Tractometry: Peering into the white matter

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Educational Course - Half Day

Brain white matter contains the highly-myelinated axons that connect neurons in proximal or distant brain regions. These connections, organized into smaller or larger axon bundles, form networks that are crucially important for brain computations. Diffusion-weighted MRI (dMRI), together with computational tractography, provide in vivo estimates of the trajectory of these tracts through the white matter. In addition, dMRI provides information about the microscopic diffusion of water molecules within the tissue. Because water diffusion is affected by the physical structure of the tissue, this makes dMRI a sensitive probe of brain tissue properties. Taken together, these methods are used for tractometry, which focuses on the measurement of the physical properties of brain tracts. This course will introduce concepts in tractometry, including basic data analysis and processing, segmentation of the white matter into major tracts, the extraction of tissue properties along the tracts, and the statistical analysis of these properties. The course will also demonstrate the application of these methods to the understanding of the role of brain connections in cognitive functions, development and brain health. A broad range of approaches, methodologies and software tools will be presented, with significant hands-on components and interactive elements. This educational course proposal includes 2 organizers plus 6 additional speakers. Our group is half women and half men, and together, we represent 5 countries and span career stages from postdoctoral scholars to Associate Professor/Senior Lecturer.

Objective

- Learners will understand the basic concepts of tract-based analysis
- Learners will use software that segments white matter into different major bundles
- Learners will compare different approaches to statistical analysis of white matter tracts.

Target Audience

This course is intended for researchers (from trainees to faculty) with an interest in brain connectivity and the biology of brain connections. Researchers who are using datasets where multi-modal measurements are available (e.g., fMRI and dMRI) will benefit from expanding their analytic tool-set to include modern robust and rigorous tractometry methods.

Presentations

From Tracts to Bundles (Tracula and Clustering)

There are two broad families of methods for obtaining the white-matter bundles that undergo tractometry analyses. In the supervised approach, the goal is to reconstruct known tracts of interest (TOIs) based on a priori neuroanatomical definitions. In the unsupervised approach, the goal is to group whole-brain tractography data into clusters based on their similarity, without a priori knowledge on pathways of the brain. This presentation will give an overview of the two approaches, discuss how both of them can benefit by use of the underlying anatomy, and end with an interactive tour of white-matter tracts.

Presenter

Anastasia Yendiki, Harvard/MGH Boston, MA, United States

New Tractography Modalities Beyond Pathway Mapping

Tractometry often has separated steps of tractography mapping and analysis, but higher sensitivity and specificity can be achieved by integrating them together as novel tractography modalities. This hands-on section will demonstrate how differential tractography adopts a “tracking-the-differences” paradigm to track pathways with neuronal change in a patient. For group studies, I will demonstrate how correlational tractography can map fiber pathways correlated with a study variable by adopting a “tracking-the-correlation” paradigm. I will use an aphasic stroke dataset to show how correlation tractography can leverage multiple regression, partial correlation, or non-parametric correlation to study the circuit mechanism.

Presenter

Fang-Cheng Yeh, University of Pittsburgh Pittsburgh, PA, United States

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Challenges with the Interpretation of Fiber Density Metrics

Various dMRI models of white matter microstructure yield metrics relating to axon or “fibre” density. One such approach based on reconstruction of fibre orientation distributions (FODs) from constrained spherical deconvolution (CSD) techniques, for example, allows to obtain a fibre-specific metric of “apparent fibre density”, which is typically analysed using the fixel-based analysis (FBA) framework. In this talk, I will first briefly describe the key concepts of the FBA framework, but mostly focus on the challenges of interpretation of (fibre) density metrics. These challenges also extend to other dMRI models and analysis frameworks involving density metrics (e.g., neurite density from NODDI).

Presenter

Thijs Dhollander, Murdoch Children’s Research Institute Melbourne, Victoria, Australia

Applications of Tractometry to High-level Cognition

Over the past two decades, tractometry methods have proven extremely productive in the domain of cognitive neuroscience, including language processing, face processing, reading, attention, decision making, memory, and more. This talk will lay out a range of studies that utilize tractometry in the context of language, speech, math, and reading. We will discuss alternative analysis approaches appropriate for different research questions, data quality and tracts of interest. We will zoom in on some potential hazards in tractometry applications in cognitive neuroscience, and discuss interpretation, over-interpretation and misinterpretation of tractometry results.

Presenter

Michal Ben-Shachar, Bar Ilan University Ramat Gan, Israel

Single-subject Analysis via High-dimensional Analysis

Most diffusion MRI (dMRI) studies of disease rely on statistical comparisons between large groups of patients and healthy controls to infer altered tissue state. However, such studies often require data from many patients before robust inferences can be made, and clinical heterogeneity presents an additional challenge. Moreover, for clinicians and researchers studying small datasets or individual patients, this approach is clearly inappropriate. In this interactive tutorial, I will show how to analyse tractometry data from a single subject (n=1) by walking through basic analysis & data visualization steps using a range of freely available tools. I will explore concepts like normative modeling, dimensionality reduction and feature extraction. Finally, I will provide tips and tricks, as well as methodological considerations on Tractometry overall.

Presenter

Maxime Chamberland, Cardiff University Brain Research Imaging Centre Cardiff, United Kingdom

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Applications of Tractomtery to Brain Development

Automated tractography and fibre-specific analysis techniques have enabled greater spatial and biological specificity to study brain development. In this talk, I will showcase recent applications of these analysis approaches with a specific focus on studying developmental patterns of microstructure at the tract-level. In particular, I will showcase the advantage of using tractometry to understand age-related changes and the effects of puberty status on brain white matter in children and adolescents. I will also showcase the power of longitudinal data to investigate tract changes within individual participants.

Presenter

Sila Genc, Cardiff University Brain Research Imaging Centre Cardiff, United Kingdom