates also with respect to other semi-supervised TS-MRF based solutions.

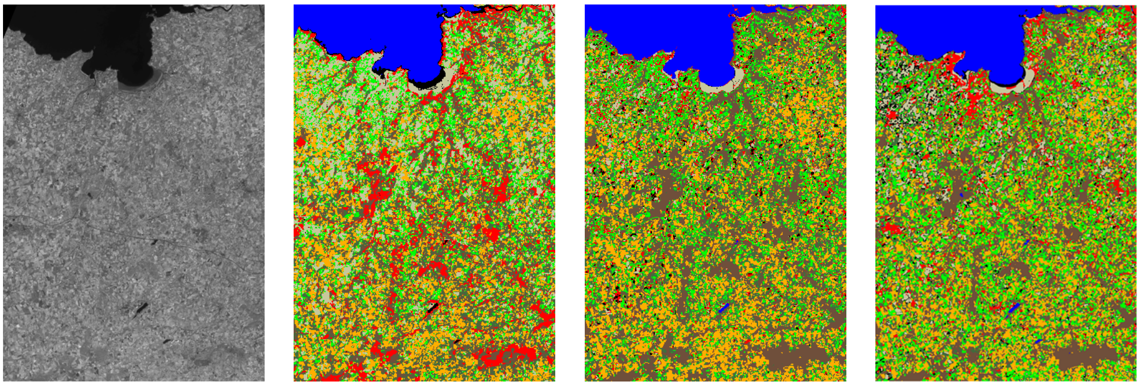
6.3.2. *Modelling complex shapes with higher-order active contours*

Keywords: *Taylor series*, *higher-order active contour*, *prior*, *quartic*, *shape*, *stable*.

Participants: Gabriel Ducret, Ian Jermyn, Josiane Zerubia [contact].

This work was funded by MBDA-EADS [http://www.mbda-systems.com] and EU project MUSCLE [http://www.muscle-noe.org].

The higher-order active contour (HOAC) framework has so far been used to model simple shapes, *e.g.* networks for road or river segmentation and circles for tree crown segmentation. The principal goal of this work is to develop a way to model more complex shapes within this framework, without losing its advantages. To model a particular shape, *e.g.* circles, a stability analysis is performed: the energy defining the HOAC model is expanded to second order in perturbations of its boundary. If parameter values exist such that every perturbation increases the second-order energy, then the shape is a local minimum and hence stable. However, while studying stability for circles, we observed in numerical experiments the formation of other, more complex stable shapes. It seems that certain perturbations can acquire non-zero but stable amplitudes. This can be explained if parameter values exist such that the second-order energy is not positive definite, while the fourth order energy is, as shown in figure 22. If such stable perturbations of, *e.g.* a circle, could be controlled, then it would be possible to model arbitrary 'star domains' using HOACs.



(a) (b) (c) (d)

Figure 21. Unsupervised segmentation of a SPOT image of Lannion Bay, France (size 1480×1024*, 3 channels, © SPOTImage / CNES): (a) channel XS3 of the source image, (b) 8-class map retrieved using the original TS-MRF algorithm (classification rate 59.8%), (c) 8-class map retrieved using the modified TS-MRF/Mean-Shift algorithm (classification rate 74.4%), (d) corresponding 8-class map from the supervised TS-MRF based segmentation, for comparison (classification rate 83.7%).*

The first step was to expand the HOAC energy to fourth order in a functional Taylor series around the circle. This expansion was performed, and solutions were then sought for the simplest case: when one Fourier component on the boundary is acquires a non-zero stable value. Such solutions exist (see figure 22), but for the moment the parameter values required to obtain them are unphysical in other ways (*e.g.* total energy unbounded below). The work is now focused on changing the interaction function defining the HOAC model in order to bring these solutions into physically acceptable parameter ranges. The next step will be to control the amplitudes of different perturbations by inverting the energy expansion to give the interaction function in terms of the amplitudes.

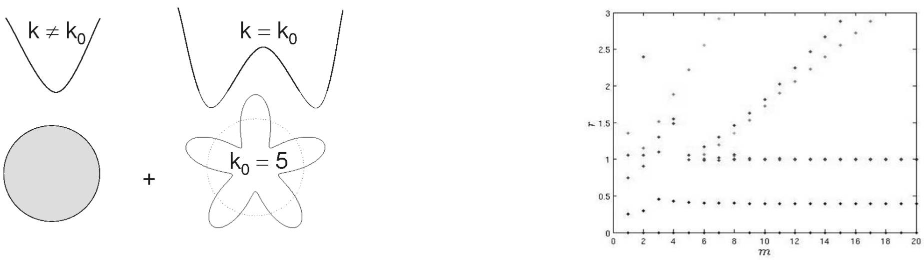


Figure 22. Left: illustration of stable but non-zero perturbation at a particular frequency. Right: the solutions to the stability equations as a function of frequency and radius.

6.3.3. Multiscale phase field higher-order active contours

Keywords: *adaptive*, *higher-order active contour*, *multiscale*, *wavelet*.

Participants: Ayoub Ait Lahcen, Ian Jermyn, Josiane Zerubia [contact].

This work was funded by EU Network of Excellence MUSCLE [http://www.muscle-noe.org].

Shape modelling is a subject of great importance in image processing and computer vision. Higher-order active contours (HOACs) incorporate sophisticated prior shape knowledge without necessarily constraining topology, via the introduction of long-range interactions between points of the region boundary. The HOAC framework [43] and its phase field equivalent [42] have been used to model networks [28] and a 'gas of circles' [7], with great success in application to problems in remote sensing image processing.

However, the increasing resolution of the imagery available in many fields (*e.g.* current satellites are between 1m and 0.5m, and will rapidly increase further) means that large image sizes and increasing image complexity are becoming more and more common. These developments suggest that a multiscale approach to shape is essential from both modelling and algorithmic perspectives. The goal of this work is to use the phase field formulation of HOACs to construct multiscale models of shape, and to apply them to the segmentation of road networks from very high resolution satellite imagery. On a modelling level, this would permit the coupling of the shape to the image at multiple scales, while algorithmically it should lead to better algorithms via simplifying approximations to the phase field energy that will fully exploit the multiscale structure. The first step was the expression of the phase field and phase field HOAC energies in terms of a wavelet basis. This involved two steps. First, in order to introduce as much independence between the wavelet coefficients of the phase field as possible, an adapted inter- but not intra-scale orthonormal wavelet basis was constructed, in which the wavelets are orthogonal with respect to a Sobolev-like inner product determined by the energy. This means that the quadratic term in the energy is diagonalized. The second step was the computation of the third and fourth order 'connection coefficients' for this adapted wavelet basis, and their organization into a comprehensible hierarchy. The results (see figure 23) show that strong interactions constitute a very small percentage of all interactions, and, most importantly, that these strong interactions are vertical in the wavelet tree, *i.e.* the interacting wavelets are all ancestors or descendants of one another. This suggests that various simplifying tree-like approximations to the full energy could lead to very efficient algorithms. The next step will be the theoretical and experimental investigation of these approximations.

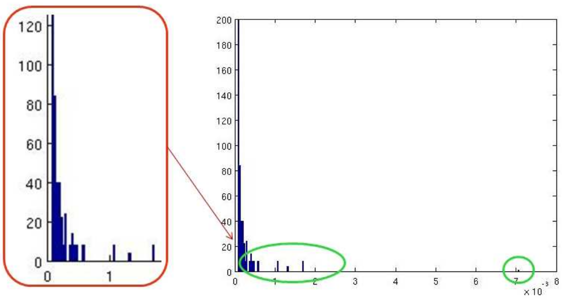


Figure 23. Histogram of the fourth order connection coefficients controlling the interactions between quadruples of wavelet coefficients in the multiscale version of a phase field HOAC model, showing the concentration of strong interactions on a small percentage of coefficients. These strong interactions are largely vertical in the wavelet tree.

6.4. Applications to biology and medicine

6.4.1. Parametric blind deconvolution in Confocal Laser Scanning Microscopy (CLSM)

Keywords: *Bayesian restoration*, *Confocal Laser Scanning Microscopy (CLSM)*, *PSF*, *Total Variation*, *blind deconvolution*.

Participants: Praveen Pankajakshan, Laure Blanc-Féraud, Josiane Zerubia [contact].

This Ph.D.was funded by a CORDI Fellowship and is also part of the P2R Franco-Israeli project [http://www-sop.inria.fr/ariana/Projets/P2R/].

Continuing from the first phase of our work, we developed and validated an Alternate Minimization (AM) algorithm for jointly estimating the parameters of the diffraction-limited Point Spread Function (PSF) of a Confocal Laser Scanning Microscopy (CLSM), and the specimen fluorescence distribution function. The CLSM is an optical fluorescence microscope that scans a specimen in 3D. It differs from a Wide Field Microscope in the use of a pinhole before the detection stage. An optical section of a3D specimen that is obtained at the detector suffers from two primary physical limitations. The diffraction-limited nature of the optical system, and the reduced amount of light detected by the photomultiplier, cause blur and photon counting noise respectively. These images can hence benefit from post-processing restoration methods based on deconvolution. Estimating the object and the PSF simultaneously using blind deconvolution is a very ill-posed problem, as one can always find many possible solution combinations of the PSF and the object that can satisfy equally the given observation. A model of the physical process of image acquisition is necessary for band-limiting the PSF estimation results and in restricting the degrees of freedom to the number of free parameters of the model. A 3D separable Gaussian model is suitable, but the parameters of such a model may vary during the course of experimentation, and so they have to be estimated directly from the observational data. Similarly, prior knowledge of the specimen introduced through a Total Variation (TV) constraint permits stabilization of the deconvolution algorithm and favours its convergence. The novelty of the approach is its application to restoring 3D biological image data by assuming that the statistical variation of the photon counting process follows Poisson statistics [26]. The results obtained by the proposed algorithm on the PSF and the specimen from the simulated data show that the PSF can be estimated to a high degree of accuracy, while those on real data show improved deconvolution as compared to a theoretically modelled PSF (see figure 24).

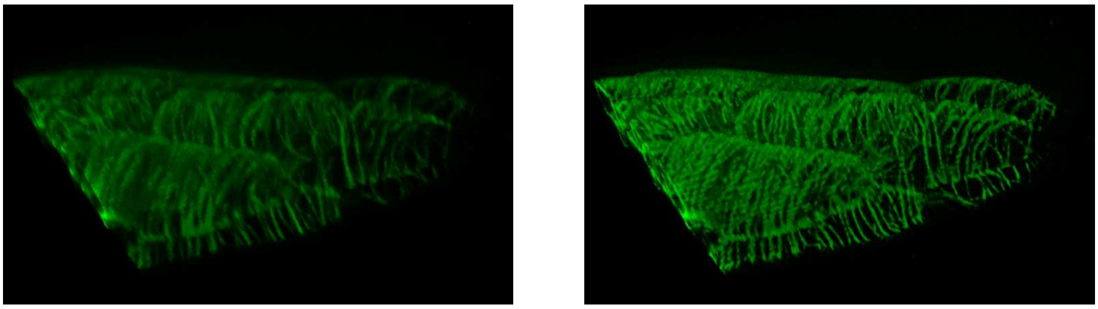


Figure 24. Rendered volume of the root apex of an Arabidopsis Thaliana (left) (©INRA) and rendering of the restored image slices (right) (©INRIA).

6.4.2. Segmentation and Deconvolution of 3D images

Keywords: *3D image*, *confocal microscopy*, *deconvolution*, *filament*, *segmentation*, *variational method*.

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

This Ph.D. is co-supervised by Prof. G. Aubert of the J.-A. Dieudonné Mathematics Laboratory of the University of Nice Sophia Antipolis [http://math1.unice.fr/] and forms part of the ANR project Detecfine in collaboration with the Pasteur Institute.

We proposed a new model to detect locally thin filaments in 2D or 3D images I of confocal microscopy. This model uses the approximation of the PSF by a Gaussian function G_σ and takes into consideration the effect of the discretization due to the CCD captors and additive Gaussian noise b.

First we show that the observed image at pixel y_i of a linear filament passing through a point x with an intensity A and a direction v, without additive Gaussian noise is given by

$$I(y_i) = \int_{C(y_i)} A e^{-\frac{(\overrightarrow{xy}.\overrightarrow{v^{\perp}})^2}{\sigma}} dy \qquad (1)$$

The next step is to use the eigenvectors and eigenvalues of the Hessian matrix H of I to perform a pre-detection. We then look for pairs (F, b) compatible with the model in equation (1), where F is a filament with the parameters (x, v, A), x is a pre-detected point, and b is Gaussian noise with a minimum L^2 norm. We use a gradient descent method in order to obtain these pairs, using H as an initial guess. If we obtain an L^2 difference for the segment centred on x that is small enough, we try to extend this segment to a consecutive segment, and we try to optimize the orientation to fit with our model. Figure 25 shows the results of our method on a real 3D image of actin filaments.

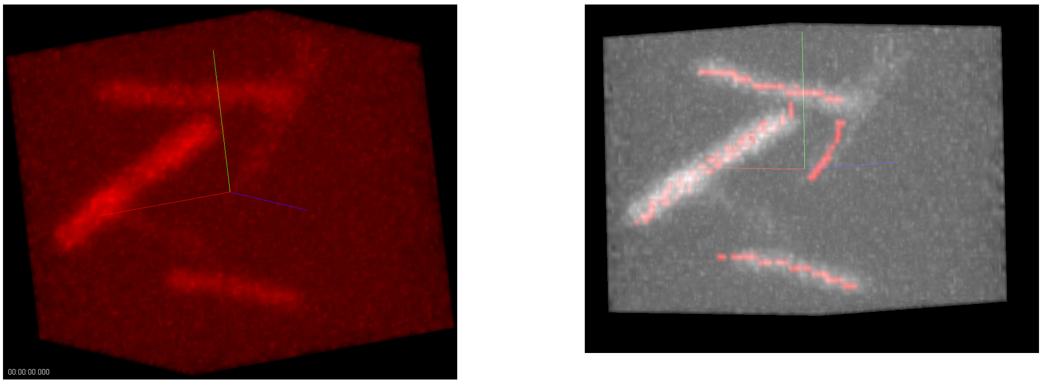


Figure 25. Left: original image (©Pasteur); right: detected filaments (©INRIA/I3S).

6.4.3. Segmentation of the vascular network in the brain

Keywords: *brain vascular network*, *tomography*, *tumour*.

Participants: Ameya Muley, Shashank Samant, Xavier Descombes [contact].

This study was partially supported by ANR project Micro-Réseaux.

The goal of the ANR project is to study the effect of different radiotherapy protocols on brain tumours. We have 3D volumes representing part of the vascular network in the brain, obtained from the synchrotron in Grenoble [12]. In some datasets, leaks of the contrast liquid disturb the segmentation of the vascular network. To subtract these areas, we have combined three criteria to distinguish the leak areas from blood vessels. These criteria are based on the radiometry, the size of the connected components and the shape of these components. By evaluating and fusing these three criteria, we are able to detect and to subtract the leak areas. In addition, we have evaluated a segmentation tool for the extraction of the vascular network from holotomography data. Unfortunately, the quality of the data was not good enough to allow a relevant segmentation to be obtained.

7. Contracts and Grants with Industry

7.1. Industrial

7.1.1. CNES Toulouse

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

Parameter estimation for marked point processes for object extraction from high resolution satellite images. Contract #2150 part 1.

7.1.2. CNES, Toulouse

Participants: Aymen El Ghoul, Ian Jermyn, Josiane Zerubia [PI].

Higher-order active contours with application to the extraction of networks (roads and rivers) from high-resolution satellite images. Contract #2150, part 2.

7.1.3. CNES Toulouse

Participants: Vladimir Krylov, Josiane Zerubia [PI].

Modelling of high resolution SAR image statistics. Contract #3311.

7.1.4. CS-SI Toulouse

Participants: Mikeal Carlavan, Laure Blanc-Féraud, Josiane Zerubia [PI].

Satellite image reconstruction from irregular sampling. Contract # 3084

7.1.5. AKKA Technologies Toulouse

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

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

7.1.6. SAGEM DS Massy

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

New methods in image processing. Contract # SPV CA CNRS/UNSA 017526, I3S laboratory. In collaboration with Prof. G. Aubert (J.-A. Dieudonné laboratory, CNRS/UNSA) and Jean-Francois Aujol (CMLA ENS Cachan).

7.1.7. MBDA-EADS, Paris

Participants: Gabriel Ducret, Ian Jermyn, Josiane Zerubia [PI].

Modelling of complex shapes using higher-order active contours. Contract # 3449.

7.1.8. DGA/CTA Arcueil

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

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

7.1.9. IFN Nogent sur Vernisson

Participants: Neismon Fahe, Xavier Descombes, Josiane Zerubia [PI].

Semi-automatic methods for forestry cartography using aerial and high resolution satellite images. Contract #1467.

7.1.10. Thales 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 #1675.

7.1.11. Thales Alenia Space Cannes

Participants: Giovanni Gherdovich, Xavier Descombes, Josiane Zerubia [PI].

Optimization of pupil configuration for Optical Aperture Synthesis. Contract #2516.

8. Other Grants and Activities

8.1. Regional

8.1.1. INRIA COLORS project 'ODEUR'

Participants: Fatih Arslan, Xavier Descombes, Josiane Zerubia [PI].

In collaboration with ONERA (Salon de Provence).

8.1.2. PACA PhD grant

Participants: Aymen El Ghoul, Ian Jermyn, Josiane Zerubia [PI].

In collaboration with Thales Alenia Space (Cannes) and the French Space Agency (CNES).

8.2. National

8.2.1. ANR programme blanc: project 'DETECFINE'

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

In collaboration with the J.-A. Dieudonné Laboratory of CNRS/UNSA (G. Aubert, L. Almeida, P. Chiron), the Pasteur Institute in Paris (J-C Olivo-Marin, C. Zimmer), SAGEM DS at Argenteuil (D. Duclos, Y. Le Guilloux), and ENS Cachan (J.F. Aujol).

8.2.2. ANR programme blanc: project 'Micro-Réseaux'

Participant: Xavier Descombes [Ariana PI].

In collaboration with IMFT (F. Plouraboue (PI), R. Guibert), CERCO (C. Fonta), and ESRF (P. Cloetens, G. LeDuc, R. Serduc).

8.3. European

8.3.1. EU project MUSCLE

Participants: Aymen El Ghoul, Gabriel Ducret, Ayoub Ait Lahcen, Ting Peng, 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. P2R Collaborative program

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

The Quantitative Image Analysis Unit at the Pasteur Institute (Paris, France), the Department of Molecular Cell Biology at the Weizmann Institute (Israel) and the Department of Electrical Engineering at the Technion Israel Institute of Technology are jointly involved in this collaborative program for discovering computational methodologies to improve the resolution of images in microscopy.

8.4.2. INRIA/FSU Associated team 'SHAPES'

Participants: Maria S. Kulikova, Aymen El Ghoul, Csaba Benetek, Ian Jermyn, Xavier Descombes, Josiane Zerubia [PI].

In collaboration with the Vision Group of Florida State University (A. Srivastava (PI), E. Klassen, A. Barbu, and J. Su). Website: http://www-sop.inria.fr/ariana/Projets/Shapes.

8.4.3. INRIA/IIPT/UIIP Associated team 'ODESSA' and ECONET project

Participants: Maria S. Kulikova, Florent Chatelain, Josiane Zerubia, Xavier Descombes [PI].

In collaboration with the Dobrushin Laboratory of the Institue for Information and Transmission Problems of the Russian Academy of Science, Moscow (E. Zhizhina (PI), E. Pechersky, R. Minlos, S. Komech), the Image Processing and Pattern Recognition Laboratory of the United Institute of Informatics Problems of the National Academy of Science of Belarus, Minsk (B. Zalesky (PI), P. Lukaskevich, A. Krauchonak), and IRIT, Toulouse (J.D. Durou). Website: http://www-sop.inria.fr/ariana/Projets/Odessa.

9. Dissemination

9.1. Conferences, Seminars, Meetings

- The members of the Ariana project-team participated actively in GdR ISIS and GdR MSPCV.
- Members of the Ariana project-team participated in the Fête de la Science at INRIA in October.
- The Ariana project-team organized numerous seminars in image processing during 2008. Sixteen researchers were invited from the following countries: Canada, Hong Kong, Iceland, Italy, Japan, France, Sweden, Switzerland, and the USA. For more information, see the Ariana project-team web site.
- Members of the Ariana project-team participated actively in the visits to INRIA Sophia Antipolis of students from the Grandes Écoles (ECP, ENS Lyon, ENPC, ISAE/Sup'Aéro) and from Sup'Com Tunis, Tunisia; helped students of the Classes Préparatoires with TIPE in France; and gave information on remote sensing image processing to high school students in Mauritius.
- The work of the Ariana project-team was reported in Interstices (podcast in July) and in Inedit 65 (special issue dedicated to the environment).
- All the members of the Ariana project-team participated in a 'brain-storming' session at the Hotel Mercure, Sophia Antipolis, in June.
- Alexis Baudour gave three seminars during meetings at Sagem DS, in January, June and November.
- Csaba Benedek visited the Department of Statistics of Florida State University, Tallahassee, Florida, USA, in December, and gave a seminar.
- Florent Chatelain presented a poster at the conference ICASSP'08, Las Vegas, Nevada, USA, in April.
- Gabriel Ducret presented his work at meetings with MBDA in May and September.
- Aymen El Ghoul presented a paper at the conference RFIA'08 in Amiens, and gave a talk at the ORFEO Methodology meeting at CNES, Paris, both in January. He gave a presentation at the workshop 'Information Mining: pursuing automation of geospatial intelligence for environment and security' at ESA in Frascati, Italy, in March. He gave seminars at Florida State University in Tallahassee, and at the University of Central Florida in Orlando, both in December. Also in December, he presented a paper at the conference ICPR'08, Tampa, Florida, USA. He gave a seminar at ENIT in Tunisia in December.
- Neismon Fahé gave a talk at the conference Space Appli'08, Toulouse, France, in April. He also gave seminars at CURAT (University of Abidjan) and at BNETD, Ivory Coast, in August.
- Alexandre Fournier gave a talk at the conference ICPR'08, Tampa, Florida, USA, in December. He gave an invited talk at the SPIE conference, San Jose, California, USA, in February.

- Raffaele Gaetano presented a talk at the conference EUSIPCO'08, Lausanne, Switzerland, in August.
- Daniele Graziani gave a talk as part of 'ANR 2008' in May. He gave a talk at ENS Cachan, Paris, France, as part of ANR project Detecfine in November.
- Maria Kulikova presented her work at a meeting of the Associated Team ODESSA in April. She presented her work during the visit of the IITP, Moscow, in July.
- Praveen Pankajakshan presented a paper at ISBI'08, Paris, France in May. He gave a seminar at the Department of Mathematics, Indian Institute of Science (IISc) Math Initiative (IMI), Bangalore, India in August. He presented his work as part of the ADSTIC seminar, I3S, Sophia-Antipolis, France, in November. Also in November, he gave a presentation at the status seminar in Medical imaging, conducted by the High council for research, scientific and technological co-operation, Paris, France.
- Ting Peng presented her work at the Beijing Institute of Surveying and Mapping and at the Beijing Municipal Committee of Communication in April. She presented a paper at the conference ISPRS'08, Beijing, China, in July.
- Olivier Zammit gave a talk at the conference EUSIPCO'08, Lausanne, Switzerland, in August. He also gave a talk at the conference PRIA'08, Nizhny Novgorod, Russia, in September.
- Ian Jermyn gave an invited talk at MCVC'08 in Cannes in February. In April, he visited the Department of Statistics of Florida State University for one week. He took part in meetings with CNES in April, with MBDA in September, and with CNES again in October. He presented his work to a delegation from the DGA in October. He gave an invited talk at a workshop in LIAMA, Beijing, in November. He gave a seminar at Warwick University, Warwick, UK in December.
- Xavier Descombes visited Auckland University for one week in February. He gave a talk at GdR Isis and at INRA Montpellier in March. In April, he visited the Department of Statistics of Florida State University for one week. He also presented a poster at ICASSP'08, Las Vegas, Nevada, USA, in April. In October, he gave a talk at CNES in Toulouse and at the conference ACIVS'08 in Juan les Pins. He was an invited speaker at Eurandom in Eidhoven in November. He took part in several meetings of ANR project 'Micro-Réseaux'.
- Laure Blanc-Féraud presented a poster and gave a talk at ICASSP'08, Las Vegas, USA, in March. She gave a talk at the GDR ISIS Journée Thématique on Inverse problems in Paris in May. She gave an invited talk at ELMI, Davos, Switzerland, also in May, and at Mifobio (Ecole thématique interdisciplinaire en MIcroscopie FOnctionnelle en BIOlogie), Carqueirane, France, in September. She gave a seminar to the MOISE project-team at INRIA Grenoble, in December.
- Josiane Zerubia made presentations of the work of the Ariana project-team in January to Vega Technologies, French Space Agency (CNES), and CS in Toulouse, and to a delegation from the Indian Institute of Science of Bangalore. In February, she attended a meeting of the P2R project. In March, she participated in the French National Geographic Institute (IGN)'Research Days' in St. Mandé. In April, she took part in a meeting with CNES in Toulouse, and attended the SpaceAppli'08 conference organized by CNES in Toulouse, where she presented a paper. In May, she helped evaluate CNES as a member of the CERT, and presented Ariana's work in a meeting with the heads of R & D of Galderma and l'Oréal. In June, she presented the work of Ariana to the Directors of the Cote d'Azur Observatory (OCA). In September, she attended the LEICA Seminar at the Pasteur Institute in Paris, and the conference SRC'08 on security at CNIT in Paris. In October, she gave a plenary talk at the conference ACIVS'08, and presented the work of Ariana to a delegation from the French Defence Agency (DGA). In November, she attended a workshop on image processing at LIAMA (Chinese Academy of Sciences), Beijing. She also attended a workshop on forestry at CIRAD in Montpellier. In December, she attended a meeting of the P2R project at the Pasteur Institute in Paris.

9.2. Refereeing

- C. Benedek was a reviewer for the journal IEEE TIP.
- F. Chatelain was a reviewer for the IEEE TIP.
- M. Kulikova was a reviewer for IEEE TIP.
- P. Pankajakshan was a reviewer for the SPIE Journal on Optical Engineering, and for IET Electronics Letters.
- P. Weiss was a referee for the conference SITIS'08, and for the journals IEEE TSP, the SIAM Journal on Scientific Computing, the International Journal of Numerical Algorithms, and the International Journal of Zhejiang University in Applied Maths.
- O. Zammit was a reviewer for the IEEE TGRS.
- I. Jermyn performed a research proposal review for Microsoft Research, a book review for Springer, and was a regular reviewer for IEEE TSP, IEEE TIP, IEEE TPAMI, Image and Vision Computing, and the Journal on Image and Video Processing. He was a reviewer for the conferences ECCV'08 and POCV'08.
- X. Descombes is a regular reviewer for the journals IEEE TIP, IEEE TMI, and IEEE TPAMI, and for IJCV. He was a reviewer for Gretsi'08. He is a proposal reviewer for the ANR (programme blanc and jeunes chercheurs). He was a reviewer for one HdR and was on two Ph.D. committees. He is also an expert for the DDRT programme on 'Jeunes Entreprises Innovantes'.
- L. Blanc-Féraud is Associated Editor of the journal Traitement du Signal. She is a regular reviewer for IEEE TIP and IEEE TSP, Signal Processing, and JMIV. She was a reviewer for the conferences ICIP'08, ICASSP'08, ISBI'08, ACVIS'08, and MICCAI'08. She is a proposal reviewer for the ANR (program blanc). She reviewed grant proposals researchers in laboratories in Switzerland, and for the COFECUB collaborative project between France and Brazil.
- J. Zerubia was a reviewer for one HdR at Sup'Com Tunis, and a member of three Ph.D. committees. She was a regular reviewer for IEEE TGRS, GRS Letters, and SFPT (Revue Française de Photogrammétrie et de Télédétection). She was a reviewer or a programme committee member for ICASSP'08, ISBI'08, ICIP'08, SPIE-ISPRS'08 ('Image and Signal Processing for Remote Sensing'), and CARI'08. She was also co-chair of the special sessions at ISBI'08 in March in Paris.

9.3. Organization

- Ian Jermyn is a member of the Comité de Suivi Doctoral at the INRIA Sophia Antipolis-Méditerranée Research Centre, and of the COST Groupe de Travail Relations Internationales of INRIA. He is co-computer systems coordinator for the Ariana project. He is a co-guest editor of the IEEE TPAMI Special Issue on Shape Analysis and Modeling.
- Xavier Descombes is a member of the scientific committee of the 'Pôle de compétitivité Optitec', and a member of the strategic committee of PopSud. He is computer systems coordinator for the Ariana project. He is PI of an ECONET project and of the Associated Team ODESSA. He was also co-organiser of a workshop on probabilistic models in image processing.
- Laure Blanc-Féraud is part of the Steering Committee of GDR ISIS. She organized two scientific days in April in Paris (on Sparsity and Irregular Sampling). She is part of the Administrative Council of Gretsi, and is a member of its board. She is a member of the evaluation committee of the ANR DEFI programme and an associate member of the IEEE BISP committee. She is part of the CNECA 3, and was involved in the recruitment of two professors. She is a member of the Commission de Spécialistes 61 of UNSA, and was a member of the recruitment committees for MCFs and Professors. She is a permanent member of the Organizing Committee of the Gretsi Peyresq Summer School. She is a jury member for the Ph.D. thesis prize of Club EEA, section Signal et Image. She was a reviewer for six Ph.D. theses and a member of two Ph.D.committees (one as president). She was a member of the committee for the evaluation of a part-time Ph.D. thesis at CEA Grenoble.

- Josiane Zerubia is an IEEE Fellow. She is a member of the Biological Image and Signal Processing Technical Committee and of the Image and Multi-Dimensionnal Signal Processing Technical Committee of the IEEE Signal Processing Society. She is an Associate Editor of the collection 'Foundation and Trends in Signal Processing' [http://www.nowpublishers.com/sig]. She is a member of the Editorial Boards of IJCV, the Revue Française de Photogrammétrie et de Télédétection of SFPT and the journal Traitement du Signal. She is an Associate Editor of the electronic journal Earthzine [http://www.earthzine.org/]. 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 Swiss National Science Foundation, the French National Network for Complex Systems (RNSC) and the Cosmo-Skymed program of the Italian Space Agency. She is principal investigator for the P2R Franco-Israeli collaborative programme and for Associated Team SHAPES. She is also principal investigator for ten of the industrial contracts and grants of the Ariana project-team. She is a member of the ORFEO group (CNES) and of the 3D working group of CNES.

9.4. Teaching

- Alexis Baudour was lab instructor for 'Mathematics for digital images' (64h) at the IUT, Nice Sophia Antipolis.
- Alexandre Fournier was an advisor for Image Processing projects (21h) at Poly'Tech Nice-Sophia Antipolis.
- Giovanni Gherdovich was teaching assistant for 'Image/Compression Project' (20h) and 'Introduction to Programming' (44h) at Poly'Tech Nice-Sophia Antipolis.
- Daniele Graziani was teaching assistant for 'Analysis' and 'Linear Algebra' at the IUT, Nice Sophia Antipolis.
- Maria Kulikova was teaching assistant for 'Document Creation with (X)HTML/XML/TEX/MSOffice' at Poly'Tech Nice-Sophia Antipolis (64h).
- Pierre Weiss was lab instructor for 'Digital signal processing' (32h), and 'Mathematics' (40h) at Poly'Tech Nice-Sophia Antipolis.
- Ian Jermyn taught 'Image analysis' (6h) at Poly'Tech Nice-Sophia Antipolis, 'Advanced techniques for space imagery' (5h) at ISAE/SUPAERO, and for the Masters 1 course 'Image processing' at ENS Lyon/UNSA (3h).
- Xavier Descombes taught 'Advanced techniques for space imagery' at ISAE/SUPAERO (20h), 'Image analysis' at Poly'Tech Nice-Sophia Antipolis (21h), at SAGEM DS (6h) and for the Masters 1 course 'Image processing' at ENS Lyon/UNSA (3h).
- Laure Blanc-Féraud taught for the Masters 2 courses VIM and Electronics (option TNS) at the University of Nice-Sophia Antipolis (15h), for the Masters 1 Mass and Math at the University of Nice-Sophia Antipolis (16h), and for the Masters 1 course 'Image processing' at ENS Lyon/UNSA (3h).
- Josiane Zerubia was director of the module 'Stochastic models in image processing' for the Masters 2 course VIM at the University of Nice-Sophia Antipolis (24h of which 12 taught). She was director of the course 'Advanced techniques for space imagery' at ISAE/SUPAERO (40h, of which 20h, taught). She also taught 3 hours at SAGEM DS and 3h for the Masters 1 course 'image processing' at ENS Lyon/UNSA, for which she is responsible for 12 hours.

9.5. PhDs

9.5.1. In progress

1. Alexis Baudour: ‘Segmentation and deconvolution of 3D images’, University of Nice-Sophia Antipolis. Defence expected in January 2009.
2. Aymen El Ghoul: ‘Phase fields for the extraction of networks from remote sensing images’, University of Nice-Sophia Antipolis. Defence expected in 2010.
3. Amhed Gamal-Eldin: ‘Marked point processes models of 3D objects: an application to the counting of King Penguins, University of Nice-Sophia Antipolis. Defence expected in 2011.
4. Giovanni Gherdovich: ‘Diffusion et birth and death dynamics for the optimization of marked point processes: an application to the counting of King Penguins’, University of Nice-Sophia Antipolis. Defence expected in 2011.
5. Maria S. Kulikova: ‘Shape recognition for scene analysis’, University of Nice-Sophia Antipolis. Defence expected in 2009.
6. Praveen Pankajakshan: ‘Blind biological image deconvolution’, University of Nice-Sophia Antipolis. Defense expected in 2009.

9.5.2. Defended in 2008

1. Alexandre Fournier: ‘Change detection and classification on urban scenes in remote sensing images’, ISAE/SUPAERO. Defended on October 31.
2. Ting Peng: ‘New higher-order active contour models, shape priors, and multiscale analysis: their application to road network extraction from very high resolution satellite images’, University of Nice-Sophia Antipolis and Graduate University of Chinese Academy of Sciences. Defended in Beijing on November 18.
3. Pierre Weiss: ‘Fast algorithms for convex optimization - Applications to image restoration and change detection’, University of Nice-Sophia Antipolis. Defended on November 21.
4. Olivier Zammit: ‘Forest fire damage assessment from a single satellite images using SVM techniques’, University of Nice-Sophia Antipolis. Defended on September 26.

9.6. Prizes

- Xavier Descombes was awarded a prize by the journal ‘La Recherche’ in the field ‘Human Health’. The prize was for work done in collaboration with Franck Plouraboué and Laurent Risser (IMFT Toulouse), Caroline Fonta (Cerco Toulouse) and Peter Cloetens (ESRF Grenoble). This work was partially supported by the ANR project ‘Micro-Réseaux’.

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