INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Odyssee

Biological and Computer Vision

Sophia Antipolis

THEME BIO

Activity Report

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2. Overall Objectives

2.1. Overall Objectives

The Odyssée team is joint to INRIA, the Ecole Normale Supérieure in Paris and the CERTIS laboratory 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 presentation of these different areas and related demos are available.

3. Scientific Foundations

3.1. Variational methods and partial differential equations for vision

We are interested in using variational methods and partial differential equations because they are the tools that allow us to

- Mathematically model a large number of computer vision problems such as segmentation, stereo, motion analysis or shape recognition.
- Study the existence and uniqueness of solutions.
- Design efficient algorithms for approximating those solutions.

Within this general framework, we are interested in the following two main areas

- Feature integration, as seen from the algorithmic and biological viewpoints. We are currently investigating:
  - *Shape from shading*, to integrate occluding edges, shadows and textures. This work is done in the context of the theory of viscosity solutions.
  - *Stereo*, a problem that also requires the integration of occluding contours, shadows and textures.
  - The combination of stereo and motion.
  - The combination of color, texture and motion for image segmentation.
- Shape representation and learning. We investigate the problem of acquiring geometric models from image sequences from the algorithmic and biologic viewpoints. We have proposed a number of mathematical formulation of this problem. We work on 3D deterministic and stochastic shapes representation and learning. Results can be included in the work on feature integration and are potentially useful for guiding segmentation and recognition.

3.2. Observing brain activity by functional imaging

Brain imaging is a well-adapted tool to improve our knowledge of brain functioning, in particular of visual perception. Challenging computer vision problems can also be posed by this type of imagery. The evolution of technology gives access to ever increasing spatio-temporal resolutions, resulting in the measurement of cortical areas whose sizes are now compatible with our modelization tools. We focus on the following modalities, Magnetic Resonance (MR), electroencephalography (EEG) and magnetoencephalography (MEG).

- In the case of MR, we use:
  - Functional magnetic resonance images (fMRI).
    This is an indirect way of measuring brain activity through the Blood Oxygenation Level Dependent (BOLD) signal which is thought to be correlated with neuronal activity. Spatial resolution is, at best, of the order of one millimeter while temporal resolution is of the order of a tenth of a second.
  - Diffusion tensor magnetic resonance imagery (DTMRI).
    This particular modality provides a measure of the diffusion of water molecules in tissues from which one can infer the geometry of the neural fibers connecting various areas of the brain (anatomical connectivity). This measure is also correlated to the electrical conductivity.
  - Anatomical magnetic resonance imagery (aMRI)
    This can provide, through an algorithmic process called segmentation, a valuable geometric description of brain areas, e.g. the cortex, the white matter, the cerebrospinal fluid, etc...
- EEG and MEG, which we note MEEG, provide measurements which are highly correlated to the electrical activity of the brain. The spatial resolution is of the order of one centimeter while the temporal resolution is of the order of one millisecond.

These three modalities are complementary from the standpoint of their spatio-temporal resolutions and of the kind of information they can deliver. We work in the following six areas.

- Spatio-temporal modeling of fMRI signals to obtain more accurate and more detailed cortical activity maps than those provided by the currently available software packages.
- Spatio-temporal modeling of MEEG signals.
- The use of DTMRI to describe anatomical connectivities and improve the existing models of electrical conductivities currently used in MEEG.
- The analysis of the well-posedness of the inversed problem in MEEG, i.e. the existence and uniqueness of a particular brain activity that best accounts for the EEG/MEG measurements.
- The development of new numerical methods for solving the MEEG problem.
- The integration of these three modalities for studying visual perception in humans and non human primates.

3.3. Modeling cortical activity

We use the results obtained within our second main research area to model the way the brain completes a visual perception task at a more general level than the "voxel" level. The spatio-temporal activity maps measured on humans and non human primates play an important role in this modeling which carries two main advantages. First we push forward the state of the art of the knowledge of the brain processes underlying visual perception and second we may discover interesting sources of inspiration for our work in computer vision.

We also study cortical activity at a finer level than the "voxel" by fitting models of neurones assemblies to the measurements provided by fMRI, MEEG and possible micro-electrodes. We have two targets

- The use of cortical columns models to analyze the cortical activity measured by fMRI or MEEG goes beyond the use of the classical models of electric dipoles and opens up new perspectives as to what algorithmic complexity underlies this activity. This is also likely to have an impact on our understanding of the inverse problem in MEEG and therefore on the way we solve it.
- Such a description is closely related to the formalism of dynamic systems and, perhaps, partial differential equations. This is a fascinating possibility of connecting with our first main research area.

4. New Results

4.1. Variational methods and partial differential equations for vision

4.1.1. Generalized Minimizing Flows

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

This work tackles an important aspect of the variational problems involving active contours, which has been largely overlooked so far: the 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, overtly or covertly, 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. We investigate the relevance of using other inner products, yielding other gradient descents, and some other minimizing flows not deriving from any inner product. In particular, we show how to induce different degrees of spatial coherence into the minimizing flow, in order to decrease the probability of getting trapped into irrelevant local minima. We show with some numerical experiments that the sensitivity of the active contours method to initial conditions, which seriously limits its applicability and its efficiency, is alleviated by our application-specific spatially coherent minimizing flows. This work appeared in [21].

4.1.2. Implementing levelsets using finite element methods – application to cortex segmentation

Participants: Théodore Papadopoulo, Jérôme Piovano.

The standard level set method has been reformulated to use a finite element approach instead of the more traditionnal finite differences one. This is done by mapping the image domain to a structured mesh. According to the litterature, this has the advantage of better accuracy in the curve evolutions while limiting the size of the band needed to represent it. Furthermore, since the band is smaller, it is much easier to maintain the distance function during the evolution.

After a first implementation that used traditional meshes, a new version has been developped both in 2D and 3D that uses quadrilateral meshes (ie pixels and voxels): this is both simpler (no need of complex tiling of the space especially for the 3D case), more coherent for image processing (the quadrilateral elements are directly related to the standard sub-pixel interpolation schemes in the image domain) and more accurate (simpletic meshes introduce anisotropy in the evolutions). The method was also extended to use region based evolution terms and was applied to the problem of cortex segmentation.

4.1.3. Image Statistics

Participants: Guillaume Charpiat, Renaud Keriven, Olivier Faugeras.

We propose a new approach to deal with the first and second order statistics of a set of images. These statistics take into account the images characteristic deformations and their variations in intensity. The central algorithm is based on non-supervised diffeomorphic image matching (without landmarks or human intervention). As they convey the notion of the mean shape and colors of an object and the one of its common variations, such statistics of sets of images may be relevant in the context of object recognition, both in the segmentation of any of its representations and in the classification of them. The proposed approach has been tested on a small database of face images to compute a mean face and second order statistics. The results are very encouraging since, whereas the algorithm does not need any human intervention and is not specific to face image databases, the mean image looks like a real face and the characteristic modes of variation (deformation and intensity changes) are sensible. This work appeared in [20], [43].

4.1.4. Shape Warping and Shape Statistics

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

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. We illustrate them on a variety of examples[8], [20], [9].

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

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

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).

4.1.6. Reconciling landmarks and level sets

Participants: Pierre Maurel, Renaud Keriven, Olivier Faugeras.

Shape warping is a key problem in statistical shape analysis. This work proposes a framework for geometric shape warping based on both shape distances and landmarks. Taking advantage of the recently proposed spatially coherent flows, our method is mathematically well-posed and uses only intrinsic shape information, namely some similarity measure between shapes and the correspondence of landmarks provided on the shape surface. No extrinsic quantity is considered, neither a diffeomorphism of the embedding space nor point correspondences in this space. Thanks to a recent extension of the level set method allowing point tracking and tangential velocities, our method is compatible with implicit representations. Moreover, a matching between shape surfaces is provided at no additional cost. Although some recent work deals with implicit representations and landmarks, 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. A preliminary version of this work appears in [55].

4.1.7. Multi-view stereo reconstruction and scene flow estimation

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

We present 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 global measure of image similarity, chosen depending on imaging conditions and scene properties. Contrarily to existing deformable surfaces methods, which integrate a matching measure computed independently at each surface point, our approach computes a global image-based matching score between the input images and the predicted images. The matching process fully handles projective distortion and partial occlusions. Neighborhood as well as global intensity information can be exploited to improve the robustness to appearance changes due to non-Lambertian materials and illumination changes, without any approximation of shape, motion or visibility. Moreover, our approach results in a simpler, more flexible, and more efficient implementation than in existing methods. The computation time on large datasets does not exceed thirty minutes on a standard workstation. Finally, our method is compliant with a hardware implementation on modern graphic processor units. Our stereovision algorithm yields very good results on a variety of datasets including specularities and translucency. We have successfully tested our motion estimation algorithm on a very challenging multi-view video sequence of a non-rigid scene[14], [33] (to appear in the International Journal of Computer Vision).

4.1.8. Digital Matting using Graph Cuts

Participants: Olivier Juan, Renaud Keriven.

Given an image, digital matting consists in extracting a foreground element from the background. Standard methods are initialized with a trimap, a partition of the image into three regions: a definite foreground, a definite background, and a blended region where pixels are considered as a mixture of foreground and background colors. Recovering these colors and the proportion of mixture between both is an under-constrained inverse problem, sensitive to its initialization: one has to specify an accurate trimap, leaving undetermined as few pixels as possible. First, we propose a new segmentation scheme to extract an accurate trimap from just a coarse indication of some background and/or foreground pixels. Standard statistical models are used for the foreground and the background, while a specific one is designed for the blended region. The segmentation of the three regions is conducted simultaneously by an iterative Graph Cut based optimization scheme. This user-friendly trimap is similar to carefully hand specified ones. As a second step, we take advantage of our blended region model to design an improved matting method. Based on global statistics rather than on local ones, our method is much faster than standard Bayesian matting, without quality loss, and also usable with manual trimaps[26], [52].

4.1.9. Motion segmentation using Graph Cuts

Participants: Olivier Juan, Renaud Keriven.

We propose a new technique to extract layers in a video sequence. To this end, we assume that the observed scene is composed of several transparent layers, that their motion in the 2D plane can be approximated with an affine model. The objective of our approach is the estimation of these motion models as well as the estimation of their support in the image domain. Our technique is based on an iterative process that integrates robust motion estimation, MRF-based formulation, combinatorial optimization and the use of visual as well as motion features to recover the parameters of the motion models as well as their support layers. Special handling of occlusions as well as adaptive techniques to detect new objects in the scene are also considered (common work with Romain Dupont and Nikos Paragios from Ecole Nationale des Ponts et Chaussées [25], [50]).

4.1.10. Active Cuts

Participant: Olivier Juan.

Graph cuts are popular in vision because standard max-flow/min-cut algorithms for graph partitioning find global optima for many challenging N-D segmentation problems. In practice, however, existing methods are not real-time yet. We point out some limitations of standard combinatorial algorithms for s-t cuts: they do not use any reasonable initial cuts often available in applications in vision and generate a single solution (min-cut) only upon termination. In contrast, our new Active Cuts (AC) algorithm starts from any given initial cut and outputs a sequence of decreasing cost intermediate cuts converging to a global minima. In the context of segmentation, our approach resembles active contours. However, instead of a local minima it is guaranteed to converge to a global solution preserving the spirit of graph cuts methods. In some applications AC converges 2-4 times faster than the state-of-the-art max-flow methods even if initial cut is far from the optimal one. Furthermore, empirical speed improves several folds when initial cut is spatially close to the optima. In practice, intermediate cuts are good approximate solutions. They can also be used to improve visual perception of graph cuts real-time performance when large volumetric data is segmented (common work with Yuri Boykov from the University of Western Ontario. To appear).

4.1.11. Graphic Processor Unit algorithms and data structures for Computer Vision

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

We investigate the use of generic programming on graphic processing units (GPGPU) and the design of specific algorithms and data structures for accelerated or real time computer vision applications: multiview reconstruction[53], graph-cuts[49], variational stereovision[54].

4.1.12. Multiview stereovision using graph cuts

Participants: Emmanuel Cornet, Renaud Keriven.

We investigate here the use of discrete optimisation techniques to deal with the problem of multiview reconstruction. Our graph cut based method makes use of edge detection in the bi-dimensional images to recover the shape of the observed object[44]

4.1.13. 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, accepted for publication 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.

4.1.14. 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, accepted for publication 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.

4.1.15. Tensor Processing for Texture and Color Segmentation

Participants: Rachid Deriche, Rodrigo De Luis-Garcia, Mikael Rousson, Carlos Alberola-López.

In this work [24], we propose an original approach for texture and color segmentation based on the tensor processing of the nonlinear structure tensor. While the tensor structure is a well established tool for image segmentation, its advantages were only partly used because of the vector processing of that information. In this work, we use more appropriate definitions of tensor distance grounded in concepts from information theory and compare their performance on a large number of images. We clearly show that the traditional Frobenius norm-based tensor distance is not the most appropriate one. Symmetrized KL divergence and Riemannian distance intrinsic to the manifold of the symmetric positive definite matrices are tested and compared. Adding to that, the extended structure tensor and the compact structure tensor are two new concepts that we present to incorporate gray or color information without losing the tensor properties. The performance and the superiority of the Riemannian based approach over some recent studies are demonstrated on a large number of gray-level and color data sets as well as real images.

4.1.16. Regularization of Mappings Between Implicit Manifolds of Arbitrary Dimension and Codimension

Participants: Rachid Deriche, Nir Sochen.

We study in this work [35] the problem of regularization of mappings between manifolds of arbitrary dimension and codimension using variational methods. This is of interest in various applications such as diffusion tensor imaging and EEG processing on the cortex. We consider the cases where the source and target manifold are represented implicitly, using multiple level set functions, or explicitly, as functions of the spatial coordinates. We derive the general implicit differential operators, and show how they can be used to generalize previous results concerning the Beltrami flow and other similar flows. As examples, we show how these results can be used to regularize gray level and color images on manifolds, and to regularize tangent vector fields and direction fields on manifolds.

4.1.17. Vector-Valued Image Regularization with PDEs: A Common Framework for Different Applications

Participants: Rachid Deriche, David Tschumperlé.

In this work appeared in [16], we develop different techniques for vector-valued image regularization, based on variational methods and PDEs. Starting from the study of PDE-based formalisms previously proposed in the literature for the regularization of scalar and vector-valued data, we propose a unifying framework that gathers the majority of these previous frameworks into a single generic anisotropic diffusion equation and apply it to a set of different applications of interest.

4.1.18. *Geodesic active regions and level set methods for motion estimation and tracking*

Participants: Rachid Deriche, Nikos Paragios.

In this work appeared in [13], we successfully adapted our geodesic active regions framework to tackle the problems of motion estimation and tracking. Partial extension of the proposed framework to address dense motion estimation and the case of moving observer is also presented.

4.2. Observing and modeling the brain

4.2.1. *Hemodynamic models investigation in Optical Imaging*

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

The mechanisms that relate cerebral activity to functional Magnetic Resonance Imaging (fMRI) acquisitions imply a long chain rule of intermediary cerebral quantities, including 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 created the first Optical Imaging set in France, we are getting new insights in some parts of so-called "hemodynamic" models. In particular, we propose that the blood flow dynamic does not relate linearily to neural activity.

4.2.2. *Blood flow recordings using high resolution Optical Imgaging*

Participants: Thomas Deneux, Ivo Vanzetta, 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 only, 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 on the structure tensor in 2D spatio-temporal images. This is also a collaboration with Ivo Vanzetta, at the INCM, CNRS Marseille. This work appeared in [57].

4.2.3. *Use of nonlinear models in fMRI analysis*

Participants: Thomas Deneux, Olivier Faugeras.

We propose methods to adapt the usual fMRI analysis tools (estimation of the hemodynamic response function, activation test) developped in 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. These methods have been used on a specific dataset acquired at the La Timone hospital in Marseille. Conclusions were that using nonlinear models instead of linear convolution is possible, and actually the analysis results done with either procedure are mostly similar. This work appeared in [45].

4.2.4. *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 Resonance 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 (see 4.2.14). The fMRI model we used is the so-called "Balloon Model", that 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. Theoretical work on this algorithm and simulation on artificial data appear in [46].

Besides, we are currently applying the method to experiments with epileptic subjects realized in the Mc Gill university (Montréal), in collaboration with Jean Gotman.

4.2.5. Variational Approaches to the Estimation, Regularization and Segmentation of Diffusion Tensor Images

Participants: Rachid Deriche, Christophe Lenglet, Mikael Rousson, David Tschumperlé.

Diffusion magnetic resonance imaging probes and quantifies the anisotropic diffusion of water molecules in biological tissues, making it possible to non-invasively infer the architecture of the underlying structures. In this work [10], we present a set of new techniques for the robust estimation and regularization of diffusion tensor images (DTI) as well as a novel statistical framework for the segmentation of cerebral white matter structures from this type of dataset. Numerical experiments conducted on real diffusion weighted MRI illustrate the techniques and exhibit promising results.

4.2.6. A Riemannian Approach to Anisotropic Filtering of Tensor Fields

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

Tensors are nowadays an increasing research domain in different areas of knowledge, especially in image processing, motivated for example by DT-MRI (Diffusion Tensor Magnetic Resonance Imaging). 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 work, we focus on the contribution of these tools to the anisotropic filtering and regularization of tensor fields. To validate our approach we present some interesting results on both, synthetic and real DT-MRI data. This work will appear in 2006 in the revue Signal Processing (special issue on Tensor Processing).

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

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

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. This work has been accepted for publication in the Journal of Mathematical Imaging and Vision (to appear late 2005 or early 2006).

4.2.8. A Riemannian Approach to Diffusion Tensor Images Segmentation

Participants: Rachid Deriche, Olivier Faugeras, Stéphane Lehéricy, Christophe Lenglet, Mikael Rousson, Kamil Ugurbil.

In this work [32], we address the problem of the segmentation of cerebral white matter structures from diffusion tensor images. Our approach is grounded on the theoretically well-founded differential geometrical properties of the space of multivariate normal distributions. We introduce a variational formulation, in the level set framework, to estimate the optimal segmentation according to the following hypothesis: Diffusion tensors exhibit a Gaussian distribution in the different partitions. Moreover, we must respect the geometric constraints imposed by the interfaces existing among the cerebral structures and detected by the gradient of the diffusion tensor image. We validate our algorithm on synthetic data and report interesting results on real datasets. We focus on two structures of the white matter with different properties and respectively known as the corpus callosum and the corticospinal tract.

4.2.9. A Riemannian Approach to Diffusion Tensors Estimation and Streamline-based Fiber Tracking

Participants: Rachid Deriche, Olivier Faugeras, Stéphane Lehéricy, Christophe Lenglet, Kamil Ugurbil.

Diffusion Tensor MRI evaluates, from a set of diffusion weighted images, the covariance matrix of the water molecules Brownian motion. In other words, it approximates the probability density function of the molecular motion by a multivariate normal distribution of zero-mean vector. In this work [30], we address the issues of diffusion tensors estimation and streamline-based fiber tracking by using the geometrical properties of the manifold of multivariate normal distributions.

4.2.10. Diffeomorphic Matching of Symmetric Positive Definite Matrix Fields

Participants: Rachid Deriche, Olivier Faugeras, Christophe Lenglet, Theo Papadopoulo.

In this work [31], we address the problem of the dense non-rigid registration of fields of symmetric, positive definite matrices. This work is motivated by the need, arising in medical imaging, to compare matrix-valued images of different brains. Geometric deformations can result from the distortions related to the acquisition procedure or from the cerebral tissues morphological variability. Diffusion Tensor Imaging (DTI) models the probability density function of the three-dimensional molecular motion by a normal distribution of 0 mean and whose covariance matrix is given by the diffusion tensor.At a conceptual level, DT images are integrable bounded functions defined on $\mathbb{R}^n$, $n = 2, 3$ with values in $S^+(3, \mathbb{R})$, the set of 3×3 real symmetric positive definite matrices. This space has an interesting and useful Riemannian geometry with closed form expressions for the geodesics and the Christoffel symbols. We extensively rely on the properties of this manifold to perform the parallel transport of tangent vectors and to define statistical quantities such as the mean and the auto-covariance matrix that have been found to be very useful for image warping. If I_1 and I_2 are two images and $\mathbf{h} : \Omega \rightarrow \mathbb{R}^n$ is a vector field defined on a bounded and regular region of interest $\Omega \subset \mathbb{R}^n$, the registration problem may be defined as that of finding a vector field $\mathbf{h}^*$ minimizing an error criterion between I_1 and $I_2 \circ \mathbf{h}$. The search for this function is done within a set of admissible functions so as to minimize an energy functional $\mathcal{I}(h)$ designed to measure the dissimilarity between the reference image (I_1) and the h-warped image ($I_2(h)$) and to penalize fast variations of the function h. Numerical experiments, using the scientific software package *Scilab*, are presented.

4.2.11. Activation Shifts from the Premotor to the Sensorimotor Territory of the Striatum during the Course of Motor Sequence Learning

Participants: H. Benali, J. Doyon, R. Deriche, O. Faugeras, S. Lehéricy, C. Lenglet, G. Sapiro, K. Ugurbil, P.F. Van de Moortele.

Previous studies suggested that associative striatal regions are involved during the acquisition of new motor skills, whereas sensorimotor regions may be critical for long-term storage. Using fMRI and DTI fiber tracking, we tested in this work [29] the hypothesis that motor representations shift from the associative to the sensorimotor compartment of the basal ganglia during the explicit learning of a sequence of finger movement over a month of training.

4.2.12. Apparent Diffusion Coefficients from High Angular Resolution Diffusion Images: Estimation and Applications

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

High angular resolution diffusion imaging (HARDI) has recently proven of great interest in characterizing non-Gaussian diffusion processes. In the white matter of the brain, non-Gaussian diffusion occurs when fiber bundles cross, kiss or diverge within the same voxel. One important goal in current research is to obtain more accurate fits of the apparent diffusion processes in these multiple fiber regions, thus overcoming the limitations of classical diffusion tensor imaging (DTI). This work [48] presents an extensive study of high order models for apparent diffusion coefficient estimation and illustrates some of their applications. In particular, we first develop the appropriate mathematical tools to work on noisy HARDI data. Using a meaningful modified spherical harmonics basis to capture the physical constraints of the problem, we propose a new regularization algorithm to estimate a diffusivity profile smoother and closer to the true diffusivities without noise. We define a smoothing term based on the Laplace-Beltrami operator for functions defined on the unit sphere. The properties of the spherical harmonics are then exploited to derive a closed form implementation of this term into the fitting procedure. We next derive the general linear transformation between the coefficients of a spherical harmonics series of order ℓ and the independent elements of the rank-ℓ high order diffusion tensor. An additional contribution of this work is the careful study of the state of the art anisotropy measures for high order formulation models computed from spherical harmonics or tensor coefficients. Their ability to characterize the underlying diffusion process is analyzed. We are able to reproduce published results and also able to recover voxels with isotropic, single fiber anisotropic and multiple fiber anisotropic diffusion. We test and validate the different approaches on apparent diffusion coefficients from synthetic data, from a biological phantom and from a human brain dataset. This work appeared in [48] and a part of it has been accepted for presentation and publication at SPIE-Medical Imaging, San Diego, Feb. 11-16, 2006

4.2.13. A linear and regularized ODF estimation algorithm to recover multiple fibers in Q-Ball imaging

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

Due to the well-known limitations of diffusion tensor imaging (DTI), high angular resolution diffusion imaging is currently of great interest to characterize voxels containing multiple fiber crossings. In particular, Q-ball imaging (QBI) is now a popular reconstruction method to obtain the orientation distribution function (ODF) of these multiple fiber distributions. The latter captures all important angular contrast by expressing the probability that a water molecule will diffuse into any given solid angle. However, QBI and other high order spin displacement estimation methods involve non-trivial numerical computations and lack a straightforward regularization process. In this work [47], we propose a simple linear and regularized analytic solution for the Q-ball reconstruction of the ODF. First, the signal is modeled with a physically meaningful high order spherical harmonic series by incorporating the Laplace-Beltrami operator in the solution. This 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 ODF estimation quantitatively using the multi-tensor synthetic model where the exact ODF can be computed. We also demonstrate that the estimated ODF can recover known multiple fiber regions in a biological phantom and in the human brain. Another important contribution of the paper is the development of ODF sharpening methods. We show that sharpening the measured ODF enhances each underlying fiber compartment and considerably improves the extraction of fibers. The proposed techniques are simple linear transformations of the ODF and can easily be computed using our spherical harmonics machinery.

4.2.14. Forward and Inverse Boundary Element solutions for EEG and MEG

Participants: Geoffray Adde, Maureen Clerc, Olivier Faugeras, Jan Kybic, Théo Papadopoulo, Renaud Keriven.

We have proposed a new integral formulation for EEG, which has led to a symmetric Boundary Element Method. We have demonstrated the far superior accuracy of this method over the existing methods in the case of dipolar sources and a head model made of concentric spheres, for which the analytical solution is known [11]. The symmetric BEM is used to solve the source localization problem of MEG-EEG, with so-called imaging techniques, which model the sources as distributed over the cortical surface [3], [18].

4.2.15. Forward EEG problem using the volumic Finite Element approach and Implicit Meshes

Participants: Maureen Clerc, Olivier Faugeras, Théodore Papadopoulo.

One of the main problems in the volumic EEG forward and inverse problems is the obtention of the mesh discretizing the head. Because the cortex is a very thin layer separated by surfaces with high curvatures, meshes describing these surfaces involve a great number of triangles. Mesh decimation is also quite difficult here because the two close surfaces need to be decimated simultaneously in order to preserve a proper topology so as to feed a 3D mesh generator with consistent data. Overall, the effort required to obtain descent mesh models of the head is several orders of magnitude more complicated than solving the EEG problem. On the other hand, it is quite easy to obtain a very accurate head segmentation using levelsets (see 4.2.21). We have thus developped a volumic finite element method that is directly based on the implicit description of the surfaces provided by the levelset segmentation. This “implicit mesh” construction is very simple and quite fast compared to the many operations needed to construct a standard mesh. Besides, this mesh representation is very compact and has a bounded complexity with respect to the image data. It allows quite a few standard algorithmic improvements such as multigrid which were previously ruled out because of the complexity of the process of creating a mesh.

4.2.16. Fast Multipole Method for the forward problem of MEEG

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

The accurate solution of the forward electrostatic problem is an essential first step before solving the inverse problem of magneto- and electro-encephalography (MEG/EEG). The symmetric Galerkin boundary element method is accurate but cannot be used for very large problems because of its computational complexity and memory requirements. We have designed a fast multipole-based acceleration for the symmetric boundary element method (BEM). It creates a hierarchical structure of the elements and approximates far interactions using spherical harmonics expansions. The accelerated method is shown to be as accurate as the direct method, yet for large problems it is both faster and more economical in terms of memory consumption [12].

4.2.17. Skull conductivity estimation by Electrical Impedance Tomography

Participants: Geoffray Adde, Jean-Michel Badier, Maureen Clerc, Jan Kybic, Theo Papadopoulo, Sylvain Vallaghé.

Localizing electrical sources of activity in the brain by solving the EEG inverse problem supposes that the conductivity of the head is known. The knowledge of skull conductivity, in particular, is important because its low conductivity gives the skull a shunting effect. We propose to estimate the skull conductivity by Electrical Impedance Imaging (EIT), a problem closely related to Electro-encephalography. In EIT, a known current is applied to the scalp, through a couple of electrodes of the EEG helmet, and the electric potential is measured at the remaining electrodes. The potential V and the current j are related by a homogeneous Poisson equation $\nabla \cdot (\sigma \nabla V) = 0$ with non-vanishing Neumann boundary condition $\frac{\partial V}{\partial n} = j$ on the scalp. In a piecewise constant conductivity model, the forward EIT problem can be solved with the Boundary Element Method, leading to the same system as for the forward EEG problem, only with a different source term [22]. We are currently evaluating the robustness of the conductivity estimation by this method. This work is done in collaboration with Jean-Michel Badier from the Neurophysiology and Neuropsychology Laboratory at La Timone hospital, Marseilles (INSERM EMI 9926) and Jan Kybic from the Center for Machine Perception, Czech Technical University. In his Master’s thesis, Sylvain Vallaghé has shown that the skull to scalp conductivity ratio can be estimated by using a focal source inside the brain, such as evoked by a somatosensory activity, combined with a dipole search, instead of imposing a current pattern on the scalp.

4.2.18. Cortical mapping

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

Cortical imaging refers to the mapping of the electric potential on the surface of the brain, from EEG measurements on the scalp. It is related to the "Cauchy problem" in functional analysis, which concerns the transmission of Cauchy data the value of a harmonic function and its normal derivative on the boundary of a conducting volume. In collaboration with our colleagues Juliette Leblond from APICS project (INRIA) and Jean-Paul Marmorat from Ecole des Mines, we propose to compare two cortical imaging methods, one based on a bounded extremal problem, and one based on a boundary element discretization and applicable to domains of arbitrary shape. The bounded extremal problem method consists in solving an approximation issue for 3D Hardy classes of analytic functions in spherical domains. Here, the (quadratic) criterion is minimized on the part of the boundary where data is available, while a constraint is put on the other part, playing the role of a regularization parameter. The symmetric boundary element method uses as unknowns both the potential and the normal current on all surfaces, making it possible to estimate the potential as well as its normal derivative on the surface of the cortex. Regularization is compulsory, due to the ill-posedness of the Cauchy problem.

The cortical imaging is applied as a preprocessing step before electromagnetic source localization, by best meromorphic approximation [23].

4.2.19. Combined fMRI and DTI of the human low level visual cortex

Participants: Jean-Luc Anton, Rachid Deriche, Olivier Faugeras, Christophe Lenglet, Muriel Roth, Nicolas Wotawa.

There are 4 main criteria to define visual cortical areas: histology, connectivity, global functional properties and retinotopy. Through fMRI, we used the last two criteria to delineate various occipital and mid-temporal areas. Based on diffusion tensor images, we then studied the connectivity patterns among these areas within and across both hemispheres. The goal of this work is twofold: (i) validate the methodology of merging fMRI and DTI and (ii) refine non-invasively our knowledge of the low level human visual cortex.

During each scanning session of less than 1.5 hour performed on a 3T MR scanner, subjects underwent three different kinds of runs. A phase-encoded retinotopic mapping was first performed to reveal the locations and borders of the occipital visual areas V1, V2, V3, hV4 and V3A. Secondly, a classical block design substraction procedure was completed to reveal the hMT+ complex (the human equivalent to macaque's MT, MST and adjacent areas), contrasting random dots pattern in coherent motion with a dynamic noise or a static condition. Finally, DTI data were obtained. For fiber tracking analysis, diffusion tensors were used as a metric to first compute the geodesic distance and then the shortest paths between the above stated areas of the visual cortex. A measure of likelihood for each computed path was derived by examining the properties of the geodesic distance function. Images were realigned and coregistered on the subject high resolution anatomical scan acquired within the scanning session. The results are analyzed on this anatomical image or a cortical surface model extracted from the latter.

We found various connections between areas of the occipital and mid-temporal cortex, in line with previous results on non-human primates. Our results show a good intra and inter-subject reproducibility. Beyond the validation of merging fMRI mappings and DTI connectivity informations, this study improves our confidence in the areas labelling and further brings insights about the famous ventral and dorsal streams in the human low level visual cortex. [41]

4.2.20. Motion direction selectivity in human visual cortex

Participants: Eric Castet, Olivier Faugeras, Nicolas Wotawa.

Motion direction selectivity has been characterized using invasive techniques in non-human primates, but it is still poorly understood on humans. We proposed an fMRI experiment to study the human cortex selectivity to this visual feature.

We first individually mapped various occipital visual areas based on retinotopic mapping and functional selectivity criteria. This area identification step was used to define 8 homogeneous Regions Of Interest (ROIs) per hemisphere. We then conducted an fMR-adaptation experiment to compare the selectivity to motion direction changes across ROIs. Basically, during each 5mn scanning session, the same motion direction was shown to the subject except during test trials where the motion direction was changed by either 0, 45 or 180 degrees. We used a region-based Hemodynamic Response Function (HRF) estimation method that considers each ROI as functionally homogeneous and then uses all the available time series within the ROI to characterize the shape of the HRF for each trial type. The underlying model is non-parametric in the sense that no prior shape of the HRF is assumed in advance, and this technique provides robust HRF estimates since smoothness constraints are introduced within the Bayesian framework. We finally computed a motion direction selectivity index for each ROI and trial type.

The most direction selective areas appeared to be hMT+ (the human equivalent to macaque's MT, MST and adjacent areas) followed by V3A (V3 "accessory"), in line with previous neuroimaging reports. These results further enhance the characterization of the occipital visual cortex and support the idea of a human dorsal motion processing stream. Besides, our study brings another proof of the efficiency of event-related adaptation paradigms to examine the functional selectivity of cortical areas to a special feature, even for low-level cognitive processes such as motion direction. Finally, the surprisingly high motion direction selectivity we observed in human area V4 emphasizes the context dependent functional selectivity of visual areas, as recently demonstrated in an electrophysiological study of post-adaptation inherited motion direction selectivity in macaque area V4. (To appear).

4.2.21. Segmenting the cortical surface

Participant: Jean-Philippe Pons.

We propose a novel framework to exert a topology control over a level set evolution. Level set methods offer several advantages over parametric active contours, in particular automated topological changes. In some applications, where some a priori knowledge of the target topology is available, topological changes may not be desirable. A method, based on the concept of simple point borrowed from digital topology, was recently proposed to achieve a strict topology preservation during a level set evolution. However, topologically constrained evolutions often generate topological barriers that lead to large geometric inconsistencies. We introduce a topologically controlled level set framework that greatly alleviates this problem. Unlike existing work, our method allows connected components to merge, split or vanish under some specific conditions that ensure that no topological defects are generated. We demonstrate the strength of our method on a wide range of numerical experiments, among which cortical surface segmentation (common work with Florent Ségonne [56], [36]).

4.2.22. Active electrode compensation for intracellular recordings

Participants: Romain Brette, Zuzanna Pikowska, Michael Rudolph, Alain Destexhe, Thierry Bal.

When recording the membrane potential of a neuron through a single-electrode, current injection induces a voltage drop across the electrode which biases the measurement. Compensating for the electrode resistance (bridge compensation) leaves capacitive transients which prevent its use in protocols with fast currents and feedback, such as the dynamic clamp or the voltage-clamp. The only option is to record in discontinuous mode, alternatively injecting and recording, but besides being limited to a low sampling rate (typically as low as 3 kHz with sharp electrodes) and introducing considerable noise, this technique produces artefacts when recording fast phenomena, such as spikes or fast fluctuations of the membrane potential. We have developed a digital on-line compensation method which allows faithful recording in continuous mode, with sampling frequency only limited by hardware constraints, and have demonstrated its use by injecting noisy synaptic conductances with a sharp electrode, using the dynamic-clamp technique (experiments done at UNIC, Gif-sur-Yvette) [19].

4.3. Modeling cortical activity

4.3.1. Modeling a biologically-inspired spiking retina model for the encoding of visual sequences

Participants: Adrien Wohrer, Thierry Vieville, Pierre Kornprobst.

In this work, our aim is to model the magnocellular pathway of a retina. The initial model presented in [40] has two objectives. First, it allows to convert a time-continuous representation into an event-driven representation of a dynamic visual sequence, which can be used afterward as an input for other neuronal simulators. Second, it provides an integrated view of the real neural encoding taking place in the magnocellular pathway, and very likely in the parvocellular pathway, when considering smaller receptive fields and saccadic displacements.

It consists of units representing ganglionar cells, modeled as Integrate and Fire neurons with three ionic channels. The first channel is a depolarizing conductance, driven by the bipolar cells connected to the ganglionar, who are assumed to behave as spatio-temporal linear filters on the input sequence. The second channel is a constant leakage conductance, while the third one corresponds to some optional horizontal inhibition between neighboring cells, as driven by amacrine cells in the biological retina, yielding redundancy removal. Thus our retina can perform an interesting alternative to such greedy algorithms as the "matching-pursuit". Besides, our model is foveated: the ganglionar cells' receptive fields grow larger with eccentricity while the cells density decreases, as in mammalians, according to a higly parametrizable log-polar sampling scheme. Furthermore, the front-end of the mechanisms integrates camera intrinsic calibration parameters and can simulate a rotation of the eye, allowing saccadic displacements or eye-tracking as possible developments.

At the implementation level, the neurons' spiking is computed thanks to an event-orientated formalism and its related software, "mvaspike", very useful as all equations become coupled through lateral inhibition. This software will allow the connection of the retina to higher-level, spike-based, treatments.

This work is still under development and subsequent validation will come, motivated by the Facets consortium requirements.

4.3.2. Biological motion recognition using fast brain-like mecanisms

Participants: Ivan Dimov, Pierre Kornprobst, Thierry Vieville.

Biological motion recognition refers to our ability to recognize a scene (motion or movement) based on the evolution of a limited number of tokens. Much work has been done in this direction showing how it is possible to recognize actions based on these points.

Following the work of Giese and Poggio and using some recent results of Thorpe et al. we propose in [27] an alternative approach based on the fact the neural information is, in the fast brain, coded by the relative order in which these neurons fire. The result of these simulations is that information from early visual processes appears to be sufficient to classify biological motion.

A step further, we explore in [28], [39] how this fast brain mechanism of labelization can be used as a feedback input to help segmenting motion. For this, consider the simple fact that the classification process is not only able to give a label but also to evaluate for each token, whether its contribution to the labelization has been positive (inlier) or negative (outlier). One way to implement this mechanism is to simply inhibit the contribution of each token and evaluate whether this transient deletion improves or impairs the labelization level of quality, which is output by the SVM like classifier. As a local feedback this loop acts as an oscillation mechanism which stabilizes at a local optimum. This inlier/outlier segmentation may help segmenting the object with respect to the background.

The biological plausibility of the present model is based on the proposed Hebbian implementation of statistical learning algorithm related to SVM and based on the Thorpe and Delorme neuronal models. It is shown that the top-down feedback is easily implemented as an interaction between the classification map (as observed in IT) and earlier cortical maps, taking into account the way feed-backs act in the brain.

4.3.3. Building a link between PDE and biological networks

Participants: Olivier Faugeras, Pierre Kornprobst, Thierry Vieville.

We revisit here the links between (i) high-level specification of how the brain represents and categorizes the causes of its sensory input and (ii) related analog or spiking neural networks .

Focusing on visual processing, we show -for a rather general class of cortical map computations- how it is possible to directly rely “what is to be done” (perceptual task) with “how to do it” (neural network calculation).

More precisely, in computer vision, efficient computations using implementations of regularization processes allows to obtain well-defined and powerful estimations. Having a biologically plausible representation of such mechanisms is thus a challenging issue.

Reviewing recent ideas about brain activity representation, we show how the key idea is to (i) represent what is to be done as an optimization problem, (ii) considering regularization mechanisms (implemented using so-called partial-differential-equations) and (iii) “compiling” the related analog or spiking neural network parameters.

The basement of the present contribution is the development of an unbiased approximation of a diffusion operator used in regularization mechanisms (introducing a summation property). A direct link between continuous formulation and the related sampled implementation is obtained. It also provides convergence properties for the related network.

Not only analog networks but also deterministic spiking neural network can implement the present specifications, using here piece-wise approximations in the so called Spike Response Model, also leading to a fast event-based simulation of such networks.

4.3.4. *Bifurcation analysis of a cortical column model*

Participants: François Grimbert, Olivier Faugeras.

In this contribution, we present a mathematical analysis of a simple model of a cortical column [51]. We first recall some known biological facts about cortical columns. We then present a mathematical model of such a column, developed by a number of people including Lopes Da Silva, Jansen, Rit. Finally we analyze some aspects of its behaviour in the framework of the theory of dynamical systems using bifurcation theory and the software package XPP-Aut developed by B. Ermentrout. This mathematical approach leads us to a compact representation of the model that allows to finally discuss its adequacy with biology. An article corresponding to this work has been submitted to Neural Computation.

4.3.5. *Models of cortical activity at a mesoscopic scale*

Participants: Camilo La Rota, Maureen Clerc, Olivier Faugeras.

This work lies at the interface between the observation and the modelling of brain activity.

We are working on two main related issues: i) MEEG signal modeling and simulation and ii) estimation of the spatiotemporal distribution of MEEG sources (dynamical inverse problem) based on models of brain activity.
Brain activity models are being constructed at a mesoscopic scale where the fundamental unit is a neuron population (or neural mass) of the size of a functional column and the observed activity, the state variables and the input and output variables are defined in terms of densities or intensities of axonal pulses, dendritic currents or waves of membrane potentials. They are structured according to known functional and anatomical structures and connectivities (e.g, layers, columns, areas, and intra-,cortico- and thalamocortical connectivities) and the dynamics are given by a system of coupled PDEs describing pulse propagations across axonal projections and arborizations, and by linear synaptic pulse-wave and nonlinear somatic wave-pulse transformations. MEEG sources are being modeled by a continuous spatiotemporal distribution of dipoles lying over the cortical surface and oriented along the normal at each surface point. Dipole moments are assumed to be generated mostly by the longitudinal intracellular currents flowing along the apical dendrites of pyramidal neurons, so their dynamics can be simply related to the dynamics of the model’s state variables. Simulations are being carried on realistic geometries of the human cortical surface obtained from anatomical MRI data and physiological and anatomical parameters are taken mostly from the existing litterature.

The dynamical MEEG inverse problem is being studied in a probabilistic (bayesian) state-space framework, where the state variables are the axonal pulse and dendritic current densities or intensities, and the evolution of the state is governed by a model describing the dynamics of brain activity. The observation model is given by the relationship between the state variables and the dipole moments and by the solution to the MEEG forward problem.

4.3.6. *Neural Network Simulation on Graphic Processor Units*

Participants: Fabrice Bernhard, 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. We describe the implementation on graphic cards and the results observed for two segmentation algorithms using impulse neural networks: an algorithm by Campbell, Wang and Jayaprakash and an algorithm by Buhmann, Lange and Ramacher [42].

4.3.7. A predictive bidimensional integrate-and-fire neuron model

Participants: Romain Brette, Wulfram Gerstner.

We introduced a two-dimensional integrate-and-fire model that combines an exponential spike mechanism with an adaptation equation, based on recent theoretical findings. We developed a systematic method to estimate its parameters with simple electrophysiological protocols (current-clamp injection of pulses and ramps) and applied it to a detailed conductance-based model of a regular spiking neuron. Our simple model predicts correctly the timing of 96% of the spikes ($\pm 2ms$) of the detailed model in response to injection of noisy synaptic conductances. The model is especially reliable in high-conductance states, typical of cortical activity in vivo, in which intrinsic conductances were found to have a reduced role in shaping spike trains. These results are promising because this simple model has enough expressive power to reproduce qualitatively several electrophysiological classes described in vitro [6].

5. Other Grants and Activities

5.1. Regional Grants

5.1.1. COLOR project

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

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++/).

5.2. National Grants

5.2.1. Large Dataset ACI: Obs-Cerv

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

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).

5.2.2. Neuroscience ACI: DYNN Dynamic of biological plausible neuronal networks

Participants: Olivier Faugeras, Pierre Kornprobst, Thierry Vieville.

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).

5.2.3. Non-rigid registration "specific action"

Participants: Guillaume Charpiat, Christophe Chefd’hotel, Olivier Faugeras, Gerardo Hermosillo, Renaud Keriven.

The contributors are: ENS Cachan (CMLA), INT (ARTEMIS), IMAG TIMC (GMCAO), INRIA (Epidaure, Odyssée), INSA (CREATIS), IRISA (Projet Vista), Louis Pasteur University (LSIIT), Paris V University (MAP5) and Paris XIII University (LAGA) (detailed presentation: http://www-artemis.int-evry.fr/ rougon/AS-RNR/).

5.3. UE Grants

5.3.1. *ImaVis: Theory and Practice of Image Processing and Computer Vision*

Participants: Rachid Deriche, Olivier Faugeras.

IMAVIS:Theory and Practice of Image Processing and Computer Vision is a four year European project, started on Sept. 2001 and numbered HPMT-CT-2000-00040 working within the framework of Marie Curie Training Sites Fellowships programme which give young researchers pursuing doctoral studies the opportunity to receive training within high-level groups in their specialised area of research. Within IMAVIS, the research groups Ariana, Epidaure and Odyssée (Coord.) located at INRIA Sophia-Antipolis are offering 108 fellow-months for PhD Students, nationals of a Member or Associated State.

Thomas Brox, from Department of Mathematics and Computer Science, Saarland University and Iasonas Kokkinos from National University of Athens spent four months each in our lab in 2002/2003.

Rodrigo de Luis-Garcia (Universidad de Valladolid - ETSI Telecomunicación) joined our group from early June to end of September 2004

Fussenegger Michael (Graz University) joined our group early September 2004 and stayed until the end of January 2005.

Carlos Alberto Castano Moraga (Universidad Las-Palmas) joined our group early November and stayed within our group until the end of July 2005.

5.3.2. *NSF-INRIA Proposal: Computational Tools for Brain Research*

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

Key-words : Diffusion Tensor Imaging, Shape statistics.
Duration : 3 years starting from July 2004.
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.

5.3.3. *FFCR Canada Proposal: Biomedical Image Analysis*

Participants: Rachid Deriche, Olivier Faugeras, Maxime Descoteaux.

Key words : Diffusion MRI, HARDI.
Duration : 1 year from August 2003 to August 2004. Extended until August 2005.
Our partner in this project is Prof. Kaleem Siddiqui from Mac-Gill McGill University (School of Computer Science and Centre For Intelligent Machines). 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 R. Deriche.

5.3.4. *PAI PICASSO*

Participants: Rachid Deriche, Olivier Faugeras, Theo Papadopoulo.

Key words : Optical flow, Biological Vision, Diffusion Tensor Imaging.
Duration : 1 year from early 2004 to the end of 2005.
This project includes the Mathematical Image Analysis group leaded by Prof. Luis Alvarez from Las-Palms University and the group leaded by Juan Ruiz Alzola which contributed a lot in DT-MRI. Our goal is to develop

algorithms for use in image analysis and DT-MRI based on variational frameworks. Exchanges of visits has already occured from Las-Palmas to Nice and vice-versa and a joint article on the subject has recently been accepted for publication in IJCV.

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

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

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/).

5.3.6. FACETS : Fast Analog Computing with Emergent Transiant States

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

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/).

5.4. International Bilateral Relations

R. Deriche has been continuously in charge of the International Affairs for the INRIA Sophia Research Unit since 1996 (see the corresponding web site: http://www-direction.inria.fr/international).

5.4.1. Miscellaneous

T. Viéville is in charge of the Doctoral Training Program for the Sophia Research Unit since 1999 and is the INRIA representative in the Univ.of Nice Scientific commitee. He is a member of the Director Advisory Board since 2002.

6. Dissemination

6.1. Services to the scientific community

R. Deriche has been invited to the advisory board of RealViZ and 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, a member of the *Expert Commission CS 61 Génie informatique, automatique et traitement du signal* at Nice Sophia-Antipolis University. R. Deriche has been 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).

Maureen Clerc coordinates the ACI Obs-Cerv.

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

Renaud Keriven is a member of a number of commitees at the Ecole Nationale des Ponts et Chaussees such as the "CS PhD thesis committee", the "PhD program committee" and educational committees.

Pierre Kornprobst is the organisor of a meeting about modeling neurons and networks using PDE, integro-differential equations and dynamical systems, within the GDR Mathématiques des Systèmes Perceptifs et Cognitifs, to be held in Paris in January 2006.

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).

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

6.2. Academic teaching

6.2.1. 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.

6.2.2. 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 teaches the 3D Vision course.

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

6.2.3. Prédoctorat d'Informatique de l'ENS

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

6.2.4. 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 with Nikos Paragios.

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

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

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

6.2.6. Master Informatique Fondamentale et Applications

Renaud Keriven teaches the Computer Vision course at the Marne la Vallée University.

6.2.7. Magistère de Mathématiques Fondamentales et Appliquées et d'Informatique de la Région Parisienne

Renaud Keriven and Rahid Deriche teach the Algorithmic Computer Vision course, now joint with the previously mentionned MPRI course.

6.3. Other teaching loads

6.3.1. 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.

6.3.2. 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 two specialisation modules "Probabilities, Numerical Analysis and Computer Science" and "Computer Vision and Image Processing".

6.3.3. Ecole Normale Supérieure Paris

Romain Brette is a tutor for 3 computer science students.

6.3.4. 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. Adrien Wohrer and Sylvain Vallaghé are teaching assistants of Image Processing course for second years students at the Computer Science Departement of UNSA IUT.

6.3.5. Centre International de Valbonne (CIV)

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

6.3.6. 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.

6.3.7. 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.

6.4. Software

6.4.1. A software to create parameterised standard video sequences used in psychophysics

Participants: Thierry Vieville, Pierre Kornprobst, Damien Montigny, Alexandre Reynaud, Benjamin Caramel.

Researchers in psychophysics have designed precised parametrized visual stimuli to evaluate some specific performances of the visual systems. These stimuli are also important to compare the results obtained by artificial systems with respect to human performances. For these reasons, a software has been developed in order to generate easily these stimuli, which will be used to evaluate future vision tasks.

VisStim, alias Visual Stimuli, is the name of the open-source plateform which allows to generate standart animated visual stimuli. These stimuli are video sequences containing geometric features moving or deforming. Depending on the choice of the parameters, on may observe some biais in the perception of the motion induced. This property makes these stimuli challenging for the experimental and theoretical analysis of biological and artificial vision.

This plateform is opened and can be completed by additional stimuli. It is based on JAVA and SVG language for the sequence generation, which is very efficient for images with geometric figures. Main stimuli parameters concern shape, motion and masks.

To know more: http://www-sop.inria.fr/odyssee/imp/visstim/

APP deposit:

IDDN.FR.001.410012.000S.P.2005.000.31235 VISSTIM (software)

IDDN.FR.001.410013.000S.P.2005.000.31235 I.M.P. (related middle-ware)

6.5. 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 ICSIT:2005 :International Conference of Computer Systems and Information Technology held in July 2005 in Algiers

Rachid Deriche has been invited to give series of lectures at USTHB (Algiers)

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,

ISMIC:2005: International Symposium on Medical Imaging and Computing,

CAIP'2005: 10th International Conference On Computer Analysis of Images and Patterns,

Scale-Space'05:4th International Conference on Scale-Space Theories in Computer Vision,

3rd IEEE Workshop on Variational, Geometric and Level Set Methods in Computer Vision

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 is a member of the advisory board of ACCV'04 and invited speaker, on the General Board of Scale-Space'03:4th International Conference on Scale-Space Theories in Computer Vision, a member of the scientific committee of AMAM'03: Applied Mathematics and Applications of Mathematics, ECVP'03: European Conference on Visual Perception, program co-chair of ICCV'03: International Conference on Computer Vision. He has been invited speaker at the 3rd Indian Conference on Computer Vision, Graphics and Image Processing and is general co-chair of the 4th Indian Conference on Computer Vision, Graphics and Image Processing.

Maureen Clerc gave an invited talk at the Workshop on Autosimilarity and Applications at INSA Toulouse, and was invited to give a seminar at the GREMAQ in Toulouse. As the coordinator of the ACI Obs-Cerv, she presented its activities at the Paristic meeting in Bordeaux (Panorama des recherches incitatives en STIC, november 2005).

Renaud Keriven is 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), International Conference on Scale-Space and Diffusion Methods in Computer Vision, IEEE Workshop on Variational, Geometric and Level Set Methods in Computer Vision (VLSM). He is the organisor of a meeting about graph-cuts and discrete optimisation methods in Computer Vision, within the GDR Mathématiques des Systèmes Perceptifs et Cognitifs, at ENS Paris in November 2005. He was invited to give a talk at the artificial vision seminar at ENS Paris.

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 was a member of the 2nd Inervis international work-shop and has organized the ACI-DYNN summer workshop and the FACETS kick-off meeting.

The researchers involved in the area 3 of the project (modeling of the brain activity) belong the *cortyxee* working group common to the CORTEX project: this every two weeks seminar allows to share scientific inputs, cooperate on bibliographical material, etc..

6.6. Theses and Internships

6.6.1. Theses defenses

- Geoffray Adde *"Méthodes de traitement d'image appliqués au problème inverse en Magnéto-Electro-Encéphalographie"*, Ecole Nationale des Ponts et Chaussées; December 2005.
- Christophe Chefd'hôtel *"Méthodes Géométriques en Vision par Ordinateur et Traitement d'Image : Contributions et Applications", "Geometric Methods in Computer Vision and Image Processing : Contributions and Applications"*, Ecole Nationale Supérieure de Cachan; April 2005.
- Jean-Philippe Pons, *"Methodological and Applied Contributions to the deformable models framework"*, Ecole Nationale des Ponts et Chaussées; November 2005.

6.6.2. Ongoing Theses

- Alexandre Chariot, *"Processeurs Graphiques et Applications en Visions Algorithmique et Biologique"*, ENPC, Site: ENPC Marne
- Guillaume Charpiat, *"Statistiques de courbes et d'images"*, ENS Paris; Site: Odyssée ENS, Paris.
- Thomas Deneux, *"Modélisation et IRMf"*, ENS; Site: Odyssée ENS, Paris.
- Maxime Descoteaux, *"IRM de diffusion à haute résolution angulaire "*, Université de Nice Sophia-Antipolis; Site: Odyssée INRIA Sophia-Antipolis.
- Irene Fasiello, *"Vision biologique"*, ENS Cachan; 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 et croissance du cerveau"*, 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.
- Christophe Lenglet, *"Processing and Analysis of Diffusion Tensor Magnetic Resonance Images"*, UNSA; Site: Odyssée INRIA Sophia-Antipolis.
- Lucero Lopez-Pérez, *"Image Processing and PDE's on Non Flat Manifolds"*, UNSA; Site: Odyssée INRIA Sophia-Antipolis.
- Jérôme Piovano, *"Extraction automatique de formes complexes : Application à la création de modèles anatomiques de la tête"*, UNSA; Site: Odyssée INRIA Sophia-Antipolis.

- Jean-Philippe Pons, *"Méthodes variationnelles et reconstruction spatio-temporelle"*, ENPC; Site: Odyssée INRIA Sophia-Antipolis.
- Sylvain Vallaghé, *"Problèmes inverses en magnéto-électroencéphalographie"*, Université de Nice Sophia-Antipolis; Site: Odyssée INRIA Sophia-Antipolis.
- Nicolas Wotawa, *"IRMf pour la rétinotopie et l'analyse de la perception du mouvement"*, UNSA; 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.

6.6.3. Internships

- Fabrice Bernhard, *"GPU-based simulation of spiking-neurons networks"*, Ecole Polytechnique, Site: ENS Paris.
- Emmanuel Cornet, *"Dense Multiview Stereovision using discrete optimisation techniques"*, Master MPRI, Site: ENPC Marne.
- Benoit Deroquemaurel, *"A GPU-based real time stereovision method"*, Ecole Polytechnique, Site: ENPC Marne.
- Ihab Hujeiri, *"Localisation visuelle automatique des électrodes d'un casque EEG"*, DEA ED-STIC Université de Nice Sophia-Antipolis, Location : Odyssée INRIA Sophia-Antipolis, from the 1st, March 2005 until the 31st, August 2005, funding : INRIA Odyssée
- Patrick Labatut, *"A GPU implementation of Dense Multiview Stereovision"*, Master MVA, Site: ENS Paris.
- Julien Mairal, *"Variational stereovision on Graphic Processor Units"*, Ecole Polytechnique, Site: ENPC Marne.
- Sylvain Vallaghé, *"Problèmes inverses en magnéto-électroencéphalographie"*, Master Mathématiques Appliquées de Grenoble, Location : Odyssée INRIA Sophia-Antipolis, from the 1st, April 2005 until the 30th, September 2005, funding : INRIA Odyssée.

7. Bibliography

Books and Monographs

[1] N. PARAGIOS, Y. CHEN, O. FAUGERAS (editors). *The Handbook of Mathematical Models in Computer Vision*, Springer, 2005.

[2] J. WEICKERT, H. HAGEN (editors). *Visualization and Processing of Tensor Fields*, Springer, Berlin, 2005.

Doctoral dissertations and Habilitation theses

[3] G. ADDE. *Méthodes de traitement d'image appliqués au problème inverse en Magnéto-Electro-Encéphalographie*, Ph. D. Thesis, Ecole Nationale des Ponts et Chaussées, 2005.

[4] C. CHEFD'HOTEL. *Geometric methods in computer vision and image processings: contributions and applications*, Ph. D. Thesis, École Normale Supérieure de Cachan, April 2005.

[5] J.-P. PONS. *Contributions méthodologiques et appliquées à la méthode des modèles déformables*, Ph. D. Thesis, Ecole Nationale des Ponts et Chaussées, 2005.

Articles in refereed journals and book chapters

[6] 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.

[7] T. BROX, R. BOOMGAARD, F. LAUZE, J. WEIJER, J. WEICKERT, P. MRAZEK, P. KORNPROBST. *Adaptive structure tensors and their applications*, J. WEICKERT, H. HAGEN (editors). , chap. 2, Springer, Berlin, 2005.

[8] 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.

[9] 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). , Springer, 2005.

[10] R. DERICHE, D. TSCHUMPERLE, C. LENGLET, M. ROUSSON. *Variational Approaches to the Estimation, Regularization and Segmentation of Diffusion Tensor Images*, in "Handbook of Mathematical Models in Computer Vision", N. PARAGIOS, Y. CHEN, O. FAUGERAS (editors). , chap. 32, Springer, 2005, p. 519–532.

[11] 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.

[12] J. KYBIC, M. CLERC, O. FAUGERAS, R. KERIVEN, T. PAPADOPOULO. *Fast Multipole Acceleration of the MEG/EEG Boundary Element Method*, in "Physics in Medicine and Biology", vol. 50, October 2005, p. 4695–4710.

[13] N. PARAGIOS, R. DERICHE. *Geodesic active regions and level set methods for motion estimation and tracking*, in "Computer Vision and Image Understanding", vol. 97, n° 3, March 2005, p. 259–282, http://authors.elsevier.com/sd/article/S1077314204001213.

[14] J.-P. PONS, R. KERIVEN, O. FAUGERAS. *Modelling Non-Rigid Dynamic Scenes from Multi-View Image Sequences*, in "The Handbook of Mathematical Models in Computer Vision", N. PARAGIOS, Y. CHEN, O. FAUGERAS (editors). , chap. 27, Springer, 2005.

[15] E. PRADOS, O. FAUGERAS. *Shape from Shading*, in "Mathematical Models in Computer Vision: The Handbook", N. PARAGIOS, Y. CHEN, O. FAUGERAS (editors). , Springer, 2005, http://cermics.enpc.fr/~paragios/paragios-chen-faugeras/.

[16] D. TSCHUMPERLE, R. DERICHE. *Vector-Valued Image Regularization with PDE's : A Common Framework for Different Applications*, in "IEEE Transactions on Pattern Analysis and Machine Intelligence", vol. 27, n° 4, April 2005, p. 506–517, ftp://ftp-sop/odyssee/Publications/2005/tschumperle-deriche:05.pdf.

[17] T. VIÉVILLE. *An unbiased implementation of regularization mechanisms*, in "Image and Vision Computing", vol. 23, n° 11, 2005, p. 981–998, http://authors.elsevier.com/sd/article/S0262885605000909.

Publications in Conferences and Workshops

[18] G. ADDE, M. CLERC, R. KERIVEN. *Imaging Methods for MEG/EEG inverse problem*, in "Proc. Joint Meeting of 5th International Conference on Bioelectromagnetism and 5th International Symposium on Noninvasive Functional Source Imaging", 2005.

[19] R. BRETTE, M. RUDOPH, Z. PIKOWSKA, T. BAL, A. DESTEXHE. *How to emulate double-electrode recordings with a single electrode? A new method of active electrode compensation.*, in "Neuroscience 2005 (SFN Annual meeting)", 2005.

[20] G. CHARPIAT, R. KERIVEN, O. FAUGERAS. *Image Statistics based on Diffeomorphic Matching*, in "10th International Conference on Computer Vision", 2005.

[21] G. CHARPIAT, R. KERIVEN, J. PONS, O. FAUGERAS. *Designing Spatially Coherent Minimizing Flows for Variational Problems Based on Active Contours*, in "10th International Conference on Computer Vision", 2005.

[22] M. CLERC, G. ADDE, J. KYBIC, T. PAPADOPOULO, J.-M. BADIER. *In vivo conductivity estimation with symmetric boundary elements*, in "Proc. Joint Meeting of 5th International Conference on Bioelectromagnetism and 5th International Symposium on Noninvasive Functional Source Imaging, Minneapolis", May 2005.

[23] M. CLERC, B. ATFEH, J. LEBLOND, L. BARATCHART, J.-P. MARMORAT, T. PAPADOPOULO, J. PARTINGTON. *The Cauchy problem applied to cortical imaging: comparison of a boundary element and a bounded extremal problem*, in "Brain Topography", D. BRANDEIS, T. KOENIG, C. MICHEL (editors). , vol. 18, n° 2, Springer Science and Business Media B.V., October 2005.

[24] R. DE LUIS GARCIA, R. DERICHE, M. ROUSSON, C. ALBEROLA-LÓPEZ. *Tensor Processing for Texture*

and Colour Segmentation, in "14th Scandinavian Conference on Image Analysis, Joensuu, Finland", June 2005, p. 1117–1127, ftp://ftp-sop.inria.fr/odyssee/Publications/2005/de-luis-garcia-deriche-etal:05.pdf.

[25] R. DUPONT, N. PARAGIOS, R. KERIVEN, P. FUCHS. *Extraction of layers of similar motion through combinatorial techniques*, in "International Workshop On Energy Minimization Methods in Computer Vision and Pattern Recognition", 2005.

[26] O. JUAN, R. KERIVEN. *Trimap Segmentation for Fast and User-Friendly Alpha Matting*, in "IEEE Workshop on Variational, Geometric and Level Set Methods, beijing", October 2005.

[27] P. KORNPROBST, T. VIÉVILLE, I. DIMOV. *Could Early Visual Processes be Sufficient to Label Motions?*, in "International Joint Conference on Neural Networks", 2005.

[28] P. KORNPROBST, T. VIÉVILLE, I. DIMOV. *Could early visual processes label and segment motions?*, in "17th IMACS World Congress, Scientific Computation, Applied Mathematics and Simulation", 2005.

[29] S. LEHERICY, C. LENGLET, J. DOYON, H. BENALI, P. VAN DE MOORTELE, G. SAPIRO, O. FAUGERAS, R. DERICHE, K. UGURBIL. *Activation Shifts from the Premotor to the Sensorimotor Territory of the Striatum during the Course of Motor Sequence Learning*, in "11th Annual Meeting of the Organization for Human Brain Mapping, Toronto", June 2005.

[30] C. LENGLET, R. DERICHE, O. FAUGERAS, S. LEHERICY, K. UGURBIL. *A Riemannian Approach to Diffusion Tensors Estimation and Streamline-based Fiber Tracking*, in "11th Annual Meeting of the Organization for Human Brain Mapping, Toronto", June 2005.

[31] C. LENGLET, O. FAUGERAS, T. PAPADOPOULO, R. DERICHE. *Diffeomorphic Matching of Symmetric Positive Definite Matrix Fields*, in "2ème Congrés National de Mathématiques Appliquées et Industrielles, Evian", May 2005.

[32] C. LENGLET, M. ROUSSON, R. DERICHE, O. FAUGERAS, S. LEHERICY, K. UGURBIL. *A Riemannian Approach to Diffusion Tensor Images Segmentation*, in "Information Processing in Medical Imaging", 2005, p. 591–602.

[33] 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.

[34] E. PRADOS, O. FAUGERAS. *Shape from Shading: a well-posed problem ?*, in "CVPR'2005,International Conference on Computer Vision and Pattern Recognition, San Diego, CA, USA, June 2005", 2005.

[35] D. SHAFRIR, N. SOCHEN, R. DERICHE. *Regularization of Mappings Between Implicit Manifolds of Arbitrary Dimension and Codimension*, in "Variational, Geometric, and Level Set Methods in Computer Vision: Third International Workshop, VLSM, Beijing, China", Lecture Notes in Computer Science, vol. 3752, Springer-Verlag GmbH, October 2005, 344.

[36] F. SÉGONNE, J.-P. PONS, E. GRIMSON, B. FISCHL. *A Novel Level Set Framework for the Segmentation of Medical Images under Topology Control*, in "Workshop on Computer Vision for Biomedical Image

Applications: Current Techniques and Future Trends", to appear, 2005.

[37] T. VIÉVILLE. *De la deuxième à la troisième dimension*, in ")i(nterstices", 2005, http://interstices.info/display.jsp?id=c_9564.

[38] T. VIÉVILLE. *La grenouille et le robot*, in ")i(nterstices", 2005, http://interstices.info/display.jsp?id=c_9559.

[39] T. VIÉVILLE, P. KORNPROBST. *How fast-brain object categorization allows top-down processes of segmentation*, in "European Conference on Visual Perception", 2005.

[40] A. WOHRER, P. KORNPROBST, T. VIÉVILLE. *A biologically-inspired spiking retina model for the encoding of visual sequences*, in "European Conference on Visual Perception", 2005.

[41] N. WOTAWA, C. LENGLET, M. ROTH, B. NAZARIAN, J.-L. ANTON, R. MAJHOUB, R. DERICHE, O. FAUGERAS. *Combined fMRI and DTI of the human low level visual cortex*, in "NeuroImage (HBM'05), Toronto, Canada", 2005.

Internal Reports

[42] F. BERNHARD, R. KERIVEN. *Spiking neurons and GPUs*, Technical report, n° 05-15, certis, 2005.

[43] G. CHARPIAT, J.-Y. AUDIBERT, R. KERIVEN, O. FAUGERAS. *Diffeomorphic Matching and Image Statistics*, Technical report, n° 05-05, CERTIS, February 2005.

[44] E. CORNET, R. KERIVEN. *Multiview stereovision using graph cuts*, Technical report, n° 05-14, certis, 2005.

[45] T. DENEUX, O. FAUGERAS. *Parameter estimation efficiency using nonlinear models in fMRI*, Technical report, n° RR-5758, INRIA, November 2005, http://www.inria.fr/rrrt/rr-5758.html.

[46] T. DENEUX, O. FAUGERAS. *EEG-fMRI fusion of non-triggered data using Kalman filtering*, Technical report, n° RR-5760, INRIA, November 2005, http://www.inria.fr/rrrt/rr-5760.html.

[47] M. DESCOTEAUX, E. ANGELINO, S. FITZGIBBONS, R. DERICHE. *A linear and regularized ODF estimation algorithm to recover multiple fibers in Q-Ball imaging*, Technical report, n° 5768, INRIA, November 2005, http://www.inria.fr/rrrt/rr-5768.html.

[48] M. DESCOTEAUX, E. ANGELINO, S. FITZGIBBONS, R. DERICHE. *Apparent Diffusion Coefficients from High Angular Resolution Diffusion Imaging: Estimation and Applications*, Technical report, n° 5681, INRIA, September 2005, http://www.inria.fr/rrrt/rr-5681.html.

[49] N. DIXIT, R. KERIVEN, N. PARAGIOS. *GPU-Cuts and Adaptive Object Extraction*, Technical report, n° 05-07, certis, 2005.

[50] R. DUPONT, N. PARAGIOS, R. KERIVEN, P. FUCHS. *Spatio-temporal Motion Estimation and Segmentation in Layers: Robust Estimators, Markov Random Fields, Visual Grouping and Graph-based Optimization*, Technical report, n° 05-06, CERTIS, 2005.

[51] F. GRIMBERT, O. FAUGERAS. *Analysis of Jansen's model of a single cortical column*, Technical report, n° RR-5597, INRIA, June 2005, http://www.inria.fr/rrrt/rr-5597.html.

[52] O. JUAN, R. KERIVEN. *Unsupervised Segmentation for Digital Matting*, Technical report, n° 05-04, CERTIS, 2005.

[53] P. LABATUT, R. KERIVEN, J. PON. *A GPU implementation of level set multiview stereo*, Technical report, n° 05-12, CERTIS, 2005.

[54] J. MAIRAL, R. KERIVEN. *A GPU implementation of variational stereo*, Technical report, n° 05-13, CERTIS, 2005.

[55] 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° 5726, INRIA, October 2005, http://www.inria.fr/rrrt/rr-5726.html.

[56] F. SÉGONNE, J.-P. PONS, F. FISCHL, E. GRIMSON. *A Novel Active Contour Framework: Multi-Component Level Set Evolution Under Topology Control*, AI memos, n° AIM-2005-020, CSAIL, MIT, 2005.

[57] I. VANZETTA, T. DENEUX, G. MASSON, O. FAUGERAS. *Cerebral blood flow recorded at high sensitivity in two dimensions using high resolution optical imaging*, Technical report, n° RR-5759, Inria, November 2005, http://www.inria.fr/rrrt/rr-5759.html.

[58] T. VIÉVILLE. *An abstract view of biological neural networks*, Technical report, n° RR-5657, INRIA, August 2005, http://www.inria.fr/rrrt/rr-5657.html.