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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].

[1] http://www.irisa.fr/visages/demo/Neurobase/index.html

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 [42]:

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

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 [47], [51].

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 [48]. 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 [40], [41], [43], 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 [45], [47], 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 [43], [45], [44], [47],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 [50]. 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 [49]. 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 reconstruction **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 [46].

5.6. Online applications

Online applications offers a web service for testing the tools developped by the members of team : Denoising based on Non Local Mean algorithm, 3D rigid registration, etc. This application support the main formats used in medical imaging data : Nifti-1, Analyze7.5, Mha, GIS. The applications are available at this url http://www.irisa.fr/visages/benchmarks.

5.7. GISViewer

The GISViewer is a graphical user interface for the visualization of medical image data. Some basic processing method can be applied : windowing, reformating, thresholding, erosion, dilatation, surface extraction. More complex processing method are also available as plug-ins : sulcal traces extraction, diffusion tensor imaging methods, patch extraction for atlas computing. The GISViewer is designed to be multi-platform because it's based on Qt library.

5.8. Dbsurg

DBSurg is a software for recording descriptions of surgical procedures based on a previously defined ontology [refs neuroimage + CAS]. DBSURG allows prospective and retrospective descriptions of planned and/or performed surgical procedures. Queries capabilities provide the neurosurgeon with tools to browse the database and to analyse occurrences of dedicated surgical characteristics. The last version that we developed, is used for different projects following French or English language interface. DBSurg is based on php and PostGreSQL.

5.9. DASH

Dash (Detection of Acoustic SHadows) was developed to detect acoustic shadows on ultrasound images. Dash was registered at APP under IDDN.FR.001.270019.000.S.P.2007.000.21000.

5.10. TMSInria

TMSInria has been developed as a neuronavigation system for transcranial magnetic stimulation. The software enables to track the patient and the stimulation probe, as well as to perform image to patient registration.

6. New Results

6.1. Image Segmentation, Registration and Analysis

6.1.1. Wavelet-based non-local means denoising

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

We have proposed here a fully automatic 3D blockwise version of the Non Local (NL) Means filter with wavelet sub-bands mixing. The proposed wavelet sub-bands mixing is based on a multi-resolution approach for improving the quality of image denoising filter. Quantitative validation was carried out on synthetic datasets generated with the BrainWeb simulator. The results showed that our NL-means filter with wavelet sub-bands mixing outperforms the classical implementation of the NL-means filter in terms of denoising quality and computation time. Comparison with well-established methods, such as non linear diffusion filter and total variation minimization, showed that the proposed NL-means filter produces better denoising results.

6.1.2. Mapping asymmetries of bilateral objects represented by point clouds

Participants: Benoît Combès, Sylvain Prima.

We developed a method to automatically quantify the local asymmetries of bilateral structures represented by point clouds. Such data can be obtained for instance by laser scanning a human face. The method relies on the robust computation of the approximate symmetry plane of the object under study. Departure from perfect symmetry is then computed for each point of the cloud, allowing to map the asymmetries of the object under study. Spatial normalisation techniques are currently developed to allow for comparison of different populations of subjects (males/females, controls/schizophrenics, etc.).

6.1.3. Deformable Segmentation of vector and tensor field MRI using Graph-Cut

Participants: Jérémy Lecoeur, Christian Barillot.

During the first half of year, I have made a review about the different existing segmentation methods in biomedical imaging. This review, available as an INRIA research report (number 6306), classifies the methods in five main fields which are contour-based, region-based, shape-based, graph-based and eventually structural-based approaches. For each of these approaches, we then explain the principal methods and illustrate them by giving few examples of each. The second half of the year was dedicated to the implementation of graph-cut based segmentation methods. Once done, we have looked at using the graph-cut paradigm for multimodal brain MRI and tensor-based images.

6.2. Image processing on Diffusion Weighted Magnetic Resonance Imaging

6.2.1. Correction of Distortions

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

Diffusion weighted MR images are acquired using specific magnetic gradients. Multiple MR acquisition are required to get enough orientation samples, in order to correctly characterise the diffusion process in the 3D space. The diffusion sensitising gradients create eddy currents in the receiver coil. These induced currents change the geometry of the acquired images by creating spatial distortions. In order to estimate properly the diffusion process for each voxel of the image the distortions must be compensated. A widely used approach for this purpose is the registration of each diffusion-weighted image to the first diffusion un-weighted image of the sequence. This registration consists in maximising a similarity criterion between the intensities of the images to be matched. In this context, efficient optimisation methods are needed to obtain good performances. We introduce a new optimisation algorithm (called NEWUOA) to address this registration problem [53].

6.2.2. Diffusion Weighted and Diffusion Tensor Image Denoising

Participants: Nicolas Wiest-Daesslé, Sylvain Prima, Pierrick Coupe, Sean Morrissey, Christian Barillot.

Diffusion tensor imaging (DT-MRI) is very sensitive to corrupting noise due to the non linear relationship between the diffusion-weighted image intensities (DW-MRI) and the resulting diffusion tensor. Denoising is a crucial step to increase the quality of the estimated tensor field. This enhanced quality allows for a better quantification and a better image interpretation. We propose different methods based on the Non-Local (NL) means algorithm. This approach uses the natural redundancy of information in images to remove the noise. The results show that the intensity based NL-means approaches give better results in the context of DT-MRI than other classical denoising methods, such as Gaussian Smoothing, Anisotropic Diffusion and Total Variation [52].

6.2.3. Methods for processing and representation of diffusion tensor MRI data

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

For the last two years, we have been developing a general purpose application for the processing of diffusion-weighted (DW) MR images. State-of-the-art techniques have been implemented to allow for individual and group studies. These techniques include: import/export routines, correction of image artifacts, tensor field estimation, computation of quantitative indices (fractional anisotropy, mean diffusivity, relative anisotropy, etc.), spatial normalization (both intra- and inter-subject, linear and non-linear), quantitative tractography (deterministic, stochastic, etc.), and visualization (e.g. ellipsoids or more general glyphs).

6.2.4. 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.

6.2.5. Motor and sensory fibers for hand function - a diffusion tensor MRI study

Participants: Romuald Seizeur, Sylvain Prima, Nicolas Wiest-Daesslé, Christian Barillot, Xavier Morandi.

We acquired 3D anatomical (T1-weighted), functional (fMRI) and diffusion-tensor (DTI) MR images for a quantitative study of the cortical hand areas in a population of 40 healthy right-handed and left-handed subjects. First, specific paradigms were used to identify cortical motor and sensory areas of the left and right hand in fMRI. DTI tractography was then performed to delineate the fiber tracts connecting these fMRI-defined regions of interest with the brain stem. Quantitative indices (fractional anisotropy, mean diffusivity) were then computed over the tracts of interest and statistics were performed to assess differences between right and left hands in the population of right and left-handed subjects.

6.3. Management of Information in Neuroimaging

6.3.1. Integration of Heterogeneous and Distributed Information in Neuroimaging

Participants: Lynda Temal, Bernard Gibaud, Christian Barillot.

Our current participation within the NeuroLOG project concerned the first work package especially on the elaboration of the proposed system architecture, the second work package on the finalization of the "OntoNeurobase" and on the Application work package for the specification of the MS meta-data. In addition we ware responsible for the integration of the technical report L3 dedicated to the overall specification of the NeuroLOG architecture.

6.3.2. Ontology of Datasets and Image processing tools in neuroimaging

Participants: Lynda Temal, Bernard Gibaud.

Based on preliminary work done during the exploratory phase of the Neurobase project, we have refined the Neurobase ontology toward a more formal and more modular ontology, called OntoNeurobase. This ontology is based on a multi-layered, modular approach to ontology design. We used DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) as a foundational ontology, providing the common philosophical foundation, together with several core ontologies, namely I&DA (Information and Discourse Acts) for modeling documents (texts and images), COPS (Core Ontology of Programs and Software) for modeling programs and software , and OntoKADS for modeling problem solving activities. Our original contribution concerns Datasets and Image processing tools in the field of neuroimaging. Our most recent work concerned (1) the hierarchy of datasets, (2) the representation of mathematical functions modeling image data, (3) image annotations relating regions of interest defined on the images to real world entities denoting the anatomy or physiology of the subject, and (4) a taxonomy of image processing. 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.

6.3.3. Ontologies for modeling brain structures in neuroimaging applications

Participants: Ammar Mechouche, Bernard Gibaud, Xavier Morandi.

We are interested in showing how such information can complement other kinds of priors such as statistical probability maps. In our system, probability maps provide a first set of assumptions about brain gyri, from which the system automatically derives a series of assumptions concerning sulci. Image annotations are obtained through a cooperation with the user, who can enforce specific labels for particular gyri and sulci. The system iterates reasoning, which limits the range of labelling possibilities. Resulting annotations are then stored as OWL instance files. The system uses 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[2]. This work has been done in collaboration with Pr Christine Golbreich (University of Versailles Saint Quentin), who is co-supervisor of Ammar Mechouches PhD thesis.

6.4. Image Guided Intervention

6.4.1. Intraoperative 3D Free-Hand Ultrasound in Neurosurgery

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 non-rigid registration of $3D$ intraoperative ultrasound data to preoperative MR images. We have extended our previous approach on rigid registration with a parametric representation of the deformation. Results on synthetic and real data have shown promising results.

6.4.2. Preoperative brain deformation in neurosurgery

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

To our knowledge, there is no study that discusses the possible intraoperative brain deformations before skull opening. The study that we proposed is set within the context of brain tumor surgery. We demonstrated the existence of deformation in preoperative phase of IGNS and necessity to update preoperative images in order to allow the recovery of registration error for MIGNS systems due to a new phenomenon that we call " preoperative brain shift ". Respecting the " VisAGeS " point of view for planning in IGNS, preoperative brain shift requires to specify a new clinical protocol for IGNS planning procedures in order to improve the surgical workflow. Description and demonstration of the phenomenon are available on our web site[3]

6.4.3. Models of surgical procedures

Participants: Pierre Jannin, Xavier Morandi.

In collaboration with the german ICCAS group, we have started this year a validation study of surgical models acquisition involving about 20 people during two weeks and providing about 1000 surgical models descriptions for analysis. We defined metrics for comparing surgical models based on measurement of structural outliers, content outliers, structural equivalence, and sequential completeness. Completion time, skills level, knowledge level, and software usability were also acquired during this study. In collaboration with the L. Morrineau at the GRESICO lab of University of South Brittany in Vannes, we have defined a methodology for identifying differences in cognitive behavior between neurosurgeons with different expertise levels. Nine neurosurgeons were interviewed. First results indicate a clear distinction between surgeons and provide a basis for further analysis. Main objective is the optimisation of information display and retrieval. 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").

6.4.4. Transcranial magnetic stimulation

Participants: Cecilia Nauczyciel-Bredoux, Pierre Hellier, Xavier Morandi, Christian Barillot.

[2] http://www.aifb.uni-karlsruhe.de/Projekte/viewProjekt?id_db=62
[3] http://www.irisa.fr/visages/demo/Demo-PBS/PreoperativeBrainShift-eng.html

We have started a collaboration with the psychiatric hospital in Rennes (Prof. B. Millet) concerning transcranial magnetic stimulation for the treatment of depression. More specifically, we have developed a neuronavigation system that is coupled with the magnetic simulation system. This enables to localize in real-time the stimulation locus on the MR image. Compared to the standard empirical localization, we have shown that the neuronavigation is more reliable to stimulate the interface between areas 9 and 46 of the Brodmann atlas.

6.5. Medical Image Computing in Multiple Sclerosis

6.5.1. Automatic Segmentation of lesions and Normal Appearing Brain Tissues (NABT) in patients with Multiple Sclerosis

Participants: Daniel Garcia-Lorenzo, Sylvain Prima, Sean Morrissey, Gilles Edan, Christian Barillot.

I set up a workflow for the automatic segmentation of Multiple Sclerosis lesions in MR images. This work consisted, in first place, in compare different algorithms of registration, inhomogeneity correction, denoising to normalize and enhance MR images and select the best workflow for this concrete application. In second place, to improve an algorithm of segmentation develop in our laboratory, STREM, to handle different sequences and multicenter studies. This work has been performed in collaboration with Dr. JC Ferré from the neuroradiology department of University Hospital of Rennes.

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 was to study how people in the literature cope with the issue of quantitative analysis of Normal Appearing White Matter tissues from MRI by using either standard weighted MRI sequences or relaxometry sequences. The outcome of this study is that quantitative MRI requires true T1/T2 parameters estimation but this may be done in spite of making these new sequences hard to normalize for multi centric experiments and hard also to set up in clinical conditions.

6.6. Computational morphometry in Parkinsonian disorders

6.6.1. Voxel based Morphometry in parkinsonian disorders

Participants: Simon Duchesne, Christian Barillot.

The objective of this work was to evaluate the ability of an automated technique based on structural, cross-sectional T1-weighted (T1w) MRI at performing differential classification of IPD patients against those with either progressive supranuclear palsy (PSP) or multiple systems atrophy (MSA). The results have demonstrated that a classification approach based on quantitative parameters of 3D brainstem morphology extracted automatically from T1w MRI has the potential to assist in the differential diagnosis of IPD versus PSP and MSA with high accuracy, thereby reducing the initial clinical error rate. This work has been performed in tight collaboration with Prof. M. Vérin from the neurlogy department of University Hospital of Rennes and Dr. Y. Rolland from the Eugene Marquis Center.

6.7. Anatomical and functional imaging in dysphasia

Participants: Clément De Guibert, Arnaud Biraben, Pierre Jannin, Christian Barillot.

Previous neuroimaging studies have been reviewed, with a distinction of specified and unspecified dysphasias [4]. The study has been designed [Objectives; Method (activation tasks, MRI protocol; data analysis); Subjects (patients' selection and criteria)]. To test the MRI protocol and the processing method, a pilot study has been conducted with normal adult and children subjects. Tests have been conducted with the initial standard preprocessing and processing tool (Statistical Parametric Mapping, SPM02 and SPM05). The preprocessing and processing steps and parameters have been specified. This work has been performed in tight collaboration with University Hospital of Rennes especially with Drs. JC Ferré and E. Le Rumeur from the neuroradiology department and C. Allaire from the 'Language Clinic'.

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[4] De Guibert C., Allaire C., Le Rumeur E. "Morphologic and functional neuroimaging findings in specified and unspecified dysphasias (specific language impairments): review and perspectives", *submitted to* Cortex.

7. Other Grants and Activities

7.1. Regional initiatives

7.1.1. 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 : 40 months, until 30/06/2007

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 ...).

7.1.2. Loriot project

Participants: Pierre Meyer, Pierre Hellier.

duration : 36 months, from 01/11/2007

This three years project is devoted to the characterization of soft tissue using intraoperative ultrasound and preoperative MR images, as well as the segmentation of relevant structures in 3D intraoperative ultrasound. This grant is being used for founding the position of Pierre Meyer.

7.1.3. 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.

7.2. National initiatives

7.2.1. 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, stroke 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.

7.3. International initiatives

7.3.1. INRIA Associated Project NeurOMIMe

Participants: Pierre Hellier, Sylvain Prima, Pierre Jannin, Sean-Patrick Morrissey, Xavier Morandi, Simon Duchesne, Pierrick Coupe, Daniel Garcia, Nicolas Wiest-Daesslé, Malar Chakravarty, Christian Barillot.

duration : 36 months, from 01/01/2006

NeurOMIMe[5] 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.

The officiel 2007 report is available online http://www.irisa.fr/visages/documents/Neuromime/FormulaireRenouvNeuroMIME08.html

7.3.2. Alliance (Egide) joint Project with the MARIARC (Magnetic Resonance And Image Analysis Research Centre) at the University of Liverpool

Participants: Sylvain Prima, Sean-Patrick Morrissey.

duration : 24 months, from 01/01/2007

This project is coordinated by Sylvain Prima and Laura Parkes (Univ. Liverpool) and aims to develop methods for the fully automatic detection and quantification of multiple sclerosis (MS) lesions and normal appearing white matter with dynamic Gadolinium enhanced magnetic resonance imaging.

8. Dissemination

8.1. Leadership within the scientific community

8.1.1. 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.
- P. Jannin was Associate Editor of a special issue of IEEE Transactions on Medical Imaging (IEEE-TMI) and of Computer Aided Surgery.

8.1.2. Peer Reviews of journals

- Reviewing process for IEEE-TPAMI (CB), IEEE TMI (PH, SP, PJ, BG), Medical Image Analysis (CB, PH, SP, PJ), Neuroimage (PH, CB, PJ), Human Brain Mapping (CB), Academic Radiology (PJ), International Journal of Computer Assisted Radiology and Surgery (PH), Biomedical Engineering online(PH), Signal Processing (CB)

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

8.1.3. Technical Program Committees (TPC) of conferences

- C. Barillot was area chair for SPIE Medical Imaging 2007, IPMI 2007, Miccai 2007 and TPC member for ECEH'07, IEEE CBMS'07, MIAR'07, ICMB'07, BIOSTEC'08
- B. Gibaud was TPC member for CARS 2007
- P. Jannin was area chair and TPC member for SPIE Medical Imaging 2007 and CARS 2007 and TPC member for MICCAI 2007, ACCV 2007
- P. Hellier was TPC member MICCAI 2007, IEEE ISBI 2007, IPMI 2007, CVPR 2007
- S. Prima was TPC member of MICCAI 2007, IEEE ISBI 2007, IEEE MMBIA 2007

8.1.4. 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 is senior member of IEEE
- C. Barillot, P. Hellier, S. Prima are members of the MICCAI society
- P. Jannin is member of SPIE

8.2. 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 (*B. Gibaud, P. Jannin*)

8.3. Participation to seminars, scientific evaluations, awards

- B. Gibaud is member of the CSS 7 evaluation committee of INSERM
- C. Barillot was member of an INSERM visiting committee
- C. Barillot is member of the board of the "Programme National de Recherche (PNR) Imagerie" (INSERM)
- C. Barillot served as expert for the Austrian Science Fund (FWF)
- B. Gibaud served as expert for ANR ('Blanc' Program)
- P. Jannin served as expert for ANR "TecSan"
- C. Barillot served as external reviewer of an FP6 IST integrated Project
- C. Barillot served as expert for ANR Program "Jeunes Chercheuses, Jeunes Chercheurs""

- P. Hellier served as expert for PAI "France-Israel"

8.4. Invitation of scientific seminars, visits

- Prof. Habib Benali, Unité Inserm U678, Paris Hopital Pitié Salpêtrière, 26/01/2007
- Dr. Karl Krissian, University of Las Palmas, Spain, 29/01/2007
- Dr. Christophe Grova, Univ McGill, Montreal, Canada, 12/03/2007
- Dr. Caroline Villard, University Louis Pasteur, Strasbourg, 25/05/2007
- Dr. Stephane Nicolau, IRCAD, Strasbourg, 13/06/2007
- Prof. Richard Prager, Dept. of Electrical Engineering, Cambridge University, UK, 23/08/2007
- Prof. Benoit Dawant, Dept. of Bio-Engineering, Vanderbilt University, TN, USA, 27/08/2007
- Prof. Klaus Hahn, GSF-Institute Biomathematics & Biometrics, University of Munich, Germany, 16/11/2007
- Dr. Eric Bardinet, CNRS UPR 640, CHU Pitié-Salpétrière, Paris, 07/12/2007
- Prof. Sandy Wells, Harvard Medical School and Brigham and Women's Hospital, Boston, MA, USA, 07/12/2007
- Prof. Anuj Srivastava, Department of Statistics, Florida State University, USA, 17/12/2007

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