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Project-Team VisAGeS

Vision Action et Gestion d'informations en Santé

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THEME BIO

Activity Report

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2. Overall Objectives

2.1. Overall objectives

Keywords: *3D free-hand ultrasound, clinical neurosciences, image segmentation and analysis, image-guided intervention, management of information in medical imaging, medical imaging, neuroimaging, registration, statistical analysis in medical imaging.*

Since 1970s, medical imaging is a very rapidly growing research domain; the last three decades have shown a rapid evolution of the dimension and quantity of data physicians have to work with. The next decade will follow this evolution by adding not only new spatio-temporal dimensions to the image data produced and used in a clinical environment but also new scales of analysis (nano or micro biological and molecular images to macro medical images). Another evolution will also consist in adding new effectors during image-guided interventional procedures (surgery, interventional radiology...). The classical way of making use of these images, mostly based on human interpretation, becomes less and less feasible. In addition, the societal pressure for a cost effective use of the equipments on the one hand, and a better traceability and quality insurance of the decision making process on the other hand, makes the development of advanced computer-assisted medical imaging systems more and more essential. According to this context, our research team is devoted to the development of new processing algorithms in the context of medical image computing and computer-assisted interventions: image fusion (registration and visualization), image segmentation and analysis, management of image-related information ...). In this very large domain, our work is primarily focused on clinical applications and for the most part on head and brain related diseases.

Research activities of the VISAGES team are concerned with the development of new processing algorithms in the field of medical image computing and computer assisted interventions: image fusion (registration and visualization), image segmentation and analysis, management of image related information ...). Since this is a very large domain, for seek of efficiency, the application of our work will be primarily focused on clinical aspects and for the most part on head and neck related diseases. Our research efforts mainly concern:

- The field of image fusion and image registration (rigid and deformable transformations) with a special emphasis on new challenging registration issues especially when statistical approaches based on joint histogram cannot be used or when the registration stage has to cope with loss or appearance of material (like in surgery or in tumor imaging for instance).
- The field of image segmentation and structure recognition, with a special emphasis on the difficult problems of i) image restoration for new imaging sequences (new Magnetic Resonance Imaging protocols, 3D ultrasound sequences ...), and *ii*) structure segmentation and labelling based on shape and statistical information.
- The field of image analysis and statistical modelling with a new focus on Voxel Based Analysis (VBA) and group analysis problems. A special attention will be given also to the development of advanced frameworks for the construction of probabilistic atlases since this complicated problem is still only partially solved.
- The field of information management in neuroimaging following the Neurobase project, for the development of distributed and heterogeneous medical image processing systems[1].

Concerning the application domains, we emphasize our research efforts on the neuroimaging domain with two up-front priorities: Image Guided Neurosurgery and Image Analysis in Multiple Sclerosis, while developing new ones especially in the interventional aspects (per-operative imagery, robotics...).

3. Scientific Foundations

3.1. Introduction

The scientific objectives of our team, concern the development of new medical image computing methods, dealing with image fusion (registration and visualization), image segmentation and analysis, and management of image-related information.

[1](http://www.irisa.fr/visages/neurobase)

In addition, since these methods are devoted (but not specific) to solve actual medical applications, a constant concern is to build an evaluation framework at each stage of the methodological development process. Therefore, this topic is present as a transversal concern among the generic developments and the applications.

3.2. Registration

Keywords: *Rigid registration*, *deformable registration*, *similarity measures*.

Image registration consists in finding a geometrical transformation in order to match *n* sets of images. Our objective is to work both, on rigid registration methods in order to develop new similarity measures for new imaging modalities, and on deformable registration to address the problem of tissue dissipation.

The registration between two images can be summarized by the expression [46]:

$$\underset{\theta \in \Theta}{arg\, min_{\Psi}} \Delta \left(\Phi_{\theta} \left(\Omega_s \right) - \Omega_t \right)$$

where Ω_s and Ω_t are respectively the two homologous sets of features respectively extracted from the source and the target images. These sets represent the two images in the registration process. They can be very different in nature, and can be deduced from a segmentation process (points, contours, crest lines ...) or directly from the image intensities (e.g. the joint histogram). Φ_{θ} is the transformation, ($\theta \in \Theta$ being the set of parameters for this transformation), Δ is the cost (or similarity) function, and Ψ is the optimization method. $\{\Omega, \Phi, \Delta, \Psi\}$ are the four major decisive factors in a registration procedure, the set Θ being a priori defined. In addition to new evolutions of these factors, a constant concern is to propose a methodology for validating this registration procedure. We already have been largely involved in these aspects in the past and will maintain this effort ([56], [62]).

In the domain of **rigid registration**, our research is more focused on new problems coming from the applications. For instance, the mono and multimodal registration of ultrasound images is still an open problem. In this context we are working in looking at new similarity measures to better take into account the nature of the echographic signal. Similarly, in the interventional theatre, new matching procedures are required between for instance video, optical or biological images and the pre-operative images (CT, MRI, SPECT/PET, Angiography ...). Some of these problems can be very challenging. For a number of new applications, there are no existing solutions to solve these problems (e.g. fusion of biological images with interventional images and images coming from the planning).

In many contexts, a rigid transformation cannot account for the underlying phenomena. This is for instance true when observing evolving biological and physiological phenomena. Therefore, **deformable registration** methods (also called non-rigid registration) are needed [57]. In this domain, we are working in the following three directions:

- Non-rigid registration algorithms benefits from the incorporation of statistical priors. These statistical priors can be expressed locally (for instance through a statistical analysis of segmented shapes) or globally (by learning statistics about deformation fields directly). Statistical priors (local and global) are useful to capture probable or relevant deformations.
- Non-rigid registration methods can be broadly sorted in two classes: geometric methods that rely on the extraction and matching of sparse anatomical structures and photometric methods that rely on image intensities directly. These two kinds of methods have their advantages and drawbacks. We are working on further cooperative approaches where information of different nature (global, hybrid and local) could be mixed in a mathematical elegant way.
- Finally, our research is focused on a better modeling of the problems, mainly in two directions: firstly the relationship between the observed data (image intensities) and the variables (registration field) should be better understood. This leads to more adapted similarity measures in specific application contexts (for instance when registering ultrasound images). Secondly, specific modeling of the deformation field is useful in specific contexts (for instance when matter is disappearing, fluid mechanics models will be more adapted than classical regularized deformation fields).

3.3. Image segmentation and analysis

Keywords: *3D ultrasound*, *MRI*, *deformable shape models*, *image restoration*, *level sets*.

This topic is very classical in computer vision. For the concern of medical image computing, we are focusing on the development of new tools devoted to the restoration of corrupted images coming from the sources and to the segmentation of anatomical structures based on deformable shape models.

Statistical methods for image restoration: New applications of medical imaging systems are parallel to the development or the evolution of new machinery which come with specific artifacts that are still only partially understood. This is the case for instance with high field MRI, 3D ultrasound imaging or other modalities. With regards to the images to process and analyze, these artifacts translate into geometric or intensity distortions that drastically affect not only the visual interpretation, but also most of the segmentation or registration algorithms, and the quantitative measures that follow. A better comprehension of these artifacts necessitates an increased dialogue between the physicists (who make the images), the computer scientists (who process the images) and the clinicians (who interpret the images). This should lead to define new, specifically-designed algorithms, based on statistical models taking into account the physics of the acquisition.

Segmentation using deformable shapes: We aim at proposing a generic framework to build probabilistic shape models in a 3D+t space applied to biomedical images with a particular emphasis on the problem of modeling anatomical and functional structures in neuroimaging (functional delineations, cortical or deep brain structures). Based on our previous contributions in this domain ([43], [44], [49]), we work on a methodological framework to segment 3D shapes and to model, in space and time, shape descriptors which can be applied to new extracted shapes; this with the aim of proposing new quantification tools in biomedical imaging.

3.4. Statistical analysis in medical imaging

Keywords: *group analysis*, *image classification*, *probabilistic brain atlas*, *voxel based analysis*.

Nowadays, statistical analysis occupies a central place for the study of brain anatomy and function in medical imaging. It is indeed a question of exploiting huge image data bases, on which we look to reveal the relevant information: measure the anatomical variability to discover better what deviates from it, to measure the noise to discover an activation, etc., in brief, to distinguish what is statistically significant of what is not.

Statistical methods for voxel-based analysis: Statistical analysis tools play a key role in the study of the anatomy and function of the brain. Typically, statisticians aim at extracting the significant information hidden below the noise and/or the natural variability. Some specific tools exist for the comparison of vector fields or geometrical landmarks. Some others have been developed for the analysis of functional data (PET, fMRI...). Thus, statistics are generally either spatial, or temporal. There is an increasing need for the development of statistics that consider time and space simultaneously. Applications include the follow-up of multiple sclerosis in MR images or the tracking of a deformable structure in an ultrasound image sequence.

Probabilistic atlases: One of the major problems in medical image analysis is to assist the clinician to interpret and exploit the high dimensionality of the images especially when he/she needs to confront his/her interpretation with "classical" cases (previous or reference cases). A solution to deal with this problem is to go through the use of an atlas which can represent a relevant *a priori* knowledge. Probabilistic atlases have been studied to tackle this problem but most of the time they rely on global references which are not always relevant or precise enough, to solve some very complex problems like the interpretation of inter-individual variations of brain anatomy and function. Based on our previous work proposing a cooperation between global and local references to build such probabilistic atlases ([51], [56]), we are working to develop a probabilistic atlas capable of labelling highly variable structure (anatomical and functional ones), or for defining relevant indexes for using with data bases systems.

Classification and group analysis: One of the major problems in quantitative image analysis is to be able to perform clustering based on descriptors extracted from images. This can be done either by using supervised or unsupervised algorithms. Our objectives is to develop statistical analysis methods in order to discriminate groups of data for clinical and medical research purposes (e.g. pathologic *vs*. normal feature, male *vs*. female, right-handed *vs.* left-handed, etc.), these data may come from descriptors extracted by using image analysis procedures (e.g. shapes, measurements, volumes, etc.).

3.5. Management of information in medical imaging

Keywords: *mediation*, *ontology*, *web services*, *workflows*, *wrapper*.

There is a strong need of a better sharing and a broader re-use of medical data and knowledge in the neuroimaging field. One of the most difficult problems is to represent this information in such a way that the structure and semantics are shared between the cognitive agents involved (i.e. programs and humans). This issue is not new, but the recent evolution of computer and networking technology (most notably, the Internet) increases information and processing tools sharing possibilities, and therefore makes this issue prevailing. The notion of "semantic web" denotes a major change in the way computer applications will share information semantics in the future, with a great impact on available infrastructures and tools. In coherence with the rest of our research topics, we are focussing on brain imaging. This deals with accessing, referring to, and using knowledge in the field of brain imaging, whatever the kind of knowledge - either general knowledge (e.g. models of anatomical structures, "know-how" knowledge such as image processing tools), or related to individuals (such as a database of healthy subjects' images). This covers both information of a numerical nature (i.e. derived from measurements such as images or 3D surfaces depicting anatomical features), of a symbolic nature (such as salient properties, names - referring to common knowledge - and relationships between entities), as well as processing tools available in a shared environment. Two major aspects are considered: (1) representing anatomical or anatomo-functional data and knowledge and (2) sharing neuroimaging data and processing tools.

4. Application Domains

4.1. Neuroimaging

Keywords: *3D ultrasound*, *brain atlas*, *clinical neuroscience*, *image-guided surgery*, *multiple sclerosis*, *multispectral MRI*, *neuroimaging*, *preoperative imaging*.

One research objective in neuroimaging is the construction of anatomical and functional cerebral maps under normal and pathological conditions.

Many researches are currently performed to find correlations between anatomical structures, essentially sulci and gyri, where neuronal activation takes place, and cerebral functions, as assessed by recordings obtained by the means of various neuroimaging modalities, such as PET (Positron Emission Tomography), fMRI (Functional Magnetic Resonance Imaging), EEG (Electro-EncephaloGraphy) and MEG (Magneto-EncephaloGraphy). Then, a central problem inherent to the formation of such maps is to put together recordings obtained from different modalities and from different subjects. This mapping can be greatly facilitated by the use of MR anatomical brain scans with high spatial resolution that allows a proper visualization of fine anatomical structures (sulci and gyri). Recent improvements in image processing techniques, such as segmentation, registration, delineation of the cortical ribbon, modeling of anatomical structures and multi-modality fusion, make possible this ambitious goal in neuroimaging. This problem is very rich in term of applications since both clinical and neuroscience applications share similar problems. Since this domain is very generic by nature, our major contributions are directed toward clinical needs even though our work can address some specific aspects related to the neuroscience domain.

Multiple sclerosis: Over the past years, a discrepancy became apparent between clinical Multiple sclerosis (MS) classification describing on the one hand MS according to four different disease courses and, on the other hand, the description of two different disease stages (an early inflammatory and a subsequently neurodegenerative phase). It is to be expected that neuroimaging will play a critical role to define *in vivo* those four different MS lesion patterns. An *in vivo* distinction between the four MS lesion patterns, and also between early and late stages of MS will have an important impact in the future for a better understanding of the natural history of MS and even more for the appropriate selection and monitoring of drug treatment in MS patients. Since MRI has a low specificity for defining in more detail the pathological changes which could discriminate between the different lesion types, but a high sensitivity to detect focal and also widespread, diffuse pathology of the normal appearing white and grey matter, our major objective within this application domain is to define new neuroimaging markers for tracking the evolution of the pathology from high dimensional data (e.g. nD+t MRI). In addition, in order to complement MR neuroimaging data, we ambition to perform also cell labeling neuroimaging (e.g. MRI or PET) and to compare MR and PET data using standard and experimental MR contrast agents and radiolabeled PET tracers for activated microglia (e.g. USPIO or PK 11195). The goal is to define and develop, for routine purposes, cell specific and also quantitative imaging markers for the improved *in vivo* characterization of MS pathology.

Modeling of anatomical and anatomo-functional neurological patterns: The major objective within this application domain is to build anatomical and functional brain atlases in the context of functional mapping for pre-surgical planning and for the study of neurodegenerative brain diseases (Multiple sclerosis, Epilepsy, Parkinson or even Alzheimer). This is a very competitive research domain; our contribution is based on our previous works in this field ([49], [51], [50], [56]),and by continuing our local and wider collaborations ...).

An additional objective within this application domain is to find new descriptors to study the brain anatomy and/or function (e.g. variation of brain perfusion, evolution in shape and size of an anatomical structure in relation with pathology or functional patterns, computation of asymmetries ...). This is also a very critical research domain, especially for many neurodegenerative brain diseases (Epilepsy or Alzheimer for instance).

Epilepsy: The principle of epilepsy surgery is to remove the Epileptic Zone (EZ) (area of the brain where epileptic seizures are originating). The anatomical determination of this EZ is individualized, and surgery will be therefore individually tailored. To delineate this EZ, different sources of information are used and a congruence of several explorations is needed. Some are static, such as MRI and PET, and some may reflect the spatio-temporal dynamics of the seizures. Integration of multimodal information about brain perfusion (ictal and interictal SPECT), metabolism (PET-F18FDG), anatomy (MRI, DTI), as well as direct recording of electrical activity (MEG/EEG) may improve significantly on its own the way epileptic patients are explored and treated. Although none of these modalities added a significant contribution to this area, SPECT/PET and MEG/EEG could help localizing the EZ in temporal lobe epilepsy and limit the use of depth electrodes recordings, especially when focussing more specifically on the particular role of sub-cortical structures (such as thalamus, caudate nucleus, pallidum, etc.). From this standpoint, our goal is to tackle several of these questions? such as:

- What is the role of sub-cortical structures in temporal and frontal epilepsy? How do these observations correlate with depth electrodes recordings? How could this knowledge impact on treatment decisions (chemically on basal ganglia, or surgically with deep brain stimulations ?
- What is the optimum use of the various imaging techniques available, in order to examine the various parts of an epileptic network, before performing a decision?

4.2. Image guided intervention

Image-guided neurosurgical procedures rely on complex preoperative planning and intraoperative environment. This includes various multimodal examinations: anatomical, vascular, functional explorations for brain surgery and an increasing number of computer-assisted systems taking place in the Operating Room (OR). Hereto, using an image-guided surgery system, a rigid fusion between the patient's head and the preoperative data is determined. With an optical tracking system and Light Emitting Diodes (LED), it is possible to track the patient's head, the microscope and the surgical instruments in real time. The preoperative data can then be merged with the surgical field of view displayed in the microscope. This fusion is called "augmented reality".

Unfortunately, the assumption of a rigid registration between the patient's head and the preoperative images only holds at the beginning of the procedure. This is because soft tissues tend to deform during the intervention. This is a common problem in many image-guided interventions, the particular case of neurosurgical procedures can be considered as a representative case. Brain shift is one manifestation of this problem but other tissue deformations can occur and must be taken into account for a more realistic predictive work.

Within this application domain, we aim at developing systems using surgical guidance tools and real-time imagery in the interventional theatre. This imagery can come from video (using augmented reality procedures), echography or even interventional MRI, biological images or thermal imagery for the future.

Per-operative imaging in neurosurgery: Our major objective within this application domain is to correct for brain deformations that occur during surgery. Neuronavigation systems make it now possible to superimpose preoperative images with the surgical field under the assumption of a rigid transformation. Nevertheless, non-rigid brain deformations, as well as brain resection, drastically limit the efficiency of such systems. The major objective here is to estimate brain deformations using 3D ultrasound and video information.

Modeling of surgical gesture expertise: Our objective is to show how the formalization of the medical expertise could improve both the planning and the surgery itself. One way is to rely on previously defined generic model describing surgical procedures. From a data base of surgical cases described by the generic model and from a limited set of parameters related to the patient (i.e. extrinsic parameters), the closest surgical case can be retrieved in order to assist the surgical planning. Similarly, global surgical scenarii representing main categories of surgical procedures could be classified according to extrinsic parameters (coming from the current case) and retrieved from the database. New experiences based on this procedure could then feed the surgical modelling. Another issue would be to use the knowledge extracted from the data base to pre-fetch the image processing procedures (to speed up or tune processing workflows parameters).

Robotics for 3D echography: This project is conducted jointly with the Lagadic project-team. The goal is to use active vision concepts in order to control the trajectory of a robot based on the contents of echographic images and video frames (taken from the acquisition theatre). Possible applications are the acquisition of echographic data between two remote sites (the patient is away from the referent clinician) or the monitoring of interventional procedure like biopsy or selective catheterisms.

3D free-hand ultrasound: Our major objective within this application domain is to develop efficient and automatic procedures to allow the clinician to use conventional echography to acquire 3D ultrasound and to propose calibrated quantification tools for quantitative analysis and fusion procedures. This will be used to extend the scope of view of an examination.

5. Software

5.1. Introduction

Our objectives concerning the software development and dissemination are directed to the set-up of a software platform at the University Hospital in order to deploy new research advances and to validate them in the clinical context with our local partners. We intend to disseminate our results via a free software distribution. Complying with both objectives requires software engineering resources, which could be partially covered in the short term by a current PRIR application "PlogICI", but a longer term alternative needs to be already foreseen.

5.2. VistaL

VistaL is a software platform of 3D and 3D+t image analysis allowing the development of generic algorithms used in different contexts (rigid and non-rigid registration, segmentation, statistical modelling, calibration of free-hand 3D ultrasound system and so on). This software platform is composed of generic C++ template classes (Image3D, Image4D, Lattice and so on) and a set of 3D/3D+t image processing libraries. VistaL is a multi-operating system environment (Windows, Linux/Unix...). VistaL APP registration number is: IDDN.FR.001.200014.S.P.2000.000.21000.

5.3. Romeo

Romeo (**RO**bust **M**ultigrid **E**lastic registration based on **O**ptical flow) is a non-rigid registration algorithm based on optical-flow. Romeo is developed using Vistal (C++ template classes describes above). Romeo estimates a regularized deformation field between two volumes in a robust way: two robust estimators are used for both the data term (optical flow) and the regularization term (smoothness of the field). An efficient multiresolution and multigrid minimization scheme is implemented so as to estimate large deformations, to increase the accuracy and to speed up the algorithm ([59]).

5.4. Juliet

Juliet (**J**oint **U**se of **L**andmarks and **I**ntensity for **E**lastic regis**T**ration) is a non-rigid registration algorithm that is built on the Romeo software. Juliet makes it possible to incorporate sparse constraints deduced from the matching of anatomical structures such as cortical sulci for instance. A sparse deformation field is introduced as a soft constraint in the minimization to drive the registration process. A robust estimator is used so as to limit segmentation errors and false matching ([58]).

6. New Results

6.1. Fluid Models for Deformable Registration

Participant: Pierre Hellier.

In collaboration with the Vista Project (Anne Cuzol and Etienne Mémin), we have proposed a new motion estimator for image sequences depicting fluid flows, or growth phenomena [53]. This decomposition consists in representing the velocity field as a sum of a divergence free component and a curl free component. The objective is to provide a low-dimensional parametric representation of optical flows by depicting them as a flow generated by a small number of vortex and source particles. Both components are approximated using a discretization of the vorticity and divergence maps through regularized Dirac measures. The resulting so called irrotational and solenoidal fields consist then in linear combinations of basis functions obtained through a convolution product of the Green kernel gradient and the vorticity map or the divergence map respectively. The coefficient values and the basis function parameters are obtained by minimization of a functional relying on an integrated version of mass conservation principle of fluid mechanics.

6.2. Statistical methods for image restoration

Participants: Arnaud Ogier, Pierre Hellier, Christian Barillot.

This work deals with the restoration problem of medical images and particularly of the ultrasound images.

The objective of the first part of this thesis was on the one hand to describe the ultrasound waves and on the other hand to study the various noises generated by this coherent system of imagery. To this end, a statistical study was carried out. The statistical study leads to complex laws and we propose to use the Mellin transformation which makes it possible to simplify calculations in certain cases. A simulator of these various laws is thus generated. Moreover, experiments on a tumble of balls indicates that the normal law can prove to be sufficient like first approximation.

In the second part of this thesis, we recall the state of the art concerning the restoration of images resulting from coherent sensors (laser, SAR, ultrasounds...) and incoherent ones (optics). We are focussing on methods developed these last ten years such as PDE, wavelets and neighborhood filters.

The last part of this thesis describes our contributions based on the work of Rudin, Osher and Fatemi bearing on total variation [61]. We are proposing, in a first approach, a modification of the original scheme by adapting the Lagrangian one to the statistics of higher orders of the image.

Then, images are projected on the basis of wavelets and minimize the total variation on the wavelet coefficients. These methods are applied to MRI and ultrasound images, thus showing the adaptability of our approach to various contexts ([60]).

6.3. Image Segmentation and Analysis

Participants: Cybele Ciofolo, Christian Barillot.

This work deals with the segmentation of 3D shapes using level sets driven by fuzzy control.

Our approach is derived from a region-based level set segmentation method, which uses regional statistics coming from the processed images. In order to take prior knowledge into account and to adapt the method to various applications, we use a fuzzy control system to drive the level sets. The role of the fuzzy controller is to automatically determine the terms of the evolution speed of the contours that are associated with the level sets.

This general principle is used to process three terms of the evolution speed. First, the fuzzy controller tunes the stopping function of the contour and the method is applied to ventricles and brain segmentation. Second the fuzzy control automatically computes the contour regularization term of the evolution speed, which leads to an efficient segmentation of the white matter. Third, the system is used to simultaneously evolve several contours by choosing their privileged propagation direction. This is applied to the brain hemispheres and grey nuclei segmentation.

Finally, in order to take anatomical variability into account, we use a statistical analysis to compute a shape model. This shape model automatically defines some parameters of the fuzzy controller.

The method was tested on 2 datasets of 18 real MRI volumes each. The quantitative evaluation by comparison with manual segmentation results showed that the simultaneous segmentation of several structures was effective. Moreover the results accuracy and the method robustness were improved by the shape model. ([47], [48]).

6.4. Statistical Modeling of Anatomical and Functional Brain Information

Participants: Jean-Marie Favreau, Master2 Computer Sciences, Cybele Ciofolo, Christian Barillot.

One of the objectives of neuroimaging is to study the brain structures of healthy or pathological subjects. The great variability of these structures requires the implementation of specific methods applied to MRI. The study of the calcarine sulcus, primary anatomical element of the brain visual areas, constitutes a delicate point. Indeed its segmentation is complicated on one hand by its localization on the inter-hemispheric fiscure, but also by its depth and its complex shape. Our work was to realize the extraction of this sulcus by starting from a selective segmentation of both hemispheres. This first segmentation allows working only on a volume restricted to the hemisphere of interests. We use then the *active ribbon* method to extract the median surface of the sulci. The shape of calcarine sulcus is highly variable according to the individuals. We set up a statistical modeling based on a learning set. It can allow the implementation of registration algorithms based on anatomical markers, with the aim of the study of the visual areas of the brain of normal but also pathological brains [54].

6.5. Management of Distributed Information in Neuroimaging

Participants: Lynda Temal, Alban Gaignard, Bernard Gibaud, Christian Barillot.

In this topic we have continued our work with the Neurobase consortium in order to develop a demonstration environment to exhibit the way neuroimaging information (data and image processing tools) can be shared. In practice we contribute to improve and test a demonstrator based on some existing modules like Le Select[2], BALC (from our grenoble partners) or VIsTAL[3]. This demonstrator has become extendable to modules largely used in neuroimaging community such as BET/FSL[4]. Several functionalities have been implemented such as a generic data wrappers & mediators (based on file & directories hierarchies, medical image processing tools (data access, restoration, segmentation, visualization, ...) through a data flow model approach ([45] [55]).

[2](http://www-caravel.inria.fr/~leselect/), BrainVISA/Anatomist(http://brainvisa.info/)
[3](http://www.irisa.fr/visages/software-fra.html)
[4](http://www.fmrib.ox.ac.uk/fsl/bet/)

The actual implementation of data flows concerns the segmentation of the brain from MRI and the brain tissue classification (white matter, grey matter, CSF), which was executed on a distributed way (between the IRISA, Medical Faculty of Rennes and Grenoble sites), for the data as well as for the image processing resources.

6.6. 3D Free-Hand Ultrasound

Participants: Pierrick Coupé, Pierre Hellier, Xavier Morandi, Christian Barillot.

3D freehand ultrasound is a technique based on the acquisition of B-scans, which can be parallel or not, whose position in 3D space is known by a 3D localizer (optic or magnetic) attached to the probe. From these irregularly distributed B-scans and their positions, a regular 3D lattice volume can be reconstructed. This reconstruction step is needed to apply conventional 3D computer vision algorithms like volumetric registration and segmentation, but is still an acute problem with regards to computation time and reconstruction quality. We have proposed a new 3D reconstruction method that explicitly takes into account the 3D probe trajectory. In the classical distance weighted interpolation, the interpolation kernel is composed of the orthogonal projections of the current point on the closest B-scans. In our modified interpolation scheme, the interpolation kernel is composed of intersections between the probe trajectory (passing through the current point) and the closest B-scans. Experiments were conducted on different data sets (phantom and intra-operative sequences) with various probe motion types and frame rates. Results indicate that this technique outperforms classical methods and is particularly interesting in an intra-operative context ([52]).

6.7. Segmentation of MS lesions in multisequence longitudinal MR images

Participants: Laure Aït-ali, Sylvain Prima, Pierre Hellier, Béatrice Carsin-Nicol, Gilles Édan, Sean-Patrick Morrissey, Christian Barillot.

We have proposed a method to segment Multiple Sclerosis (MS) lesions over time in multidimensional Magnetic Resonance Imaging (MRI) sequences. We have developed a robust algorithm that allows the segmentation of the image abnormalities using the whole time series simultaneously, by proposing an original rejection scheme for outliers. We have validated this approach using the BrainWeb simulator and performed preliminary experiences on longitudinal multiple sequences of clinical data acquired on the 3T scanner recently installed at the Pontchaillou Hospital [41], [42].

6.8. Using brain symmetry to improve registration speed

Participant: Sylvain Prima.

We have proposed a method to improve multimodal rigid registration speed for volumetric images of the brain. Our idea is to use the gross bilateral symmetry of the brain to constrain the registration algorithm. More precisely, the 6-parameter global optimization scheme is replaced by three consecutive 3-parameter optimization schemes consisting of the computation of the mid-sagittal plane on the two images followed by a constrained registration of the two images based on these two estimated planes. This 3-step process is faster than the direct estimation of the rigid transformation, without loss of accuracy or robustness.

7. Contracts and Grants with Industry

7.1. Medience

Participants: Lynda Temal, Alban Gaignard, Bernard Gibaud, Christian Barillot.

Medience is a start-up of INRIA. Since 2004, through the ACI project "Neurobase", we have collaboration with Medience to develop a "middleware" system capable of accessing to heterogeneous and distributed resources (data, processing) in the context of neuroimaging.

8. Other Grants and Activities

8.1. Regional initiatives

8.1.1. PRIR contract of Brittany region council PlogICI

Participants: Alban Gaignard, Daniel Garcia-Lorenzo, Bernard Gibaud, Pierre Hellier, Pierre Jannin, Sylvain Prima, Christian Barillot.

This two years project is devoted to the development of a software platform dedicated to clinical neuroimaging and image guided neurosurgery applications. The objective is to build a software core made of proprietary libraries (e.g. Vistal) and public libraries available in the domain of 3D medical imaging or 3D rendering (e.g. VTK, ITK ...).

8.1.2. AMStrIC project

Participants: Laure Aït-Ali, Sylvain Prima, Christian Barillot.

This three years project is devoted to the development of a solution for processing MRI data for the purpose of detecting MS lesions from spatiotemporal observations. This grant is being used for partial founding the position of Laure Aït-Ali.

8.1.3. TRITECH project

Participants: Arnaud Ogier, Pierre Hellier, Christian Barillot.

This three years project is devoted to the development of a solution for processing ultrasound data for the purpose of improving the capabilities of segmentation and registration procedures to work on 3D free-hands ultrasound acquisitions. This grant is being used for founding the position of Arnaud Ogier.

8.2. National initiatives

8.2.1. ACI NeuroBase

Participants: Lynda Temal, Alban Gaignard, Bernard Gibaud, Christian Barillot.

We are coordinating a national proactive concerted action ("ACI") of the French ministry of research entitled "NeuroBase: An information system for the management of distributed and heterogeneous neuroimaging data" for the period 2002-2005.

In addition to our group and the TexMex project from IRISA, this action is performed in collaboration with INRIA teams (Caravel - Rocquencourt and Epidaure - Sophia-Antipolis), INSERM unit U594 and SIC team at CNRS-TIMC, both from Grenoble and the IFR 49 "Functional Neuroimagery" (Paris-Orsay, Dir. D. LeBihan). This IFR includes partners from CHU la Pitié-Salpétrière, INSERM unit U494 and CEA-SHFJ.

8.3. International initiatives

8.3.1. International project on validation of non-rigid registration methods

Participants: Pierre Hellier, Christian Barillot.

We are involved in an international evaluation project led by J. Stern from the University of Minnesota, USA[5]. This project aims at evaluating the performances of non-rigid inter-subject registration methods. The evaluation is based on the designation of various "goodness of warp" metrics, including anatomical and functional data. This international project also involves the following state-of-the-art registration methods: SPM (London, UK), AIR (UCLA, USA), HAMMER (Upenn, USA), ANIMAL (MNI, Canada) and ROMEO (IRISA, France). The goal is to set up an automated test, which eventually may be distributed on the web, including all relevant data sets and results. So any researcher dealing with deformable registration could make

[5](http://www.neurovia.umn.edu/)

use of the test bed to evaluate and improve their own software or to simply replicate our experiments. Another goal would be to extend the test bed with other relevant datasets.

In order to facilitate automatic computation and storage of many different results and to do "apple-to-apple" comparisons, the U. of Minnesota will treat the results of each registration of source brain image to target brain image as the description of a transformation warp which will be read and evaluated by the test bed software. All of the registration programs that are included in the evaluation phase of the project will be integrated into the test bed and the raw data substrate of evaluation will ultimately be automatically produced by the test bed software.

9. Dissemination

9.1. Leadership within the scientific community

9.1.1. Editorial board of journals

- C. Barillot is Associate Editor of IEEE Transactions on Medical Imaging (IEEE-TMI).
- C. Barillot is Associate Editor of Medical Image Analysis (MedIA)[from 01/11/2005].
- C. Barillot serves in the peer review committee of the Journal of Computer Assisted Tomography.

9.1.2. Guest Editorial of journals

- C. Barillot and P. Hellier were guest Editor of a special issue of MICCAI 2004 in *Medical Image Analysis, Vol.9(5)*.
- P. Hellier and C. Barillot were guest Editor of a special issue of MICCAI 2004 in *Computer Assisted Surgery* Vol.9(5).
- P. Hellier and C. Barillot were guest Editor of a special issue of MICCAI 2004 in *Academic Radiology* Vol.9(5).

9.1.3. Peer Reviews of journals

- Reviewing process for IEEE TMI (CB, PH, SP, PJ, BG), IEEE TBE (SP, PJ), IEEE TITB (BG), Medical Image Analysis (CB,PH,SP), Neuroimage (CB), Academic Radiology (PH), TSI (CB), Signal Processing (CB)

9.1.4. Conference board organization

- C. Barillot was member of the executive committee of MICCAI 2005
- P. Jannin was member of the executive committee of CARS 2005

9.1.5. Technical Program Committees (TPC) of conferences

- C. Barillot was TPC member for MICCAI 2005, IPMI 2005, SPIE Medical Imaging 2006,
- P. Hellier was TPC member of MICCAI 2005, RFIA 2006, IEEE ISBI 2006
- S. Prima was TPC member of MICCAI 2005, IEEE ISBI 2006

9.1.6. Scientific societies

- C. Barillot is vice Chair of the MICCAI Society, is member of the board of MICCAI and co-founder of the MICCAI society.
- P. Jannin is General Secretary of ISCAS
- B. Gibaud is member of the AIM
- C. Barillot and P. Jannin are members of IEEE EMBS

9.2. Teaching

Teaching on 3D Medical Imaging (visualization, segmentation, fusion, management) in the following tracks:

- DIIC-INC, IFSIC, University of Rennes I : 6h (*C. Barillot*)
- DEA GBM, University of Tours-Angers-Nantes-Rennes : 6h (*C. Barillot, B. Gibaud, P. Jannin, X. Morandi*)
- "Maîtrise de Sciences Biologiques et Médicales : Anatomie Imagerie Morphogenèse", University of Rennes I : 5h (*C. Barillot, B. Gibaud, P. Jannin*)
- DEA Informatique Fondamentale et Applications, U. Marne la Vallée: 3h (*C. Barillot*)

9.3. Participation to seminars, scientific evaluations, awards

- B. Gibaud is member of the CSS 7 evaluation committee of INSERM
- C. Barillot served as external reviewer of the TechnoVision research program

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