Graph Theoretic Models of Brain Networks

Organizers:
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Understanding neuronal connectivity has become a central focus of neuroscience in light of several unprecedented, large-scale international initiatives to comprehensively map wiring diagrams of nervous systems – so-called connectomes – at resolutions ranging from the microscopic (on the scale of a few nanometers) to macroscopic (on the scale of millimeters and centimeters). The diversity of the data produced by these efforts, which is collected using measurement techniques that include electron microscopy, tract tracing and magnetic resonance imaging, and in species such as the nematode worm, Drosophila fruit fly, mouse, macaque and human, pose a major challenge for systematic evaluation, comparison and integration across studies.

Graph theory – a branch of mathematics concerned with modeling systems of interacting elements – provides a unifying and powerful framework for characterizing these varied data. It rests on the assumption that any network can be represented in abstract form as a graph of nodes connected by edges. In connectomics, the nodes correspond to neurons or neuronal populations and the edges to structural or functional connections.

Graph theory has had a major impact on neuroscience, revealing new insights into the organizational properties of brain networks and their generative mechanisms. Many such properties are conserved across resolution scales, measurement technique and species, suggesting that they are fundamental aspects of neural structure and function. Graph theory has also provided a powerful platform for mapping, at a connectome-wide level, the effects of disease and other experimental manipulations.

This workshop provides an integrated overview of the field, covering both basic concepts and advanced applications in the graph theoretic analysis of brain networks. The first half of the workshop will focus on fundamentals such as how a network graph is constructed from neural connectivity data; the different types of graph models available for brain networks; key graph theoretic concepts and measures such as small-worlds, clustering, paths, diffusion processes, centrality, hubs, and modularity; statistical methods for connectome-wide analyses; and the clinical applications of graph theory. The second half of the workshop will consider advanced topics, including the integration of graph theoretic models across resolution scales and other kinds of 'omics data; the use of multilayer networks in modeling dynamic changes in brain connectivity and other applications; generative modeling of brain network organization; the analysis of high-resolution functional connectivity networks with magnetoencephalography; and the way in which graph theory can be used to understand how disease spreads through brain networks.

Graph theory will play an increasingly important role in attempts to understand the massive amounts of data generated by large collaborative projects such as the Human Connectome Project. An integrated and comprehensive educational workshop on the topic is thus timely and necessary to provide researchers with the knowledge required to make the most of such rich data. Attendees will leave this workshop with a detailed understanding of the fundamental principles of graph theory, the application of graph theoretic methods to neuroscientific data, and insight into emerging trends and advanced applications. Attendees will also understand the correct use and interpretation of core graph theoretic measures and the limitations of graph theoretic models.

Course Schedule
8:00- 8:40
An Introduction to graph theory and connectomics
Alex Fornito, Monash Institute of Cognitive & Clinical Neurosciences, Melbourne, Australia

8:40- 9:10
Efficiency in brain networks: from shortest-paths to random-walks through the lens of information
Joaquin Goni, Purdue University, West Lafayette, United States

9:10-9:50
Network infrastructure for integration: hubs and rich club
Martijn van den Heuvel, Rudolf Magnus Inst. of Neuroscience, Utrecht, Netherlands

9:50 – 10:30
Break

10:30-11:10
Applications of community detection to characterize brain systems in health and disease
Damien Fair, Oregon Health & Science University, Portland, OR, United States

11:10-11:50
Statistical connectomics and clinical applications
Andrew Zalesky, *University of Melbourne, Melbourne, Australia*

11:50-12:00
Q & A / Discussion

12:00-13:00
Lunch

13:00-13:40
Integrating analyses across scales of nervous systems: from micro to macro
Edward T Bullmore, University of Cambridge, Cambridge, United Kingdom

13:40-14:10
Multilayer and Dynamic Network Approaches to Understanding Human Brain Structure and Function
Danielle Bassett, University of Pennsylvania, Philadelphia, PA, United States

14:10-14:50
Generative models of brain networks
Richard Betzel, University of Pennsylvania, Philadelphia, United States

14:50-15:20
Break

15:20-15:50
High resolution functional networks measured with MEG
Mark Woolrich, University of Oxford, Oxford, United Kingdom

15:50-16:30
Network models of disease spread and neurodegeneration

Ashish Raj, Weill Cornell Medical College, New York, United States