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Activity Report 2013

Team ARAMIS

Algorithms, models and methods for images and signals of the human brain

RESEARCH CENTER
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THEME
Computational Neuroscience and Medecine

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Team ARAMIS

Keywords: Neuroimaging, Image Processing, Signal Processing, Medical Images, Machine Learning

ARAMIS is a joint team between Inria, CNRS, Inserm and University Pierre and Marie Curie within the Brain and Spinal cord Institute (ICM). It is located in the Pitié-Salpêtrière Hospital in Paris.

Creation of the Team: 2012 October 01.

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2. Overall Objectives

2.1. Introduction

Understanding brain function and its alterations requires the integration of multiple levels of organization, operating at different spatial and temporal scales. The integration of such a large variety of data is now possible thanks to the recent emergence of large-scale multimodal datasets (e.g. Alzheimer's disease neuroimaging initiative [ADNI], gene expression atlases from the Allen Institute...). In this context, mathematical and computational approaches are becoming increasingly important because: i) they provide formalized, operational and flexible frameworks from integrating multiple processes and scales; ii) they allow automated processing and analysis of massive datasets. These approaches can then be used to find biomarkers of a disease, for genotype/phenotype correlations, or to characterize functional responses for instance.

2.2. Highlights of the Year

Olivier Colliot was invited to give a lecture at the National Academy of Medicine in October 2013.

Stanley Durleman was invited to give a presentation at the Rank Prize Funds symposium "Medical Imaging meets Computer Vision" in March 2013.

3. Research Program

3.1. General aim

The overall aim of our project is to design new computational and mathematical approaches for studying brain structure (based on anatomical and diffusion MRI) and functional connectivity (based on EEG, MEG and intracerebral recordings). The goal is to transform raw unstructured images and signals into formalized, operational models such as geometric models of brain structures, statistical population models, and graph-theoretic models of brain connectivity. This general endeavor is addressed within the three following main objectives.

3.2. Modeling brain structure: from imaging to geometric models

Structural MRI (anatomical or diffusion-weighted) allows studying in vivo the anatomical architecture of the brain. Thanks to the constant advance of these imaging techniques, it is now possible to visualize various anatomical structures and lesions with a high spatial resolution. Computational neuroanatomy aims at building models of the structure of the human brain, based on MRI data. This general endeavor requires addressing the following methodological issues: i) the extraction of geometrical objects (anatomical structures, lesions, white matter tracks...) from anatomical and diffusion-weighted MRI; ii) the design of a coherent mathematical framework to model anatomical shapes and compare them across individuals. Within this context, we pursue the following objectives.

First, we aim to develop new methods to segment anatomical structures and lesions. We are most specifically interested in the hippocampus, a structure playing a crucial role in Alzheimer's disease, and in lesions of vascular origin (such as white matter hyperintensities and microbleeds). We pay particular attention to the robustness of the approaches with respect to normal and pathological anatomical variability and with respect to differences in acquisition protocols, for application to multicenter studies. We dedicate specific efforts to the validation on large populations of patients acquired in multiple centers.

Then, we develop approaches to estimate templates from populations and compare anatomical shapes, based on a diffeomorphic deformation framework and matching of distributions. These methods allow the estimation of a prototype configuration (called template) that is representative of a collection of anatomical data. The matching of this template to each observation gives a characterization of the anatomical variability within the population, which is used to define statistics. In particular, we aim to design approaches that can integrate multiple objects and modalities, across different spatial scales.

3.3. Modeling dynamical brain networks

Functional imaging techniques (EEG, MEG and fMRI) allow characterizing the statistical interactions between the activities of different brain areas, i.e. functional connectivity. Functional integration of spatially distributed brain regions is a well-known mechanism underlying various cognitive and perceptual tasks. Indeed, mounting evidence suggests that impairment of such mechanisms might be the first step of a chain of events triggering several neurological disorders, such as the abnormal synchronization of epileptic activities. Naturally, neuroimaging studies investigating functional connectivity in the brain have become increasingly prevalent.

Our team develops a framework for the characterization of brain connectivity patterns, based on connectivity descriptors from the theory of complex networks. The description of the connectivity structure of neural networks is able to characterize for instance, the configuration of links associated with rapid/abnormal synchronization and information transfer, wiring costs, resilience to certain types of damage, as well as the balance between local processing and global integration. Furthermore, we propose to extend this framework to study the reconfiguration of networks over time. Indeed, neurophysiological data are often gathered from longitudinal recording sessions of the same subject to study the adaptive reconfiguration of brain connectivity. Finally, connectivity networks are usually extracted from different brain imaging modalities (MEG, EEG, fMRI or DTI) separately. Methods for combining the information carried by these different networks are still missing. We thus propose to combine connectivity patterns extracted from each modality for a more comprehensive characterization of networks.

3.4. Methodologies for large-scale datasets

Until recently, neuroimaging studies were often restricted to series of about 20-30 patients. As a result, such studies had a limited statistical power and could not adequately model the variability of populations. Thanks to wider accessibility of neuroimaging devices and important public and private funding, large-scale studies including several hundreds of patients have emerged in the past years. In the field of Alzheimer's disease (AD) for instance, one can cite the Alzheimer's Disease Neuroimaging Initiative (ADNI) including about 800 subjects (patients with AD or mild cognitive impairment (MCI) and healthy controls) or the French cohort MEMENTO including about 2000 subjects with memory complaint. These are most often multicenter studies in which patients are recruited over different centers and images acquired on different scanners. Moreover, cohort studies include a longitudinal component: for each subject, multiple images are acquired at different time points. Finally, such datasets often include multimodal data: neuroimaging, clinical data, cognitive tests and genomics data. These datasets are complex, high-dimensional and often heterogeneous, and thus require the development of new methodologies to be fully exploited.

In this context, our objectives are:

- to develop methodologies to acquire and standardize multicenter neuroimaging data;
- to develop imaging biomarkers based on machine learning and longitudinal models;
- to design multimodal analysis approaches for bridging anatomical models and genomics.

The first two aspects focus on neuroimaging and will be tightly linked with the CATI project. The last one builds on our previous expertise in morphometry and machine learning, but aims at opening new research avenues combining imaging and "omics" data. This is will be developed in strong collaboration with the new biostatistics/bioinformatics platform of the IHU-A-ICM.

4. Application Domains

4.1. Introduction

We develop different applications of our new methodologies to brain pathologies, mainly neurodegenerative diseases, epilepsy and cerebrovascular disorders. These applications aim at:

- better understanding the pathophysiology of brain disorders;
- designing biomarkers of pathologies for diagnosis, prognosis and assessment of drug efficacy;
- developping brain computer interfaces for clinical applications.

These applications are developed in close collaboration with biomedical researchers of the ICM and clinicians of the Pitié-Salpêtrière hospital.

4.2. Understanding brain disorders

The approaches that we develop allow to characterize anatomical and functional alterations, thus making it possible to study these alterations in different clinical populations. This can provide provide new insights into the mechanisms and progression of brain diseases. This typically involves the acquisition of neuroimaging data in a group of patients with a given pathology and in a group of healthy controls. Measures of anatomical and functional alterations are then extracted in each subject (for instance using segmentation of anatomical structures, shape models or graph-theoretic measures of functional connectivity). Statistical analyses are then performed to identify: i) significant differences between groups, ii) correlations between anatomical/functional alterations on the one hand, and clinical, cognitive or biological measures on the other hand, iii) progression of alterations over time.

We propose to apply our methodologies to study the pathophysiology of neurodegenerative diseases (mostly Alzheimer's disease and fronto-temporal dementia), epilepsy, cerebrovascular pathologies and neurodevelopmental disorders (Gilles de la Tourette syndrome). In neurodegenerative diseases, we aim at establishing the progression of alterations, starting from the early and even asymptomatic phases. In Gilles de la Tourette syndrome, we study the atypical anatomical patterns that may contribute to the emergence of symptoms. In epilepsy, we aim at studying the relationships between the different functional and structural components of epileptogenic networks.

4.3. Biomarkers for diagnosis, prognosis and clinical trials

Currently, the routine diagnosis of neurological disorders is mainly based on clinical examinations. This is also true for clinical trials, aiming to assess the efficacy of new treatments. However, clinical diagnoses only partially overlap with pathological processes. For instance, the sensitivity and specificity of clinical diagnosis of Alzheimer's disease (AD) based on established consensus criteria are of only about 70-80% compared to histopathological confirmation. Furthermore, the pathological processes often begin years before the clinical symptoms. Finally, clinical measures embed subjective aspects and have a limited reproducibility and are thus not ideal to track disease progression. It is thus crucial to supplement clinical examinations with biomarkers that can detect and track the progression of pathological processes in the living patient. This has potentially very important implications for the development of new treatments as it would help: i) identifying patients with a given pathology at the earliest stage of the disease, for inclusion in clinical trials; ii) providing measures to monitor the efficacy of treatments.

The derivation of biomarkers from image analysis approaches requires large-scale validation in well-characterized clinical populations. The ARAMIS team is strongly engaged in such efforts, in particular in the field of neurodegenerative disorders. To that purpose, we collaborate to several national studies (see section Partnerships) that involve multicenter and longitudinal acquisitions. Moreover, ARAMIS is strongly involved in the CATI which manages over 15 multicenter studies, including the national cohort MEMENTO (2000 patients).

4.4. Brain computer interfaces for clinical applications

A brain computer interface (BCI) is a device aiming to decode brain activity, thus creating an alternate communication channel between a person and the external environment. BCI systems can be categorized on the base of the classification of an induced or evoked brain activity. The central tenet of a BCI is the capability to distinguish different patterns of brain activity, each being associated to a particular intention or mental task.

Hence adaptation, as well as learning, is a key component of a BCI because users must learn to modulate their brainwaves to generate distinct brain patterns. Usually, a BCI is considered a technology for people to substitute some lost functions. However, a BCI could also help in clinical rehabilitation to recover motor functions. Indeed, in current neuroscience-based rehabilitation it is recognized that protocols based on mental rehearsal of movements (like motor imagery practicing) are a way to access the motor system because they can induce an activation of sensorimotor networks that were affected by lesions. Hence, a BCI based on movement imagery can objectively monitor patient's progress and their compliance with the protocol, monitoring that they are actually imagining movements. It also follows that feedback from such a BCI can provide patients with an early reinforcement in the critical phase when there is not yet an overt sign of movement recovery. The BCI approaches that we develop are based on the characterization of the information contained in the functional connectivity patterns. We expect to significantly increase the performance of the BCI system with respect to the sole use of standard power spectra of the activity generated by single local brain areas. Such an improvement will concretely provide the user with a more precise control of the external environment in open-loop BCI tasks and a more coherent feedback in the closed-loop BCI schemes.

5. Software and Platforms

5.1. SACHA

Participants: Marie Chupin [Correspondant], Ludovic Fillon.

SACHA ("Segmentation Automatisée Compétitive de l'Hippocampe et de l'Amygdale") is a software for the fully automatic segmentation of the hippocampus and the amygdala from MRI 3D T1 brain scans. It has been validated in various populations including healthy controls and patients with Alzheimer's disease, epilepsy and depression. It has been successfully applied to over 3,000 subjects, both controls, from adolescents to elderly subjects, and patients with different types of pathologies. The current stable version is fully automatic and focused on cross-sectional segmentation. The software can be used both as a command-line program or through a graphical user interface (GUI). The core of the program is coded in C++. It has a dependency to the AIMS library (http://www.brainvisa.info) and preprocessing steps rely on processes in Matlab from SPM (http://www.fil.ion.ucl.ac.uk/spm/). The GUI is coded in Python and is based on BrainVISA (http://www.brainvisa.info). The software has been registered at the APP (French agency for software protection).

5.2. WHASA

Participants: Marie Chupin [Correspondant], Ludovic Fillon, Thomas Samaille.

WHASA ("White matter Hyperintensity Automatic Segmentation Algorithm") is a software for the fully automatic segmentation of age-related white matter hyperintensities from MRI FLAIR and 3D T1 brain scans. It has been validated on a population showing a wide range of lesion load, and is being further evaluated on elderly subjects with few clinical abnormalisties and with different acquisition characteristics. The current stable version is fully automatic and focused on cross-sectional segmentation. The software can be used both as a Matlab command-line or through a graphical user interface (GUI). The core of the program is coded in Matlab. It has a dependency to the SPM environment (http://www.fil.ion.ucl.ac.uk/spm/). The GUI is coded in Python and is based on BrainVISA (http://www.brainvisa.info). The software has been registered at the APP (French agency for software protection).

5.3. Deformetrica

Participants: Stanley Durrleman [Correspondant], Alexandre Routier, Pietro Gori.

Deformetrica is a software which estimates diffeomorphic deformations between sets of geometric objects in 2D and 3D. Those deformations are estimated either for the registration of two of such objects sets or for the construction of an atlas from several of such sets (a template model set and deformations mapping the template model to each set). Geometric objects could be grey-level images, surface meshes, polygonal lines or unstructured point sets. The method relies on the metric on currents for the comparison of point sets and the sum of squared differences for the comparison of images.

The software is written in C++ and relies on the ITK and VTK libraries. It is a command-line software.

The release of the software to the scientific community is planned for 2014.

5.4. qualiCATI

Participants: Marie Chupin [Correspondant], Hugo Dary, Nicolas Vibet, Urielle Thoprakarn, Aude Costard, Amadou Tall, Cyril Poupon, Vincent Perlbarg, Mélanie Pélégrini-Issac.

qualiCATI is a software designed for comprehensive quality control of multimodal MRI data acquisition in large multicentre clinical studies. The software is built as a platform receiving several modules, developped by several CATI engineers. The first module is dedicated to acquisition requirement checking and conversion to nifti format. The second module aims at making 3DT1 acquisition quality check more systematic, and relies both on visual inspection and quantitative indices. The third module allows a simultaneous evaluation of the clinical part of the CATI acquisition protocol. The fourth module embeds automatic indices to evaluate resting state fMRI acquisition. The last module, up to now, is dedicated to first preprocessings and quality indices for dMRI. qualiCATI requires training for the visual parts, and is closely linked with a team of clinical research assistants. It has been used to analyse over 3000 subjects from over 10 multi centre research projects initiated before or after the CATI started. Other modules will be added in the future to embed new aspects of the MRI protocol proposed by the CATI. The Aramis team is in charge of the second and third modules and jointly in charge of the first module. The software is centered on a graphical user interface (GUI). The whole program is coded in Python within the pyPTK environment developped by Cyril Poupon (Neurospin). It has dependencies to SPM (http://www.fil.ion.ucl.ac.uk/spm/) and brainVISA environments as well as specific tools for DICOM management.

6. New Results

6.1. Spatial and anatomical regularization of SVM

Participants: Rémi Cuingnet, Joan Glaunès, Marie Chupin, Habib Benali, Olivier Colliot [Correspondant].

We developed a general framework to introduce spatial and anatomical priors in SVM for brain image analysis based on regularization operators. A notion of proximity based on prior anatomical knowledge between the image points is defined by a graph (e.g. brain connectivity graph) or a metric (e.g. Fisher metric on statistical manifolds). A regularization operator is then defined from the graph Laplacian, in the discrete case, or from the Laplace-Beltrami operator, in the continuous case. The regularization operator is then introduced into the SVM, which exponentially penalizes high frequency components with respect to the graph or to the metric and thus constrains the classification function to be smooth with respect to the prior. It yields a new SVM optimization problem whose kernel is a heat kernel on graphs or on manifolds. We then present different types of priors and provide efficient computations of the Gram matrix. The proposed framework is finally applied to the classification of brain magnetic resonance (MR) images (based on gray matter concentration maps and cortical thickness measures) from 137 patients with Alzheimer's disease and 162 elderly controls. The results demonstrate that the proposed classifier generates less-noisy and consequently more interpretable feature maps (Figure 1) with high classification performances.

More details in [4].

6.2. Segmentation of the hippocampus in neurodegenerative dementias

Participants: Leonardo Cruz de Souza, Marie Chupin, Maxime Bertoux, Stéphane Lehéricy, Bruno Dubois, Foudil Lamari, Isabelle Le Ber, Michel Bottlaender, Olivier Colliot [Correspondant], Marie Sarazin.

Our team develops various applications of our automatic segmentation method SACHA to neurological disorders, in particular in neurodegenerative dementias. This research is done in close collaboration with IM2A (Institut de la Mémoire et de la Maladie d'Alzheimer, Bruno Dubois and Marie Sarazin) at Pitié-Salpêtrière hospital.

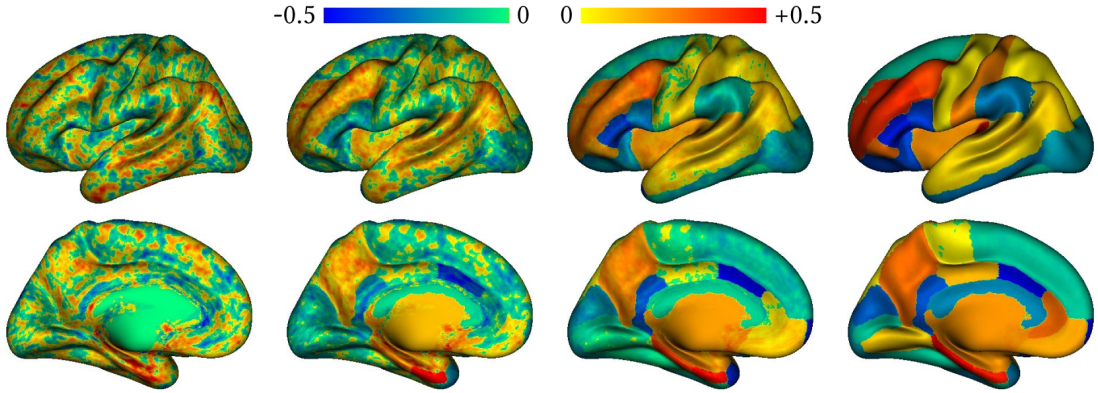


Figure 1. Anatomical regularization of support vector machines for automatic classification of patients with Alzheimer's disease. The figure displays the normalized vector orthogonal to the optimal margin hyperplane, for increasing levels of regularization.

We previously showed that automatic hippocampal segmentation can discriminate patients with Alzheimer's disease (AD) from elderly control subjects, with high sensitivity and specificity. In patients with Alzheimer's disease, we further studied the relationship between hippocampal atrophy and memory deficits. We also showed that hippocampal volume loss is correlated to tau and hyperphosphorylated tau levels measured in the cerebro-spinal fluid (CSF) but not with $A\beta_4 2$ levels.

Here, our objective was to study the ability of hippocampal volumetry (HV) to differentiate between two neurodegenerative dementias: Alzheimer's disease (AD) and fronto-temporal dementia (FTD). Seventy-two participants were included: 31 AD patients with predominant and progressive episodic memory deficits associated with typical AD cerebrospinal fluid (CSF) profile and/or positive amyloid imaging (PET with 11C-labeled Pittsburgh Compound B [PiB]), 26 patients with behavioral variant FTD (bvFTD) diagnosed according to consensual clinical criteria and with no AD CSF profile, and 15 healthy controls without amyloid retention on PiB-PET exam. HV were segmented with our automated method and were normalized to total intracranial volume (nHV). Significant reductions in HV were found in both AD and bvFTD patients compared with controls, but there were no significant difference between AD and bvFTD patients. Mean nHV distinguished normal controls from either AD or bvFTD with high sensitivity (80.6% and 76.9%, respectively) and specificity (93.3% for both), but it was inefficient in differentiating AD from bvFTD (9.7% specificity). There was no difference in the clinical and neuropsychological profiles according to HV in bvFTD and AD patients. In conclusion, when considered alone, measures of HV are not good markers to differentiate AD from bvFTD. Hippocampal sclerosis associated with FTD may explain the high degree of overlap in nHV between both groups.

More details in [5].

6.3. Diffeomorphic Iterative Centroids for Template Estimation on Large Datasets

Participants: Claire Cury [Correspondant], Joan Glaunès, Olivier Colliot.

A common approach for analysis of anatomical variability relies on the estimation of a template representative of the population. The Large Deformation Diffeomorphic Metric Mapping is an attractive framework for that purpose. However, template estimation using LDDMM is computationally expensive, which is a limitation

for the study of large datasets. We proposed an iterative method which quickly provides a centroid of the population in the shape space. This centroid can be used as a rough template estimate or as initialization of a template estimation method. The approach was evaluated on datasets of real and synthetic hippocampi segmented from brain MRI. The results showed that the centroid is correctly centered within the population and is stable for different orderings of subjects. When used as an initialization, the approach allows to substantially reduce the computation time of template estimation.

More details in [30].

6.4. Sparse Adaptive Parameterization of Variability in Image Ensembles

Participants: Stanley Durrleman [Correspondant], Sarang Joshi, Stéphanie Allassonnière.

We introduce a new parameterization of diffeomorphic deformations for the characterization of the variability in image ensembles. Dense diffeomorphic deformations are built by interpolating the motion of a finite set of control points that forms a Hamiltonian flow of self-interacting particles. The proposed approach estimates a template image representative of a given image set, an optimal set of control points that focuses on the most variable parts of the image, and template-to-image registrations that quantify the variability within the image set. The method automatically selects the most relevant control points for the characterization of the image variability and estimates their optimal positions in the template domain. The optimization in position is done during the estimation of the deformations without adding any computational cost at each step of the gradient descent. The selection of the control points is done by adding a L^1 prior to the objective function, which is optimized using the FISTA algorithm.

Figure 2. Left: template image estimated from 20 images of the US postal database. Momentum vectors are placed at the most variable places and paramterize mappings from the template to each image in the data set. Right: sample images from the data set (top) and template image deformed to match the corresponding sample image (bottom)

Related publication: [12]

6.5. Toward a comprehensive framework for the spatiotemporal statistical analysis of longitudinal shape data

Participants: Stanley Durrleman [Correspondant], Xavier Pennec, Alain Trouvé, José Braga, Guido Gerig, Nicholas Ayache.

We introduce a comprehensive framework for the statistical analysis of longitudinal shape data. The proposed method allows the characterization of typical growth patterns and subject-specific shape changes in repeated time-series observations of several subjects. This can be seen as the extension of usual longitudinal statistics of scalar measurements to high-dimensional shape or image data.

The method is based on the estimation of continuous subject-specific growth trajectories and the comparison of such temporal shape changes across subjects. Differences between growth trajectories are decomposed into morphological deformations, which account for shape changes independent of time, and time warps, which account for different rates of shape changes over time.

Given a longitudinal shape data set, we estimate a mean growth scenario representative of the population, and the variations of this scenario both in terms of shape changes and in terms of change in growth speed. Then, intrinsic statistics are derived in the space of spatiotemporal deformations, which characterize the typical variations in shape and in growth speed within the studied population. They can be used to detect systematic developmental delays across subjects.

In the context of neuroscience, we apply this method to analyze the differences in the growth of the hippocampus in children diagnosed with autism, developmental delays and in controls. Result suggest that group differences may be better characterized by a different speed of maturation rather than shape differences at a given age. In the context of anthropology, we assess the differences in the typical growth of the endocranium between chimpanzees and bonobos. We take advantage of this study to show the robustness of the method with respect to change of parameters and perturbation of the age estimates.

Related publication: [13]

6.6. Bayesian Atlas Estimation for the Variability Analysis of Shape Complexes

Participants: Pietro Gori [Correspondant], Olivier Colliot, Yulia Worbe, Linda Marrakchi-Kacem, Sophie Lecomte, Cyril Poupon, Andreas Hartmann, Nicholas Ayache, Stanley Durrleman.

We propose a Bayesian framework for multi-object atlas estimation based on the metric of currents which permits to deal with both curves and surfaces without relying on point correspondence. This approach aims to study brain morphometry as a whole and not as a set of different components, focusing mainly on the shape and relative position of different anatomical structures which is fundamental in neuro-anatomical studies. We propose a generic algorithm to estimate templates of sets of curves (fiber bundles) and closed surfaces (sub-cortical structures) which have the same "form" (topology) of the shapes present in the population. This atlas construction method is based on a Bayesian framework which brings to two main improvements with respect to previous shape based methods. First, it allows to estimate from the data set a parameter specific to each object which was previously fixed by the user: the trade-off between data-term and regularity of deformations. In a multi-object analysis these parameters balance the contributions of the different objects and the need for an automatic estimation is even more crucial. Second, the covariance matrix of the deformation parameters is estimated during the atlas construction in a way which is less sensitive to the outliers of the population.

Related publication: [33]

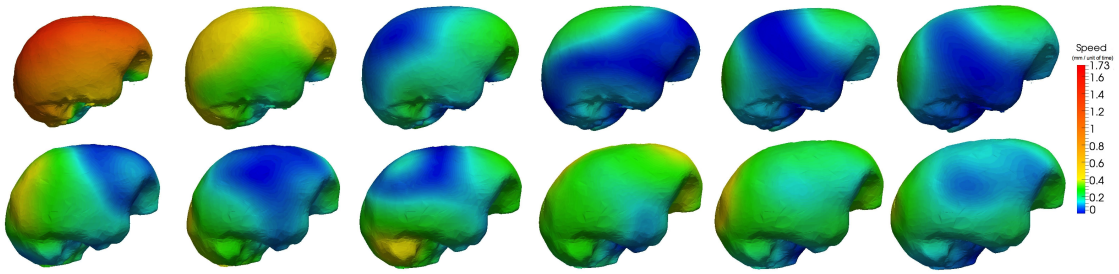
6.7. Geodesic regression of shape and image data

Participants: James Fishbaugh [Correspondant], Marcel Prastawa, Guido Gerig, Stanley Durrleman.

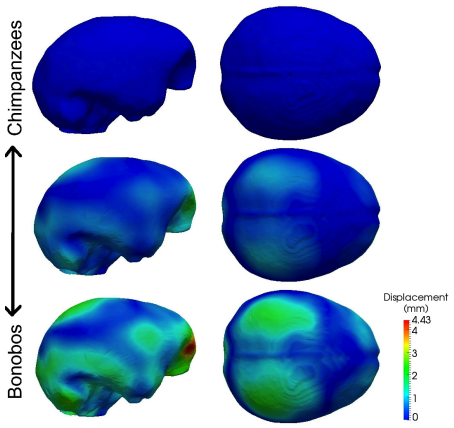
Shape regression is emerging as an important tool for the statistical analysis of time dependent shapes. We develop a new generative model which describes shape change over time, by extending simple linear regression to the space of shapes represented as currents in the large deformation diffeomorphic metric mapping (LDDMM) framework. By analogy with linear regression, we estimate a baseline shape (intercept) and initial momenta (slope) which fully parameterize the geodesic shape evolution. This is in contrast to previous shape regression methods which assume the baseline shape is fixed. We further leverage a control point formulation, which provides a discrete and low dimensional parameterization of large diffeomorphic transformations. This flexible system decouples the parameterization of deformations from the specific shape representation, allowing the user to define the dimensionality of the deformation parameters. We present an optimization scheme that estimates the baseline shape, location of the control points, and initial momenta simultaneously via a single gradient descent algorithm.

Shapes can be given as 3D meshes (as in [32]) or as 3D images (as in [31]).

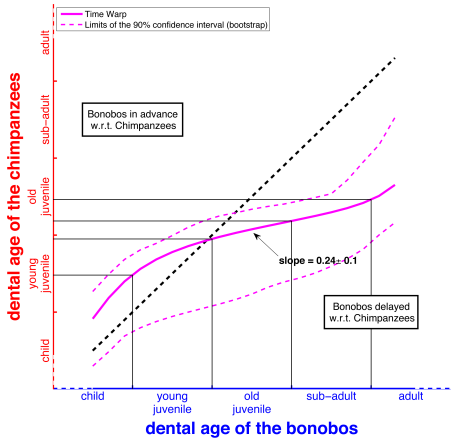
Related publications: [32], [31].



a- Temporal regression of endocasts of bonobos (top) and chimpanzees (bottom)



b - morphological deformation



c - time warp

Figure 3. A species-specific continous growth scenario is estimated from 3D anatomical models of endocrania (a). These two scenarios are matched using a morphological deformation (b) and a time warp (c). The morphological deformation shows that endocasts of bonobos are on average rounder and less elongated than endocasts of chimpanzees. The time-warp shows that the growth of the bonobos is in advance with respect to the chimpanzees at childhood and then that it drastically slows down during juvenility

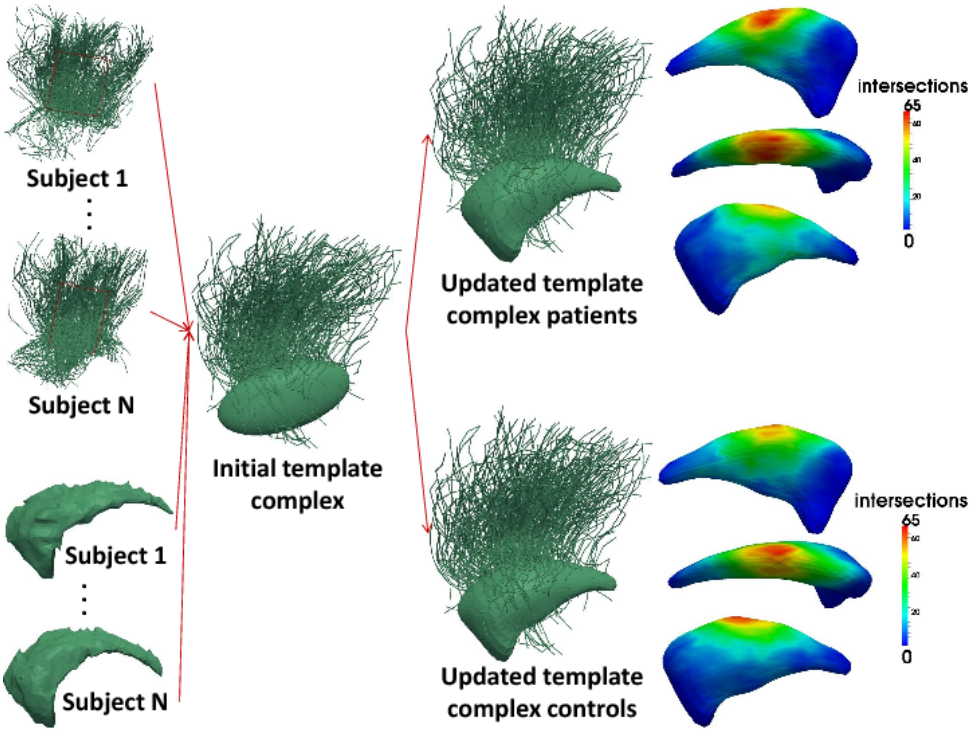


Figure 4. Atlas construction from a data set of left caudate nucleus and its associated fiber bundle that were segmented in images of patients with Gilles de la Tourette syndrome and controls. An initial template complex determines the topology of the model. Its shape is optimized given the patients data or the controls data only, thus resulting in two atlases showing different distributions of the fibers on the surface of the nucleus.

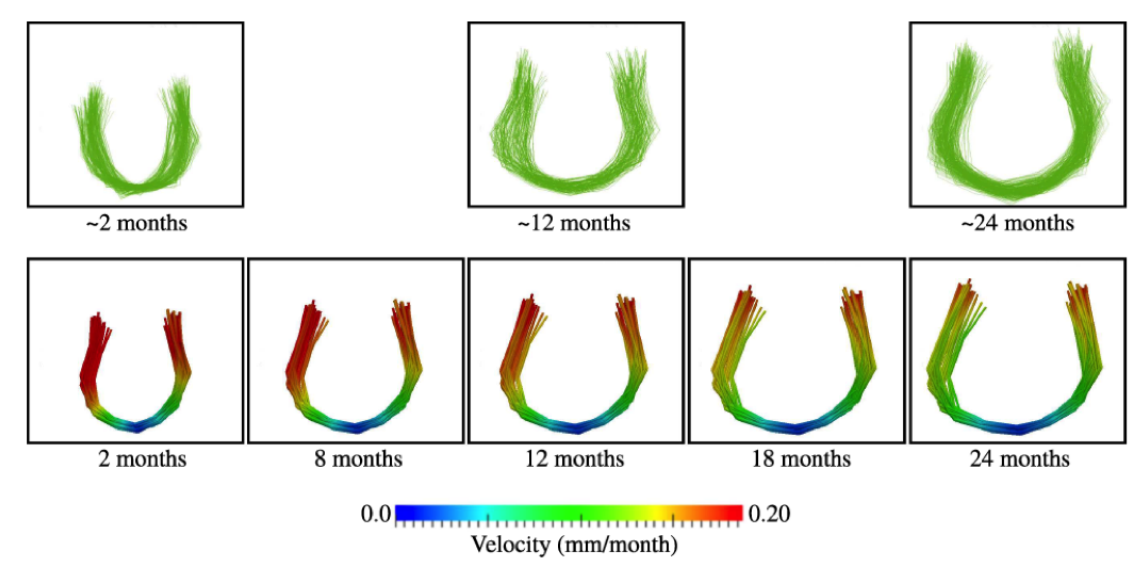


Figure 5. Average development of genu fiber tract from 2 to 24 months. Top row shows observed data for all subjects, which is clustered around 2, 12, and 24 months. Bottom row shows genu fiber tracts estimated from geodesic regression at several time points with velocity of fiber development displayed on the estimated fibers.

6.8. Discriminating brain microbleeds using phase contrast MRI in a multicentre clinical dataset

Participants: Takoua Kaaouana [Correspondant], Marie Chupin, Didier Dormont, Ludovic de Rochefort, Thomas Samaille.

Brain microbleeds (BMBs) have emerged as a new imaging marker of small vessel diseases and they may play a crucial role in degenerative pathology such as Alzheimer's disease. Composed of hemosiderin, BMBs can be efficiently detected with MRI sequences sensitive to magnetic susceptibility (e.g. gradient recalled echo T2*W images). Nevertheless, that identification remains challenging because of confounding structures and lesions. Most T2*-weighted hyposignals result from local magnetic field inhomogeneity and can be identified either as BMBs, veins or brain micro-calcifications (BMCs). Differential diagnosis of BMBs and BMCs usually requires an additional CT scan. Quantitative susceptibility mapping techniques were proposed to discriminate between diamagnetic and paramagnetic structures, but they require a full 3D dataset and complex post-processing. We introduced a fast 2D phase processing technique including unwrapping and harmonic filtering thus yielding the internal field map, namely the field map generated only by sources within the volume of interest. We demonstrate its applicability and robustness on multicenter data acquired in standardized clinical settingand and its ability to discriminate between paramagnetic BMBs and diamagnetic BMCs through the use of the orientation of the dipolar pattern.

Related publications: [36].

6.9. Network symmetries and functional modules in the brain

Participants: Vincenzo Nicosia, Miguel Valencia, Mario Chavez [Correspondant], Albert Diaz-Guilera, Vito Latora.

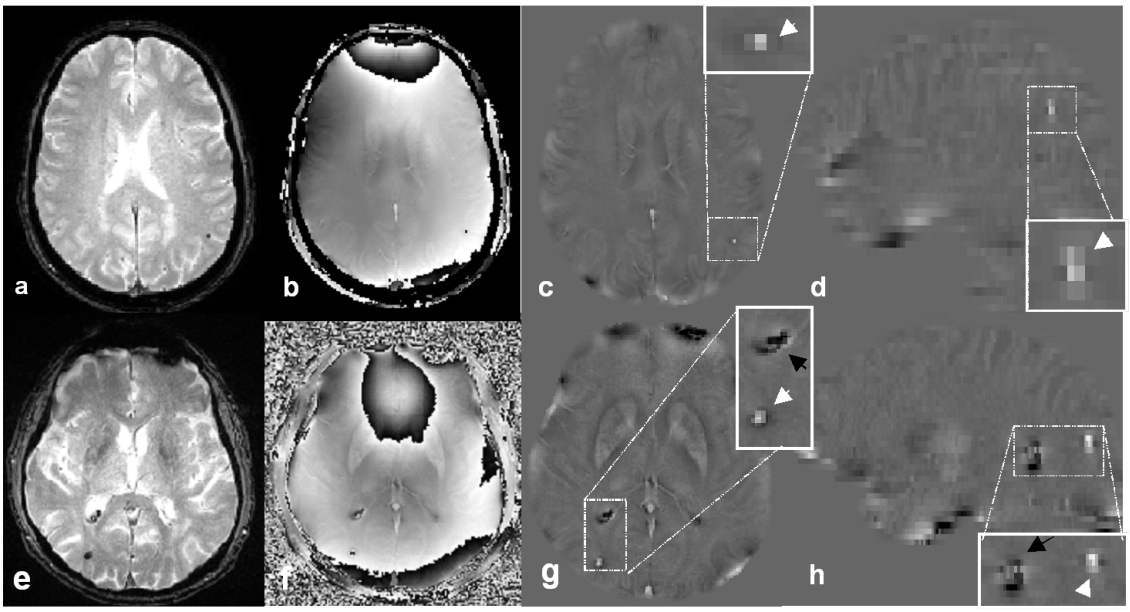


Figure 6. Philips (a,b,c,d) and Siemens (e,f,g,h) sample cases. Magnitude image (a,e), native phase image (b,f), and internal field map; axial (c,g) and sagittal (d,h). Zoom in white rectangle showing a dipolar pattern BMB (white arrow) and a physiologic calcification of the choroid plexus (black arrow).

We study the classical Kuramoto model in which the oscillators are associated to the nodes of a network and the interactions include a phase frustration, thus preventing full synchronization. The system organizes into a regime of remote synchronization where pairs of nodes with the same network symmetry are fully synchronized, despite their distance on the graph. We provide analytical arguments to explain this result and we show how the frustration parameter affects the distribution of phases. An application to brain networks suggests that anatomical symmetry plays a role in neural synchronization by determining correlated functional modules across distant locations.

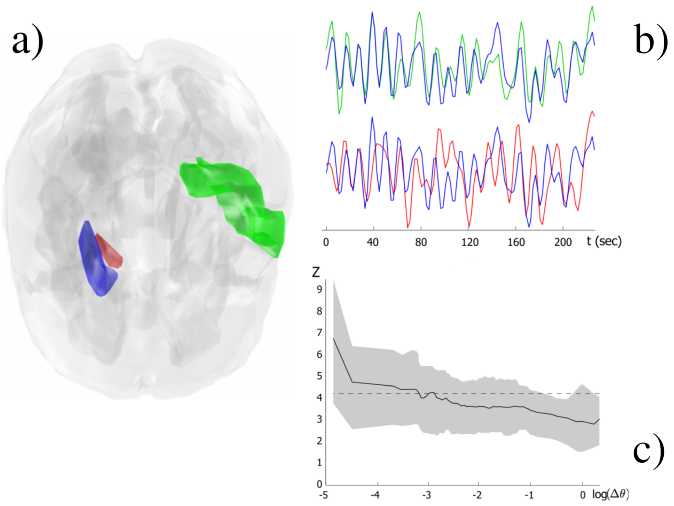


Figure 7. a) Brain areas with similar and dissimilar phases of the frustrated Kuramoto model are colored and superimposed onto an anatomical image. b) Examples of functional data from one subject recorded at the brain areas indicated in panel a). Colors are the same as those used in the anatomical image. c) Functional correlation (normalised values) Z between pairs of nodes as a function of their phase differences $\Delta\theta$ according to the simulated Kuramoto dynamics. The black solid curve corresponds to the average value over all the subjects, while the gray area covers the 5^{th} and the 95^{th} percentiles of the distribution. The dashed horizontal line indicates the threshold for statistical significant correlations ($p < 0.05$, corrected for multiple comparisons).

Related publication: [19]

6.10. Accessibility of cortical networks during motor tasks

Participants: Mario Chavez [Correspondant], Fabrizio de Vico Fallani, Miguel Valencia, Mario Chavez, Julio Artieda, Vito Latora, Donatella Mattia, Fabio Babiloni.

Recent findings suggest that the preparation and execution of voluntary self-paced movements are accompanied by the coordination of the oscillatory activities of distributed brain regions. We used electroencephalographic source imaging methods to estimate the cortical movement-related oscillatory activity during finger ex- tension movements. We applied network theory to investigate changes (expressed as differences from the baseline) in the connectivity structure of cortical networks related to the preparation and execution of the movement. We computed the topological accessibility of different cortical areas, measuring how well an area can be reached by the rest of the network. Analysis of cortical networks revealed specific agglomerates of cortical sources that become less accessible during the preparation and the execution of the finger movements. The observed changes neither could be explained by other measures based on geodesics or on multiple paths, nor by power changes in the cortical oscillations.

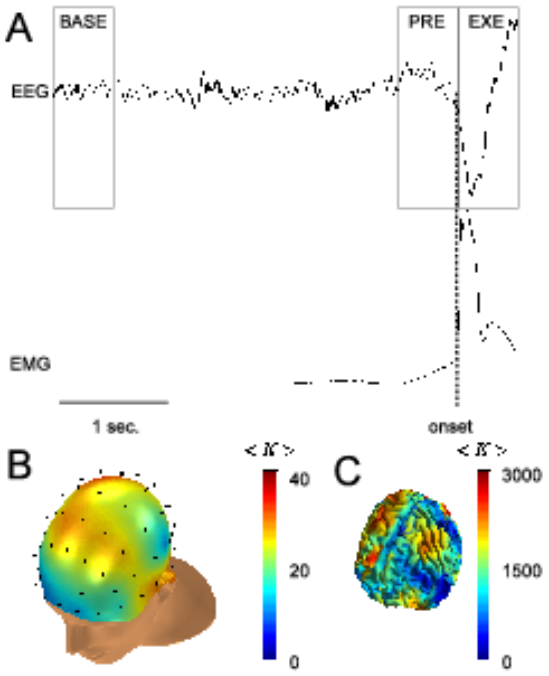


Figure 8. a) Averaged EMG and EEG (recorded at the postcentral region) signals of a subject during the execution of finger movements. Boxes define the three temporal epochs of EEG activity studied here: baseline (BASE), preparation (PRE) and execution period (EXE). Vertical dotted line indicates the movement onset. Examples of scalp and source-level networks obtained from one subject, at the frequency band Beta1, during the epoch EXE are shown in panels b) and c), respectively. Color map codes the number of connections.

Related publication: [3]

6.11. Abnormal functional connectivity between motor cortex and pedunculopontine nucleus following chronic dopamine depletion

Participants: Miguel Valencia, Mario Chavez [Correspondant], Julio Artieda, J. Paul Bolam, Juan Mena-Segovia.

The activity of the basal ganglia is altered in Parkinson's disease (PD) as a consequence of the degeneration of dopamine neurons in the substantia nigra pars compacta. This results in aberrant discharge patterns and expression of exaggerated oscillatory activity across the basal ganglia circuit. Altered activity has also been reported in some of the targets of the basal ganglia, including the pedunculopontine nucleus (PPN), possibly due to its close interconnectivity with most regions of the basal ganglia. However, the nature of the involvement of the PPN in the pathophysiology of PD has not been fully elucidated. We recorded local field potentials in the motor cortex and the PPN in the 6-hydroxydopamine (6-OHDA)-lesioned rat model of PD under urethane anesthesia. By means of linear and nonlinear statistics, we analyzed the synchrony between the motor cortex and the PPN, and the delay in the interaction between these two structures. We observed the presence of coherent activity between the cortex and the PPN in low- (5-15 Hz) and high-frequency bands (25-35 Hz) during episodes of cortical activation. In each case the cortex led the PPN. Dopamine depletion strengthened the interaction of the low-frequency activities by increasing the coherence specifically in the theta and alpha ranges and reduced the delay of the interaction in the gamma band. Our data show that cortical inputs play a determinant role in leading the coherent activity with the PPN, and support the involvement of the PPN in the pathophysiology of PD.

Related publication: [25]

6.12. Subthalamic Nucleus High-Frequency Stimulation Restores Altered Electrophysiological Properties of Cortical Neurons in Parkinsonian Rat

Participants: Bertrand Degos, Jean Michel Deniau, Mario Chavez [Correspondant], Nicolas Maurice.

Electrophysiological recordings performed in parkinsonian patients and animal models have confirmed the occurrence of alterations in firing rate and pattern of basal ganglia neurons, but the outcome of these changes in thalamo-cortical networks remains unclear. Using rats rendered parkinsonian, we investigated, at a cellular level in vivo, the electrophysiological changes induced in the pyramidal cells of the motor cortex by the dopaminergic transmission interruption and further characterized the impact of high-frequency electrical stimulation of the subthalamic nucleus, a procedure alleviating parkinsonian symptoms. We provided evidence that a lesion restricted to the substantia nigra pars compacta resulted in a marked increase in the mean firing rate and bursting pattern of pyramidal neurons of the motor cortex. These alterations were underlain by changes of the electrical membranes properties of pyramidal cells including depolarized resting membrane potential and increased input resistance. The modifications induced by the dopaminergic loss were more pronounced in cortico-striatal than in cortico-subthalamic neurons. Furthermore, subthalamic nucleus high- frequency stimulation applied at parameters alleviating parkinsonian signs regularized the firing pattern of pyramidal cells and restored their electrical membrane properties.

Related publication: [7]

6.13. Non-parametric resampling of random walks for spectral networks clustering

Participants: Fabrizio de Vico Fallani [Correspondant], Vincenzo Nicosia, Vito Latora, Mario Chavez.

Parametric resampling schemes have been recently introduced in complex network analysis with the aim of assessing the statistical significance of graph clustering and the robustness of community partitions. We proposed a method to replicate structural features of complex networks based on the non-parametric resampling of the transition matrix associated with an unbiased random walk on the graph. We tested this bootstrapping technique on synthetic and real-world modular networks and we showed that the ensemble of replicates obtained through resampling can be used to improve the performance of standard spectral algorithms for spectral clustering of graphs.

Related publication: [43]

6.14. Multiscale topological properties of functional brain networks during motor imagery after stroke

Participants: Fabrizio de Vico Fallani [Correspondant], Floriana Pichiorri, Giovani Morone, Marco Molinari, Fabio Babiloni, Febo Cincotti, Donatella Mattia.

In recent years, network analyses have been used to evaluate brain reorganization following stroke. However, many studies have often focused on single topological scales, leading to an incomplete model of how focal brain lesions affect multiple network properties simultaneously and how changes on smaller scales influence those on larger scales. In an EEG-based experiment on the performance of hand motor imagery (MI) in 20 patients with unilateral stroke, we observed that the anatomic lesion affects the functional brain network on multiple levels. In the beta (13–30 Hz) frequency band, the MI of the affected hand (Ahand) elicited a significantly lower smallworldness and local efficiency (Eloc) versus the unaffected hand (Uhand). Notably, the abnormal reduction in Eloc significantly depended on the increase in interhemispheric connectivity, which was in turn determined primarily by the rise of regional connectivity in the parieto-occipital sites of the affected hemisphere. Further, in contrast to the Uhand MI, in which significantly high connectivity was observed for the contralateral sensorimotor regions of the unaffected hemisphere, the regions with increased connectivity during the Ahand MI lay in the frontal and parietal regions of the contralaterally affected hemisphere. Finally, the overall sensorimotor function of our patients, as measured by Fugl–Meyer Assessment (FMA) index, was significantly predicted by the connectivity of their affected hemisphere. These results improve on our understanding of stroke-induced alterations in functional brain networks.

Related publication: [6]

6.15. Wavelet analysis in ecology and epidemiology: impact of statistical tests

Participants: Bernard Cazelles, Kevin Cazelles, Mario Chavez [Correspondant].

Wavelet analysis is now frequently used to extract information from ecological and epidemiological time series. Statistical hypothesis tests are conducted on associated wavelet quantities to assess the likelihood that they are due to a random process. Such random processes represent null models and are generally based on synthetic data that share some statistical characteristics with the original time series. This allows the comparison of null statistics with those obtained from original time series. When creating synthetic datasets, different techniques of resampling result in different characteristics shared by the synthetic time series. Therefore, it becomes crucial to consider the impact of the resampling method on the results. We have addressed this point by comparing seven different statistical testing methods applied with different real and simulated data. Our results showed that statistical assessment of periodic patterns is strongly affected by the choice of the resampling method, so two different resampling techniques could lead to two different conclusions about the same time series. Moreover, we showed the inadequacy of resampling series generated by white noise and red noise that are nevertheless the methods currently used in the wide majority of wavelets applications in epidemiology. Our results highlight that the characteristics of a time series, namely its Fourier spectrum and autocorrelation, are important to consider when choosing the resampling technique. Results suggest that data-driven resampling methods should be used such as the hidden Markov model algorithm and the ‘beta-surrogate’ method.

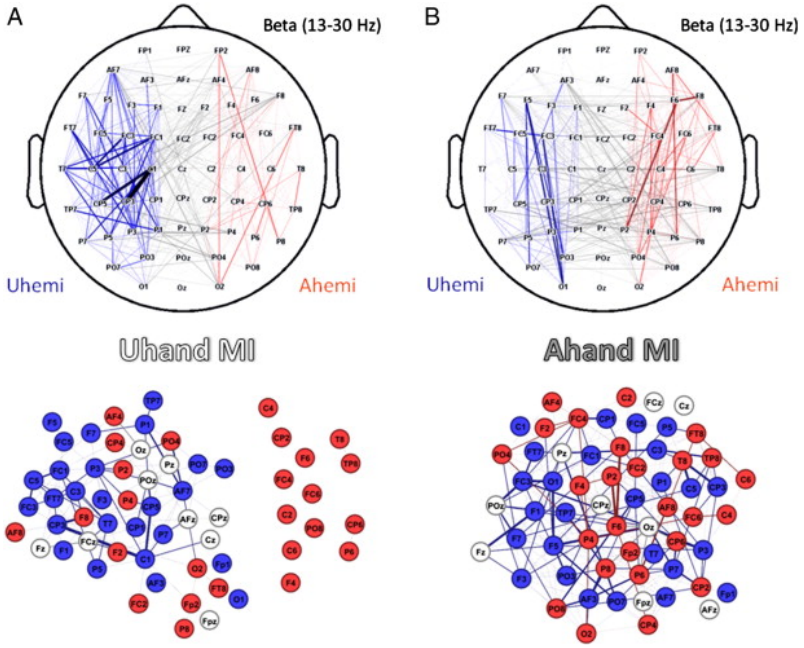


Figure 9. Grand average of brain networks in the Beta band during the MI of the unaffected Uhand and affected Ahand hand. Top plots: Scalp representation relative to Uhand (panel A) and Ahand (panel B) condition. Nodes are positioned according the actual EEG montage scheme. Blue and red lines denote the links within the unaffected (Uhemi) and the affected (Ahemi) hemisphere, respectively. Gray lines denote the inter-hemispheric links. The intensity of the color and the thickness of the lines vary as function of the number of patients exhibiting that significant link. Bottom part: graph representation of the brain networks relative to Uhand (panel A) and Ahand (panel B) condition. In this representation nodes are spatially repositioned through a force-based algorithm so that all the links are approximately of equal length with as few crossing edges as possible. Only links that were in common to more than 4 patients (20% of the sample) are illustrated here. Blue and red nodes indicate scalp electrodes placed over the undamaged (Uhemi) and damaged (Ahemi) hemisphere, respectively. The midline scalp electrodes (from Fpz to Oz) are illustrated as white nodes

Related publication: [2]

7. Bilateral Contracts and Grants with Industry

7.1. Patents

Participants: Thomas Similowski [Inventor], Mathieux Raux [Inventor], Pierre Pouget [Inventor], Jacques Martinerie [Inventor], Mario Chavez [Inventor].

Patent title: Procédé de caractérisation de l'état physiologique d'un patient à partir de l'analyse de son activité électrique cérébrale, et dispositif de surveillance faisant application

Publication date: 07.11.2013

Publication number: WO 2013/164462 Al

Abstract: The invention relates to a method for detecting a physiological state of a patient deviating from a reference physiological state, in which, after having determined, in Q frequency band, R reference matrices which correspond to the reference physiological state, the following steps are repeated in a loop: carrying out measurements, in M time segments, of an electroencephalographic signal; filtering and centring the measurements in Q frequency bands to obtain and determine MxQ scaled matrices of spatial covariance; for each time segment m, calculating a deviation from the reference physiological state, and comparing each of the deviations from the reference physiological state to a predefined threshold. The invention also relates to a monitoring device.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

8.1.1.1. ANR HM-TC

Participants: Olivier Colliot [Correspondant], Marie Chupin, Didier Dormont, Denis Schwartz, Dominique Hasboun, Linda Marrakchi-Kacem, Yohan Attal, Claire Cury.

Project acronym: HM-TC

Project title: Model of the hippocampo-cortical connectivity in "temporal consciousness" in normal and pathological memory derived from multimodal anatomical and functional brain imaging (aMRI, DT-MRI, MEG, fMRI)

Duration: Nov 2009- Nov 2014

Amount: 2M€

Coordinator: Olivier Colliot (ARAMIS) and Gianfranco Dalla Barba

Other partners: CENIR, ENS Cachan, Neurospin, Grenoble Institut des Neurosciences

Abstract: The aim of this project is to evaluate the role of the medial temporal lobe and its connections with various cortical regions in temporal consciousness related tasks and to derive a neuro-computational model of memory processing from multimodal imaging data. Temporal consciousness is defined as the ability to specify one's own time-location with respect to past, present and future, and is thus a more general framework than episodic memory. Based on an original cognitive model and relying on memory dysfunctions called confabulations, different groups of participants (controls, patients with Alzheimer's disease, patients with several memory disorders) will be evaluated through behavioural tests, MEG, anatomical, functional and diffusion-tensor MRI. New signal and image processing methods will be developed for all these modalities, in order to describe in a more robust and precise way both the anatomy and the function of the medial

temporal lobe. First, using in vivo ultra high field MRI acquisitions (7 Tesla), we will build a precise anatomical atlas of the hippocampus and its inner structure. This model will allow designing efficient MEG source reconstruction in these regions, and new methods to analyse anatomical and functional connectivity. Using the most recent mathematical achievements in the theory of diffeomorphic deformations, we will propose new registration and morphometry methods in order to analyze very precisely the structural alterations of the medial temporal lobe. These new methods will be applied to the neuroimaging data acquired for the project in order to analyse extensively the relationships between memory disorders and structural and functional brain alterations revealed by neuroimaging.

8.1.2. IHU

Participants: Olivier Colliot, Mario Chavez, Stanley Durrleman, Marie Chupin, Didier Dormont, Dominique Hasboun, Damien Galanaud, Fabrizio de Vico Fallani.

Project acronym: IHU-A-ICM

Project title: Institute of Translational Neuroscience

Founded in 2011

General Director: Bertrand Fontaine

The IHU-A-ICM program was selected, in 2011, in a highly competitive national call for projects. A 10-year, 55M€ program, has been implemented by a recently created foundation for scientific cooperation. Based on the clinical and scientific strenghts of the ICM and the hospital Department of Nervous System Diseases, it mainly supports neuroscience research, but is also invested in improving care and teaching. ARAMIS is strongly involved in the IHU-A-ICM project, in particular in WP6 (neuroimaging and electrophysiology), WP7 (biostatistics), WP2 (Alzheimer) and WP5 (epilepsy). We have started collaborations with the new bioinformatics/biostatistics platform (IHU WP7, head: Ivan Moszer), in particular through a joint project on the integration of imaging and genomics data.

8.1.3. CATI (Alzheimer Plan)

Participants: Olivier Colliot [Correspondant], Marie Chupin [Correspondant], Stanley Durrleman, Didier Dormont, Chabha Azouani, Ali Bouyahia, Johanne Germain, Xavier Badé, Hugo Dary, Ludovic Fillon, Takoua Kaaouana, Alexandre Routier, Sophie Lecomte.

Project acronym: CATI

Project title: Centre d'Acquisition et de Traitement des Images

Founded in 2011

Amount: 9M€

Coordinator: Jean-François Mangin

Other partners: Neurospin, CENIR, Inserm U678, IM2A

Abstract: The CATI project (funded by the National Alzheimer Plan for 9M€, 2.1M€ for ARAMIS) aims at creating a national platform for multicenter neuroimaging studies. CATI aims to be a national resource for the scientific, medical and industrial research community and will provide a wide range of services: access to a national acquisition network, standardization of acquisitions, image quality control, image analysis, databasing/archiving, meta-analyses. Through CATI, our team coordinates a large network composed of over 30 image acquisition centers. CATI already supports over 15 multicenter projects including the national cohort MEMENTO (2300 subjects). CATI is integrated with France Life Imaging (PI: F. Lethimonnier) and the Neugrid for you (N4U, PI: G. Frisoni) network.

8.1.4. Institut Carnot

Participant: Mario Chavez [Correspondant].

ARAMIS is supported by the "Programme de Maturation Carnot" for the following projects:

Etude des interactions cortex-respiration. (Coordinators: P. Pouget and M. Chavez)

Evaluating anesthetic depth using electroencephalographical recording in human and non-human primates. (Coordinators: P. Pouget and M. Chavez)

8.1.5. Other National Programs

Participants: Olivier Colliot, Marie Chupin, Stanley Durrleman, Didier Dormont, Damien Galanaud.

ARAMIS is a partner of the following national projects :

- PHRC (Programme Hospitalier de Recherche Clinique) PredictPGRN, co-funding by Alzheimer Plan, *Caractérisation multimodale prospective de la démence frontotemporale dûe à des mutations du gène PGRN à un stade symptomatique et présymptomatique*. (Coordinator : A. Brice)
- PHRC (Programme Hospitalier de Recherche Clinique) ImaBio3, co-funding by Roche (pharmaceutical industry), *Rôle des réactions cellulaires sanguines, inflammatoires et immunitaires anti-amyloïde centrales et périphériques dans la maladie d'Alzheimer débutante*. (Coordinator : M. Sarazin)
- PHRC (Programme Hospitalier de Recherche Clinique) CAPP, *Caractérisation linguistique, anatomique/métabolique et biologique des différentes formes d'aphasie primaire progressive : vers le rationnel pour des essais pharmacologiques et des rééducations du langage ciblées*. (Coordinator: M. Teichmann)

8.2. European Initiatives

8.2.1. FP7 Projects

Participants: Stefan Thurner, Vito Latora, Albert Diaz-Guilera, Maxi San Miguel, Cecilia Mascolo, Mirco Musolesi, Mario Chavez [Correspondant].

Project acronym: LASAGNE

Project title: multi-LAyer SpAtiotemporal Generalized NEtworks

Founded in 2012

Amount: 1.6M€

Coordinator: Stefan Thurner

Other partners: Medical University of Vienna, Queen Mary University of London, Universitat de Barcelona, Universitat de les Illes Balears,University of Cambridge, University of Birmingham.

Abstract: The aim of the LASAGNE project is to provide a novel and coherent theoretical framework for analysing and modelling dynamic and multi-layer networks in terms of multi-graphs embedded in space and time. To do this, we will treat time, space and the nature of interactions not as additional dimensions of the problem, but as natural, inherent components of the very same generalised network description. The theory will be validated on real-world applications involving large and heterogeneous data sets of brain networks, on- and off-line social systems, healthcare systems, and transportation flows in cities. The LASAGNE project will provide new quantitative opportunities in different fields, ranging from the prediction of pathologies to the diffusion of ideas and trends in societies, and for the management of socio-technological systems.

8.3. International Initiatives

8.3.1. Informal International Partners

S. Durrleman has an enduring collaboration with the Scientific Computing and Imaging (SCI) Institute at the University of Utah (USA). He is consultant for NIH Grant "4D shape analysis for modeling spatiotemporal change trajectories in Huntington's Disease "predict-HD". He is part of the PhD committees of J. Fishbaugh and A. Sharma supervised by professor Guido Gerig.

M. Chupin and O. Colliot have an enduring collaboration with the Center for Magnetic Resonance Research, University of Minnesota, USA (P-F Van de Moortele, T. Henry, M. Marjanska, K. Ugurbil) a leading center in 7T MRI.

D. Galanaud has an enduring collaboration with the Massachusetts General Hospital, Harvard University, USA (R. Gupta).

M. Chavez has enduring collaborations with the Center for Applied Medical Research, Pampelune, Spain (M. Valencia), the Departement of Physics, Queen Mary University of London, UK (V. Latora) and the Anatomical Neuropharmacology Unit, University of Oxford, UK (J. Mena-Segovia).

8.4. International Research Visitors

8.4.1. Visits of International Scientists

In September 2013, the team welcome James Fishbaugh, as part of its training as PhD candidate at the University of Utah under the supervision of professor Guido Gerig.

9. Dissemination

9.1. Scientific Animation

O. Colliot acts as a reviewer for NeuroImage, NeuroImage: Clinical, IEEE TMI, Human Brain Mapping, Neurobiology of Aging and MICCAI.

O. Colliot is a member of the Editorial Board of the ISTE-Wiley-Hermes "Neural Engineering" book series.

O. Colliot acts as an expert for the Canada Foundation for Innovation (CFI), Fonds National de la Recherche Scientifique (Belgium), Alzheimer Nederland, and the FCS Sciences et Technologies pour l'Aéronautique et l'Espace.

O. Colliot gave an invited presentation at the National Academy of Medicine (title: "Biomarqueurs IRM de la maladie d'Alzheimer: apport du traitement des images"), October 2013.

O. Colliot gave invited talks at the meeting of the French Society of Neurology (October 2013), at University College London (may 2013) and at the CERCO CNRS Toulouse (may 2013).

S. Durrleman gave an invited presentation at the Rank Prize Funds symposium "Medical Imaging meets Computer Vision" (march 2013)

S. Durrleman gave an invited presentation at the imaging seminar of Université Paris Dauphine (April 2013)

S. Durrleman was organizer of the MICCAI Workshop "Mathematical Fundation of Computational Anatomy" (MFCA) together with X. Pennec, S. Joshi, M. Nielsen, T. Fletcher and S. Sommer, which was held in Nagoya, Japan in September 2013.

S. Durrleman was part of the scientific committee of the conference "Geometric Science of Information" (GSI) held in August 2013 in Paris.

S. Durrleman acts as reviewer for Medical Image Analysis (MedIA), NeuroImage, NeuroImage: Clinical, International Journal on Computer Vision (IJCV), and for the conferences Medical Image Computing and Computer Aided Intervention (MICCAI) and Information Processing in Medical Imaging (IPMI).

M. Chavez co-organized the CNRS school "Graphical models for the characterisation of information flow in complex networks: Application in neuroimaging", which took place in June 2013 at the l'Institut National Polytechnique de Grenoble, France

M. Chavez is Associated Editor of the physics journal "Chaos, Solitons and Fractals"

M. Chavez acts as an expert for the French "Agence National de la Recherche (ANR)" and the "Fond National Suisse de la Recherche Scientifique (FNSRS)"

M. Chavez currently acts as reviewer for different journals such as P Natl Acad Sci USA; Phys Rev Lett; Phys Rev E; J. Neurosci Methods and Clin Neurophysiol.

D. Dormont is member of the board of the French Society for Neuroradiology.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master: Olivier Colliot coordinates the module "Méthodes d'imagerie médicale" of the Master 2 in Computer Science of Université Pierre et Marie Curie.

Master: Olivier Colliot, Master in Computer Science, 12 hours (eqTD), Université Pierre et Marie Curie

Master: Stanley Durrleman, Master in Computer Science, 8 hours (eqTD), Université Pierre et Marie Curie

Master: Olivier Colliot, Master in Cognitive Science, 4.5 hours (eqTD), Ecole Normale Supérieure (Ulm)

Master: Stanley Durrleman, Master in Applied Mathematics, 2 hours (eqTD), Ecole Normale Supérieure (Cachan)

Master: Marie Chupin, Master in Computer Science, 3 hours (eqTD), Université Pierre et Marie Curie

Master: Dominique Hasboun, Master in Biology, 4 hours, Ecole Normale Supérieure (Ulm)

Master: Dominique Hasboun, Master in Cognitive Science, 12 hours, Ecole Normale Supérieure (Ulm)

Master: Dominique Hasboun, Master in Biology, 15 hours, Université Pierre et Marie Curie

Master: Dominique Hasboun, Master in Medical Physics, 7 hours, Université Paris-Sud

Master: Fabrizio De Vico Fallani, Master in "Me´thodologies et applications en imagerie me´dical", 3 hours (eqTD), Université Pierre et Marie Curie

Master: Damien Galanaud, Master in Medical Physics, 4 hours, Université Paris-Sud

Engineering school: Olivier Colliot, 4.5 hours (eqTD), Telecom ParisTech

Engineering school: Dominique Hasboun, 3 hours, ENSEA

Medical school: Didier Dormont is the Director of the University Diploma (DIU) “Diagnostic and Therapeutic Neuroradiology", Université Pierre et Marie Curie

Medical school: Didier Dormont, Courses for Medical Students, Université Pierre et Marie Curie

Medical school: Dominique Hasboun, Courses for Medical Students, Université Pierre et Marie Curie

Medical school: Damien Galanaud, Courses for Medical Students, Université Pierre et Marie Curie

Medical school: Didier Dormont organizes and participates to the practical teaching of Neuroradiology for Medical Students in the Department of Diagnostic Neuroradiology of Pitié Salpêtrière University Hospital

Medical school: Didier Dormont organizes and participates to the practical teaching of Neuroradiology for Radiology Specializing Residents in the Department of Diagnostic Neuroradiology of Pitié Salpêtrière University Hospital

Medical school: Didier Dormont, Courses to the university diplomas (DU) : "Maladie d'Alzheimer", and "Imagerie Vasculaire non Invasive"

Medical school: Damien Galanaud, courses to the University Diploma (DIU) “Diagnostic and Therapeutic Neuroradiology", Université Pierre et Marie Curie

Medical school: Dominique Hasboun, courses to the University Diploma (DIU) “Diagnostic and Therapeutic Neuroradiology", Université Pierre et Marie Curie

Paramedical studies: Dominique Hasboun, Psychomotricity, 50 hours, Université Pierre et Marie Curie

9.2.2. Supervision

HdR : Fabrizio de Vico Fallani, Université Pierre et Marie Curie, Oct 7th, 2013

PhD : Thomas Samaille, Segmentation automatique des anomalies de la substance blanche du sujet âgé, Université Pierre et Marie Curie, June 4th 2013, advisor: Didier Dormont, co-advisors: Marie Chupin, Olivier Colliot

PhD in progress : Claire Cury, Approches morphométriques pour les grandes bases de données - Application à l'imagerie génétique, Université Pierre et Marie Curie, Started in 2011, advisor: Olivier Colliot

PhD in progress : Takoua Kaaouana, Détection automatique et analyse des micro-saignements cérébraux : Application à des séquences d'imagerie cliniques et à de grandes populations de sujets, Université Pierre et Marie Curie, Started in 2012, advisor: Didier Dormont, co-advisors: Marie Chupin, Ludovic de Rochefort

PhD in progress: Pietro Gori, Statistical analysis of neuronal connectivity in patients with Gilles de la Tourette syndrome based on anatomical structures extracted from both structural and diffusion images, Université Pierre et Marie Curie, Started in 2012, advisors: N. Ayache, O. Colliot and S. Durrleman

PhD in progress: Jean-Baptiste Schiratti, Méthodes et algorithmes pour l'analyse statistique de données anatomiques longitudinales – application à la caractérisation des phases pré-symptomatiques des maladies neurodégénératives, Ecole Polytechnique, Started in 2013, advisors: S. Allassonnière and S. Durrleman

PhD in progress: Barbara Gris, Approche modulaire des me´thodes de grandes de´formations pour l'appariement de formes, Ecole Normale Supérieure de Cachan, Started 2013, advisors: A. Trouvé and S. Durrleman

Master 2: Lorraine Hamelin, Morphométrie des sillons cérébraux dans la maladie d'Alzheimer, Université Pierre et Marie Curie, Feb-Sept 2013, advisors: Olivier Colliot and Marie Sarazin

Master 2: Pauline Bezivin, Etude comparative de biomarqueurs longitudinaux dans la maladie d'Alzheimer, Université de Rennes, Mar-Aug 2013, advisors: Olivier Colliot, Stanley Durrleman and Grégory Operto

Internship: Fanny Cohen, Morphométrie dans une forme génétique de démence fronto-temporale, Telecom Bretagne, July 2012-June 2013, advisor: Olivier Colliot

Internship Master 1: Andrei Besedin, Evaluation de métriques pour le recalage iconique - application au ciblage pré-opératoire en stimulation cérébrale profonde, February 2013 - August 2013), Master Bioengineering, Université Paris Descartes, advisors: S. Durrleman, E. Bardinet and S. Fernandez-Vidal

Master 2: Margherita Tringali, Mise en oeuvre d'un protocole expérimental pour la détection des patterns d'activité cérébrale par une Interface Cerveau Machine, Université Pierre et Marie Curie, Feb-Sept 2013, advisors: Mario Chavez and Fabrizio De Vico Fallani

Master 1: Boris Tchangang, Réalisation d'une interface graphique pour l'analyse de signaux EEG sous le logiciel Matlab, Institut Supérieur des Bio-Sciences, Université Paris Est, Créteil, Feb-Sept 2013, advisors: Mario Chavez

Internship: Martina Corazzol, Hierarchy of neural organisation in the zebra fish spinal cord: causality analysis of in-vivo calcium imaging data, April-August 2013, advisor: Fabrizio De Vico Fallani

9.2.3. Juries

Olivier Colliot participated, as referee, to the PhD committee of Jean-Baptiste Fiot (Université Paris-Dauphine, CEREMADE), entitled "Mathematical methods of image analysis for cross-sectional and longitudinal population studies", defended on Sep 17th, 2013 (supervisor: Laurent D. Cohen).

Olivier Colliot participated, as examiner, to the HDR committee of Fabrizio de Vico Fallani (Université Pierre et Marie Curie), defended on Oct 7th, 2013.

Stanley Durrleman participated, as examiner, to the PhD committee of Olivier Mirat (Université Paris Descartes), entitled "Analyse haut-débit du comportement spontané d'un organisme modèle "simple"", defended on Sept 25, 2013 (supervisor: Claire Wyart).

Stanley Durrleman participated, as examiner, to the PhD committee of Alexandre Imperiale (Université Pierre et Marie Curie), entitled "Imaged-based data assimilation methods for the personalization of mechanical models", defended on Dec 11, 2013 (supervisors: D. Chapelle and Ph. Moireau).

Stanley Durrleman partipates to the PhD committees of James Fishbaugh and Anuja Sharma, PhD students at the University of Utah under the supervision of professor Guido Gerig.

Fabrizio De Vico Fallani partipates to the PhD committee of Jonas Chatel Goldman, PhD student at the Université Joseph Fourier (Genoble) under the supervision of Marco Congedo.

Didier Dormont participated as examiner (he was also the Supervisor of the PhD with Marie Chupin) to the PhD committee of Thomas Samaille entitled "Segmentation automatique des anomalies de la substance blanche du sujet âgé.", defended on June the 4th of 2013.

Didier Dormont participated as examiner to the committee of the Medical Thesis (Paris-Sud University) of Gersende Favé entitled "Apport du tenseur de diffusion et de la spectroscopie comme outil pronostic de l'évolution neurologique des patients atteints d'hémorragie méningée grave », defended on June the 17th of 2013.

Didier Dormont participated as examiner to the committee of the Medical Thesis (Paris VI University) of Raphael Dautry, defended on June the 24th of 2013.

Didier Dormont participated as examiner to the committee of the Medical Thesis (Paris-Sud University) of Nadya Pyatigorskaya entitled "Mesure de la charge en fer par IRM dans les formes génétiques de la maladie de Parkinson », defended on September the 12th of 2013.

Didier Dormont participated as examiner to the committee of the Medical Thesis (Paris V University) of Marie Lémery Magnin entitled "Etude de la perfusion des gliomes de bas grade de l'enfant», defended on September the 30th of 2013.

9.3. Popularization

The team is involved in the BrainCatalogue project (coordinator: Roberto Toro, Institut Pasteur) dedicated to the popularization of neuroanatomical knowledge. The project features MRI scans and 3D reconstructions for various vertebrates species (bear, mouse, macaque, dolphin, leopard, rhinoceros, human, squirrel ...).

The team has participated to the ICM "Donor days".

10. Bibliography

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