EE599: Computational imaging and Brain Connectivity

Instructor: Richard M. Leahy
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1. Schedule

Lectures: 11.00am - 12.20pm Tuesday/Thursday
Office hours: 12.30pm - 2.00pm Tuesday/Thursday

1. Course Outline and Objectives

Over the past decade we have seen revolutionary developments in our ability to detect and visualize networks in the living brain. These techniques use a combination of MRI and electrophysiological measurements to investigate both structural connectivity (brain wiring) and functional connectivity (task-based dynamic changes in brain networks). The goal of this course is to survey the technology used in brain mapping, to study the mathematical tools that are used to analyze networks, and to develop hands-on experience in working with brain data to extract network representations using a range of freely-available research software.

The course will combine lectures from the instructor with guest lectures from experts in brain anatomy, brain connectivity and MR imaging. There will be weekly reading assignments and computer assignments. Students will work in teams to apply the software reviewed in the course to experimental data.

2. Reading Assignments

Weekly reading assignments will include a combination of research and survey articles and on-line resources related to the research software that we will study in this class.

3. Prerequisites

The primary preprequisite is an interest in this topic. While the focus of the course is the computational methodologies for investigating connectivity, rather than its neuroscientific implications, I have tried to structure the course so that it is accessible to non-signal processing students. As noted below, assessment will be largely based on project work which will involve use of software for image analysis, however we will largely use existing software and actual implementation of methods is not required for these projects.

4. Course Evaluation

Grading on this course will be as follows:

Three (approximately monthly) in-class quizzes (10% each): quizzes will focus on technical material covered during the lectures. (30% total).

Two computational projects : students will use software described in the course to analyze brain data and prepare a report on their findings. The first project will be worth 25% of the grade, the final project will be worth 45% of final grade and will include a presentation during the final week of classes. (70% total).

5. Course Outline

Week 1: The Brain: Jessica Wisnowski

- Introduction to brain and cortical anatomy
- Brain development and connectivity
- The role of large scale connectivity mapping in brain research

Week 2: Structural brain imaging: Justin Haldar

- Intro to MRI
- Contrast mechanisms in MRI
- Typical sequences for 3D MRI brain imaging
- Artifacts and challenges in analyzing structural MRIs

Week 3: Cortical analysis of MRI: Richard Leahy/David Shattuck

- Automated extraction of cortical surfaces from MRI
- Cortical extraction with *BrainSuite*
- Exploring volumetric MRI data with *BrainSuite*

Week 4: Volumetric analysis and 3D image registration: Richard Leahy/Anand Joshi

- A unified view on image registration: features and regularizers
- Rigid and affine image registration
- Nonlinear image registration

Week 5: Surface and volume Registration: Anand Joshi/Richard Leahy

- Surface registrations: sulcal curves and curvature
- Surface-constrained volumetric registration
- Use of 3D atlases in intersubject registration
- Automated registration and labeling with *BrainSuite*
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Week 6: Basics of diffusion imaging: Justin Haldar

- MRI imaging of diffusion
- Diffusion tensor imaging
- The ODF, Q-Ball, HARDI and spectral diffusion imaging

Week 7: Analysis of diffusion data and fiber tracking: Justin Haldar

- Artifacts and noise in diffusion MRI
- Preprocessing of diffusion data
- Estimation of tensors and ODFs

- Fiber tracking with *BrainSuite*
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Week 8: Basics of fMRI and event-related studies: TBD

- The BOLD signal and contrast mechanisms in fMRI
- Univariate analysis of fMRI
- Statistical considerations: thresholding for significance
- Network effects in event related fMRI

Week 9: Resting state networks and fMRI: Jessica Wisnowski/Richard Leahy

- Historical perspectives
- Acquisition and preprocessing of resting state fMRI data
- Network analysis with seeded correlations

Week 10: Resting state networks and fMRI Richard Leahy/Anand Joshi

- Network analysis using independent components
- Network analysis using the partial correlation
- Investigation of resting state networks using *Matlab*

Week 11: Introduction to electrophysiology: Richard Leahy/Francois Tadel

- Measurement: single unit recordings, local field potentials, ECoG, EEG and MEG
- Forward and inverse methods for EEG and MEG
- Cortical source estimation with *BrainStorm*.

Week 12: Pairwise interactions in dynamic systems: Richard Leahy/Syed Ashrafulla

- Non-parametric methods: cross-correlations and coherence
- Parameteric: AR modeling and Granger causality
- Computational investigations using *BrainStorm*

Week 13: Pairwise interactions in dynamic systems: Richard Leahy/Sergul Aydore

- Phase-coupling and other nonlinear interactions
- Dynamic causal modeling and related models

Week 14: Multinode network analysis (i): Richard Leahy/Sergul & Syed

- MVAR modeling
- Partial correlation, coherence and phase models
- Computational examples using *Matlab*
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Week 15: Graph-based network analysis: Richard Leahy/Yu-Teng Chang

- Graph-based models of brain networks
- Characterization and analysis of brain networks
- Analysis using *Brain Connectivity Toolbox*

6. Statement for Students with Disabilities

Any student requesting academic accommodations based on a disability is required to register with Disability Services and Programs (DSP) each semester. A letter of verification for approved accommodations can be obtained from DSP. Please be sure the letter is delivered to me (or to TA) as early in the semester as possible. DSP is located in STU 301 and is open 8:30 a.m.–5:00 p.m., Monday through Friday. The phone number for DSP is (213) 740-0776.

7. Statement on Academic Integrity

USC seeks to maintain an optimal learning environment. General principles of academic honesty include the concept of respect for the intellectual property of others, the expectation that individual work will be submitted unless otherwise allowed by an instructor, and the obligations both to protect one's own academic work from misuse by others as well as to avoid using another's work as one's own. All students are expected to understand and abide by these principles. Scampus, the Student Guidebook, contains sections on Student Conduct and Sanctions for Academic Dishonesty: http://web-app.usc.edu/scampus/university-governance/. Students will be referred to the Office of Student Judicial Affairs and Community Standards for further review, should there be any suspicion of academic dishonesty. The Review process can be found at: http://www.usc.edu/student-affairs/SJACS/.