IN PARTNERSHIP WITH:
CNRS

INSERM

Université Rennes 1

Activity Report 2015

Project-Team VISAGES

Vision, Action and information manaGement System in health

IN COLLABORATION WITH: Institut de recherche en informatique et systèmes aléatoires (IRISA)

RESEARCH CENTER
Rennes - Bretagne-Atlantique

THEME
Computational Neuroscience and Medecine

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Creation of the Project-Team: 2005 July 04

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2. Overall Objectives

2.1. Overall objectives

Medical Imaging, Neuroinformatics, Neuroimaging, Medical Image Computing, Modeling of normal and pathological behavior of the human brain, e-health & HealthGrids

The Unit/Project VISAGES U746 is a research team jointly affiliated to INSERM (National Institute of Health and Scientific Research), Inria (National Institute of Research in Computer Sciences and Automation) and IRISA / UMR CNRS 6074, University of Rennes I. We are located in Rennes, France on both medical and sciences campus. The team has been created in 2005. Our ambition is to set up a multidisciplinary team merging researchers in image processing and medical doctors. The goal of VISAGES is to constitute a multidisciplinary team. Even though, research in medical imaging could find motivation and recognition based on methodological breakthroughs alone, the ultimate goal, when dealing with medical imaging research, is to make the clinical practice benefit from the basic and applied research, while keeping the excellence of the methodological research. This objective entails the creation of teams encompassing clinical and scientific researchers to design and conduct research projects together. Our aim through the past period was to build a research team able to perform a research going from a novel and basic stage to original clinical experimentation with clear medical impact.

Our research activities are focused on the research and development of new algorithms in medical imaging in the context of the pathologies of the central nervous system. In this context, we are addressing the general problems of the better understanding of normal and pathological brain organs and systems behavior, at different scales, and the promotion and the support of Virtual Organizations of biomedical actors by means of healthgrid's technologies. The medical application objectives are focused on pathologies of the central nervous system, with a particular effort on extraction of new imaging biomarkers for brain pathologies (e.g. Multiple Sclerosis, neuropaediatrics, strokes, psychiatry, ...). More generally, our application objectives concern the following diseases: Multiple sclerosis, epilepsy, dementia, neuro-degenerative brain diseases, brain vascular diseases.

3. Research Program

3.1. Research Program

The scientific foundations of our team concern the development of new processing algorithms in the field of medical image computing : image fusion (registration and visualization), image segmentation and analysis, management of image related information. Since this is a very large domain, which can endorse numerous types of application; for seek of efficiency, the purpose of our methodological work primarily focuses on clinical aspects and for the most part on head and neck related diseases. In addition, we emphasize our research efforts on the neuroimaging domain. Concerning the scientific foundations, we have pushed our research efforts:

- 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 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 labelling based on shape, multimodal and statistical information.
- Following the Neurobase national project where we had a leading role, we wanted to enhance the development of distributed and heterogeneous medical image processing systems.

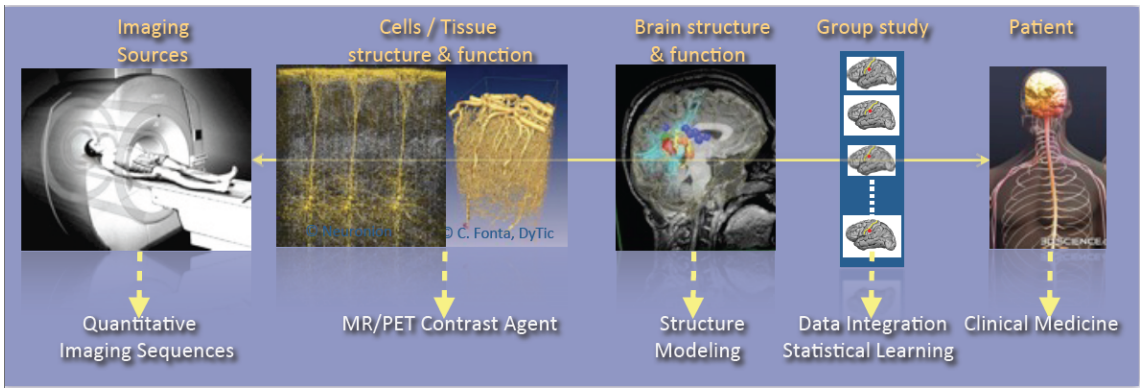

Figure 1. The major overall scientific foundation of the team concerns the integration of data from the Imaging source to the patient at different scales : from the cellular or molecular level describing the structure and function, to the functional and structural level of brain structures and regions, to the population level for the modelling of group patterns and the learning of group or individual imaging markers

As shown in figure 1, research activities of the VISAGES U746 team are tightly coupling observations and models through integration of clinical and multi-scale data, phenotypes (cellular, molecular or structural patterns). We work on personalized models of central nervous system organs and pathologies, and intend to confront these models to clinical investigation studies for quantitative diagnosis, prevention of diseases, therapy planning and validation. These approaches are developed in a translational framework where the data integration process to build the models inherits from specific clinical studies, and where the models are assessed on prospective clinical trials for diagnosis and therapy planning. All of this research activity is conducted in tight links with the Neurinfo imaging platform environments and the engineering staff of the platform. In this context, some of our major challenges in this domain concern:

- The elaboration of new descriptors to study the brain structure and function (e.g. variation of brain perfusion with and without contrast agent, evolution in shape and size of an anatomical structure in relation with normal, pathological or functional patterns, computation of asymmetries from shapes and volumes).
- The integration of additional spatio-temporal imaging sequences covering a larger range of observation, from the molecular level to the organ through the cell (Arterial Spin Labeling, diffusion MRI, MR relaxometry, MR cell labeling imaging, PET molecular imaging, ...). This includes the elaboration of new image descriptors coming from spatio-temporal quantitative or contrast-enhanced MRI.
- The creation of computational models through data fusion of molecular, cellular, structural and functional image descriptors from group studies of normal and/or pathological subjects.
- The evaluation of these models on acute pathologies especially for the study of degenerative, psychiatric or developmental brain diseases (e.g. Multiple Sclerosis, Epilepsy, Parkinson, Dementia, Strokes, Depression, Schizophrenia, ...) in a translational framework.

In terms of methodological developments, we are particularly working on statistical methods for multidimensional image analysis, and feature selection and discovery, which includes:

- The development of specific shape and appearance models, construction of atlases better adapted to a patient or a group of patients in order to better characterize the pathology;
- The development of advanced segmentation and modeling methods dealing with longitudinal and

multidimensional data (vector or tensor fields), especially with the integration of new prior models to control the integration of multiscale data and aggregation of models;

- The development of new models and probabilistic methods to create water diffusion maps from MRI;
- The integration of machine learning procedures for classification and labeling of multidimensional features (from scalar to tensor fields and/or geometric features): pattern and rule inference and knowledge extraction are key techniques to help in the elaboration of knowledge in the complex domains we address;
- The development of new dimensionality reduction techniques for problems with massive data, which includes dictionary learning for sparse model discovery. Efficient techniques have still to be developed to properly extract from a raw mass of images derived data that are easier to analyze.

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.

4.2. 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. MRI has a low specificity for defining in more detail the pathological changes which could discriminate between the different lesion types. However, it has a high sensitivity to detect focal and also widespread, diffuse pathology of the normal appearing white and gray matter. Our major objective within this application domain is then 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.

4.3. 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 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, 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.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

- In 2015, the Neurinfo platform obtained the IBISA label. The IBISA label is a national label for technological platforms awarded by the GIS IBISA on an annual basis.
- In 2015, Edan G was elected Fellow of the European Academy of Neurologie.

6. New Software and Platforms

6.1. Anima

KEYWORDS: Filtering - Medical imaging - Diffusion imaging - Registration - Relaxometry
SCIENTIFIC DESCRIPTION Anima is a set of libraries and tools developed by the team as a common repository of research algorithms. As of now, it contains tools for image registration, statistical analysis (group comparison, patient to group comparison), diffusion imaging (model estimation, tractography, etc.), quantitative MRI processing (quantitative relaxation times estimation, MR simulation), image denoising and filtering, and segmentation tools. All of these tools are based on stable libraries (ITK, VTK), making it simple to maintain.

- Participants: Laurence Catanese, Olivier Commowick, René-Paul Debroize, Florent Leray, Renaud Hédouin and Guillaume Pasquier
- Contact: Olivier Commowick
- URL: https://github.com/Inria-Visages/Anima-Public/wiki
- APP number: IDDN.FR.001.460020.000.S.P.2015.000.31230

6.2. MedInria

KEYWORDS: Segmentation - Health - DWI - Visualization - Medical imaging
SCIENTIFIC DESCRIPTION It aims at creating an easily extensible platform for the distribution of research algorithms developed at Inria for medical image processing. This project has been funded by the D2T (ADT MedInria-NT) in 2010 and renewed in 2012. The Visages team leads this Inria national project and participates in the development of the common core architecture and features of the software as well as in the development of specific plugins for the team's algorithm.

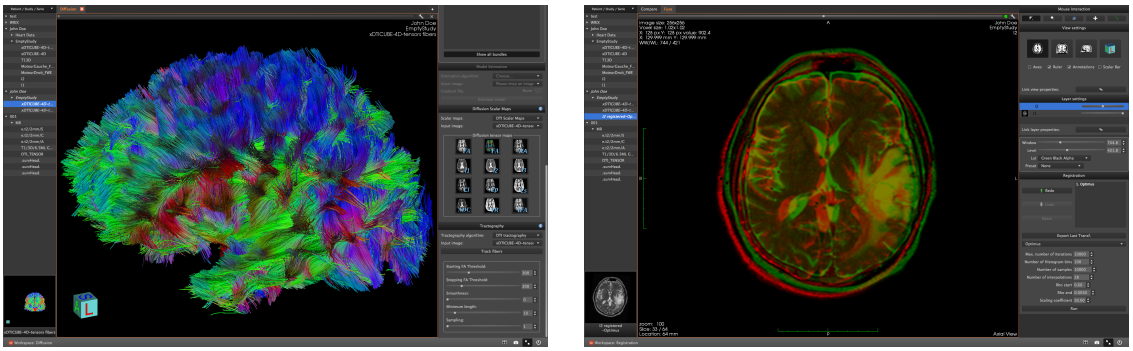

Figure 2. The medInria software platform: Tractography overlapped with 3D image (left), and Fused view of registered images (right)

FUNCTIONAL DESCRIPTION MedInria is a free software platform dedicated to medical data visualization and processing as illustrated in figure 2.

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- Partners: HARVARD Medical School - IHU - LIRYC - IHU - Strasbourg - NIH
- Inria structures involved : ASCLEPIOS, ATHENA, PARIETAL, VISAGES
- Contact: Olivier Commowick
- URL: http://med.inria.fr
- APP number: IDDN.FR.001.130017.000.S.A.2012.000.31230

6.3. autoMRI

KEYWORDS: Magnetic Resonance Imaging (MRI) - functional MRI (fMRI) - Arterial Spin Labeling (ASL) - functional ASL (fASL) - Statistical Parametric Mapping (SPM) - Automation
SCIENTIFIC DESCRIPTION This software is highly configurable in order to fit to a wide range of needs. Pre-processing includes segmentation of anatomical data, as well as co-registration, spatial normalization and atlas building of all data types. The analysis pipelines perform either within-group analysis or between-group or one subject-versus-group comparison and produce statistical maps of regions with significant differences. These pipelines can be applied to structural data to exhibit patterns of atrophy or lesions, to ASL (both pulsed or pseudo-continuous sequences) or PET data to detect perfusion or metabolic abnormalities (see figure 3, left), to relaxometry data to detect deviations from a template (see figure 3, right), to functional data - either BOLD or ASL - to outline brain activations related to block or event-related paradigms. In addition to the standard General Linear Model approach, the ASL pipelines implement an a contrario approach and, for patient-specific perfusion study, an heteroscedastic variance model. Besides, the vascular pipeline processes 4D MRA data and enables accurate assessment of hemodynamic patterns.
FUNCTIONAL DESCRIPTION Based on MATLAB and the SPM8 toolbox, autoMRI provides complete pipelines to pre-process and analyze various types of images (anatomical, functional, perfusion, metabolic, relaxometry, vascular). A new version of the ASL post-processing part was developed in Python and Nipype, therefore not requiring the disponibility of Matlab licences.

- Participants: Isabelle Corouge, Cédric Meurée, Pierre Maurel and Elise Bannier
- Contact: Isabelle Corouge
- URL: http://www.irisa.fr/visages/

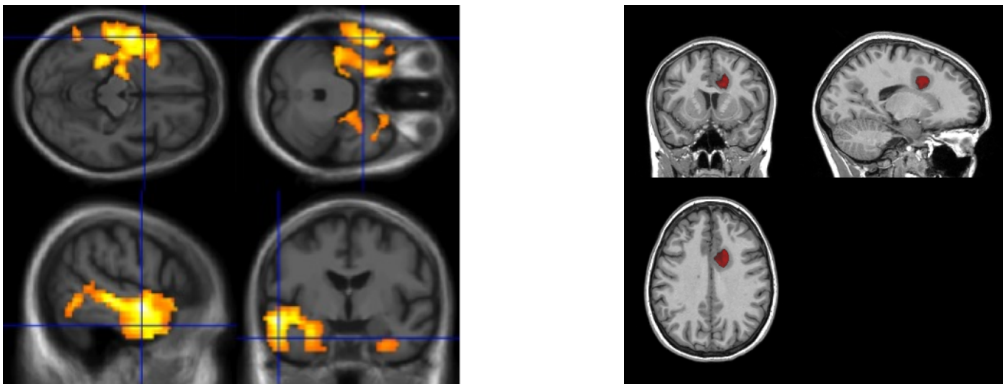

Figure 3. Illustrations of results obtained with autoMRI: Conjunction map showing areas of hypoperfusion and hypometabolism in semantic dementia (left) and detection of relaxometry defect in an MS patient (right).

6.4. Shanoir

KEYWORDS: Shanoir - Webservices - Biology - Health - DICOM - Neuroimaging - Medical imaging - PACS - Nifti

FUNCTIONAL DESCRIPTION SHAring NeurOImaging Resources (Shanoir, Previously InriaNeuroTk) is an open source software platform designed to structure, manage, archive, visualize and share neuroimaging data with an emphasis on multi-centric collaborative research projects. It provides common features of neuroimaging data management systems along with research-oriented data organization and enhanced accessibility (see figure 4).

Shanoir is a secured J2EE application running on a JBoss server, reachable via graphical interfaces in a browser or by third party programs via web services. It behaves as a repository of neuroimaging files coupled with a relational database hoding meta-data. The data model, based on OntoNeurolog, an ontology devoted to the neuroimaging field, is structured around the concept of "research study". A research study includes patients who themselves have examinations that either produce image acquisitions or clinical scores. Each image acquisition is composed of datasets represented by their acquisition parameters and image files. The system only keeps anonymous data.

Image file imports are possible from various sources (DICOM CDs, PACs, image files in NIfTI / Analyze format) using either online wizards, with completions of related meta-data, or commande line tools. Once de-identified during the import phase, DICOM header's customizable feature. Shanoir can also record any executed processing allowing to retrieve workflows applied to a particular dataset along with the intermediate data.

The clinical scores resulting from instrument based assessments (e.g. neuropsychological tests) can also be entered and easily retrieved and exported in different formats (Excel, CSV, Xml). Scores and image acquisitions are bound together which makes relationship analysis possible. The instrument database is scalable and new measures can be added in order to meet specific project needs, by use of intuitive graphical interfaces.

Using cross-data navigation and advanced search criteria, the users can quickly point to a subset of data to be downloaded. Client side applications have as well been developed to illustrate how to locally access and exploit data through the available web services. With regards to security, the system requires authentication and user rights are tunable for each hosted studies. A study responsible can thereby define the users allowed to see, download or import data into his study or simply make it public.

Shanoir serves neuroimaging researchers in organizing efficiently their studies while cooperating with other laboratories. By managing patient privacy, Shanoir allows the exploitation of clinical data in a research context. It is finally a handy solution to publish and share data with a broader community.

Shanoir integrates the enterprise search platform, Apache Solr, to provide the users a vast array of advanced features such as near real-time indexing and queries, full-text search, faceted navigation, autosuggestion and autocomplete.

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- Partners: Université de Rennes 1 - CNRS - INSERM
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- URL: http://shanoir.gforge.inria.fr
- APP number: IDDN.FR.001.520021.003.S.A.2008.000.31230 (2014/08/20)

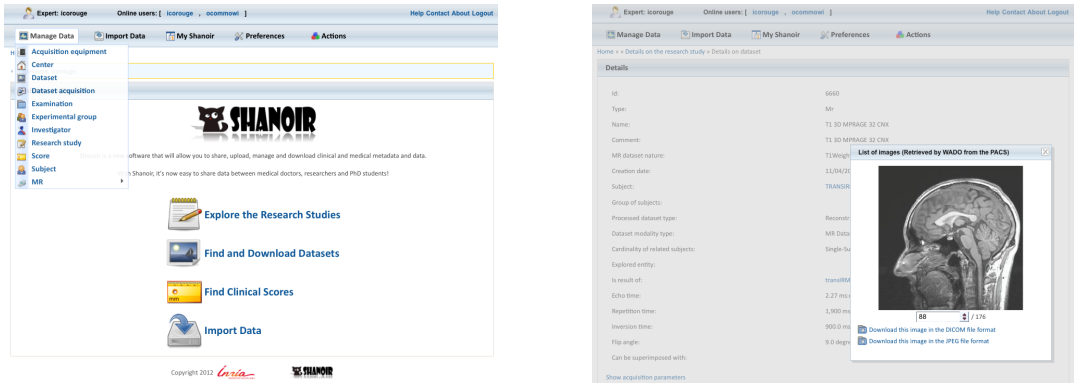

Figure 4. The SHANOIR software is a web application to share, archive, search and visualize neuroimaging data.

6.5. QtShanoir

KEYWORDS: Shanoir - Qt - Webservices - Soap - C++ - Health - DICOM - Plug-in - Medical imaging - Nifti
SCIENTIFIC DESCRIPTION QtShanoir is based on Qt/C++ librairie. It interacts with the Shanoir server using SOAP web services provided. This application queries the server and displays hierarchical data extracted in tree view. Data could also be easily downloaded or uploaded on the server. In order to extend the Shanoir environment, QtShanoir is developed to contain two shared libraries: - « GUI » that represents all user interfaces. - « DAO » that takes in charge the data model. This library assures the connection to the server and provides all QtShanoir services : research, download and upload of Processed Dataset (NIfTI). QtShanoir dynamic libraries are already reused and integrated in other projects: in the software medInria and in an under development command line program.
FUNCTIONAL DESCRIPTION QtShanoir is a graphical client application of the medical imaging database Shanoir. This application provides various functionalities to satisfy researchers' needs. It allows users to: - explore neuroimaging data derived from multicenter research trials. Through an intuitive user interface, users could easily visualize voluminous amount of structured data: studies, patients and datasets extracted from Shanoir - download and to upload data from the server. This application is available on Windows, UNIX, MacOs X. It is integrated as a plugin in medInria, a multi-plateform for medical image processing and visualization.

- Participants: Olivier Commowick, Justine Guillaumont, Florent Leray, and Wefa Hakem
- Contact: Olivier Commowick
- URL: http://qtshanoir.gforge.inria.fr
- APP number: IDDN.FR.001.130017.000.S.A.2012.000.31230 (2012/02/08)

6.6. ShanoirUploader

KEYWORDS: Shanoir - Webservices - Java - Biology - Health - DICOM - Neuroimaging - Medical imaging - PACS

SCIENTIFIC DESCRIPTION ShanoirUploader is a desktop application on base of JavaWebStart (JWS). The application can be downloaded and installed using an internet browser. It interacts with a PACS to query and retrieve the data stored on it as illustrated in figure 5. After this ShanoirUploader sends the data to a Shanoir server instance in order to import these data. This application bypasses the situation, that in most of the clinical network infrastructures a server to server connection is complicated to set up between the PACS and a Shanoir server instance.

FUNCTIONAL DESCRIPTION ShanoirUploader is a Java desktop application that transfers data securely between a PACS and a Shanoir server instance (e.g., within a hospital). It uses either a DICOM query/retrieve connection or a local CD/DVD access to search and access images from a local PACS or the local CD/DVD. After having retrieved the data, the DICOM files are locally anonymized and then uploaded to the Shanoir server. A possible integration of a hash creation application for patient identifiers is provided as well. The primary goals of that application are to enable mass data transfers between different remote server instances and therefore reduce the waiting time of the users, when importing data into Shanoir. Most of the time during import is spent with data transfers.

- Participants: Justine Guillaumont, Michael Kain, Christian Barillot, Yao Yao, Inès Fakhfakh
- Contact: Christian Barillot
- URL: http://shanoir.gforge.inria.fr
- APP number: IDDN.FR.001.380026.000.S.P.2015.000.31230 (2015/09/11)

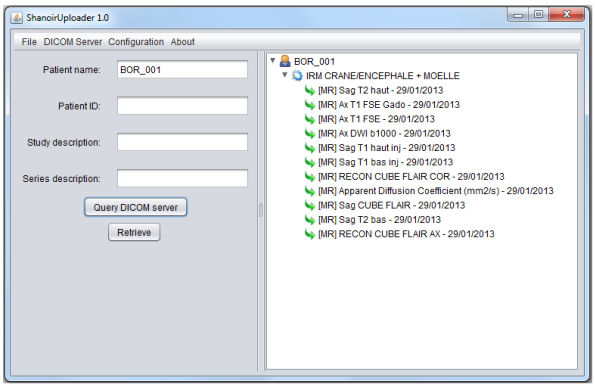

Figure 5. The ShanoirUploader software is a desktop application designed to interact with a PACS to query and retrieve the data stored on any PACS.

6.7. iShanoir

KEYWORDS: Shanoir - Biology - Health - Neuroimaging - Mobile application - Medical imaging - Biomedical imaging

FUNCTIONAL DESCRIPTION iShanoir is an iOS application, designed for iPhone and iPad. On base of this application a Shanoir server can be accessed. For this the Shanoir SOAP web-services are called. As shown in figure 6, iShanoir can be used to access and navigate in the data tree structure, stored on a Shanoir server. iShanoir displays as well additional meta data corresponding to the data entities in the tree structure. On base of these informations image files (NIfTI and DICOM) can be selected and downloaded on a local iPhone/iPad in a temporary cache. From this cache the files can be opened and displayed with a viewer that the user has already installed on his device.

- Participants: Michael Kain, Christian Barillot
- Contact: Christian Barillot
- URL: http://shanoir.gforge.inria.fr

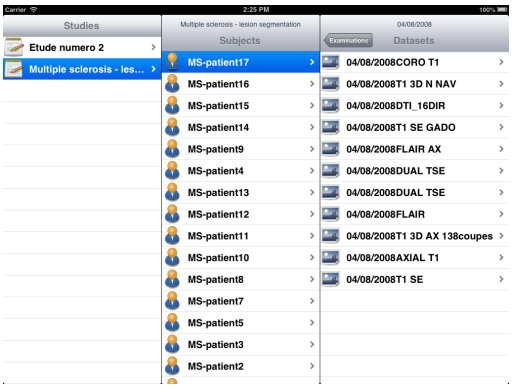

Figure 6. The iShanoir software is a desktop application designed to...

6.8. Integration of EEG and fMRI

Participants: Marsel Mano, Lorraine Perronnet.

Related to the project Hemisfer there have been development of new functions, scripts and demos for the acquisition and processing of the EEG and fMRI data in Real-time. These include:

- Functions for fMRI header info reader, volume reader, motion correction, slice time correction nifty output conversion, real time fMRI initialization, real time fMRI processing, z-score calculation, volume smoother, alignment, etc., functions for real time EEG data acquisition, filtering, power calculation and display.
- Scripts for various protocols used in offline fMRI experiments, real time processing loop for EEG and fMRI.
- Demo for real time acquisition of the EEG and fMRI data, demo for real time processing efficiency of the fMRI data, demo for the real time processing of EEG data, real time z-Score for fMRI data.
- Several small aux functions for I/O interfaces (e.g. com, serial)

In the current stage the prototype also relies on various other free toolboxes (e.g. SPM, pnet)

- Keywords: medical imaging, EEG, fMRI
- Software benefit: integration of EEG and fMRI processing
- Type of human computer interaction: C++ API, shell scripts
- OS/Middleware: Windows, Mac and Linux.
- Required library or software : SPM, pnet.
- Programming language: C++, shell scripts

6.9. Platforms

6.9.1. The Neurinfo Platform

VISAGES is the founding actor of an experimental research platform which was installed in 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 has been supported under the "Contrat de Projets Etat-Région" (C. Barillot is the PI) and has received a total amount of 4.01 M€ for the period 2007–2014. European (FEDER), National (through Ministry of research, Inria, Inserm and ANR) and local councils (Brittany Region, Ille et Vilaine, and Rennes Metropole) have joined their effort to support this operation for a total amount of 4010 k€ (600 k€ for the infrastructures, 2850 k€ for the equipments and 560 k€ for the functioning). This application was set up through the Regional PIMATGI initiative coordinated by INSERM in Brittany (C. Roux). The overall PIMATGI initiative served for the financing of three distinct, but complementary, platforms: Neurinfo, TheraFONC as a technical platform dedicated to therapy guided by functional imaging especially in the oncology domain (Inserm U 650 - LaTIM, Dir. Ch. Roux, Brest), and TherA-Image as a platform dedicated to image guided mini-invasive surgery and therapy especially in the domain of cardio-vascular diseases (U642 -LTSI, Dir. L. Senhadji, Rennes).

Concerning the Neurinfo Platform, the activity domain is a continuum between methodological and technological research built around specific clinical research projects. The ambition is to do innovation in science, technology and medical technology transfer for the implementation on the clinical field. On the medical field, the translational research domain mainly concerns medical imaging and more specifically the clinical neurosciences. Among them are multiple sclerosis, epilepsy, neurodegenerative, neurodevelopmental and psychiatric diseases, surgical procedures of brain lesions, neuro-oncology and radiotherapy planning. Beyond these CNS applications, the platform is also open to alternative applications. Neurinfo ambitions to support the emergence of research projects based on their level of innovation, their pluri-disciplinarity and their ability to foster collaborations between different actors (public and private research entities, different medical specialties, different scientific profiles).

In this context, a new research 3T MRI system (Siemens Verio system) was acquired in summer 2009 in order to develop the clinical research in the domain of morphological, functional, structural and cellular in-vivo imaging. In 2014 a new equipment for simultaneous recording of EEG and MRI images has been acquired from Brain Product. In 2015, a mock scanner for experimental set-up has been acquired as well as a new High Performance Computing environment made of one large computing cluster and a data center that is shared and operated by the Inria center at IRISA (UMR CNRS 6074). The computation cluster (240 cores) and the data center (up to 50 TB) are dedicated to host and process imaging data produced by the Neurinfo platform, but also by other research partners that share their protocols on the Neurinfo neuroinformatics system (currently more than 30 sites).

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.

7. New Results

7.1. Image Computing: Detection, Segmentation, Registration and Analysis

7.1.1. Symmetric Block-Matching Registration for the Distortion Correction of Echo-Planar Images

Participants: Renaud Hédouin, Olivier Commowick, Elise Bannier, Christian Barillot.

We introduce a new approach to correct geometric and intensity distortion of Echo Planar Images (EPI) from images acquired with opposite phase encoding directions. A new symmetric block-matching registration algorithm has been developed for this purpose relying on new adapted transformations between blocks and a symmetric optimization scheme to ensure an opposite symmetric transformation. Our results show the ability of our algorithm to robustly recover EPI distortion while obtaining sharper results than the popular TOPUP algorithm [24], [34].

7.1.2. Quantitative analysis of T2/T2 relaxation time alteration*

Participants: Benoit Combès, Anne Kerbrat, Olivier Commowick, Christian Barillot.

T2 and T2* relaxometric data becomes a standard tool for the quantitative assessment of brain tissues and of their changes along time or after the infusion of a contrast agent. Being able to detect significant changes of T2/T2* relaxation time is an important issue. Generally, such a task is performed by comparing the variability level in the regions of interest to the variability in the normal appearance white matter. However, in the case of T2 and T2* relaxometry, this solution is highly problematic. Indeed the level of noise in the normal appearance white matter is significanlty smaller than the level of noise in more intense region (e.g. MS lesions). Our aim is to provide a Bayesian analysis of T2/T2* relaxometry estimation and alteration. More specifically, we build posterior distributions for the relaxation time and the relaxation offset by elucidating the dedicated Jeffreys priors. Then the resulting posterior distributions can be evaluated using a Monte Carlo Markov Chain algorithm. Such an analysis has three main advantages over the classical estimation procedure. First it allows in a simple way to compute many estimators of the posterior including the mode, the mean, the variance and confidence intervals. Then, it allows to include prior information. Finally, becauce one can extract confidence interval from the posterior, testing properly whether the true relaxometry time is included within a certain range of value given a confidence level is simple.

7.1.3. MRI quantitative imaging: Myelin Water Fraction (MWF) quantification in Multiple Sclerosis

Participants: Olivier Commowick, Elise Bannier, Christian Barillot.

Multi-echo T2 relaxometry is potentially a relevant imaging method for MWF quantification in the study of multiple sclerosis (MS). However, to ensure accurate estimation, a large number of echoes are still required that can drive to very long acquisitions. In practice, 32 echo times ranging from 10 ms to 320 ms and an echo spacing (ESP) of 10 ms are used1. Analysis of the decay curve of the consecutive echoes allows the estimation of the T2 spectrum. The proposed approach makes use of recent spatial regularization methods for MWF estimation from clinically compatible acquisitions (typically 11 echoes acquired within 6 minutes). The algorithms were evaluated on both synthetic and clinical data. This work was done during the internship of Lucas Soustelle [32], [29].

7.1.4. Classification of Multiple Sclerosis Lesions using Adaptive Dictionary Learning

Participants: Hrishikesh Deshpande, Pierre Maurel, Christian Barillot.

This work presents a sparse representation and an adaptive dictionary learning based method for automated classification of Multiple Sclerosis (MS) lesions in Magnetic Resonance (MR) images. Manual delineation of MS lesions is a time-consuming task, requiring neuroradiology experts to analyze huge volume of MR data. This, in addition to the high intra- and inter-observer variability necessitates the requirement of automated MS lesion classification methods. Among many image representation models and classification methods that can be used for such purpose, we investigate the use of sparse modeling. In the recent years, sparse representation has evolved as a tool in modeling data using a few basis elements of an over-complete dictionary and has found applications in many image processing tasks including classification. We propose a supervised classification approach by learning dictionaries specific to the lesions and individual healthy brain tissues, which include White Matter (WM), Gray Matter (GM) and Cerebrospinal Fluid (CSF). The size of the dictionaries learned for each class plays a major role in data representation but it is an even more crucial element in the case of competitive classification. Our approach adapts the size of the dictionary for each class, depending on the complexity of the underlying data. The algorithm is validated using 52 multi-sequence MR images acquired from 13 MS patients. The results demonstrate the effectiveness of our approach in MS lesion classification.

This work has been published in the journal of Computerized Medical Imaging and Graphics, Elsevier, 2015 [15]. Part of this work is published as a conference paper in ISBI 2015 [22].

7.1.5. Robust Detection of Multiple Sclerosis Lesions

Participants: Yogesh Karpate, Olivier Commowick, Christian Barillot.

Multiple sclerosis (MS) is a disease with heterogeneous evolution among the patients. Quantitative analysis of longitudinal Magnetic Resonance Images (MRI) provides a spatial analysis of the brain tissues which may lead to the discovery of biomarkers of disease evolution. Better understanding of the disease will lead to a better discovery of pathogenic mechanisms, allowing for patient-adapted therapeutic strategies. To characterize MS lesions, we have proposed two new approaches. The first one consists in a novel paradigm to detect white matter lesions based on a statistical framework [26]. It aims at studying the benefits of using multi-channel MRI to detect statistically significant differences between each individual MS patient and a database of control subjects. This framework consists in two components. First, intensity standardization is conducted to minimize the inter-subject intensity difference arising from variability of the acquisition process and different scanners. The intensity normalization maps parameters obtained using a robust Gaussian Mixture Model (GMM) estimation not affected by the presence of MS lesions. The second part studies the comparison of multi-channel MRI of MS patients with respect to an atlas built from the control subjects, thereby allowing us to look for differences in normal appearing white matter, in and around the lesions of each patient. Experimental results demonstrate that our technique accurately detects significant differences in lesions consequently improving the results of MS lesion detection.

Then we have presented an automatic algorithm for the detection of multiple sclerosis lesions (MSL) from multi-sequence magnetic resonance imaging (MRI) [25]. We built a probabilistic classifier that can recognize MSL as a novel class, trained only on Normal Appearing Brain Tissues (NABT). Patch based intensity information of MRI images is used to train a classifier at the voxel level. The classifier is in turn used to compute a probability characterizing the likelihood of each voxel to be a lesion. This probability is then used to identify a lesion voxel based on simple Otsu thresholding. The proposed framework was evaluated on 16 patients and our analysis reveals that our approach is well suited for MSL detection and outperforms other benchmark approaches.

7.2. Image processing on Diffusion Weighted Magnetic Resonance Imaging

7.2.1. Interpolation and Averaging of Multi-Compartment Model Images

Participants: Renaud Hédouin, Olivier Commowick, Christian Barillot.

Multi-compartment diffusion models (MCM) are increasingly used to characterize the brain white matter microstructure from diffusion MRI. We address the problem of interpolation and averaging of MCM images as a simplification problem based on spectral clustering. As a core part of the framework, we propose novel solutions for the averaging of MCM compartments. Evaluation is performed both on synthetic and clinical data, demonstrating better performance for the "covariance analytic" averaging method. We then present an MCM template of normal controls constructed using the proposed interpolation [23].

7.2.2. The DTI Challenge: Toward Standardized Evaluation of Diffusion Tensor Imaging Tractography for Neurosurgery

Participants: Olivier Commowick, Sylvain Prima.

Diffusion tensor imaging (DTI) tractography reconstruction of white matter pathways can help guide brain tumor resection. However, DTI tracts are complex mathematical objects and the validity of tractography-derived information in clinical settings has yet to be fully established. To address this issue, the DTI Challenge was initiated, an international working group of clinicians and scientists whose goal was to provide standardized evaluation of tractography methods for neurosurgery. The purpose of this empirical study was to evaluate different tractography techniques in the first DTI Challenge workshop. Eight international teams from leading institutions reconstructed the pyramidal tract in four neurosurgical cases presenting with a glioma near

the motor cortex. Tractography methods included deterministic, probabilistic, filtered, and global approaches. Standardized evaluation of the tracts consisted in the qualitative review of the pyramidal pathways by a panel of neurosurgeons and DTI experts and the quantitative evaluation of the degree of agreement among methods. The evaluation of tractography reconstructions showed a great inter-algorithm variability. Although most methods found projections of the pyramidal tract from the medial portion of the motor strip, only a few algorithms could trace the lateral projections from the hand, face, and tongue area. In addition, the structure of disagreement among methods was similar across hemispheres despite the anatomical distortions caused by pathological tissues. The DTI Challenge provides a benchmark for the standardized evaluation of tractography methods on neurosurgical data. This study [18] suggests that there are still limitations to the clinical use of tractography for neurosurgical decision making.

7.2.3. Diffusion MRI abnormalities detection with orientation distribution functions: A multiple sclerosis longitudinal study

Participants: Olivier Commowick, Jean-Christophe Ferré, Gilles Edan, Christian Barillot.

We proposed a new algorithm for the voxelwise analysis of orientation distribution functions between one image and a group of reference images [13]. It relies on a generic framework for the comparison of diffusion probabilities on the sphere, sampled from the underlying models. We demonstrated that this method, combined to dimensionality reduction through a principal component analysis, allows for more robust detection of lesions on simulated data when compared to classical tensor-based analysis. We then demonstrated the efficiency of this pipeline on the longitudinal comparison of multiple sclerosis patients at an early stage of the disease: right after their first clinically isolated syndrome (CIS) and three months later. We demonstrated the predictive value of ODF-based scores for the early detection of lesions that will appear or heal.

7.3. EEG and MR Imaging

7.3.1. On the feasibility and specificity of simultaneous EEG and ASL MRI at 3T

Participants: Elise Bannier, Marsel Mano, Isabelle Corouge, Lorraine Perronnet, Christian Barillot.

Brain functional imaging can be performed using several approaches, including EEG, BOLD and ASL MRI. To date, only a few studies have addressed the issue of connecting EEG signal to ASL perfusion. ASL imaging relies on control and label RF pulses, generating alternate gradient patterns as well as higher SAR. The aim of this study was to assess ASL-EEG at 3T in terms of safety as well as EEG and MR signal quality [19].

7.3.2. Symmetrical EEG-FMRI Imaging by Sparse Regularization

Participants: Pierre Maurel, Nicolas Raillard, Saman Noorzadeh, Christian Barillot.

This work [28] considers the problem of brain imaging using simultaneously recorded electroencephalography (EEG) and functional magnetic resonance imaging (fMRI). To this end, we introduce a linear coupling model that links the electrical EEG signal to the hemodynamic response from the blood-oxygen level dependent (BOLD) signal. Both modalities are then symmetrically integrated, to achieve a high resolution in time and space while allowing some robustness against potential decoupling of the BOLD effect. The novelty of the approach consists in expressing the joint imaging problem as a linear inverse problem, which is addressed using sparse regularization. We consider several sparsity-enforcing penalties, which naturally reflect the fact that only few areas of the brain are activated at a certain time, and allow for a fast optimization through proximal algorithms. The significance of the method and the effectiveness of the algorithms are demonstrated through numerical investigations on a spherical head model. This is a joint work with T.Oberlin and R.Gribonval.

7.4. Applications in Neuroradiology and Neurological Disorders

7.4.1. Brain perfusion gender differences using ASL in young adults

Participants: Léa Itmi, Pierre Maurel, Isabelle Corouge, Jean-Christophe Ferré, Christian Barillot.

The use of population models is becoming increasingly important in cerebral imaging, particularly using Arterial Spin Labeling perfusion imaging. Therefore, it is important to know the limits of the models before applying them, to guarantee the reliability of the results. It is now well-known that brain perfusion, in particular cerebral blood flow (CBF), changes with age, and this effect needs to be taken into account when evaluating brain perfusion images. But gender differences have not been well studied yet. It is known that female brain perfusion is, in average, higher than male brain perfusion, but only few studies have investigated whether some regional perfusion differences exist or not. This work aims to assess whether, as for the age, gender differences should be taken into account when analyzing brain perfusion images. We then focus on adult subjects and study the CBF gender differences. We compared the raw CBF means and the means after normalization, we also investigated perfusion asymetries. We used atlases for the region comparisons and the General Linear Model for the voxel level. Our results confirmed that women have a higher CBF than men, and showed that this difference can be suppressed with a normalization process, but no specific major regional difference or asymmetry was found.

7.4.2. Arterial Spin Labeling Motor Activation Presurgical Mapping for Brain Tumor Resection

Participants: Isabelle Corouge, Elise Bannier, Jean-Christophe Ferré.

Functional Arterial Spin Labeling (fASL) has demonstrated its greater specificity as a marker of neuronal activity than the reference BOLD fMRI for motor activation mapping in healthy volunteers. Motor fASL is yet to be investigated in the context of tumors, under the assumption that fASL would be less sensitive to venous contamination induced by the hemodynamics remodeling in the tumor vicinity than BOLD fMRI. As the arterial transit time may be shortened in activation areas, this preliminary study explores the ability of fASL to map the motor areas at different post-labeling delays (PLD) in healthy subjects and patient with brain tumor [21].

7.4.3. Dynamic assessment of macrophages infiltration and tissue damage in MS lesions

Participants: Anne Kerbrat, Benoit Combès, Olivier Commowick, Jean-Christophe Ferré, Elise Bannier, Christian Barillot, Gilles Edan.

Inflammation is a dynamic and complex process that could be beneficial when it supports tissue repair but also detrimental when excessive, leading to worsen tissue injury. In multiple sclerosis, it is well known from pathological and MRI studies that the prognostic between white matter lesions differed at the lesion level. Thus, 10 to 30% of T2 hyperintense lesions are seen as area of persistent hypointensity on T1-w images. These T1 hypointensity are areas of pathologically confirmed severe axonal loss. Complementary, quantitative MRI such as Diffusion imaging, magnetization transfer imaging and relaxometry can quantify and characterize tissue changes on MRI before, during, and after the evolution of a new MRI-detected lesion. They are related to damage to myelin and axons. However, identifying in vivo the dynamic pathophysiological processes that leads to these various degree of demyelination and axonal loss in MS lesions remained challenging. In recent year, molecular and cellular imaging of the inflammatory process have been developed. Although some techniques remains at the pre-clinical level, MRI using non targeted USPIO as contrast agent can be used in MS patients. USPIO are phagocyted in periphery by macrophages and migrate to the central nervous system to characterize in vivo macrophages infiltrations within lesions. The association of cellular imaging and longitudinal quantitative MRI consist of a great opportunity to assess more specifically the overall process. In a recent study from our group, we demonstrated that infiltration of activated macrophages evidenced by USPIO enhancement, was present at the onset of MS and associated with higher local loss of tissue structure [17]. This year, we pursued this work by analyzing a longitudinal study with USPIO infusion every 3 months, associated with quantitative MRI assessment including MTI, diffusion imaging and relaxometry with the objectives of describing relationships between macrophages infiltration and quantitative MRI metrics reflecting tissue structure along time.

7.4.4. The effect of water suppression on the hepatic lipid quantification, as assessed by the LCModel, in a preclinical and clinical scenario

Participant: Elise Bannier.

This work investigates the effect of water suppression on the hepatic lipid quantification, using the LCModel. MR spectra with and without water suppression were acquired in the liver of mice at 4.7 T and patients at 3 T, and processed with the LCModel. The Cramer-Rao Lower Bound (CRLB) values of the seven lipid resonances were determined to assess the impact of water suppression on hepatic lipid quantification. A paired t test was used for comparison between the CRLBs obtained with and without water suppression. For the preclinical data, in the high (low) fat fraction subset an overall impairment in hepatic lipid quantification, i.e. an increase of CRLBs (no significant change of CRLBs) was observed in spectra acquired with water suppression. For the clinical data, there were no substantial changes in the CRLB with water suppression. Because (1) the water suppression does not overall improve the quantification of the lipid resonances and (2) the MR spectrum without water suppression is always acquired for fat fraction calculation, the optimal data-acquisition strategy for liver MRS is to acquire only the MR spectrum without water suppression. For quantification of hepatic lipid resonances, it is advantageous to perform MR spectroscopy without water suppression in a clinical and preclinical scenario (at moderate fields) [14].

7.5. Management of Information in Neuroimaging

Participants: Michael Kain, Olivier Commowick, Elise Bannier, Inès Fakhfakh, Justine Guillaumont, Florent Leray, Yao Yao, Christian Barillot.

The major topic that is addressed in this period concern the sharing of data and processing tools in neuroimaging (through the “Programme d’Investissement d’Avenir” project such as OFSEP and FLI-IAM) which led to build a suitable architecture to share images and processing tools, started from the NeuroBase project (supported by the French Ministry of Research). Our overall goal within these projects is to set up a computer infrastructure to facilitate the sharing of neuroimaging data, as well as image processing tools, in a distributed and heterogeneous environment. These consortium gathered expertise coming from several complementary domains of expertise: image processing in neuroimaging, workflows and GRID computing, ontology development and ontology-based mediation. This enables a large variety of users to diffuse, exchange or reach neuroimaging information with appropriate access means, in order to be able to retrieve information almost as easily as if the data were stored locally by means of the "cloud computing" Storage as a Service (SaaS) concept As an example, the Shanoir environment has been succesfully deployed to the Neurinfo platform were it is routinely used to manage images of the research studies. It is also currently being deployed for two large projets: OFSEP ("Observatoire Français de la Sclérose en Plaques") where up to 30000 patients will be acquired on a ten years frame, and the Image Analysis and Mangment (IAM) node of the France Life Imaging national infrastructure (FLI-IAM). Our team fulfills multiple roles in this nation-wide FLI project. Christian Barillot is the chair of the IAM node, Olivier Commowick is participating in the working group workflow and image processing and Michael Kain is the technical manager of the node. Apart from the team members, software solutions like medInria and Shanoir are part of the final software platform.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Siemens

duration: 5 years from 2011/10/26
In the context of the Neurinfo imaging platform, a partnership between Siemens SAS - Healthcare and University of Rennes 1 was signed in October 2011 for 5 years. This contract defines the terms of the collaboration between Siemens and the Neurinfo platform. The Neurinfo platform has received work in progress (WIP) sequences from Siemens in the form of object code for evaluation in the context of clinical research. The Neurinfo platform has also received source code of selected MRI sequences. This is a major advance in the collaboration since it will enable the development of MRI sequences on site.

8.2. Bilateral Grants with Industry

8.2.1. MEDday

As part of its activities, MEDday led the final testing phase on patients diagnosed from Multiple Sclerosis in order to find treatment of progressive multiple sclerosis. This is done in partnership with several hospitals in France. The goal is to achieve an effective treatment for this disease. The role of the team in this industrial grant is to develop new algorithms to perform the processing and the analysis of the images from this study.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Biogenouest

The VisAGeS team and the Neurinfo platform integrated the Biogenouest "Groupement d'Intérêt Scientifique (GIS)" in 2012.

Biogenouest is a Western France life science and environment core facility network. Research programmes are undertaken in the fields of Marine biology, Agriculture/Food-processing, Human health, and Bioinformatics. Set up in keeping with the inter-regional principle of complementarity, Biogenouest coordinates over twenty technological core facilities in both the Brittany and Pays de la Loire regions.

9.1.2. Projet Fondation de France: PERINE

Participants: Elise Bannier, Isabelle Corouge, Olivier Commowick, Jean-Christophe Ferré, Christian Barillot.

This study evaluates the effect of prenatal exposure to neurotoxicants on the developing brain. Following previous studies in the PELAGIE cohort this MRI study involves ASL, Diffusion and working memory as well as motor inhibition BOLD fMRI together with neuropsychological tests in children. Inclusions have started in November 2014 and will continue over 2 years.

9.1.3. Fondation de l'Avenir - Depression, suicide and fMRI

Participants: Elise Bannier, Isabelle Corouge, Jean-Christophe Ferré, Christian Barillot.

initial duration: 12 months from November 2012. Project extended in 2015.

In collaboration with EA 4712 "Comportement et Noyaux Gris Centraux" of the University of Rennes I, a complementary funding (20 000€) was obtained to support an ongoing fMRI research project on emotions, impulsivity and suicide. The study protocol and the fMRI task was finalized. Inclusions started in early 2013. The project was extended in 2014 to recruit more patients.

9.1.4. Fondation de l'Avenir - Stroke, rehabilitation and fMRI

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

duration: 12 months from November 2012. Project extended in 2015.

A complementary funding (20 000€) was obtained to support a new research project on rehabilitation of stroke patients. The fMRI protocol was setup, the task developed and validation on volunteers is ongoing. Patient inclusions started in spring 2013. This project was also extended to 2014 to recruit more patients. Group analysis on the control group was performed and a paper will be submitted soon.

9.1.5. Projet Fondation de France: EPMR-MA

Participants: Pierre-Yves Jonin, Elise Bannier, Christian Barillot, Isabelle Corouge, Quentin Duché, Jean-Christophe Ferré.

duration: 2 years from July 2015

This project evaluates memory effects in healthy adults and in patients presenting cognitive impairments using BOLD fMRI and diffusion MRI. A pilot study has been completed in 2015 in order to optimize the experimental design. The inclusions of patients wil start early 2016.

9.2. National Initiatives

9.2.1. ANR

9.2.1.1. ANR "TRANSLATE-MS-REPAIR", RPIB 2012 program

Participants: Laurence Catanese, Olivier Commowick, Isabelle Corouge, Jean-Christophe Ferré, Elise Bannier, Gilles Edan, Christian Barillot.

It is now commonly admitted that MS is not only an inflammatory disease but a neurodegenerative disease as well. This project is devoted to show that the olesoxime molecule is not only neuroprotective, but it has the ability to promote the maturation of oligodendrocyte progenitor cells (OPCs) into myelinating oligodendrocytes. However, before considering a large-scale clinical trial to assess efficacy. An important aspect is that to date, no treatment for neuroprotection / remyelination has reached the stage of clinical proof of concept that aims Trophos company who is leading this project. It appears that the best criteria for assessing neuroprotective/remyelinating effect of the drug candidate, are MRI criteria. However, these imaging criteria have not yet been validated for use in multicentre trials - so we will also check the feasibility of such measures under this condition. In addition to Trophos company, the partners of this project are AP-HM/CNRSCEMEREM-CRMBM, CHU Rennes, CHU Reims, and Inria-VISAGES.

9.2.1.2. ANR "MAIA", 2015 generic projects program

Participants: Maia Proisy, Pierre Maurel, Olivier Commowick, Jean-Christophe Ferré, Christian Barillot.

Each year in France, 55 000 children are born prematurely, i.e., before the 37th week of gestation. Long-term studies of the outcome of prematurely born infants have clearly documented that the majority of such infants may have significant motor, cognitive, and behavioral deficits.

However, there is a limited understanding of the nature of the cerebral abnormality underlying these adverse neurologic outcomes. In this context, the emergence of new modalities of 3D functional MRI, e.g., Arterial Spin Labeling (ASL), or optical imaging technologies, e.g., Near InfraRed Spectroscopy (NIRS), brings new perspectives for extracting cognitive information, via metabolic activity measures. Other classical technics devoted to cerebral signal measurement, such as ElectroEncephaloGraphy (EEG), provide cognitive information at the cortical level. Each of these various non-invasive imaging technologies brings substantial and specific information for the understanding of newborn brain development.

This project aims at developing innovative approaches for multi-image / multi-signal analysis, in order to improve neurodevelopment understanding methods. From a fundamental point of view, mathematics and computer science have to be considered in association with imaging physics and medicine, to deal with open issues of signal and image analysis from heterogeneous data (image, signal), considered in the multiphysics contexts related to data acquisition (magnetic, optic, electric signals) and biophysics modeling of the newborn brain. A sustained synergy between all these scientific domains is then necessary.

Finally, the sine qua non condition to reach a better understanding of the coupled morphological- cognitive development of premature newborns, is the development of effective software tools, and their distribution to the whole medical community. The very target of this project will be the design of such software tools for medical image / signal analysis, actually operational in clinical routine, and freely available. Academic researchers and industrial partners will work in close collaboration to reach that ambitious goal.

9.2.2. Competitivity Clusters

9.2.2.1. The HEMISFER Project

Participants: Elise Bannier, Isabelle Bonan, Isabelle Corouge, Jean-Christophe Ferré, Jean-Yves Gauvrit, Pierre Maurel, Lorraine Perronnet, Christian Barillot.

The HEMISFER project ("Hybrid Eeg-MrI and Simultaneous neuro-FEedback for brain Rehabilitation") will be conducted at Inria Rennes with the support of the Cluster of Excellence "CominLabs" [1]. The goal of HEMISFER is to make full use of the neurofeedback paradigm in the context of rehabilitation and psychiatric disorders. The major breakthrough will come from the use of a coupling model associating functional and metabolic information from Magnetic Resonance Imaging (fMRI) to Electro-encephalography (EEG) to "enhance" the neurofeedback protocol. We propose to combine advanced instrumental devices (Hybrid EEG and MRI platforms), with new man-machine interface paradigms (Brain computer interface and serious gaming) and new computational models (source separation, sparse representations and machine learning) to provide novel therapeutic and neuro-rehabilitation paradigms in some of the major neurological and psychiatric disorders of the developmental and the aging brain (stroke, attention-deficit disorder, language disorders, treatment-resistant mood disorders, ...). This project will be conducted with the HYBRID and PANAMA Teams from Inria Rennes, the EA 4712 team from University of Rennes I and the ATHENA team from Inria Sophia-Antipolis. This work will benefit from the research 3T MRI and MRI-compatible EEG systems provided by the NeurInfo in-vivo neuroimaging platform on which these new research protocols will be set up. A budget of 500keuros will be provided by the CominLabs cluster in the next 3 years to support this project (through experimental designs, PhDs, Post-docs and Expert Engineers).

9.2.2.2. France Life Imaging (FLI)

Participants: Christian Barillot, Olivier Commowick, Florent Leray, Michael Kain, Yao Yao.

France Life Imaging (FLI) is a proposed large-scale research infrastructure project aimed at establishing a coordinated and harmonized network of biomedical imaging in France. This project was recently selected by the call “Investissements d’Avenir - Infrastructure en Biologie et Santé”. One node of this project is the node Information Analysis and Management (IAM), a transversal node build by a consortium of teams that will contribute to the construction of a network for data storage and information processing. Instead of building yet other dedicated facilities, the IAM node will use already existing data storage and information processing facilities (LaTIM Brest; CREATIS Lyon; CIC-IT Nancy; Visages U746 Inria Rennes; CATI CEA Saclay; LSIIT/ICube Strasbourg) that will increase their capacities for the FLI infrastructure. Inter-connections and access to services will be achieved through a dedicated software platform that will be developed based on the expertise gained through successful existing developments. The IAM node has several goals. It aims first at building a versatile facility for data management that will inter-connect the data production sites and data processing for which state-of-the-art solutions, hardware and software, will be available to infrastructure users. Modular solutions are preferred to accommodate the large variety of modalities acquisitions, scientific problems, data size, and adapted for future challenges. Second, it aims at offering the latest development that will be made available to image processing research teams. The team VISAGES fulfills multiple roles in this nation-wide project. Christian Barillot is the chair of the node IAM, Olivier Commowick is participating in the working group workflow and image processing and Michael Kain the technical manager. Apart from the team members, software solutions like medInria and Shanoir will be part of the final software platform.

9.2.2.3. OFSEP

Participants: Justine Guillaumont, Elise Bannier, Christian Barillot, Olivier Commowick, Gilles Edan, Isabelle Corouge, Jean-Christophe Ferré, Michael Kain, Inès Fakhfakh.

The French Observatory of Multiple Sclerosis (OFSEP) is one of 10 projects selected in January 2011 in response to the call for proposal in the “Investissements d’Avenir - Cohorts 2010” program launched by the French Government. It allows support from the National Agency for Research (ANR) of approximately € 10 million for 10 years. It is coordinated by the Department of Neurology at the Neurological Hospital Pierre Wertheimer in Lyon (Professor Christian Confavreux), and it is supported by the EDMUS Foundation against multiple sclerosis, the University Claude Bernard Lyon 1 and the Hospices Civils de Lyon. OFSEP is based on a network of neurologists and radiologists distributed throughout the French territory and linked to 61 centers. OFSEP national cohort includes more than 50,000 people with Multiple Sclerosis, approximately half of the patients residing in France. The generalization of longitudinal monitoring and systematic association

[1] https://iww.inria.fr/cominlabs-newsletter/april-2013-four-projects-selected/#hemisfer

of clinical data and neuroimaging data is one of the objectives of OFSEP in order to improve the quality, efficiency and safety of care and promote clinical, basic and translational research in MS. For the concern of data management, the Shanoir platform of Inria has been retained to manage the imaging data of the National OFSEP cohort in multiple sclerosis.

9.2.3. Collaboration with the CEA (Commissariat à l'Energie Atomique): Standardization of Arterial Spin Labeling acquisitions and imaging data quality assessment in the context of dementia related studies

Participants: Elise Bannier, Christian Barillot, Isabelle Corouge, Jean-Christophe Ferré, Cédric Meurée.

duration: from August 2014 to December 2015

Around 900,000 people are affected by various forms of dementia in France. As an early and reliable diagnosis remains difficult to provide, neuroimaging is crucial as a diagnosis assistance by analyzing structural and functional brain abnormalities related to these diseases. The CATI (Centre pour l'Acquisition et le Traitement des Images) is a multicenter neuroimaging network dedicated to the management of dementia related imaging protocols. As VisAGeS and the Neurinfo platform are recognized for their expertise in Arterial Spin Labeling (ASL) acquisition and post-processing, a collaboration contract was signed between Inria and CEA, the coordinator of the CATI initiative, in order to host an engineer in the VisAGeS team for one year. The collaboration resulted in the standardization of the ASL acquisition parameters of the CATI protocols, the setup of these parameters on the scanneres participating in the CATI studies, as well as the development and the integration of post-processing and quality assessment tools into qualiCATI, the quality control software of the CATI.

9.2.4. PEPS JCJC CNRS INS2I: FastMicroDiff: Fast acquisition for microstructure-enabled diffusion MRI

Participants: Elise Bannier, Emmanuel Caruyer.

duration: from January 2015 to December 2015 Diffusion MRI is a unique tool for the observation of brain white matter structure in vivo. Several studies have shown that it is possible to estimate intrinsic tissue parameters from diffusion, such as axonal diameter, axonal density, orientation dispersion, compartment-specific diffusion coefficients, etc. However, the reconstruction of these parameters requires specific acquisition protocols, which are to date very long and therefore poorly compatible with in vivo applications. Besides, recent development have shown that a higher sensitivity to some microstructural paramters could be obtained using non-conventional diffusion gradient sequences, such as oscillating gradient waveforms. This project aims at developping faster acquisition methods, using sparse representation for microstructure-enabled diffusion signal and time-varying diffusion sensitizing gradients.

In cooperation with the Neurinfo imaging platform and Siemens, a modification of the protocol to enable the use of non-rectangular gradient pulses has been developped and is being tested on phantom. A group of 6 healthy subjects will be scanned using this novel protocol, and acquisition will be repeated 3 times for each subject so that we can evaluate the reproducibility of the technique.

9.2.5. PHRC EMISEP: Evaluation of early spinal cord injury and late physical disability in Relapsing Remitting Multiple Sclerosis

Participants: Elise Bannier, Christian Barillot, Emmanuel Caruyer, Olivier Commowick, Gilles Edan, Jean-Christophe Ferré, Anne Kerbrat.

duration: from January 2014 to December 2017 Multiple Sclerosis (MS) is the most frequent acquired neurological disease affecting young adults (1/1000 inhabitants in France) and leading to impairment. Early and well adapted treatment is essential in patients presenting aggressive forms of MS. This PHRC project focuses on physical impairment and especially on the ability to walk. Several studies, whether epidemiolgic or based on brain MRI, have shown that several factors were likely to announce aggressive development of the disease, such as age, number of focal lesions on baseline MRI, clinical activity. However, this factors only

partially explain physical impairment progression, preventing their use at the individual level. Spinal cord is often affected in MS, as demonstrated in postmortem or imaging studies. Yet, early radiological depiction of spinal cord lesions is not always correlated with clinical symptoms. Preliminary data on a reduced number of patients, and only investigating the cervical spinal cord, have shown that diffuse spinal cord injury, observed via diffusion or magnetisation transfer imaging, would be correlated with physical impairment as evaluated by the EDSS score. Besides, the role of early spinal cord affection (first two years) in the evolution of physical impairment remains unknown.

In this project, we propose to address these different issues and to perfom a longitudinal study on Relapsing Remitting Multiple Sclerosis (RRMS) patients, recruited in the first year of the disease. Our goal is to show that diffuse and focal lesions detected on the spinal cord MRI in the first 2 years can be used to predict disease evolution and physical impairment at 5 years. Twelve centers are involved in the study to include 80 patients.

To date, 40 of the 80 subjects have been included. A PhD student started in November 2015 to work on diffusion imaging in the spinal cord.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. EuroBioimaging

Type: CAPACITIES

Defi: Provide access and training in imaging technologies, and share the best practice and image data in order to make Euro-BioImaging an engine that will drive European innovation in imaging research and technologies

Instrument: Combination of COLLABORATIVE PROJECTS and COORDINATION and SUPPORT ACTIONS

Objective: Euro-BioImaging is a large-scale pan-European research infrastructure project on the European Strategy Forum on Research Infrastructures (ESFRI) Roadmap.

Duration: December 2010 - 2016

Coordinators: Jan Ellenberg (EMBL) and Oliver Speck (University of Magdeburg)

Partner: EMBL (Germany); Erasmus Medical Center (Netherlands) for WG11

Inria contact: C. Kervrann, C. Barillot

Abstract: Euro-BioImaging is a pan-European infrastructure project whose mission is to build a distributed imaging infrastructure across Europe that will provide open access to innovative biological and medical imaging technologies for European researchers. The project is funded by the EU and currently the consortium is finalizing the basic principles for the operation of future Euro-BioImaging organisation.

Euro-BioImaging will be governed by representatives of the European countries that will join Euro-BioImaging (Euro-BioImaging member states).

The infrastructure established by Euro-BioImaging will consist of a set of geographically distributed but strongly interlinked imaging facilities (Euro-BioImaging Nodes), which will be selected among the leading European imaging facilities based on an independent evaluation process.

Inria and the Visages team is involved through the FLI national infrastructure and contributes to the WG11 Working Group on Data Storage and Analysis. This WG performs a series of tasks to define a European Biomedical Imaging Data Storage and Analysis infrastructure plan for the construction phase.

9.3.2. Collaborations in European Programs, except FP7 & H2020

9.3.2.1. COST-AID

Program: COST

Project acronym: AID (oc-2010-2-8615)

Project title: Arterial spin labeling Initiative in Dementia

Acceptation date: 18/05/2011

Coordinator: X. Golay, UCL, London, UK

Other partners: Ghent University (BE), Liege University (BE), Hospital Cantonal de Geneve (CH), Fraunhofer MEVIS (D), Freiburg University (D), Max Planck Institute for Human Cognitive & Brain Sciences (D), Glostrup Hospital (DK), Hospital Santa Creu I Sant Pau (ES), Universidad Rey Juan Carlos (ES), University of Narvarra (ES), INSERM U836 Grenoble (FR), University of Rennes I (FR), Centro San Giovanni di Dio - Fatebenefratelli (IT), Fondazione Instituto Neurologico Besta (IT), Leiden University Medical Center (NL), UMC Utrecht (NL), VU University Medical Centre (NL), Instituto Superior Técnico (PT), University of Porto (PT), Lund University Hospital (SE), Uppsala University Hospital (SE), Skane University Hospital (SE), Bogazici University (TR), King's College London (UK), University College London (UK), University of Nottingham (UK), University of Oxford (UK)

Abstract: Dementia is a major clinical challenge with care costs approaching 1% of global GDP. Recent estimates suggest that delaying disease onset by 5 years would halve its prevalence. As new disease-modifying treatments will be specific to causative diseases, expensive and bear significant side effects, early diagnosis of dementia will be essential. Current diagnostic criteria include the use of image-based biomarkers using radiotracers. The AID Action aims at coordinating the development of an alternative and cost-effective tool based on an MRI technique, Arterial Spin Labeling (ASL), to obtain reproducible brain perfusion measurements in dementia patients by bringing together scientists and clinicians from across Europe through the flexibility of the COST mechanism. The scientific program is centered around four work packages and three workgroups aiming at developing standards, improving the reliability of the technique and as establishing it as a possible clinical trial outcome measure. Development of MRI methods, post-processing tools, protocols of cross-validation, statistical analyses and launch of clinical and comparative studies will be undertaken. The main benefit of this Action will be to provide a cost-effective alternative to radiotracer-based biomarkers, and help care providers throughout Europe balancing the need for early diagnosis of dementia with the necessary healthcare cost containment. The Visages team is involved in the workgroups ASL data acquisition (E. Bannier), ASL data analysis (C. Barillot, I. Corouge, P. Maurel, C. Meurée) and clinical validation of ASL in cognitive impairment (J.-C. Ferré).

9.3.2.2. Kic-EIT-eHealth

Program: KIC-EIT: European Institute of Innovation and Technology

Project acronym: e-Health

Project title: Innovation for healthy living and active ageing

Acceptation date: 01/12/2014

website: http://eithealth.eu/about-us/

EIT Health aims to promote entrepreneurship and develop innovations in healthy living and active ageing, providing Europe with new opportunities and resources. EIT Health will enable citizens to lead healthier and more productive lives by delivering products, services and concepts that will improve quality of life and contribute to the sustainability of healthcare across Europe. EIT Health is a strong, diverse and balanced partnership of best-in-class organisations in education, research, technology, business creation and corporate and social innovation. EIT Health intends to foster cooperation and unlock Europe's innovation and growth potential – developing and retaining the best talents, creating high-quality jobs and boosting the global competitiveness of European industry.

Visages is involved in this project through the Inserm and Inria institutions. C. Barillot is representing Inria as one expert in the dedicated WG "Healthy Brain". Visages is also concerned by the WG "big data".

9.4. International Initiatives

9.4.1. Inria Associate Teams not involved in an Inria International Labs

9.4.1.1. BARBANT

Title: Boston and Rennes, a Brain image Analysis Team

International Partner (Institution - Laboratory - Researcher):

Harvard University (United States) - Mathematics Department - Simon K. Warfield

Start year: 2012 (renewed 2015)

See also: https://team.inria.fr/barbant/

BARBANT is an Inria associate team shared between Inria VisAGeS research team and the Computational Radiology Laboratory at the Boston Children's hospital (Harvard Medical School). This associate team aims at better understanding the behavior of normal and pathological Central Nervous System (CNS) organs and systems. Pathologies of particular interest to us are multiple sclerosis, psychiatric, and pediatric diseases such as pediatric multiple sclerosis or tuberous sclerosis. A major challenge is to characterize the future course of the pathological processes in each patient as early as possible in order to predict the progression of the disease and/or adverse neurological outcomes, and to develop better techniques for both monitoring response to therapy and for altering therapy (duration, dose and nature) in response to patient-specific changes in imaging characteristics. At term, this project will allow to introduce objective figures to correlate qualitative and quantitative phenotypic markers coming from the clinic and image analysis, mostly at the early stage of the pathologies. This will allow for the selection or adaptation of the treatment for patients at an early stage of the disease.

In 2015, Renaud Hedouin had a 3 month visit in Boston in the context of the BARBANT associated team

9.4.1.2. Informal International Partners

- Collaboration with Duke University, NC : From November 2014 to February 2015, Hrishikesh Deshpande visits Duke University (in Durham, North Carolina, United States) to collaborate with Professor Guillermo Sapiro on classification using Dictionary Learning. This visit was partially founded by a mobility grant from the doctoral school MATISSE.
- Collaboration with the MS Center, Dpt. of Neurology and Center for Clinical Neuroscience, Charles University in Prague on Brain atrophy in Multiple Sclerosis. O. Commowick, C. Barillot, A. Kerbray and G. Edan had a two-days visit in April 2015.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- Within the BARBANT associate team, P. Simon K. Warfield, Dr. Benoit Scherrer and Dr. Maxime Taquet (Computational Radiology Laboratory, Harvard Medical School) visited us for a workshop on multiple sclerosis and diffusion image processing.

9.5.2. Visits to International Teams

- Several members of the Visages team (Christian Barillot, Olivier Commowick, Renaud Hédouin, Yogesh Karpate) visited the Computational Radiology Laboratory (Harvard Medical School) for an associate team (BARBANT) meeting to discuss new research topics.

9.5.2.1. Explorer programme

Hédouin Renaud

Date: Sep 2015 - Dec 2015

Institution: Boston Children's Hospital (United States)

Renaud Hédouin visited the Computational Radiology Laboratory at Boston Children's Hospital, United States, for a 3 month exchange within the BARBANT associate team working on distortion correction topic.

9.5.2.2. Research stays abroad

- From November 2014 to February 2015, Hrishikesh Deshpande visits Duke University (in Durham, North Carolina, United States) to collaborate with Professor Guillermo Sapiro on classification using Dictionary Learning. This visit was partially founded by a mobility grant from the doctoral school MATISSE.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair, scientific chair

- C. Barillot was Chair of the MAPPING Miccai Workshop, Munich, Germany, 2015 https://project.inria.fr/fli/en/mapping-workshop/

10.1.1.2. Member of the organizing committees

- C. Barillot is member of the Board of Directors of IPMI conference series (Information Processing in Medical Imaging)
- C. Barillot was member of the Scientific Program Board of ESMRMb 2015 (Edinburgh, UK)
- G. Edan is founder and co-organizer of the annual ARSEP-MRI symposium since 2015
- G. Edan is co-chair of the executive board of the "European charcot foundation" symposium since 2000

10.1.2. Scientific events selection

- C. Barillot is area chair of SPIE Medical Imaging 2015

10.1.2.1. Chair of conference program committees

- C. Barillot was Chair of MAPPING Miccai Workshop, Munich, Germany, 2015

10.1.2.2. Member of the conference program committees

- C. Barillot was TPC member of MICCAI workshops (Patch-MI 2015, MCV 2015), CCGrid - Life 2015
- O. Commowick was TPC member of MICCAI 2015
- O. Commowick was TPC member of IEEE ISBI 2015
- P. Maurel was TPC member of IEEE ISBI 2015
- E. Bannier reviewed for ISMRM 2015

10.1.3. Journal

10.1.3.1. Member of the editorial boards

- C. Barillot is member of Editorial Boards of Medical Image Analysis, Current Medical Imaging Reviews, ISRN Signal Processing
- C. Barillot is Editor-in-Chief of Frontiers in ICT: Computer Image Analysis.

10.1.3.2. Reviewer - Reviewing activities

- IEEE TIP (CB), IEEE TMI (OC, PM), Medical Image Analysis (CB, SP, OC), NeuroImage (CB, OC, IC), Neuroimage clinical (CB), Hum. Brain Map. (CB), Phys. Med. Biol. (CB), Computer Methods and Programs in Biomedicine (CB), Comput. Med Im & Graph (CB), Comp Meth & Prog in Biomed (CB), IEEE Signal Proc. Let. (CB), Magnetic Resonance in Medicine (EC), Plos-ONE (CB, EC), IJICT (CB), IJSISE (CB), IJCVR (CB), Journal of Mathematical Imaging and Vision (CB, PM), Magma (CB), Trans on Parallel and Dist. Sys. (CB), Neurobiology of Aging (IC).

10.1.4. Invited talks

- G. Edan - “Natural history of Multiple Sclerosis”, International congress of Multiple Sclerosis, Porto, Feb 2015 (Porto)2015
- I. Corouge and J. Guillaumont - "Shanoir: a solution for neuro-imaging data management", Gen2bio National congress, La Baule, March 2015
- B Carsin-Nicol and J. Guillaumont - "Présentation du protocole IRM recommandé par l’OFSEP et du projet Shanoir", CIRGO - Colloque inter-régional du Grand Ouest , Nantes, December 2015
- C. Barillot - "Science Data Ecosystem in Medical Imaging", Data Science symposium : Science Data Ecosystem workshop, IRISA, Nov. 19th
- C. Barillot - "Imagerie de population: Noeud FLI-IAM", Journées Françaises de Radiologie, Paris, Oct. 15th, 2015

10.1.5. Leadership within the scientific community

- G. Edan was elected Fellow of the European Academy of Neurologie. Member of the EAN teaching committee in 2015
- C. Barillot is member of the Scientific Council of the INS2I Institute of CNRS since 2011 and is Chairman of the Board since 2015 (http://csins2i.irisa.fr)
- C. Barillot is member of the C3N committee (CNRS)
- C. Barillot is member of the scientific board of "GIS France Grilles"
- C. Barillot is member of the Governing Board of the "Pole de compétitivité Images & Réseaux"

10.1.6. Scientific expertise

- C. Barillot chaired an evaluation committe for the FET-Flagship "Human Brain Project"
- C. Barillot reviewed for the Vienna Business Agency Foundation
- C. Barillot reviewed for the National Medical Research Council (NMRC), Singapore
- C. Barillot reviewed for the Research Council of KU Leuven
- C. Barillot reviewed for the Royal Netherlands Academy of Arts and Sciences.
- C. Barillot was member of the admission committee for the Research Director competition of CNRS

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

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

Master 2 SIBM, University of Angers-Brest-Rennes: 26h (*C. Barillot, E. Bannier, E. Caruyer, O. Commowick, I. Corouge, J.-Y. Gauvrit, S. Prima*):

C. Barillot is responsible for one semester.

J.-Y. Gauvrit is the coordinator for the Master.

Master 1 SIBM, University of Rennes: 5h (S. Prima)

Ecole Supérieure d’Ingénieur de Rennes (ESIR): 60h in medical imaging (P. Maurel)

Other topics:

Ecole Supérieure d'Ingénieur de Rennes (ESIR): 60h in general image processing (P. Maurel), 60h in algorithmics and complexity (P. Maurel) and 14h in graphical user intergace programming (B. Combès)

ENS Rennes: 24h in introduction to image processing (P. Maurel)

ISTIC - Université of Rennes 1: 12h in Software Engineering (E. Caruyer)

G. Edan: regular seminar of university Cambridge UK: "From epidemiological data to therapeutic strategies in MS" June 2015

G. Edan – Milan (Italy), Preceptorship on MRI in Multiple Sclerosis - "MRI in clinical trial" (2012-2015)

10.2.2. Supervision

PhD Hrishikesh Deshpande, Dimensionality Reduction and Statistical Learning for Computational Modeling of Natural Evolution of Brain Pathologies, Inria, from December 2012, Christian Barillot, Pierre Maurel

PhD Renaud Hédouin, Biomarker discovery in brain imaging by using diffusion MRI, Inria/Inserm, from November 2013, Christian Barillot, Olivier Commowick

PhD Yogesh Karpate, Quantitative analysis of MRI in Multiple Sclerosis in the context of the clinically isolated syndroma, INSERM, from December 2011, Christian Barillot, Olivier Commowick. Defended in September 2015.

PhD Lea Itmi, Quantitative Analysis Of Arterial Spin Labeling MRI For Robust Parametric Information Of Perfusion Maps, Inria / Siemens, from Mar 2014, Christian Barillot, Pierre Maurel

PhD Lorraine Perronnet, Neurofeedback Using Virtual Reality And Combining Eeg-Mri For Brain Rehabilitation, Inria/CominLabs Hemisfer project, from Dec 2013, Christian Barillot, Maureen Clerc (Inria Sophia-Antipolis), Anatole Lecuyer (HYBRID project), Fabien Lotte (Inria Bordeaux)

PhD Haykel Snoussi, Diffusion MRI detection of early occurring spine lesions in relapsing-remitting multiple sclerosis with late physical impairment, from Nov 2015, Christian Barillot, Gilles Edan, Emmanuel Caruyer

PhD Pierre-Yves Jonin, Relationships between context-free and context-rich memory : cognitive and neural subtrates. Inria/Inserm/CNRS from Oct 2014, Christian Barillot (co-supervisor)

PhD Maia Proisy, Perfusion in neonates and in pediatric diseases. Univ. Rennes /CHRU Rennes from Oct 2014, Jean-Christophe Ferre (supervisor)

PhD Anne Kerbrat, Quantitative MR imaging in MS for Brain and Spine. Univ. Rennes /CHRU Rennes from Oct 2014, Gilles Edan (supervisor)

10.2.3. Juries

- O. Commowick: PhD, Yogesh Karpate, Inserm, Sep. 2015
- S. Prima: PhD, Reviewer, Sophie Maingault, Université de Bordeaux, mai 2015
- C. Barillot: PhD, Committee Chair: Aurélie Emilien, Univ. Bordeaux, Dec. 2014; Charlotte Dutilleul, Univ. Toulse 3-Paul Sabatier, Jul. 2015; Nicolas Cordier, Univ. Nice-Sophia Antipolis, Nov. 2015
- C. Barillot: PhD, Reviewer: Zehan Wang, Imperial College London, Dec. 2014 ; Alia Lemkaddem, EPFL - CH, Feb. 2015; Vikash Gupta, Univ. Nice-Sophia Antipolis, Mar. 2015

10.3. Popularization

- Conference/public debate : C. Barillot "Imagerie de population: Noeud FLI-IAM", Journées Françaises de Radiologie

- Exposition : Stand démonstration Inria, Journées Françaises de Radiologie
- Exposition : Stand démonstration FLI-IAM, SFRMBM
- Press : G. Edan "Les maladies du cerveau, un enjeux majeur a relever", Ouest-France
- Popularization Web site: C. Barillot "Neurofeedback to Leverage EEG and MRI Simultaneously", lettre d'information Emergences Inria (http://emergences.inria.fr/2015/Newsletter36/L36_NEUROFEEDBACK)
- Audiovisual: "MedInria", France 3 Cote d'Azur (http://pluzz.francetv.fr/videos/jt_1920_cote_dazur.html)
- Conference/public debate : JY Gauvrit,"Les progrès de l'image du cerveau", Espace des Sciences, Rennes, March 17th

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