Topics in Neuroimaging Analysis:
Functional (Network) Connectivity, Dynamics, and Multimodal Fusion

PSYCH 8910 & CSC 8910
Spring Semester, 2023

Location: The TReNDS Center, 55 Park Place NE, 18th Floor, #1802
Time: Tues 3-5:30

Instructor: Vince D Calhoun vcalhoun@gsu.edu
Phone: 505 514-5850
Office: 55 Park Place NE, 18th Floor, #1829
Office Hours: TBA and by appointment

General fMRI/MRI Texts (optional):
Functional Magnetic Resonance Imaging (ISBN 0878932887)
Scott A. Huettel, Allen W. Song, Gregory McCarthy
The Statistical Analysis of Functional MRI Data (ISBN 9780387781907)
Nicole A. Lazar
Principles of Magnetic Resonance Imaging: A Signal Processing Perspective (ISBN 0780347234)
Zhi-Pei Liang and Paul C. Lauterbur
Introduction to Resting State fMRI Functional Connectivity (ISBN 0198808224)
Janine Bijsterbosch, Stephen Smith, Christian Beckmann

Prerequisites:
The student should be enrolled in an academic program at the graduate level. The assumption is that the student has some understanding of how MRI works, either through taking NEU 8605/PSYC 8605 (Experimental Methods in MRI), previous research experience, or with consent of the instructor.

Course Description/Syllabus:
This graduate-level course will provide an overview of approaches to study functional (network) connectivity in functional magnetic resonance imaging (fMRI) data and will cover a variety of topics including brain networks/connectome, dynamic connectivity, and multimodal data fusion. FMRI is a widely-used brain imaging technique which produces a series of images which are sensitive to localized changes in blood oxygenation which occur in the brain intrinsically and are modulated while performing a task. We will briefly review the basics of MRI and the fMRI signal as well as preprocessing. Most of the course will focus on the analysis of the time series data produced by functional magnetic resonance imaging of the brain with various approaches including linear modeling, seed-based functional connectivity, and blind source separation tools, such as independent component analysis. We will also cover methods that can be used to combine fMRI data with other imaging modalities such as structural MRI or EEG, in a joint analysis, i.e., multimodal data fusion. Several software packages will be introduced for possible use in the projects order to demonstrate the concepts and learn how to read in and manipulate the data.

Learning objectives:
- To learn current state-of-the-art approaches for neuroimaging analysis
- To learn manipulation of and analysis of neuroimaging data with particular emphasis on data-driven/network-based approaches (i.e., sets of coherent voxels within the brain).
- To learn how to provide constructive critiques of methodological approaches
- Hands-on experience with SPM, GIFT, and FIT software tools both via the GUI and command line

Examinations and Assignments
Grading will be based on weekly quizzes (20%) a term paper (30%) and a project (40%). The remaining 10% will be for attendance and class participation.

Quizzes: The quizzes will be multiple choice, hosted on iCollege, and based on the previous week's lecture.

Term Paper: The term paper is an assignment to read literature on a selected fMRI method and to either critically review the method or to explore a small modification of the method under guidance. This assignment will be a 2000-word critique of an fMRI paper (paper is to be selected by the student and approved by the instructor) and will constitute 30% of the final.

You should avoid being overly critical of the small issues and rather to focus upon the big issues. Are their conclusions supported by the results? Were the algorithm comparisons fair? Are there some things they didn't consider that might be important? These kinds of questions are more important than pointing out that they made a minor notational error (for example).

Your assignment should have the following components (at a minimum):

1. A brief (one paragraph) outline of the approach and the basic results and conclusions drawn.
2. A more detailed critique of the analysis (3 to 4 paragraphs) focusing on major issues as discussed above.
3. A brief (1-2 paragraphs) outline of an alternate approach to address the same question - how would your alternate approach address your criticisms of their approach.

Project: Analysis of an existing fMRI data set. You should utilize an existing fMRI data set (there are many available via the web). Some examples are provided below:

Data sets provided:

-Developmental resting fMRI data (two subjects, unprocessed & preprocessed)
-Schizophrenia resting fMRI data (two subjects, preprocessed) + Group ICA output (311 subjects)
-GIFT example data (three subjects, task fMRI)

You should select one aspect of the processing to address (e.g., fMRI preprocessing, activity detection, functional connectivity, multimodal fusion of two or more modalities). The goal is to implement your own analysis or approach (can be by using an existing software package, or developing your own approach) and apply to the data. You can compare your results to those computed using an available Matlab package, SPM12 (http://www.fil.ion.ucl.ac.uk/spm/), the group ICA of fMRI Toolbox, GIFT (http://trendscenter.org/software/gift), or the fusion ICA toolbox, FIT (http://trendscenter.org/software/fit), which we will learn during the course. This is your opportunity to be creative and also to do something which is of interest to you.

The project write-up (~5000 words) should consist of 1) a brief introduction to the issue being addressed, 2) a formulation of the approach that will be applied, 3) a simple simulation illustrating the approach works [this should also include some quantitative comparison with the ground truth], 4) results from the method applied to fMRI data, 5) a discussion of the results (did they work? If so, what are the strengths of this approach? If not, why not?) and concluding paragraph. The code used to process the data should be included in an appendix. Students will be required to give a 15-20 minute presentation in class about the project. The project and presentation together will consist of 40% of your grade.

Participation: Class participation and attendance will constitute the remaining 10% of your grade.

Course Web Page: Course material can be accessed through the iCollege platform. Readings and course lectures will also be provided at this site.

Holidays:
MLK: Jan 16th (Mon)
Spring Break: Mar 13-19

Syllabus (Jan 9 – Apr 24, Finals: Apr 25-May 2):

Section 1: Introduction & Review

Jan 10: Week 1: fMRI fundamentals (review): MRI physics, BOLD fMRI, preprocessing I (review): artifacts, motion correction, MRICron

Jan 17: Week 2: Preprocessing II (review): transformation to standard brain spaces, noise in fMRI, design and modeling of task fMRI, SPM 1

Jan 24: Week 3: Modeling (review): group analysis, hemodynamic modeling, delays in fMRI, balloon model, SPM 2, and data

Section 2: Networks and Graphs

Jan 31: Week 4: Resting fMRI, Functional connectivity, effective connectivity (SEM/DCM), graph analysis, wavelet methods, clustering methods, data visualization

Feb 7: Week 5: **(approval of critique paper)** Data-driven connectivity, Introduction to independent component analysis, single-subject ICA of fMRI, GIFT 1

Feb 14: **[**TBD**]**

-McKeown MJ, Jung TP, Makeig S, Brown G, Kindermann SS, Lee TW, Sejnowski TJ. Related Articles, Spatially independent activity patterns in functional MRI data during the stroop color-naming task. Proc Natl Acad Sci U S A. 1998 Feb 3;95(3):803-10.
-V. D. Calhoun and T. Adali, "Multisubject independent component analysis of fMRI: a decade of intrinsic networks, default mode, and neurodiagnostic discovery," IEEE Rev Biomed Eng, vol. 5, pp. 60-73, 2012, PMC4433055.

Section 4: Dynamics, Covariation, and Multimodal Fusion

Feb 21: Week 7: **(topic for project due)** Week 6: Group ICA, back-reconstruction, inference, group comparisons, impact of preprocessing, autocorrelation, task vs rest, network overlap, GIFT 2

Feb 28 Week 8: Dynamic (time-varying) connectivity, temporal/spatial dynamics, time-frequency approaches

Mar 7 Week 9: **(critique paper due)** Source-based morphometry, covariation of structural patterns, comparison with resting fMRI networks, spatially constrained SBM.

-A. Iraji, et al., "Tools of the trade: Estimating time-varying connectivity patterns from fMRI data," Soc Cogn Affect Neurosci, Aug 12 2020.
-D. J. Lurie, et al., "Questions and controversies in the study of time-varying functional connectivity in resting fMRI," Netw Neurosci, 2019.
-V. D. Calhoun, R. Miller, G. Pearlson, and T. Adali, "The chronnectome: time-varying connectivity networks as the next frontier in fMRI data discovery," Neuron, vol. 84, pp. 262-274, Oct 22 2014.
-C. N. Gupta, J. A. Turner, and V. D. Calhoun, "Source-based morphometry: a decade of covarying structural brain patterns," Brain Struct Funct, vol. 224, pp. 3031-3044, Dec 2019.
-V. D. Calhoun and J. Sui, "Multimodal fusion of brain imaging data: A key to finding the missing link(s) in complex mental illness," Biol Psychiatry Cog Neurosci Neuroimg., v 1, p. 230-244, 2016.

Section 5: Additional topics

Mar 14 Week 10: Spring Break [no class]

Mar 21 Week 11: Multimodal data fusion, EEG/MEG, diffusion/structural MRI, joint ICA, mCCA, mCCA+jICA, subspace methods, FIT software

Mar 28: Week 12: Apr 4: Week 13: Deep Learning: A Brief Introduction and Application to NeuroImaging

-B. Rashid and V. Calhoun, "Towards a brain-based predictome of mental illness," Human Brain Mapping, vol. 41, pp. 3468-3535, Aug 15 2020, PMC7375108.
-C. J. Urban and K. M. Gates, "Deep learning: A primer for psychologists," Psychol Methods, vol. 26, pp. 743-773, Dec 2021.
-W. Yan, G. Qu, W. Hu, A. Abrol, B. CAi, C. Qiao, S. Plis, Y. Wang, and V. D. Calhoun, "Deep Learning in Neuroimaging: Promises and Challenges," IEEE Signal Proc. Magazine, 2022.

Section 6: Project presentation

Apr 11, 18: Week 13-15: (**project due last week of class)** Student project presentations