

McGill University, Department of Neurology & Neurosurgery

NEUR608

Neuroimaging Data Science

Fall term 2021 Course Syllabus

Montreal Neurological Institute

zoom

Time: Fridays 9.00AM-12.00

Instructors: Boris Bernhardt PhD / Bratislav Mistic PhD

Email: boris.bernhardt@mcgill.ca / bratislav.mistic@mcgill.ca

Overall goal. The goal is to familiarize students with several powerful analytical approaches that can be applied to complex datasets, such as those derived from modern neuroimaging. After providing the basics of neuroimaging and statistical analysis, we will cover unsupervised as well as supervised learning, associative techniques and causal models, and give an introduction into graph theoretical analysis and meta-analyses. We will also provide guidelines for effective data visualization. A basic understanding of statistical analysis and MATLAB/python programming are prerequisites to this course.

Learning Objectives. By the end of the course, the students should be able to:

1. Have an understanding of the covered analytical techniques.
2. Be able to implement these techniques in their own data.
3. Propose a neuroimaging analysis project in which these techniques are applied.

Teaching method. In the 3-hour long seminar, the instructors will first provide a brief overview of the methodology. Students will read the assigned articles prior to the class and prepare a critical summary of the article's strengths and weaknesses. One student will present the article to the class, and lead the discussion. In the second part of the class, students will carry out practical exercises on some of the covered techniques on their own laptop, with guidance by

both instructors. As a final assignment, students will present a mock research paper with analyses utilizing one or more of the covered methods.

W01: Introduction (B. Masic & B. Bernhardt) - September 3

The session discusses the organization of the course. At the end of the class, a short GitHub and Matlab crash course is given.

Practice session:

- GitHub 101
- Matlab 101

W02: Multimodal imaging and connectome analysis (B. Bernhardt) - September 10

This section provides a brief introduction into state-of-the-art neuroimaging and network generation techniques.

Papers:

- 1) Meier-Hein et al. (2018) *The challenge of mapping the human connectome based on diffusion tractography*. Nature Comms. 8: 1349
- 2) Huntenburg et al. (2018) *A systematic relationship between functional connectivity and intracortical myelin in the human cerebral cortex*. Cerebral Cortex. 27(2): 981-997

Reviews (Optional):

- 1) Craddock et al. (2015) *Connectomics and new approaches for analyzing human brain functional connectivity*. Gigascience. 4: 13.
- 2) Jbabdi et al. (2015) *Measuring Macroscopic Brain Connections in vivo*. Nature Reviews Neuroscience. 15: 1546–1555

Practice session:

- Diffusion mri preprocessing with mrtrix3
- Myelin mapping in matlab
- Resting-state functional connectivity mapping in matlab

W03: Data compression and dimensionality reduction (B. Masic) - September 17

The session is focused on exploratory multivariate dimensionality reduction techniques. We will give a theoretical overview of Eigen-decomposition and singular value decomposition (SVD). We will then discuss the implementation and interpretation of these techniques with a focus on

principal components analysis (PCA), factor analysis (FA) and independent components analysis (ICA), non-negative matrix factorization (NMF).

Papers:

- 1) Amico & Goni (2017) *The quest for identifiability of human functional connectomes*. Sci Rep 8(1): 8254.
- 2) Shine, J. M., Breakspear, M., Bell, P. T., Martens, K. A. E., Shine, R., Koyejo, O., ... & Poldrack, R. A. (2019). *Human cognition involves the dynamic integration of neural activity and neuromodulatory systems*. Nature neuroscience, 22(2), 289.

Practice:

- PCA/FA/ICA analysis of imaging. Model complexity, statistical inference, interpretation.

W04: The generalized linear model and linear mixed models (B. Bernhardt) - September 24

The session gives an overview into the generalized linear model and linear mixed effects models. The practical session provides an introduction to SurfStat for Matlab, where an exemplary cross-sectional group comparison of cortical thickness data is provided, a covariance network analysis, and longitudinal cortical thickness analysis.

Papers:

- 1) Raznahan et al. (2013) *Patterns of coordinated anatomical change in human cortical development: a longitudinal neuroimaging study of maturational coupling*. Neuron. 72(5): 873-84
- 2) Vasa et al. (2011) *Adolescent tuning of association cortex in human structural brain networks*. Cerebral Cortex 2018; 28: 281-294

Practice:

- Cortical thickness analysis using SurfStat for Matlab

W05: Associative Techniques (B. Masic) – October 1

This session will focus on techniques used to associate two or more data sets to one another, with a particular focus on canonical correlation analysis (CCA) and partial least squares (PLS) analysis.

Papers:

- 1) Drysdale et al. (2016) *Resting-state connectivity biomarkers define neurophysiological subtypes of depression*. *Nature Medicine*. 23(1): 28-38
- 2) Kebets, V., Holmes, A. J., Orban, C., Tang, S., Li, J., Sun, N., ... & Yeo, B. T. (2019). Somatosensory-Motor Dysconnectivity Spans Multiple Transdiagnostic Dimensions of Psychopathology. *Biological Psychiatry*.

Reviews (optional):

- 1) Worsley, K. J., Poline, J. B., Friston, K. J., & Evans, A. C. (1997). Characterizing the response of PET and fMRI data using multivariate linear models. *NeuroImage*, 6(4), 305-319.
- 2) McIntosh, A. R., & Mišić, B. (2013). Multivariate statistical analyses for neuroimaging data. *Annual review of psychology*, 64, 499-525.

Practice:

- PLS analysis of a sample fMRI data set using the Rotman-Baycrest toolbox.

W06: Clustering (B. Bernhardt) - October 8

The session will provide an overview of different techniques to partition high dimensional datasets into subgroups.

Papers:

- 1) Kelly et al. (2012) *A convergent functional architecture of the insula emerges across imaging modalities*. *NeuroImage* 61: 1129-42
- 2) Yeo et al. (2011) *The organization of the human cerebral cortex estimated by intrinsic functional connectivity*. *J Neurophysiol*. 106: 1125–1165, 2011.

Practice:

- Performing k-means and hierarchical clustering

W07: Statistical learning (O Benkarim, B. Bernhardt) - - October 15

The section will introduce several supervised learning frameworks (e.g., LDA, Support Vector Machines, Trees, Random forests).

Papers:

- 1) Chang (2015) *A sensitive and specific neural signature of picture induced negative affect*. *PLoS Biology*, 13(6): e1002180.

- 2) Bzdok & Ioannidis (2019) *Exploration, Inference and Prediction in Neuroscience and Biomedicine. TINs*

Practice:

- Supervised prediction task using Nilearn

W08: Software development, gradients, and transcriptomic associations (R Markello, R Vos de Wael, B Mistic, & B Bernhardt) - October 22

Overview & discussion of open access software for imaging transcriptomics (abagen) and connectome gradient generation (brainspace) developed at the MNI.

Papers:

- 1) Vos de Wael et al. (2020) *BrainSpace: a toolbox for the analysis of macroscale gradients in neuroimaging and connectomics datasets*. *Comm Biol*, 3:102.
- 2) Arnatkeviciute et al. (2019). A practical guide to linking brain-wide gene expression and neuroimaging data. *NeuroImage*, 11(4), 289-301.

W09: Graph theory I (B. Mistic) - October 29

The section will give a short refresher on neuroimaging based connectome analysis and introduce basic graph theoretical concepts (definition of a graph, small world model, centrality analysis).

Paper:

- 1) van den Heuvel et al. (2012) *High-cost, high-capacity backbone for global brain communication*. *PNAS*. 11372–11377
- 2) Betzel, R. F., Avena-Koenigsberger, A., Goñi, J., He, Y., De Reus, M. A., Griffa, A., ... & Van Den Heuvel, M. (2016). *Generative models of the human connectome*. *Neuroimage*, 124, 1054-1064.

Reviews (optional):

- 1) Bullmore, E., & Sporns, O. (2009). *Complex brain networks: graph theoretical analysis of structural and functional systems*. *Nature reviews neuroscience*, 10(3), 186.

- 2) Bullmore, E., & Sporns, O. (2012). *The economy of brain network organization*. Nature Reviews Neuroscience, 13(5), 336.

Practice:

- Comparative connectome analysis in animal models, based on the brain connectivity toolbox.

W10: Graph theory II (B. Misić) - November 5

The section will provide further important theoretical and practical insights into graph theoretical analysis (partitions and communities, stochastic block modeling, network diffusion models).

Papers:

- 1) Goni et al. (2015) *Resting brain functional connectivity predicted by analytic measures of network communication*. PNAS, 111(2), 833-838.
- 2) Wang, P., Kong, R., Kong, X., Liégeois, R., Orban, C., Deco, G., ... & Yeo, B. T. (2019). *Inversion of a large-scale circuit model reveals a cortical hierarchy in the dynamic resting human brain*. Science advances, 5(1), eaat7854.

Reviews (optional):

- 1) Breakspear, M. (2017). *Dynamic models of large-scale brain activity*. Nature Neuroscience, 20(3), 340.
- 2) Avena-Koenigsberger, A., Misić, B., & Sporns, O. (2018). *Communication dynamics in complex brain networks*. Nature Reviews Neuroscience, 19(1), 17.

Practice:

- Brain connectivity toolbox 2.

W11: Meta analysis techniques (B. Bernhardt) - November 12

This session will review methods of identifying and amalgamating data from published and unpublished sources. It will further address methods of evaluating for publication bias and

between study heterogeneity. Finally, we will introduce available tools in the neuroimaging literature (Neurosynth, BrainMap).

Papers:

- 1) Pauli et al (2016) *Regional specialization within the human striatum for diverse psychological functions*. PNAS, 113 (7): 1907–1912
- 2) Liebermann and Eisenberger (2015) *The dorsal anterior cingulate cortex is selective for pain: results from large-scale reverse inference*. PNAS. 112(49): 15250-15255.
- 3) Wager et al. (2016) *Pain in the ACC?* PNAS 113(18): E2474-75

Practice:

- *Interaction with Neurosynth.*

W12) Reproducibility (J.B. Poline, B. Misic & B. Bernhardt) - November 19

W13) Students present final papers (B. Misic & B. Bernhardt) - November 26