Advances in Discrete Networks

December 12-14, 2014

December 12, 2014

9:00 a.m. - Prof. Mason Porter, Oxford University

Title: *Multilayer Community Structure and Functional Brain Networks*

Abstract: Networks arise pervasively in biology, physics, technology, social science, and myriad other areas. A network consists of a collection of entities (called nodes) that interact via edges. Many networks have cohesive meso-scale structures called "communities" which consist of sets of nodes that are tightly connected to each other in some fashion.

In this talk, I will introduce "multilayer networks," in which nodes can be connected to each other in multiple ways, and examine applications of multilayer community structure to functional brain networks (and other problems). I will spend a lot of time illustrating multilayer networks in general and hope to convince you that such general structures — which allow one to throw away less information than usual when studying networks — are very useful to consider in neuroscience.

10:00 a.m. - Prof. Nina Fefferman, Rutgers University

Title: *A Local Density-Based Method for Network Comparison*

Abstract: Networks are used across many fields to quantify and characterize patterns of interactions. The comparison of different networks, though, still remains an open area of research. In this talk, I'll present a new similarity metric, the n-tangle, that focuses on structural similarity between networks based on the distribution of edge density in network subgraphs. I'll show how this approach can be applied to networks of different size and structure, and/or to describe changes over time in dynamic networks, and will provide a few example analyses of well-studied network data to demonstrate the use of n-tangle comparisons.

11:30 a.m. - Prof. Dimitri Krioukov, Northeastern University

Title: *Lorentz-invariant edge-independent maximum-entropy ensembles of random graphs and simplicial complexes*

Abstract: Exponential random graph models (ERGs) have been an active area of research over the last decade. ERGs are maximum-entropy ensembles of graphs with "soft" constraints. A soft constraint fixes the expected value of a graph observable to a given value. If observables are graph edges, then their expected values are the probabilities of connections in the graph ensemble. Such ensembles are most general maximum-entropy graph ensembles in which all edges are independent Bernoulli random variables. If the Lagrangian multipliers coupled to edge observables are geodesics distances between points in a Poisson point process on a Lorentz-invariant manifold, then the expected values of some important structural properties in the resulting ensembles mimic the values of these properties observed in many real networks. The Erdõs–Rényi random graphs, random geometric graphs, and random graphs with given power-law sequences of expected degrees are all degenerate limit cases of these Lorentz-invariant ensembles. The problems of generalizing these ensembles to random simplicial complexes of higher dimensions, and deriving their rigorous large-N limits, e.g., graphons, are also discussed.

2:00 p.m. - Prof. Duane Nykamp, University of Minnesota

Title: *Exploiting low-rank network structure to construct effective equations of neuronal network dynamics*

Abstract: We explore the implications on neuronal network dynamics of effective low-rank network structure. We demonstrate how network activity can be captured by a few projections of the activity on to directions that are determined by low-rank approximations of the network connectivity matrix. For networks with small high-order statistics among their edges, the activity projections correspond to the average activity of different types of synapses, yielding effective equations for the synaptic drives of the network. In such cases, the critical network structures can be linked to frequencies of low-order network motifs within the larger network. The approach requires no closure conditions beyond the low-rank structure and provides a mechanism to reconstruct the distribution of network activity across the population from the small number of activity projections. The equations illustrate how network connectivity affects the dimension of the effective dynamics of the network.

3:00 p.m. - Prof. Igor Belykh, Georgia State University

Title: *Repulsive Inhibition Promotes Synchrony in Excitatory Bursting Networks: Help from the Enemy*

Abstract: We show that the addition of pairwise repulsive inhibition to excitatory networks of bursting neurons induces synchrony, in contrast to one's expectations. Through stability analysis, we reveal the mechanism underlying this purely synergetic phenomenon and demonstrate that it originates from the transition between bursting of different types, caused by excitatory-inhibitory synaptic coupling. This effect is generic and observed in different models of bursting neurons and fast synaptic interactions. We also find a universal scaling law for the synchronization stability condition for large networks in terms of the number of excitatory and inhibitory inputs each neuron receives, regardless of the network size and topology. This general law is in sharp contrast with linearly coupled networks with positive (attractive) and negative (repulsive) coupling where the placement and structure of negative connections heavily affect synchronization.

December 13, 2014

9:00 a.m. - Prof. Adilson Motter, Northwestern University

Title: *To what extent can networks be controlled? And what for?*

Abstract: Numerous systems are now modeled as complex networks of coupled dynamical entities. Nonlinearity and high-dimensionality are hallmarks of the dynamics of complex networks but have generally been regarded as obstacles to control. In this talk, I will discuss recent approaches to control nonlinear network dynamics that are effective in large networks and even in the presence of constraints, noise, and uncertainty. I will also discuss applications to physical, biomedical, and ecological problems, including transient stability, drug target identification, cascade control, and network repurposing.

10:00 a.m. - Prof. Reka Albert, Penn State University

Title: *Network analysis and discrete dynamic modeling elucidates the outcomes of within-cell networks*

Abstract: Interaction networks formed by gene products form the basis of cell behavior (growth, survival, apoptosis, movement). Experimental advances in the last decade helped uncover the structure of many molecular-to-cellular level networks, such as protein interaction or metabolic networks. These advances mark the first steps toward a major goal of contemporary biology: to map out, understand and model in quantifiable terms the various networks that control the behavior of the cell. Such an understanding would also allow the development of comprehensive and effective therapeutic strategies. This talk will focus on my group's recent work on discrete dynamic modeling of signal transduction networks in various organisms. These models can be developed from qualitative information yet show a dynamic repertoire that can be directly related to the real system's outcomes. For example, our model of the signaling network inside T cells predicted therapeutic targets for the blood cancer T-LGL leukemia, several of which were validated experimentally. I will then present an enriched network representation that includes the regulatory logic. Extension of existing network measures and analyses, performed on this expanded network, allows an efficient way to determine the dynamic repertoire of the network and to predict manipulations that can stabilize or, conversely, block, certain outcomes.

11:30 a.m. - Prof. Ginestra Bianconi, Queen Mary University of London

Title: *Structure and Dynamics of Mutlilayer Networks*

Abstract: Many complex systems from interdependent infrastructures and to the brain cannot be fully understood if we dont consider their multilayer network structure. A multilayer network is a system of different interacting networks characterized by different types of structural correlations that have been shown to strongly affect the dynamical processes defined on them.

Here we will discuss recent results on modelling the correlated structure of multilayer networks by non-equilibrium and equilibrium statistical mechanics approaches. Moreover we will present results related to the robustness of a special type of multilayer networks, i.e. network of networks. We will show in particular that the percolation in these systems can be discontinuous or continuous, and in addition to this can display not one but many phase transitions corresponding to the percolation of different layers of the network of networks.

2:00 p.m. - Prof. Ashok Litwin-Kumar, Columbia University

Title: *Formation and maintenance of neuronal assemblies through synaptic plasticity*

Abstract: The architecture of the brain is flexible, permitting neuronal networks to store recent sensory experiences as specific synaptic connectivity patterns. However, it is unclear how these patterns are maintained over long periods of time and in the face of the high variability of neural activity. Here we demonstrate, using a large scale cortical network model, that realistic synaptic plasticity rules coupled with homeostatic mechanisms lead to the formation of neuronal assemblies that reflect previously experienced stimuli. Due to this connectivity structure, the neuronal dynamics exhibit metastability, with different stable states for each stimulus. Spontaneous switching between these states stabilizes, rather than erases, the learned connectivity patterns.

Spontaneous and evoked activity contains a signature of learned assembly structures, leading to testable predictions about the effect of recent sensory experience on the statistics of neural activity. Our work outlines requirements for synaptic plasticity rules capable of modifying spontaneous dynamics and shows that this modification is beneficial for stability of learned network architectures.

3:00 p.m. - Prof. Sayan Mukherjee, Duke University

Tite: *Networks as Random Simplicial Complex*

Abstract: Random graphs have served as one useful model for networks. In this talk I will discuss modeling higher-order interactions in networks as simplicial complexes. Topics I will cover include:

1) an investigation of how spectral graph theory carries over to simplicial complex models

2) random walks on simplicial complexes

3) how to randomly sample simplicial complex networks using ideas from computational geometry.

4:30 p.m. - Prof. Omer Angel, University of British Columbia

Title: *Unimodular Planar Graphs*

Abstract: I will discuss unimodularity in the context of planar random graphs, and some of its consequences. In particular we show that such graphs are local limits of planar graphs if and only if they correspond to a locally finite circle packing, if and only if $p_c = p_u$ for percolation on these graphs. We also relate these properties to expansion and mean degree. I shall also discuss the key motivating examples of random planar maps and random hyperbolic maps. Joint with Tom Hutchcroft, Asaf Nachmias and Gourab Ray.

December 14, 2014

9:00 a.m. - Prof. Yannis Kevrekidis, Princeton University

Title: *Coarse-graining the dynamics of (and on) complex networks: an equation free/variable free approach*

Abstract: Complex, large scale networks often dynamically evolve in time. One can discriminate several different forms for such an evolution: (a) dynamics ON networks, when the connectivity of the network is fixed, but properties of the nodes evolve (e.g. concentrations in a complex biochemical reaction network); (b) dynamics OF networks, where the connectivity of the network itself is evolving edges either form or disappear in time; finally (c) both properties of the nodes and existence/weights of edges evolve, giving us dynamics "of and on" networks, sometimes termed, adaptive network dynamics.

I will begin by describing an approach to coarse-graining the dynamics of large networks whose connectivity changes dynamically. The approach is formulated within our equation-free framework, given a full, detailed model of the network evolution dynamics. We assume that we know what the crucial macroscopic network features are, the "dependent variables" in terms of which we can write macroscopic evolution equations (e.g. the network degree distribution). We then perform short bursts of detailed network evolution simulations from which we estimate the right-hand-sides (and the actions of the Jacobians) of the unavailable closed "macro" evolution equations on the fly. The approach involves repeated use of lifting and restriction operators that translate between actual network realizations and their (appropriately chosen) coarse observables. I will show how to accelerate temporal simulations (through coarse projective integration), and to implement coarse grained fixed point algorithms (through matrix-free Newton-Krylov GMRES). The scope and applicability of the approach will be discussed - including an interesting "technology transfer" between heterogeneous network dynamics and uncertainty quantification algorithms.

I will then discuss the selection of "the right macroscopic" variables based on data-mining mining tools, in particular manifold-learning techniques like Diffusion Maps. We extend these data mining approaches to cases in which every data points in a time series is a "snapshot" of an evolving graph. We are thus able to detect intrinsic low-dimensionality in ensembles of graphs, and detect the appropriate coarse variables. One of the main challenges in mining graph evolution data is the definition of a suitable pairwise similarity metric in the space of graphs. We explore two practical solutions for this problem: one based on finding subgraph densities, and one using spectral graph information. We demonstrate the data-mining process by detecting and parametrizing low-dimensional families of graphs arising from graph construction algorithms as well as from dynamic graph evolution laws.

10:00 a.m. - Prof. Mei Yin, University of Denver

Title: *Asymptotics for exponential random graphs*

Abstract: Exponential random graph models have received exponentially growing attention in recent years. This talk will focus on two variations of the standard model: the constrained exponential random graph model and the sparse exponential random graph model. Emphasis will be made on the variational principle of the limiting free energy, concentration of the limiting probability distribution, phase transitions and asymptotic structures. Joint work with Richard Kenyon and with Lingjiong Zhu.

11:30 a.m. - Prof. Bard Ermentrout, University of Pittsburgh

Title: *Graphs, dynamics, persistent activity*

Abstract: Persistent or re-entrant activity (PA) in systems of coupled neurons, cardiac myocytes, etc is a common feature that can be desired or pathological, depending on the context. This activity arises in networks of excitable elements when there are re-entrant paths. Simultaneous activation (synchronization) of the units leads to silencing of the persistent activity. Thus, PA and quiescence represent two stable states of the network (bistability). A natural question is how does the topology of the connectivity between the elements in the network affect the existence of re-entrant or persistent activity. In this talk, I will first relate re-entrant activity in excitable units, to non-synchronous locked patterns in networks of coupled oscillators. With this convenient homotopy, I will turn my attention to systems of equations of the form:

$$x_i' = \sum_j g_{ij} \sin(x_j - x_i + \alpha)$$

where g_{ij} is the connection graph of 0's and 1's. I will focus almost entirely on regular undirected graphs where each node has exactly k edges. With a brief introduction to $k = 2$, I will present some recent results on $k = 3$ and $k > 3$ where the graphs either have some symmetry or are random. I will construct stable nonsynchronous solutions (re-entrant) and also explore the dynamics on random regular graphs. I will also present some interesting examples that lead to so-called "long links" that have recently been discussed by Lee DeVille, earlier in the semester. This work was done in collaboration with Lawrence Udeigwe and a small army of undergraduate students.