INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Odyssee

Biological and Computer Vision

Sophia Antipolis

THEME BIO

Activity Report

2006

Table of contents

1. Team

Head of project-team
Olivier Faugeras [DR, INRIA, site : INRIA Sophia, ENS Paris, HdR]

Vice-Head of project-team
Rachid Deriche [DR, INRIA, site : INRIA Sophia, HdR]
Renaud Keriven [ICPC, ENPC, site : ENS Paris and ENPC Champs-sur-Marne, HdR]

Administrative assistant
Marie-Cecile Lafont [TR, INRIA, site : INRIA Sophia]

Research scientists
Romain Brette [MdC, ENS Ulm, site : ENS Paris]
Bruno Cessac [MdC en détachement, de Université de Nice Sophia-Antipolis, site : INRIA Sophia-Antipolis]
Maureen Clerc [IPC, ENPC, site : INRIA Sophia]
Pierre Kornprobst [CR, INRIA, site : INRIA Sophia]
Theodore Papadopoulo [CR, INRIA, site : INRIA Sophia]
Thierry Viéville [DR, INRIA, site : INRIA Sophia, HdR]

Post-doctoral fellows
Christian Bénar [PostDoc, INRIA, site : Laboratoire Marseille and INRIA Sophia]
Sabir Jacquir [PostDoc, INRIA, site : INRIA Sophia, projet Odyssée and LIRMM (Montpellier), projet DEMAR]
Vincent Pavan [PostDoc, INRIA, site : ENS Paris]

Ph. D. students
Chariot Alexandre [Ph.D. student, ENPC grant, ENPC Champs-sur-Marne, From sept. 2005, site : ENPC Champs-sur-Marne]
Guillaume Charpiat [Ph.D. student, ENS grant, ENS Paris, from the 1st, October 2003 until 13th, December 2006, site : ENS Paris]
Thomas Deneux [Ph.D. student, ENS grant, ENS Paris, from the 1st, May 2003 until 9th, May 2006, site : ENS Paris]
Maxime Descoteaux [Ph.D. student, Canadian grant with INRIA Additional funding, Universite de Nice Sophia-Antipolis, from the 1st,February 2005, site : INRIA Sophia]
Romain Dupont [Ph.D. student, ENPC grant, ENPC Champs-sur-Marne, until the 14th, december 2006, site : ENPC Champs-sur-Marne]
Maria-Jose Escobar [Ph.D. student, Conicyt grant and INRIA allowance, Université de Nice Sophia-Antipolis, from the 1st, January 2006, site : INRIA Sophia]
Patrick Etyngier [Ph.D. student, ENPC grant, ENPC Champs-sur-Marne, From sept. 2004, site : ENPC Champs-sur-Marne]
Francois Grimbert [Ph.D. student, Grant half financed from the PACA Region and from INRIA fundings, Université de Nice Sophia-Antipolis, from the 1st, October 2004, site : INRIA Sophia]
Patrick Labatut [Ph.D. student, ENS grant, ENS Paris, from the 1st, October 2005, site : ENS Paris]
Christophe Lenglet [Ph.D. student, Grant half financed from the PACA Region and from INRIA fundings, Université de Nice Sophia-Antipolis, from the 1st, October 2003, site : INRIA Sophia]
Pierre Maurel [Ph.D. student, ENS grant, ENS, from the 1st, October 2005, site : ENS Paris]
Mickael Pechaud [Ph.D. student, ENS grant, ENS, from the 1st, October 2006, site : ENS Paris]
Adrien Wohrer [Ph.D. student, AMX, grant with INRIA additional funding, Ecole Polytechnique, from the 1st, September 2004, site : INRIA Sophia]
Alexandre Gramfort [Ph.D. student, en détachement INRIA, ENST, from the 1st, September 2006, site : ENS Paris]
Jérôme Piovano [Ph.D. Student, MESR and Monitorat grant, Universite de Nice Sophia-Antipolis, from the 1st, September 2004, site : INRIA Sophia]

Jonathan Touboul [Ph.D. student, en détachement INRIA, scientifique du contingeant, Université de Nice Sophia-Antipolis, from the 1st, July 2005, site : INRIA Sophia]
Sylvain Vallaghé [Ph.D. student, MESR and Monitorat grant, Universite de Nice Sophia-Antipolis, from the 1st, October 2005, site : INRIA Sophia]
Sandrine Chemla [Ph.D. student, MESR and Monitorat grant, Universite de Nice Sophia-Antipolis, from the 1st, November 2006, site : INRIA Sophia]
Demian Wassermann [Ph.D. student, INRIA CORDI allowance, from the 26th, November 2006 until 25th, November 2006, site : INRIA Sophia]

Graduate student interns

Sandrine Chemla [Graduate students intern INRIA, INRIA allowance, Université de Nice Sophia-Antipolis, from the 1st, March 2006 until 30th September 2006, site : INRIA Sophia]
Léonard Gérard [Graduate students intern INRIA, INRIA allowance, ENS Paris, from the 1st, October 2006 until 31st, March 2007, site : INRIA Sophia]
Ketty Nguyen [Graduate students intern INRIA, INRIA allowance, Université de Nice Sophia-Antipolis, from the 27th, March 2006 until 30th September 2006, site : INRIA Sophia]
Manh Tien Nguyen [Graduate students intern INRIA/DREI, INRIA allowance, Institut Polytechnique de Hanoï, from the 1st, March 2006 until 31st, August 2006, site : INRIA Sophia]
Demian Wassermann [Graduate students intern INRIA/DREI, INRIA allowance, Université de Buenos Aires, from the 15th, April 2006 until 15th, August 2006, site : INRIA Sophia]

Students interns

Angelino Elaine [Student Intern, INRIA allowance, Harvard College, USA, from the 16th, June 2006 until 15th August 2006, site : INRIA Sophia]
Benjamin Cohen [Student Intern, INRIA allowance, ENS Paris, from the 6th, June 2006 until 28th July 2006, site : INRIA Sophia]
Shaun Fitzgibbons [Student Intern, INRIA allowance, Harvard College, USA, from the 12th, June 2006 until 14th July 2006, site : INRIA Sophia]
Charf Eddin M'Sakni [Student Intern, INRIA allowance, Université de Nice Sophia-Antipolis, from the 1st, June 2006 until 31st July 2006, site : INRIA Sophia]
Pierre Repetto [Student Intern, INRIA allowance, Université de Nice Sophia-Antipolis, from the 1st, June 2006 until 31st July 2006, site : INRIA Sophia]
Emilien Tlapale [Student Intern, INRIA allowance for 1 month, Université de Nice Sophia-Antipolis, from the 15th, June 2006 until 15th August 2006, site : INRIA Sophia and INCM Marseille]
Nader Salmlan [Student Intern, INRIA allowance, Université de Nice Sophia-Antipolis, from the 1st, June 2006 until 31st July 2006, site : INRIA Sophia]
Peter Savadjief [Student Intern, McGill University, from the 1st, May 2006 until 5th, September 2006, site : INRIA Sophia]

Visiting scientists

Jan Kybic [Invited Researcher, PAI Procope, Czeck Technical University of Prague, from the 19th, June 2006 until 30th, June 2006, site : INRIA Sophia]
Maher Moakher [Invited Researcher, INRIA, University of Tunis, from the 10th, December 2006 until 16th, December 2006, site : INRIA Sophia]
Carl-Fredrik Westin [Invited Researcher, INRIA, Harvard Medical School, from the 11th, December 2006 until 15th, December 2006, site : INRIA Sophia]
Jean-Jacques Slotine [Invited Professor, INRIA, Massachusetts Intitute of Technology, from the 19th, September 2006 until 30th, October 2006, site : INRIA Sophia]
Andreas Spiegler [Ph.D. Visiting Student, Projet PROCOPE, Max Planck Institute, from the 1st, November 2006 until 30th, November 2006, site : INRIA Sophia]

2. Overall Objectives

2.1. Overall Objectives

The Odysséeteam is joint to INRIA, the Ecole Normale Supérieurein Paris and the CERTISlaboratory at Ecole Nationale des Ponts et Chaussées. It is located in Sophia-Antipolis, rue d'Ulm in Paris and in Champs-sur-Marne, close to Paris.

The scientific focus of the laboratory is the combined study of **computer and biological vision**. We think that a more detailed knowledge of the visual perception in humans and non-human primates can have a potential impact on algorithm design, performance evaluation and cues on such questions as how to interface an artificial vision system with people, possibly handicapped.

From a more general viewpoint and at another level, biological visual perception, in particular in non human primates and humans is poorly understood and modeled. Making progress in this understanding is a grand scientific and philosophic challenge that frames our work.

We conduct research in the following three main areas.

- Variational methods and partial differential equations for vision
- Observing the brain with functional imagery
- Modeling cortical activity

A detailed presentationof these different areas and related demos are available.

3. Scientific Foundations

3.1. Variational methods and partial differential equations for vision

The paradigm provided by variational methods and partial differential equations is interesting because it allows:

- to model mathematically a very large number of vision problems, e.g. segmentation, stereo, motion, object recognition, etc...
- to study the existence and uniqueness of the solutions of the resulting equations
- to design provably correct, sometimes efficient, algorithms for computing approximations to these solutions.

Under this banner we currently focus on two main items:

- **Feature integration**: we study feature integration from the computational and biological viewpoints and to propose mathematical formulations.
  - *shape from shading*: in the framework of the theory of the viscosity solutions of Hamilton-Jacobi equations, we study the integration of occluding boundaries, shadows, and textures.
  - *stereo*: we study the integration occluding boundaries, shadows, textures and shape.
  - *motion and stereo*: we study the integration of these two modalities.
- **Shape**: we study the problem of the acquisition of geometric models from image sequences from the computational and biological viewpoints and propose mathematical formulations. The representation of 3D shapes, deterministic and stochastic, the learning of these representations and, in connection with our work on feature integration, their use for segmentation and recognition are research that we currently actively pursue.

3.2. Functional imaging for observing brain activity

We focus on Magnetic Resonance Imaging (MRI), Electro-encephalography (EEG) and Magneto-encephalography (MEG).

- Within MRI we use three main modalities:
  - *Functional Magnetic Resonance Imaging*(fMRI) provides a measure of part of the brain activity causing variations in the blood flow and correlated to neuronal activity. The spatial resolution is, in the best cases, of the order of one millimeter, the temporal resolution of the order of a tenth of a second.
  - *Diffusion Magnetic Resonance Imaging*(dMRI) provides a measure of the amount of water molecules in biological tissues which relates to the structure of nervous fibers connecting different brain structures and, probably, to the electrical conductivity of the tissues.
  - *Anatomical Magnetic Resonance Imaging*(aMRI) provides implicitely a geometric description of the brain structures, e.g. the cortex, which can be extracted through segmentation.
- EEG and MEG which we collectively call MEEG provide measurements which are very directly correlated to the electrical activity of the brain with a spatial resolution of the order of one centimeter and temporal resolution of the order of one millisecond. The three modalities appear as complementary in terms of their resolutions and of the information they can recover.

Under this banner, we currently focus on the following six items:

- The spatio-temporal modelling of fMRI signals in order to obtain brain activation maps more relevant than those provided by currently available software.
- The spatio-temporal modelling of MEEG data.
- The use of dMRI for describing some aspects of brain connectivity and improve the physical models of electrical conductivity that are used in MEEG.
- The analysis of the existence and uniqueness of a solution to the MEEG inverse problem, i.e. the problem of the computation of the electrical activity of the brain that best explains the measurements.
- The development of new numerical methods for solving this problem.
- The integration of these three modalities to study visual perception in humans and monkeys.

3.3. Modeling brain activity

We are also studying cortical activity at a finer level by fitting models of groups of neurons to the measured fMRI and MEEG activities and/or to microelectrode recordings. Our goal is twofold:

- The use of models of cortical columns in analyzing the fMRI and MEEG activities goes beyond the classical electric dipole model and allows to put forward the computational aspect of this activity. It may also help us to better constrain the inverse MEEG problem.
- Such a description also ties in naturally with dynamical systems and possibly partial differential equations. There is a fascinating potential for coupling this line of research with the one in area I.

In order to initiate this activity we now study, considering a few general computational mechanisms (classification and categorisation, trajectory generation), to which extend it is possible to develop biologically plausible mechanisms which implement such functionnalities.

4. Application Domains

Our research is mostly targeted toward the acquisition of new fundamental knowledge about the brain but there are two applications that we keep in mind for the mid- and long term.

- Epilepsy: trough our collaborations with Pr. Chauvel's group in La Timone, Marseille, we are applying our work on source localization (Pole 2) on MR image processing and analysis (Poles 1 and 2) and our work on neural mass models (Pole 3) to epileptic patients. The arrival in early 2007 of the MEG machine there will strengthen further this collaboration.
- Brain Computer Interface (BCI): our acquisition in 2007 in Sophia-Antipolis and Champs-sur-Marne of two EEG systems will allow us to start exploring this interesting application of our research and will certainly foster new avenues.

5. New Results

5.1. Variational methods and partial differential equations for vision

5.1.1. Computer Vision and P.D.E.: Theoretical foundations

Participants: Gilles Aubert, Pierre Kornprobst.

Partial differential equations and variational methods were introduced into image processing about 15 years ago, and intensive research has been carried out since then. The main goal of this work is to present the variety of image analysis applications and the precise mathematics involved. It is intended for two audiences. The first is the mathematical community, to show the contribution of mathematics to this domain and to highlight some unresolved theoretical questions. The second is the computer vision community, to present a clear, self-contained, and global overview of the mathematics involved in image processing problems.

During the four years since the publication of the first edition, there has been substantial progress in the range of image-processing applications covered by the PDE framework. The main goals of the second edition are to update the first edition by giving a coherent account of some of the recent challenging applications, and to update the existing material. In addition, this book provides the reader with the opportunity to make his own simulations with a minimal effort. To this end, programming tools are made available, which will allow the reader to implement and test easily some classical approaches.

Publications: [1]

5.1.2. Explicit Reconstruction for Image Inpainting

Participants: Pierre Kornprobst, Gilles Aubert.

Image inpainting refers to techniques which allow to fill in a gap Omega given the intensities around it. In this paper, we focus on geometric image inpainting for which several PDE based models have been proposed. Most of them rely on a transport or/and a diffusion equation of the intensity inside Omega. The direction of the reconstructed isophotes and the gray levels are generally computed in a coupled way. Instead, we propose in this paper a two step approach. First we estimate the tangents of the missing isophotes using a tensor field diffusion process. Then we simply recover the gray levels by integrating along integral curves of the tensors principal eigenvectors. Such an approach has very few parameters to tune and we illustrate its performance on several synthetic and real examples.

Publications: [76]

5.1.3. Multi-Valued Motion Fields Estimation for Transparent Sequences with a Variational Approach

Participants: Alonso Ramirez-Manzanares, Mariano Rivera, Pierre Kornprobst, Francois Lauze.

Most optical flow algorithms provide flow fields as single valued functions of the image sequence domains. Only a very few of them attempt to recover multiple motion vectors at given location, which is necessary when some transparent layers are moving independently. In this report we introduce a novel framework for modeling multivalued motion fields, and propose an energy minimization formulation with smoothing terms and terms implementing velocity model competition. We illustrate the capabilities of this approach on synthetic and real sequences.

Publications: [80]

5.1.4. Efficient Segmentation of Piecewise Smooth Images

Participants: Jerome Piovano, Mikael Rousson, Théodore Papadopoulo.

The extraction of piecewise smooth regions from an image is of great interest in different domains, and still remains a challenging task. For example, this is very useful in medical imaging where organs or structures of interest are often characterized by smooth intensity regions. This problem has been formulated as the minimization of an energy by Mumford and Shah.

In this work, we propose a fast and robust segmentation model for piecewise smooth images. Rather than modeling each region with global statistics, we introduce local statistics in an energy formulation. The shape gradient of this new functional gives a contour evolution controlled by local averaging of image intensities inside and outside the contour. To avoid the computational burden of a direct estimation, we express these terms as the result of convolutions. This makes an efficient implementation via recursive filters possible, and gives a complexity of the same order as methods based on global statistics. This approach leads to results similar to the general Mumford-Shah model but in a faster way, without solving a Poisson partial differential equation at each iteration.

5.1.5. A Multiphase Level Set based Segmentation Framework with Pose Invariant Shape Prior

Participants: Rachid Deriche, Michael Fussenegger, Axel Pinz.

Level set based segmentation has been used with and without shape priors, to approach difficult segmentation problems in several application areas. This work, published in ACCV 2006, addresses two limitations of the classical level set based segmentation approaches: They usually deliver just two regions - one foreground and one background region, and if some prior information is available, they are able to take into account just one prior but not more. In these cases, one object of interest is reconstructed but other possible objects of interest and unfamiliar image structures are suppressed.

The approach we propose in this work can simultaneously handle an arbitrary number of regions and competing shape priors. Adding to that, it allows the integration of numerous pose invariant shape priors, while segmenting both known and unknown objects. Unfamiliar image structures are considered as separate regions. We use a region splitting to obtain the number of regions and the initialization of the required level set functions. In a second step, the energy of these level set functions is robustly minimized and similar regions are merged in a last step. All these steps are considering given shape priors. Experimental results demonstrate the method for arbitrary numbers of regions and competing shape priors.

Publications: [51]

5.1.6. Multi-region level set tracking with transformation invariant shape priors

Participants: Rachid Deriche, Michael Fussenegger, Axel Pinz.

Tracking of regions and object boundaries in an image sequence is a well studied problem in image processing and computer vision. So far, numerous approaches tracking different features of the objects (contours, regions or points of interest) have been presented. Most of these approaches have problems with robustness. Typical reasons are noisy images, objects with identical features or partial occlusions of the tracked features.

In this work, published in ACCV:2006, we propose a novel level set based tracking approach, that allows robust tracking on noisy images. Our framework is able to track multiple regions in an image sequence, where a level set function is assigned to every region. For already known or learned objects, transformation invariant shape priors can be added to ensure a robust tracking even under partial occlusions. Furthermore, we introduce a simple decision function to maintain the desired topology for multiple regions. Experimental results demonstrate the method for arbitrary numbers of shape priors. The approach can even handle full occlusions and objects which are temporarily hidden in containers.

Publications: [53], [52]

5.1.7. Bone Enhancement Filtering: Application to Sinus Bone Segmentation and Simulation of Pituitary Gland Surgery

Participants: Maxime Descoteaux, Michel Audette, Kiyoyuki Chinzei, Kaleem Siddiqi.

Simulation of pituitary gland surgery raises many interesting challenges since a precise classification of all tissues (soft tissues, vessels, bones) in the pituitary gland area is needed to create a realistic simulator for endoscopic surgery. In particular, bone structures are very thin and have diffusive edges in the CT dataset. Thus, the common method of thresholding the data is insufficient and produces incomplete segmentations that have many holes. In this paper, we focus on a better segmentation of paranasal sinus bones. We present a novel multi-scale bone enhancement measure that can be used to drive a geometric flow to segment any sheet-like structure. The measure is designed to capture sheet-like structure using the local shape information from the eigenvalue decomposition of the Hessian matrix. It is maximum on the center sheet of the bone structure and provides local estimates of the width and orientation of the bone structure. These can be used to create a vector field which is orthogonal to the bone boundaries so that the flux maximizing flow algorithm can be applied to recover the bone structure. Hence, the sheetness measure has the essential properties to be incorporated in the computation of anatomical models for the simulation of pituitary surgery, enabling it to better account for the presence of sinus bones. We present synthetic examples that validate our approach quantitatively and show a comparison between the existing segmentation techniques of paranasal sinus CT data.

Publications: [24] [86]

Links: MICCAI presentation : http://www-sop.inria.fr/odyssee/team/Maxime.Descoteaux/docs/descoteaux_miccai05.pdf

5.1.8. Shape and Optimization in Computer Vision

Participant: Renaud Keriven.

In this "Habilitation a Diriger les Recherches" work, we review our latest work under the point of view of Optimization, Shape and ... Shape Optimization.

Publications: [15]

5.1.9. Stochastic Active Contours

Participants: Olivier Juan, Gheorghe Postelnicu, Renaud Keriven.

Based on recent work on Stochastic Partial Differential Equations (SPDEs), we present a simple and well-founded method to implement the stochastic evolution of a curve. First, we explain why great care should be taken when considering such an evolution in a Level Set framework. To guarantee the well-posedness of the evolution and to make it independent of the implicit representation of the initial curve, a Stratonovich differential has to be introduced. To implement this differential, a standard Ito plus drift approximation is proposed to turn an implicit scheme into an explicit one. Subsequently, we consider shape optimization techniques, which are a common framework to address various applications in Computer Vision, like segmentation, tracking, stereo vision etc. The objective of our approach is to improve these methods through the introduction of stochastic motion principles. The extension we propose can deal with local minima and with complex cases where the gradient of the objective function with respect to the shape is impossible to derive exactly. Finally, as an application, we focus on image segmentation methods, leading to what we call Stochastic Active Contours.

Publications: [27], [14]

5.1.10. Generalized Gradients: Priors on Minimization Flows

Participants: Guillaume Charpiat, Pierre Maurel, Jean-Philippe Pons, Renaud Keriven, Olivier Faugeras.

This work tackles an important aspect of the variational problem underlying active contours: optimization by gradient flows. Classically, the definition of a gradient depends directly on the choice of an inner product structure. This consideration is largely absent from the active contours literature. Most authors, explicitely or implicitely, assume that the space of admissible deformations is ruled by the canonical L2 inner product. The classical gradient flows reported in the literature are relative to this particular choice. Here, we investigate the relevance of using (i) other inner products, yielding other gradient descents, and (ii) other minimizing flows not deriving from any inner product. In particular, we show how to induce different degrees of spatial consistency into the minimizing flow, in order to decrease the probability of getting trapped into irrelevant local minima. We report numerical experiments indicating that the sensitivity of the active contours method to initial conditions, which seriously limits its applicability and efficiency, is alleviated by our application-specific spatially coherent minimizing flows. We show that the choice of the inner product can be seen as a prior on the deformation fields and we present an extension of the definition of the gradient toward more general priors (to appear in IJCV).

Publications: [74] [11]

5.1.11. Point correspondences and tangential velocities in the level set framework

Participants: Jean-Philippe Pons, Gerardo Hermosillo, Renaud Keriven, Olivier Faugeras.

In this work, we overcome a major drawback of the level set framework: the lack of point correspondences. We maintain explicit backward correspondences from the evolving interface to the initial one by advecting the initial point coordinates with the same speed as the level set function. Our method leads to a system of coupled Eulerian partial differential equations. We show in a variety of numerical experiments that it can handle both normal and tangential velocities, large deformations, shocks, rarefactions and topological changes. Applications are many in computer vision and elsewhere since our method can upgrade virtually any level set evolution. We complement our work with the design of non zero tangential velocities that preserve the relative area of interface patches; this feature may be crucial in such applications as computational geometry, grid generation or unfolding of the organs' surfaces, e.g. brain, in medical imaging (to appear in the Journal of Computational Physics).

Publications: [89], [89]

Links:

[Demo page : http://www-sop.inria.fr/odyssee/research/pons-hermosillo-etal:03/demo/index.html

5.1.12. Distance-Based Shape Statistics

Participants: Guillaume Charpiat, Pierre Maurel, Renaud Keriven, Olivier Faugeras.

This article deals with statistics on sets of shapes. The approach is based on the Hausdorff distance between shapes. The choice of the Hausdorff distance between shapes is itself not fundamental since the same framework could be applied with another distance. We first define a smooth approximation of the Hausdorff distance and build non-supervised warpings between shapes by a gradient descent of the approximation. Local minima can be avoided by changing the scalar product in the tangent space of the shape being warped.When non-supervised warping fails, we present a way to guide the evolution with a small number of landmarks. Thanks to the warping fields, we can define the mean of a set of shapes and express statistics on them. Finally, we come back to the initial distance between shapes and use it to represent a set of shapes by a graph, which with the technic of graph Laplacian leads to a way of projecting shapes onto a low dimensional space.

Publications: [40]

5.1.13. Shape Warping and Shape Statistics

Participants: Guillaume Charpiat, Pierre Maurel, Renaud Keriven, Olivier Faugeras.

We propose a framework for dealing with two problems related to the analysis of shapes: the definition of the relevant set of shapes and that of defining a metric on it. Following a recent research monograph by Delfour and Zolesio, we consider the characteristic functions of the subsets of the plane and their distance functions. The L2 norm of the difference of characteristic functions, the L1 and the W1,2 norms of the difference of distance functions define interesting topologies, in particular that induced by the well-known Hausdorff distance. Because of practical considerations arising from the fact that we deal with image shapes defined on finite grids of pixels we restrict our attention to subsets of the plane of positive reach in the sense of Federer, with smooth boundaries of bounded curvature. For this particular set of shapes we show that the three previous topologies are equivalent. The next problem we consider is that of warping a shape onto another by infinitesimal gradient descent, minimizing the corresponding distance. Because the distance function involves an inf, it is not differentiable with respect to the shape. We propose a family of smooth approximations of the distance function which are continuous with respect to the Hausdorff topology, and hence with respect to the other two topologies. We compute the corresponding Gateaux derivatives. They define deformation flows that can be used to warp a shape onto another by solving an initial value problem. We show several examples of this warping and prove properties of our approximations that relate to the existence of local minima. We then use this tool to produce computational definitions of the empirical mean and covariance of a set of shape examples. They yield an analog of the notion of principal modes of variation.

Publications: [22] [84] [85]

5.1.14. Reconciling Landmarks and Level Sets

Participants: Pierre Maurel, Renaud Keriven, Olivier Faugeras.

Shape warping is a key problem in statistical shape analysis. This paper proposes a framework for geometric shape warping based on both shape distances and landmarks. Our method is compatible with implicit representations and a matching between shape surfaces is provided at no additional cost. It is, to our knowledge, the first time that landmarks and shape distances are reconciled in a pure geometric level set framework. The feasibility of the method is demonstrated with two- and three-dimensional examples. Combining shape distance and landmarks, our approach reveals to need only a small number of landmarks to obtain improvements on both warping and matching.

Publications: [61], [88]

5.1.15. Robust Segmentation of Hidden Layers in Video Sequences

Participants: Olivier Juan, Romain Dupont, Renaud Keriven.

We propose a robust method for extracting motion layers in video sequences. Taking advantage of temporal continuity, our framework considers both the visible and the hidden parts of each layer in order to increase robustness. Moreover, the hidden parts of the layers are recovered, which could be of great help in many high level vision tasks. Modeling the problem as a labeling task, we state it in a MRF-optimization framework and solve it with a graph-cut algorithm.

Publications: [13], [45], [75]

5.1.16. Fast Level Set Multi-View Stereo on Graphics Hardware

Participants: Patrick Labatut, Renaud Keriven, Jean-Philippe Pons.

We show the importance and feasibility of much faster multi-view stereo reconstruction algorithms relying almost exclusively on graphics hardware. Reconstruction algorithms have been steadily improving in the last few years and several state-of-the-art methods are nowadays reaching a very impressive level of quality. However all these modern techniques share a very lengthy computational time that completely forbids their more widespread use in practical setups: the typical running time of such algorithms range from one to several hours. One possible solution to this problem seems to lie in the use of graphics hardware: more and more computer vision techniques are taking advantage of the availability of cheap computational horsepower and divert graphics hardware from its original purpose to accelerate the early stages of some algorithms. We present here an almost full implementation on graphics hardware of a multi-view stereo algorithm based on surface deformation by a PDE: this algorithm tries to minimize the error between input images and predicted ones by reprojection via the surface. As it mainly works on whole images, it is well suited for graphics hardware. We show how we succeeded to bring the whole reconstruction time within minutes. Results for synthetic and real data sets are presented with computational times and compared with those of other state-of-the-art algorithms.

Publications: [57], [58]

Links:

Multi-View Stereo Evaluation : http://vision.middlebury.edu/mview/

5.1.17. Fast and efficient dense variational stereo on GPU

Participants: Julien Mairal, Alexandre Chariot, Renaud Keriven.

Thanks to their high performance and programmability, the latest graphics cards can now be used for scientific purpose. They are indeed very efficient parallel Single Instruction Multiple Data (SIMD) machines. This new trend is called General Purpose computation on Graphics Processing Unit. Regarding the stereo problem, variational methods based on deformable models provide dense, smooth and accurate results. Nevertheless, they prove to be slower than usual disparity-based approaches. In this paper, we present a dense stereo algorithm, handling occlusions, using three cameras as inputs and entirely implemented on a Graphics Processing Unit. Experimental speedups prove that our approach is efficient and perfectly adapted to the GPU, leading to nearly video frame rate reconstruction.

Publications: [60]

5.1.18. Modelling Dynamic Scenes by Registering Multi-View Image Sequences

Participants: Jean-Philippe Pons, Renaud Keriven, Olivier Faugeras.

We have designed a new variational method for multi-view stereovision and non-rigid three-dimensional motion estimation from multiple video sequences. Our method minimizes the prediction error of the shape and motion estimates. Both problems then translate into a generic image registration task. The latter is entrusted to a similarity measure chosen depending on imaging conditions and scene properties. In particular, our method can be made robust to appearance changes due to non-Lambertian materials and illumination changes. Our method results in a simpler, more flexible, and more efficient implementation than existing deformable surface approaches. We have implemented our stereovision method in the level set framework and we have obtained results comparing favorably with state-of-the-art methods, even on complex non-Lambertian real-world images including specularities and translucency. Using our algorithm for motion estimation, we have successfully recovered the 3D motion of a non-rigid event and we have synthesized time-interpolated 3D sequences. To appear in IJCV.

Publications: [91], [90]

Links:

Demo page : http://www-sop.inria.fr/odyssee/research/pons-keriven-etal:04b/demo/index.html

5.2. Functional imaging for observing brain activity

5.2.1. Use of nonlinear models in fMRI analysis

Participants: Thomas Deneux, Olivier Faugeras.

We propose methods to adapt the usual fMRI analysis tools to infere the cerebral activity from a linear context to the larger framework of nonlinear dynamical models. More specifically we use a model parameter estimation scheme relying on the integration of differential systems, and define a statistic Fisher test for testing the existence of a response to an experimental condition. This Fisher test can also be used to compare different hemodynamic models. These methods have been used on a specific dataset acquired at the La Timone hospital in Marseille.

Publications: [23]

5.2.2. EEG-fMRI fusion

Participants: Thomas Deneux, Christian Bénar, Olivier Faugeras.

We propose a new approach to integrate multimodal functional data, and in particular simultaneous functional Magnetic Resonnance Imaging (fMRI) and Electroencephalography (EEG) acquisitions. Our method relies on biophysiological models that relate the different modalities measures to a common neural activity. The EEG model is based on the propagation of currents through the different head tissues, and can be formalized as a linear transformation, whose matrix is computed via the Boundary Elements Method. The fMRI model we used is the so-called "Balloon Model", which summarizes the energy demand, blood and blood oxygen dynamics implied in the measures. The fusion algorithm relies on Kalman filtering techniques; its novelty is to allow integration of both spatial and temporal aspects of the EEG and fMRI.

Publications: [42]

5.2.3. A Fast and Rigorous Anisotropic Smoothing Method for DT-MRI

Participants: Carlos Alberto Castaño Moraga, Christophe Lenglet, Rachid Deriche, Juan Ruiz-Alzola.

Tensors are nowadays an increasing research domain in different areas, especially in image processing, motivated for example by diffusion tensor magnetic resonance imaging (DT-MRI). Up to now, algorithms and tools developed to deal with tensors were founded on the assumption of a matrix vector space with the constraint of remaining symmetric positive definite matrices. On the contrary, our approach is grounded on the theoretically well-founded differential geometrical properties of the space of multivariate normal distributions, where it is possible to define an affine-invariant Riemannian metric and express statistics on the manifold of symmetric positive definite matrices. In this paper, we focus on the contribution of these tools to the anisotropic filtering and regularization of tensor fields. To validate our approach we present promising results on both synthetic and real DT-MRI data.

Publications: [38], [21] [16]

5.2.4. DTI Segmentation by Statistical Surface Evolution

Participants: Christophe Lenglet, Mikael Rousson, Rachid Deriche.

We address the problem of the segmentation of cerebral white matter structures from diffusion tensor images (DTI). A DTI produces, from a set of diffusion-weighted MR images, tensor-valued images where each voxel is assigned with a 3*3 symmetric, positive-definite matrix. This second order tensor is simply the covariance matrix of a local Gaussian process, with zero-mean, modeling the average motion of water molecules. As we will show in this paper, the definition of a dissimilarity measure and statistics between such quantities is a nontrivial task which must be tackled carefully. We claim and demonstrate that, by using the theoretically well-founded differential geometrical properties of the manifold of multivariate normal distributions, it is possible to improve the quality of the segmentation results obtained with other dissimilarity measures such as the Euclidean distance or the Kullback-Leibler divergence. The main goal of this paper is to prove that the choice of the probability metric, i.e., the dissimilarity measure, has a deep impact on the tensor statistics and, hence, on the achieved results. We introduce a variational formulation, in the level-set framework, to estimate the optimal segmentation of a DTI according to the following hypothesis: Diffusion tensors exhibit a Gaussian distribution in the different partitions. We must also respect the geometric constraints imposed by the interfaces existing among the cerebral structures and detected by the gradient of the DTI. We show how to express all the statistical quantities for the different probability metrics. We validate and compare the results obtained on various synthetic data-sets, a biological rat spinal cord phantom and human brain DTIs.

Publications: [29], [59], [77]

5.2.5. Statistics on the Manifold of Multivariate Normal Distributions: Theory and Application to Diffusion Tensor MRI Processing

Participants: Christophe Lenglet, Mikael Rousson, Rachid Deriche, Olivier Faugeras.

This work is dedicated to the statistical analysis of the space of multivariate normal distributions with an application to the processing of Diffusion Tensor Images (DTI). It relies on the differential geometrical properties of the underlying parameters space, endowed with a Riemannian metric, as well as on recent works that led to the generalization of the normal law on Riemannian manifolds. We review the geometrical properties of the space of multivariate normal distributions with zero mean vector and focus on an original characterization of the mean, covariance matrix and generalized normal law on that manifold. We extensively address the derivation of accurate and efficient numerical schemes to estimate these statistical parameters. A major application of the present work is related to the analysis and processing of DTI datasets and we show promising results on synthetic and real examples.

Publications: [30], [78]

5.2.6. *Control Theory and Fast Marching Methods for Brain Connectivity Mapping*

Participants: Emmanuel Prados, Christophe Lenglet, Jean Philippe. Pons, Nicolas Wotawa, Rachid Deriche, Olivier Faugeras, Stefano Soatto.

We propose a novel, fast and robust technique for the computation of anatomical connectivity in the brain. Our approach exploits the information provided by Diffusion Tensor Magnetic Resonance Imaging (or DTI) and models the white matter by using Riemannian geometry and control theory. We show that it is possible, from a region of interest, to compute the geodesic distance to any other point and the associated optimal vector field. The latter can be used to trace shortest paths coinciding with neural fiber bundles. We also demonstrate that no explicit computation of those 3D curves is necessary to assess the degree of connectivity of the region of interest with the rest of the brain. We finally introduce a general local connectivity measure whose statistics along the optimal paths may be used to evaluate the degree of connectivity of any pair of voxels. All those quantities can be computed simultaneously in a Fast Marching framework, directly yielding the connectivity maps. Apart from being extremely fast, this method has other advantages such as the strict respect of the convoluted geometry of white matter, the fact that it is parameter-free, and its robustness to noise. We illustrate our technique by showing results on real and synthetic datasets. OurGCM(Geodesic Connectivity Mapping) algorithm is implemented in C++ and will be soon available on the web.

Publications: [63], [79] [17]

5.2.7. *Apparent Diffusion Coefficients from High Angular Resolution Diffusion Imaging: Estimation and Applications*

Participants: Maxime Descoteaux, Elaine Angelino, Shaun Fitzgibbons, Rachid Deriche.

High angular resolution diffusion imaging has recently been of great interest in characterizing non-Gaussian diffusion processes. One important goal is to obtain more accurate fits of the apparent diffusion processes in these non-Gaussian regions, thus overcoming the limitations of classical diffusion tensor imaging. This paper presents an extensive study of high-order models for apparent diffusion coefficient estimation and illustrates some of their applications. Using a meaningful modified spherical harmonics basis to capture the physical constraints of the problem, a new regularization algorithm is proposed. The new smoothing term is based on the Laplace-Beltrami operator and its closed form implementation is used in the fitting procedure. Next, the linear transformation between the coefficients of a spherical harmonic series of order L and independent elements of a rank-L high-order diffusion tensor is explicitly derived. This relation allows comparison of the state-of-the-art anisotropy measures computed from spherical harmonics and tensor coefficients. Published results are reproduced accurately and it is also possible to recover voxels with isotropic, single fiber anisotropic, and multiple fiber anisotropic diffusion. Validation is performed on apparent diffusion coefficients from synthetic data, from a biological phantom, and from a human brain dataset.

Publications: [25], [44], [87]

Links:

Magnetic Resonance in Medicine (MRM): http://www3.interscience.wiley.com/cgi-bin/abstract/112661185/ABSTRACT

5.2.8. *A fast and robust ODF estimation algorithm in Q-ball imaging*

Participants: Maxime Descoteaux, Elaine Angelino, Shaun Fitzgibbons, Rachid Deriche.

We propose a simple and straightforward analytic solution for the Q-ball reconstruction of the diffusion orientation distribution function (ODF) of the underlying fiber population. First, the signal is modeled with a high order spherical harmonic series using a Laplace-Beltrami regularization method which leads to an elegant mathematical simplification of the Funk-Radon transform using the Funk-Hecke formula. In doing so, we obtain a fast and robust model-free ODF approximation. We validate the accuracy of the estimation quantitatively against synthetic data generated from the multi-tensor model and show that our estimated ODF can recover known multiple fiber regions in a biological phantom and in the human brain.

Publications: [43]

5.2.9. *Analytic ODF Estimation and Validation in Q-Ball Imaging*

Participants: Maxime Descoteaux, Rachid Deriche, Peter Savadjiev, Jennifer Campbell, Bruce Pike, Kaleem Siddiqi.

Q-Ball Imaging (QBI) is a high angular resolution diffusion imaging (HARDI) reconstruction method to infer fiber bundles with crossing, kissing or diverging configurations, with advantages over diffusion tensor imaging (DTI) in these situations. QBI seeks to reconstruct the orientation distribution function (ODF) of the underlying fiber population. We present a fast analytic solution to the ODF reconstruction and compare the ODF reconstructions using the original QBI technique of D. Tuch on a biological phantom and on in-vivo human brain data. This abstract shows that the analytic solution and the standard QBI qualitatively agree with ground truth as evidenced by the crossings in the phantom and our knowledge of human anatomy.

Publications: [44]

5.2.10. *Simultaneous estimation of single dipolar source and head tissue conductivities*

Participants: Sylvain Vallaghé, Maureen Clerc, Théodore Papadopoulo, Jean-Michel Badier.

Knowledge of precise conductivity values of head tissues is important for inverse source problem in MEG/EEG : significant error on conductivities can largely affect accuracy of a source estimate. The three-layer isotropic conductivity model is one of the most common for source reconstruction in EEG and MEG. Although it is very simple, as it describes the head as three nested regions (brain, skull, scalp) with constant and isotropic conductivities, the classical normalized conductivity values of 1, 0.0125, 1 for brain, skull and scalp are being abandoned. Indeed, methods of conductivity estimation in vivo such as EIT show a wide variability among subjects, especially for skull conductivity.

In EIT, a small electric current is injected on the scalp while the subject is idle, and EEG data is recorded in the same time. Then conductivity values are inferred from knowledge of current sources and scalp potential. In this work, we study a new approach to estimate conductivities in vivo. We hope to avoid several drawbacks of EIT methods : first the current injection is slightly invasive, and moreover the skull has a reflecting effect. The greater part of injected current remains in the scalp, and therefore the corresponding EEG data is not very relevant for brain conductivity estimation. This is why we consider a current source localized inside the brain, and coming from a sensory stimulus, such as finger stimulation. This type of primary sensory response is well modeled by a single current dipole. The advantage of this model is that the inverse source problem is well-posed, without having to add regularization or a priori hypothesis. So our approach is to estimate simultaneously a single dipolar source and the conductivity values from EEG data only. Such a method has already been proposed for spherical head models, and with additional MEG data. The use of EEG data only makes our approach much simpler ; and in order to improve accuracy we work with a realistic head model.

We study the method with simulations of EEG evoked potentials computed on real meshes, using a symmetric BEM formulation for the forward problem. The inverse problem, corresponding to dipolar source and conductivity reconstruction, is modeled as the minimization of least square error between the EEG measurements and the prediction of the forward problem. The robustness of the method is tested by adding noise to EEG measurements simulations. Finally, to validate the method, we plan to realize a real experiment, and to compare the results to conductivity estimates given by EIT on the same subjects.

Publications: [65]

5.2.11. Generalized head models for MEG/EEG: boundary element method beyond nested volumes

Participants: Jan Kybic, Maureen Clerc, Olivier Faugeras, Renaud Keriven, Théodore Papadopoulo.

Accurate geometrical models of the head are necessary for solving the forward and inverse problems of magneto- and electro-encephalography (MEG/EEG). Boundary element methods (BEMs) require a geometrical model describing the interfaces between different tissue types. Classically, head models with a nested volume topology have been used. In this paper, we demonstrate how this constraint can be relaxed, allowing us to model more realistic head topologies. We describe the symmetric BEM for this new model. The symmetric BEM formulation uses both potentials and currents at the interfaces as unknowns and is in general more accurate than the alternative double-layer formulation.

Publications: [28]

5.2.12. Implicit Meshes for MEG/EEG Forward Problem with 3D Finite Element Method

Participants: Théo Papadopoulo, Sylvain Vallaghé, Maureen Clerc.

OBJECTIVE: 3D Finite Element (FE) methods for EEG and MEG can cope with very realistic head models including the anisotropic effects of compartiments such as skull and white matter. Their use is limited in practice because of their computational cost and the complexity of the steps required for constructing accurate mesh representations of the head. This work proposes a method that builds FE matrices directly from segmentations without relying on such intermediate representations, which greatly simplifies volumic FE matrix assembly computations.

FRAMEWORK: In the field of image processing, levelset methods have become very popular in the recent years. These methods encode interfaces implicitly as zero-crossings of an image whose values are the signed distances to the interface. Manipulating the interface is achieved by changing the image values. The interfaces obtained by segmenting MR images can be represented in such a way (e.g., the grid associated to the MR image can be used). We assume that the continuous image space is obtained from the discrete space using Q1 elements (piecewise trilinear interpolation over voxels).

METHOD: With the levelset segmentation, every voxel is labeled with the tissues it contains and for voxels that overlap two head compartments, the levelset provides an implicit mathematical model of the interface. The FE matrix coefficients for each compartment are computed directly by integrating the proper polynomial functions over the respective domains delimited by the levelset function. This leads to discretizations that are regular (the image grid is used), compact (if S is the number of voxels of the MR image, the size of the data structure for the mesh cannot exceed $N \times S$, where $N = 7$ for isotropic meshes and $N = 13$ for anisotropic grids or conductivities) and easy to handle (solutions are simply 3D images). Furthermore, many numerical optimization schemes such as parallelization or multiscale techniques become much simpler than with traditional tetrahedral meshes.

Publications: [62]

5.2.13. EEG source localization by best approximation of functions

Participants: Maureen Clerc, Théo Papadopoulo, Juliette Leblond, Jean-Paul Marmorat, Laurent Baratchart.

Dipolar source models allow to express the source with a small number of parameters, and dipole fitting methods are routinely used in many applicative settings. The main drawback of such methods resides in their instability according to the number of dipoles in the model, particularly when the different sources present coherent time-courses. We are studying the applicability of Best Rational Approximation techniques to dipolar source estimation. This should lead to a new method, which does not require any assumption on the number of sources nor on the decorrelation of their time-courses. In a first step, we assume the geometry to be spherical, and the electric potential and normal current flow to be known on the sphere delimiting the brain compartment. This requires to solve a cortical mapping problem, a difficult issue for which we have recently proposed two novel solutions (one based on Boundary Elements, and the other on Best Constrained Approximation). The source localization inside the sphere relies on a Best Rational Approximation technique on circular slices. Using the values of the potential and the normal current on the boundary, a projection of the potential on spherical harmonics allows to filter outside sources. This procedure is related to the Source Signal Separation in MEG. This provides a function V-. The squared function V-^2, considered on a disk sliced out of a sphere, is rational with a triple pole at a position, related to the dipolar parameters. From the values of V-^2 on the boundary, compute the positions of its triple pole on a set of parallel disks. This is where best rational approximation schemes can efficiently be used. A careful analysis of the respective positions of the poles across the disks provides the position and moment of the dipolar source. Applied in the case of several sources, V-^2 is no longer rational in the disks but admits branching singularities.However, the method still provides us with poles that converge to their positions, from which the dipole positions can be recovered. Dipolar moments may also be estimated using residues computations. The first results of this algorithm concern for a 3-sphere model . Cortical mapping is performed with the Boundary Element method, and the source position estimated by rational approximation is compared to the true position. We find that the difference between them is quite small. Experiments are being conducted to dynamic situations involving several sources, and an extension is also being considered to more realistic geometries.

Publications: [41]

5.2.14. Topography-Time-Frequency Decompositions for single-event M/EEG analysis

Participants: Christian Bénar, Maureen Clerc, Théo Papadopoulo.

Events measurable in EEG and MEG, such as event-related potentials and fields, oscillations or epileptic spikes, often present significant variability across different realizations. This variability may convey useful information, but is lost in the classical procedure of signal averaging. Our goal is to design a general method for modeling and tracking M/EEG events, applicable for both low and high frequencies and taking into account the spatial structure (topography) of the events. We investigated the extraction of spatial and time-frequency patterns from the data in order to build topography-time-frequency templates.

Publications: [36], [37]

5.2.15. Hemodynamic models investigation in Optical Imaging

Participants: Thomas Deneux, Ivo Vanzetta, Olivier Faugeras, Guillaume Masson.

The mechanisms that relate cerebral activity to the signals measured in functional Magnetic Resonance Imaging (fMRI) involve a number of intermediary quantities such as oxygen metabolism, vascular blood flow, blood volume and hemoglobin oxygenation. Thanks to our collaboration with the Cognitive Vision team in the INCM, CNRS Marseille, laboratory head Guillaume Masson, and in particular with Ivo Vanzetta, who set the first Optical Imaging center on the behaving monkey in Europe, we were able to improve so-called "hemodynamic" models. In particular, we proposed that the blood flow dynamic does not relate linearly to neural activity. This work is described in the PhD thesis [12], chapter 6.

5.2.16. Blood flow recordings using high resolution Optical Imaging

Participants: Thomas Deneux, Ivo Vanzetta, Stéphane Fisher, Amiram Grinvald, Guillaume Masson, Olivier Faugeras.

We propose a new method to estimate blood velocity in the vessels on the surface of the brain, based on intrinsic Optical Imaging, instead of the costly laser-doppler probe technique commonly used. The method relies on the fact that blood isn't homogeneous at a short scale; rather its hemoglobin concentration fluctuates along single vessels, since hemoglobin molecules are packed in red blood cells (or clusters thereof). When recording the blood volume at the surface of the brain at a high sampling rate (200Hz), particle motion can be observed. We have developed an algorithm that estimates these motions, based either on the structure tensor or on the Gabor filter in 2D spatio-temporal images. This is also a collaboration with Ivo Vanzetta, at the INCM, CNRS Marseille. This work has been published in [66].

5.3. Modeling brain activity

5.3.1. Exact simulation of integrate-and-fire models with synaptic conductances

Participant: Romain Brette.

Computational neuroscience relies heavily on the simulation of large networks of neuron models. There are essentially two simulation strategies: 1) using an approximation method (e.g. Runge-Kutta) with spike times binned to the time step; 2) calculating spike times exactly in an event-driven fashion. In large networks, the computation time of the best algorithm for either strategy scales linearly with the number of synapses, but each strategy has its own assets and constraints: approximation methods can be applied to any model but are inexact; exact simulation avoids numerical artefacts but is limited to simple models. Previous work has focused on improving the accuracy of approximation methods. In this paper we extend the range of models that can be simulated exactly to a more realistic model, namely an integrate-and-fire model with exponential synaptic conductances.

Publications: [20]

5.3.2. Dynamics of noisy inhibitory networks of integrate-and-fire neurons: a stochastic network theory approach

Participants: Jonathan Touboul, Romain Brette.

The dynamics of large networks of inhibitory neurons with noisy external drive has been studied by several authors using the Fokker-Planck equation (Brunel and Hakim (1999), Neural Computation 11, 1621-1671). Under the assumption of a sparse random connectivity, they found that the network can be in one of two regimes, according to the parameters: a desynchronized stationary regime, and a weakly synchronized oscillatory regime. Independently, other authors in the field of probability theory have studied stochastic networks of interacting nodes with linear dynamics (i.e., dX = -dt) and random reset (Cottrell (1992), {\it Stochastic Processes and their Applications} 40, 103-127; Fricker, Robert, Saada and Tibi (1994), {\it Annals of Applied Probability} 4, 1112-1128). They found in locally connected networks that, the dynamics can be ergodic or not ergodic depending on the parameters. In the former case, they found an expression for the invariant probability measure. In the latter case, they showed that part of the network stops firing. We try to build a bridge between these two approaches. We show that the stochastic network model considered in Fricker et al (1994) is formally equivalent to a network of noisy perfect integrators with instantaneous inhibitory interactions. We interpret their results in this context. The duality between the two frameworks corresponds to the duality between time-driven and event-driven simulation (see Reutimann, Giugliano and Fusi (2003), {\it Neural Computation } 15: 811-830). We show that replacing perfect integrators by the classic leaky integrate-and-fire models used in the computational neuroscience community (used e.g. in Brunel and Hakim 1999) amounts to replacing state-independent interactions by state-dependent interactions in the stochastic network analyzed in Fricker et al (1994). Within this framework, we exhibit Markov processes representing the state of the network. We extend the ergodic theory to this new model and find that the non-ergodic case disappears in the leaky integrate and fire network. We study various network topologies and we examine the limit of large networks using scaling limits (also called fluid limits). We show that synaptic delays can also be included in this framework. In summary, our approach provides a new theoretical tool, complementary to the more customary Fokker-Planck framework, to the analysis of spiking neural networks. This work was supported by the European Commission (FACETS Project, FP6-2004-IST-FET).

Publications: [64]

Links:

Neuromath 06 : http://www.crm.es/CMathNeuroscience/

5.3.3. The statistics of spikes trains for some simple types of neuron models

Participants: Olivier Faugeras, Theodore Papadopoulo, Jonathan Touboul, Etienne Tanré, Mireille Bossy, Denis Talay.

This paper describes some preliminary results of a research program for characterizing the statistics of spikes trains for a variety of commonly used neuron models in the presence of stochastic noise and deterministic input. The main angle of attack of the problem is through the use of stochastic calculus and ways of representing (local) martingales as Brownian motions by changing the time scale. Alternatively, Gaussian properties of the noise, when relevant, can also be used.

Publications: [50]

Links:

NeuroComp 2006: http://neurocomp.loria.fr/

5.3.4. *Reverse-engineering of the visual brain cortical maps computation using optical-imaging*

Participants: Frédéric Chavane, Sandrine Chemla, Pierre Kornprobst, Alexandre Reynaud, Thierry Viéville.

We asked whether optical imaging could be used to characterize the underlying computations given the activity of a brain area.

If biological neural network information is mainly related to the synaptic input (thus to the membrane potential in this case), it is however usually modeled with high-level representation of the related processing (e.g. variational specification of neural-map computation in relation to local diffusion mechanisms in neural networks), allowing to relate the observed activity with certain classes of underlying computations (e.g.: early-vision processes, winner-take-all mechanisms, etc.).

Considering a very simple experimental paradigm, we analyze if the precision of the data is sufficient to estimate robustly the underlying diffusion mechanisms. More generally, we propose to estimate the required precision in terms of scale and dynamics for such a reverse-engineering paradigm to be valid.

Neuronal activity diffusion estimation seems feasible, given the proposed assumptions and actual data sets. Further investigation on diffusion map recovery are in progress. Using real data we have been able to recover some diffusion estimation and have observed that estimating diffusion under restricted assumptions.

The next step is to propose to evaluate, given the activity of a spiking network which related membrane potential is measured using optical-imaging (here during the observation of V1), what is the underlying diffusion process? This is a highly constrained meso-scopic model of the neuronal activity, likely more robust to estimate than in a less specific case.

Publications: [55]

5.3.5. *Bifurcation Analysis of Jansen's Neural Mass Model*

Participants: François Grimbert, Olivier Faugeras.

We present a mathematical model of a neural mass developed by a number of people, including Lopes da Silva and Jansen. This model features three interacting populations of cortical neurons and is described by a six-dimensional nonlinear dynamical system. We address some aspects of its behavior through a bifurcation analysis with respect to the input parameter of the system. This leads to a compact description of the oscillatory behaviors observed in Jansen and Rit (1995) (alpha activity) and Wendling, Bellanger, Bartolomei, and Chauvel (2000) (spike-like epileptic activity). In the case of small or slow variation of the input, the model can even be described as a binary unit. Again using the bifurcation framework, we discuss the influence of other parameters of the system on the behavior of the neural mass model.

Publications: [26]

Links:

XPP-Aut Webpage: http://www.math.pitt.edu/~bard/xpp/xpp.html

Neural Computation: http://neco.mitpress.org/cgi/reprint/18/12/3052

5.3.6. *2D multilayer models of neural fields*

Participants: François Grimbert, Olivier Faugeras.

In this contribution, we model V1 by a continuous 2D neural field with multiple layers. For this purpose we use a neural mass approach and obtain an integro-differential neural field equation (NFE) including realistic connectivity parameters based on biological data. We discuss existence and uniqueness issues for this NFE and extend the work of Coombes on existence and stability of bump solutions to the NFE. This work aims at contributing to model extrinsic optical imaging signals, in collaboration with Frédéric Chavane (DyVA Team, INCM, Marseille).

Publications: [54], [49]

Links:

DyVA Team: http://www.incm.cnrs-mrs.fr/equipedyva.php

[Neuromath 06: http://www.crm.es/CMathNeuroscience/]

Neurocomp 06: http://neurocomp.loria.fr/index.php?lien=accueil

5.3.7. *One step towards an abstract view of computation in spiking neural-networks*

Participants: Sandrine Chemla, Pierre Kornprobst, Olivier Rochel, Thierry Viéville.

Neural network information is mainly conveyed through (i) event-based quanta, spikes, whereas high-level representation of the related processing is almost always modeled in (ii) some continuous framework. Here, we propose a link between (i) and (ii) which allows to derive the spiking network parameters given a continuous processing and also obtain an abstract interpretation of the related processing.

In event based neural network models, the output of a neuron is entirely characterized by the sequence of spike firing times and the Gerstner and Kistler Spike Response Model of a biological neuron defines the state of a neuron via a single variable. At the computational level, using piece-wise linear profiles yields a closed-form calculation of the spiking events, thus allows to obtain an efficient and exact implementation of (1) in event-based massive neuronal simulators such as MVASPIKE.

Using this model and following Maas and Natchslager, we represent the signal as the last spike delay with respect to a given temporal reference, consider piece-wise linear response profiles (as approximations of Hodhkins-Huxley related profiles), introduce a temporal discretization of the input current, and obtain a direct link with continuous representation of neural map computation:

- the resistive coefficient being proportional to the spiking threshold

- the variational apporach diffusion being in direct relation with the synaptic weights

- the corrective term being controlled by the axonal delay

- the input gain being controlled by the input resistance

with closed-form correspondence allowing to explicitly calculate the neural network parameters given an abstract continuous representation.

This relationship is valid only in a given temporal window, with saturation outside, as for analog networks. Here it appears that fast adaptive delays (as observed in recent intra-cellular experiments of e.g. Fregnac et al.) is a crucial element in this model. In the derivation a constraint coherent with S.T.D.P. adaptation rules (yielding the same constraint) as derived by, e.g., Guyonneau. It also corresponds to what is obtained from a variational framework relating the neuronal weights to a continuous diffusion operator, as introduced by Cottet. This last formulation is in direct relation with a sub-class of Cohen-Grossgerg dynamical systems.

We illustrate the previous derivation with an event-based implementation of an early-vision processing layer, for a 1D spiking neural network, correspond to an edge-preserving smoothing of the input, using a non-linear diffusion operator.

Publications: [70], [69], [68], [56]

5.3.8. Self-organizing receptive fields using a variational approach

Participants: Frédéric Alexandre, Nicolas Rougier, Thierry Viéville.

Self organizing-maps, as e.g. introduced by Kohonen, are artificial neural networks characterized by competitive learning of the processing elements. They thus can be used for the pattern analysis of input signal. Here we consider, as a working example, the self-organization of visual receptive fields, as it occurs in V1 and study to which extend using a variational approach may help specifying such a mechanism.

The goal of the present contribution is thus humble in the sense that we simply would like to explore at a technical level, the advantages and limits of the variational specification in this case. This formulation includes non-linear formulation of self-organizing maps as proposed by Fort and Pages, while unusual non-linear profiles allowing edge preserving smoothing, via non-linear diffusion are introduced. This criterion also acts as a convergence function (\'a la Lyapounov) of the underlying dynamical system.

The assumption is that they contribute to regularize the learning process. As such, they likely speed-up the convergence. They however constraint the solution to be taken in a more restrictive space of smoother functions. Experimental results are going to confront these assumptions to the ground truth.

A step ahead, the “arg max” rule itself is implemented by a winner-take-all mechanism, given an initial condition, the formulation leading to a local distributed implementation and guaranties the convergence towards a local minimum of the criterion.

A theoretical result predicts a stable interaction though feed-backs between these two layers and an experimental verification is proposed here.

Publications: [33]

5.3.9. Neural Network Simulation on Graphic Processor Units

Participants: Fabrice Bernhard, Alexandre Chariot, Renaud Keriven.

The use of impulse neural networks to solve problems of computer vision derives from the aim to bring together computer vision and biological vision. Impulse neural networks, studied in computational neurosciences, are unfortunately slow to simulate. The goal of this work is to evaluate the relevance of using modern graphics hardware to accelerate the simulation of impulse neural networks, as well in the domain of computer vision as more generally in computational neurosciences.

Publications: [34], [39]

5.3.10. Biologically-inspired spiking retina model for the encoding of visual sequences

Participants: Adrien Wohrer, Thierry Viéville, Pierre Kornprobst.

This work aims at modelling a biologically-plausible spiking retina. A detailed retina model has been developped, and implemented into a highly-parametrizable software called "RetinaSpike". The model and resulting software have been conceived to be used in a customizable fashion, that can include or not any of the following biological features:

- Spatio-temporal linear filter implementing the basic Center/Surround organization of retinal filtering.
- Non-linear Contrast Gain Control mechanism providing dynamical adaptation to the local level of contrast. This stage is modelled as a dynamical shunting feedback by amacrine cells onto bipolar cells; the resulting model reproduces contrast-dependent amplitude and phase non-linearities, as measured in real mammalian retinas by Shapley and Victor 78.
- Spike generation by one or several layers of ganglion cells paving the visual field. Magnocellular and Parvocellular pathways can be modelled in the same framework according to the parameters chosen. Large-scale simulatiions can be pursued on up to 50,000 spiking cells.
- Possibility of a global radial inhomogeneity modeling the foveated structure of mammalian retinas. In this case, the spatial scales of filtering, and the density of spiking cells, both depend on the eccentricity from the center of the retina.
- Possibility to include a basic microsaccades generator at the input of the retina, to account for fixational eye movements.

The validity of the whole model has been tested by reproducing different experimental intra-cellular recordings on mammalian ganglion cells, and provides a good fit to these recordings. The contrast gain control stage (2) was found particularly mandatory to obtain this fit. Thus, "RetinaSpike" can produce reliable input to other neuronal simulators modeling visual processing in the cortex.

Amongst immediate future extensions are:

- Inclusion of a front-end transformation to simulate pure rotations of the eye.
- Implementation of spike-based synchronies between neighboring ganglion cells, as observed in real mammalian retinas. At the implementation level, such addition is straightforward, thanks to the underlying event-orientated formalism and its related software, "MvaSpike". This work was partially supported by the FACETS European Project.

Publications: [83], [71], [72], [73]

Links:

Some demos and how to get the software?: http://www-sop.inria.fr/odyssee/team/Adrien.Wohrer/retina/index.html

The FACETS project: http://facets.kip.uni-heidelberg.de/

5.3.11. Biological Motion Recognition Using a MT-like Model

Participants: Maria-Jose Escobar, Adrien Wohrer, Pierre Kornprobst, Thierry Viéville.

We propose a bio-inspired system for biological motion recognition in image sequences. Our system has two main contributions. We propose a bio-inspired spiking V1 model that transforms a video sequence into spikes train according to local motion detectors. The motion detectors are directionally spatial-temporal filters properly tuned for a certain range of velocity. At the same time we propose a method to obtain a histogram map representation for the velocity distribution of V1 output. This histogram map acts as a MT-like model containing the spatial-temporal information of an event. We also propose a distance between histogram maps to realize motion categorization. In order to evaluate the performance of our approach, we ran our system in Giese database which contains 40 sequences and two actions, walk and march. The results reveal that motion categorization can be reliably estimated from the analysis of spike trains together with a coarse estimation of their spatial position.

Publications: [48], [46], [47]

5.3.12. Biologically plausible trajectory generators

Participants: Thierry Viéville, Cécile Vadot.

Considering the biological or artificial control of a trajectory generation, we propose a biologically plausible model based on harmonic potentials. Such methods assume that obstacles to avoid (or constraints not to violate) correspond to maxima of the potential, while the goal corresponds to a unique minimum. The corresponding algorithm thus behaves as if one throws a sheet onto this state space, this hyper-surface relief being elevated on obstacles, with a hole at the goal location, so that finding a trajectory reduces to “roll down” along this relief towards the minimal height location. The originality of the present work is to build an harmonic potential (thus without local minimum) as a finite linear combination of elementary harmonic functions. The set of these components samples the border of the admissible domain bounded by obstacles or constraints. This leads to an internal representation of the problem as a non-topographical map incrementally builded during the system exploration and non-linearly linked to the real problem geometry. As such, it provides a biologically plausible quantitative model of some hippocampus mechanisms and of the related cognitive maps, in coherence with usual biological assumptions about such behavior.

Publications: [82], [67]

Links:

Results presentation: ftp://ftp-sop.inria.fr/odyssee/Publications/2002/vieville-vadot:02-slides.pdf

Implementation available: http://www-sop.inria.fr/odyssee/team/Thierry.Vieville/personal/imp/imp/trajectory/package-summary.html

A tiny demo: http://www-sop.inria.fr/odyssee/team/Thierry.Vieville/personal/imp/imp/trajectory/doc-files/trajectory-applet.html

5.3.13. The SOLAIRE Project: A Gaze-Contingent System to Facilitate Reading for Patients with Scotomas

Participants: Emilien Tlapale, Jean-Baptiste Bernard, Eric Castet, Pierre Kornprobst.

Reading is a major issue for visually impaired patients suffering from a blind area in the fovea. Current systems to facilitate reading do not really benefit from recent advances in computer science, such as computer vision and augmented reality. On the SOLAIRE project (Système d'Optimisation de la Lecture par Asservissement de l'Image au Regard), we develop an augmented reality system to help patients to read more easily, resulting from a strong interaction between ophthalmologists and researchers in visual neuroscience and computer science. The main idea in this project is to control the display of the text read with the gaze, taking into account the specific characteristics of the scotoma for every individual. This report describes the system.

Publications: [81]

6. Other Grants and Activities

6.1. Regional Grants

6.1.1. EEG++ : Conductivity estimation for electro-encephalography

Participants: Maureen Clerc, Théo Papadopoulo, Jean-Michel Badier, Patrick Marquis.

Duration : 2005-01 to 2006-12

EEG++ is an INRIA Color project (collaborations locales) to trigger the collaboration between Odyssée and "La Timone" hospital in Marseille on the subject of conductivity estimation for electro-encephalography (detailed presentation: http://www-sop.inria.fr/odyssee/contracts/eeg++/).

6.2. National Grants

6.2.1. OBS-CERV : ACI Masse de Données

Participants: Maureen Clerc, Olivier Faugeras, Renaud Keriven, Juliette Leblond, Jan Kybic, Théodore Papadopoulo, Rachid Deriche.

Duration : 2003-09 to 2006-09

This three year grant has been funded in 2003. Its main purpose is to make progress toward a virtual meta-sensor combining the advantages of the various non-invasive sources of information about the brain activity. This involves manipulating and linking the information provided by some very large heterogenous data sets such as MEG and EEG or various types of MRI images, including Diffusion MRI (detailed presentation: http://www-sop.inria.fr/odyssee/contracts/obs-cerv).

6.2.2. DYNN : Dynamic of biological plausible neuronal networks

Participants: Olivier Faugeras, Pierre Kornprobst, Thierry Viéville.

This French project is a forum for common scientific activities in the field of biologically plausible neural networks. It involves 13 teams from computer and life science (detailed presentation: http://www-sop.inria.fr/odyssee/contracts/aci-dynn/index.html).

6.3. EU Grants

6.3.1. VISIONTRAIN : Computational and Cognitive Vision Systems: A Training European Network

Participants: Maureen Clerc, Rachid Deriche, Olivier Faugeras, Renaud Keriven, Pierre Kornprobst, Theo Papadopoulo, Thierry Viéville.

This Marie Curie RTN proposal has just been accepted for grants by the European Commission. This proposal includes 17 partners and is focused on the training programme of 20 PhD students and will finance salaries for early state researchers (doctoral studies) on the basis of a 3-year contract as well as experienced researchers (less than 10 years of research experience). The ambitious overall objective of this project is to further advance the state of the art in the understanding of the computational, cognitive, and biological bases of visual processes. Hiring PhD students and Post-Doc within this program is planned for mid-2005 (web site: http://visiontrain.inrialpes.fr/).

6.3.2. FACETS : Fast Analog Computing with Emergent Transiant States

Participants: Rachid Deriche, Olivier Faugeras, Renaud Keriven, Pierre Kornprobst, Theo Papadopoulo, Thierry Viéville.

FACETS is an integrated project within the biologically inspired information systems branch of IST-FET. The FACETS project aims to address, with a concerted action of neuroscientists, computer scientists, engineers and physicists, the unsolved question of how the brain computes. It combines a substantial fraction of the European groups working in the field into a consortium of 13 groups from Austria, France, Germany, Hungary, Sweden, Switzerland and the UK. About 80 scientists will join their efforts over a period of 4 years, starting in September 2005. A project of this dimension has rarely been carried out in the context of brain-science related work in Europe, in particular with such a strong interdisciplinary component (web site: http://facets.kip.uni-heidelberg.de/).

6.4. International Grants

6.4.1. INRIA/NSF : Computational Tools for Brain Research

Participants: Rachid Deriche, Olivier Faugeras, Chistophe Lenglet, Guillaume Charpiat.

Duration : 2004-07 to 2007-07

Key words : Diffusion Tensor Imaging, Shape statistics.

This NSF-INRIA Collaborative scheme includes the Center for Magnetic Resonance Research (K. Ugurbil) and the Department of Electrical and Computer Engineering University of Minnesota (prof. G. Sapiro). Exchange of visits and collaborative work has already started. Christophe Lenglet spent one month late 2003, one month during november 2004 and two weeks in July 2005 at the CMRR. R. Deriche and C. Lenglet visited the CMRR for a week during the SIAM Imaging conference held at Minneapolis in May 2006. During this visit the Diffusion MRI Softwares we developped have been transfered to the CMRR.

6.4.2. FFCR/INRIA : Biomedical Image Analysis

Participants: Rachid Deriche, Olivier Faugeras, Maxime Descoteaux.

Duration : 2006-08 to 2007-08

Duration : 1 year from August 2006 to August 2007. Extended until August 2007.

Our partnera in this project are Prof. Kaleem Siddiqui from McGill University (School of Computer Science and Centre For Intelligent Machines), Bruce Pike and Jennifer Campbell from McGill (Brain Imaging Center). Our broad goal is to develop algorithms for the analysis and processing of biomedical images, specifically brain images, which are based on formulations using partial differential equations, variational methods and differential geometry. Exchanges of visits has already occured from McGill University to INRIA and following these visits, Maxime Descoteaux joined our group early 2005 and started a PhD thesis at Nice University under the supervision of Rachid Deriche. Maxime Descoteaux visited for a month McGill early 2006. P. Savadjiev visited Odyssée and spent 4 months from May to early September. R.Deriche, C. Lenglet and M. Descoteaux visited McGill in April 2006 and gave a series of seminares

6.4.3. PROCOPE : Multimodal functional imaging of the Brain

Participants: Maureen Clerc, Olivier Faugeras, Theo Papadopoulo.

Duration : 2006-01 to 2007-12

Key words : MEG, EEG, Brain Functional Imaging, multimodal integration.

Through this Procope project (Projet d'Actions Intégrées funded by the Egide), we collaborate with the Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig. Our partners in this group are Alfred Anwander and Thomas Knoesche. Our project is to compare and co-develop methods for MEG/EEG source localization, and on diffusion MRI, and work on the integration of both modalities.

6.4.4. BARRANDE : Multimodal functional imaging of the Brain

Participants: Maureen Clerc, Olivier Faugeras, Theo Papadopoulo.

Duration : 2006-01 to 2007-12

Key words : MEG, EEG, Brain Functional Imaging, multimodal integration.

Though this Barrande project (Projet d'Actions Intégrées funded by the Egide), we collaborate with the Center for Machine Perception of the Czech Technical University, Prague. Our main partner in this group is Jan Kybic. The topic of this joint project is to develop spatio-temporal methods for cortical activity estimation using MEG/EEG.

7. Dissemination

7.1. Services to the scientific community

Rachid Deriche has been invited to the advisory board of RealViZand VisionIQ. He is an expert member of the scientific committee of the 4 year European project (2004-2008) "Visitor"under the Marie-Curie actions for young researcher mobility. R. Deriche is a member of the editorial board of the International Journal of Computer Vision and a member of the editorial board of Computational Imaging and Vision book series. R. Deriche has been co-organiser of Mathematical Image Analysis: 2006 and involved in many PhD thesis committees as chairman, reviewer or examiner.

Olivier Faugeras is a member of the Institut de France, Académie des Sciences. He has been invited to a number of companies scientific advisory boards such as RealViZ and VISIONIQ. He chairs the scientific board of the "Institut Français du Pétrole" (IFP), is a member of the board of the "Fondation d'entreprise EADS". He was a member of the "International Review panel of ICT Research in the UK". He is a member of the editorial board of several scientific Journals including the International Journal of Computer Vision

Renaud Keriven is a member of the scientific committee of Ecole Superieure d'Ingenieurs en Electronique et Electrotechnique. He is a member of a number of committees at the Ecole Nationale des Ponts et Chaussees such as the "CS PhD thesis committee", the "PhD program committee" and educational committees. He has been involved in many PhD thesis committees as reviewer or examiner.

Maureen Clerc coordinates the ACI Obs-Cerv. She is also in charge of two Projets d'Actions Intégrées of Egide: a Procope Project (2006-2007) with the Max Planck Institute, Leipzig, and a Barrande Project (2006-2007) with the Center for Machine Perception, Czech Technical University, Prague.

Romain Brette is a member of the editorial board of Cognitive Neurodynamics, a new journal to be published by Springer from 2006.

Pierre Kornprobst origanized a meeting about modeling neurons and networks using PDE, integro-differential equations and dynamical systems, within the GDR Mathématiques des Systèmes Perceptifs et Cognitifs (January 2006). He was invited to write, in collaboration with Gilles Aubert (Université de Nice Sophia-Antipolis), two review articles for two new encyclopedias. The first is the Encyclopedia of Mathematical Physics, published by Elsevier, which aims at producing an authoritative and comprehensive reference source covering the entire range of mathematical physics. In our contribution (see Aubert, Kornprobst 2006), we propose an overview of main mathematical concepts used in image processing (stochastic approaches, variational approaches and wavelet theory). The second the "Encyclopédie de l'informatique et des systèmes d'information" published by Vuibert. In our contribution (see Aubert, Kornprobst 2006), we give an introduction of most popular tools used in image processing.

Théo Papadopoulo is a member of the "Software development committee" of the Sophia-Antipolis INRIA Research Unit. He is also member of a working group in charge of organizing prospective presentations for INRIA (a COST working group).
1

Thierry Viéville is the scientific animator of the)i(nterstices project .

7.2. Academic teaching

7.2.1. Master STIC

Nice-Sophia Antipolis University:

Rachid Deriche teaches the *Geometrical Advanced Techniques in Image Processing and Vision* course,

Théodore Papadopoulo teaches the *3D Vision* course.

Thierry Viéville teaches the *biological and computer models of motion perception* course and helps for the Master organization regarding bi-disciplinary (life and computer sciences modules).

Each course includes 15 hours of lectures. Rachid Deriche and Olivier Faugeras are members of the scientific committee of this Master.

7.2.2. Master "Mathématiques Appliquées", parcours MVA (Mathematics/Vision/Learning)

Ecole Normale Supérieure Cachan - Paris 5 University - Ecole Normale Supérieure Ulm - Paris-Dauphine University - Ecole Nationale Supérieure des Télécommunications - École Polytechnique - Ecole Nationale des Ponts et Chaussées - Ecole Centrale Paris - Ecole Généraliste des Ingénieurs de Marseille.

Olivier Faugeras teaches the Modèles mathématiques pour les signaux neuronaux course.

Théodore Papadopoulo and Maureen Clerc teach the Inverse Problems for Brain functional imaging course.

Renaud Keriven teaches the Virtual and Augmented Reality course (with Nikos Paragios).

7.2.3. Diplôme d'Informatique de l'ENS

Romain Brette teaches the Introduction to Numerical Calculus course with Jean Ponce at Ecole Normale Supérieure Paris.

Olivier Faugeras and Romain Brette teach the *Neurons and populations of neurons: modelling and simulation* course at Ecole Normale Supérieure Paris.

Renaud Keriven teaches the Algorithmic Computer Vision course.

7.2.4. Master Parisien de Recherche en Informatique (MPRI)

Jointly with Ecole Normale Supérieure Paris, Ecole Normale Supérieure Cachan, Paris VI , Paris VII and Paris XI Universities, E.N.S.T., École Polytechnique, CNRS, CEA and INRIA.

Renaud Keriven teaches the Algorithmic Computer Vision course.

Rachid Deriche teaches the *Geometrical flows and Image Modelling*course

7.2.5. Master Traitement Avance des Images (IMA), Paris 6 University

Renaud Keriven teaches the Algorithmic Computer Vision course.

7.2.6. Master à l'ESINSA, partie de l'EPU (Ecole Polytechnique Universitaire), Sophia Antipolis

Pierre Kornprobst teaches an *image processing and partial differential equation*course.

7.2.7. EPUNSA, Polytech'Nice Sophia- Département Electronique, Sophia Antipolis

Sandrine Chemla is a teaching assistant of *numerical electronics*courses (combinatory logic and sequential logic) for first and second years students.

7.2.8. Master Systemes Informatiques (SI), Marne University

Renaud Keriven teaches the Computer Vision course.

7.3. Other teaching loads

7.3.1. Institut National des Télécommunications, Evry

École d'Ingénieurs - third year - Option: Traitement et Applications de l'Image. Rachid Deriche teaches the Computer Vision and Image Processing courses.

7.3.2. Ecole Nationale des Ponts et Chaussées

Maureen Clerc is in charge of a course in the curriculum: Frequency analysis and applications.

Renaud Keriven is in charge of the main Computer Science course and of the specialisation module "Computer Vision and Image Processing".

Patrick Etyngier and Alexandre Chariot are teaching assistants in the main Computer Science course.

7.3.3. Ecole Normale Supérieure Paris

Romain Brette is a tutor for 3 computer science students.

7.3.4. Université de Nice Sophia-Antipolis

Jérôme Piovano is a teaching assistant of courses "Initiation à la programmation impérative" (24h), "Introduction à la programmation fonctionnelle"(24h), "Electronique numérique et analogique" (48h), "Introduction à la programmation en Java"(24h) for first and second years DEUGs MI,MP,SM. Sylvain Vallaghé is a teaching assistant of courses "Méthodes numériques de la physique" (28h), "Traitement d'image" (20h) and "Initiation à Latex" (17h) for first and third years Licences MI, P.

7.3.5. Centre International de Valbonne (CIV)

François Grimbert is a Maple teaching assistant (48h) for PCSI preparatory classes.

7.3.6. Université de Jussieu Paris

Pierre Maurel and Thomas Deneux are teaching assistants (64h) for Computer Science License in courses "Projet Java" (first year) and "Outils, systèmes et réseau" (second year), respectively.

7.3.7. Ecole Polytechnique Palaiseau

Irène Fasiello and Guillaume Charpiat are teaching assistants in the course "Analyse numérique et optimisation" for second year students at the Ecole Polytechnique.

7.4. Software

7.4.1. A biological retina simulator

Participants: Adrien Wohrer, Pierre Kornprobst, Thierry Viéville.

A detailed retina model has been developped, and implemented into a highly-parametrizable software called "RetinaSpike". The model and resulting software have been conceived to be used in a customizable fashion, that can include several biological features.

7.4.2. Softwares for Diffusion MRI

Participants: Christophe Lenglet, Maxime Descoteaux, Demian Wassermann, Rachid Deriche

The geometric and variational methods developped to estimate Diffusion Tensor MRI from raw data, regularize noisy set of DT-MRI, segment volumetric DT-MRI images and perform white matter fibers tracking have all been added as an extension of the Brainvisa software platform for visualization and analysis of multimodality brain data and also as a toolbox for SPM5.

All these algorithms have been transfered to our partners at the Center for Magnetic Resonance Research (CMRR, A multi-disciplinary research center in the Department of Radiology at the University of Minnesota Medical School (K. Ugurbil) and also at Centre Hospitalier La Pitié Salpêtrière - Service de Neuroradiologie (S. Lehericy)

Additional softwares dealing with HARDI processing (High Angular Resolution Diffusion ImagING) have also been developped and ported on the BrainVisa and SPM5 platforms. They provide the Orientation Diffusion Functions estimation through the use of Q-Ball Imaging and help to track white matter fibers with possible crossings. ODF Sharpening, ODF GFA and conversions between Spherical Harmonics and HODTs are also parts of this software package.

A visualization library was developed in C++ and VTK. It runs under Linux and Windows and provides tools to display scalar images, DTI (tensors), HARDI (ODFs), fibers and surfaces.

7.4.3. OpenMEEG

Participants: Geoffrey Adde, Jean-Michel Badier, Maureen Clerc, Alexandre Gramfort, Renaud Keriven, Perrine Landreau, Théo Papadopoulo, Denis Schwartz.

The code for M/EEG forward/inverse problems using the symmetric BEM method developped by Geoffrey Adde during his PhD thesis has been released as an open source package. Work is currently done to integrate this code in the BrainVisa/BrainStorm toolbox so that these tools can be used more easily by the M/EEG neuroscientist and clinical community.

OpenMeeg website

7.4.4. BrainMatcher

Participants: Christophe Chefd'Hotel, Wouter Depuydt, Gerardo Hermosillo, Olivier Faugeras, Guy Orban, Théo Papadopoulo.

We have open sourced the algorithm for warping an fMRI image onto an anatomical MR image. The algorithm has been developed in the PhD theses of Gerardo Hermosillo and Christophe Chefd'Hotel and uses our variational approaches to derive a partial differential equation to compute a diffeomorphism that aligns the first image with the second. This software package has been written by Chefd'Hotel and has been used routinely since 2004 by the neuroscientists in Professor Guy Orban's laboratory in their work with fMRI images of macaque monkeys and humans. Théo Papadopoulo has recently helped the Leuven group to upgrade the software to work on their new machines. BrainMatcher website

7.4.5. Specification of FacetsML: an extension to NeuroML

Participants: Nicolas Debeissat, Manh-Tien Nguyen, Thierry Viéville.

The goal of this software development is to design a common data/computation model for computational neuroscience simulations (focusing on spiking-neurons and networks) and build an electronic knowledge repository with the related contribution (e.g.: microcircuit, in vivo data, hardware models, algorithms, ..).

As a 1st step we have provided and evaluated both a declarative (FacetsML) and a procedural (PyNN) description of neuronal networks. Both specifications are available as open-source document bundles, on the INRIA forge. A further step, a prototype WYSIWYG editor for FacetsML has been developed, for evaluation not only by computer scientists but also by colleagues in other disciplines. All FacetsML specifications are computer language independent, written in XML (XSD schema and XSL transformation) and based on W3C standards. Utility tools are developed in Java for maximal portability. Technical tools are developed in Python.

The FACETS consortium has provided and evaluated a detailed concept for the related electronic knowledge repository.

7.5. Participation to workshops, seminars and miscellaneous invitations

Rachid Deriche is an Area Chair of the ECCV:2006 : 9th European Conference on Computer Vision and an Area Chair of the RFIA:2006 15e congrès francophone AFRIF-AFIA Reconnaissance des Formes et Intelligence Artificielle

Rachid Deriche has co-organised TAIMA:2006: Traitement et Analyse de l'Information :Méthodes et Applications held in Hammamet, Tunisia. He has been the general co-chair of this workshop, ever since its first edition in 1999.

Rachid Deriche has been invited to give a keynote speech at JETIM:2006 : 2ème Journées d'Etudes Algéro-Françaises en Imagerie Médicale held in Algiers in Nov. 2006

Rachid Deriche has been invited to give a keynote speech at Vision by Brains and Machines:2006 held in Montevideo in Nov. 2006

Rachid Deriche has been invited to give a keynote speech at Méthodes Mathématiques du Traitement d'Images:2006 held in Paris in Dec. 2006

Rachid Deriche has been invited to give a keynote speech at The Maghrebian Conference on Sofware Engineering and Artificial Intelligence (MCSEAI)held in Agadir in Dec. 2006

Rachid Deriche is a member of several program committees such as ICCV:2005: 10th International Conference on Computer Vision where he received an award for his reviews and has been invited to be an area-chair for ICCV:2007
. Other coneferences where R. Deriche has been active are : MIA:06,ISBI:2006,MICCAI:06..

Olivier Faugeras has been a member of the Conference Board of the European Conference on Computer Vision, ever since he started the Conference in 1990. He has been plenary speaker at the 18th International Conference of Pattern Recognition.

Maureen Clerc was a plenary speaker at the meeting of the MAS group of the SMAI society. As the coordinator of the ACI Obs-Cerv, she organized a 2-day meeting for its final reunion.

Renaud Keriven has been invited to give a keynote speech at the "Images and Mathematical Models" workshop, Rennes, December 2006.

Renaud Keriven has been a member of the Program Committees of the following International Conferences: International Conference on Computer Vision and Pattern Recognition (CVPR), International Conference on Image Processing (ICIP), International Conference on Pattern Regognition (ICPR), European Conference on Computer Vision (ECCV), International Conference on Computer Vision (ICCV), Brazilian Symposium on Computer Graphics and Image Processing (BSCGIP), Scale Space and Variational Methods (SSVM), International Symposium on 3D Data Processing, Visualization and Transmission (3DPVT).

Romain Brette gave an invited talk at a workshop on single neuron modelling at EPFL Lausanne, and at a workshop on neural simulation in Graz (Austria).

Pierre Kornprobst has been a member of the Program Committee of the European Conference on Computer Vision 2006. He was invited to give a talk in a meeting about PDEs in image processing organised by GDR ISIS and GDR MACS. He was invited to form part of the jury of the PhD defense by Gloria Haro (advisor: Vincent Caselles).

Théo Papadopoulo is a member of the Program Committee of the 2006 European Conference on Computer Vision and of the 2006 International Conference on Computer Vision and Pattern Recognition. He also was a member of the Program Comittee of the 10th International Conference on Computer Vision.

Thierry Viéville has co-organized The 1st French Computational Neuro-Science Conference with the INRIA CORTEX project, has been in the jury of five PhD's in Computational NeuroScience and invited in three French lab's for seminars.

7.6. Theses and Internships

7.6.1. Theses defenses

- Renaud Keriven, *"Shapes and Optimization in Computer Vision"*, HDR thesis, Marne University; Site: Odyssée ENPC, Champs sur Marne. June, 2006
- Romain Dupont, *"Hidden Layers segmentation in video sequences"*, ENPC; Site: Odyssée ENPC, Champs sur Marne. December 14th, 2006
- Guillaume Charpiat, *"Distance-based shape statistics for image segmentation with priors"*, ENS Paris; Site: Odyssée ENS, Paris. December 13th, 2006
- Thomas Deneux, *"Hemodynamic Models: Investigation and Application to Brain Imagery Analysis"*, ENS; Site: Odyssée ENS, Paris. May 2006
- Olivier Juan *"On Some Extensions of Level Sets and Graph Cuts towards their Applications to Image and Video Segmentation"*, ENPC, Champs sur Marne; Site: Odyssée ENPC, Paris. May 2006
- Christophe Lenglet, *"Geometric and Variational Methods for Diffusion Tensor Magnetic Resonance Image Processing"*, UNSA; Site: Odyssée INRIA Sophia-Antipolis. December 12th, 2006
- Lucero Lopez-Pérez, *"Régularisation d'images sur des surfaces non-planes"*, UNSA; Site: Odyssée INRIA Sophia-Antipolis. December 15th, 2006
- Nicolas Wotawa *"IRMf pour la rétinotopie et l'analyse de la perception du mouvement"*, UNSA; Site: Odyssée INRIA Sophia-Antipolis, April 2006

7.6.2. Ongoing Theses

- Alexandre Chariot, *"Processeurs Graphiques et Applications en Visions Algorithmique et Biologique"*, ENPC, Site: ENPC Marne
- Sandrine Chemla, *"Biologically plausible computation mechanisms in Cortical areas."*, Université de Nice Sophia-Antipolis; Site: Odyssée INRIA Sophia-Antipolis.
- Maxime Descoteaux, *"IRM de diffusion à haute résolution angulaire "*, Université de Nice Sophia-Antipolis; Site: Odyssée INRIA Sophia-Antipolis.
- Marie-José Escobar, *"From classification to categorization: biologically plausible models"*, Université de Nice Sophia-Antipolis; Site: Odyssée INRIA Sophia-Antipolis.
- Patrick Etyngier, *"Shape priors and stereovision"*, ENPC, Site: ENPC Marne
- Irene Fasiello, *"Vision biologique"*, ENS Cachan; Site: Odyssée ENS, Paris
- Alexandre Gramfort, *" Imagerie cérébrale fonctionnelle par magnétoencéphalographie: application au système visuel"*, ENST; Site: Odyssée ENS, Paris

- François Grimbert, *"Modélisation d'ensembles de colonnes corticales et application à l'électroencephalographie et à la magnétoencephalographie"*, UNSA; Site: Odyssée Sophia-Antipolis.
- Pierre Maurel, *"Statistiques de formes, expressions faciales et epilepsie"*, ENS Paris; Site: Odyssée ENS, Paris.
- Olivier Juan, *"Rotoscopie et applications à la réalite virtuelle"*, ENPC; Site: Odyssée ENPC, Marne.
- Patrick Labatut, *"Mouvement et formes tridimensionnelles"*, ENS, Site: ENS Paris.
- Mickael Pechaud, *"Discrete optimization and brain imaging methods"*, ENS Paris; Site: Odyssée ENS, Paris.
- Jérôme Piovano, *"Extraction automatique de formes complexes : Application à la création de modèles anatomiques de la tête"*, UNSA; Site: Odyssée INRIA Sophia-Antipolis.
- Sylvain Vallaghé, *"Problèmes inverses en magnéto-électroencéphalographie"*, Université de Nice Sophia-Antipolis; Site: Odyssée INRIA Sophia-Antipolis.
- Adrien Wohrer, *"Perception du mouvement par des neurones à impulsions"*, UNSA, Site: Odyssée INRIA Sophia-Antipolis.
- Jonathan Touboul, *"Modèles stochastiques de réseaux de neurones biologiques"*, UNSA, Site: Odyssée INRIA Sophia-Antipolis.
- Demian Wasswermann, *"Diffusion MRI Processing and Applications"*, UNSA, Site: Odyssée INRIA Sophia-Antipolis

7.6.3. Internships

- Sandrine Chemla, *"Biologically plausible computation mechanisms in Cortical areas."*, Master IGGMV; Site: Odyssée INRIA Sophia-Antipolis.
- Léonard Gérard, *"Variational approaches to cortical maps computational models."*, Master ENS Lyon; Site: Odyssée INRIA Sophia-Antipolis.
- Ketty Nguyen, *"Algorithme pour estimation de mouvements transparents."*, Master Stic de l'Université de Nice-Sophia-Antipolis; Site: Odyssée INRIA Sophia-Antipolis.
- Manh Tien Nguyen, *"Formalisation de modèles neuro-biologiques des neurones à spikes."*, INRIA Internship program - Institut Polytechnique de Hanoï; Site: Odyssée INRIA Sophia-Antipolis.
- Jonathan Platkiewicz, *"."*, ENS; Site: Odyssée ENS Paris.
- Demian Wasswermann, *"Diffusion MRI Processing."*INRIA Internship program - Universidad Buenos-Aires ; Site: Odyssée INRIA Sophia-Antipolis.

8. Bibliography

Major publications by the team in recent years

[1] G. AUBERT, P. KORNPROBST. *Mathematical problems in image processing: partial differential equations and the calculus of variations (Second edition)*, Applied Mathematical Sciences, vol. 147, Springer-Verlag, 2006.

[2] R. BRETTE, W. GERSTNER. *Adaptive exponential integrate-and-fire model as an effective description of neuronal activity*, in "Journal of Neurophysiology", vol. 94, 2005, p. 3637–3642.

[3] G. CHARPIAT, O. FAUGERAS, R. KERIVEN. *Approximations of Shape Metrics and Application to Shape Warping and Empirical Shape Statistics*, in "Foundations of Computational Mathematics", Use charpiat-faugeras-etal:05 instead., 2004.

[4] T. DENEUX, O. FAUGERAS. *Using nonlinear models in fMRI data analysis: model selection and activation detection*, in "NeuroImage", vol. 32, 2006, p. 1669–1689, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/deneux-faugeras:06.pdf.

[5] M. DESCOTEAUX, E. ANGELINO, S. FITZGIBBONS, R. DERICHE. *Apparent Diffusion Coefficients from High Angular Resolution Diffusion Imaging: Estimation and Applications*, in "Magnetic Resonance in Medicine", vol. 56, 2006, p. 395–410, ftp://ftp-sop/odyssee/Publications/2006/descoteaux-angelino-etal:06c.pdf.

[6] O. FAUGERAS, G. ADDE, G. CHARPIAT, C. CHEFD'HOTEL, M. CLERC, T. DENEUX, R. DERICHE, G. HERMOSILLO, R. KERIVEN, P. KORNPROBST, J. KYBIC, C. LENGLET, L. LOPEZ-PEREZ, T. PAPADOPOULO, J.-P. PONS, F. SÉGONNE, B. THIRION, D. TSCHUMPERLÉ, T. VIÉVILLE, N. WOTAWA. *Variational, geometric, and statistical methods for modeling brain anatomy and function*, in "NeuroImage", Special issue: Mathematics in Brain Imaging - Edited by P.M. Thompson, M.I. Miller, T. Ratnanather, R.A. Poldrack and T.E. Nichols., vol. 23S1, 2004, p. S46-S55.

[7] F. GRIMBERT, O. FAUGERAS. *Bifurcation Analysis of Jansen's Neural Mass Model*, in "Neural Computation", vol. 18, n^{o} 12, December 2006, p. 3052–3068.

[8] J. KYBIC, M. CLERC, T. ABBOUD, O. FAUGERAS, R. KERIVEN, T. PAPADOPOULO. *A Common Formalism for the Integral Formulations of the Forward EEG Problem*, in "IEEE Transactions on Medical Imaging", vol. 24, n^{o} 1, January 2005, p. 12-28.

[9] C. LENGLET, M. ROUSSON, R. DERICHE. *DTI Segmentation by Statistical Surface Evolution*, in "IEEE Transactions on Medical Imaging,", vol. 25, n^{o} 06, jun 2006, p. 685–700, ftp://ftp-sop/odyssee/Publications/2006/lenglet-rousson-etal:06c.pdf.

[10] T. VIÉVILLE, S. CRAHAY. *Using an Hebbian Learning Rule for Multi-Class SVM Classifiers*, in "Journal of Computational Neuroscience", vol. 17, n^{o} 3, 2004, p. 271–287, http://journals.kluweronline.com/article.asp?PIPS=5384399.

Year Publications

Doctoral dissertations and Habilitation theses

[11] G. CHARPIAT. *Distance-based shape statistics for image segmentation with priors*, Ph. D. Thesis, Ecole Polytechnique, 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/PhDs/charpiat:06.pdf.

[12] T. DENEUX. *Hemodynamic Models: Investigation and Application to Brain Imagery Analysis*, Ph. D. Thesis, Ecole Polytechnique, 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/PhDs/deneux:06.pdf.

[13] R. DUPONT. *Suivi des Parties Cachées dans une Séquence Vidéo*, Ph. D. Thesis, Ecole des Ponts, December 2006.

[14] O. JUAN. *Quelques extentions des Level Sets et des Graph Cuts.*, Ph. D. Thesis, Ecole des Ponts, May 2006, http://www.enpc.fr/certis/Papers/06PhDa.pdf.

[15] R. KERIVEN. *Formes et Optimisation en Vision par Ordinateur. Méthodes et Applications.*, Habilitation a Diriger les Recherches, Université Marne la Vallée, jun 2006, http://www.enpc.fr/certis/Papers/06hdr+annex.pdf.

[16] C. LENGLET. *Geometric and Variational Methods for Diffusion Tensor MRI Processing*, Ph. D. Thesis, University of Nice-Sophia Antipolis, 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/PhDs/lenglet:06.pdf.

[17] N. WOTAWA. *Low-level visual cortex and motion perception: an MRI study*, Ph. D. Thesis, Université de Nice Sophia-Antipolis, April 2006.

Articles in refereed journals and book chapters

[18] G. AUBERT, P. KORNPROBST. *Mathematics of Image Processing*, in "Encyclopedia of Mathematical Physics, Oxford", J. P. FRANÇOISE, G. NABER, S. TSOU (editors). , vol. 3, Elsevier, 2006, p. 1–9, http://www.elsevier.com/locate/emp.

[19] G. AUBERT, P. KORNPROBST. *Traitement des images numériques*, in "Encyclopédie de l'informatique et des syst'emes d'information", J. AKOKA, I. COMYN-WATTIAU (editors). , chap. 18, n^{o} 6, Vuibert, November 2006, p. 861–879, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/aubert-kornprobst:06b.pdf.

[20] R. BRETTE. *Exact simulation of integrate-and-fire models with synaptic conductances.*, in "Neural Computation", vol. 18, n^{o} 8, 2006, p. 2004–2027.

[21] C. A. CASTAÑO-MORAGA, C. LENGLET, R. DERICHE, J. RUIZ-ALZOLA. *A Riemannian Approach to Anisotropic Filtering of Tensor Fields*, in "Signal Processing [Special Issue on Tensor Signal Processing]", vol. 87, n^{o} 2, 2006, p. 263-276, ftp://ftp-sop/odyssee/Publications/2006/castano-moraga-lenglet-etal:06.pdf.

[22] G. CHARPIAT, O. FAUGERAS, R. KERIVEN, P. MAUREL. *Approximations of shape metrics and application to shape warping and empirical shape statistics*, in "Statistics and Analysis of Shapes", H. KRIM, A. YEZZI (editors). , chap. 15, Birkhäuser, 2006.

[23] T. DENEUX, O. FAUGERAS. *Using nonlinear models in fMRI data analysis: model selection and activation detection*, in "NeuroImage", vol. 32, 2006, p. 1669–1689, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/deneux-faugeras:06.pdf.

[24] M. DESCOTEAUX, M. AUDETTE, K. CHINZEI, K. SIDDIQI. *Bone Enhancement Filtering: Application to Sinus Bone Segmentation and Simulation of Pituitary Gland Surgery*, in "Computer Aided Surgery", vol. 11, n^{o} 5, September 2006, p. 247–255.

[25] M. DESCOTEAUX, E. ANGELINO, S. FITZGIBBONS, R. DERICHE. *Apparent Diffusion Coefficients from High Angular Resolution Diffusion Imaging: Estimation and Applications*, in "Magnetic Resonance in Medicine", vol. 56, 2006, p. 395–410, ftp://ftp-sop/odyssee/Publications/2006/descoteaux-angelino-etal:06c.pdf.

[26] F. GRIMBERT, O. FAUGERAS. *Bifurcation Analysis of Jansen's Neural Mass Model*, in "Neural Computation", vol. 18, n^{o} 12, December 2006, p. 3052–3068.

[27] O. JUAN, R. KERIVEN, G. POSTELNICU. *Stochastic Motion and the Level Set Method in Computer Vision: Stochastics Active Contours*, in "International Journal of Computer Vision", vol. 69, n^{o} 1, August 2006, p. 7-25.

[28] J. KYBIC, M. CLERC, O. FAUGERAS, R. KERIVEN, T. PAPADOPOULO. *Generalized head models for MEG/EEG: boundary element method beyond nested volumes*, in "Phys. Med. Biol.", vol. 51, 2006, p. 1333-1346, http://www.iop.org/EJ/abstract/0031-9155/51/5/021/.

[29] C. LENGLET, M. ROUSSON, R. DERICHE. *DTI Segmentation by Statistical Surface Evolution*, in "IEEE Transactions on Medical Imaging,", vol. 25, n^o 06, jun 2006, p. 685–700, ftp://ftp-sop/odyssee/Publications/2006/lenglet-rousson-etal:06c.pdf.

[30] C. LENGLET, M. ROUSSON, R. DERICHE, 0. FAUGERAS. *Statistics on the Manifold of Multivariate Normal Distributions: Theory and Application to Diffusion Tensor MRI Processing*, in "Journal of Mathematical Imaging and Vision", vol. 25, n^o 3, October 2006, p. 423-444, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/lenglet-rousson-etal:06.pdf.

[31] E. PRADOS, F. CAMILLI, O. FAUGERAS. *A unifying and rigorous Shape From Shading method adapted to realistic data and applications*, in "Journal of Mathematical Imaging and Vision", vol. 25, n^o 3, 2006, p. 307–328.

[32] E. PRADOS, F. CAMILLI, O. FAUGERAS. *A viscosity solution method for Shape-From-Shading without image boundary data*, in "Mathematical Modelling and Numerical Analysis (M2AN)", vol. 40, n^o 2, 2006, p. 393–412, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/prados-camilli-etal:06.pdf.

Publications in Conferences and Workshops

[33] F. ALEXANDRE, N. ROUGIER, T. VIÉVILLE. *Self-organizing receptive fields using a variational approach*, in "International Conf. on Cognitive and Neural Systems", 2006.

[34] F. BERNHARD, R. KERIVEN. *Spiking neurons on GPUs*, in "Workshop General purpose computation on graphics hardware, Readings, UK", October 2006, http://www.enpc.fr/certis/Papers/06gpu-iccs_b.pdf.

[35] T. BROX, R. VAN DEN BOOMGAARD, F. LAUZE, J. VAN DE WEIJER, J. WEICKERT, P. MRÀZEK, P. KORNPROBST. *Adaptive structure tensors and their applications*, in "Visualization and Processing of Tensor Fields", J. WEICKERT, H. HAGEN (editors). , Springer, 2006, p. 19–47.

[36] C. BÉNAR, T. PAPADOPOULO, M. CLERC. *Time-frequency-topography adaptive templates for single-trial MEG/EEG analysis*, in "Proceedings of HBM", 2006.

[37] C. BÉNAR, T. PAPADOPOULO, M. CLERC. *Topography-Time-Frequency models for single-event M/EEG analysis*, in "Proceedings of Biomag", 2006.

[38] C. A. CASTAÑO-MORAGA, C. LENGLET, R. DERICHE, J. RUIZ-ALZOLA. *A fast and rigorous anisotropic smoothing method for DT-MRI*, in "Third IEEE International Symposium on Biomedical Imaging: From Nano to Macro, Arlington, Virginia, US", 2006, ftp://ftp-sop/odyssee/Publications/2006/castano-lenglet-etal:06b.pdf.

[39] A. CHARIOT, R. KERIVEN, R. BRETTE. *Simulation rapide de modèles de neurones impulsionnels sur carte graphique*, 2006, http://www.enpc.fr/certis/Papers/06neurocompa.pdf.

[40] G. CHARPIAT, P. MAUREL, R. KERIVEN, O. FAUGERAS. *Distance-Based Shape Statistics*, in "International Conference on Acoustics, Speech, and Signal Processing", Special Session: Statistical Inferences on Nonlinear Manifolds with Applications in Signal and Image Processing, 2006.

[41] M. CLERC, J. LEBLOND, J.-P. MARMORAT, L. BARATCHART. *EEG source localization by best approximation of functions*, in "Proceeding of HBM", 2006.

[42] T. DENEUX, O. FAUGERAS. *EEG-fMRI fusion of non-triggered data using Kalman filtering*, in "IEEE International Symposium on Biomedical Imaging", 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/deneux-faugeras:06b.pdf.

[43] M. DESCOTEAUX, E. ANGELINO, S. FITZGIBBONS, R. DERICHE. *A fast and robust ODF estimation algorithm in Q-ball imaging*, in "Third IEEE International Symposium on Biomedical Imaging: From Nano to Macro, Arlington, Virginia, USA", April 2006, ftp://ftp-sop/odyssee/Publications/2006/descoteaux-angelino-etal:06b.pdf.

[44] M. DESCOTEAUX, E. ANGELINO, S. FITZGIBBONS, R. DERICHE. *Apparent Diffusion Coefficients from High Angular Resolution Diffusion Imaging: Estimation and Applications*, in "SPIE Medical Imaging, San-Diego", February 2006, ftp://ftp-sop/odyssee/Publications/2006/descoteaux-angelino-etal:06.pdf.

[45] R. DUPONT, O. JUAN, R. KERIVEN. *Robust Segmentation of Hidden Layers in Video Sequences*, in "8th International Conference on Pattern Recognition, Hong Kong", August 2006, http://www.enpc.fr/certis/Papers/06icpr_b.pdf.

[46] M.-J. ESCOBAR, A. WOHRER, P. KORNPROBST, T. VIÉVILLE. *Biological motion recognition using an MT-like model*, in "1ère conférence francophone de Neurosciences Computationelles", October 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/escobar-wohrer-etal:06.pdf.

[47] M.-J. ESCOBAR, A. WOHRER, P. KORNPROBST, T. VIÉVILLE. *Biological motion recognition using an MT-like model*, in "Proceedings of 3rd Latin American Robotic Symposium", 2006.

[48] M.-J. ESCOBAR, A. WOHRER, P. KORNPROBST, T. VIÉVILLE. *Can we recognize motion from spike train analysis?*, 2006.

[49] O. FAUGERAS, F. GRIMBERT. *2D multilayer models of neural fields*, in "1ère conférence francophone de Neurosciences Computationelles", October 2006.

[50] O. FAUGERAS, T. PAPADOPOULO, J. TOUBOUL, E. TANRÉ, M. BOSSY, D. TALAY. *The statistics of spikes trains for some simple types of neuron models*, in "1ère conférence francophone de Neurosciences Computationelles", October 2006.

[51] M. FUSSENEGGER, R. DERICHE, A. PINZ. *A Multiphase Level Set based Segmentation Framework with Pose Invariant Shape Priors*, in "The Seventh Asian Conference on Computer Vision, Hyderabad, India", SPRINGER (editor). , Lecture Notes in Computer Science (LNCS), January 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/fussenegger-deriche-etal:06.pdf.

[52] M. FUSSENEGGER, R. DERICHE, A. PINZ. *Multi region tracking with pose invariant shape priors*, in "30th Workshop of the Austrian Association for Pattern Recognition", 2006, p. 133-142, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/fussenegger-deriche-etal:06c.pdf.

[53] M. FUSSENEGGER, R. DERICHE, A. PINZ. *Multiregion level set tracking with transformation invariant shape priors*, in "The Seventh Asian Conference on Computer Vision, Hyderabad, India", SPRINGER (editor). , Lecture Notes in Computer Science (LNCS), January 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/fussenegger-deriche-etal:06b.pdf.

[54] F. GRIMBERT, O. FAUGERAS. *Cortex as a Continuum of Cortical Columns*, in "Conference on Mathematical Neuroscience", 2006.

[55] P. KORNPROBST, F. CHAVANE, S. CHEMLA, A. REYNAUD, T. VIÉVILLE. *Reverse-engeneering of the visual brain cortical maps computation using optical-imaging*, 2006, 54.

[56] P. KORNPROBST, T. VIÉVILLE, S. CHEMLA, O. ROCHEL. *Modeling cortical maps with feed-backs*, 2006, 53.

[57] P. LABATUT, R. KERIVEN, J.-P. PONS. *A GPU Implementation of Level Set Multi-View Stereo*, in "International Conference on Computational Science – Workshop General Purpose Computation on Graphics Hardware (GPGPU): Methods, Algorithms and Applications", LNCS, vol. 3994, May 2006, p. 212–219, http://www.enpc.fr/certis/Papers/06gpu-iccs_a.pdf.

[58] P. LABATUT, R. KERIVEN, J.-P. PONS. *Fast Level Set Multi-View Stereo on Graphics Hardware*, in "International Symposium on 3D Data Processing, Visualization and Transmission", jun 2006, http://www.enpc.fr/certis/Papers/063dpvt_a.pdf.

[59] C. LENGLET, M. ROUSSON, R. DERICHE. *A statistical framework for DTI segmentation*, in "Third IEEE International Symposium on Biomedical Imaging: From Nano to Macro, Arlington, Virginia, USA", April 2006, ftp://ftp-sop/odyssee/Publications/2006/lenglet-rousson-etal:06b.pdf.

[60] J. MAIRAL, K. KERIVEN, A. CHARIOT. *Fast and efficient dense variational stereo on GPU*, in "3rd International Symposium on 3D Data Processing, Visualization and Transmission", 2006, http://www.enpc.fr/certis/Papers/063dpvt_b.pdf.

[61] P. MAUREL, R. KERIVEN, O. FAUGERAS. *Reconciling Landmarks and Level Sets.*, in "18th International Conference on Pattern Recognition", vol. 4, IEEE Computer Society, August 2006, p. 69–72, http://www.di.ens.fr/~pmaurel/publi/ICPR06_Landmarks_LevelSets_Maurel.pdf.

[62] T. PAPADOPOULO, S. VALLAGHÉ, M. CLERC. *Implicit Meshes for MEG/EEG Forward Problem with 3D Finite Element Method*, in "Proceedings of the Biomag conference", August 2006.

[63] E. PRADOS, C. LENGLET, J. PONS, N. WOTAWA, R. DERICHE, O. FAUGERAS, S. SOATTO. *Control Theory and Fast Marching Methods for Brain Connectivity Mapping*, in "Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition, New York, NY", June 2006, ftp://ftp-sop/odyssee/Publications/2006/prados-lenglet-etal:06.pdf.

[64] J. TOUBOUL, R. BRETTE. *Dynamics of noisy inhibitory networks of integrate-and-fire neurons: a stochastic network theory approach*, 2006.

[65] S. VALLAGHÉ, J.-M. BADIER, M. CLERC. *Simultaneous estimation of single dipolar source and head tissue conductivities*, in "Proceedings of HBM", 2006.

[66] I. VANZETTA, T. DENEUX, G. MASSON, O. FAUGERAS. *Cerebral blood flow recorded at high sensitivity in two dimensions using high resolution optical imaging two dimensions using high resolution optical imaging*, in "IEEE International Symposium on Biomedical Imaging", 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/vanzetta-deneux-etal:06.pdf.

[67] T. VIÉVILLE. *About biologically plausible trajectory generators*, in "International Joint Conference on Neural Networks", 2006.

[68] T. VIÉVILLE, P. KORNPROBST. *Modeling Cortical Maps with Feed-Backs*, in "International Joint Conference on Neural Networks, Vancouver", 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/vieville-kornprobst:06.pdf.

[69] T. VIÉVILLE, P. KORNPROBST. *Modeling cortical maps with feed-backs*, in "International Conf. on Cognitive and Neural Systems", 2006.

[70] T. VIÉVILLE, O. ROCHEL. *One step towards an abstract view of computation in spiking neural-networks*, in "International Conf. on Cognitive and Neural Systems", 2006.

[71] A. WOHRER, P. KORNPROBST, T. VIÉVILLE. *From Light to Spikes: a Large-Scale Retina Simulator*, in "International Joint Conference on Neural Networks, Vancouver", 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/wohrer-kornprobst-etal:06b.pdf.

[72] A. WOHRER, P. KORNPROBST, T. VIÉVILLE. *Contrast gain control through a feedback in the retina*, in "1ère conférence francophone de Neurosciences Computationelles", October 2006, ftp://ftp-sop.inria.fr/odyssee/Publications/2006/wohrer-kornprobst-etal:06c.pdf.

[73] A. WOHRER, G. MASSON, L. PERRINET, P. KORNPROBST, T. VIÉVILLE. *Contrast sensitivity adaptation in a virtual spiking retina and its adequation with mammalians retinas*, in "29th European Conference on Visual Perception", 2006, 67.

Internal Reports

[74] G. CHARPIAT, P. MAUREL, J.-P. PONS, R. KERIVEN, O. FAUGERAS. *Generalized Gradients: Priors on Minimization Flows*, RR, n^{o} 06-23, ENPC, March 2006, http://www.enpc.fr/certis/Papers/06certis23.pdf.

[75] R. DUPONT, O. JUAN, R. KERIVEN. *Robust Segmentation of Hidden Layers in Video Sequences*, Technical report, n^{o} 06-21, CERTIS, January 2006.

[76] P. KORNPROBST, G. AUBERT. *Explicit Reconstruction for Image Inpainting*, Research Report, n^{o} 5905, INRIA, April 2006, http://hal.inria.fr/inria-00071360.

[77] C. LENGLET, M. ROUSSON, R. DERICHE. *DTI Segmentation by Statistical Surface Evolution*, Technical report, n^{o} 5843, INRIA, February 2006, http://hal.inria.fr/inria-00070183.

[78] C. LENGLET, M. ROUSSON, R. DERICHE, O. FAUGERAS. *Statistics on Multivariate Normal Distributions: A Geometric Approach and its Application to Diffusion Tensor MRI*, Technical report, n^{o} 5242, INRIA, June 2004, http://hal.inria.fr/inria-00070756.

[79] E. Prados, C. Lenglet, J. Pons, N. Wotawa, R. Deriche, O. Faugeras, S. Soatto. *Control Theory and Fast Marching Methods for Brain Connectivity Mapping*, Technical report, n^{o} 5845, INRIA, February 2006, http://hal.inria.fr/inria-00070181.

[80] A. Ramirez-Manzanares, M. Rivera, P. Kornprobst, F. Lauze. *Multi-Valued Motion Fields Estimation for Transparent Sequences with a Variational Approach*, Technical report, n^{o} 5920, INRIA, May 2006, http://hal.inria.fr/inria-00077285.

[81] E. Tlapale, J.-B. Bernard, E. Castet, P. Kornprobst. *Le Projet SOLAIRE: Un Système d'Optimisation de la Lecture par Asservissement de l'Image au Regard*, Technical report, n^{o} RT-0326, INRIA, October 2006, http://hal.inria.fr/inria-00102542.

[82] T. Viéville. *An improved biologically plausible trajectory generator*, Technical report, n^{o} 4539-2, INRIA, February 2006, http://hal.inria.fr/inria-00072049.

[83] A. Wohrer, P. Kornprobst, T. Viéville. *A Biologically-Inspired Model for a Spiking Retina*, Technical report, n^{o} 5848, INRIA, February 2006, http://hal.inria.fr/inria-00070178.

References in notes

[84] G. Charpiat, O. Faugeras, R. Keriven. *Approximations of Shape Metrics and Application to Shape Warping and Empirical Shape Statistics*, in "Foundations of Computational Mathematics", vol. 5, n^{o} 1, February 2005, p. 1–58.

[85] G. Charpiat, R. Keriven, O. Faugeras. *Image Statistics based on Diffeomorphic Matching*, in "10th International Conference on Computer Vision", 2005.

[86] M. Descoteaux, M. Audette, K. Chinzei, K. Siddiqi. *Bone Enhancement Filtering: Application to Sinus Bone Segmentation and Simulation of Pituitary Gland Surgery*, in "Medical Image Computing and Computer-Assisted Intervention (MICCAI)", Lecture Notes in Computer Science, vol. 3749, Springer–Verlag, October 2005, p. 9–16.

[87] M. Descoteaux, E. Angelino, S. Fitzgibbons, R. Deriche. *Apparent Diffusion Coefficients from High Angular Resolution Diffusion Imaging: Estimation and Applications*, Technical report, n^{o} 5681, INRIA, September 2005, http://hal.inria.fr/inria-00070332.

[88] P. Maurel, R. Keriven, O. Faugeras. *Reconciling landmarks and level sets: geometric shape warping and matching using generalized gradients and correspondence-augmented implicit representations*, Technical report, n^{o} 5726, INRIA, October 2005, http://hal.inria.fr/inria-00070292.

[89] J.-P. Pons, G. Hermosillo, R. Keriven, O. Faugeras. *How to Deal with Point Correspondences and Tangential Velocities in the Level Set Framework*, Technical report, n^{o} 4857, INRIA, 2003, http://hal.inria.fr/inria-00071726.

[90] J.-P. Pons, R. Keriven, O. Faugeras. *Modelling Dynamic Scenes by Registrating Multi-View Image Sequences*, Technical report, n^{o} 5321, INRIA, 2004, http://hal.inria.fr/inria-00070679.

[91] J.-P. PONS, R. KERIVEN, O. FAUGERAS. *Modelling Dynamic Scenes by Registering Multi-View Image Sequences*, in "International Conference on Computer Vision and Pattern Recognition", vol. 2, 2005, p. 822–827.