McGill University, Department of Neurology & Neurosurgery

NEUR608

NEUROIMAGING DATA SCIENCE

Fall term 2019 Course Syllabus

Montreal Neurological Institute

BELL ROOM

Time: Fridays 12:00-15:00

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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 based 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.

INSTRUCTIONAL 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 weakness. 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. Misic + B. Bernhardt)
The session discusses the overall organization of the course. At the end of the class, a short Matlab crash course is given.

Practice:
Matlab 101

W02: Multi-modal imaging and in-vivo connectivity analysis (B. Bernhardt)
This section provides a brief introduction into state-of-the-art neuroimaging techniques.

Papers:
Meier-Hein et al. (2018) *The challenge of mapping the human connectome based on diffusion tractography*. Nature Comms. 8: 1349

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):
Craddock et al. (2015) *Connectomics and new approaches for analyzing human brain functional connectivity*. Gigascience. 4: 13.

Jbabdi et al. (2015*) Measuring Macroscopic Brain Connections in vivo*. Nature Reviews Neuroscience.1546–1555

Practice:
Visualization of neuroimaging data.

W03: Data compression and dimensionality reduction (B. Misic)
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:
Amico & Goni (2017) *The quest for identifiability of human functional connectomes.* Sci Rep 8(1): 8254.

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)
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:
Vasa et al. (2018) *Adolescent Tuning of Association Cortex in Human Structural Brain Networks*. Cerebral Cortex. 28: 281-94

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

Review (optional):
Alexander-Bloch, Giedd, Bullmore (2013) *Imaging structural co-variance between human brain regions.* Nature Reviews Neuroscience. 14(5): 322-36

Practice:
Cortical thickness analysis using SurfStat for Matlab

W05: ASSOCIATIVE TECHNIQUES (B. MISIC)
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:
Drysdale et al. (2016) *Resting-state connectivity biomarkers define neurophysiological subtypes of depression.* Nature Medicine. 23(1): 28-38

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*.

Review (optional):
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.

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 TECHNIQUES (B. BERNHARDT)
The session will provide an overview of different techniques to partition high dimensional datasets into subgroups.

Paper:
Kelly et al. (2012) *A convergent functional architecture of the insula emerges across imaging modalities.* NeuroImage 61: 1129-42

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 in Matlab and R

W07: CONFIRMATORY TECHNIQUES AND CAUSAL MODELS (B. MISIC)
Confirmatory analyses to assess "causal" influence, including mediation analysis, path analysis/structural equation modeling (SEM), dynamic causal modeling (DCM) and confirmatory factor analysis.

Papers:
Brodersen et al. (2011) *Generative embedding for model-based classification of fMRI data.* PLoS Comput Biol, 7(6):e1002079.

Bullmore, E., Horwitz, B., Honey, G., Brammer, M., Williams, S., & Sharma, T. (2000). How good is good enough in path analysis of fMRI data?. *NeuroImage*, *11*(4), 289-301.

Review (optional):
Mišić B., and McIntosh A.R. (2015) Effective Connectivity. In: Arthur W. Toga,editor. *Brain Mapping: An Encyclopedic Reference*, vol. 1, pp. 587-592. Academic Press: Elsevier

No practice session but feed-back on project ideas

W08: GRAPH THEORY I (B. MISIC)

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:
van den Heuvel et al. (2012) *High-cost, high-capacity backbone for global brain communication.* PNAS. 11372–11377

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):

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

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.

W09: GRAPH THEORY II (B. MISIC)
The section will provide further important theoretical and practical insights into graph theoretical analysis (partitions and communities, stochastic block modeling, network diffusion models).

Paper:
Goni et al. (2015) *Resting brain functional connectivity predicted by analytic measures of network communication.* PNAS, 111(2), 833-838.

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):
Breakspear, M. (2017). *Dynamic models of large-scale brain activity.* Nature Neuroscience, 20(3), 340.

Avena-Koenigsberger, A., Misic, B., & Sporns, O. (2018). *Communication dynamics in complex brain networks.* Nature Reviews Neuroscience, 19(1), 17.

Practice:
Brain connectivity toolbox 2.

W10: Statistical learning (B. Bernhardt)
The section will introduce several supervised learning frameworks (e.g., LDA, Support Vector Machines, Trees, Random forests).

Paper:
Berman et al. (2013) *Dimensionality of brain networks linked to life-long individual differences in self-control.* Nature Communications. 4: 1373

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

Practice:
Supervised prediction task.

W11: Meta analysis techniques (B. Bernhardt)
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:
Pauli et al (2016*) Regional specialization within the human striatum for diverse psychological functions.* PNAS, 113 (7): 1907–1912

Liebermann and Eisenberger (2015) *The dorsal anterior cingulate cortex is selective for pain: results from large-scale reverse inference.* PNAS. 112(49): 15250-15255.

Wager et al. (2016) *Pain in the ACC?* PNAS 113(18): E2474-75

Practice:
Interaction with Neurosynth.

W12) Reproducibility (J.B. Poline + B. Bernhardt + B. Misic)

Papers:

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