Master 2 Internship - 2024

Anatomy and microstructure informed tractography for connectivity evaluation

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Keywords: diffusion MRI, microstructure, tractography, connectivity, optimization, Riemannian geometry.

Context:

Magnetic resonance imaging (MRI) is a non-invasive imaging method that allows the visualization of the brain. In particular, it can detect abnormalities in brain structure associated with pathology, potentially before the onset of symptoms. A recent development in MRI has been quantitative MRI, a set of techniques for characterizing quantitative parameters of the brain's interne structure: its microstructure. Relaxometry [1], for example, uses advanced model estimation methods to characterize the brain's magnetic properties and the proportion of the different tissues, such as myelin, that are essential for normal brain function. Another modality, diffusion MRI [2], quantifies the diffusion of water molecules (constrained by their environment), enabling us to infer a number of microstructure parameters, such as the arrangement of nerve fibers, the different tissues making them up and their properties (axon diameter, proportion of neuronal cell bodies, etc.). Studies on diffusion MRI have shown a great potential to highlight subtle changes of microstructure in the brain [2] and provides an effective tool to investigate the neural mechanisms that may contribute to the emergence of pathologies such as multiple sclerosis (MS) [3] and depression [4]. However, these studies are still limited, as they do not take into account the internal architecture of brain fibers. In MS, for example, conventional diffusion measurements correlate poorly with a patient's clinical status at a given time t, and with disease evolution [5]. To overcome this, recent developments have focused on the study of diffusion MRI parameters along fibers [6] or on the study of connections between different brain regions (the connectome) [7].

Although very promising, such approaches are still limited for several reasons. Firstly, most of the studies use a simple diffusion model such as diffusion tensor imaging (DTI) , which cannot estimate fibers with different orientation in one voxel in complex areas. Moroever, the interpretation of changes in the measured diffusion tensor is complex and should be performed with care. Furthermore, the estimation of cerebral fibers (tractography [8], illustrated in figure 1) is not yet reliable. A recent study [9] highlighted a number of problems, not least the excessive presence of false positives, which require manual filtering by the user - an arduous and time-consuming task. To overcome these limitations, more complex models capable of representing multiple orientations within a voxel were subsequently developed. Among them, multi-fiber models aims to recover the fiber orientation distribution (ODF) within a voxel [10]. These methods have the ability to better differentiate crossing fibers during tractography.

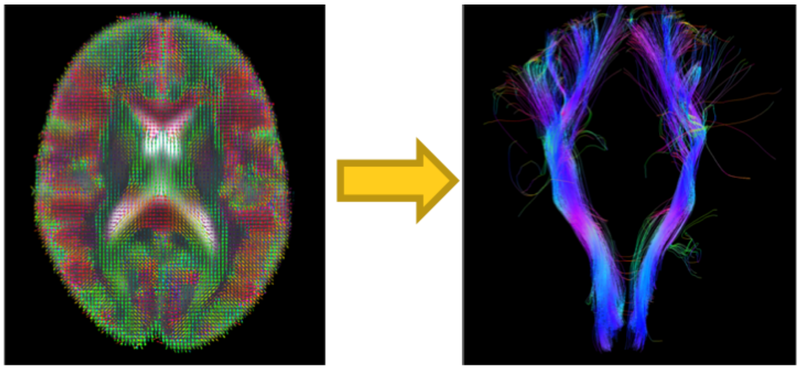

Figure 1 – Exemple de tractographie du faisceau cortico-spinal.

Despite this, these fiber estimation methods need to be improved [9] and new approaches have been proposed that include anatomical a priori to guide the algorithms in complex regions. In the Empenn team, we are currently developing methods for creating anatomical a priori using Riemannian geometry, for use in tractography, as described in figure 2.

Aims of the internship:

This internship will focus on two major subjects:

- Improving a priori estimation using microstructural features to guide tractography. This work will be based on techniques developed during Thomas Durantel's thesis (Fig. 2.b).

- Incorporation of anatomical a priori - fiber bundle atlas, microstructural information from relaxometry or diffusion imaging along known, manually delineated fibers - and data to help tractography and avoid false positives (Fig 2 c.).

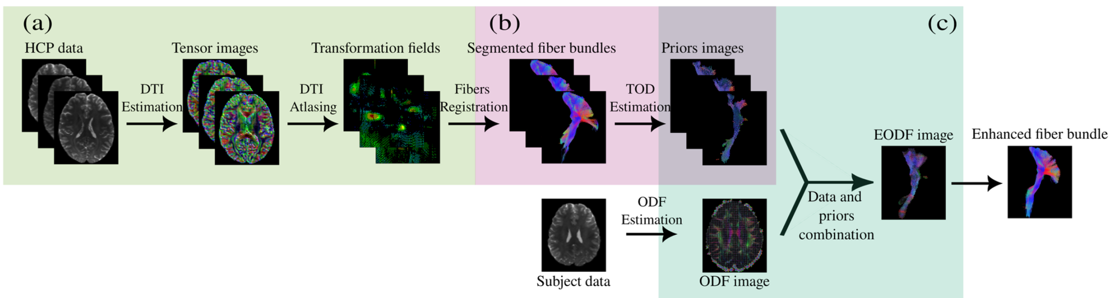

Figure 2 – Overview of the microstructure informed tractography method

The methods developed will be based on track orientation distribution (TOD) approaches and on the Riemannian optimization tools and geometry [11].

The developed approach will be tested on a cohort of patients suffering from depression, with the aim of better estimating the microstructure and thus better understanding the neuronal modifications caused by this disease.

Location: The recruited person will work at Inria/IRISA, UMR CNRS 6074, among the Empenn U1228 team. The work will be in close link with the research MRI platform Neurinfo (http://www.neurinfo.org) and clinicians working on depression.

Requirements: We look for candidates strongly motivated by challenging research topics in neuroimaging. The applicant should present a good background in applied mathematics. Basic knowledge in image processing would be a plus. Good knowledge of computer science aspects is also mandatory, especially in Python and C++.

References :

[1] Paul Tofts. Quantitative MRI of the brain : measuring changes caused by disease. Wiley, 2004.

[2] Peter J Basser, James Mattiello, and Denis LeBihan. Mr diffusion tensor spectroscopy and imaging. Biophysical journal, 66(1) :259–267, 1994.

[3] M. Rovaris, A. Gass, R. Bammer, S. J. Hickman, O. Ciccarelli, D. H. Miller, and M. Filippi. Diffusion MRI in multiple sclerosis. Neurology, 65(10) :1526–1532, 2005.

[4] Julie Coloigner, Jean-Marie Batail, Olivier Commowick, Isabelle Corouge, Gabriel Robert, Christian Barillot, and Dominique Drapier. White matter abnormalities in depression : a categorical and phenotypic diffusion MRI study. Neuroimage-Clinical, 22 :101710, February 2019.

[5] C R Guttmann, S S Ahn, L Hsu, R Kikinis, and F A Jolesz. The evolution of multiple sclerosis lesions on serial MR. American Journal of Neuroradiology, 16(7) :1481–1491, 1995.

[6] Stephen M. Smith, Mark Jenkinson, Heidi Johansen-Berg, Daniel Rueckert, Thomas E. Nichols, Clare E. Mackay, Kate E. Watkins, Olga Ciccarelli, M. Zaheer Cader, Paul M. Matthews, and Timothy E.J. Behrens. Tract-based spatial statistics : Voxelwise analysis of multi-subject diffusion data. NeuroImage, 31(4) :1487 – 1505, 2006.

[7] Hae-Jeong Park and Karl Friston. Structural and functional brain networks : From connections to cognition. Science, 342(6158), 2013.

[8] Ben Jeurissen, Maxime Descoteaux, Susumu Mori, and Alexander Leemans. Diffusion mri fiber tractography of the brain. NMR in Biomedicine, 32(4) :e3785, 2019. e3785 NBM-17-0045.R2.

[9] Klaus H. Maier-Hein, Peter F. Neher, Jean-Christophe Houde, et al. The challenge of mapping the human connectome based on diffusion tractography. Nature Communications, 8(1) :1349, 2017.

[10] Tuch DS, Reese TG, Wiegell MR, Wedeen VJ. Diffusion MRI of complex neural architecture. *Neuron.* 2003;40:885–995.

[11] Dhollander, Thijs, et al. "Track orientation density imaging (TODI) and track orientation distribution (TOD) based tractography." *NeuroImage* 94 (2014): 312-336.