Development of normative and pathological models of cortical folding by machine learning on graphs

1. DESCRIPTION OF THE PHD THESIS PROJECT

1.1 OBJECTIVES OF THE PROJECT BASED ON THE CURRENT STATE OF THE ART

In neuroscience, characterizing the shape of the brain is a key issue in understanding its organization and its dysfunctions in psychiatric and neurological diseases. For this purpose, non-invasive brain imaging techniques, and in particular Magnetic Resonance Imaging (MRI), offer unparalleled opportunities to identify markers of these pathologies, such as for example cortical folding abnormalities as described in [1].

We have recently identified a new set of features for characterizing cortical folding, the sulcal pits, and developed a method for automatic extraction of these points from anatomical MRI scans [2]. We then proposed to model cortical folding patterns using graphs, defined a graph kernel that allows to compare the patterns modeled, and demonstrated the relevance of these approaches by integrating them in a brain morphometric method based on machine learning [3]. This approach is illustrated on Fig.1.

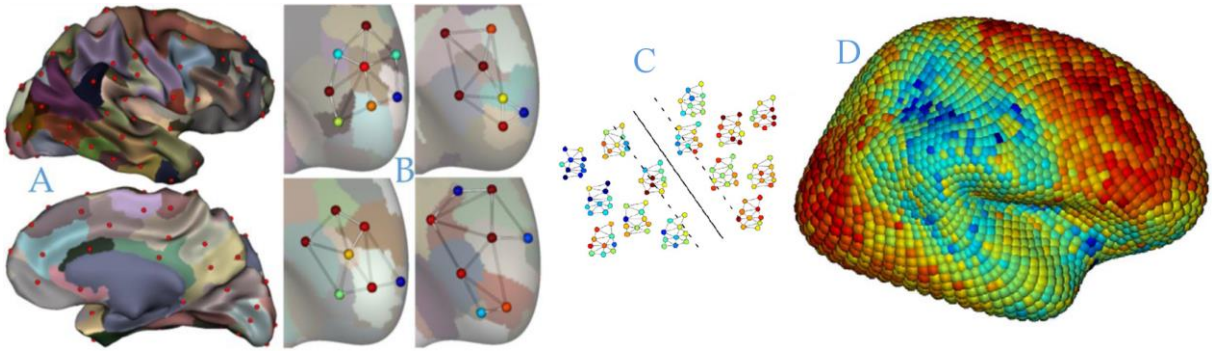

Figure 1 (adapted from [3]) : illustration of the modeling of cortical folding patterns as attributed graphs (A,B) used for a classification task (C) allowing to visualize the differences in the shape of the cortex between two populations of subjects (D).

The objective of this PhD thesis is to extend this work both in terms of methodological developments and large-scale applications, allowing to refine the imaging markers of psychiatric and neurological pathologies.

For references [1] [2] [3], see the publications from our team below.

1.2 METHODOLOGY

First, the student will exploit the databases recently made available by the international scientific community (Human Connectome Project https://www.humanconnectome.org/, UK Biobank https://www.ukbiobank.ac.uk/, ABCD https://abcdstudy.org/, ABIDE http://fcon_1000.projects.nitrc.org/indi/abide/) to develop normative models of cortical folding and its development during brain maturation. This will require work on scaling up our methods in order to be able to manage these databases whose sizes are one to two orders of magnitude larger than those currently in use.

Secondly, the student will develop new methods of graph processing and machine learning. A large variety of graph kernels can be investigated to optimize and adapt the graph similarity measures depending on the application [7-8]. Spectral analysis and deep convolutional networks on graphs (e.g. [4-6]) will allow to study the multi-scale nature of folding patterns.

References:

[4] P. Veličković, G. Cucurull, G. Casanova, A. Romero, P. Liò, Y. Bengio, Graph attention networks. ICLR 2018.
[5] W.L. Hamilton , R. Ying, J. Leskovec, Inductive representation learning on large graphs. NIPS 2017.
[6] J. Atwood, D. Towsley, Diffusion-convolutional neural networks. NIPS 2016.
[7-8] see the publications from our team below.

1.3 WORK PLAN

The two lines of research described above can be run in parallel. A plausible publication plan would be: Year #1-novel application of the current method to a large dataset; Year #2-methodological developments and corresponding technical publication; Year #3-application of the new method to a large dataset.

1.4 SUPERVISOR AND RESEARCH GROUP DESCRIPTION

This PhD project will be co-supervised by Guillaume Auzias, François-Xavier Dupé and Olivier Coulon. As further described in section 4 and visible in the publication list below, this project lies at the crossroad between their respective domains of expertise. In addition, the candidate will benefit from the joint efforts from each of their research teams:

G.Auzias and O.Coulon are principal members of the MeCA team from the Institute for Neurosciences of La Timone (INT, http://www.int.univ-amu.fr/?lang=en). MeCA is a computational anatomy and methods team with a solid experience in developing methods for surface-based analysis of cortical morphometry. The INT is one of the top French neuroscience research institutes with 150 staff members gathered in 10 inter-disciplinary teams examining different aspects of the cerebral organization. It is located on the medical campus of Aix-Marseille University.

F.X. Dupé is member of the QARMA team from the Laboratoire d'Informatique et Systèmes (LIS, http://qarma.lis-lab.fr), a machine learning team with a solid experience on both theoretical and applicative aspect of machine learning with a strong emphasis on deep learning. The LIS is Aix-Marseille University's computer science laboratory exploring the different aspect of computer science from automatic to theoretical conception of computers.

2. RECENT PUBLICATIONS

[1] G. Auzias, M. Viellard, S. Takerkart, N. Villeneuve, F. Poinso, D. Da Fonseca, N. Girard, C. Deruelle, 'Atypical sulcal anatomy in young children with autism spectrum disorder', NeuroImage: Clinical, vol. 4, pp. 593–603, 2014.

[2] G. Auzias, L. Brun, C. Deruelle, and O. Coulon, 'Deep sulcal landmarks: Algorithmic and conceptual improvements in the definition and extraction of sulcal pits', NeuroImage, vol. 111, pp. 12–25, May 2015.

[3] S. Takerkart, G. Auzias, L. Brun, and O. Coulon, 'Structural graph-based morphometry: A multiscale searchlight framework based on sulcal pits', Medical Image Analysis, vol. 35, pp. 32–45, Jan. 2017.

[7] Takerkart, S., Berton, G., Malfait, N., & Dupé, F. X. (2017, May). Learning from Diffusion-Weighted Magnetic Resonance Images using graph kernels. In International Workshop on Graph-Based Representations in Pattern Recognition (pp. 39-48). Springer, Cham.

[8] Bougleux, S., Dupé, F. X., Brun, L., & Mokhtari, M. (2012, November). Shape similarity based on a treelet kernel with edition. In Joint IAPR International Workshops on Statistical Techniques in Pattern Recognition (SPR) and Structural and Syntactic Pattern Recognition (SSPR) (pp. 199-207). Springer, Berlin, Heidelberg.

[9] Sellami, A., Dupé, F. X., Cagna, B., Kadri, H., Ayache, S., Artières, T., & Takerkart, S. (2020). Mapping individual differences in cortical architecture using multi-view representation learning. IEEE IJCNN 2020.

3. EXPECTED PROFILE OF THE CANDIDATE

We are seeking a PhD candidate who meets the following requirements:

1) Master degree in data science, electrical engineering or a similar field;

2) Proficient with computer programming (python will be our language of choice);

3) Good knowledge and/or experience in signal and image processing,

4) Good knowledge and/or experience in machine learning / data science / multivariate statistics.

Experience with graph structures would be a plus. Prior experience in neuroscience is not a requirement, but interest in the field and high motivation are of course necessary. Good reading/writing/communication skills in English are also essential.

4. SUPERVISORS' PROFILE

Guillaume Auzias was recruited as a CNRS researcher on November 2017, He supervised more than 20 master fellows and research engineers, and is currently co-supervisor of one PhD thesis, started on September 2018.

Characterizing cortical folding pattern both locally and globally is at the center of the research program of Guillaume Auzias from his PhD on spatial alignment across individuals (Auzias et al. 2008; Auzias et al. 2011;

Mangin et al. 2016) to his post-doctoral work on folds organization and alignment (Auzias et al. 2013), and sulcal pits in adults (Auzias, Brun, et al. 2015; Takerkart et al. 2017). He has an interdisciplinary training in neuroimaging with a background in both Applied Mathematics and Computer Sciences (PhD) and neurosciences (post-doctoral training). He published research articles in both fields with new methods for neuroimaging (IEEE TMI) and applications in neurosciences and clinical neuroimaging (J Neurosci, Biol Psychiatry, Am J Psychiatry).

He created the Marseille Young Autism Database (MYAD: http://www.int.univ-amu.fr/MYAD) through collaborations between INT and the Neuroradiology and Pediatric Psychiatry Departments of CHU Timone. MYAD led to several publications from the team (Auzias et al. 2014; Brun et al. 2016) and as well as from the large international consortium ENIGMA using both our dataset and analysis methods (van Rooij et al. 2018; Postema et al. 2019). G Auzias is one of the main contributors of the cortical surface toolbox developed by MeCA team (https://meca-brain.org/software/, https://gauzias.github.io/slam/). This free and open source toolbox is distributed in the BrainVISA software (http://brainvisa.info). It has been used by several research group outside the team such as in (Le Guen et al. 2018; Le Guen et al. 2017).

François-Xavier Dupé was recruited as a computer science assistant professor in September 2011. He has supervised several master and is currently co-supervisor of one post-doc. He did his PhD around two problematics: image processing and graph classification. Now his main research subjects are sparse optimization (using greedy methods) and graph learning (using kernels and more recently neural networks). He is involved in several interdisciplinary projects with specifically one with INT around graph regression (Sellami et al. 2020).

Olivier Coulon is a senior researcher and leader of the MeCA team. He supervised 8 PhD theses and many Master students.

VISA DU RESPONSABLE DE L'INSTITUT ET DU DIRECTEUR DE LABORATOIRE CONCERNÉS

Visa du responsable de l'institut,	**Visa du directeur du laboratoire,**
NOM Prénom	**NOM Prénom**
	Masson, Guillaume
Fait à Marseille, le 15/05/2020	Fait à Marseille, le 14 mai 2020
Signature	Signature

Institut Neurosciences Timone
Directeur
Guillaume Masson