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Project-Team VisAGeS

Vision Action et Gestion d'informations en Santé

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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].

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

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.

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 [47]:

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

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 [54], [63].

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 [55]. In this domain, we are working in the following three directions:

- Non-rigid registration algorithms benefit 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 an elegant mathematical 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 [45], [46], [50], 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 functions 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 functions. Based on our previous work proposing a cooperation between global and local references to build such probabilistic atlases [52], [54], 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 terms of applications since both clinical and neuroscience applications share similar problems. Since this domain is very generic by nature, our major contributions are directed towards 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 [50], [52], [51], [54],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 in 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 already needs to be 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 described 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 [57]. Romeo has been registered at APP with number: IDDN.FR.001.200014.SP.2000.000.21000.

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 [56]. Juliet has been registered at APP with number: IDDN.FR.001.45001.001.S.A.2001.000.21000.

5.5. Tulipe

TULIPE (**T**hree dimensional **UL**trasound reconstructioin **I**ncorporating Prob**E** trajectory) was developed using Vistal and is a registered at APP under IDDN.FR.001.120034.S.A.2006.000.21000. 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. Tulipe 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 Tulipe, the interpolation kernel is composed of intersections between the probe trajectory (passing through the current point) and the closest B-scans [53].

6. New Results

6.1. Image Segmentation, Registration and Analysis

6.1.1. Non-local means for image restoration

Participants: Pierrick Coupé, Pierre Yger, Sylvain Prima, Pierre Hellier, Christian Barillot.

A critical issue in the context of image restoration is the problem of noise removal while keeping the integrity of relevant image information. Denoising is a crucial step to increase image conspicuity and to improve the performances of all the processings needed for quantitative imaging analysis. The method we have proposed is based on an optimized blockwise version of the Non Local (NL) Means fillter [49]. This approach uses the natural redundancy of information in image to remove the noise. If the performances of the NL-means filter have been already shown for 2D image, the critical aspect of extending the method to 3D images is the computational burden. To overcome this problem, we propose improvements to reduce the computational complexity. These different improvements allow us to divide by a factor of 350 the computational time. A fully-automated version of the blockwise NL-means filter has been performed, exhibiting good denoising results without expensive computational burden and without external parameter tuning. Tests were carried out on synthetic datasets and on real MR images from two specific sequences T1-w and T2-w. The quantitative results show that the blockwise approach outperforms the classical implementation of the NL-means filter, and also other classical denoising methods, such as Anisotropic Diffusion Filter [61] and Total Variation minimization process [62]. We have performed large scale experimentations to get qualitative results on real 3T T1-w MR images and T2-w images with Multiple Sclerosis (MS) lesions [33].

6.1.2. A new optimisation algorithm for medical image registration

Participants: Nicolas Wiest-Daesslé, Pierre Yger, Sylvain Prima, Christian Barillot.

In this work, we proposed to use a recently introduced optimisation method (termed NEWUOA, for NEW Unconstrained Optimization Algorithm) in the context of rigid registration of medical images. This optimisation method was compared with two other widely used algorithms, the Powell's direction set and Nelder-Mead's downhill simplex methods. We evaluated the performances of these three algorithms to optimise different image similarity measures for different mono- and multimodal problems. Images from the BrainWeb project were used as a gold standard for validation purposes. We showed that the proposed optimisation algorithm is more robust, more accurate and faster than the two other methods [43].

6.1.3. Shape analysis and level sets for segmentation of brain structures

Participants: Cybèle Ciofolo, Christian Barillot.

We have proposed a new method to segment 3D structures with competitive level sets driven by a shape model and fuzzy control. To this end, several contours evolve simultaneously towards previously defined targets. The main contribution of this work is the original introduction of a priori information provided by a shape model, which is used as an anatomical atlas, into a fuzzy decision system. The shape information is combined with the intensity distribution of the image and the relative position of the contours. This combination automatically determines the directional term of the evolution equation of each level set. This leads to a local expansion or contraction of the contours, in order to match the borders of their respective targets. The shape model is produced with a principal component analysis, and the resulting mean shape and variations are used to estimate the target location and the fuzzy states corresponding to the distance between the current contour and the target. By combining shape analysis and fuzzy control, we take advantage of both approaches to improve the level set segmentation process with a priori information. Experiments have been done for the 3D segmentation of deep brain structures from MRI, and a quantitative valuation was performed on a 18 volumes dataset [31].

6.2. Image processing on Diffusion Weighted Magnetic Resonance Imaging

6.2.1. Computation of the mid-sagittal plane in diffusion tensor MR brain images

Participants: Sylvain Prima, Nicolas Wiest-Daesslé, Christian Barillot.

We proposed a method for the automated computation of the mid-sagittal plane of the brain in diffusion tensor MR images. We proposed to estimate this plane as the one that best matches the two hemispheres of the brain by reflection symmetry. This is done via the automated minimisation of a correlation-type global criterion over the tensor image. The minimisation is performed using the NEWUOA algorithm in a multiresolution framework. We validated our algorithm on synthetic diffusion tensor MR images. We quantitatively compared this computed plane with similar planes obtained from scalar diffusion images (such as FA and ADC maps) and from the B0 image (that is, without diffusion sensitisation). Finally, we showed some results on real diffusion tensor MR images [41].

6.2.2. Basic methods for processing and representation of diffusion tensor MRI data

Participants: Nicolas Wiest-Daesslé, Sylvain Prima, Naman Singhal, Christian Barillot.

We developed a general purpose application implementing most of the state-of-the-art methods for the pre- and post-processing of diffusion-weighted (DW) MRI data obtained from different MRI scanners. Tests were performed on the two MRI scanners of the Rennes university hospital: 1.5T Siemens Symphony and 3T Philips Achieva MRI scanners. The application includes import/export routines for DW-MRI raw data, low-level algorithms for retrospective correction of image artefacts (noise, distortions) and higher-level algorithms for image processing and analysis (tensor algebra, registration, visualisation). Preliminary experiments have been performed on DW-MRI data from individual MS patients. As expected from the literature, changes in the diffusion parameters computed from the tensor field were revealed, and additional studies are currently under investigation to validate these outcomes.

6.3. Management of Information in Neuroimaging

6.3.1. Federation of Heterogenous and Distributed Information in Neuroimaging

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

In this topic we have continued our work with the Neurobase project in order to develop a demonstration environment to exhibit the way neuroimaging information (data and image processing tools) can be shared. Our goal was to elaborate a demonstrator based on some existing modules like Le Select[2], BrainVISA/Anatomist[3], BALC (from our Grenoble partners) or VIsTAL[4]. Several functionalities are being implemented such as data wrappers and mediators, medical image processing methods (data access, image processing, segmentation, visualization,) through a data flow model approach (see Figure 2 of [48]). In the Neurobase demonstrator, we have proposed architecture with a generic server model based on the LeSelect with a PostGres/SQL data base for managing the storage of temporary image data computed from Data Flow process. The data flow processes for image processing workflow procedures can be executed from a Tomcat server. We are actually implementing data flows being able to process image denoising, brain segmentation, brain tissue classification (white matter, grey matter, CSF). The computation mapping implemented in the current version (i.e. where data meet the image processing codes) can be in principle performed everywhere in the collaborative network. In practice, because we haven't set up efficient processing servers on each collaborative site, in current experiments, codes are executed were the data are located. At the present time, security aspects are just addressed by using a SSH tunnelling for the transactions between the servers and the clients. Confidentiality of the data including anonymization has to be performed by the publisher. This issue should be addressed in future versions, especially within the scope of the new "ANR: Technologies Logielles" Project called NeuroLOG which has been accepted this year.

6.3.2. Ontologies for modelling brain structures in neuroimaging applications

Participants: Ammar Mechouche, Bernard Gibaud.

[2] http://www-caravel.inria.fr/Fprototype_LeSelect.html
[3] http://brainvisa.info/
[4] http://www.irisa.fr/visages/software-fra.html

The general objective of this work is to model and represent knowledge about brain anatomical structures in ways that facilitate sharing and re-use for various purposes. Based on first results obtained during Olivier Dameron's PhD thesis, our current objective is to represent symbolic knowledge about cortical structures (gyri and sulci) and to demonstrate the added value of this knowledge for the interpretation and annotation of MRI images. For example we are interested in showing how such information can complement other kinds of priors such as statistical probability maps. Therefore, our recent works have explored the feasibility of the joint use of an OWL ontology of brain cortical structures (focusing of the representation of part-of and topology relationships) and of rules (represented in SWRL), modelling complex dependencies between those relationships. Merging these two kinds of knowledge is made using the KAON2 reasoner[5].

This work has been done in collaboration with Pr Christine Golbreich (LIM, UPRES 3888, Rennes), who is co-supervisor of Ammar Mechouche's PhD thesis [37], [38].

6.3.3. Ontology of Datasets and Image processing tools in neuroimaging

Participants: Lynda Temal, Bernard Gibaud.

Based on the work done during the exploratory phase of the Neurobase project, we have refined the Neurobase ontology towards a more formal and more modular ontology, called OntoNeurobase. Therefore, we adopted a specific, multi-layered, modular approach to ontology design, and we used DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) as a foundational ontology together with three core ontologies, namely I&DA (Information and Discourse Acts) for modelling documents (texts and images), COPS (Core Ontology of Programs and Software) for modelling programs and software, and OntoKADS for modelling problem solving activities. Our original contribution concerns Datasets and Image processing tools in the field of neuroimaging [42]. This work has been done in collaboration with Michel Dojat (INSERM U594) and Gilles Kassel and his colleagues from LaRIA (CNRS FRE 2733) in Amiens.

6.4. Image Guided Neurosurgery

6.4.1. Intraoperative 3D Free-Hand Ultrasound

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

We have continued our efforts in using ultrasound images during neurosurgical procedures. More specifically, we have adressed the problem of rigid registration of $3D$ intraoperative ultrasond data to preoperative MR images. This is still a challenging problem due to the difference of information contained in each image modality. To overcome this difficulty, we introduce a new probabilistic function for similarity measurements based on the mean curvature of MR isophots and US hyperchogenic structures. Experiments were carried out on 3 patients and compared with three other registration approaches. The results show that the proposed method converges robustly compared to the standard registration techniques, with a computational time compatible with intraoperative use.

6.4.2. Ultrasound shadows detection

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

Acoustic shadows appear in ultrasound images as regions of low signal intensity after boundaries with very high acoustic impedance differences. Acoustic shadows can be viewed as informative features to detect lesions, calcifications, gallstones; or can be considered as damageable artifacts for image processing tasks such as segmentation, registration or $3D$ reconstruction. In both cases, the detection of these acoustic shadows is useful. We have proposed a new geometrical method to detect the shadows based on statistical analysis of intensity profiles along the lines that compose the B-scan image. Results demonstrate that this detection improves the accuracy of $3D$ reconstruction of intraoperative ultrasound.

6.4.3. Multimodal and deformable validation phantom

Participants: Pierre Hellier, Xavier Morandi.

[5] http://www.aifb.uni-karlsruhe.de/Projekte/viewProjekt?id_db=62

The validation of registration processes is difficult when no ground truth is available. In the context of image-guided neurosurgery, the validation of non-rigid registration of ultrasound images is particularly needed and yet very challenging. We have designed a polyvinyl-alcohol (PVA) phantom to mimic the elastic properties of the human tissues. The phantom can be mechanically deformed and imaged with ultrasound and magnetic resonance imaging modalities. So as to provide a ground truth to validate the estimaion of deformations, fiducials were introduced. The use of chemical contrast agents makes it possible to change the $T1$ value of the fiducials (thus changing the contrast in the MR images) without changing the echogeneicity of the fiducial. This phantom is also intended to be used for other validation purposes such as segmentation, reconstruction and enoising methods. Further work is needed to disseminate the validation phantom and the evaluation platform.

6.4.4. *Surface-based intraoperative imagery in neurosurgery*

Participants: Perrine Paul, Pierre Jannin.

Research on intra operative anatomical brain deformations focused on detection, quantification and tracking of surface brain deformations. The objective was to provide the surgeon with cheap, robust and reliable quantitative information about anatomical surface deformations during surgery. Following the development of brain operative surface acquisition system using stereovision from images of surgical microscope, we introduced a method for anatomical features video tracking from surgical microscope video flow. From this video tracking method, we introduced a new surface registration method. This method includes 3 terms: one is related to image intensity similarities, one is related to geometrical distance and the third one is related to the anatomical features tracked in video. This surface registration method is adapted to the 3D reconstructed surface from stereoscopic images. It allows precise and robust computation of deformation fields between brain surfaces. Performance evaluation showed high improvement of accuracy in comparison with usual registration methods, such as ICP. The method for brain surface acquisition was published in [59] and preliminary results for the registration method in [60]. This approach is limited to cortical surface deformations quantification. However it provides an interesting real-time constraint for volumetric approach. Video tracking in surgical microscope images is also a new challenging area.

6.4.5. *Surgical Workflows and Integration of pre- and intra-operative information for neurosurgical procedure*

Participants: Omar El Ganaoui, Pierre Jannin, Xavier Morandi.

Research on modelling surgical procedures focused on understanding of complexity and extent of the surgical work domain to be modelled. The main long term objective consists in defining a global methodology for surgical modelling as well as for the identification of the different surgical aspects to be modelled. Collaborations were set up with the ICCAS research institute (International Center of Computer Assisted Surgery) from Leipzig University (Germany) and the GRESICO (Groupe de REcherche en Sciences de l'Information et de la COgnition) laboratory from the Université de Bretagne Sud in Vannes (France). With the german ICCAS group, we refined and adapted a methodology previously defined in the lab for surgical modelling [58]. We have demonstrated the importance of using upper level ontology for surgical ontology [2]. Then, we identified the different phases for data acquisition, analysis, treatment and visualization adapted to surgical models [3]. With the GRESICO lab, we are starting discussions for defining a methodology for specifying different surgical aspects to be modelled. A method based on abstraction hierarchy is under development. Two publications were accepted in international conferences which served as a basis for a PROCOPE funding proposal submitted in May 2006 (result expected in December 2006). Discussions and works with the ICCAS group started in November 2004 were used as a basis for the creation of a new DICOM group (WG 24: "DICOM in Surgery"). P. Jannin is a co-chair of one of the 10 project groups constituting the WG 24. Finally, these topics are an important part of the ITEA proposal submitted in September 2006 which gathers major European actors in computer assisted radiology and surgery. Complexity of this project requires an international collaborative work involving different surgical disciplines. This conceptual approach has to be used in a clinical context for identifying added values and for publications. The initial investment is heavy but the issue is directly proportional. Resulting applications may impact surgical planning, surgical performance as well as surgical education.

6.5. Medical Image Computing in Multiple Sclerosis

6.5.1. Spatio-temporal segmentation of evolving 3D structures, application to segmentation of Multiple Sclerosis lesions

Participants: Laure Aït-Ali, Sylvain Prima, Sean Morrissey, Béatrice Carsin-Nicol, Gilles Edan, Christian Barillot.

Multiple sclerosis (MS) is a prototype inflammatory autoimmune disorder of the central nervous system. Today, clinical markers are used for the diagnosis as well as for drugs assessment. However, these markers are subjective and show poor inter- and intra-rater reliability. Magnetic resonance imaging (MRI) becomes a mandatory surrogate exam for a better understanding of the disease. To make the lesions detection less fastidious and error prone, we have proposed to automatically segment MS lesions over time in longitudinal MR multi-sequences.

We use a robust algorithm that allows the spatio-temporal segmentation of the abnormalities and propose an original rejection scheme for outliers. Our approach comes from a parametric clustering segmentation method, which uses multi-sequence intensities coming from the processed MR volumes. The parameters are robustly computed using a new estimator: the Trimmed Likelihood Estimator. Three MS lesions subtypes are then extracted among the outliers: enhancing lesions, T1 “black holes” and T2 hyper-intense lesions.

Our algorithm is calibrated on simulated data for various artifacts. Our main results for this year was to extensively calibrate the method in order to quantitatively validate it on MS patients scans [28], [29], [27].

6.5.2. Automatic Characterisation of the Normal Appearing White Matter (NAWM) in Multiple Sclerosis

Participants: Mathieu Monziol, Sylvain Prima, Sean Morrissey, Christian Barillot.

The purpose of this work is to propose an automatic approach to analyse the variations of the intensities of brain tissues in Magnetic Resonance Images, variations which are not visible by human inspection but which nevertheless characterise a pathological evolution of the subject’s brain tissues. The problem can be regarded either in term of variation of MRI intensities with regard to a "normal" model (differentiation of a subject in a study of group), or in term of a non visible variation of intensities in longitudinal MRI sequences on the same patient. The application of this concerns Multiple Sclerosis where it was recently shown that variations of intensities not visible by human inspection are relevant and give quantitative indicators of the evolution of the Multiple Sclerosis pathology.

6.6. Computational morphometry in Parkinsonian disorders

6.6.1. Voxel based Morphometry in parkinsonian disorders

Participants: Simon Duchesne, Bernard Gibaud, Christian Barillot.

Reported error rates for initial clinical diagnosis in Parkinsonian disorders can reach up to 35%. Reducing this initial error rate is an important research goal. The objective of this work is to evaluate the ability of automated MR-based classification techniques in the differential diagnosis of Parkinson’s disease (PD), multiple systems atrophy (MSA) and progressive supranuclear palsy (PSP) patients.

The Neuroprotection and Natural history in Parkinsonian Plus Syndromes (NNIPPS) is a European-funded randomized, multi-centric clinical trial of MSA and PSP that aims to assess the neuroprotective effect of riluzole. The imaging component of the NNIPPS study has collected over 630 MRI scans at baseline. Additionally, the Movement Disorders clinic at the Centre Hospitalier Universitaire de Rennes has performed over 100 scans of subjects with either probable MSA/PSP or PD. All of these scans are or will be used in our analyses.

A preliminary study [35] was conducted on 10 probable PD patients and 10 patients with diagnostic of either probable MSA or PSP. T1-weighted (T1w) MR images were processed using an appearance-based technique built on extracted patterns of tissue transformations and deformations. Classification accuracy (agreement with long-term clinical follow-up) reached 85%, demonstrating the potential of such an approach. In parallel, an MRI-based atlas of the pons and a specific brainstem segmentation protocol were developed to perform three-dimensional pontine volumetry in young adults [34], aging and Parkinsonian diseases.

6.6.2. Surface-based Morphometry in Parkinsonian disorders

Participants: Duygu Tosun, Simon Duchesne, Christian Barillot.

MR imaging had played an important role in diagnosis of numerous neurodegenerative disorders. It was recently that MRI was considered useful in establishing a differential diagnosis in Parkinson's Plus Disorder (PPD) patients. The objective of this project is to develop a cortical morphometry analysis framework to better understand the alteration on the brain structure due to PPD and propose a diagnosis framework differentiating Multiple System Atrophy (MSA) and Progressive supranuclear palsy (PSP) complementary to intensity-based MRI analysis. Affects (e.g., atrophy, disturbance) on the cortical geometry will be quantified using the local and regional cortical complexity measures (i.e., shape index, curvedness, and regional bending energy), measures on sulcal depth and width, and gray matter tissue density (i.e., cortical thickness). A statistical analysis on these cortical features will be carried out to test for population related (MSA versus PSP versus PD) shape differences.

6.7. Anatomical and functionnal imaging in dysphasia

Participants: Clément De Guibert, Simon Duchesne, Pierre Jannin, Christian Barillot.

Dysphasia is a developmental language-structural disorder in children that have currently received no neurobiological explanation. Morphometric (MRI) and functional (SPECT) neuroimaging have previously provided a few but inconstant results, implicating in some cases the language-related cerebral regions, although without clear localization and lateralisation. In the present research, we study with functional (fMRI) and diffusion-weighted MRI (DW-MRI) a population of dysphasic children from 7 to 14 years old, compared with paired normal children, with the aim to better figure out the localization and the lateralisation of anatomical and functional cerebral abnormalities in this disorder, by means of actual neuroimaging techniques and image processing. The project takes place in the context of a delegation of Clément De Guibert from the University of Rennes II Linguistics Department (Assistant Professor at UHB Rennes II) to INRIA (Project / Unit Visages, U746), and is achieved with the collaboration of the Radiology and Medical Imagery Department and the Reference Center of developmental language disorders of the University Hospital of Rennes (CHU, Pontchaillou).

7. Contracts and Grants with Industry

7.1. Contracts and Grants with Industry

7.1.1. contrats

Participants: Eric Poiseau, Bernard Gibaud.

IHE

Since 2001, the IDM Laboratory has been involved with IHE since its beginning in Europe. It organized the European connect-a-thons and contributed to the development of the European part of IHE. In order to better manage the IHE Connect-a-thon, a web tool known as Kudu was developed within the laboratory. Kudu consists of a database and a set of PHP scripts. The role of Kudu is to manage "the registration of companies to the connect-a-thon", "the configuration of the systems", and "the test to be performed by system before and during the connect-a-thon". The Kudu tool is now used for the management of the North American and Japanese connect-a-thons.

Following the merging of the IDM laboratory and the Visages Unit/Project, IHE became a development project of INRIA hosted by IRISA. The new project is lead by Eric Poiseau, hosts an associate engineer and will soon recruit 2 expert engineers. This new project will still organize the European connect-a-thon, manage at the European level the development of tools for the evaluation of the implementation of IHE within companies product. Aside those activities, IHE Development will try to provide connections between INRIA research project and industry in the field of healthcare IT

7.1.2. contrats

Participants: Perrine Paul, Pierre Jannin.

Medtronic: Cifre convention

duration : 36 months, until 31/12/2006

This contract is dedicated to support the Cifre convention between Medtronic and Irisa/University of Rennes 1 regarding Perrine Paul's Ph.D. The goal of the Ph.D. is to enable augmented reality in the surgical room by using the outputs of the surgical microscope cameras for the development of brain operative surface acquisition using stereovision from images of surgical microscope.

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, Vincent Gratsac, Bernard Gibaud, Pierre Hellier, Pierre Jannin, Sylvain Prima, Christian Barillot.

duration : 36 months, until 31/12/2006

This two-year 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.

duration : 36 months, until 31/12/2006

This three-year 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 partially funding the position of Laure Aït-Ali.

8.1.3. SIMUPACE project

Participants: Jérémy Lecoeur, Christian Barillot.

duration : 36 months, from 01/11/2006

This three years project is devoted to the development of a solution for processing medical images from multi-dimensional signatures in order to study brain pathologies and to segment brain structures with complex image representation. This grant is being used for founding the position of Jérémy Lecoeur.

8.2. National initiatives

8.2.1. ANR "Technologies Logicielles", NeuroLOG Project

Participants: Lynda Temal, Sylvain Prima, Sean-Patrick Morrissey, Gilles Edan, Bernard Gibaud, Christian Barillot.

duration : 36 months, from 01/10/2006

The NeuroLOG project has for objective to build a software environment in an open environment for the integration of resources in medical imaging (data, images and also image processing tools) and to confront this environment to target applications coming mainly from the neuroimaging and the oncology domains. This project intends to address problems related to:

- The management and the access to semi-structured heterogenous and distributed data in an open environment;
- The control and the security of the access of the sensitive medical data;
- The control of data and computing workflows involved in high demanding processing procedures by accessing grid computing infrastructures;
- The extraction and the quantification of parameters for relevant application such as multiple sclerosis, strokes and brain tumours.

In addition to our Unit/Project and the Paris project from IRISA, this grant is conducted by CNRS/I3S at Sophia-Antipolis and is performed in collaboration with INRIA team Asclepios (Sophia-Antipolis), INSERM unit U594 from Grenoble, IFR 49 "Functional Neuroimagery" (Paris La Pitié Salpêtrière), the CNRS/LARIA at Amiens and Business Objects and Visioscopie for the industrial part.

8.3. International initiatives

8.3.1. INRIA Associated Project NeurOMIMe

Participants: Pierre Hellier, Sylvain Prima, Sean-Patrick Morrissey, Xavier Morandi, Simon Duchesne, Pierrick Coupe, Laure Aït-Ali, Christian Barillot.

duration : 24 months, from 01/01/2006

NeurOMIMe[6] stands for "Objective Medical Image Methods Evaluation for Neurological and Neurosurgical Procedures". This International INRIA action is coordinated by Christian Barillot (Visages) and Louis Collins (IPL, Univ. McGill) and relates research dealing with medical image processing in clinical neurosciences performed in both collaborative sites: IRISA/Visages on one part and the Image Processing Laboratory of the McConnell Brain Imaging Centre at the Montreal Neurological Institute (Univ. Mc Gill, Montreal, Canada) on the other part.

One important research objective in neuroimaging is to create anatomical and functional cerebral maps under normal and pathological conditions. The goal of this INRIA associated project-team is to combine the respective research efforts in clinical neuroinformatics of the VisAGeS and IPL teams, and thus benefit from the resulting cross-fertilization. We aim at addressing specific aspects of medical image processing for the purpose of neurological diseases analysis and their treatment through surgery. Both teams have significant experience in developing medical imaging software aimed at:

- improving neurosurgical practice through pre-operative planning, intra-operative guidance and imaging of brain deformations;
- improving neurological exploitation of the spatio-temporal and multiparametric MRI data produced in the context of brain diseases (e.g. multiple sclerosis -MS- lesions); and
- improving basic understanding of brain anatomy and cerebral function by using computerized procedures to model their relationship, especially in the context of the effect of pathology on brain structures (e.g. epilepsy, dementia, neurodegenerative diseases).

Through this project, the two teams will share their own, but complementary, expertise by distributing algorithms and data dealing within the clinical needs described above, in order to compare and cross-validate the different procedures developed at each site; then improve on the excellence and efficiency of these procedures.

[6] http://www.irisa.fr/visages/documents/FormulaireNeurOMIMe.html

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).
- C. Barillot serves in the peer review committee of the Journal of Computer Assisted Tomography.
- C. Barillot serves in the peer review committee of Neuroimage.

9.1.2. Peer Reviews of journals

- Reviewing process for IEEE TMI (CB, PH, SP, PJ, BG), Medical Image Analysis (CB, PH, SP)

9.1.3. Conference board organization

- C. Barillot was scientific chair of the Inria-Industries meeting co-sponsored by INSERM and dedicated on "Information, Communication and Sciences Technologies to assist Medicine ", Rocquencourt, jan. 2006

9.1.4. Technical Program Committees (TPC) of conferences

- C. Barillot was area chair for SPIE Medical Imaging 2006, and TPC member for ECEH'06, ECCV/CVAMIA'06, JETIM'06, MIAR'06, MICCAI'06, MMBIA'06, WBIR'06
- B. Gibaud was TPC member for CARS 2006
- P. Jannin was TPC member for SPIE Medical Imaging 2006, CARS 2006
- P. Hellier was TPC member of MICCAI 2006, RFIA 2006, IEEE ISBI 2006, MMBIA 2006
- S. Prima was TPC member of MICCAI 2006, IEEE ISBI 2006

9.1.5. Scientific societies

- P. Jannin is General Secretary of ISCAS
- B. Gibaud is member of the AIM
- C. Barillot, S. Duchesne and P. Jannin are members of IEEE EMBS
- C. Barillot, S. Duchesne, P. Hellier, P. Jannin, S. Prima are members of the MICCAI society

9.2. Teaching

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

- DIIC-INC, IFSIC, University of Rennes I : 2h (*C. Barillot*), 2h (*P. Hellier*), 2h (*P. Jannin*), 2h (*S. Prima*)
- Master 2 SIBM, University of Angers-Brest-Rennes : 26h (*C. Barillot, S. Prima, B. Gibaud, P. Jannin, X. Morandi, S.P. Morrissey*), C. Barillot, B. Gibaud and P. Jannin are responsible for three different semesters.
- Master "Rayonnements ionisants et application ", Univ. de Nantes: 4h (*C. Barillot*)
- Master "Méthodes de traitement de l'information biomédicale", University of Rennes I : 6h (*B. Gibaud*)
- Master "Equipements biomédicaux", UTC Compiègne: 3h (*B. Gibaud*)
- Master " Signaux et Images en Médecine ", University Paris XII Val de Marne: 3h (*B. Gibaud*)
- European School for Medical Physics:3h (*P. Jannin*)

9.3. Participation to seminars, scientific evaluations, awards

- B. Gibaud is member of the CSS 7 evaluation committee of INSERM
- C. Barillot was member of the INSERM admission jury for CR2 and CR1 positions
- B. Gibaud served as expert for ANR (TecSan and Masse de données)
- C. Barillot served as external reviewer of an FP6 IST integrated Project
- C. Barillot served as expert for ANR "Programme Blanc"
- P. Hellier served as expert for PAI "France-Israel"

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