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Statistical Physics of Socio-Economic Systems

Lecturer

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Description of the course

This course provides an introduction to the use of Statistical Physics tools for the analysis and understanding of socio-economic systems. Most systems in this realm are composed by elements (generically termed *agents*) that do not act in isolation and are inhomogeneous. As a result of their interaction, complex behaviour is usually observed at a macroscopic scale and the systems operate usually in out-of-equilibrium conditions. Therefore, advanced techniques from Statistical Mechanics are suited for understanding some of their properties.

The objectives of the course is to allow the students to understand the parsimonious modelling approach taken to uncover the mechanisms behind large-scale phenomena and assimilate its underlying difficulties, limitations and strengths. Special emphasis will be given at the interpretation of the parameters included in the models. A second objective is to give the students a glimpse on state-of-the-art techniques for data analysis and model validation. All the activities of the course include training in simulation and data analysis as an integral part of the activities, for the students to gain practical experience.

The course is organised in two main parts: *Complex Networks* and *Modelling*. The first part of the course will include (but be not limited to): multiplicative growth processes (which pervade the growth of technological and social networks), phase transitions in network topology (like the small-world effect, transitions from hierarchical to decentralised networks), mesoscale network properties (like communities), scaling laws (of trees) and different kinds of percolation transitions (when subjected to random or targeted attacks).

The second part of the course deals with simple models of socio-economic systems some of which were inspired in Statistical Physics, some others that exhibit a rich behaviour when analysed with such techniques. These include: Voter model (which exhibits coarsening without surface tension), Axelrod model (which exhibits transitions from homogeneous to disordered states), Threshold models (sensibility to initial conditions), and processes of diffusion and spreading (epidemiology and product adoption) which exhibit fundamentally different properties than on regular lattices.

Workload statement

The course consists of 2 bi-weekly modules, each of them comprising 10 hours theory and 10 hours practice. Each module is distributed in four classes (2:30 hours each) and four practical classes in the computer lab (2:30 hours each). A final oral evaluation of two hours will take place, where all students must participate.

Total time: 40 hours

Lecture programme

Lecture 1. Graph theory introduction

a. Basic Definitions, Statistical Distributions, Universality, Self-Organised Criticality

b. Scale-Invariance of Degree Distribution, Small-World Effect, Clustering

- **Practice:** Short introduction to programming with Python, numpy, scipy, NetworkX and igraph

Lecture 2. Node properties: Communities and Ranking

a. Community Detection: Connection to Potts model and spin glass, Louvain method

b. Centrality of nodes. Detection of important nodes: HITS Algorithm (and its limitations), PageRank

- **Practice:** Detecting communities in real data. Identifying important nodes in networks

Lecture 3. Graph Modelling

a. Static models of Graphs: Erdős–Rényi, Watts-Strogatz Small-World, Fitness models and self-organised fitness model: The connection to Economic Networks

b. Dynamical Models of Graphs: Yule-Simon model, The Matthew effect, Barabási-Albert model. Growth by preferential attachment.

- **Practice:** Programming growth models and measuring their macroscopic properties.

Lecture 4. Nestedness in networks

a. Mutualistic networks in ecology and economics. Models of network growth: The Social Climbing Game. Nestedness detection and Nested Assemblies

b. Discontinuous transitions from hierarchical to decentralised systems. Robustness and fragility in organisations.

- **Practice:** Data analysis and programming of the models introduced

Lecture 5. Consensus and spreading

a. Voter model, continuous opinion formation models, Threshold models

b. Epidemics and spreading: Compartmental models, SI, SIR, SIS, SIRS models. Bass model

- **Practice:** Data analysis and programming of the models introduced

Lecture 6. Percolation, Self-organised criticality and segregation

a. Forest-fire model, sandpile models

b. Schelling model of segregation

- **Practice:** Data analysis and programming of the models introduced

Lecture 7. Social dynamics

a. The role of media and advertisement.

b. Stochastic resonance in the response to influence. The role of system size.

- **Practice:** Data analysis and programming of the models introduced

Lecture 8. Advanced topics: Blockchain systems

a. Centralisation of decentralised systems, unexpected emergent properties and the role of incentives

b. The limits of socio-technical systems: Phase transitions and efficiency collapse

- **Practice:** Data analysis and programming of the models introduced

Target and prerequisites

The course is targeted to advanced Degree (Licenciatura), Post-graduate (Master and PhD levels) students of Physics or other Exact Sciences. They must have prior knowledge on Linear Algebra, Statistical Physics and preferably Nonlinear Dynamics (not binding).

Solid programming skills (or the willingness to develop this knowledge prior to the course) are a necessary requirement. The practical part of the course will be dictated in Python (for didactic purposes).

Final evaluation

The students (arranged in small groups) will develop a project consisting in reproducing related work in the Literature and making specific (commonly agreed on) extensions to them. They will present the results of their analyses to the rest of the participants in the evaluation period mentioned above.

Course dates

- From 20th March to 19th April

Bibliography

1. Caldarelli, G. (2007): Scale-free Networks
2. Jackson, M. O. (2010): Social and Economic Networks, Princeton University Press.
3. Newman, M. E. J. (2010): Network. An Introduction, Oxford University Press.
4. Easley, D. & Kleinberg, J. (2010): Networks, Crowds, and Markets: Reasoning About a Highly Connected World, Cambridge University Press.
5. Miller, John H., and Page, S. E. (2009). Complex adaptive systems: An introduction to computational models of social life. Princeton University Press.
6. Slanina, F. (2013): Essentials of Econophysics Modelling, Oxford University Press.