Network Frontier Workshop
Highlighting leading-edge research in network dynamics

Program

December 6 – 7, 2015

Northwestern University
Norris University Center
1999 Campus Drive
Evanston, IL 60208
USA

Organization:
Adilson E. Motter, Scientific Organizer
Luciana Z. Tytenicz, Administrative Organizer
Daniel M. Abrams, Advisory Board Member
Takashi Nishikawa, Advisory Board Member
David J. Schwab, Advisory Board Member
## Schedule

### Sunday, December 6

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<td>8:55 – 9:00</td>
<td>Opening Remarks</td>
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<td>9:00 – 9:30</td>
<td>Louis Pecora (United States Naval Research Laboratory, USA)</td>
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<td><em>Finding and Forming Synchronized Clusters in Complex Networks of Oscillators Using Symmetries</em></td>
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<td>9:30 – 10:00</td>
<td>Maurizio Porfiri (New York University, USA)</td>
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<td><em>Synchronization and Control in Networks of Stochastically Coupled Oscillators</em></td>
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<td>10:00 – 10:15</td>
<td>Jie Sun (Clarkson University, USA)</td>
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<td><em>Sustainable Dynamical Perturbations in Complex Network Synchronization</em></td>
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<td>10:15 – 10:30</td>
<td>Yogesh S. Virkar (University of Colorado, Boulder, USA)</td>
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<td><em>The Hamiltonian Mean Field Model: Effect of Network Structure on Synchronization Dynamics</em></td>
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<td>11:00 – 11:30</td>
<td>Lora Billings (Montclair State University, USA)</td>
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<td><em>Pre-Extinction Dynamics in Stochastic Populations</em></td>
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<td>Daniel K. Wells (Northwestern University, USA)</td>
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<td><em>Control of State Transitions in Biophysical Networks</em></td>
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<td>12:30 – 2:15</td>
<td>Lunch Break and Talk (Allen Center)</td>
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<td>1:30 – 1:45</td>
<td>John C. Paolillo (Indiana University, USA)</td>
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<td><em>The Politics of Conspiracy on YouTube</em></td>
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<td>2:15 – 2:45</td>
<td>Jeff Moehlis (University of California, Santa Barbara, USA)</td>
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<td><em>Brain Control – It’s Not Just for Mad Scientists</em></td>
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<td>2:45 – 3:15</td>
<td>Alessandro de Moura (University of Aberdeen, Scotland)</td>
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<td><em>Signatures of Evolution in DNA Replication: How Physics and Mathematics Can Help Understand Biology</em></td>
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<td>3:15 – 3:30</td>
<td>Sahil Shah (Northwestern University, USA)</td>
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<td><em>Network-Based Identification of Driver Genes in Expression Data</em></td>
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<td>3:30 – 3:45</td>
<td>Otti D’Huys (Duke University, USA)</td>
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<td><em>Extreme Transients in Experimentally Biologically Inspired Networks</em></td>
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<td>4:15 – 4:45</td>
<td>Radhakrishnan Mahadevan (University of Toronto, Canada)</td>
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<td><em>Role of Redundancy and Synthetic Rescues in Metabolic Engineering</em></td>
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<td>4:45 – 5:15</td>
<td>Alexander DeLuna (Langebio Cinvestav, Mexico)</td>
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<td><em>Aging Mechanisms Revealed by Large-Scale Genetic Analysis of Yeast Lifespan</em></td>
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<td>Brian Thompson (Army Research Laboratory, USA)</td>
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<td><em>Active Defense Strategies for Limiting Disruption to Network Functionality Due to Propagating Malware</em></td>
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<td>Xin Lin (Rensselaer Polytechnic Institute, USA)</td>
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<td><em>Long-Term Failure Prediction Based on ARP Model of Global Risk Network</em></td>
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<td>Shai Revzen (University of Michigan, Ann Arbor, USA)</td>
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<td>8:45 – 9:15</td>
<td>Kenneth Showalter</td>
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<td>Andrey L. Shilnikov</td>
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<td>10:15 – 10:30</td>
<td>Nasir Ahmad</td>
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<td>Rajarshi Roy</td>
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<td>Erik M. Bollt</td>
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<td>Feng Shi</td>
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<td>Prakash Narayan</td>
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<td>Saray Shai</td>
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<td>Igor Mezić</td>
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<td>Mario Di Bernardo</td>
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<td>5:15 – 5:30</td>
<td>Elad Harel</td>
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<td>5:30 – 6:00</td>
<td>Daniel Diermeier</td>
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Posters

Bradly J. Alicea (University of Illinois, Urbana-Champaign, USA)
The Network Architecture of Embryo Developmental Regulation

Sergei Sergeevich Avedisov (University of Michigan, USA)
Modal Analysis of Connected Vehicle Systems with Long Range Vehicle-to-Vehicle Communication

Christian Bick (University of Exeter, United Kingdom)
Dynamics of Asynchronous Networks

David Burstein (University of Pittsburgh, USA)
Enumeration of Graphs with Fixed Degree Sequences and Applications

Young Sul Cho (Northwestern University, USA)
Two Types of Discontinuous Percolation Transitions in Cluster Merging Processes

Andrew B. Cowley (University of Colorado, Boulder, USA)
Maximization of Entropy in Networks of Excitable Systems

Faryad Darabi Sahneh (Kansas State University, USA)
Delocalized Epidemics on Graphs

Jeremie A. Fish (Clarkson University, USA)
Information Flow in Transient Network Dynamics

Jin Ge (University of Michigan, USA)
Optimization of Connected Cruise Control with Time Delay

Olga Golovneva (New York University, USA)
Stochastic Non-Fast Switching in Complex Networks: Windows of Opportunity

Aleksandar Haber (Northwestern University, USA)
Identification of Dynamical Models of Chemical Reaction Networks

Joseph D. Hart (University of Maryland, College Park, USA)
Minimal Chimeras?

Nicholas Haynes (Duke University, USA)
Information Processing in Time-Delay Autonomous Boolean Networks

Chaozhe He (University of Michigan, USA)
Fuel Economy Optimization of Heavy Duty Vehicles in an Information Rich World

Meilin Huang (Gustavus Adolphus College, USA)
Selective Pressure-Induced Change in Network Structure Accelerates the Emergence of Autocatalytic Networks
Yuriy Hulovatyy (University of Notre Dame, USA)  
*Exploring the Structure and Function of Temporal Networks with Dynamic Graphlets*

Hsuan-Wei Lee (University of North Carolina, Chapel Hill, USA)  
*Social Clustering in Opinion Formation and Epidemic Spread on Coevolving Networks*

Matthias Leiss (ETH Zurich, Switzerland)  
*How Communication Networks Lead to Collectively Meaningful Behavior*

Nan Li (University of Michigan, USA)  
*Dynamical Analysis and Optimization of Heterogeneous Connected Vehicle Systems*

Hongyu Meng (Northwestern University, USA)  
*Independent Noise Can Synchronize Interacting Networks of Pulse-Coupled Oscillators*

Azadeh Nematzadeh (Indiana University, USA)  
*Optimal Network Modularity for Fast Global Information Diffusion*

Wubing Qin (University of Michigan, USA)  
*Digital Effects and Stochastic Delays in Connected Cruise Control (CCC)*

Mehdi Sadeghpour (University of Michigan, USA)  
*Stochastic Delays in Gene Regulatory Networks*

Amirhossein Sajadi (Case Western Reserve University)  
*Dynamics of Power Grid Influenced by Large Scale Offshore Wind Power*

Saleh Soltan (Columbia University, USA)  
*Generation of Synthetic Spatially Embedded Power Grid Networks*

Jiang Tao (Huazhong University of Sciences and Technology, China)  
*A Wong-Zakai Approximation for Random Invariant Manifolds*

Dane Taylor (University of North Carolina, Chapel Hill, USA)  
*Topological Data Analysis of Contagion Maps for Examining Spreading Processes on Networks*

Thomas P. Wytock (Northwestern University, USA)  
*Can Gene Expression Guide Reprogramming?*

Yang Yang (Northwestern University, USA)  
*Identifying Vulnerable Spots in Real Power-Grid Networks*

Linjun Zhang (University of Michigan, USA)  
*Motif-Based Design of Connected Vehicle Networks*
Pre-Extinction Dynamics in Stochastic Populations (Dec 6, 11:00am)

It has long been known that noise can significantly affect physical and biological dynamical systems at a wide variety of levels. Specifically, we focus on systems in which small perturbations cause rare events, such as population extinction. Extinction risk is an important question in both population dynamics and ecological community dynamics. We observe that in stochastic population models, the intrinsic noise can cause random switching between metastable states before the population goes extinct. Modeling the dynamics of the network of metastable states may provide insight to the complex behavior of the system. Using this framework, we can understand pre-extinction cycling dynamics and quantify the impact of control methods to decrease the mean time to extinction. Our methods include a master equation approach using an WKB (Wentzell-Kramers-Brillouin) approximation along with probabilistic arguments to understand the delay in complex extinction events. These findings can be extended to more complicated systems, but underscore the importance of and challenges in developing methods to analyze large stochastic networks.

Aging Mechanisms Revealed by Large-Scale Genetic Analysis of Yeast Lifespan (Dec 6, 4:45pm)

Lifespan is a complex trait with clear genetic underpinnings. With a growing number of aging-related proteins and gene-regulatory pathways in hand, the next great challenge is to describe how such genetic aging factors are integrated with one another and how they are affected by environmental cues. To this end, we developed an automated method based on the stationary-phase competitive survival of Saccharomyces cerevisiae knockout strains labeled with fluorescent-protein variants, allowing for systematically finding chronological lifespan factors at high resolution and scoring the genetic interactions (epistasis) among them. In this talk, I will present a genome-wide survey of genes that mediate lifespan extension by dietary restriction, along with a lifespan-epistasis network based on over 10,000 chronological lifespan phenotypes. With this information, we describe a connection of the Swr1 histone-exchange complex with lifespan extension by dietary restriction, along with a lifespan-epistasis network based on other relevant pathway crosstalks. Our high-resolution lifespan phenotyping screens provide new insights into the gene-network wiring of aging cells.
Signatures of Evolution in DNA Replication: How Physics and Mathematics Can Help Understand Biology
(Dec 6, 2:45pm)

DNA replication is one of the most important tasks a cell will ever undertake. Recent advances in DNA sequencing technology have made it possible to acquire quantitative data of unprecedented quality and resolution about the dynamics of this fundamental biological process. In this talk I will show how mathematical modelling helped solve some long-standing questions in the field. Using this problem as an example, I will also talk more generally about how mathematics and physics can have an impact on biology.

Self-Organizing and Multiplex Control of Complex Networks
(Dec 7, 4:45pm)

In this talk, we will discuss decentralized and distributed algorithms to control the collective behavior of complex networks. As a representative example, we will focus on the problem of reaching consensus or synchronization in a network of linear or nonlinear, possibly heterogeneous, systems (that we shall term as the “open-loop network”). Firstly, a multiplex control architecture will be presented to achieve control of the collective behavior of a complex network of interest when the nodes are heterogeneous and affected by disturbances or uncertainties. The idea is to deploy the control action across multiple layers so that different types of strategies can be used concurrently to better achieve the control objective or to enhance robustness of the closed loop network. The design of a multiplex PID (Proportional-Integral-Derivative) control network will be presented that is able to steer towards consensus or synchronization an heterogeneous ensemble of linear or nonlinear agents with disturbances. This is achieved by deploying on the links of the open loop network different types of coupling [proportional (P), integral (I) or derivative (D)] through different layers, each characterized by a different structure. Conditions linking the strength of the control gains will be derived that link their values with the structural properties of the open loop network and each of the control layers. It will be shown that the main advantage of the multiplex strategy is that the control effort can be substantially reduced by changing the structure of the layers of the control architecture. We will then discuss its robustness to measurement errors and noise and present an adaptive extension of the architecture where the control gains can be adapted in real time so that the network can self-organize to best achieve the desired goal.

Modeling Public Opinion
(Dec 7, 5:30pm)

Understanding the dynamics of public opinion is of central importance for the study of political systems. Over the last decades two research traditions have emerged that propose different and largely unconnected approaches to the study of public opinion. The first tradition applies methods from statistical physics and complex systems to public opinion research and is almost entirely theory-based. The second, political science-based approach relies on mass opinion surveys and is empirical in nature. I will contrast and compare these approaches and suggest potential research directions that could integrate the two traditions to improve our understanding of public opinion.
Latent Space Models for Complex Networks  
(Dec 7, 2:45pm)

Studies of social systems have traditionally focused on analyzing networks induced by social interactions, while discarding rich contextual information on nodes and their properties. At the same time, empirical evidence points to strong correlations between node attributes and their interactions. Here we suggest a viable framework for analyzing attribute-rich and multi-modal social data based on latent space models. In this approach, each node is assigned an unobserved (latent) position in some space, so that both the nodes’ attributes and their interactions depend on their coordinates in this space. This “shared” latent space allows to capture observed correlations between the attributes and network structure. We perform extensive experiments where the goal is predict missing links in a network using attributes, or predict user attributes based on network information, and observe that the proposed method outperforms other baselines in both prediction tasks.

Control of Networks of Chemical Oscillations: Synchronization Engineering and Optimal Entrainment  
(Dec 7, 9:15am)

Complex system responses can emerge from interactions among nonlinear rhythmic components. External signals can be used to control the behavior of complex rhythms, both to tune essential behavior, such as by heart pacemakers, or to alter pathological behavior, such as by deep-brain “antipacemakers” in tremors or Parkinson’s disease. In such applications, a mild control is desired so that the system can be tuned to a desired behavior without destroying its fundamental nature. In the presentation, a methodology is presented that applies phase models to describe and tune complex dynamic structures to desired states; weak, nondestructive signals are used to alter interactions among nonlinear rhythmic elements. Experiments on electrochemical reactions on electrode arrays are used to demonstrate the power of mild model-engineered feedback to achieve a desired response. Applications are made to the generation of cluster states, restoring rhythmicity in diffusively coupled dynamical networks, and to the design of rotating waves in regular rings and small-world type networks. Finally, phase model analysis is combined with calculus of variation to derive a waveform with which robust or fast entrainment of an oscillator is achieved with minimum power, area, and magnitude forcing signal. The theory is
tested in electrochemical entrainment experiments in which sinusoidal and higher harmonic nontrivial optimal waveforms are obtained depending on experimental conditions. The proposed method will give a convenient way to obtain optimal waveform for entrainment (e.g., in design of cardiac pacemakers and injection locked electronic oscillators) and could test the optimality of current waveforms used in many applications.

**Daniel B. Larremore**

*Omidyar Fellow*

*Santa Fe Institute, USA*

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**Networks and the Evolution of Malaria’s Virulence in Humans and Apes**  (Dec 6, 11:30am)

Despite extensive research and public health efforts, there remain hundreds of millions of malaria cases annually, causing over half a million deaths, mostly children. Key to malaria’s ongoing transmission is the fact that humans develop only a weak immunity, stemming from the parasite’s evasion of the immune system by sequential expression of camouflage-like proteins on the surface of infected red blood cells. The genetic variation within the camouflage-encoding var genes is sufficiently high dimensional that immunity to a single camouflage variant doesn’t hinder future infections. What’s more, each parasite genome contains ~60 different var genes, which rapidly recombine, precluding the use of traditional phylogenetic techniques. I will present a series of investigations to understand the key mechanisms and constraints underlying the ongoing evolution of var genes. We first developed a framework capable of mapping rapidly recombining genes to networks in which evolutionary constraints are revealed in large-scale network structures. Applying this approach to multiple genomes, we identified the parts of the camouflage proteins that evolve differently than others. To improve the quality of network community detection, we developed a bipartite stochastic block model, and then applied it to an expanded data set including var genes from ape-infecting malaria parasites. This revealed the deep origins of the malaria parasite’s current immune evasion strategy, which evolved tens of millions of years ago in an ancient ancestor of extant malaria species. This frames the current adaptive struggle in humans in a broader evolutionary context, with implications for parasite population genetics as malaria prevention efforts shift toward elimination. It also begs for the continued development of principled network-based models to answer open biological questions.

**Radhakrishnan Mahadevan**

*Associate Professor*

*Chemical Engineering and Applied Chemistry*

*University of Toronto, Canada*

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**Role of Redundancy and Synthetic Rescues in Metabolic Engineering**  (Dec 6, 4:15pm)

Bioprocess development for biofuels and biochemicals typically requires several rounds of metabolic engineering to meet process targets including product yield, titer and productivity, all of which impact the process economics. Recent advances in experimental and computational technologies have enabled the detailed characterization of biological systems. In particular, the molecular components of these systems including the list of genes, proteins they encode, and compounds that interact with these proteins can be determined. Similar advances in computational modeling techniques have allowed the development of genome-scale models of metabolism in several organisms. In this talk, the use of such models for metabolic engineering will be presented. We will also examine the role of the redundant pathways from a design perspective and present computational results on how these pathways is valuable for robust design. Finally, we will present model-based strategy for metabolic engineering that relies on synthetic rescue mechanism in yeast and explain how compartmentalization of metabolism can potentially create an opportunity to couple redox balance to the production of target compounds.
Strongly Coupled Oscillators: a Koopman-Theoretic Approach (Dec 7, 4:15pm)

We discuss a class of physical systems that exhibit interesting global coupling phenomena that are due to both local nonlinearity and strong local coupling. Examples are drawn from molecular dynamics and power grid dynamics. A fairly general theory of such systems is provided, based on applications of Koopman operator formalism.

Brain Control – It’s Not Just for Mad Scientists (Dec 6, 2:15pm)

Some brain disorders are hypothesized to have a dynamical origin; in particular, it has been hypothesized that some symptoms of Parkinson’s disease are due to pathologically synchronized neural activity in the motor control region of the brain. We have developed a procedure for determining an optimal electrical deep brain stimulus which desynchronizes the activity of a group of neurons by maximizing the Lyapunov exponent associated with their phase dynamics, work that could lead to an improved method for treating Parkinson’s disease.

Shared Information (Dec 7, 2:15pm)

Shannon’s mutual information between two random variables is a fundamental and venerable concept in information and communication theory, statistics and beyond. What is a measure of mutual dependence among an arbitrary number of random variables? A notion of “shared information” among multiple terminals, that observe correlated random variables and communicate interactively among themselves, is shown to play a useful role in certain problems of distributed processing and computation. A larger role for shared information, which for two terminals particularizes to mutual information, is an open question. This talk is based on joint works with Imre Csiszár, Sirin Nitinawarat, Himanshu Tyagi and Shun Watanabe.

Finding and Forming Synchronized Clusters in Complex Networks of Oscillators Using Symmetries (Dec 6, 9:00am)

Many networks are observed to produce patterns of synchronized clusters, but it has been difficult to predict these clusters in general or understand the conditions for their formation. We show the intimate connection between network symmetry and cluster synchronization. We apply computational group theory to reveal the clusters and determine their stability. In complex networks the symmetries can number in the millions, billions, and more. The connection between symmetry and cluster synchronization is experimentally explored using an electro-optic network. In networks with Laplacian coupling clusters are possible which do not
directly result from symmetries; however, it is possible to construct all possible synchronized clusters starting from the symmetry clusters. We show how to do this using the computational group theory as an aid and how to derive the variational equations for all the clusters.

**Maurizio Porfiri**

Professor  
Mechanical and Aerospace Engineering  
New York University, USA

**Synchronization and Control in Networks of Stochastically Coupled Oscillators** (Dec 6, 9:30am)

The study of synchronization has attracted the interest of researchers from different fields of science and engineering for its pervasiveness across natural and technological settings. While most of the existing research has focused on static networks, in many instances, the coupling strength or the network topology may vary in time. In this presentation, we focus on stochastic networks, and we specifically address mean square synchronization of networks of chaotic maps. We demonstrate the possibility of formulating a master stability function for a class of stochastic networks and we offer a toolbox of close-form results to study blinking networks and stochastic pinning control.

**Rajarshi Roy**

Professor of Physics  
Institute for Research in Electronics and Applied Physics  
Institute for Physical Science and Technology  
University of Maryland, College Park, USA

**Networks in the Laboratory** (Dec 7, 11:00am)

Optoelectronics provide a versatile platform for learning about dynamics, synchronization and cluster formation in networks, large and small. We will discuss global synchronization, and the stability of synchronized clusters and chimera states. Experiments with networks of time-delayed feedback oscillators and liquid crystal spatial light modulator systems will be described.

**Shai Revzen**

Assistant Professor  
Electrical Engineering and Computer Science  
University of Michigan, Ann Arbor, USA

**Synchronization and Dimensionality Reduction in Networks of Hybrid Phase Oscillators: A Perspective from Legged Locomotion** (Dec 6, 7:00pm)

Phase oscillators are a common reduced model for oscillatory systems. When the equations of motion of a network of phase oscillators are discontinuous (and meet some technical requirements), the resulting model is a hybrid dynamical system. Such models can arise for power grids, for neural nets, and in describing legged locomotion of animals and robots. I present recent results on the dynamics of this class of models, which show surprising advantages for control and stabilization of locomotion thanks to the use of legs. The results apply broadly to networks of hybrid oscillators.

**Kenneth Showalter**

Professor, C. Eugene Bennett Chair in Chemistry  
West Virginia University, USA

**Phase-Lag Synchronization in Networks of Coupled Chemical Oscillators** (Dec 7, 8:45am)

Chemical oscillators with a broad frequency distribution are photochemically coupled in network topologies. Experiments and simulations show that the network synchronization occurs by phase-lag synchronization of clusters of oscillators with zero- or nearly zero-lag synchronization. Symmetry also plays a role in the synchronization, the extent of which is explored as a function of coupling strength, frequency distribution, and the highest frequency oscillator location. The phase-lag synchronization occurs through connected synchronized clusters, with the highest frequency node or nodes.
setting the frequency of the entire network. The synchronized clusters successively “fire,” with a constant phase difference between them. For low heterogeneity and high coupling strength, the synchronized clusters are made up of one or more clusters of nodes with the same permutation symmetries. As heterogeneity is increased or coupling strength decreased, the phase-lag synchronization occurs partially through clusters of nodes sharing the same permutation symmetries. As heterogeneity is further increased or coupling strength decreased, partial synchronization and, finally, independent unsynchronized oscillations are observed. The relationships between these classes of behavior are explored with numerical simulations, which agree well with the experimentally observed behavior.


Abstracts – Contributed Talks

Nasir Ahmad
University of Illinois at Chicago, USA

Analyzing Multivariate Time Series Data Using a Network-Based Approach (Dec 7, 10:15am)

In a recent paper, we adopted a network science and non-parametric approach to supplement statistical analyses in the study of any data set. Essentially, two values in a data set are connected if they are “similar” to one another (akin to homophily in social networks); i.e., if they lie within a certain range of one another. The value with the highest degree therefore becomes the mode of the distribution and represents the main “trend” (as opposed to the mean that is usually considered to represent the main trend). In this talk, we apply the methodology to energy and resource consumption data at the country level from 1960 to 2010, using data from the World Bank data catalog, and analyze how trends have evolved in the past 50 years. We are notably able to track the evolution of every single country compared to the main trend by calculating how far it lies from the mode in terms of distance (hops) in the network. In fact, we can plot how the distance from the mode varies year after year on a polar scale, resulting in what we call “orbital” diagrams. We can also compare how this distance varies across variables. For instance, we can compare the total distance of GDP with energy use to get an overall energy “cost” of an increasing GDP (i.e., the number of additional hops in energy for an increase in one hop for GDP). Finally, we also compare whether the “peers” of a country for one set of data (e.g., CO₂ emissions, GDP).

Co-author: S. Derrible

Michelle A. Birkett
Northwestern University, USA

Racial Disparities and the Influence of Residential and Social Spaces on the Structure of HIV Transmission (Dec 6, 12:00pm)

Black young men who have sex with men (YMSM) are particularly affected by the HIV epidemic, with an annual incidence higher than any other age, race, or risk group. However, mechanisms which produce these racial disparities in HIV are poorly understood. In this talk I will present a broader multilevel social-contextual framework that examines the role of homophobia, racism, and poverty in shaping the transmission networks of YMSM. Data will be presented from two datasets. The first will examine the role of residential neighborhood in the sexual connections of YMSM through an examination of 3,140 individuals across 77 Chicago community areas. The second will examine the role of social spaces, specifically venues and bars that men attended in order to meet sexual partners. Our findings suggest several mechanisms for how social contextual factors impact the social and sexual network structure of individuals and their communities, and therefore affect the flow of disease through a population.

Co-authors: P. Janulis, G. Phillips II
**Erik M. Bollt**  
*Rutgers University, USA*  

**Identifying the Coupling Structure in Complex Systems Through the Optimal Causation Entropy Principle**  
*(Dec 7, 12:15pm)*

Inferring the coupling structure of complex systems from time series data in general by means of statistical and information-theoretic techniques is a challenging problem in applied science. The reliability of statistical inferences requires the construction of suitable information-theoretic measures that take into account both direct and indirect influences, manifest in the form of information flows, between the components within the system. In this work, we present an application of the optimal causation entropy (oCSE) principle to identify the coupling structure and jointly apply the aggregative discovery and progressive removal algorithms based on the oCSE principle to infer the coupling structure of the system from the measured data.  
*Co-authors: J. Sun, D. Taylor, and W. Lord*

**Daniel J. Case**  
*Northwestern University, USA*  

**Nonlinear Flows in Microfluidic Networks**  
*(Dec 7, 9:45am)*

The laminar flow regime within microfluidic systems typically results in a linear relation between flow rates and applied pressure differentials. Precise control of flows through a microfluidic system, such as the opening or closing of channels, is often achieved by nonlinear input from hardware external to the system (i.e., pumps and computers). In this presentation, I will discuss how nonlinear flow behavior typically generated by such external hardware can instead be induced by the network structure of the system. We expect this work to contribute towards furthering the development of portable microfluidic systems and expanding their applications outside of the laboratory setting.  
*Co-authors: J.-R. Angilella and A.E. Motter*

**Otti D’Huys**  
*Duke University, USA*  

**Extreme Transients in Experimental Biologically Inspired Networks**  
*(Dec 6, 3:30pm)*

Systems with switch-like interactions, such as genetic regulatory networks, are well modeled by autonomous Boolean networks. We present an experimental implementation of gene regulatory networks on a field-programmable gate array; unlike most mathematical descriptions, our system shows non-ideal behavior associated with noise, asymmetries and we explicitly implement the delays arising from transcription, translation and spatial transport in cells. In particular, we investigate two basic gene regulatory circuits, the toggle switch and the repressilator. In both circuits we find that delays along the links can give rise to extremely long transient behavior (up to a billion times the typical timescale of the dynamics), and we show how to control the transient duration.  
*Co-authors: J. Lohmann, N.D. Haynes, E. Schoell and D.J. Gauthier*

**Elad Harel**  
*Northwestern University, USA*  

**Emergence of Long-Range Energy Transport in Quantum Networks**  
*(Dec 7, 5:15pm)*

At the nanoscale, quantum mechanics plays an important role in determining how energy moves through and between coupled molecular units. Typically, energy migration is short range because of its susceptibility to trapping. Here, we discuss ways in which long-range energy transfer may emerge in certain classes of quantum networks that experience periodic external electric fields. Specifically, we consider a hexagonal and periodic lattice with each site coupled to its nearest neighbor by dipole-dipole coupling. After an initial excitation event, the system experiences free evolution in the presence of periodic fields that rotate the dipole moment by prescribed angles in the far field (i.e. with no spatial bias). We demonstrate that when the spacing of near-impulsive fields is appropriately tuned, energy that is normally trapped between a few sites is then suddenly allowed to migrate nearly indefinitely through the network, only limited by the system’s coherence time. We find that the rules that govern emergent properties in such quantum networks are drastically different than those in classical networks.  

**Xin Lin**  
*Rensselaer Polytechnic Institute, USA*  

**Long-Term Failure Prediction Based on ARP Model of Global Risk Network**  
*(Dec 6, 5:30pm)*

Risks that threaten modern societies form an intricately interconnected network. Hence, it is important to understand how risk materializations in distinct domains influence each other. In [1], we study the global risks network defined by World Economic Forum experts in the
such as static network analysis that would otherwise be missed by a simpler approach. Our framework captures results by constructing the dynamic network from longitudinal data. We thoroughly evaluate choices of parameters relevant for communication events. We apply the framework to study the pattern with time, 2) clustering nodes with similar interactions, and 3) linking the clusters with trait interplays that have not been studied to date and could lead to novel insights by domain scientists.

Co-authors: Y. Hulovatyy, A. Striegel, T. Milenkovitch

Mark J. Panaggio
Rose-Hulman Institute of Technology, USA

Basins of Attraction for Chimera States (Dec 7, 12:00pm)

Chimera states are dynamical patterns in networks of coupled oscillators in which regions of synchronous and asynchronous oscillation coexist. These partially synchronized patterns have been observed in a variety of experiments and bear a resemblance to dynamical behavior in the heart and brain. In many topologies, chimeras are bistable with a fully synchronized state. Therefore, the steady state behavior depends on the initial phases and can only be predicted through knowledge of the basins of attraction. In this talk, I will discuss the emergence of chimera states in networks of phase oscillators that are organized in two groups. I will present analytical and numerical results revealing the structure of the basins of attraction of chimeras in the continuum limit and a simple control strategy for switching between chimeras and the fully synchronized state. I will also show that these results provide valuable insight into the dynamics in finite systems with a small number of oscillators as well.

Co-authors: E.A. Martens, D.M. Abrams

Lei Meng
University of Notre Dame, USA

On the Interplay between Individuals’ Evolving Interaction Patterns and Traits in Dynamic Multiplex Social Networks (Dec 7, 3:15pm)

The interplay between individuals’ social interactions and traits has been studied extensively but traditionally from static or homogeneous social network perspectives. The recent availability of dynamic and heterogeneous (multiplex) network data has introduced a variety of new challenges. Namely, to what extent does an individual shape the social network(s) the individual participates in and/or to what extent do the social networks shape the individual? Novel computational models are needed that can cope with data dynamics and heterogeneity. We introduce a computational framework that is broadly applicable to many dynamic, multiplex domains, which focuses on: 1) measuring changes in node interaction patterns with time, 2) clustering nodes with similar evolving patterns, and 3) linking the clusters with trait similarities. We apply the framework to study the interplay between evolving topology and traits in an 18-month social network dataset encompassing both digital communications and co-location instances, while also thoroughly evaluating choices of parameters relevant for constructing the dynamic network from longitudinal communication events. Our framework captures results that would otherwise be missed by a simpler approach such as static network analysis alone. It uncovers network-trait interplays that have not been studied to date and could lead to novel insights by domain scientists.

Co-authors: A. Moussawi, G. Korniss and B. Szymanski

John C. Paolillo
Indiana University, USA

The Politics of Conspiracy on YouTube (Dec 6, 1:30pm)

Starting from a set of 1003 channels collected through browsing videos on conspiracy-related topics (9/11, JFK, New World Order, Chemtrails, UFOs, Nibiru/Planet X, Genetically Modified Organisms, etc.), more than 70,000 associated channels were identified, including mainstream news channels (CNN, BBC, RT, etc.), channels parasitizing television media networks by re-circulating old copyrighted content (e.g. from the History channel, BBC documentaties, etc.), specialized YouTube news channels (e.g., Newsy, The Young Turks, etc.), personalities with a dual presence on social media and mainstream broadcast media (Alex Jones, David Icke, Richard Hoagland, etc.), and religious ministries, in addition to channels devoted to one or more common current conspiracy theories. Preliminary observations indicate that there exists a network of information exchange in which anti-government/libertarian
personalities are highly central both in their network position and in the success of propogating their messages. Nonetheless, there is strong segmentation in the network separating channels into ideologically distinct groups. These observations indicate the necessity of regarding conspiracy theories in terms of their relation to general processes of political communication, rather than as isolated eccentricities.

Sahil Shah  
Northwestern University, USA

**Network-Based Identification of Driver Genes in Expression Data** (Dec 6, 3:15pm)

Gene expression profiles can identify individual differentially expressed genes, but not the genes that are central to the systems that underlie a phenotype. To address this gap, we incorporate a global gene interaction network with expression data and develop a novel algorithm to identify these “mechanistic driver genes.” To evaluate its performance, we apply it to both real and synthetic data.  
*Co-authors: R. Braun and W. Kath*

Saray Shai  
University of North Carolina, Chapel Hill, USA

**Multiplex Networks in Metropolitan Areas: Generic Features and Local Effects** (Dec 7, 3:30pm)

Most large cities are spanned by more than one transportation system. These different modes of transport have usually been studied separately: it is however important to understand the impact on urban systems of the coupling between them. We report an empirical analysis of the coupling between the street network and the subway for the two large metropolitan areas of London and New York. We observe a similar behavior for network quantities related to quickest paths suggesting the existence of generic mechanisms operating beyond the local peculiarities of the specific cities studied. An analysis of the betweenness centrality distribution shows that the introduction of underground networks operate as a decentralizing force creating congestions in places located at the end of underground lines. Also, we find that increasing the speed of subways is not always beneficial and may lead to unwanted uneven spatial distributions of accessibility. In fact, for London—but not for New York—there is an optimal subway speed in terms of global congestion. These results show that it is crucial to consider the full, multimodal, multilayer network aspects of transportation systems in order to understand the behavior of cities and to avoid possible negative side-effects of urban planning decisions.

Feng Shi  
University of Chicago, USA

**How Science Thinks: Dynamic Network Models of Science’s Unfolding Structure** (Dec 7, 1:30pm)

Science is a complex system. It is built up from strong interactions between diverse, differentiated components (e.g., scientists, knowledge, institutions) and manifests periods of incremental effort punctuated by bursts of controversy or transformation. We thus model science as a dynamic hypergraph of knowledge and explore how this fabric provides a substrate for future scientific discovery. We first develop a random walk model for scientific discoveries, which, when fitted to millions of papers recorded in PubMed, successfully predicts future dyadic connections and reveals intriguing modal dispositions in the way biomedical science evolves. Given the remarkable predictive power of the simple random walk model, we continue to develop an advanced mixed-membership stochastic block model for hypergraphs and a new inference method that is able to estimate this model for massive hypergraphs. The hypergraph block model performs very well in predicting higher-order (i.e., group) interactions for the PubMed dataset, and provides a principled way to study how novelty and fitness of combinations of knowledge are related to scientific impact.  
*Co-authors: J.G. Foster and J.A. Evans*

Andrey L. Shilnikov  
Georgia State University, USA

**Bifurcation Theory for Networks** (Dec 7, 10:00am)

My original area of expertise is the theory of applied dynamical systems and global bifurcations. I study dynamics and their origin in diversely phenomenological systems and in exact models from life sciences. Of my special interest is a new emergent cross-disciplinary field known as mathematical neuroscience. Its scopes include nonlinear models of individual neurons and networks. In-depth analysis of such systems requires development of advanced mathematical tools paired with sophisticated computations. I derive models and create bifurcation toolkits for studying a stunning array of complex activities, such as multistability of individual neurons and polyrhythmic bursting patterns discovered in
multifunctional central pattern generators governing vital locomotor behaviors of animals and humans.

Jie Sun
Clarkson University, USA

Sustainable Dynamical Perturbations in Complex Network Synchronization (Dec 6, 10:00am)

How much perturbation can a network sustain without losing synchronization? We derive low-dimensional master basin functions which yield analytical estimates of the (nonlocal) stable synchronization regions for arbitrarily large networks under single-node perturbations. The master basin functions reveal the intricate non-monotonic relation between a node’s dynamical fragility and degree. Furthermore, we develop analytical approximations of the stability region under sparse multi-node perturbations, providing an objective measure for the design of robust synchronization networks against dynamical perturbations.

Brian Thompson
Army Research Laboratory, USA

Active Defense Strategies for Limiting Disruption to Network Functionality Due to Propagating Malware (Dec 6, 5:15pm)

Much of the existing literature on cyber defense focuses on detection and response: developing better detection mechanisms, combating malware that has already been detected, or efficiently patching known vulnerabilities. However, some of the most crippling cyber-attacks in history were achieved by evading detection for a long time, propagating malware throughout a network for months or years undetected. On the other hand, some viral attacks spread very quickly, infecting an entire network before exploited vulnerabilities can be identified or patches developed. In this work, we explore active defense mechanisms to sustain network functionality while limiting the spread of malware — detected or not — by deciding when nodes should undergo a quarantine-and-clean operation. We propose a continuous-time stochastic model and derive analytical results for the optimal solution, which we validate in a more realistic environment using agent-based simulation.

Co-authors: H. Cam and J. Morris-King

Yogesh S. Virkar, USA
University of Colorado, Boulder, USA

The Hamiltonian Mean Field Model: Effect of Network Structure on Synchronization Dynamics (Dec 6,10:15am)

The Hamiltonian Mean Field (HMF) model of coupled inertial, Hamiltonian rotors is a prototype for conservative dynamics in systems with long-range interactions. We consider the case where the interactions between the rotors are governed by a network described by a weighted adjacency matrix. By studying the linear stability of the incoherent state, we find that the transition to synchrony occurs at a coupling constant $K$ inversely proportional to the largest eigenvalue of the adjacency matrix. We derive a closed system of equations for a set of local order parameters and use these equations to study the effect of network heterogeneity on the synchronization of the rotors. We find that for values of $K$ just beyond the transition to synchronization the degree of synchronization is highly dependent on the network’s heterogeneity, but that for large values of $K$ the degree of synchronization is robust to changes in the heterogeneity of the network’s degree distribution. Our results are illustrated with numerical simulations on Erdős-Rényi networks and networks with power-law degree distributions.

Co-author: J. Restrepo

Daniel K. Wells
Northwestern University, USA

Control of State Transitions in Biophysical Networks (Dec 6, 12:15pm)

Noise is a fundamental part of intracellular processes. While the response of biological systems to noise has been studied extensively, there has been limited understanding of how to exploit it to induce a desired cell state. Here I will present a scalable, quantitative method based on the Freidlin-Wentzell action to predict and control noise-induced switching between different states in genetic networks that, conveniently, can also control transitions between stable states in the absence of noise. I will discuss applications of this methodology to predict control interventions that can induce lineage changes and to identify new candidate strategies for cancer therapy. This framework offers a systems approach to identifying the key factors for rationally manipulating network dynamics, and should also find use in controlling other classes of complex networks exhibiting multi-stability.

Bradly J. Alicea  
*University of Illinois, Urbana-Champaign, USA*

**The Network Architecture of Embryo Developmental Regulation**

There are two basic forms of animal development: mosaic (as found in roundworms and sea squirts) and regulative (as found in amphibians and mammals). How might one distinguish between each type of development? Using a four-dimensional spatial representation \((x,y,z,i)\), where \(i\) is a cell’s unique location in a lineage tree organized by differentiation code (a binary code for size asymmetry in daughter cells), major features of the developmental process are revealed. To establish the role of mosaic mechanisms, we can map the cell division process to a computational representation of *C. elegans* embryogenesis using a directed, acyclic graph (DAG) and a differentiation code. Mosaic development is identifiable by observing spatial localization of progenitor and descendent cells. This three-dimensional compartmentalization should be consistent with nesting in the cell lineage tree. Regulative development should demonstrate spatial “smearing”, or deviations from the compartmentalization of the mosaic process. In a complementary manner, complex network statistics and Levy flight signatures confirm the role of regulative developmental mechanisms. Specifically, degree distributions and connectivity patterns in both lineage and physical space allow for heuristic, network-based indicators of differences in developmental types for a given model organism.  

[Extended abstract available online](#)  
*Co-author: G. Orosz*

Christian Bick  
*University of Exeter, U.K.*

**Dynamics of Asynchronous Networks**

Systems that have the structure of a network of interconnected nodes are abundant in nature and technology. Many mathematical models of such networks are given as ordinary differential equations defined by smooth vector fields. These traditional or “synchronous” network models, however, fail to incorporate nonsmooth features seen in real world; for example, individual nodes of a network cannot stop and restart in finite time. Asynchronous networks are an attempt to set up a mathematical framework to study systems that exhibit stopping of nodes and their bifurcations. We also consider asynchronous networks with function: given some set of initial conditions a desired final output state has to be reached. We discuss deadlocks – dynamical states that prevent a network from completing its function – and indicate how functional networks can be decomposed into simpler components.  

*Co-authors: M. Field and A. Mohapatra*

David Burstein  
*University of Pittsburgh, USA*

**Enumeration of Graphs with Fixed Degree Sequences and Applications**

For many applications, we want to construct synthetic graphs from a given degree sequence. There are typically many realizations of graphs from a given degree sequence, however, and we would like to uniformly sample graphs from this set. To this end, we seek asymptotics for counting the number of graphs that realize a sparse degree sequence. The previous best asymptotics [1] only allow for the maximum degree to be \(o(E^{1/3})\), where \(E\) is the number of edges. Since for many real world networks, including neuronal networks, the maximum degree can scale much larger than \(o(E^{1/3})\) we present novel results that allow for the counting of sparse...
graphs with maximum degree $O(E^{1/2-w})$ where $w$ is an arbitrarily small positive number. We then briefly consider some applications of our aforementioned results.


Co-author: J. Rubin

Young Sul Cho
Northwestern University, USA

Two Types of Discontinuous Percolation Transitions in Cluster Merging Processes

Percolation is a paradigmatic model in disordered systems and has been applied to various natural phenomena. The percolation transition is known as one of the most robust continuous transitions. However, recent extensive studies have revealed that a few models exhibit a discontinuous percolation transition (DPT) in cluster merging processes. Unlike the case of continuous transitions, understanding the nature of discontinuous phase transitions requires a detailed study of the system at hand, which has not been undertaken yet for DPTs. Here we examine the cluster size distribution immediately before an abrupt increase in the order parameter of DPT models and find that DPTs induced by cluster merging kinetics can be classified into two types. Moreover, the type of DPT can be determined by the key characteristic of whether the cluster kinetic rule is homogeneous with respect to the cluster sizes. We also establish the necessary conditions for each type of DPT, which can be used effectively when the discontinuity of the order parameter is ambiguous, as in the explosive percolation model.

Co-author: B. Kahng

Andrew B. Cowley
University of Colorado, Boulder, USA

Maximization of Entropy in Networks of Excitable Systems

Networks of excitable nodes have been used to model a variety of systems, including neuronal networks, gene regulatory networks, and some forms of social contagion. In some of these cases, particularly in neuroscience, there are nodes that inhibit the excitation of other nodes. The balance between excitatory and inhibitory nodes can greatly affect the collective dynamics of the network. In this work we investigate, using both a biologically realistic model and a simple binary model, how the balance between excitatory and inhibitory nodes affects the variability of macroscopic dynamical states. We find, in agreement with previous experiments on mice, that this variability is maximized in the “critical state”, when excitatory and inhibitory nodes balance to produce a power-law distribution of neuronal avalanche sizes. We verify the results of the numerical simulations with analytical investigations of the binary model. To analyze the binary model, we treat the macroscopic variable as undergoing a random walk, where the drift and diffusion coefficients can be determined from the model parameters. Our results provide a foundation to the experimental results which suggest that maximization of the variability of macroscopic dynamical states is a potential benefit of criticality in excitable networks.

Co-authors: J. Restrepo, W. Shew, D.B. Larremore and V. Agrawal

Faryad Darabi Sahneh
Kansas State University, USA

Delocalized Epidemics on Graphs

Susceptible-infected-susceptible (SIS) epidemic process on complex networks can show metastability, resembling an endemic equilibrium. However, the metastable state can be localized on small subgraphs of the contact network. Such infections are not really interesting because a true outbreak concerns network-wide invasion of the contact graph rather than localized infection of certain sites within the contact network. Unfortunately, exact Markov equations for the SIS process on graphs has an exponentially enormous state-space size, making exact analysis extremely challenging. Accordingly, existing approaches to localization phenomenon suffer from two major drawbacks: 1) they use approximate mean-field models, and 2) they fully rely on the solution of these models in the neighborhood of their phase transition point, where their approximation accuracy is worst, as statistical physics tell us. We propose a dispersion entropy measure which quantifies the localization of infections in a generic contact graph. Specifically, we find an upper bound for the dispersion entropy of the possible metastable state in the exact SIS process. As a result, we find sufficient conditions such that any initial infection over the network either dies out or reaches a localized metastable state. Our proposed methods offer a new paradigm in studying spreading processes on complex networks.

Co-authors: A. Vajdi and C. Scoglio
Jeremie A. Fish  
Clarkson University, USA

Information Flow in Transient Network Dynamics

The dynamical evolution of a complex system is characterized by the sharing and flow of information among the individual components. Such flow of information is the complex systems analogy of the energy transfer in physical processes, and is related to both the structure of the network and the underlying coupled dynamics. For dynamical processes that are non-stationary such as the synchronization of networks, essentially no information can be extracted after the system settles to its (synchronization) attractor as in such states all the nodes would appear indistinguishable from one another. Instead, we focus on the transient dynamics toward such attracting sets, and show that the information flow computed from the transient states can effectively reveal topological properties of the underlying network dynamics.

Co-authors: J. Sun and E. Bollt

Jin Ge  
University of Michigan, USA

Optimization of Connected Cruise Control with Time Delay

LQ is used to systematically optimize CCC design with delay. Optimal controllers prefer short connectivity links, and feedback gains for both non-delay and distributed-delay terms are given recursively. The string stability is ensured with robustness and tunability. Future research includes optimization of nonlinear CCC controllers with online identification of heterogeneous human gains and reaction times, and performance degradation analysis with packet drops.

Co-author: G. Orosz

Olga Golovneva  
New York University, USA

Stochastic Non-Fast Switching in Complex Networks: Windows of Opportunity

Networks of dynamical systems are commonly used to describe complex systems in nature. Individual nodes of the network may interact intermittently through on-off coupling forming switching topology and affecting the collective dynamics of the systems, including synchronizability. We focus on the networks whose topology vary deterministically or stochastically in time with beyond so-called “fast-switching” limit. Moreover, each link activates independently, so that the network is almost surely disconnected at each time (“blinking” networks). Synchronization can be studied by analyzing the linear stability of an augmented system, associated with the linear mean square transverse dynamics. From the spectral analysis of this system, we determine effective bounds for the switching frequency that ensure synchronization. As an example, we consider a blinking network composed of two linearly coupled oscillators, whose individual dynamics are described by a “sigmoid” map. First, we determine regions of stable synchronization for static coupling. Then, we provide numerical evidence of synchronization of the stochastic system and the existence of so-called “windows of opportunity”, that is, “resonant” switching frequencies that ensure synchronization. Our results are expected to aid in understanding synchronization of evolving dynamical networks and establish effective means for controlling the system dynamics through dynamic rewiring.

Co-authors: M. Porfiri, I. Belykh, R. Jetter

Aleksandar Haber  
Northwestern University, USA

Identification of Dynamical Models of Chemical Reaction Networks

Current first-principles models of complex chemistry, such as combustion reaction networks, often give inaccurate predictions of the time variation of chemical species. Moreover, the high complexity and dimensionality of these models render them impractical for real-time prediction and control of chemical network processes. These limitations have motivated us to search for an alternative paradigm that is able to both identify the correct model from the observed dynamical data and reduce complexity while preserving the underlying network structure. We present one such modeling paradigm under the scenarios of complete and incomplete observability of the dynamics. The proposed approach is applicable to combustion chemistry and a range of other chemical reaction networks.

Co-author: A.E. Motter
**Minimal Chimeras?**

Since the initial observation of chimera states, there has been much discussion on the conditions under which these states emerge. The emphasis thus far has mainly been to analyze large networks of coupled oscillators; however, recent studies have begun to focus on the opposite limit: what is the smallest system of coupled oscillators in which chimeras can exist? We experimentally observe and analyze the stability of the “minimal” chimera in a network of four globally coupled chaotic opto-electronic oscillators. By examining the equations of motion, we demonstrate that symmetries in the network topology allow a variety of synchronous states to exist including chimera and cluster synchronous states. Using the group theory approach recently applied to cluster synchronization, we show how to derive the variational equations for these synchronous patterns and calculate their linear stability. We find that these chimera states appear in regions of multistability between global, cluster, and desynchronized states.

*Co-authors: K. Bansal, T.E. Murphy and R. Ray*

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**Fuel Economy Optimization of Heavy Duty Vehicles in an Information Rich World**

We introduce a mathematical framework that allows us to optimize the speed profile and select the optimal gears for heavy-duty vehicles in order to minimize fuel consumption, while taking into account grade, headwind, and the traffic environment. The corresponding optimal control problem has mixed control-state constraints. Applying Pontryagin’s maximum principle a bang-bang type controller with singular-arc is obtained. The key idea is to solve the corresponding boundary value problem analytically for a simple scenario (linear damped system with quadratic elevation profile) and use this result to initialize a numerical continuation algorithm. Then the numerical algorithm can be used to gradually introduce nonlinearities (air resistance, engine saturation), implement data-based elevation profiles, and incorporate external perturbations (wind, traffic). This approach enables real-time optimization in dynamic traffic conditions, therefore can be implemented on board.

*Co-author: G. Orosz*

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**Information Processing in Time-Delay Autonomous Boolean Networks**

We present an experimental platform for high-speed information processing that exploits the high-dimensional dynamics produced by complex networks built with asynchronous digital logic. Concretely, we use field-programmable gate arrays to rapidly construct networks of hundreds of Boolean nodes connected by time-delay links. We demonstrate that these networks project input signals into a high-dimensional state space, and this projection improves the performance of machine learning algorithms on tasks such as pattern recognition. In addition, we show that varying network parameters such as connectivity and link delays affects the system’s performance on benchmark tasks.

*Co-authors: S. Apostel, O. D’Huys and D.J. Gauthier*

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**Selective Pressure-Induced Change in Network Structure Accelerates the Emergence of Autocatalytic Networks**

We study an autocatalytic network model in which population and network structure coevolve on two time scales, governed by chemical kinetics and natural selection, respectively. Previous work has shown that selective pressure is essential for an autocatalytic network to sustain itself in a fluctuating environment upon emergence from a random, sparse network. However, little is known about its other effects despite its key role in evolution. Through numerical simulation and analytical approximation, we discover that selective pressure can induce denser and non-random network structure from the very beginning. Such change occurs before, and independent of, the onset of an autocatalytic network, accelerating the emergence of the autocatalytic network and enhancing its robustness. These effects become more pronounced at higher network sparsity and selective stringency. These findings may provide insight into the emergence of complexity and the origins of life.

*Co-authors: L.A.N. Amaral, D. Beard and V. Yang*
Yuriy Hulovatyy  
*University of Notre Dame, USA*

**Exploring the Structure and Function of Temporal Networks with Dynamic Graphlets**

With increasing availability of temporal real-world networks, how to efficiently study these data? One can model a temporal network as a single aggregate static network, or as a series of time-specific snapshots, each being an aggregate static network over the corresponding time window. Then, one can use established methods for static analysis on the resulting aggregate network(s), but losing in the process valuable temporal information either completely, or at the interface between different snapshots, respectively. Here, we develop a novel approach for studying a temporal network more explicitly, by capturing inter-snapshot relationships. We base our methodology on well-established graphlets (subgraphs), which have been proven in numerous contexts in static network research. We develop new theory to allow for graphlet-based analyses of temporal networks. Our new notion of dynamic graphlets is different from existing dynamic network approaches that are based on temporal motifs (statistically significant subgraphs). When we aim to characterize the structure and function of an entire temporal network or of individual nodes, our dynamic graphlets outperform the static graphlets, in both social and biological domains. Clearly, accounting for temporal information helps. We apply dynamic graphlets to temporal age-specific molecular network data to deepen our limited knowledge about human aging.

*Co-authors: H. Chen and T. Milenkovic*

Hsuan-Wei Lee  
*University of North Carolina, Chapel Hill, USA*

**Social Clustering in Opinion Formation and Epidemic Spread on Coevolving Networks**

Coevolving or adaptive networks are networks with nodes changing their states and network topologies coevolving with the dynamical processes on them. We study opinion formation (voter model) and disease propagation (SIS model) on coevolving networks and introduce a simple social network model that has a probability to close a triangle while rewiring. Our model directly reinforces network transitivity and creates nonzero clustering coefficients, which is an important feature of social networks. By using an improved compartmental formalism method, our semi-analytical approximation provides good predictions of the opinion or disease prevalence and the degree distribution of networks in their statistically stationary states. Furthermore, in the SIS model, we study the bifurcation diagrams and find there exists a universal disease prevalence curve, seemingly independent of initial network topologies.

*Co-authors: N. Malik, F. Shi and P.J. Mucha*

Matthias Leiss  
*ETH Zurich, Switzerland*

**How Communication Networks Lead to Collectively Meaningful Behavior**

Knowledge about how groups of individuals self-organize to achieve a common goal in complex environments is nascent but needed to advance thinking on collective behavior and network performance. To contribute to this research topic, we studied the structure and node dynamics of the communication network of a large hedge fund in relation to its trading activity, while controlling for information inflow due to business news and direct email contact to other institutional investors and investment banks. Analyzing 1.2 million transactions in US equities executed by 97 human traders and supervised by 55 portfolio managers with an overall volume of 900 billion USD suggests that a large fraction (33%) of their trading is statistically indistinguishable from a random walk. While these nonsystematic trades significantly underperform, they can be related with certain characteristics of the communication network consisting of 2 million emails and 6 million instant messages. We find that a more clustered and a more balanced internal communication, as well as a more diverse network of information sources, are closely associated with systematic trading. Our results add to the understanding of how decision-makers may cooperate in complex environments for achieving individual and collective goals.

*Co-authors: C. Schulz, E.-Á. Horváth, D. Helbing and B. Uzzi*

Nan Li  
*University of Michigan, USA*

**Dynamical Analysis and Optimization of Heterogeneous Connected Vehicle Systems**

Advanced driver assistance systems (ADAS) have been used to improve vehicle safety and passenger comfort in the last couple of decades. Vehicle-to-vehicle (V2V) communication has the potential to further enhance the performance of these systems by allowing the vehicle to monitor a larger traffic environment. Recently, connected cruise control (CCC) was proposed to regulate the longitudinal motion of vehicles, which utilizes V2V.
Information broadcast by multiple vehicles ahead. This can be used to improve traffic conditions even with low penetration of CCC vehicles. When mixing CCC vehicles to the flow of human-driven vehicles, a hybrid system is created since human-driven vehicles operate in continuous time while CCC vehicles are controlled by digital controllers. We investigate stability and disturbance attenuation in such heterogeneous systems and optimize CCC controllers to achieve best fuel economy. This way, the benefits of CCC can be quantified at the vehicle as well as at the system level.

Co-author: G. Orosz

Hongyu Meng
Northwestern University, USA

Independent Noise Can Synchronize Interacting Networks of Pulse-Coupled Oscillators

Structured networks comprised of subnetwork modules are ubiquitous. In oscillator networks with such a structure each subnetwork may exhibit coherent oscillatory dynamics, raising the question of synchronization of the oscillations in different subnetworks. Motivated by the observation of rhythms and their interaction in different brain areas, we study a network consisting of two networks of pulse-coupled integrate-fire neurons. Each of the neurons receives noisy input. Through mutual inhibition the neurons in each subnetwork can synchronize and exhibit collectively an ING-rhythm. In the absence of coupling between the networks these rhythms will in general have different frequencies. We investigate the interaction between these different rhythms. Strikingly, we find that increasing the noise level in the neuronal input can induce a synchronization of the rhythms of the two networks, even though the inputs to different neurons are statistically independent of each other, sharing no common component. Based on a heuristic phase model for the neurons we conclude that due to the noise only a fraction of neurons may spike in each cycle, which is critical to synchronize different networks.

Co-authors: A. Flammini and Y.-Y. Ahn

Wubing Qin
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Digital Effects and Stochastic Delays in Connected Cruise Control (CCC)

Emerging technologies in wireless vehicle-to-vehicle (V2V) communication can be used in advanced driver assistance systems to improve mobility, fuel economy, and safety of intelligent transportation systems. Such connected vehicle systems allow vehicles to obtain information about the motion of multiple vehicles ahead and may lead to more advanced longitudinal controller. However, in V2V communication, packets are broadcasted about every 100 ms using dedicated short range communication (DSRC) devices and consequently digital effects and delays become non-negligible. The other difficulty is that the unreliability of wireless communication may result in packet drops while exchanging information, leading to the stochastic delay variations in the controlled system. We demonstrate and analyze those digital effects and stochastic delays caused by packet drops in this poster.

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Optimal Network Modularity for Fast Global Information Diffusion

Size and duration are the two most relevant macroscopic characteristics of an information cascade in a social network. Indeed, in several contexts (e.g. marketing) triggering wide and fast information cascades is an highly desirable goal that can be achieved only by fronting the costs associated to identifying influential agents and/or increasing the set of initial spreaders. Both the size and the duration of the information cascade depend heavily on the specific transmission mechanism, the structure of the social network and the size and position of the initial spreader set. Here we study how the network structure affects the time needed for a large cascade to affect all the agents in a network. Specifically we study whether modular structure can expedite the diffusion of information in a scenario of complex contagion (as described by the linear threshold model.) It has been shown that there is an optimal range in modularity (for a sufficiently large number of initial spreaders) that allows an information cascade born in one community to spread to the entire system. Within this range, we show that it is possible to fine tune the modularity to achieve minimum spreading time. The time-minimizing modularity is such to provide sufficient internal links in the originating community to generate a fast wide cascade within such community, and sufficient external links to initiate and support a wide cascade in the rest of the network.

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**Stochastic Delays in Gene Regulatory Networks**

Genes in gene regulatory networks (GRNs) interact with each other through their protein products. These proteins are called transcription factors because they bind to other genes and regulate their transcription. Delays in GRNs are caused by the amount of time it takes for a protein to be produced. Transcription of a gene into an mRNA transcript and subsequent translation of the mRNA transcript into proteins are among the time-consuming biological processes that lead to the production of proteins. These delays are quite random since the biomolecular interactions are noisy. We therefore investigate the effects of stochastic delays on the dynamics of GRNs. We consider, in particular, a piecewise constant delay that can take finitely many values and analyze the stability of equilibria in continuous time. Our results show that the stability regions are different from those one can obtain using approximating deterministic models.

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**Dynamics of Power Grid Influenced by Large Scale Offshore Wind Power**

Injecting a significant amount of power from renewable sources into an existing power grid, regardless of their share and penetration level, has a huge impact on its control, stability, and resiliency. In addition, the nature of these sources such as wind and solar will introduce new challenges to the control of electric power networks as its stochasticity increases the uncertainty associated with power system states and the attendant complexity of power systems. In particular, despite the fact that the offshore wind farms inject the power directly into the transmission system on the shore, transfer capability, thermal limit, line congestion, reactive power support, and meeting the requisite ramping rate to provide the short term power reserve all pose significant challenges to transmission system operators. This work discusses how a large scale offshore wind farm impacts the dynamics and stability of an interconnected power grid.

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**Generation of Synthetic Spatially Embedded Power Grid Networks**

The development of algorithms for enhancing the resilience and efficiency of the power grid requires evaluation with topologies of real transmission networks. However, due to security reasons, such topologies and particularly the locations of the substations and lines are usually not publicly available. Therefore, we study the structural properties of the North American grids and present an algorithm for generating synthetic spatially embedded networks with similar properties to a given grid. The algorithm uses the Gaussian Mixture Model (GMM) for node density estimation and generates nodes with similar spatial distribution to the nodes in a given network. Then, it uses two procedures, which are inspired by the historical evolution of the grids, to connect the nodes. The algorithm has several tunable parameters that allow generating grids similar to any given grid. We apply it to the Western Interconnection (WI) and to grids that operate under the SERC Reliability Corporation (SERC) and the Florida Reliability Coordinating Council (FRCC), and show that the generated grids have similar structural and spatial properties to these grids. To the best of our knowledge, this is the first attempt to consider the spatial distribution of the nodes and lines and its importance in generating synthetic grids.

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**A Wong-Zakai Approximation for Random Invariant Manifolds**

Random invariant manifolds are geometric objects useful for understanding complex dynamics under stochastic influences. But these random objects are difficult to be visualized geometrically or computed numerically. The current work provides a perturbation approach to approximate these random invariant manifolds. We first discuss the existence of a random invariant manifold for a class of stochastic evolutionary equations. Then, we approximate the random invariant manifold by the invariant manifold of a new systems with smooth colored noise (or integrated Ornstein-Uhlenbeck processes). The convergence results in this paper are pathwise Wong-Zakai type approximations.

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Topological Data Analysis of Contagion Maps for Examining Spreading Processes on Networks

Social and biological contagions are influenced by the spatial embeddedness of networks. Historically, many epidemics spread as a wave across part of the Earth’s surface; however, in modern contagions long-range edges – for example, due to airline transportation or communication media – allow clusters of a contagion to appear in distant locations. Here we study the spread of contagions on networks through a methodology grounded in topological data analysis and nonlinear dimension reduction. We construct “contagion maps” that use multiple contagions on a network to map the nodes as a point cloud. By analyzing the topology, geometry, and dimensionality of manifold structure in such point clouds, we reveal insights to aid in the modeling, forecast, and control of spreading processes. Our approach highlights contagion maps also as a viable tool for inferring low-dimensional structure in networks.

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Identifying Vulnerable Spots in Real Power-Grid Networks

The current understanding of cascading failures in real power-grid networks has been limited by the lack of realistic large-scale modeling. Using the first continent-wide physical model for the propagation of line failures, I will report on the identification and analysis of the set of transmission lines that are vulnerable to cascading failures in the North American power grid. Our results have the potential to provide new understanding of the origins and causes of cascading failures, with relevant implications for power grid design and operation.

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Can Gene Expression Guide Reprogramming?

Cell reprogramming experiments, which transform human cells from one cell type to another, are labor and time intensive requiring lots of trial and error. At the same time, vast repositories of gene expression data exist connecting gene expression to cell function. This poster demonstrates how to apply data from repositories to guide future experiments. The Gene Expression Omnibus (GEO) database contains experiments which measure the response of the whole cell’s gene expression before and after knocking down a single gene. GEO also contains many repeated measurements of human cell lines. Taken together, relating gene expression to cell type and measuring responses to gene knockdowns provide the information needed to develop a strategy to push one cell toward another. Our analysis establishes a proof of concept that manipulating gene expression of one or two genes can reprogram from one cell type to another. We motivate further research in this area by exploring the effect of new perturbations on the system and by suggesting some clinical applications of our method.

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Motif-Based Design of Connected Vehicle Networks

We investigate the effects of heterogeneous connectivity structures and information delays on the dynamics of connected vehicle systems (CVSs), which are comprised of vehicles equipped with connected cruise control (CCC) as well as conventional vehicles. First, a general framework is presented for CCC design that incorporates information delays and allows a large variety of connectivity structures. Then, we present delay-dependent criteria for plant stability and head-to-tail string stability of CVSs. The stability conditions are visualized by using stability diagrams, which allow one to evaluate the robustness of vehicle networks against information delays. To achieve modular and scalable design of large networks, we also propose a motif-based approach. Our results demonstrate the advantages of CCC vehicles in improving traffic efficiency, but also show that increasing the penetration of CCC vehicles does not necessarily improve the robustness if the connectivity structure or the control gains are not appropriately designed.

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Acknowledgments