INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team VisAGeS

Vision, Action and information manaGement System in health

Rennes - Bretagne-Atlantique

Theme : Computational Medicine and Neurosciences

Activity Report

2010

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2. Overall Objectives

2.1. Overall objectives

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:

- In 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).
- In the field of image analysis and statistical modeling with a new focus on image feature and group analysis problems. A special attention was also to the develop advanced frameworks for the construction of atlases and for automatic and supervised labeling of brain structures.
- In 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 labeling based on shape, multimodal and statistical information.
- The field of information management in neuroimaging we aim at enhancing the development of distributed and heterogeneous medical image processing systems

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

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 [63]:

$$\underset{\theta \in \Theta}{arg\, min_{\Psi}} \Delta\left(\Phi_{\theta}\left(\Omega_{s}\right)-\Omega_{t}\right)$$

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 [68], [73], [70], [71], [67].

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 [69]. 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 or registering two textured reconstructed surfaces from stereovision [72]). 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

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 [61], [62], [64], 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

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 [66], [68], 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 and knowledge in medical imaging and image-guided neurosurgery

There is a strong need of a better sharing and a broader re-use of medical data and knowledge in the neuroimaging and neurosurgical fields. 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 and neurosurgery. For 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. For neurosurgery, this deals with modeling and understanding the procedural and conceptual knowledge involved in the peri-operative process. This improved understanding and the associated formalization would lead to the development of context aware and intelligent surgical assist systems. Following an ontological approach, models should be defined for describing concepts and associated semantics used by the neurosurgeons when taking a decision or performing an action. Then, methods are required for acquiring/capturing both types of knowledge. Knowledge acquisition could be performed following different elicitation strategies, such as observations, interviews with experts, protocol or discourse analysis. Then we aim at analyzing the acquired data for better understanding of the surgical knowledge and for extracting formal models of surgical knowledge. We will focus on two aspects: 1) the procedural knowledge dedicated to the surgical scenario followed by the surgeon when performing a surgical procedure including main phases and the list of activities and 2) the conceptual knowledge involved in the cognitive processes followed by the surgeon in problem solving.

4. Application Domains

4.1. Neuroimaging

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 developmental, neurodegenerative or even psychiatric brain diseases (Multiple sclerosis, Epilepsy, Parkinson, Dysphasia, Depression or even Alzheimer). This is a very competitive research domain; our contribution is based on our previous works in this field [64], [66], [65], [68],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 developmental or neurodegenerative brain diseases.

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" or "augmented virtuality".

Unfortunately, it is now fully admitted that this first generation of systems still have a lot of limitations. These limitations explain their relative added value in the surgeon's decision-making processes. One of the most well known limitations is the issue related to soft tissue surgery. 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. Other important limitations are related to the interactions between the systems and the surgeon. The information displayed in the operative field of view is not perfectly understood by the surgeon. Display modes have to be developed for better interpretation of the data. Only relevant information should be displayed and when required only. The study of information requirements in image guided surgery is a new and crucial topic for better use of images during surgery. Additionally, image guided surgery should be adapted to the specificities of the surgical procedure. They have to be patient specific, surgical procedure specific and surgeon specific. Minimally invasive therapies in neurosurgery emerged this last decade, such as Deep Brain Stimulation and Transcranial Magnetic Stimulation. Similar issues exist for these new therapies. Images of the patient and surgical knowledge must help the surgeon during planning and performance. Soft tissue has to be taken into account. Solutions have to be specific. Finally, it is crucial to develop and apply strong and rigorous methodologies for validating and evaluating methods and systems in this domain. At its beginning, Computer Assisted Surgery suffered from poor validation and evaluation. Numbers were badly computed. For instance, Fiducial Registration Error (FRE) was used in commercial systems for quantifying accuracy. It is now definitively obvious that FRE is a bad indicator of the error at the surgical target. Within this application domain, we aim at developing methods and systems, which overcome these issues for safer surgery. Intra operative soft tissue deformations will be compensated 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. For optimizing the surgical process and the interactions between the user and the CAS systems, we aim at studying the surgical expertise and the decision-making process involving procedural and conceptual knowledge. These approaches will help developing methods for better planning and performance of minimally invasive therapies for neurosurgery, such as Transcranial Magentic Stimulation (TMS) and Deep Brain Stimulation (DBS). All along this research, frameworks will be developed and applied for validation and evaluation of the developed methods and systems.

Intra-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 study and estimate brain deformations using 3D ultrasound and video information.

Modeling of surgical expertise: Research on modeling surgical expertise are divided into two aspects: 1) understanding and modelling the surgical process defined as the list of surgical steps planned or performed by the surgeon, 2) understanding and modelling the surgeonÕs information requirements via cognitive analysis of decision-making process and problem solving process. For the first aspect, the main long term objective consists in defining a global methodology for surgical process modelling including description of patient specific surgical process models (SPM) and computation of generic SPM from patient specific SPMs. 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. Resulting applications may impact surgical planning, surgical performance as well as surgical education. For the second aspect, we study the cognitive processes followed by surgeon during decision and action processes. In surgical expertise, dexterity is not the only involved skill. With the GRESICO laboratory from the Universit de Bretagne Sud, we will adapt models from cognitive engineering to study differences in cognitive behaviour between neurosurgeons with different expertise levels as well as information requirements in a decision making or problem solving.

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.

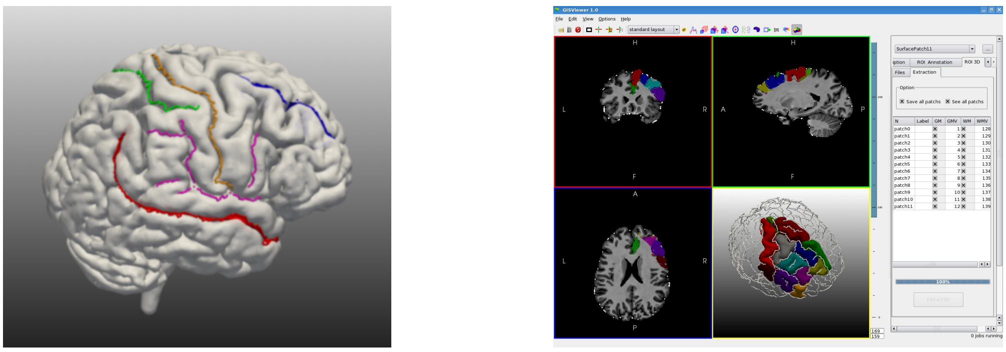
3D free-hand ultrasound: Our major objective within this application domain is to develop efficient and automatic procedures to allow the clinician to use conventional echography to acquire 3D ultrasound and to propose calibrated quantification tools for quantitative analysis and fusion procedures. This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

5. Software

5.1. Vistal

Participant: Alexandre Abadie.

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, diffusion tensor image processing, tractography). 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.



(a) (b)

Figure 1. Some ViSTAL results screenshots: a) ViSTAL Brain surface and sulci modelisation, b) The ROI3D Extraction view

See also the web page http://vistal.gforge.inria.fr.

- Keywords: medical image processing, image analysis, registration, segmentation, denoising
- Software benefit: New methodological image processing, some GPU based algorithms, easy to use C++ library
- APP: IDDN.FR.001.200014.S.P.2000.000.21000

- License: Licence Propriétaire
- Type of human computer interaction: C++ API and less complete Python API
- OS/Middleware: Windows, Mac et Linux.
- Required library or software: CMake (GPL) - ITK (BSD) - VTK (BSD) - Boost (BSD) - Libxml++ (LGPL) - CppUnit (LGPL)
- Programming language: C/C++, Python
- Documentation: Documentation Doxygen, documentation utilisateur.

5.2. Shanoir

Participants: Guillaume Renard, Adrien Férial, Alexandre Abadie [correspondant], Bernard Gibaud, Christian Barillot.

Shanoir (Sharing NeurOImaging Resources) is an open source neuroinformatics platform designed to share, archive, search and visualize neuroimaging data. It provides a user-friendly secure web access and offers an intuitive workflow to facilitate the collecting and retrieving of neuroimaging data from multiple sources and a wizzard to make the completion of metadata easy. Shanoir comes along many features such as anonymization of data, support for multi-centres clinical studies on subjects or group of subjects.

Shanoir APP registration number is : IDDN.FR.001.520021.000.S.P.2008.000.31230

See also the web page http://www.shanoir.org

- Keywords: neuroimaging, ontology, sharing neuroimage
- Software benefit: full featured neuroimaging management system with additionnal web services
- APP: IDDN.FR.001.200014.S.P.2000.000.21000
- License: Licence QPL
- Type of human computer interaction: Online web application, web service (SOAP messages based)
- OS/Middelware: Windows, Mac et Linux.
- Required library or software : Java 1.6, JBoss server, JBoss Seam, JSF, JPA Hibernate, EJB, Richfaces, Faceless, Ajax4JSF, Dcmtk, Dcm4chee.
- Programming language: Java
- Documentation : see the website

5.3. QtM3d

Participants: Alexandre Abadie [correspondant], Romain Carpentier.

QtM3d is a C++ library implementing a widget that can be re-used with the Qt development framework. With this new widget, it is now easy to display 3D images, superpose them and changing their display parameters. A new volume rendering (VTK based) is also available.

QtM3d APP registration number is : IDDN.FR.001.490037.000.S.P.2010.000.31230

See also the web page https://www.irisa.fr/visages/members/aabadie/demos

- Keywords: visualization, medical imaging
- Software benefit: offers a great solution for medical images visualization and can ben easily reused in larger applications
- APP: IDDN.FR.001.490037.000.S.P.2010.000.31230
- License: no defined licence for the moment
- Type of human computer interaction: C++ library
- OS/Middelware: Windows, Mac et Linux.
- Required library or software : Qt, ITK, VTK, Vistal (optional)
- Programming language: C++
- Documentation : none available

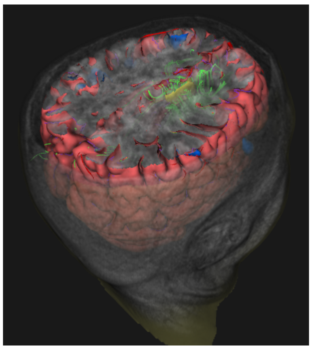


Figure 2. A QtM3d multiple data visualization

5.4. QtDcm

Participants: Alexandre Abadie [correspondant], Romain Carpentier, Nicolas Wiest-Daesslé.

QtDcm is a C++ library implementing a widget that can be re-used with the Qt development framework. With this new widget, it is now easy to view the content of a Dicom CD-Rom, to manage dicom Query/Retrieve from a PACS and to convert downloaded data in the nifti format (easy to use medical image format with our processing methods).

QtDcm APP registration number is : IDDN.FR.001.490036.000.S.P.2010.000.31230

See also the web page https://www.irisa.fr/visages/members/aabadie/demos

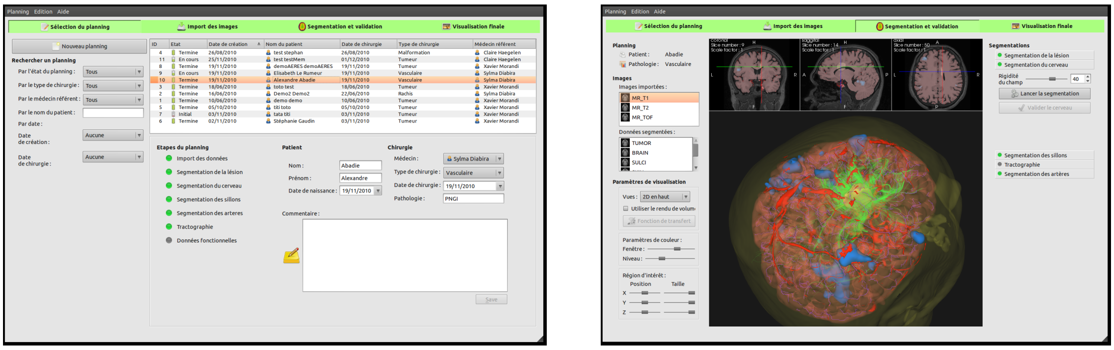
- Keywords : medical imaging, dicom
- Software benefit: offers a great solution to query medical images storage server (Dicom PACS). Can be easily re used in larger Qt applications
- APP: IDDN.FR.001.490036.000.S.P.2010.000.31230
- License: no defined licence for the moment
- Type of human computer interaction: C++ library
- OS/Middelware: Linux (Windows and Mac no yet tested)
- Required library or software : Qt, Dcmtk
- Programming language: C++
- Documentation : none available

5.5. IGNSPlanner

Participants: Alexandre Abadie [correspondant], Romain Carpentier, Pierre Jannin, Xavier Morandi.

IGNSPlanner is a software that assists the neurosurgeon during the pre-operative phase of a surgery. With this application the surgeon can create a new planning (stored in a local database), import the patient data from a Dicom PACS (or a CD-Rom), process the imported data and do some segmentation (manual and automatic) and plan his future intervention. The application has been presented in the Société de NeuroChirurgie de Langue Française (SNCLF) [48].

IGNSPlanner APP registration number is : IDDN.FR.001.490035.000.S.P.2010.000.31230



(a) (b)

Figure 3. Some IGNSPlanner screenshots: a) Planning management panel, b) A full 3D scene

See also the web page https://www.irisa.fr/visages/activities/theme1/projects/igns/index#explanations_in_videos

- Keywords : neurosurgery, dicom, medical imaging, functionnal mri, tractography, segmentation.
- Software benefit: The application is very easy to use despite the complexity of some process, fully integrated in a clinical information system (dicom), the process are optimized for time saving
- APP: IDDN.FR.001.490035.000.S.P.2010.000.31230
- License: no defined licence for the moment
- Type of human computer interaction: Keyboard and mouse, tactile interfaces will be supported soon
- OS/Middelware: Linux (Windows and Mac no yet tested)
- Required library or software : Libraries : QtM3d, QtDcm, Qt, VTK, ITK, Vistal, Dcmtk - Softwares : Vistal-Tools, Mricron, Dcm4che2
- Programming language: C++
- Documentation : none available

5.6. AutoMRI

Participant: Camille Maumet.

autoMRI is an SPM-based set of tools to study structural and functional MRI data. This software is currently made up of three modules : autofMRI, autoVBM and autoROI. autofMRI produces statistical maps of activations and deactivations at the group or the subject level based on functional MRI data. It can deal with block or event-related designs and is highly configurable in order to fit to a wide range of needs. autoVBM performs between-group voxel-based morphometric analysis in order to outline regions of grey (or white) matter volume reduction and increase. To further study a morphometric or a functional analysis, regions of interest analysis can be performed with autoROI. This module also provides the user with laterality indexes.

- Keywords : fMRI, MRI, SPM, automation
- Software benefit: Automatic MRI data analysis based on SPM. Once the parameters are set, the analysis can be run without human interaction.
- APP: Coming soon
- License: Ceccil
- Type of human computer interaction: Matlab function (script, no GUI)
- OS/Middleware: Linux/Windows
- Required library or software : Matlab, SPM, SPM toolboxes : Marsbar, LI-toolbox, NS
- Programming language: Matlab
- Documentation : Available

5.7. CLARCS: C++ Library for Automated Registration and Comparison of Surfaces

Participants: Benoît Combès, Sylvain Prima.

Within the 3D-MORPHINE ARC project (http://3dmorphine.inria.fr), we conceived and implemented a C++ library (named CLARCS) for the automated analysis and comparison of surfaces. One of the primary goal of this library is to allow the assessment and quantification of morphological differences of free-form surfaces from medical or paleoanthropological data. Labelisation of the software to the APP has been initiated.

5.8. SUBANA: SUrface-BAsed Neuronavigation on Atlas for TMS

Participants: Benoît Combès, Sylvain Prima.

In collaboration with Charles Garraud (http://www.syneika.com) and Pierre Hellier (http://serpico.rennes.inria.fr), we developed a software for i) the automated surface reconstruction of the face and skull cap from sparsely acquired points and ii) the automated nonlinear registration of free-form surfaces. The latter step is implemented using the CLARCS library. The primary goal of this software is the surface-based neuronavigation for transcranial magnetic stimulation The APP registration number is: IDDN.FR.001.440010.000.S.P.2010.000.31230

6. New Results

6.1. Image Segmentation, Registration and Analysis

6.1.1. 3D automated quantification of asymmetries on fossil endocasts

Participants: Benoît Combès, Sylvain Prima.

We proposed a new method for the automated quantification of global 3D shape asymmetries of virtual endocranial casts. These asymmetries have been hypothesized to be linked to functional specialization of the brain, and especially language and handedness. To date, it is not clear whether they are present in extant or extinct species other that *Homo sapiens*. We mathematically define the symmetry plane of the endocast as the 3D plane which best superposes the "right" and "left" sides of the endocranial surface. Then, we compute a 3D pointwise deformation field between the two sides of the endocast, allowing to match homologous points, and to assess their relative spatial position. The analysis of this 3D deformation field allows quantifying the shape asymmetries everywhere on the endocast. We illustrated our method on the endocast of STS 5 (Mrs. Ples, *Australopithecus africanus*) whose very high resolution CT scan has been segmented using ITK-SNAP. The results suggest an opposite shape asymmetry in the fronto-temporal and occipital regions [49]. This work was led within the ARC 3D-MORPHINE (http://3dmorphine.inria.fr).

6.1.2. An efficient EM-ICP algorithm for symmetric consistent non-linear registration of point sets

Participants: Benoît Combès, Sylvain Prima.

We proposed a new algorithm for non-linear registration of point sets. We estimate both forward and backward deformations fields best superposing the two point sets of interest and we make sure that they are consistent with each other by designing a symmetric cost function where they are coupled. Regularization terms are included in this cost function to enforce deformation smoothness. Then we proposed a two-step iterative algorithm to optimize this cost function, where the two fields and the fuzzy matches between the two sets are estimated in turn. Building regularizers using the RKHS theory allows to obtain fast and efficient closed-form solutions for the optimal fields. The resulting algorithm is efficient and can deal with large point sets [28]. This work was led within the ARC 3D-MORPHINE (http://3dmorphine.inria.fr).

6.1.3. *Mapping the distance between the brain and the inner surface of the skull and their global asymmetries*

Participants: Marc Fournier, Benoît Combès, Sylvain Prima.

The primary goal of this work was to describe i) the pattern of pointwise distances between the human brain (pial surface) and the inner surface of the skull (endocast) and ii) the pattern of pointwise bilateral asymmetries of these two structures. We used a database of MR images to segment meshes representing the outer surface of the brain and the endocast. We proposed automated computational techniques to assess the endocast-to-brain distances and endocast-and-brain asymmetries, based on a simplified yet accurate representation of the brain surface, that we call the brain hull. We computed two meshes representing the mean endocast and the mean brain hull to assess the two patterns in a population of normal controls. The results showed i) a pattern of endocast-to-brain distances which are symmetrically distributed with respect to the mid-sagittal plane and ii) a pattern of global endocast and brain hull asymmetries which are consistent with the well-known Yakovlevian torque. Our study is a first step to validate the endocranial surface as a surrogate for the brain in fossil studies, where a key question is to elucidate the evolutionary origins of the brain torque. It also offers some insights into the normal configuration of the brain/skull interface, which could be useful in medical imaging studies (e.g. understanding atrophy in neurodegenerative diseases or modeling the brain shift in neurosurgery). [35]. This work was led within the ARC 3D-MORPHINE (http://3dmorphine.inria.fr).

6.1.4. *Reconstructing the skull of hominids*

Participants: Benoît Combès, Marc Fournier, Sylvain Prima.

Fossil remains are often subject to taphonomic (*i.e.* post mortem) deformations. Even worse, they are often broken, which makes the analysis of these bones and the classification of their owner within the tree of life a difficult task. In this work, conducted during the master's internship of Denis Fortun, we developed a method for the automated reconstruction of hominid skulls from fragments. The method is based on a template skull to which the cranial fragments of the unknown fossil are registered using an affine deformation model. A preliminary coarse alignment is made using descriptors invariant to the searched transformation. Using this initial coarse transformation as a starting point, a fine registration is made using an EM-ICP algorithm [28]. The algorithm was applied on a famous fossil fragmentary skull from South Africa, still embedded in breccia (TM 1511). The breccia was CT scanned in 2007, and the fragments were later segmented manually. These were then superposed on the virtual skull of STS 5 (Mrs. Ples, *Australopithecus africanus*) using our algorithm. This work was led within the ARC 3D-MORPHINE (http://3dmorphine.inria.fr).

6.1.5. *Incorporating Priors On Expert Performance Parameters for Segmentation Validation and Label Fusion: a Maximum A Posteriori STAPLE*

Participant: Olivier Commowick.

The algorithm for Simultaneous Truth And Performance Level Estimation (STAPLE), originally presented for segmentation validation, has since been used for many applications, such as atlas construction and decision fusion. However, the manual delineation of structures of interest is a very time consuming and burdensome task. Further, as the time required and burden of manual delineation increase, the accuracy of the delineation is decreased. Therefore, it may be desirable to ask the experts to delineate only a reduced number of structures or the segmentation of all structures by all experts may simply not be achieved. Fusion from data with some structures not segmented by each expert should be carried out in a manner that accounts for the missing information.

We presented [29] a new algorithm that allows fusion with partial delineation and which can avoid convergence to undesirable local optima in the presence of strongly inconsistent segmentations. The algorithm extends STAPLE by incorporating prior probabilities for the expert performance parameters. This is achieved through a Maximum A Posteriori formulation, where the prior probabilities for the performance parameters are modeled by a beta distribution. We demonstrated that this new algorithm enables dramatically improved fusion from data with partial delineation by each expert in comparison to fusion with STAPLE.

6.1.6. Construction of Patient Specific Atlases from Locally Most Similar Anatomical Pieces

Participant: Olivier Commowick.

This work resulted from a strong collaboration between our team and Asclepios research team and was primarily conducted at Asclepios research team (Liliane Ramus and Grégoire Malandain).

Radiotherapy planning requires accurate delineations of the critical structures. To avoid manual contouring, atlas-based segmentation can be used to get automatic delineations. However, the results strongly depend on the chosen atlas, especially for the head and neck region where the anatomical variability is high. To address this problem, atlases adapted to the patient's anatomy may allow for a better registration, and already showed an improvement in segmentation accuracy. However, building such atlases requires the definition of a criterion to select among a database the images that are the most similar to the patient. Moreover, the inter-expert variability of manual contouring may be high, and therefore bias the segmentation if selecting only one image for each region.

To tackle these issues, we presented [46] an original method to design a piecewise most similar atlas. Given a query image, we propose an efficient criterion to select for each anatomical region the K most similar images among a database by considering local volume variations possibly induced by the tumor. Then, we presented a new approach to combine the K images selected for each region into a piecewise most similar template. Results showed that this method reduces the over-segmentation seen with an average atlas while being robust to inter-expert manual segmentation variability.

6.2. Image processing on Diffusion Weighted Magnetic Resonance Imaging

6.2.1. Diffusion Direction Imaging: a new model for DW-MRI

Participants: Aymeric Stamm, Christian Barillot.

Diffusion Magnetic Resonance Imaging is the reference *in vivo* modality to study brain white matter connectivity, both on normal and pathological brains. Its use is currently based on the analysis of scalar maps (mean diffusivity and fractional anisotropy [FA]), tensor maps (diffusion tensor imaging [DTI] and tractography) or higher-order models (q-balls, ODF). These approaches suffer from various drawbacks. Widespread DTI modeling, in particular, is insufficiently robust to noise and has difficulties coping with multiple fiber directions. Latter limitation is alleviated by higher-order approaches that are, unfortunately, still not applicable to clinical routine. We proposed a new diffusion MRI model, called Diffusion Direction Imaging (DDI) to overcome these limitations. Modeling diffusion directions with Fisher directional statistics, we derived a close form expression of measurements that allows the direct estimation of diffusion parameters. On synthetic data, this new model proved more accurate and more robust to noise than DTI for estimating fiber directions and FA, in clinical acquisition conditions. This work is conducted with Patrick Perez from Technicolor. Patent applications (Europe and USA) were submitted for this invention [60], [59].

6.2.2. A Comprehensive Riemannian Framework for the Analysis of White Matter Fiber Tracts

Participants: Meena Mani, Christian Barillot.

A quantitative analysis of white matter fibers is based on different physical features (shape, scale, orientation and position) of the fibers, depending on the specific application. Due to the different properties of these features, one usually designs different metrics and spaces to treat them individually. We proposed a comprehensive Riemannian framework that allows for a joint analysis of these features in a consistent manner. For each feature combination, we provided a formula for the distance, i.e. quantification of differences between fibers and a formula for geodesics, i.e. optimal deformations of fibers into each other. We have shown how this framework behaves in the context of clustering fiber tracts from the corpus callosum and studied the results from different combinations of features [41].

6.2.3. Comparative Analysis of Tractography Algorithms for the Study of Corticospinal Tract

Participants: Romuald Seizeur, Nicolas Wiest-Daesslé, Sylvain Prima, Camille Maumet, Jean-Christophe Ferré, Xavier Morandi.

In this work, anatomical, diffusion-weighted and functional 3T MRI were acquired on 15 right-handed healthy subjects to analyze the portions of the corticospinal tract dedicated to hand motor and sensory functions. The three MR images were then registered and regions of interest were delineated i) in the mid-brain using 3D T1-weighted MRI, and ii) in the cortex using fMRI using hand motor and sensory tasks. Four tractography algorithms were then compared using these two ROIs from diffusion-weighted MRI after the diffusion tensors had been computed. The first results suggest that more sophisticated models are needed to identify the tracts of interest, mainly due to the numerous fiber crossings in the ventrolateral tract fibers [58].

6.3. Management of Information and Semantic Processing

6.3.1. Introduction

A better sharing of resources (by "resources" we denote data, models and image processing tools) is one of the keys for the success of future research in the medical imaging domain, and for an optimal use of its achievements in the context of translational medicine. For example, the discovery and the validation of new imaging biomarkers for the diagnosis of neurological diseases and the monitoring of their evolution and treatment highly depends on collaborative work associating expert centers with similar or complementary skills. Suitable information infrastructures must be provided to support such collaborative work, enabling an easy sharing of images (and associated data) and a flexible sharing, re-use and interoperable use of processing tools available at the different sites. Traditionally, sharing can be envisaged according to two different models, a "centralized" one and a "federated" one. Our assumption is that the latter is much more suited to the biomedical research field, especially due to the legitimate wish of involved organizations of defining and controlling how their data should be organized and shared. One of the most critical aspects of the design of such federated systems is the definition of common semantics of shared information. Ontologies and semantic web technologies are today the best available technology to provide powerful solutions to this problem. Ontologies provide both a reference vocabulary and explicit definitions (using formal semantics) of entities, which can be used to reason about entities, classify them, and retrieve them from data repositories. One of our basic assumptions is that such technologies should be used in the imaging domain to make the nature and content of the images explicit and to relate them to other kinds of data : biological data, clinical data, neuropsychological data, genomic data, etc.

6.3.2. NeuroLOG Project: Sharing of Data and Sharing of Processing Tools in Neuroimaging

Participants: Christian Barillot, Bernard Gibaud, Bacem Wali, Franck Michel.

Our participation in the NeuroLOG project (ANR ANR-06-TLOG-024) concerned primarily three workpackages : WP1 - data distribution, WP2 - ontologies and semantic processing, and WP5 - applicative testbests. Regarding WP1, our major achievement in 2010 was the refinement and the deployment of the middleware (called NeuroLOG server) to share the data as well as the processing tools [42]. Visages was more specifically in charge of data and metadata management, which includes (1) all aspects of mapping the heterogeneous data from the different NeuroLOG sites onto the common federated schema (using DATA FEDERATOR, SAP) and (2) the actual sharing of image files throughout the federated system. An important achievement was also to be able to re-import processed images into the NeuroLOG databases, so that they can be visible and shared in the federated system. Concerning WP2, a final version of the ontology (OntoNeuroLOG) was delivered, with important extensions concerning MR protocols and MR sequences, and neuropsychological and clinical scores [26]. This ontology is provided in three different forms: a set of semi-formal textual documents (in ONTOSPEC format), a set of OWL ontologies, and a relational implementation (common federated schema). The set of semantic mappings was also extended to enable semantic processing (using METAMORPHOSES and CORESE) of the shared metadata. Finally, a prototype implementing semantic services was developed to facilitate the sharing and re-use of processing tools, based on the semantic annotation of shared processing tools (kind of processing provided by the service, constraints on input variables, pre and post conditions). An applicative testbed was deployed federating resources from Rennes (VISAGES), Grenoble (GIN), Paris Salptrire (ICM) and Nice-Sophia (Asclepios).

NeuroLOG is a collaborative project, supported by ANR (Agence National de la Recherche), through grant ANR-06-TLOG-024. The partners with whom we have the tightest relations are: I3S (Sophia) and Business Objects (SAP), for WP1; MIS (Amiens), GIN (Grenoble) and Piti-Salptrire (Paris) for WP2; GIN (Grenoble) and Piti-Salptrire (Paris) for WP5.

6.3.3. Semantic Annotation of Anatomic Images in Neuroimaging

Participants: Bernard Gibaud, Tristan Moreau, Xavier Morandi.

This project aims at exploring the feasibility of relying on symbolic knowledge provided by ontologies to assist the annotation of anatomical images. The basic assumption underlying this work is that ontologies not only can provide a reference vocabulary to annotate images, but they can also provide useful prior knowledge that may help the annotation process itself. In his PhD work in 2009 Ammar Mechouche developed an hybrid approach based on this idea. We have started this year a new project on the semantic annotation of cortical structures, that aims at achieving a joint annotation of cortical regions and fiber bundles from anatomical MRI images and DTI images. In a preliminary phase of the project (Master student work of Elsa Magro in 2010) we investigated in a population of 20 healthy subjects the connections within the central area, based on a ROI parcellation deduced from the sulcal folds [55]. This study brought interesting results about U-fibers connecting the precentral and postcentral gyri. In the following of the project we are going to propose new methods to jointly annotate regions of the brain cortex and fiber bundles connecting them, based on a prior knowledge embedded in an ontology.

6.3.4. Semantic Annotation of Models and Simulated Medical Images

Participants: Bernard Gibaud, Germain Forestier.

This project is carried out in the context of the Virtual Imaging Platform (VIP) project, an ANR project aiming at setting up a platform for facilitating the use of image simulation software in medical imaging, and coordinated by Creatis (Lyon). The platform will integrate simulation software to generate image of different modalities (i.e. MR, CT, PET, US). In this project, VISAGES is in charge of coordinating the development of an application ontology to support the annotation of the data shared in this platform (simulated images, anatomical models and physiological models used in simulations), as well as the annotation of simulation software components, in order to facilitate their interoperation within the platform. The work completed in 2010 was first the definition of the "universe of discourse", done in close cooperation with all the specialists of the different simulation environments involved. Regarding the ontology's design itself, one of the key problem that we have started to address is the design of a common conception of the models used in image simulation, i.e. embracing a wide-spectrum of possible models, with a clear categorization of model components focusing on anatomy, physiology, pathology, etc. and as independent as possible of imaging modality, so that such models may be use or re-used as input of multiple simulators.VIP is a collaborative project, supported by ANR (Agence National de la Recherche), through grant ANR-AA-PPPP-000. The partners with whom we have the tightest relations are: Creatis (Lyon), I3S (Sophia), CEA-LETI (Grenoble).

6.4. Image Guided Intervention

6.4.1. An Anthropomorphic Polyvinyl Alcohol Brain phantom based on Colin27 for Use in Multimodal Imaging

Participants: Romain Carpentier, Xavier Morandi, Jean-Yves Gauvrit.

We have proposed a method for the creation of an anatomically and mechanically realistic brain phantom from polyvinyl alcohol cryogel (PVA-C) for validation of image processing methods for segmentation, reconstruction, registration, and denoising [27]. PVA-C is material widely used in medical imaging phantoms for its mechanical similarities to soft tissues. The phantom was cast in a mold designed using the left hemisphere of the Colin27 brain dataset Holmes et al. (1998) and contains deep sulci, a complete insular region, and an anatomically accurate left ventricle. Marker spheres and inflatable catheters were also implanted to enable good registration and simulate tissue deformation, respectively. The phantom was designed for triple modality imaging, giving good contrast images in computed tomography, ultrasound, and magnetic resonance imaging. Multimodal data acquired from this phantom are made freely available to the image processing community (http://pvabrain.inria.fr) and will aid in the validation and further development of medical image processing techniques.

6.4.2. Study of Surgical Process Models in Interventional Neuroradiology

Participants: Pierre Jannin, Xavier Morandi, Brivael Trelhu, Jean-Yves Gauvrit.

Two studies were performed for studying surgical processes in interventional neuroradiology for the first time. The first study aimed at auantifying effects of "low dose" protocol on the operator during NeuroInterventional procedures. Fifteen embolizations of cerebral aneurysms have been analyzed with "low dose" or "normal dose" protocols. The procedure was split up into six phases made of a sequence of activities. For each we recorded the surgical process model. The metric used to compare both protocols was the time of each phase and of each activity. We analyzed the phases in which X-rays were used and we separated the phases of navigation from the ones of treatment. We found that the treatment phase tended to be longer when low dose protocol has been used. The second study consisted in assessing operator skills during NeuroInterventional procedures using surgical process modeling methodology. Sixteen cerebral angiographies, performed by a senior or a resident, have been analyzed. The procedure was split up into three phases (arterial access, navigation and closure of the access). The total and mean time for each recorded activity were analyzed. The study showed that the total time of use of fluoroscopy and the total time of moving the X-ray system were longer in the junior group. Both studies are submitted to journals and international conferences.

6.4.3. Study of Surgical Process Models in Spinal Surgery

Participants: Pierre Jannin, Xavier Morandi, Brivael Trelhu.

Evaluating surgical practice in the operating room is difficult, and its assessment is largely subjective. We recorded standardized spine surgery processes to ascertain whether any significant differences in surgical practice could be observed between senior and junior neurosurgeons. Twenty-four procedures of lumbar discectomies, performed by a senior surgeon or a resident, were consecutively recorded by a senior neurosurgeon. The data recorded were general parameters (operating time for the whole procedure and for each step), and general and specific parameters of the surgeon's activities (number of manual gestures, number and duration of actions performed, use of the instruments, and use of interventions on anatomic structures). We were able to outline a relationship between surgical practice, as determined by a method of objective measurement using observation software, and surgical experience: gesture economy evolves with seniority. This study was published in Neurosurgery [24]. It was the first study of this kind published in neurosurgical journal.

6.4.4. Similarity Measures for Surgical Process Models

Participants: Brivael Trelhu, Pierre Jannin, Xavier Morandi.

We studied similarity measures for comparing surgical process models allowing to take into account sequential aspect of the surgical processes. From recordings of surgical process models manually acquired in the operating room, we were able to extract rules explaining combination of surgical activities. A similarity measure was defined based on these rules. We applied the metrics and the approach in spinal surgery for comparing two populations of surgical processes. This helped identifying differences based on sequentiality.

6.4.5. Surgical Phases Detection from Microscope Videos by Machine Learning

Participants: Florent Lalys, Pierre Jannin, Xavier Morandi.

In order to better understand and describe surgical procedures by surgical process models, the field of workflow segmentation has recently emerged. It aims to recognize high-level surgical tasks in the Operating Room, with the help of sensor or human-based systems. In collaboration with Carl Zeiss Medical Systems (Oberkochen, Germany), our approach focused on the automatic recognition of phases by microscope images analysis. We developed a hybrid method that combines Support Vector Machine and discrete Hidden Markov Model. We first performed features extraction and selection on surgical microscope frames to create an images database.

SVMs were trained to extract surgical scene information, and then outputs were used as observations for training a discrete HMM. Our framework was tested on pituitary surgery, where six phases were identified by neurosurgeons. Cross-validation studies permitted to find a percentage of detected phases of 93 that allows the use of the system in clinical applications such as post-operative videos indexation. This work was published at IPCAI conference and MICCAI satellite workshop [38], [39].

6.4.6. MR Template in Model Guided Deep Brain Stimulation (DBS)

Participants: Pierre Jannin, Xavier Morandi, Florent Lalys, Claire Haegelen.

Deep Brain Stimulation (DBS) is a surgical procedure used from about 20 years mainly for functional neurosurgery of Parkinson disease. It consists of inserting and stimulating an electrode within deep brain structures such as the sub thalamic nucleus (STN). For patients suffering of movement disorders, medical therapy could be not effective. In that case high frequency electrical stimulation via the electrode will considerably reduce the functional pathology. However, post stimulation side effects have been recently outlined, especially psychological ones. There is a need for better understanding these side effects through clinical scores and improving targeting with additional data, information, and knowledge. We built a 3T MR mono subject template in order to make easier comparison between different subjects which serves as the common coordinate system. This template allow visualization of spatially complex structures as well as increased contrast. We demonstrated that this mono subject template increased the signal to noise ratio, contrast and accutance compared to MR images. We also showed that it greatly improved the accuracy of template based registration. The registration workflow between pre and post operative images and the anatomical MR template was validated on clinical data. Results were published in Neuroimage [19].

6.4.7. Automated Surgical Planning in Model Guided DBS

Participants: Caroline Villard, Pierre Jannin, Xavier Morandi, Claire Haegelen.

Surgical Planning consists in identifying optimal access to the target based on anatomical references and constrained by healthy functional areas. We studied an approach to find the optimal position of an electrode, for assisting surgeons in planning Deep Brain Stimulation. We formalized the rules governing this surgical procedure into geometric constraints. Then we used a formal geometric solver, and a template built from 15 MRIs, to propose a space of possible solutions and the optimal one. We retrospectively tested our approach for 8 implantations from 4 patients, and compare them with the trajectory of the electrode that was actually implanted. The results showed a slight difference with the reference trajectories, with a better evaluation for our proposition. This work was published at MICCAI satellite workshop (MMBIA) [32].

6.5. Medical Image Computing in Multiple Sclerosis

6.5.1. Longitudinal Follow-up of USPIO Enhanced Lesions of CIS Patients

Participants: Nicolas Wiest-Daesslé, Christian Barillot, Gilles Edan, Jean-Christophe Ferré, Olivier Luong, Olivier Commowick, Elise Bannier, Sylvain Prima.

It has been suggested that ultra-small super paramagnetic particles of iron oxide (USPIO) was a MRI marker of macrophage activity in Multiple Sclerosis (MS) and explored another physiopathological phenomenon than gadolinium-based (Gd) contrast material, which correlates with Blood Brain Barrier leakage. Previous works have shown different patterns of USPIO enhancements of MS lesions and different normal appearing white matter (NAWM) signal changes for primary-progressive and relapsing-remitting MS. A multicenter study was initiated to explore SHU555C-USPIO as a marker for clinical predictive value of patients with clinically isolated syndrome (CIS), in association and comparison with Gd MRI and quantitative MRI (q-MRI). The aim of this work this year was to get a first evaluation of the preliminary radiological results of this study.

6.5.2. Modeling Multimodal Lesion Appearances and Evolution for a Better Understanding of MS

Participants: Olivier Luong, Olivier Commowick, Christian Barillot.

This work concerns the extraction of MR imaging biomarkers for multiple sclerosis (MS) using statistical analysis tools. We use information from several imaging modalities to define relevant features of MS lesions, such as their texture, shape, location, etc. The objective is then to identify a set of imaging criteria that exhibits a strong correlation with the clinical findings.

There are two components related to this field of research: the first is to automatically classify MS lesions according to known clinical types. To do so, lesions are first automatically detected using tools that have been previously developed. We then extract various lesion descriptors, such as their texture, shape, contrast enhancement patterns, etc. The large dimension as well as the heterogeneity of these descriptors make classification difficult. Therefore, we aim at utilizing dimensionality reduction tools, such as principal component analysis or manifold learning, to determine the underlying structure of the data. The second component is to propose a global brain model with MS, including atrophy and changes in the normal appearing white matter. As an application of this work we are designing a model of inflamed human brain for the MRI simulator SIMRI. This work was conducted within the VIP project. VIP is a collaborative project, supported by ANR (Agence National de la Recherche), through grant ANR-AA-PPPP-000.

6.6. Arterial Spin Labelling

6.6.1. Construction and Evaluation of a Quantitative Arterial Spin Labeling Brain Perfusion Template at 3T

Participants: Jan Petr, Camille Maumet, Pierre Maurel, Jean-Yves Gauvrit, Jean-Christophe Ferré, Christian Barillot, Isabelle Corouge, Elise Bannier.

Arterial spin labeling (ASL) allows non-invasive imaging and quantification of brain perfusion by magnetically labeling blood in the brain-feeding arteries. ASL has been used to study cerebrovascular diseases, brain tumors and neurodegenerative disorders as well as for functional imaging. The use of a perfusion template could be of great interest to study inter-subject regional variation of perfusion and to perform automatic detection of individual perfusion abnormalities [51], [50]. However, low spatial resolution and partial volume effects (PVE) issues inherent to ASL acquisitions remain to be solved [40], [45], [44]. The purpose of our work was to enhance the template quality by using DARTEL non-rigid registration and by correcting for PVE. PICORE-Q2TIPS ASL datasets were acquired on 25 healthy volunteers at 3T. Four methods of creating the template were evaluated using leave-one-out cross correlation. Subsequently, these methods were applied to hyper-perfusion detection on functional ASL data of 8 healthy volunteers and compared with the standard generalized linear model (GLM) activation detection.

6.6.2. Arterial Spin Labeling for Motor Activation Mapping : Reproducibility in Comparison with BOLD fMRI

Participants: Jan Petr, Jean-Yves Gauvrit, Jean-Christophe Ferré, Christian Barillot, Isabelle Corouge, Elise Bannier.

Arterial spin labeling can be applied to task related functional MRI (fASL) with the advantage of being more direct biomarker of neuronal activity than the standard BOLD fMRI. We have shown that fASL allows motor activation mapping with high intra-subject reproducibility regarding activation location and quantification and that these results were strongly co-localized with BOLD fMRI. This work was conducted during the master thesis of Hélène Raoult [23].

6.7. Anatomical and Functional Imaging in Dysphasia

6.7.1. f-MRI Language Mapping in Children: A Panel of Language Tasks using Visual and Auditory Stimulation without Reading or Metalinguistic Requirements

Participants: Camille Maumet, Clément De Guibert, Pierre Jannin, Jean-Christophe Ferré, Christian Barillot.

In the context of presurgical mapping or investigation of neurological and developmental disorders in children, language fMRI raises the issue of the design of a tasks panel achievable by young disordered children. Most language tasks shown to be efficient with healthy children require metalinguistic or reading abilities, therefore adding attentional, cognitive and academic constraints that may be problematic in this context.

This study [25] experimented a panel of four language tasks that did not require high attentional skills, reading, or metalinguistic abilities. Two reference tasks involving auditory stimulation (words generation from category, "category"; auditory responsive naming, "definition") were compared with two new tasks involving visual stimulation. These later were designed to tap spontaneous phonological production, in which the names of pictures to be named involve a phonological difference (e.g. in French poule/boule/moule; "phon-diff") or change of segmentation (e.g. in French car/car-te/car-t-on; "phon-seg"). Eighteen healthy children participated (mean age: 12.7+/-3years).

Data processing involved normalizing the data via a matched pairs pediatric template, and inter-task and region of interest analyses with laterality assessment. The reference tasks predominantly activated the left frontal and temporal core language regions, respectively. The new tasks activated these two regions simultaneously, more strongly for the phon-seg task. The union and intersection of all tasks provided more sensitive or specific maps. The study demonstrated that both reference and new tasks highlight core language regions in children, and that the latter are useful for the mapping of spontaneous phonological processing. The use of several different tasks may improve the sensitivity and specificity of fMRI.

7. Other Grants and Activities

7.1. Regional initiatives

7.1.1. qASLIM project

Participants: Jan Petr, Jean-Christophe Ferré, Jean-Yves Gauvrit, Christian Barillot.

duration : 12 months, from 01/01/2010

This one years project is devoted to the development of a solution for processing Arterial Spin labelling data from MRI. The objective of this grant was to develop new quantitative procedures for exploitation of ASL sequences in brain pathologies. This grant was awarded with the collaboration of Siemens medical Systems France. This grant was used for founding the position of Jan Petr.

7.1.2. CPER 2007-2013, NeurInfo Platform

Participants: Elise Bannier, Isabelle Corouge, Adrien Férial, Nicolas Wiest-Daesslé, Jean-Yves Gauvrit, Christian Barillot.

duration : 7 years, from 01/01/2007 Visages is the founding actor of a new experimental research platform which has just been installed August 2009 at the University Hospital of Rennes. The University of Rennes 1, Inria, Inserm for the academic side, and the University Hospital of Rennes and the Cancer Institute “Eugene Marquis” for the clinical side, are partners of this neuroinformatics platform called "’NeurINFO" (http://www.neurinfo.org). This platform concerns the in-vivo human imaging for clinical research and neuroinformatics especially in the context of CNS pathologies. A new research 3T MRI system has been acquired in summer 2009 in order to develop the clinical research in the domain of morphological, functional, structural and cellular in-vivo imaging. Visages and its partners in the Neurinfo project are committed to use this new research platform for developing new regional, national and international collaborations around fundamental and applied clinical research projects dealing with in-vivo medical imaging. In the next three years, additional equipments will arrive among them are two PET labs for experimentation of new ligands for molecular imaging, an in vivo confocal microscope for interventional imaging in neurosurgery and large computing facilites for storage and processing of large collection of data. This new platform has been supported under the “Contrat de Projets Etat-Région“ (C. Barillot is the PI) and have received a total amount of 5.1 Meuros for the period of 2007–2013. A specific technical staff to conduct this platform is under recruitment in order to make this new environment open to a large scientific and clinical community.

7.1.3. CREBEN - "Centre REgional Breton d'Expertise en Neuroradiologie"

Participants: Jean-Yves Gauvrit, Jean-Christophe Ferré.

The CREBEN project "Centre REgional Breton d'Expertise en Neuroradiologie" is dedicated to disseminate e-medicine and e-radiology in the field of stroke emergency followup (within 6 hours after infarct) at the scale of Brittany. In september 2010, this project was awarded the prize "Cercle Santé Société" by the Altran foundation http://www.altran.com/prix/laureat2010/.

7.2. National initiatives

7.2.1. ODL Vignes

Participants: Alexandre Abadie, Romain Carpentier, Pierre Jannin, Xavier Morandi.

duration : 24 months, from 01/10/2008

This two years project is devoted to the ongoing development of a software platform for intraoperative imaging. This grant funds the position of Romain Carpentier.

7.2.2. ANR "Technologies Logicielles", NeuroLOG Project

Participants: Bacem Wali, Franck Michel, Daniel Garcia-Lorenzo, Bernard Gibaud, Christian Barillot.

duration : 40 months, from 01/04/2007

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), GIN INSERM Research Center U836 from Grenoble, IFR 49 "Functional Neuroimagery" (Paris La Pitié Salpétrière), the MIS Laboratory at Amiens and Business Objects (now part of the SAP Group) and Visioscopie for the industrial part.

Our current participation within the NeuroLOG project concerned the first work package, especially on the elaboration of the proposed system architecture, and the implementation of the Data Manager and Metadata Manager; the second work package, on the development of the "OntoNeuroLog" ontology, and the Application work package, on the specification of the different test bed applications.

7.2.3. ANR USComp

Participants: Jan Petr, Christian Barillot.

We participate in the US comp project, headed by Lagadic project. UScomp aims at developing methods to compensate in real-time the soft tissue motion. Organs are imaged with an ultrasound probe held by a robotic arm. Within the project, we have contributed to develop a real-time ultrasound processing thanks to a GPU implementation of an adapted NL-means approach, the implementation of a graph cut segmentation method is being developed through the post doc position of Jan Petr.

7.2.4. ANR "Neurological and Psychiatric diseases" NUCLEIPARK

Participants: Christian Barillot, Sylvain Prima, Olivier Commowick.

This three-year project, led by CEA/NEUROSPIN (Cyril Poupon) in Saclay, started in fall 2009. It involves a collaboration with Visages and Odyssee INRIA project-teams and INSERM La Pitié-Salpétrière, Paris. Its goal is to study high field MR imaging (7T and 3T) of the brainstem, the deep nuclei and their connections in the parkinsonian symdromes, with applications to prognosis, pathophysiology and improvement of therapeutic strategies methodological solutions. Our contribution in this project is on processing of diffusion imaging and on study of cortical differences between the different populations.

7.2.5. ANR Cosinus VIP

Participants: Bernard Gibaud, Olivier Luong, Christian Barillot, Olivier Commowick.

VIP is collaborative project supported by ANR "Conception and Simulation"; it was accepted in 2009 (around 1 million euros). VIP aims at building a computing environment enabling multi-modality, multi-organ and dynamic (4D) medical image simulation, using GRID infrastructure. The goal is to integrate proven simulation software of the four main imaging modalities (MRI, US, PET and X-Ray/CT), and to cope interoperability challenges among simulators. The partners are CREATIS in Lyon (maain contractor, Principal Investigator: Tristan Glatard), UNS-I3S in Nice, CEA-LETI in Grenoble and MAAT-G Maat G, a spanish company. The role of VISAGES in this project concerns primarily Task 1.1 and Task 3.3, focusing respectively on ontologies development and application to multiple sclerosis images simulation. This grant serves as support for the positions of Olivier Luong (PhD student) and Germain Forestier (post-doc).

7.2.6. 3D-MORPHINE: Computational methods for the automated analysis of virtual hominid endocasts (2009-2010)

Participants: Benoît Combès, Marc Fournier, Sylvain Prima.

duration : 24 months, from 01/01/2009

Over the last 15 years, CT has been extensively used to build "virtual" endocranial casts in a precise and non-invasive way. Studying endocasts is of the utmost importance, as they constitute the only way to indirectly assess global (size, shape) and sometimes local characteristics (meningeal/sulcal/gyral patterns) of the external cerebral anatomy of extinct species, and especially hominids. To date, there exist only few tools to study virtual endocasts in an automated or semi-automated way, and in an objective and reproducible manner. The objective of this Collaborative Research Initiative (ARC) coordinated by Sylvain Prima is to devise, implement, validate and apply new computational methods for the automated and objective morphometric analysis of extant and extinct hominid cranial endocasts. This work is jointly led by the Visages Team at INRIA Rennes, the Asclepios Team at INRIA Sophia Antipolis and the ICAR team at CNRS Montpellier, as well as the Museum national d'Histoire naturelle in Paris, the Museum of Toulouse, the Transvaal Museum (Pretoria, South Africa) and the Royal Museum for Central Africa (Tervuren, Belgium). Web: http://3dmorphine.inria.fr.

7.3. International initiatives

7.3.1. INRIA Associated Project NeurOMIMe

Participants: Pierre Jannin, Jean-Christophe Ferré, Xavier Morandi, Olivier Commowick, Sylvain Prima, Olivier Luong, Daniel Garcia-Lorenzo, Alexandre Abadie, Christian Barillot, Nicolas Wiest-Daesslé, Elise Bannier, Claire Haegelen.

duration : 36 months, from 01/01/2006, renewed in 15/12/2008

NeurOMIMe[1] 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.

[1] http://www.irisa.fr/visages/collaborations/neuromime

The official yearly report is available online (http://www.irisa.fr/visages/collaborations/neuromime).

8. Dissemination

8.1. Animation of 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 is Associate Editor of ISRN Signal Processing.
- C. Barillot is Associate Editor of Current Medical Imaging Reviews.
- 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 is Deputy Editor of the International Journal of Computer Assisted Radiology and Surgery.

8.1.2. Workshop/Symposium Organization

- S. Prima was the co-organiser and chairman (with Gérard Subsol from CNRS, Montpellier and José Braga from Univ. Paul Sabatier, Toulouse) of a symposium at the 79th annual meeting of the AAPA (American Association of Physical Anthropologists) in Albuquerque, April 2010 (http://physanth.org/annual-meeting/2010). The aim of this symposium (http://3dmorphine.inria.fr/doku.php?id=symposium) was to foster the use of computational methods for the automated and objective analysis of virtual hominid endocasts. The talks provided both methodological and applicative views on this problem, with the input from both computer scientists and physical anthropologists.

8.1.3. Peer Reviews of journals

- C. Barillot is reviewing for IEEE TMI, Medical Image Analysis, NeuroImage, IEEE T. on Ultrasonics, Ferroelectrics, and Frequency Control, Magnetic Resonance in Medicine, Medical Physics, J. of Neuroscience Methods and Intl J. of Biomedical Imaging
- P. Jannin is reviewing for IEEE TMI, Medical Image Analysis, NeuroImage, Academic Radiology, International Journal of Computer Assisted Radiology and Surgery and Academic Radiology
- B. Gibaud is reviewing for IEEE TMI
- S. Prima is reviewing for IEEE TMI, IEEE TPI, IEEE TBE, IEEE TITB, Medical Image Analysis, International Journal of Computer Assisted Radiology and Surgery, Machine Vision and Applications, Pattern Recognition Letters, American Journal of Physical Anthropology, Journal of Anatomy
- O. Commowick is reviewing for IEEE TMI, Medical Image Analysis and NeuroImage

8.1.4. Technical Program Committees (TPC) of conferences

- C. Barillot was area chair for SPIE Medical Imaging 2010, Miccai 2010 and TPC member for MICCAI workshop on Medical Computer Vision 2010, MIAR 2010, WBIR 2010, ICPR 2010, IEEE ISBI 2010,Eurographics Workshop on Visual Computing for Biology and Medicine (VCBM'2010)
- B. Gibaud was TPC member for CARS 2010
- P. Jannin was area chair and TPC member for SPIE Medical Imaging 2010 and CARS 2010 and TPC member for MICCAI 2010
- O. Commowick was TPC member MICCAI 2010, IEEE ISBI 2010
- S. Prima was TPC member of MICCAI 2010, IEEE ISBI 2010

8.1.5. Scientific societies

- P. Jannin is General Secretary of ISCAS
- B. Gibaud is member of the AIM
- B. Gibaud is member of the Board of Directors of EuroPACS
- C. Barillot and P. Jannin are members of IEEE EMBS
- C. Barillot is senior member of IEEE
- C. Barillot, O. Commowick, S. Prima, P. Jannin 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) and Image Guided Surgery in the following tracks:

- Master 2 SIBM, University of Angers-Brest-Rennes : 26h (*C. Barillot, O. Commowick, S. Prima, B. Gibaud, P. Jannin, X. Morandi, J. Petr, JY Gauvrit*), C. Barillot, B. Gibaud and P. Jannin are responsible for three different semesters. C. Barillot is the coordinator for the Master.
- Master 1 SIBM, University of Rennes : 24h (*S. Prima, B. Gibaud, P. Jannin*), P. Jannin is responsible for one semester.
- Master "Rayonnements ionisants et application ", Univ. de Nantes: 4h (*C. Barillot*)
- Master "Méthodes de traitement de l'information biomédicale et hospitalière", University of Rennes I : 9h (*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*)
- P. Maurel assistant professor at ESIR, (Engineering School of University of Rennes 1): 2nd year, option "imagerie numérique" (Méthodes mathématiques pour l'analyse d'images). Total of 48 hours.

8.3. Participation to seminars, scientific evaluations, awards

- C. Barillot served as external reviewer for the recruitment commission of University of Strastbourg
- C. Barillot served in the panel committee of ANR Blanc International program (SIMI3 panel)
- C. Barillot served as expert for ANR-IST France-Japan program
- B. Gibaud served as expert for ANR ('Blanc' Program)
- C. Barillot served as external reviewer of an FP6 IST integrated Project
- C. Barillot is elected-member of the Scientific Board of CNRS-INS2I.
- C. Barillot served as a Scientific Delegate to AERES (French National Scientific Evaluation Institute) for the Research Units Section in the Health Science domain.
- S. Prima served as an expert for the ANR ("DEFIS" Program and "Blanc international" Program).
- P. Maurel served as an expert for the ANR ("Blanc international" Program).

8.4. Invitation of scientific seminars, visits

- Dr. B. Batrancourt, INSERM-La Pitié Salpétrière, Paris, 12/02/2010
- M. Sean Chen, Montreal Neurological Institute, Montreal, Canada, 26/03/2010
- Dr. Nicolas Padoy, John Hopkins Univ. Baltimore, MD, 03/12/2010

8.5. Dissemination toward non specialists

- S. Prima had an article in INRIA's newsletter INédit: "Our ancestor's brain" in May 2010.
- S. Prima had an article on the blog Neuroanthropologia: http://neuroantropologia.wordpress.com/2010/06/29/endorfine-digitali in June 2010.

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