Thesis Proposal

October 17, 2022

Contents

1 Introduction

1.1 Diffusion MRI Background

Use Derek Jones' book. Use Maxime's paper HARDI.
There is a Fourier relationship between the signal attenuation and the diffusion propagator such that

$$E\left(\vec{q},t\right)=\int_{\mathbb{R}^3}p\left(\vec{r},t\right)exp\left(-2\pi i\vec{q}^T\vec{r}\right)d\vec{r} \tag{1}$$

$$E\left(\mathbf{q},t\right)=\int_{\mathbb{R}^3}p\left(\mathbf{r},t\right)exp\left(-2\pi i\mathbf{q}^T\mathbf{r}\right)d\mathbf{r} \tag{2}$$

1.2 State-of-the-art

1.2.1 Diffusion Spectrum Imaging

1.2.2 Q-Ball Imaging

1.2.3 Diffusion Orientation Transform

1.2.4 Symmetric Tensor Decomposition

1.2.5 Spherical Deconvolution Methods

1.2.6 Diffusion Basis Functions Decomposition

1.2.7 Multi-Tensor

1.2.8 DIAMOND

1.3 Problem Statement

Although the literature contains a wide variety of techniques for resolving crossing fascicles, most of these methods provide information only about the orientation of crossing fascicles but not about the microstructure.
Classical measures like FA with DTI are very sensitive to white matter anomalies . However, it is now very well-known that FA is not specific, i.e. several different microstructure scenarios may lead to the same FA, see Figure 1. For example, the following scenarios could lead to the same FA of 0.4 :

- Crossing fiber voxel.
- Single fiber population demyelinating (going from FA of ~0.7 to 0.4).
- Voxel that has partial volume with a CSF.
- Isotropic freewater from neuroinflammation contaminating the voxel leading to a drop of a high FA voxel to a low FA of 0.4.

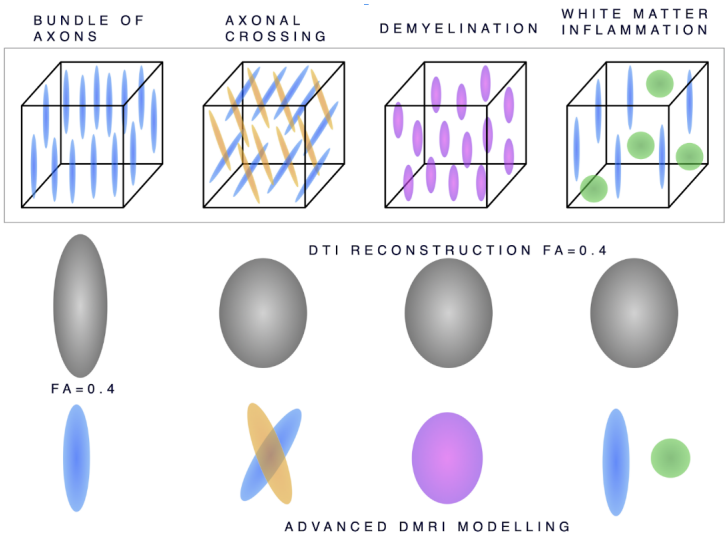

Figure 1: Limitations of DTI and potential of advanced diffusion MRI modeling for improved brain connectivity mapping and track-specific white matter tissue assessment.

It is thus clear that each fascicle that traverses a voxel should have its diffusivities (fascicle-MD, fascicle-AD and fascicle-RD) and fiber-specific FA (fascicle-FA), which is recently also coined fixel-based FA (a fixel is a fiber element) . Fixel-based analysis needs to be translated to neurodegenerative diseases and this is still a very important open problem.

1.4 Objective

Our main objective is to setup a robust (to noise and crossing fibers) pipeline for the automatic extraction and statistical analysis of track-specific white matter measures. Estimated fixel-based orientations and metrics will be used as indirect proxies to axon loss, demyelination and neuroinflammation. In particular, the fixel-based radial diffusivity (fixel-RD) could help to account for demyelination in MS patients as in [22]. In order to achieve this, there are two main problems that have to be addressed:

1. Fast, accurate and robust to noise and fiber crossing voxel-wise estimation of fixel-based metrics in diffusion MRI signal using the multi-tensor based method MRDS. This demands to improve the model selector step in MRDS to better estimate the number of tensors per voxel. Besides, parallezation of MRDS is necessary to ensure fast fitting of the MRDS method to the diffusion MRI signals.

2. Multimetric analysis of white matter tracts in different fiber bundles. It's required to adapt the tractometry_flow pipeline to integrate the MRDS metrics into the statistical analysis.

Although automating tract-profiling and metrics for white matter could improve brain connectivity mapping through crossing fiber regions and pathologies in the human brain, we will focus to demostrate the application of our pipeline to multiple sclerosis (MS) disease.

2 Methods

2.1 Data

2.1.1 Synthetic Data

2.1.2 In-Vivo Data

2.2 Preprocessing

2.2.1 TractoFlow

2.2.2 Rician Bias Correction

2.3 MRDS

2.4 Tractometry

3 Results

3.1 Experiments on Synthetic Data

3.2 Experiments on In-Vivo Data

3.2.1 Controls

3.2.2 MS Patients

4 Research Activities

4.1 Expected Schedule

Fall 2022

- Attending ISMRM 2022 Workshop on Diffusion MRI.
- Running MRDS on myelo_inferno control subjects.
- Submission of the abstract to ISMRM 2023 (November 9th).
- Thesis Proposal Presentation.

Winter 2023

- Parallelization of MRDS using CUDA or OpenCL.
- Improving model selector in MRDS using NUFO maps and/or tractography with COMMIT.

Summer 2023

- Preparing abstract about MRDS modifications.
- Attending ISMRM 2023 Annual Meeting & Exhibition.

Fall 2023

- Submission to ISMRM 2024
- Intership with NYU MRI Biophysics Group.

Winter 2024

- Submission to a journal.

Summer 2024

- Thesis writing
- Intership with Imeka integrating MRDS.

Fall 2024

- Thesis Submission
- Thesis Defense

4.2 Conference Abstracts & Journal Pubblications

- Robust Estimation of Fascicle-based Fractional Anisotropy on Fiber Crossings [17].
- Tractography from Gaussian multi-compartmental ODFs [18].
- Structural connectivity estimates are accurate: the outcome of diffusion-simulated connectivity (DiSCo) challenge [19].
- Real-Time Rendering of Massive Multi-Tensor Fields Using Modern OpenGL [20].
- paper about MRDS optimization.
- paper about results of the study using MRDS and tractometry_flow on the myelo_inferno.

4.3 Collaborations

Imeka Intership with Imeka Solutions Inc.; a company specialized in brain imaging specifically white matter, neuroinflammation, free-water and more. We will develop mechanisms and modify others already in place to integrate the MRDS-based pipeline into the Imeka's software infrastructure. This could enable the ability to test the pipeline on large public and clinical Imeka databases with more than $5,000$ MRI exams (Duration: 3-6 months).

NYU Collaboration with the NYU MRI Biophysics Group, which is one of the most relevant laboratories in the field. It will focus on multimetric analysis of white matter tracts in the multi-compartment standard model (Duration: 3-6 months).

UMC Possible Collaboration with Chen-Pei Lin applying MRDS to her multi-shell post-mortem Parkinson brain data.

5 Conclusions

References

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