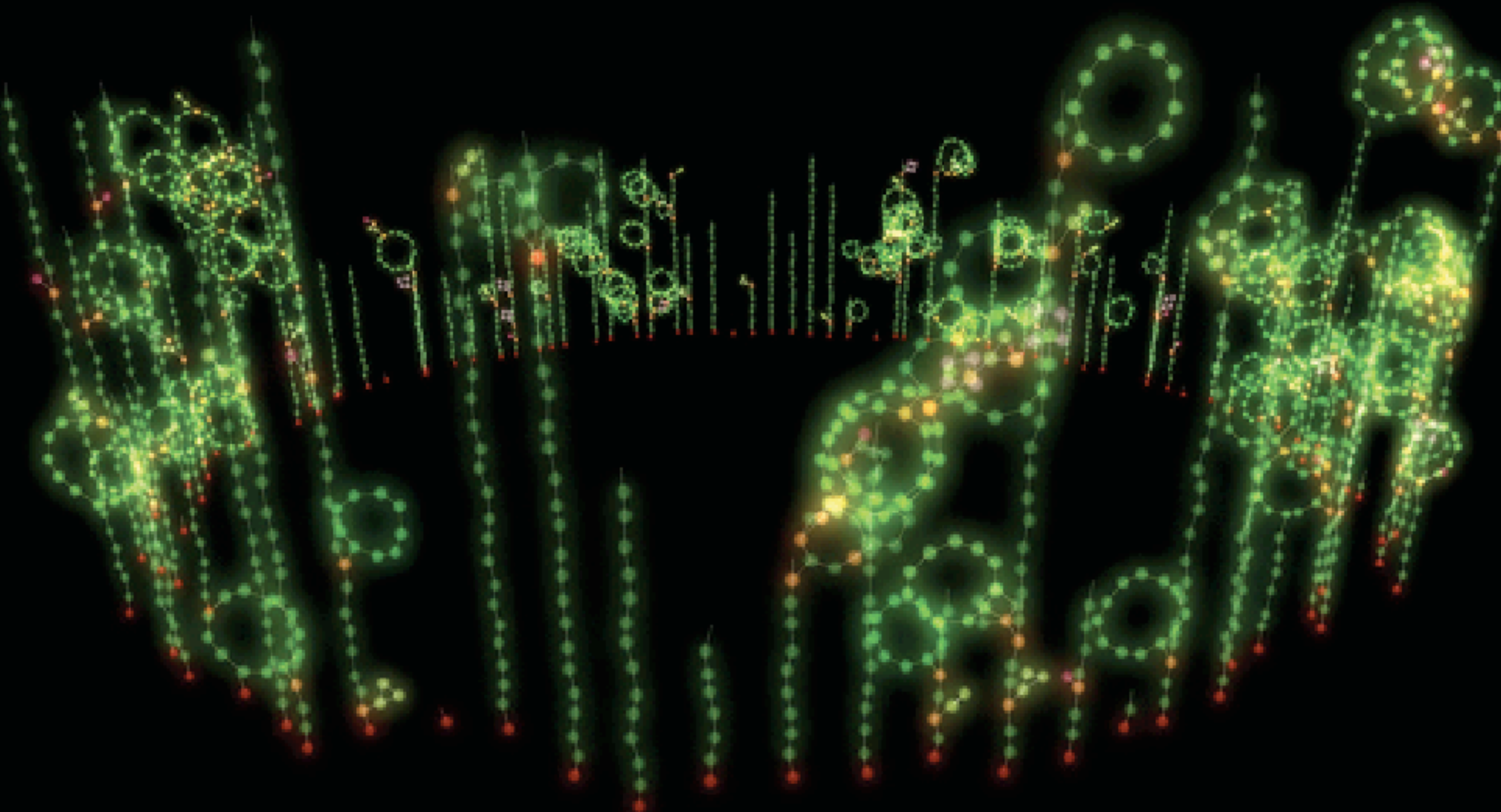
SYMPOSIUM

CONTROLLING COMPLEX NETWORKS

from Biological to Social and Technological Systems

June 19-20 2017
Indianapolis, Indiana, USA
JW Marriott Indianapolis (White River D)

Organizers:
Yang-Yu Liu
Albert-László Barabási



JOHN TEMPLETON FOUNDATION

NetSci

Symposium of Controlling Complex Systems

June 19-20, 2017

Indianapolis, Indiana

Program

June 19

8:00-8:10	WELCOME ADDRESS (Albert-László Barabási)
	SESSION I (Chair: Yang-Yu Liu)
8:10-8:50	**Adilson Motter**: *Controlling the States of Nonlinear Networks*
8:50-9:30	**Stefano Boccaletti**: *Explosive Synchronization in Networked Dynamical Systems*
9:30-9:50	Contributed Talk 1: **Shuang Gao**: *The Control of Arbitrary Size Networks of Linear Systems via Graphon Limits*
9:50-10:10	COFFEE BREAK
10:10-10:50	**Jürgen Kurths**: *Quantifying Stability in Power Grids*
10:50-11:30	**Raissa D'Souza**: *Nonlinear control at multiple scales: from nanoscale oscillators, to interdependent infrastructure, to macaque monkeys*
11:30-12:10	**Ingo Scholtes**: *Controllability of temporal networks: An analysis using higher-order networks*
12:10-12:30	Contributed Talk 2: **Xizhe Zhang**: *Input graph: the hidden geometry in controlling complex networks*
12:30-2:00	LUNCH BREAK
	SESSION II (Chair: Marco Tulio Angulo)
2:00-2:40	**Gang Yan**: *Network control principles unveil neuronal roles in C. elegans nervous system*
2:40-3:20	**Dong Kong**: *Genetic and Optic Dissection of the Networks in Neuron-Metabolism*
3:20-3:40	Contributed Talk 3: **Oscar M. Granados**: *Controlling Global Banking Networks: From Letter to Qubit*
3:40-4:00	Contributed Talk 4: **Laura Seaman**: The 4D Nucleome of Cancer
4:00-4:10	COFFEE BREAK
4:10-4:50	**John H. Abel**: *Control of the Mammalian Circadian Oscillator*
4:50-5:30	**Gábor Balázsi**: *Controlling metastasis-regulatory networks*
5:30-5:50	Contributed Talk 5: **Yandong Xiao**: *Mapping ecological networks of microbial communities*
5:50-6:30	**Indika Rajapakse**: *Mathematics of Cellular Reprogramming: Controlling the double helix*

June 20

	SESSION III (Chair: Gang Yan)
8:30-9:10	**John Bechhoefer**: *Physical limits to control, from Maxwell to Landauer*
9:10-9:50	**Alex Arenas**: *Control of coupled oscillator networks with application to microgrid technologies*
9:50-10:10	Contributed Talk 6: **Goran Muric**: *Using LTI system theory in complex networks analysis*
10:10-10:30	COFFEE BREAK
10:30-11:10	**Luis M. Rocha**: *Canalization in the dynamics of complex networks drives dynamics, criticality and control*
11:10-11:50	**Jorge G. T. Zañudo:** *Structure-based control of complex networks with nonlinear dynamics*
11:50-12:30	**Jorge Cortés**: *Time-Varying Actuator Scheduling in Complex Networks*
12:30-2:00	LUNCH BREAK
	SESSION IV (Chair: Jorge G. T. Zañudo)
2:00-2:40	**Justin Ruths**: *Influence Maximization through Structural Controllability*
2:40-3:20	**Marco Tulio Angulo:** *Controlling microbial communities: a theoretical framework*
3:20-3:40	Contributed Talk 7: **Xu-Wen Wang**: *Controlling complex networks with conformity behavior*
3:40-4:00	Contributed Talk 8: **Liang Tian**: *Articulation Points in Complex Networks*
4:00-4:20	COFFEE BREAK
4:20-5:00	**Wei Lin:** *Finding the roles of time delays and randomness*
5:00-5:40	**Alex Olshevsky**: *Sparse control of linear systems by input selection*
5:40-6:20	**Jinhu Lü**: *When Structure Meets Function in Evolutionary Dynamics on Complex Networks*
6:20-6:30	CONCLUSION ADDRESS (Albert-László Barabási)

Invited Speakers (in alphabetic order of first name)

Adilson Motter (Northwestern University, USA)

Title: Controlling the States of Nonlinear Networks

Abstract: In recent years, much progress has been made in the control analysis of networks with linear dynamics. The dynamics of most real networks are nonlinear, however, and nonlinear systems require fundamentally different approaches. In this talk, I will report on a general framework to observe and control the states of networks with nonlinear dynamics. The framework is highly scalable and naturally accounts for modeling uncertainties, limitations in numerical precision, and constraints on the sensing and actuation actions.

Bio: Motter's research is focused on the dynamical behavior of complex systems and networks. He is the Charles Morrison Professor of Physics at Northwestern University in Evanston, Illinois, where he holds an Endowed Professorship since 2011. He received his Ph.D. degree in 2002, and prior to joining the Northwestern faculty in 2006 he held positions as Director's Postdoctoral Fellow at the Center for Nonlinear Studies of LANL and as Guest Scientist at the Max Planck Institute for the Physics of Complex Systems. Motter's honors include a Sloan Research Fellowship, an NSF CAREER Award, the Weinberg Award for Excellence in Mentoring, the Erdős-Rényi Prize in Network Science, and a Simons Foundation Fellowship. Motter is a Fellow of the American Physical Society (APS) and the American Association for the Advancement of Science (AAAS). He has served in the editorial boards of various journals, including Physical Review X, and is the Past Chair of the APS Topical Group on Statistical & Nonlinear Physics.

Alex Arenas (Universitat Rovira i Virgili, Spain)

Title: **Control of coupled oscillator networks with application to microgrid technologies**

Abstract: The control of complex systems and network-coupled dynamical systems is a topic of vital theoretical importance in mathematics and physics with a wide range of applications in engineering and various other sciences. Motivated by recent research into smart grid technologies, we study the control of synchronization and consider the important case of networks of coupled phase oscillators with nonlinear interactions—a paradigmatic example that has guided our understanding of self-organization for decades. We develop a method for control based on identifying and stabilizing problematic oscillators, resulting in a stable spectrum of eigenvalues, and in turn a linearly stable synchronized state. The amount of control, that is, number of oscillators, required to stabilize the network is primarily dictated by the coupling strength, dynamical heterogeneity, and mean degree of the network, and depends little on the structural heterogeneity of the network itself.

Bio: Prof. Alex Arenas (Barcelona, 1969) got his PhD in Physics in 1996. In 1995, he got a tenure position at Dept. Computer Science and Mathematics (DEIM) at Universitat Rovira i Virgili, and in 1997 he became associate professor at the same department. In 2000, he was visiting scholar at the Lawrence Berkeley Lab. (LBL) in the Applied Mathematics group of Prof. Alexandre Chorin (University of California, Berkeley). After this visit, he started a collaboration with Berkeley, and in 2007 he became visiting researcher of LBL. Arenas has written more than 160 interdisciplinary publications in major peer reviewed including Nature, Nature Physics, PNAS, Physics Reports and Physical Review Letters, which have received more than 9000 citations. He is one of the few Europeans serving as Associate Editors of the most important publication in physics worldwide, the American Physical Society journal, Physical Review. He is in charge of the Complex Networks and Interdisciplinary Physics section of Physical Review E. He got the James Mc Donnell Foundation award for the study of complex systems in 2011. He was also recognized as ICREA Academia-Institució Catalana de Recerca i Estudis Avançats, a catalan award that promotes the most recognized scientists from Catalonia. He serve as Editor in Journal of Complex Networks, and in Network Neuroscience. He was elected for the Steering Committee of the Complex Systems Society in 2012. He is the leader of the research group ALEPHSYS.

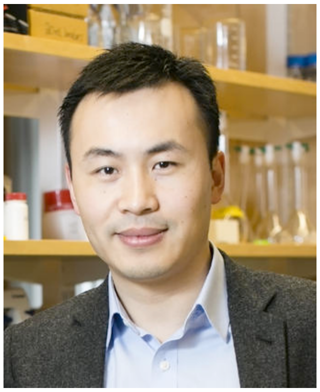
Alex Olshevsky (Boston University, USA)

Title: **Sparse control of linear systems by input selection**

Abstract: We consider the problem of input selection for making a linear system controllable by affecting the fewest possible variables. We discuss the complexity of this problem, in particular giving a polynomial-time approximation algorithm with an order-optimal performance guarantee. We discuss a fundamental obstacle for input selection algorithms that achieve control with energy constraints and, time permitting, explain some fundamental limitations on the number of inputs needed to efficiently control a stable system.

Bio: Alex Olshevsky is an assistant professor at the ECE at Boston University. He received a B.S. in applied mathematics and electrical engineering from Georgia Tech in 2004, and an M.S. and PhD from MIT in 2006 and 2010, both in electrical engineering and computer science. Previously, he was a postdoctoral scholar at Princeton University and an assistant professor at the University of Illinois, Urbana-Champaign. He is a recipient of the NSF CAREER Award, the Young Investigator award from the Air Force, two best paper awards from SIAM and INFORMS, and three awards for teaching/advising during his time at the University of Illinois. His research interests focus on control and optimization, especially for large-scale, multi-agent, and networked systems.

Dong Kong (Tufts University, USA)



Title: **Genetic and Optic Dissection of the Networks in Neuron-Metabolism**

Abstract: It is known that metabolism is precisely tuned to a dynamically stable state – a process often referred to as homeostasis, which allows organisms to survive and function effectively in a broad range of environmental conditions. To achieve this balanced state, the brain receives feedback signals from the body communicating metabolic status, integrates them with input from the external world as well as the emotional state, and then “appropriately” modifies feeding behaviors and physiological processes. When these regulatory functions go awry, eating disorders, obesity, cancer, or neurodegenerative diseases can result. The long-term goal of our research is to bridge molecular, cellular, and system approaches to decipher the neuronal modulatory and circuitry mechanisms behind these processes. Understanding these above mechanisms will provide novel insights on the treatment and prevention of various health-threatening human diseases.

Bio: Dr. Dong Kong joined Tufts University School of Medicine as an Assistant Professor in 2014. He obtained a Ph.D. in Genetics and Molecular Biology from Model Animal Research Center & Nanjing University, China and finished his thesis project at Harvard Medical School. Dr. Kong received his post-doctoral trainings first at the Division of Endocrinology, Beth Israel Deaconess Medical Center and then at the Department of Neurobiology of Harvard Medical School. His group is now leveraging and combining a battery of cutting-edge technologies, ranging from genetically engineered mouse models, recombinant viral vectors and viral tracing system, optogenetic and pharmacogenetic approaches, patch-clamp electrophysiology, to 2-photon laser scanning microscopy and 2-photon laser uncaging methods (2PLSM/2PLU), to interrogate the following questions: 1) how neurons in the central nervous system translate their intrinsic firing properties to the controlling of feeding behaviors and metabolic regulations, and what circuits are involved; 2) how metabolic signals, including circulating metabolites, hormones, and neuropeptides, act on circuit neurons, shape their firing outputs, and modulate related synaptic neurotransmission; and 3) what kinds of molecules, ion channels, or cellular signaling pathways are rooted to bear these physiological processes and how their dysfunctions contribute to the pathogenesis of disorders in both metabolism and cognition.

Gábor Balázsi (Stony Brook University, USA)

Title: **Controlling metastasis-regulatory networks**

Abstract: Most cancer patients die of metastasis, a process of cancer cells migrating into the bloodstream and colonizing new sites in the body. Why this happens is elusive. It does not seem to be driven by new point mutations compared to the primary tumor. Instead, protein levels seem to change in metastatic cells, making them migratory and invasive. This suggests that by controlling protein levels, we might be able to prevent metastasis. So, which proteins should we control and how? We have developed synthetic gene circuits that work as genetic dial knobs, enforcing uniform and linearly inducer-dependent levels of a chosen protein across cell populations. These synthetic gene circuits could deliver precise perturbations to unravel the connectivity and dynamics of metastasis-regulatory networks, which are important steps towards rational reprogramming of metastatic cancer cells.

Bio: Gábor Balázsi received his undergraduate Physics degree at the Babeş-Bolyai University in Kolozsvár (Cluj), Romania. In 1997, he started graduate school at the University of Missouri at Saint Louis, USA, as a PhD student with Professor Frank Moss. His PhD research was on perturbation propagation and synchronization in normal and epileptic neurons and glial cells. In 2002, he continued as a postdoctoral fellow in Systems Biology at Northwestern University in Chicago, studying gene-regulatory network response to environmental changes with Professors Zoltán N. Oltvai and Albert-László Barabási. In 2005 he became a postdoctoral fellow at Boston University with Professor James J. Collins. There he designed synthetic gene circuits to study how cellular diversity promotes drug resistance. He continued and expanded these efforts in his own laboratory over the last decade (8 of which were at the University of Texas MD Anderson Cancer Center in Houston, Texas), building a growing library of synthetic gene circuits first in yeast, and then in cancer cells. As the Henry Laufer Associate Professor of Physical and Quantitative Biology at Stony Brook University he leads an interdisciplinary research group, which utilizes synthetic gene circuits to control gene expression in yeast and human cells. Their goal is to understand fundamental biological processes underlying microbial drug resistance and cancer progression. Dr. Balázsi was one of the recipients of the 2009 NIH Director’s New Innovator Award, which was created to “stimulate highly innovative research and support promising new investigators”. His research group is half-experimental and half-computational, fostering interdisciplinary training while advancing the frontiers of quantitative biology.

Gang Yan (Tongji University, China)

Title: **Network control principles unveil neuronal roles in *C. elegans* nervous system**

Abstract: Recent advances on the controllability of complex systems have offered a powerful mathematical framework to systematically explore the structure-function relationship in various biological, social and technological networks. Despite the theoretical advances, we lack direct experimental proof of the validity of these widely used control principles. In this talk, we fill this gap by applying the control framework to the connectome of the nematode *C. elegans*, allowing us to predict the role of each neuron in the locomotor response to touch stimuli. We predict that the control of locomotion requires twelve neuronal classes, which include all previous experimental results based on laser ablation of specific neuronal groups. Importantly, control principles implicate one novel neuron, unveiling its previously unknown role in *C. elegans* locomotion. Counterintuitively, control principles predict that, for example, within a six-neuron class, the ablation of three individual neurons should not affect locomotion, but the individual ablation of other three neurons are sufficient to impair *C. elegans* locomotion. All these predictions are confirmed by new ablation experiments and worm tracker analyses. We find that our predictions are robust to missing and rewired connections in the current connectome, indicating the potential applicability of the developed analytical framework to larger and less-characterised connectomes.

Bio: Gang Yan is a professor in School of Physics Science and Engineering, Tongji University, Shanghai, China. He received his B.Sc. and Ph.D. degree at University of Science and Technology of China (USTC) in 2005 and 2010 respectively. During 2007-09, he was a visiting PhD student in the Centre for Chaos and Complex Networks at City University of Hong Kong. Prior to joining Tongji, he was research scientist in the Temasek Laboratories at National University of Singapore, Singapore; and postdoctoral researcher in the Center for Complex Network Research at Northeastern University, Boston, USA. He is a recipient of the Thousand Young Talents Plan (2016).

Indika Rajapakse (University of Michigan, USA)

Title: **Mathematics of Cellular Reprogramming: Controlling the double helix**

Abstract: In 2007, a remarkable discovery was made that with just four external inputs (transcription factors), it was possible to change differentiated cells into embryonic-like cells. This type of cellular reprogramming changes the fundamental nature of a cell. It invites the possibility of building a universal template for transcription factor-guided reprogramming. I will present our work on an algorithm for cellular reprogramming, done jointly with Roger Brockett, that uses advanced genomics technologies + control theory.

Bio: After my initial training in electrical engineering and mathematics, I pursued postdoctoral work with Dr. Mark Groudine at Fred Hutchinson Cancer Research Center in Basic Sciences, where I developed new approaches for exploring the dynamics of human genome, both experimentally and analytically. I am currently developing a universal algorithm for genome reprogrammability (=controllability) in human cells, with emphasis on understanding cell cycle dynamics. I am an Assistant Professor in the University of Michigan Department of Computational Medicine & Bioinformatics (Medical School) and Department of Mathematics.

Ingo Scholtes (ETH Zürich, Switzerland)

Title: Controllability of temporal networks: An analysis using higher-order networks

Abstract: In this talk, we address the controllability of networked systems with dynamic topologies. We specifically investigate the influence of order correlations in the activation sequence of time-stamped links. Studying empirical data on temporal networks, we show that such order correlations can both increase or decrease the time needed to achieve full controllability. Counter-intuitively, we find that the effect of these correlations on controllability can be opposite compared to diffusion processes, even when considering the same data set. We finally show that the framework of higher-order networks, which we have introduced in recent works, can be applied to study controllability in temporal networks. We particularly demonstrate that the spectral properties of a higher-order Laplacian matrix explain the complex effect of order correlations on controllability. Our work highlights the importance of higher-order network abstractions which capture both topological and temporal characteristics of temporal networks.

Bio: Ingo Scholtes is a lecturer at the Chair of Systems Design at ETH Zurich. He has a background in computer science and mathematics and obtained his doctorate degree from the University of Trier, Germany. At CERN, he designed a large-scale data distribution system which is used to monitor particle collision data from the ATLAS detector. His research integrates both applied and theoretical aspects in data mining and network science, with applications in information systems, software engineering, and social sciences. In 2014 he was awarded a Junior-Fellowship of the German Informatics Society. His current interests focus on limitations of graph-analytic methods and how to overcome them with higher-order modeling techniques.

Jinhu Lü (Chinese Academy of Sciences, China)

Title: **When Structure Meets Function in Evolutionary Dynamics on Complex Networks**

Abstract: Evolutionary dynamics play a fundamental role in exploring the underlying mechanism of collective behaviors over a multi-agent network. Traditionally, evolutionary dynamics focus on the analysis of evolutionary behaviors of unstructured complex systems. However, recent research reveals that system structure is essential in the formation of collective behaviors. This talk shows the intrinsic relation between structure and function of a complex dynamical network with evolutionary dynamics.

Bio: Jinhu Lü is a Chinese Academy of Sciences Distinguished Professor and the Director of Research Center for Network Science, AMSS, Chinese Academy of Sciences. He was a Professor and ARC Future Fellow in RMIT University, Australia and a Visiting Fellow in Princeton University, USA. Currently, Prof. Lü is a Chief Scientist of National Key Research and Development Program of China and a Leading Scientist of Innovative Research Groups of National Natural Science Foundation of China. His research interest includes complex networks, and nonlinear circuits and systems. He is an ISI Highly Cited Researcher in Engineering (2014, 2015, 2016). He received the prestigious Ho Leung Ho Lee Foundation Award in 2015, the State Natural Science Award three times from the Chinese government in 2008, 2012, and 2016 respectively, and the Australian Research Council Future Fellowships Award in 2009. He is the General Co-Chair of IECON 2017. He is also an IEEE Fellow.

John Bechhoefer (Simon Fraser University, Canada)

Title: **Physical limits to control, from Maxwell to Landauer**

Abstract: Almost exactly one hundred and fifty years ago, in February 1868, James Clerk Maxwell submitted an article, “On governors,” that was the first theoretical study of control theory, anticipating the vast range of technological applications of control concepts. In December 1867 his letter to Tait outlined the “Maxwell demon” thought experiment, the first attempt to connect information with physics. These two works have not traditionally been connected, although they were done within two months of each other. We now recognize them as reflecting two basic aspects of control theory, the practical and the fundamental. Here, I will present an experiment that unites the two: using feedback to create otherwise-impossible system dynamics, we create a Maxwell demon that can reach the fundamental limits to control set by thermodynamics. In particular, we test—and then extend—Rolf Landauer’s 1961 prediction that information erasure requires dissipation that must at least compensate any work extracted by virtue of information. Surprisingly, we found that some experimental protocols are “good” and can reach fundamental limits when executed slowly enough, whereas others are “bad” and can never reach such limits, no matter how slow the execution. These fundamental limits are benchmarks for evaluating the performance of practical information engines, such as those active within cells and other complex systems.

Bio: John Bechhoefer is Professor of Physics at Simon Fraser University, near Vancouver, British Columbia, in Canada. He has a background in experimental nonlinear dynamics and pattern formation, with applications to both soft matter and biophysical systems. Starting in graduate school at the University of Chicago, he has been fascinated by feedback and associated issues in control theory. This fascination led to a long tutorial presentation in Reviews of Modern Physics that is being updated and expanded to a book. His current research is at the intersection of thermodynamics, statistical physics, control theory, and information theory.

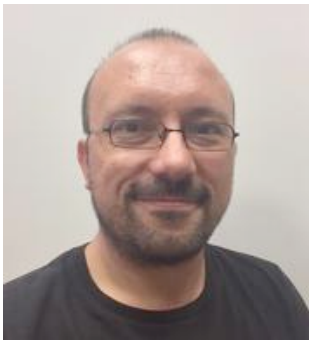
John H. Abel (Harvard University, USA)

Title: **Control of the Mammalian Circadian Oscillator**

Abstract: Mammalian circadian rhythms are driven by interlocked genetic feedback loops present in nearly all cells of the body. There has been considerable recent interest in the use of small-molecule pharmaceuticals to achieve clock phase shifts or to enhance the amplitude of circadian oscillation at a tissue scale. Because the effect of these drugs changes dynamically throughout the day, a control approach is necessary to correctly apply pharmaceutical perturbations to the system. In this talk, we present recent progress in solving phase shifting and population synchrony problems by optimal control and nonlinear model predictive control (MPC) approaches, and show conditions where the performance of the latter approaches the former. We present a control formulation that allows independent manipulation of phase and synchrony for a population of oscillators. Lastly, we present progress toward implementing these control algorithms *in vivo*.

Bio: John H. Abel is a fourth year Ph.D. Candidate in Systems Biology at Harvard University in the group of Dr. Francis J. Doyle III. He received his B.S. from Tufts University in 2013, and his M.S. from UC Santa Barbara in 2015, both in Chemical Engineering. He was awarded the Mellichamp Fellowship in Systems Biology at UC Santa Barbara, and is a NIH T32 Trainee in Sleep, Circadian, and Respiratory Neurobiology at Harvard Medical School/Brigham and Women's Hospital.

Jorge Cortés (University of California, San Diego, USA)

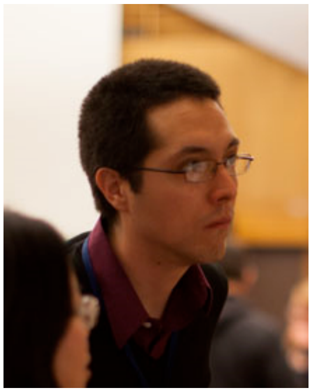


Title: **Time-Varying Actuator Scheduling in Complex Networks**

Abstract: This talk examines to what extent the capability of actuating a different set of nodes over time can improve the controllability of large-scale, time-varying network systems. Intuitively, the ability to actuate different nodes at different times allows for targeted interventions at different network locations, and can ultimately decrease the control effort to accomplish a desired task. Yet, from a practical standpoint, the implementation of time-varying control schemes requires the ability to geographically relocate actuators or the presence of actuation mechanisms at different, possibly all, network nodes, and more sophisticated control policies. To justify the additional implementation costs and control complexity, in this talk we seek to characterize network topologies and dynamics that benefit from time-varying actuator schedules, and quantify the associated control improvement. Our analysis shows that time-varying actuator policies should be used when the network has multiple heterogeneous central nodes, as measured by new notion of nodal communicability that we term $2k$-communicability. We illustrate our results with examples of deterministic and random networks. This is joint work with Erfan Nozari and Fabio Pasqualetti.

Bio: Jorge Cortes is a Professor with the Department of Mechanical and Aerospace Engineering at the University of California, San Diego. He received the Licenciatura degree in mathematics from the Universidad de Zaragoza, Spain, in 1997, and the Ph.D. degree in engineering mathematics from the Universidad Carlos III de Madrid, Spain, in 2001. He held postdoctoral positions at the University of Twente, The Netherlands, and at the University of Illinois at Urbana-Champaign, USA. He was an Assistant Professor with the Department of Applied Mathematics and Statistics at the University of California, Santa Cruz from 2004 to 2007. He is the author of "Geometric, Control and Numerical Aspects of Nonholonomic Systems" (New York: Springer-Verlag, 2002) and co-author of "Distributed Control of Robotic Networks" (Princeton: Princeton University Press, 2009). He received a NSF CAREER award in 2006 and was the recipient of the 2006 Spanish Society of Applied Mathematics Young Researcher Prize. He has co-authored papers that have won the 2008 IEEE Control Systems Outstanding Paper Award, the 2009 SIAM Review SIGEST selection from the SIAM Journal on Control and Optimization, and the 2012 O. Hugo Schuck Best Paper Award in the Theory category. He has been an IEEE Control Systems Society Distinguished Lecturer (2010-2014) and is an IEEE Fellow.

Jorge G. T. Zañudo (Pennsylvania State University, USA)



Title: **Structure-based control of complex networks with nonlinear dynamics**

Abstract: What can we learn about controlling a system solely from its underlying network structure? Here we adapt a recently developed framework for control of networks governed by a broad class of nonlinear dynamics that includes the major dynamic models of biological, technological, and social processes. This feedback-based framework provides realizable node overrides that steer a system towards any of its natural long term dynamic behaviors, regardless of the specific functional forms and system parameters. We use this framework on several real networks, identify the topological characteristics that underlie the predicted node overrides, and compare its predictions to those of structural controllability in control theory. Finally, we demonstrate this framework's applicability in dynamic models of gene regulatory networks and identify nodes whose override is necessary for control in the general case, but not in specific model instances.

Bio: Jorge G. T. Zañudo is a postdoctoral researcher (Stand Up To Cancer - The V Foundation Convergence Scholar) at the Department of Physics of The Pennsylvania State University where he works under the supervision of Réka Albert. He is currently a visiting scientist at the Dana-Farber Cancer Institute and at the Broad Institute in Levi Garraway's lab. He received his B.S. in Physics from Universidad de Guadalajara and his Ph.D. in Physics from The Pennsylvania State University, where his Ph.D. advisor was Réka Albert. His Ph.D. work consisted on developing theoretical and computational methods for analyzing logic-based models of the dynamics of signal trandsuction and regulatory networks. His current work is in developing control methods for network models, and in building and analyzing logic-based network models of drug resistance in breast cancer and melanoma.

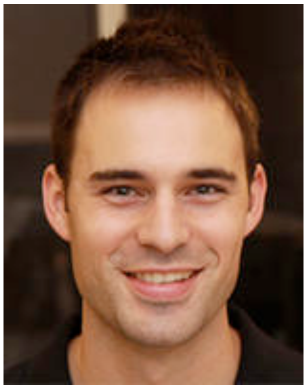
Jürgen Kurths (Potsdam Institute for Climate Impact Research, Germany)

Title: **Quantifying Stability in Power Grids**

Abstract: The human brain, power grids, arrays of coupled lasers and the Amazon rainforest are all characterized by multistability. The likelihood that these systems will remain in the most desirable of their many stable states depends on their stability against significant perturbations, particularly in a state space populated by undesirable states. Here we claim that the traditional linearization-based approach to stability is in several cases too local to adequately assess how stable a state is. Instead, we quantify it in terms of basin stability, a new measure related to the volume of the basin of attraction. Basin stability is non-local, nonlinear and easily applicable, even to high-dimensional systems. It provides a long-sought-after explanation for the surprisingly regular topologies of neural networks and power grids, which have eluded theoretical description based solely on linear stability. Specifically, we employ a component-wise version of basin stability, a nonlinear inspection scheme, to investigate how a grid's degree of stability is influenced by certain patterns in the wiring topology. Various statistics from our ensemble simulations all support one main finding: The widespread and cheapest of all connection schemes, namely dead ends and dead trees, strongly diminish stability. For the Northern European power system we demonstrate that the inverse is also true: `Healing' dead ends by addition of transmission lines substantially enhances stability. This indicates a crucial smart-design principle for tomorrow's sustainable power grids: add just a few more lines to avoid dead ends. Further, we analyse the particular function of certain network motifs to promote the stability of the system. Here we uncover the impact of so-called detour motifs on the appearance of nodes with a poor stability score and discuss the implications for power grid design. Next, it will be shown that basin stability is only a first approach in studying even larger perturbations. Therefore, further techniques based on survivability and maximum thresholds are introduced and discussed.

Bio: Jürgen Kurths got his PhD in 1983and his Dr. habil. in 1990. He was full Professor at the University of Potsdam from 1994-2008 and has been Professor of Nonlinear Dynamics at the Humboldt University, Berlin and chair of the research domain Transdisciplinary Concepts of the Potsdam Institute for Climate Impact Research since 2008 and a 6th century chair at the Institute for Complex Systems and Mathematical Biology at Kings College of the Aberdeen University (UK) since 2009. He is a fellow of the American Physical Society and of the Fraunhofer Society (Germany) and is a member of the Academia Europaea. He got an Alexander von Humboldt research award and a 1000 Talents award for foreign experts from China and was awarded the L.F. Richardson Medal of the European Geosciences Union. He was a Burgers Visiting Professor at University of Maryland in 2015 and is a Chapman Professor at the University of Alaska (Fairbanks) since 2016. He is editor-in-chief of the AIP journal CHAOS and is in the editorial board of more than 10 journals, among them Europhys. Lett., PLoS ONE, European Physics J. ST and Nonlinear Processes in Geophysics and of the Springer Series Complexity.

Justin Ruths (University of Texas at Dallas, USA)



Title: **Influence Maximization through Structural Controllability**

Abstract: In many applications we care to manipulate the states of a network in order to influence more buyers to adopt a product or less people to contract a disease rather than trying to distinguish between nodes in these networks by way of a specific target state. I will explore the interconnections between the problem of influence maximization and the property of structural controllability. The inciting observation for this discussion is that we find specific structurally controllable configurations of inputs are able to lead to surprisingly high activation levels in influence propagation. Unpacking why the stochastic, event-based, and binary-valued process of influence maximization can be solved so neatly by the techniques from deterministic, continuous, real-valued structural control is the focus of this talk.

Bio: Justin Ruths received a B.S. in Physics from Rice University, M.S. degrees in Mechanical and Electrical Engineering from Columbia University and Washington University in Saint Louis, respectively, and a Ph.D. in Systems Science and Applied Mathematics from Washington University in Saint Louis. In 2011, he joined Engineering Systems and Design as a founding faculty member of Singapore University of Technology and Design where he served as an assistant professor for five years. As of August 2016 he is an assistant professor with appointments in Mechanical Engineering and Systems Engineering at University of Texas at Dallas. His research includes studying the fundamental properties of controlling networks, bilinear systems theory, attack detection methods for cyber-physical systems, and solving computational optimal control problems focused on neuroscience and quantum control applications.

Luis M. Rocha (Indiana University, Bloomington, USA)

Title: **Canalization in the dynamics of complex networks drives dynamics, criticality and control**

Abstract: Network Science has provided predictive models of many complex systems from molecular biology to social interactions. Most of this success is achieved by reducing multivariate dynamics to a graph of static interactions. Such network structure approach has provided many insights about the organization of complex systems. However, there is also a need to understand how to control them; for example, to revert a diseased cell to a healthy state or a mature cell to a pluripotent state in systems biology models of biochemical regulation. Based on recent work [1,2] we show that the control of complex networks crucially depends on redundancy that exists at the level of variable dynamics. To understand the effect of such redundancy, we have been studying automata networks---both systems biology models of known biochemical regulation processes and large ensembles of network motifs. In these discrete dynamical systems, redundancy has been conceptualized as canalization: when a small subset of inputs is sufficient to control the output of an automaton. We introduce and discuss two types of canalization: effective connectivity and input symmetry. We show that effective connectivity strongly influences the controllability of multivariate dynamics. In particular, we show how the predictions made by structure-only methods can both undershoot and overshoot the number and which sets of variables actually control automata networks. Specifically, we discuss the effect of effective connectivity on several structure-only controllability theories: structural controllability, minimum dominating sets, and feedback vertex sets [1,3]. Mapping the effective connectivity of automata networks --- how control pathways operate --- thus reveals the dynamical modularity [4] and robustness present in such models [2], highlighting the importance of canalizing dynamics in determining control. We also demonstrate that effective connectivity is an order parameter of Boolean Network dynamics [5] , leading to a new theory for criticality in Boolean networks based on canalization, which substantially outperforms the existing theory based on the original connectivity of complex networks. Input symmetry is also shown to affect criticality, especially in networks with large in-degree, though to a lesser degree than effective connectivity [6].

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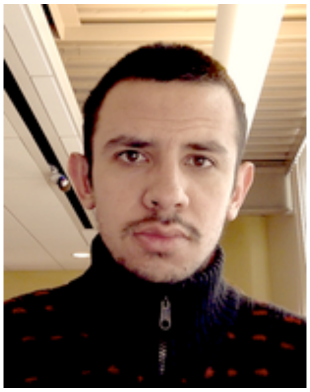
[6] S. Manicka and L.M.Rocha. [2017]. In Preparation.

Bio: Luis M. Rocha is Professor of Informatics in the School of Informatics & Computing at Indiana University, Bloomington, where he is director of the Complex Systems graduate Program of the Informatics PhD Program, member of the Indiana University Networks Institute, and core faculty of the Cognitive Science Program. Dr. Rocha is a Fulbright Scholar and is also the director of the Computational Biology Collaboratorium and in the Direction of PhD program in Computational Biology at the Instituto Gulbenkian da Ciencia, Portugal. He is also a Visiting Professor of the Neuroscience Program, at the Champalimaud Foundation in Portugal. His research is on complex networks & systems, computational & systems biology, and computational intelligence. He received his Ph.D in Systems Science in 1997 from the State University of New York at Binghamton. From 1998 to 2004 he was a permanent staff scientist at the Los Alamos National Laboratory, where he founded and led a Complex Systems Modeling Team during 1998-2002, and was part of the Santa Fe Institute research community. He has organized major conferences in the field such as the Tenth International Conference on the Simulation and Synthesis of Living Systems (Alife X) and the Ninth European Conference on Artificial Life (ECAL 2007). He has published many articles in scientific and technology journals, and has been the recipient of several scholarships and awards. At Indiana University, he has received the Indiana University, School of Informatics & Computing, Trustees Award for Teaching Excellence in 2006 and 2015 after developing the complex systems training program and syllabi for several courses.

Marco Tulio Angulo (Universidad Nacional Autónoma de México, Mexico)



Title: **Controlling microbial communities: a theoretical framework**

Abstract: Microbial communities perform key functions for the host they associate with or the environment they reside in. Our ability to control those microbial communities is crucial for maintaining or even enhancing the well-being of their host or environment. But this potential has not been fully harvested due to the lack of a systematic method to control those complex microbial communities. Here we introduce a theoretical framework to rigorously address this challenge, based on the new notion of structural accessibility. This framework allows the identification of minimal sets of “driver species” through which we can achieve feasible control of the entire community. We apply our framework to control the core microbiota of a sea sponge and the gut microbiota of gnotobiotic mice infected with C. difficile. This control-theoretical framework fundamentally enhances our ability to effectively manage and control complex microbial communities, such as the human gut microbiota. In particular, the concept of driver species of a microbial community holds translational promise in the design of probiotic cocktails for various diseases associated with disrupted microbiota.

Bio: Marco Tulio got his Dr.Eng. degree in Automatic Control from UNAM, México, in 2012. He was a Visiting Research Scholar (2014) and Postdoctoral Research Fellow (2015) in the Center for Complex Network Research (CCNR), Northeastern University, Boston. During 2015, he was also Sponsored Staff Collaborator in the Channing Division of Network Medicine, Harvard Medical School, and Brigham and Women's Hospital, Boston. In 2016, he joined the Institute of Mathematics, UNAM, as a CONACyT Research Fellow. His research interest are focused on understanding, diagnosing and controlling complex systems by blending Systems Theory (e.g., control theory and system identification) with Network Science. In particular, his research interests include rigorous methods for network reconstruction, control of microbial communities, and understanding the performance tradeoffs giving rise to the network structures we observe in nature.

Raissa D'Souza (University of California, Davis, USA)

Title: **The quest for nonlinear control at multiple scales: from nanoscale oscillators, to interdependent infrastructure, to macaque monkey societies**

Abstract: An overarching goal across disciplines is to develop control schemes for nonlinear systems. Yet each specific system has its own idiosyncrasies, design principles and set of constraints. Here we present advances towards this general goal using systems at three different scales. Probing into control of more classic nonlinear phenomena, we study both theoretically and empirically the attractor space of synchronization for a ring of reactively coupled nanoscale oscillators. The goal is to understand attractor switching networks and to design small control interventions. At the scale of critical infrastructure, consisting of collections of power girds, water networks and gas networks, our focus is on understanding interdependence and leveraging it for resilience and restoration efforts. This work relies on system identification techniques, multivariate optimization methods and graphs products. Finally at the scale of social systems we study the multilayered interactions found in macaque monkey societies, including aggression, grooming, policing and hudling networks. Our focus is on multi-layered ranking metrics, mechanisms underlying formation of hierarchy and multilayered interactions leading to abrupt societal collapse.

This work is a collaboration between research teams at UC Davis, California Institute of Technology, Rice University, and University of Washington, in particular Brianne Beisner, Airlie Chapman, Jim Crutchfield, Leonardo Duenas-Osorio, Jeff Emenheiser, Warren Fon, Andres Gonzalez, Matthew Matheny, Mehran Mesbahi, Marton Posfai, Michael Roukes, and Anastasiya Salova.

Bio: Raissa D'Souza is Professor of Computer Science and of Mechanical Engineering at the University of California, Davis, as well as an External Professor at the Santa Fe Institute. She received a PhD in Statistical Physics from MIT in 1999, then was a postdoctoral fellow, first in Fundamental Mathematics and Theoretical Physics at Bell Laboratories, and then in the Theory Group at Microsoft Research. Her interdisciplinary work on network theory spans the fields of statistical physics, theoretical computer science and applied math, and has appeared in journals such as Science, PNAS, and Physical Review Letters. She is a Fellow of the American Physical Society, serves on the editorial board of numerous international mathematics and physics journals, has organized key scientific meetings like NetSci 2014, was a member of the World Economic Forum's Global Agenda Council on Complex Systems, and is currently the President of the Network Science Society.

Stefano Boccaletti (Institute for Complex Systems, Italy)

Title: **Explosive Synchronization in Networked Dynamical Systems**

Abstract: Explosive synchronization refers to a first order like phase transition (abrupt and generally irreversible) between incoherence and coherence of networked oscillators. I will discuss genericity of such a transition in complex networks, and will summarize the main consequences arising when phase oscillators organize collectively by means of explosive synchronization.

Bio: Stefano Boccaletti got his PhD in Physics at the University of Florence on 1995. In October 1998 he was awarded the individual EU grant “Marie Curie” n. ERBFMBICT983466. He is Senior Researcher at the CNR-Institute for Complex Systems, and Honorary Professor of : the Weizmann Institute of Science, the Tel Aviv University, the University of Bar Ilan, the University of Navarre, and the Technical University of Madrid. In 2015, he was awarded the PhD honoris causa by the University Rey Juan Carlos of Madrid. Currently, he is the Scientific Attache' at the Italian Embassy in Israel. He is Author of publications in Physics Journals, which have been cited more than 17,000 times. Editor of 4 books, and Author of other 3. Editor in Chief of the Elsevier Journal Chaos Solitons and Fractals and member of the Editorial Board of several other International journals of physics and applied mathematics. He has been invited to about 85 International Conferences and Seminars as a plenary lecturer or keynote speaker, and he directly organized 15 Workshops. All relevant biometric information is accessible at the Google Scholar profile: https://scholar.google.it/citations?user=BEC76f4AAAAJ&hl=it&oi=ao

Wei Lin (Fudan University, China)

Title: **Finding the roles of time delays and randomness**

Abstract: Time delays and randomness are omnipresently observed in many nature and artificial systems. Naturally, two kinds of questions arise: "How to identify the time delays when a certain amount of datasets are obtained from the experiments or real-world systems?" and "How to characterize the intrinsic roles of time delays and randomness that are played in coupled network systems?" In this talk, we introduce recent works that address the previous two questions, and show the significance of time delays as well as randomness in dealing with various systems of physical or/and biological significance.

Bio: Dr. Wei Lin received the Ph.D. degree in applied mathematics from Fudan University, Shanghai, China, in January, 2003, with specialization in nonlinear dynamical systems. fDr. Lin has been a Full Professor in applied mathematics at Fudan University since December, 2009. Currently, he is serving as the Vice Dean of the School of Mathematical Sciences, as the Director of the Centre for Computational Systems Biology, and as the Vice Dean of the Institute of Science and Technology for Brain-Inspired Intelligence, Fudan University, China. From 2008 to 2013, he held a Staff Scientist position at the CAS-MPG Partner Institute for Computational Biology, Shanghai, China. He is now the Senior Member of IEEE, the Vice Chair of the Shanghai Society of Nonlinear Sciences, the Board Member of the International Physics and Control Society, the Associate Editor of the International Journal of Bifurcation and Chaos, and the member of Editorial Advisory Board of CHAOS. His current research interests include bifurcation and chaos theory, stability and oscillations in hybrid systems, stochastic systems and complex networks, data assimilation, causality analysis, and their applications to systems biology and artificial intelligence. Dr. Lin received the Excellent Young Scholar Fund from NSFC in 2013, and is a Highly Cited Chinese Researcher in General Engineering according to Elsevier.

Contributed Speakers (in alphabetic order of first name)

Goran Muric (TU Dresden, Germany)

Title: **Using LTI system theory in complex networks analysis**

Abstract: Throughout the years, the electrical circuits have been characterized mostly by using the Linear Time-Invariant (LTI) system theory. LTI is suitable to describe the behavior of the system consisted of numerous interconnected components. We show that the same mathematical toolbox could be used for the complex network analysis. Given the topology of a network in terms of an undirected graph we form a state space representation of a linear system to quantify the node spreading power. By observing the system response we can accurately identify the most influential spreader. This approach extends the possibility for further utilization of the already established tools from the system theory in the field of complex networks analysis.

Ref: Murić G, Jorswieck E, Scheunert C (2016) Using LTI Dynamics to Identify the Influential Nodes in a Network. PLoS ONE 11(12): e0168514.

Bio: Goran is a PhD student at the Faculty of Electrical and Computer Engineering at the University of Technology in Dresden, Germany. His research is oriented toward the resilience of communication networks and modeling dynamics within the networks. He is also interested in social networks and particularly in optimizing team's performance.

Website: http://www.muric.info

Laura Seaman (Umichigan, USA)

Title: **The 4D Nucleome of Cancer**

Abstract: Cancer is a disease of uncontrolled cell division caused by changes in the normal 46 human chromosomes. These changes include translocations in which normally separate pieces of the genome are physically connected, and copy number changes in which a region is amplified. We analyze genomic structure and function through through graph adjacency matrices and corresponding node measurements. These measurements are combined to elucidate how chromosomal aberrations affect the 4D nucleome, i.e. the dynamics of nuclear structure and function. This work provides insight into the effect of nuclear organization in cancer and lays a foundation for future work on reprogramming a cancer cell.

Bio: Laura Seaman is a fourth year PhD candidate in Bioinformatics at the University of Michigan studying under Indika Rajapakse in the 4D+ Genome Lab. She studies genomic controllability of cancer cells focusing on characterizing nuclear structure and function in cancer. She received her B.S. in Biological Engineering from MIT. She is graduating in August and will be joining Draper as a machine intelligence scientist.

Liang Tian (Harvard Medical School, USA)

Title: **Articulation points in complex networks**

Abstract: An articulation point in a network is a node whose removal disconnects the network. Those nodes play key roles in ensuring connectivity of many real-world networks, from infrastructure networks to protein interaction networks and terrorist communication networks. Despite their fundamental importance, a general framework of studying articulation points in complex networks is lacking. Here we develop analytical tools to study key issues pertinent to articulation points, such as the expected number of them and the network vulnerability against their removal, in an arbitrary complex network. We find that a greedy articulation point removal process provides us a different perspective on the organizational principles of complex networks. Moreover, this process results in a rich phase diagram with two fundamentally different types of percolation transitions. Our results shed light on the design of more resilient infrastructure networks and the effective destruction of terrorist communication networks.

Ref: Tian L, Bashan A, Shi D-N, Liu Y-Y. Articulation Points in Complex Networks. Nature Communications 2017;8:14223.

Bio: Liang Tian is a postdoctoral research fellow in the Channing Division of Network Medicine at Brigham and Women's Hospital and Harvard Medical School, working with Prof. Yang-Yu Liu. Dr. Tian is a statistical physicist by training. He is currently working on percolation transitions on complex networks, as well as dynamics and functions of the human microbiome. Prior to joining Prof. Liu's lab, he completed his Ph.D. in theoretical physics at Nanjing University of Aeronautics and Astronautics and Hong Kong Baptist University (Joint Program). His dissertation work focused on statistics and dynamics of complex networks.

Oscar M. Granados (UTADEO, Columbia)

Title: **Controlling Global Banking Networks: From Letter to Qubit**

Abstract: This talk presents the evolution and control of the global banking network with the use of the principles of control theory. Studying several moments of stress or financial crisis (emergency) with different information systems where the banking networks have interacted, I design a computational algorithm. This algorithm simulates and determines which and how many nodes of the global banking network require to be controlled (the smallest number possible) to obtain control of the entire network, also determining the driver nodes and the degree distribution property of each of them or the nodes that are most vulnerable. This research uses the random networks and the Cayley graphs in interconnection networks because the networks do not always have an extensive connection, in other cases, the nodes depend on the financial markets characteristics or the majority of the nodes of the network maintain the same importance. In other words, a heterogeneous and dynamical topology. Finally, I demonstrate that this proposal defines a new form of financial ecology.

Keywords: Banking, Complex Systems, Networks, Control Theory

Bio: I am an economist with expertise in financial markets and international banking business and strategy. Currently, I am working on banking networks and financial ecology. The two primary goals of my current research are to combine tools from complexity, biological systems, and network science to develop a trans-disciplinary perspective about past and future of banking business, banking networks and global business. Secondly, to develop a proposal of (new) financial ecology theory. I am Associate Professor of Department of Economics and International Trade at Universidad Jorge Tadeo Lozano (Colombia). I worked in international banking for fifteen years. Since 2005, I am a Partner of the merchant banking firm Hisbruck. Previously I served as strategy advisor to the Colombian Ministry of Foreign Affairs.

Shuang Gao (McGill University, Canada)

Title: **The Control of Arbitrary Size Networks of Linear Systems via Graphon Limits**

Abstract: To achieve control objectives for extremely complex and very large scale networks using standard methods is a challenging, if not intractable, task. In this work we propose a novel way to approximately control network systems which lie in sequences with well defined limits as the number of nodes goes to infinity, this is achieved by the use of *graphon* theory together with the control theory of infinite dimensional systems. More specifically, the general controllability problem is analyzed for the infinite limit system and then the resulting control law is applied to members of the sequence of network systems. The theory then provides an upper bound for the error incurred by this approximate graphon control methodology. Examples in the case of the minimum energy control of the state distribution of large scale network systems will be given.

Joint work with Peter E. Caines.

Bio:

Shuang Gao is a PhD candidate at CIM, ECE, McGill university, Montreal, Canada, advised by Professor Peter E. Caines. He received his Bachelor's degree in Automation (2011) and Master's degree in Control Science and Engineering (2013) from Harbin Institute of Technology.

Peter E. Caines received the BA in mathematics from Oxford University in 1967 and the PhD in systems and control theory in 1970 from Imperial College, University of London, supervised by David Q. Mayne, FRS. In 1980, he joined McGill University, Montreal, where he is James McGill Professor and Macdonald Chair in the Department of Electrical and Computer Engineering. In 2000, his paper on adaptive control with G. C. Goodwin and P. J. Ramadge (IEEE TAC, 1980) was recognized by the IEEE Control Systems Society as one of the 25 seminal control theory papers of the 20th century. He received the IEEE Control Systems Society Bode Lecture Prize in 2013, is a Fellow of CIFAR, SIAM, IEEE, the IMA (UK) and the Royal Society of Canada (2003), and is a member of Professional Engineers Ontario. Peter Caines is the author of *Linear Stochastic Systems* (Wiley,1988) which is to be republished as a SIAM Classic. His research interests include stochastic, mean field game and hybrid systems theory together with their applications to natural and artificial systems.

Title: **The Control of Arbitrary Size Networks of Linear Systems via Graphon Limits**

To achieve control objectives for extremely complex and very large scale networks using standard methods is a challenging, if not intractable, task. In this work we propose a novel way to achieve approximate control for such networks by using the theory of graphons and infinite dimensional system theory.

Consider an interlinked network S^N of linear dynamical subsystems $\{S_i^N; 1 \leq i \leq N\}$, each with an n dimensional state space. Each subsystem is uniquely associated to a vertex of the N node graph G_N whose undirected edges correspond to the dynamical interactions between the subsystems. We specify the (symmetric) linear dynamics for the network S^N via the equation

$$\dot{x}_t = A_N \circ x_t + B_N \circ u_t, x_t, u_t \in R^{nN}, A_N, B_N \in R^{nN \times nN}, \tag{1}$$

where $A_N = A_N^T$ denotes a (matrix weighted) adjacency matrix of G_N, $B_N = B_N^T$ denotes a linear input-to-state mapping, and $\circ$ denotes the so called averaging operator given by $A_N \circ x = \frac{1}{N} A_N x$. The adjacency matrices can be represented by step functions (see [3]) in the graphon space $\mathbf{G_1^{sp}}$, i.e. the space of symmetric measurable functions $W_1 : [0,1]^2 \to [-1,1]$. Then trajectories of the system (1) correspond one-to-one with the trajectories of the system

$$\dot{x}_t^s = A_s^{[N]} x_t^s + B_s^{[N]} u_t^s, \quad x_t^s, u_t^s \in L^2_{step}[0,1], A_s^{[N]}, B_s^{[N]} \in \mathbf{G_1^{sp}},$$

where $[A_s^{[N]} x_s](\alpha) := \int_0^1 A_s^{[N]}(\alpha,\beta) x_s(\beta) d\beta, x_s \in L^2[0,1]$. $\mathbf{G_1^{sp}}$ is compact under the cut metric [3] and complete under the $L^2[0,1]^2$ metric. Let the graphon sequences $\{A_s^{[N]}\}$ and $\{B_s^{[N]}\}$ be Cauchy sequences of step functions in $L^2[0,1]^2$ with graphon limits A and B (which will then necessarily also be the limits in the cut metric, see [3]). The limit system $(A; B)$ is given by

$$LS^\infty : \dot{x}_t = A x_t + B u_t, \quad x_t, u_t \in L^2[0,1], A, B \in \mathbf{G_1^{sp}},$$

where A and B are graphons, and hence as operators on $L^2[0,1]$ are bounded and hence continous; furthermore, A generates a C_0-semigroup. Specializing the theory in [1] to the case of $L^2[0,1]$ Hilbert state spaces, one can show that the graphon system LS^∞ has a unique mild solution $x \in C([0,T]; L^2[0,1])$ for any $x_0 \in L^2[0,1]$ and any $u \in L^2[0,T; L^2[0,1]]$ (see [1]).

Define $W_T = \int_0^T e^{At} B B^T e^{A^T t} dt$ as the *controllability Gramian operator*, then the criterion for exact controllability (see [1]) of LS^∞ is that, for all $h \in L^2[0,1]$, $\langle W_T h, h \rangle \geq c_T \|h\|^2$, where $c_T > 0$.

The proposed graphon control strategy consists of the following steps: (1) Consider the general control problem of steering the states of each member of a sequence S of network systems $\{S^N; 1 \leq N \leq \infty\}$ to each of a sequence x_T of desired states $\{x_T^N; 1 \leq N \leq \infty\}$, where it is assumed that S converges to some limit system LS^∞ and x_T to some x_T^∞. (2) Specify the corresponding control problem CP^∞ for LS^∞ on $L^2[0,1]$ and choose a tolerance $\varepsilon > 0$. (3) Find the control law u^∞ for CP^∞. (4) Then Theorem 1 below and the convergence of the x_T sequence yield N_ε such that $x_T^N(u^N)$ is within ε of x_T^∞ and of x_T^N for all $N \geq N_\varepsilon$.

Theorem 1 ([2])**.** *Assume $(A; B)$ and $(A_s^N; B_s^{[N]})$ are exactly controllable, then there exist controls u^∞ and u^N such that*

$$\|x_T^\infty(u^\infty) - x_T^N(u^N)\|_2 \leq \|A_\Delta^N\|_2 \|B\|_2 \int_0^T e^{T-\tau}(T-\tau) \cdot \|u_\tau^\infty\|_2 d\tau + \|B_\Delta^N\|_2 \int_0^T e^{(T-\tau)\|A_s^{[N]}\|_2} \cdot \|u_\tau^\infty\|_2 d\tau$$

where $x_T^\infty(u^\infty) = x_T^\infty$, $A_\Delta^N = A - A_s^{[N]}$ and $B_\Delta^N = B - B_s^{[N]}$.

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[3] L. Lovász. *Large networks and graph limits*, volume 60. American Mathematical Soc., 2012.

Xizhe Zhang (Northeastern University, China)

Title: **Input graph: the hidden geometry in controlling complex networks**

Abstract: Controlling complex networks [1] is important in various natural and technological systems. In general, many control schemes may exist because of the structural complexity of a network. The existence of numerous control schemes in a network promotes us to wonder: what is the underlying relationship of all control schemes and possible driver nodes? Here we introduce input graph [2], a simple geometry that reveals the complex relationship between all control schemes and driver nodes. The input graph is constructed by replacing the original edges with new edges reflecting control correlations of nodes.

We prove that the node adjacent to a driver node in the input graph will appear in another control scheme, and the connected nodes in input graph have the same type in control, which they are either all possible driver nodes or not. Therefore, the emergence of the giant connected component in input graph provides a clear topological explanation of the bifurcation phenomenon [3] in dense networks, and the complex control correlation of nodes of the original network can be reduced into a few simple connected components of the input graph.

Furthermore, we present an efficient method to alter the control modes [3] of a network and precisely manipulate the control types of any node, which is the first approach to solving this problem as we know. We also reduce the computational complexity of finding all possible driver nodes from O(N1/2L)+O(NL) [3] to O(N1/2L), which ran several orders of magnitude faster than the existing method [3] on large real networks. We believe that input graph is important because it (i) presents a framework that reveals the inherent correlation of MISs and nodes in control and (ii) enables the design and manipulation of a suitable MIS of a network under constraints. Ultimately, these findings provide an insight into control principles of complex networks and offer a general mechanism to design a suitable control scheme for different purposes.

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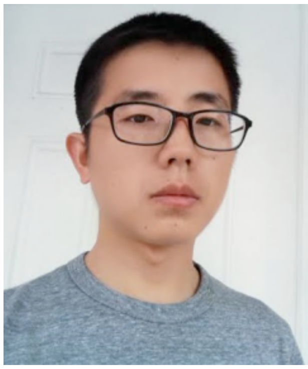
Bio: Xizhe Zhang is Associate Professor of the School of Computer Science and Engineering at Northeastern University, China, where he has been since 2006. He is a Visiting Professor at the Washington University in St. Louis. He received a B.S., M.S., and Ph.D. from Jilin University of China in 2000, 2003 and 2006. He also currently serves as Associate Editor of Frontier of Computer Science. His research interests are in analyzing controllability of complex network and information spreading of online social networks.

Xu-Wen Wang (Harvard Medical School, USA)



Title: **Controlling complex networks with conformity behavior**

Abstract: Controlling complex networks accompanied by common conformity behavior is a fundamental problem in social and physical science. Conformity behavior that individuals tend to follow the majority in their neighborhood is common in human society and animal communities. Despite recent progress in understanding controllability of complex networks, the existent controllability theories cannot be directly applied to networks associated with conformity. We propose a simple model to incorporate conformity-based decision making into the evolution of a network system, which allows us to employ the exact controllability theory to explore the controllability of such systems. We offer rigorous theoretical results of controllability for representative regular networks. We also explore real networks in different fields and some typical model networks, finding some interesting results that are different from the predictions of structural and exact controllability theory in the absence of conformity.

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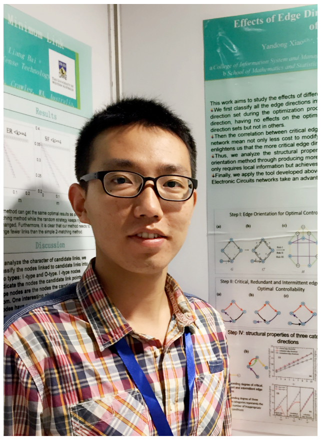
Bio: Xu-Wen Wang is a lecturer at the East China Jiaotong University in China. He received a B.S in Physics from Southwest University in 2004, and a PhD in Theoretical Physics from University of Science and Technology of China (USTC) in 2015. Now, he is a visiting scholar in Harvard Medical School.

Yandong Xiao (Harvard Medical School, USA)



Title: **Mapping the ecological networks of microbial communities**

Abstract: Microbes form complex and dynamic ecosystems that play key roles in the health of the animals and plants with which they are associated. The inter-species interactions can often be represented by a directed, signed and weighted ecological network, where nodes represent microbial species and edges represent ecological interactions. Mapping the ecological networks of microbial communities is a necessary step towards understanding their assembly rules and predicting their temporal behavior. However, the utility of current mapping methods, which rely on detailed knowledge of the population dynamics model coupled with time-resolved metagenomics, has been very limited. Indeed, many host-associated microbial communities are governed by complex dynamical rules that are challenging to infer. Furthermore, those communities typically exhibit intrinsic stability, rendering the longitudinal data that existing methods rely on not very informative. To circumvent these limitations, here we develop a new computational method that maps the ecological networks of microbial communities from steady-state data. Our method can infer the inter-species interaction types (positive, negative or neutral) without assuming any detailed population dynamics model. Using the classic Generalized Lotka-Volterra model, our method can also identify the inter-species interaction strengths and intrinsic growth rates. We validate our method using synthetic data and then apply it to real data of a small soil microbial community. Our method offers a novel framework to infer inter-species interactions and represents a key step towards the ecological modeling of the microbial communities.

Bio: Yandong Xiao is a visiting PhD student supervised by Professor Yang-Yu Liu at Brigham and women's hospital and Harvard Medical School. He received a bachelor in Information system engineering from National University of Defense Technology in 2008. His research interests focus on control theory of complex network, dynamical analysis of complex ecological system and modeling the microbiome-based therapy (e.g. Fecal Microbiota Transplantation) on human gut microbiota dysbiosis (e.g. Clostridium Difficile Infection, Inflammatory bowel disease).