NetSci2020 satellite - Multiscale analysis of dynamical processes on networks

Date: Sunday 20 September 2020

Times: 1.20om to 6pm CET (Italy Time)

Tentative program

13.20-13.30 Welcome by the satellite organizers

13.30-13.50 Mattia Frasca, The Master Stability Function for Synchronization in Simplicial Complexes

13.50-14.10 Sarika Jalan, Interlayer adaptation-induced explosive synchronization in multiplex networks

14.10-14.30 Philipp Hoevel, Synchronization in (modular) neuronal networks

14.30-14.50 Lorenzo Zino, On imitation dynamics in population games on networks with community patterns

14.50-15.10 Pietro De Lellis, Vulnerability of network dynamical systems from time-series

15.10-15.40 Virtual coffee break

15.40-16.00 Manlio De Domenico, Multiscale analysis of complex networks: from spectral entropy to diffusion geometry

16.00-16.20 Giovanni Russo, On noise induced collective behaviors in multi-scale networks

16.20-16.40 Naama Brenner, Dynamics and exploratory adaptation in heterogeneous networks

16.40-17.00 Hernan Makse, Symmetry and synchronization in genetic and brain networks

17.00-18.00 “Lighting” contributed presentations, Q&A time, concluding remarks

Abstracts

S. Boccaletti, The Master Stability Function for Synchronization in Simplicial Complexes

All interesting and fascinating collective properties of a complex system arise from the intricate way in which its components interact. Various systems in physics, biology, social sciences and engineering have been successfully modelled as networks of coupled dynamical systems, where the graph links describe pairwise interactions. This is, however, too strong a limitation, as recent studies have revealed that higher-order many-body interactions are present in social groups, ecosystems and in the human brain, and they actually affect the emergent dynamics of all these systems. We introduce a general framework that allows us to study coupled dynamical systems accounting for the precise microscopic structure of their interactions at any possible order. We consider the most general ensemble of identical dynamical systems, organized on the nodes of a simplicial complex, and interacting through synchronization-non-invasive coupling function. The simplicial complex can be of any dimension, meaning that it can account, at the same time, for pairwise interactions, three-body interactions and so on. In such a broad context, we show that complete synchronization, a circumstance where all the dynamical units arrange their evolution in unison, exists as an invariant solution, and we give the necessary condition for it to be observed as a stable state. Moreover, for specific coupling forms, such a necessary condition is given in terms of a Master Stability Function.

S. Jalan, Interlayer adaptation-induced explosive synchronization in multiplex networks

The multilayer nature of networks has broadened the landscape of network science. In this multilayer description, different kinds of relationships or interactions between the nodes are modeled by allowing the units to be arranged in several layers, either simultaneously or in an alternating fashion. An example of multilayer system can be the transport system of a country or state in which cities or towns would be the nodes, and a distinct network of each bus, train, and flight connectivity among the nodes (cities) denotes different layers. Furthermore, a close relationship between structure and dynamics in the process of synchronization in complex networks has been the object of study for a long time; however, it has proved to be particularly important in the case of the "explosive synchronization," where the ensemble reaches suddenly to a fully coherent state through a discontinuous, irreversible first-order like transition known as Explosive synchronization (ES), often in the presence of a hysteresis loop. It is known that intralayer adaptive coupling among connected oscillators instigates ES in multilayer networks. Taking an altogether different cue in the present work, we consider interlayer adaptive coupling in a two-layer multiplex network of phase oscillators and show that the scheme gives rise to ES with an associated hysteresis. The hysteresis is shaped by the interlayer coupling strength and the frequency mismatch between the mirror nodes. We provide a rigorous mean-field analytical treatment and show that the analytical predictions are in fair agreement with the numerical assessments. Moreover, the analytical predictions provide extensive insight into how adaptive interlayer coupling suppresses the formation of a giant cluster, eventually giving birth to ES. The study will help in spotlighting the role of interlayer adaptation in the emergence of ES in real-world systems represented by multilayer architecture. In particular, it is relevant to those systems which have limitations towards changes in intralayer coupling strength.

P. Hoevel, Synchronization in (modular) neuronal networks

Synchronization phenomena are widely studied across many fields. Among the wide spectrum of dynamical scenarios, some more peculiar patterns of synchronization can also be observed in complex systems. These include the surprising coexistence of coherent and incoherent parts of coupled identical oscillators, a hybrid state that became known as chimera. In my presentation, I will discuss synchronization patterns and chimera-like states in the modular multilayer topology of the connectome of Caenorhabditis elegans. In the special case of a designed network with two layers, one with electrical intra-community links and one with chemical inter-community links, chimera-like states are known to exist. Aiming at a more biological approach based on the actual connectivity data, the considered network consists of two synaptic (electrical and chemical) and one extrasynaptic (wireless) layers. Analyzing the structure and properties of this layered network using Multilayer-Louvain community detection, modules are identified whose nodes are more strongly coupled with each other than with the rest of the network. Based on this topology, we study the dynamics of coupled Hindmarsh-Rose neurons. A tendency of the wireless coupling to moderate the average coherence of the system can be observed: for stronger wireless coupling, the levels of synchronization decrease both locally and globally, and chimera-like states are not favored. In addition, I will highlight implications of the multilayer connection on the locomotory behavior and on neuronal activity patterns that control forward locomotion. For this purpose, the Hindmarsh-Rose equations for neuronal activity are combined with a leaky integrator model for muscular activity.

L. Zino, On imitation dynamics in population games on networks with community patterns

We deal with imitation dynamics for population games on networks. Imitation dynamics are a general class of learning protocols in which a population of individuals exchanges information through pairwise interactions. By means of these interactions, individuals get aware of the actions played by the others and the corresponding rewards, and may revise their action, imitating the ones observed from the others. The pattern of interactions that regulates the learning process is determined at a mesoscopic level by a community structure, which models, for instance, age or gender groups. In this talk, we study the asymptotic behavior of imitation dynamics. First, we characterize the set of equilibrium points of the dynamics. Then, for the class of potential games and under some mild assumptions on the community structure, we prove global asymptotic convergence to the set of Nash equilibria of game.

P. De Lellis, Vulnerability of network dynamical systems from time-series

From natural to technological settings, network dynamical systems constitute a powerful approach to study collective dynamics. A critical area of study in network dynamical systems entails the analysis of causal influence, which, in principle, requires the manipulation of topological and dynamic characteristics. In most applications, any of these manipulations is unfeasible and the researcher can only record the time-series of a few accessible units, from which he/she must pinpoint causal influence among the network units. For example, can we identify the most influential financial agent in the market from the time-series of the orders placed in the book? For linear time-invariant dynamics and undirected topologies, we demonstrate the possibility of exactly detecting the most influential nodes in the network without a calibrated mathematical model, using only time-series of a real experiment where all nodes are plagued by noise. We illustrate the approach on two real-world datasets: firearm prevalence in the U.S. and players' movements in a soccer game. Just as our conclusions support the emergence of influential States which have a less stringent legal environment, they hint at the instrumental role of players who are critical to the offense strategy of the team.

M. De Domenico, Multiscale analysis of complex networks: from spectral entropy to diffusion geometry

We will use diffusive processes on the top of arbitrary complex networks to define a framework for their multiscale analysis. On the one hand, we will characterize the interplay between structure and dynamics through the lens of diffusion geometry and show how it can be used to characterize a class of collective phenomena. On the other hand, we will discuss how diffusive processes can be used to quantify the von Neumann entropy of the network and the ground for a set of information-theoric tools that can be applied for the analysis of networks, without relying on the arbitrary choice of specific scalar distributions.

G. Russo, On noise induced collective behaviors in multi-scale networks

This talk is focused on the study of noise-induced emerging behaviors in complex networks. Our main goal is to explore how the interplay between the dynamics at the nodes, the network topology and noise diffusion processes play a key role in determining stability of certain manifolds in the network state-space. After introducing the mathematical framework, we present a perhaps counter-intuitive result for network synchronization. Indeed we show how certain noise diffusion processes (also termed as relative-state-dependent noise) force stability of the synchronization/consensus manifold that, without noise, would be unstable. Applications of the results are also discussed.

N. Brenner, **Dynamics and exploratory adaptation in heterogeneous networks**

Biological networks support not only complex dynamics but also plasticity, adaptation and learning in many contexts. Cells in particular, exhibit exploratory behavior, potentially providing a capacity to adapt to an endless variety of unforeseen conditions. Such cellular plasticity has been repeatedly observed, but its relation to network properties and its dynamic characteristics are not well understood. I will present a random network model of gene regulation showing the feasibility of such adaptation based on purely stochastic dynamics and stress sensing. Convergence in high-dimensional gene expression space is not a-priori guaranteed; indeed, we find it to be non-universal and dependent on network properties. Successfully adapting network ensembles are heterogeneous and have outgoing hubs – “master regulators”, a known feature of gene networks. Feedback analysis of such heterogeneous networks reveals the unique organizing role of the hubs in stabilizing fixed points across the ensemble, which in turn increases success in exploratory adaptation. These findings establish a biologically plausible mechanism of adaptation by exploratory dynamics, that benefits from the structural properties of gene networks. It more generally suggests a deep connection between cellular plasticity and learning theory.

H. Makse, Symmetry and synchronization in genetic and brain networks

The success of symmetries in explaining the physical world, from general relativity, to the standard model of particle physics and all phases of matter, raises the question of why the same concept could not be equally applied to explain emergent properties of biological systems. In other words, if life is an emergent property of physics, why the same symmetry principles that explain physics cannot explain the organizing principles of life? Here we show that a particular form of symmetry, called symmetry fibration, explains the building blocks of genetic networks and the connectome. This result opens the way to understand how the structure of information-processing networks emerges from the bottom up.

Our speakers

Stefano Boccaletti, CNR-Institute of Complex Systems, Via Madonna del Piano, Sesto Fiorentino, Florence 50019, Italy and Unmanned Systems Research Institute, Northwestern Polytechnical University, Xi'an 710072, China and Moscow Institute of Physics and Technology, Dolgoprudny, Moscow Region, 141701, Russian Federation, -- https://www.isc.cnr.it/staff-members/stefano-boccaletti/

Stefano Boccaletti received the PhD in Physics at the University of Florence on 1995, and a PhD honoris causa at the University Rey Juan Carlos of Madrid on 2015. He was Scientific Attach\'e of the Italian Embassy in Israel during the years 2007-2011 and 2014-2018. He is currently Director of Research at the Institute of Complex Systems of the Italian CNR, in Florence. His major scientific interests are i) pattern formation and competition in extended media, ii) chaos recognition, control and synchronization, and iii) the structure and dynamics of complex networks. He has co-authored the first experimental evidence of bulk-boundary transition in pattern formation in nonlinear active optics; the first experimental evidence of domain coexistence in two-dimensional pattern formation in passive optics, and the first experimental evidence of control of complex two-dimensional patterns in nonlinear passive optics. He introduced the classification method of complex networks in terms of their propensity to synchronization, which is the common standard today. Boccaletti has about 95 invited participations to International Conferences, Workshops and Schools. He is Editor in Chief of the Journal “Chaos, Solitons and Fractals” (Elsevier) from 2013, and member of the Academia Europaea since 2016. He was elected member of the Florence City Council from 1995 to 1999. Boccaletti has published 332 papers in peer-reviewed international Journals, which received more than 27,000 citations (Google Sholar). His h factor is 61 and his i-10 index is 201. With more than 10,000 citations, the monograph ¨Complex Networks: Structure and Dynamics¨, published by Boccaletti in Physics Reports on 2006 converted into the most quoted paper ever appeared in the Annals of that Journal.

Naama Brenner, Dept. of Chemical Engineering & Network Biology Research Lab
Technion – Israel Institute of Technology, ISRAEL, https://biophysics.net.technion.ac.il/

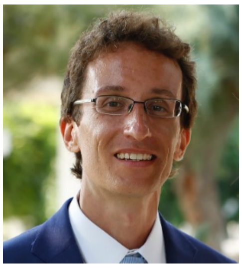
Naama Brenner received a PhD in Theoretical Physics from the Technion. She was postdoctoral fellow at NEC Research Institute in Princeton, where she worked in Computational Neuroscience with special interest in sensory adaptation and multiple timescales in neural coding. Upon returning to Israel she joined the group of scientists and engineers who founded InSightec Ltd, to develop a focused-ultrasound system for noninvasive tumor ablation. Naama then joined Chemical Engineering at Technion to establish a theoretical biophysics research group, and initiated with other Technion researchers the Network Biology Research Lab. Current research in her group includes cellular adaptation and learning, phenotypic variability and interactions in microbial populations, synaptic fluctuations.

Manlio De Domenico, CoMuNe Lab, Fondazione Bruno Kessler, https://comunelab.fbk.eu/

Physicist, Senior Researcher at FBK (Italy) where he leads the CoMuNe Lab, national coordinator of the Italian Chapter of the Complex Systems Society, Adjoint Professor of Network Science at University of Trento and Visiting Professor at Universitat Rovira i Virgili. His research focuses on collective phenomena emerging from natural and artificial interdependent systems, with contributions to multiscale modeling and analysis of multilayer networks, their structure, dynamics, information capacity and resilience to shocks. His applications range from biological to socio-technical systems, with impact on systems medicine, smart city engineering, risk assessment and policy-making in response to epidemics and infodemics.

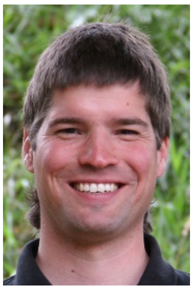
Pietro De Lellis, University of Naples Federico II, -- https://sites.google.com/site/pierodelellis/

Pietro De Lellis received the Ph.D. degree in automation engineering from the University of Naples Federico II, Italy, in 2009, where he is currently a Tenured Assistant Professor of Automatic Control. As a visiting Ph.D. student, in 2009 he spent six months at the NYU Tandon School of Engineering, where he was later appointed Postdoctoral Fellow and Visiting Professor. He has authored more than 70 scientific publications that, according to Google Scholar (August 2020), received over 1800 citations. His research interests include analysis, synchronization, and control of complex networks, collective behavior analysis, formation control, decentralized estimation, and evolving financial networks.



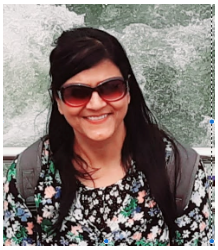
Philipp Hövel, School of Mathematical Sciences, University College Cork, Ireland, -- http://publish.ucc.ie/researchprofiles/D019/philipphoevel

Dr. Philipp Hoevel is a trained mathematician and physicist. His mission is to lift the boundaries between data-driven research, theoretical approaches, and numerical simulations addressing interdisciplinary questions based on an overlap of nonlinear dynamics, network science, and control theory. Besides mathematical modeling and analytical investigations, he has always looked for experimental validation of his theoretical findings and a combination of the models with empirical data. His interdisciplinary research concept has led to better insight and fundamental understanding of synchronization processes and other dynamical phenomena and sparked investigations of real-world relevance in field of neuroscience, epidemiology, and beyond.



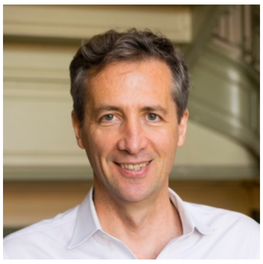
Sarika Jalan, Indian Institute of Technology Indore, India and IBS Research Center Daejeon, South Korea, -- www.iiti.ac.in/~sarika

Sarika Jalan is a Professor at the Indian Institute of Technology Indore, India. She obtained her Ph.D. in Physics with a specialization in nonlinear dynamics. Her current research revolves around the spectral and dynamical properties of multilayer networks. She is an Editorial board member of Chaos, Solitons & Fractals, and a member of the editorial advisory board of Chaos: An interdisciplinary journal of nonlinear science.



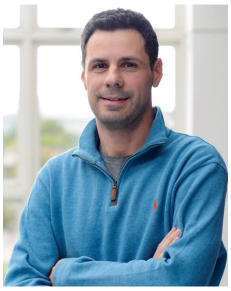
Hernan Makse, City College of New York, https://hmakse.ccny.cuny.edu

Hernan research focuses on the theoretical understanding of Complex Systems from a Statistical Physics viewpoint. He is working towards the development of new emergent laws for complex systems, ranging from brain networks to biological networks and social systems. Treating these complex systems from a unified theoretical approach, he uses concepts from statistical mechanics, network and optimization theory, machine learning, and big-data science to advance new views on complex systems and networks.



Giovanni Russo, University of Salerno, Department of Information and Electrical Engineering and Applied Mathematics (DIEM), https://sites.google.com/view/giovanni-russo/home

Giovanni Russo (SMIEEE ’19) is, since February 2020, an Associate Professor of Automatic Control at the University of Salerno (Italy). He obtained his Ph.D. in 2010 from the University of Naples Federico II under the supervision of Prof. M. di Bernardo. Soon after his Ph.D. he accepted a job offer from Ansaldo STS and was the lead system engineer of the Honolulu Rail Transport Project. In Nov. 2015, he joined IBM Research. Within IBM, he was a Research Staff Member in Optimization, Control and Decision Science. Before joining University of Salerno (September 2018 to February 2020) he has been with University College Dublin. His research is at the intersection of control, applied mathematics, networked systems and information theory.



Lorenzo Zino, Faculty of Science and Engineering, University of Groningen, Groningen, The Netherlands --- https://lorenzozino90.wixsite.com/lzino

Lorenzo Zino majored in Mathematical Engineering at Politecnico di Torino in 2014 and received his PhD degree in Pure and Applied Mathematics from Università di Torino - Politecnico di Torino (joint program) in 2018. He had short term research fellowships at Politecnico di Torino and New York University. Since October 2019, he is a Research Fellow with the University of Groningen. His research interests include but are not limited to the modeling, the analysis, and the control aspects of dynamics on networks (epidemics, opinion dynamics, diffusion of innovation, etc.), applied probability, network modeling and analysis, and game theory.