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Tractography Based Visual Diagnostics

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Dresden, May 24, 2020

Task Description

The aim of the project is to perform visual diagnosis of healthy and diseased subjects based on fiber tracts derived from diffusion MRI (dMRI) volume of the human brain. The goals are:

1) Literature review on state-of-the-art methods and toolboxes related to dMRI volume pre-processing, fiber orientation estimation, fiber tracking and tract segmentation.
2) Pre-processing of the dMRI datasets to eliminate noise and prevalent distortion/motion correction.
3) Study and implementation of fiber orientation estimation at a single voxel resolution of dMRI volume.
4) Study and implementation of fibï¿¼er tracking and segmentation methods using Region of interest (ROI).
5) Qualitative and Quantitative evaluation of tracking and segmentation methods for healthy and diseased subjects.

Note: The team consists of 4 members with 3 participants for CMS-VC-TEA.

Optional goals:

a) Study and implement a VR user interface to perform immersive evaluation of fiber tract results.

Declaration of authorship

I hereby declare that I wrote this thesis on the subject

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independently. I did not use any other aids, sources, figures or resources than those stated in the references. I clearly marked all passages that were taken from other sources and cited them correctly.

Furthermore I declare that – to my best knowledge – this work or parts of it have never before been submitted by me or somebody else at this or any other university.

Dresden, May 24, 2020

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Contents

1 Introduction

TODO

- Check references of section about ad
- review glossary. any "tba"?
- emph for acrfull
- definition of MRI, dMRI
- explanation dti, fa

1.1 Alzheimer's Disease (AD)

One example for an application of dMRI is the analysis of *Alzheimer's Disease (AD)*. Symptoms of this disease include short-term memory disorder and disorientation in space and time in its early stages, as well as long-term memory disorder, disorientation in situation and person, and semantic paraphrases later on.

The most common doctrine currently relies on the *Amyloid Hypothesis*, naming the accumulation of amyloid-β peptide Aβ42 in structures of the hippocampus, forebrain and neocortex as cause of the disease. The reasons for the amyloid-β peptide's neurotoxicity are still being discussed[Haa09].

Meanwhile, recent studies using PET imaging have contradicted this hypothesis, evaluating the accumulation of Aβ42 to be a common process in the elderly[MLS+06][ANS+08] while showing only weak correlations with clinical disease syndromes[RJF+08][RER+10][LVS+11][RKD+12]. Instead, it has been suggested to view AD as a large-scale network disconnection syndrome, associated with said protein accumulation as well as cortical atrophy, and functional disconnections between brain regions[CPT16].

Some success in analyzing this network disconnection has been made with a novel approach called *fixel-based analysis (FBA)*[RTS+17]. The following paragraphs refer to a study analyzing the differences between white matter structures of AD patients and healthy individuals[MRD+18] using FBA.

Figure 1.1 shows a partial human tractography. The marked area in subfigure B includes the centrum

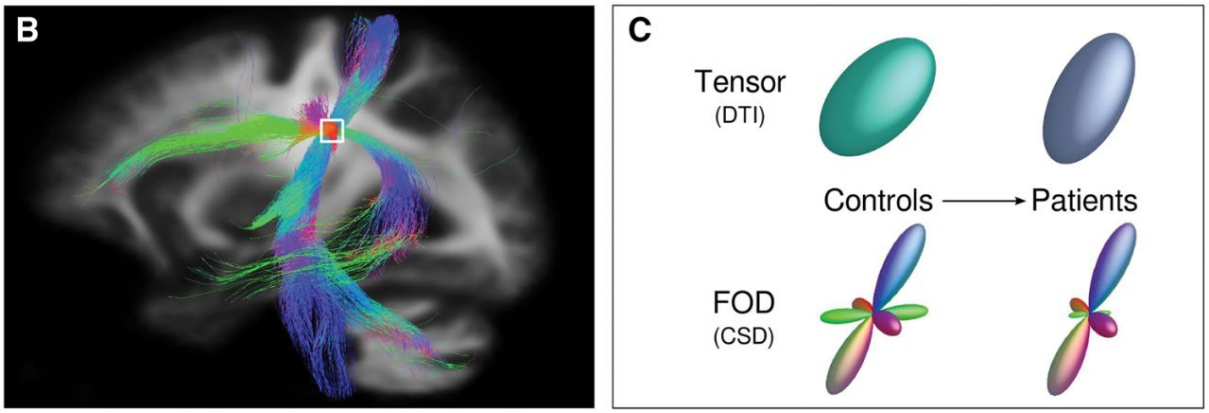

Figure 1.1: Significant voxel-wise increases in fractional anisotropy in Alzheimer's disease compared to healthy controls; from [MRD+18]

semiovale where several fibre tracts cross, some of which could specifically be shown to exhibit significant white matter degeneration in AD patients, whereas others were relatively preserved.

Subfigure C demonstrates how this would manifest in a single voxel for DTI versus for CSD. For DTI, the degeneration of white matter along a single axis (here: Forel axis) causes a misleading increase in FA. CSD however, can resolve the diffusion axes and depicts the white matter degeneration specifically along the Forel axis.

Figure 1.2 summarizes the analysis results of the cited study for both AD patients and subjects with mild cognitive impairment (MCI, second aspect of the study). On the left, the mean fibre density and cross-section (diamonds) and 95% confidence intervals (bars) of several tracts of interest for both groups are depicted as significantly below the control mean derived from a group of healthy subjects. The bar colors correspond to the colors of the tracts of interest shown in glass brain representations on the right. Please refer to the original paper for more explicit information.

This shows that MRI together with certain analysis techniques can be useful for gaining a better understanding of neuro-degenerative diseases like AD.

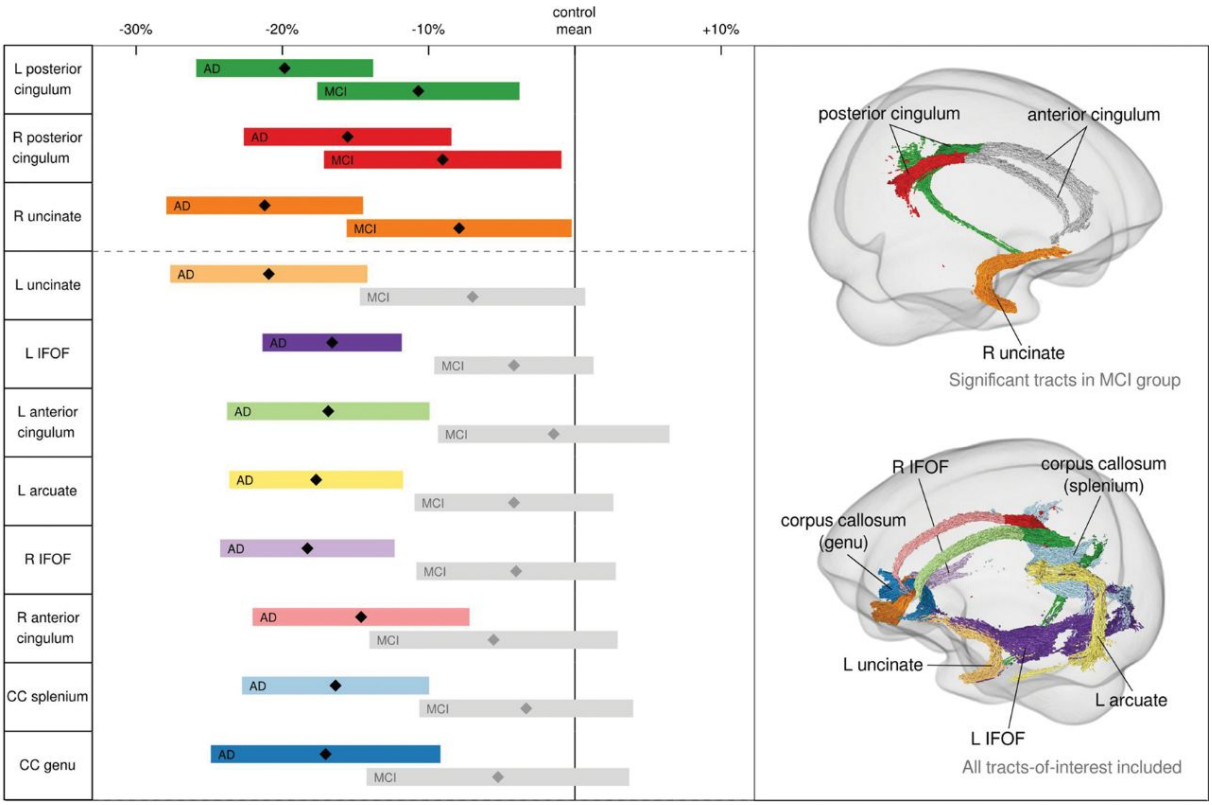

Figure 1.2: Significant tracts in MCI from tract-of-interest analysis comparing diagnostic groups; from [MRD+18]

2 Evaluation

In 2009, the National Institutes of Health (NIH), a part of the U.S. Department of Health and Human Services[nihb], launched the Human Connectome Project (HCP) in ”an ambitious effort to map the neural pathways that underlie human brain function.”[niha]. Its goal is to advance the capabilities of both imaging and analysis of human brain connections, hoping this will accelerate the progress of human connectomics.

HCP is carried out by two research consortia:

- *Harvard/MGH-UCAL*: Massachusetts General Hospital/Harvard University and the University of California Los Angeles (UCLA), focuses on creating a new magnetic resonance imager optimized for measuring connectome data
- *WU/Minn*: Washington University in St. Louis/University of Minnesota/Oxford University, focuses on mapping macroscopic brain circuitry and researching its connection to behavior. That includes data acquisition from 1200 subjects with a magnetic induction of $3T$ and from 200 subjects at $7T$[ESB+13].

Main directives of both consortia also include the improvement of existing and development of new imaging protocols and processing techniques. The collected data and software are made publicly available, the process of which is managed by the Connectome Coordination Facility.

First results published only few years after the initiation of HCP inspired further projects, i.e. the Lifespan HCP acquiring imaging data across all ages split into four subprojects (prenatal, 0-5, 6-21, and 36-100+ years), as well as several projects focusing on connectomes related to diseases, such as AD.

Bibliography

[ANS+08] Howard Jay Aizenstein, Robert D. Nebes, Judith A. Saxton, Julie C. Price, Chester A. Mathis, Nicholas D. Tsopelas, Scott K. Ziolko, Jeffrey A. James, Beth E. Snitz, Patricia R. Houck, Wenzhu Bi, Ann D. Cohen, Brian J. Lopresti, Steven T. DeKosky, Edythe M. Halligan, and William E. Klunk. Frequent Amyloid Deposition Without Significant Cognitive Impairment Among the Elderly. *Archives of Neurology*, 65(11):1509–1517, 11 2008.

[CPT16] Rebecca G Canter, Jay Penney, and Li-Huei Tsai. The road to restoring neural circuits for the treatment of alzheimer's disease. *Nature*, 539(7628):187–196, November 2016.

[ESB+13] David C. Van Essen, Stephen M. Smith, Deanna M. Barch, Timothy E.J. Berens, Essa Yacoub, and Kamil Ugurbil. The wu-minn human connectome project: An overview. *NeuroImage*, 80:62 – 79, 2013. Mapping the Connectome.

[Haa09] Christian Haass. Alzheimer - mechanismen und therapeutische anseatze. warum wir im alter dement werden. *Biologie in unserer Zeit*, 39(2):92–100, 2009.

[LVS+11] Cristian Leyton, Victor Villemagne, Sharon Savage, Kerryn Pike, Kirrie Ballard, Olivier Piguet, James Burrell, Christopher Rowe, R John, and Hodges. Subtypes of progressive aphasia: application of the international consensus criteria and validation using β-amyloid imaging. *Brain*, 01 2011.

[MLS+06] M. A. Mintun, G. N. LaRossa, Y. I. Sheline, C. S. Dence, S. Y. Lee, R. H. Mach, W. E. Klunk, C. A. Mathis, S. T. DeKosky, and J. C. Morris. [11c]pib in a nondemented population. *Neurology*, 67(3):446–452, 2006.

[MRD+18] Remika Mito, David Raffelt, Thijs Dhollander, David N Vaughan, J-Donald Tournier, Olivier Salvado, Amy Brodtmann, Christopher C Rowe, Victor L Villemagne, and Alan Connelly. Fibre-specific white matter reductions in alzheimer's disease and mild cognitive impairment. *Brain*, 141(3):888–902, 01 2018.

[niha] Connectome programs.

[nihb] Who we are.

[RER+10] Christopher C. Rowe, Kathryn A. Ellis, Miroslava Rimajova, Pierrick Bourgeat, Kerryn E. Pike, Gareth Jones, Jurgen Fripp, Henri Tochon-Danguy, Laurence Morandeau, Graeme O'Keefe, Roger Price, Parnesh Raniga, Peter Robins, Oscar Acosta, Nat Lenzo, Cassandra Szoeke, Olivier Salvado, Richard Head, Ralph Martins, Colin L. Masters, David Ames, and Victor L. Villemagne. Amyloid imaging results from the australian imaging, biomarkers and lifestyle (aibl) study of aging. *Neurobiology of Aging*, 31(8):1275 – 1283, 2010. Alzheimer's Disease Neuroimaging Initiative (ADNI) Studies.

[RJF+08] Gil D. Rabinovici, William J. Jagust, Ansgar J. Furst, Jennifer M. Ogar, Caroline A. Racine, Elizabeth C. Mormino, James P. O'Neil, Rayhan A. Lal, Nina F. Dronkers, Bruce L. Miller, and Maria Luisa Gorno-Tempini. Aβ amyloid and glucose metabolism in three variants of primary progressive aphasia. *Annals of Neurology*, 64(4):388–401, 2008.

[RKD+12] K.M. Rodrigue, K.M. Kennedy, M.D. Devous, J.R. Rieck, A.C. Hebrank, R. Diaz-Arrastia, D. Mathews, and D.C. Park. β-amyloid burden in healthy aging. *Neurology*, 78(6):387–395, 2012.

[RTS+17] David A. Raffelt, J.-Donald Tournier, Robert E. Smith, David N. Vaughan, Graeme Jackson, Gerard R. Ridgway, and Alan Connelly. Investigating white matter fibre density and morphology using fixel-based analysis. *NeuroImage*, 144:58 – 73, 2017.

[UpA] UpAndRunning. Connectome - homepage.

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