Explosive transitions in complex networks: new opportunities, new dangers

Overview

Phase transitions in complex networks have been extensively studied since already long ago. In the majority of cases, these transitions are of the second-order type, i.e. continuous and reversible. Recently, however, discontinuous and irreversible transitions phenomena have been reported in complex networks' structure and dynamics. Explosive percolation, discovered in 2009, corresponds to an abrupt change in the network's structure, and explosive synchronization generates a sudden emergence of a collective state in the networks' dynamics. The two phenomena have stimulated investigations and debates, attracting attention in many relevant fields, which have provided insights on what structural and dynamical properties are needed for inducing such abrupt transformations, as well as have greatly enhanced our understanding of phase transitions in networked systems. The intention of this course intention is to offer here a overview of this subject, with the twofold aim of present the existing results and pointing out possible directions for applications and future research.

In this course we will introduce a variety of mathematical tools based on algebraic graph theory, linear algebra and dynamics that constitutes a basis for the analysis of large scale complex interconnected systems.

The primary objectives of the course are as follows:

1) Providing a general introduction to the structure and dynamics in complex networks.

2) Offering the main concepts and tools for the study of phase transitions in complex networks.

3) Considering the special conditions that yield to the apparition of explosive transitions.

4) Updating the most recent developments in the subject, with a discussion of future applications.

The course will be divided in 15 hours of lectures and 6 hours of tutorials that will be covered in five working days, each one completing a module:

- Module A will introduce the structure, nature and concepts of complex network, as well as an introduction to modelization: random network and the small-world property, the Barabasi-Albert model, modifications and applications. The structure of real networks will be considered in this part.
- Module B will board the processes and phase transitions in complex networks. The concept of percolation and giant component will be introduced. We will explain the explosive percolation under Achlioptas rule and other algorithms. In this part we will consider application of these concept to the study of robustness and efficiency in real networks as the case of catastrophic cascading in Power Grids. The module will finish with a tutorial on computer simulation of network percolation and the implementation of the Achlioptas process.
- Module C will be devoted to spreading and epidemics in complex networks. We will first consider the homogeneous and heterogeneous epidemics models (SI SIR, SIS) and the main immunization strategies. Then, we will explore the factors that can lead to explosive epidemic spreading or the explosive propagation in social networks and opinion behaviour. The module will close with a tutorial in computer simulation of the SIR epidemic process and the study of the explosive effects of reinfection.

- Module D will introduce the concept of synchronization in nature, and its modelization with the Kuramoto model for full and complex networks. We will considered the different phase transition paths to coherence in complex network: structure vs. dynamics. We will briefly considered the analysis of general synchronization by means of the master stability function. As an application, we will introduce the study of coherence in brain dynamics.

- Module E will be dedicated to the explosive synchronization in complex networks. The effect of structure-dynamics correlations will be studied. We will consider where the explosive synchronization can be found in nature, social and technological networks, including applications, prospectives and future work. The module will finish with a tutorial in computer simulation of regular and explosive synchronization in the Kuramoto model.

On each working day there will be a total of two lecture periods each of ninety minutes duration in the morning, and three tutorials in the afternoons. The time frame for each day will be the following:

First period: 9.00-10.30 am, Coffee break: 10.30-11.15 am, Second period: 11.15 am-12.45 pm.

Tutorials: 2:00-4:00 pm.

Modules	**A: Complex Networks Theoretic Concepts.** **B: Percolation and processes in networks: explosive percolation.** **C: Explosive spreading and epidemics.** **D: Paths to synchronization.** **E: Explosive synchronization.** **Number of participants for the course will be limited to fifty.**
You Should Attend If…	▪ you are an Undergraduate, Master or PhD level scholar who would like to be introduced to the new and growing interdisciplinary area of Network Science ▪ you are a young and budding member of the faculty at various Engineering and Computer Science departments wanting to learn the developments and further developing research programs in the respective departments. ▪ you are a scholar in governmental, industrial or consulting agencies who wishes to expand understanding the state of the art in this area.
Fees	The participation fees for taking the course is as follows: **Participants from abroad : US $500** **Industry/ Research Organizations: Rs 10,000** **Academic Institutions: Students Rs 3,000, faculty Rs 5,000** The above fee include all instructional materials, computer use for tutorials and assignments, laboratory equipment usage charges, 24 hr free internet facility. The participants will be provided with accommodation on payment basis.
Dates	15 to 19 January, 2018.

The Faculty

Dr. I. Leyva completed her PhD in Physics with specialization in nonlinear dynamics of extended systems in Madrid, Spain in 2001. She jointed the Laser Systems Group of INOA, Florence, Italy, as a post-doctoral researcher. During this period she worked on nonlinear optical extended systems and chaotic dynamics and competition in complex networks. Since 2009 she is Associate Professor in the Universidad Rey Juan Carlos of Madrid, where she founded the Complex Systems Group, that develops new theoretical tools to the analysis of the relationship between structure and dynamics in Biological Networks, specially phase transitions. She is also permanent staff of the Center of Biomedical Technology as member of the Biological Networks Lab, studying the interrelation between topology and function in the brain micro-connectome by means of pioneer simultaneous optical and electrophisiological recording in *in vitro* neural cultures.

Dr. Sarika Jalan is completed her PhD in Physics with specialization in nonlinear dynamics and Complex Systems from Physical Research Laboratory, India in 2005. She has six years post-doctoral experience at MPI-MiS, Leipzig , MPI-PKS and NUS, Singapore. During this period she worked on spectral properties of complex systems as well as applications to biological systems. Upon joining IIT Indore In December 2010, she established Complex Systems Lab, which focuses on inter-disciplinary research, utilizing techniques from Physics, Mathematics, Bio-informatics and Computer Science. Using network theory, nonlinear dynamics and computational techniques, the lab on one hand works on developing tools pertaining to complex systems research and on other hand applies these techniques to real world systems coming from Biology and Social science.

Course Coordinator

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