Name: Complex systems - 34068

Type: elective **Semester:** 2nd

ECTS: 5

Periodicity: annual

Departments involved: Department of Fundamental Physics (UB)
Department of Physics and Nuclear Engineering (UPC)

Coordinator: Albert Diaz-Guilera
Professors: Albert Diaz-Guilera, Romualdo Pastor-Satorras, Marian Boguñà Espinal

Language: Catalan / Spanish / English

Prerequisite:

Aims:

The aim of this subject is to offer an introduction to the characterization and study of complex systems, defined as those formed by a large number of interacting elements, with nonlinear interactions, and showing emergent global properties that are very different from those shown by the elementary components. The course offers an introduction to the theoretical and numerical tools for the study of general systems in general and will consider the application to certain particular examples.

Syllabus:

PART I: INTRODUCTION

1. Introduction to complex systems. Definitions. Examples: systems with nonlinear interactions; nonlinear discrete systems. Applications.
2. Scale invariance: complex systems with scale invariance. Dimensional analysis. Critical phenomena. Percolation.

PART II: SYSTEMS WITH NONLINEAR INTERACTIONS

3. Motivation: continuous and pulse-like nonlinear interactions. Examples.
4. Deterministic models: self-consistent mean-field solutions. Analysis of the solutions.
5. Stochastic models: Fokker-Planck equation. Solution and stability analysis of the solutions. Relation with dynamical systems, bifurcation diagrams.
6. Numerical methods: Brownian simulations (agents). Finite size effects. Solution of differential equations with partial derivatives. Spectral methods.

PART III: NON-EQUILIBRIUM DISCRET SYSTEMS

7. Non-equilibrium statistical mechanics: Introduction to non-equilibrium discrete systems. Contact processes. Universality classes. Breaking of detailed balance. Master equations. Field equations.
8. Self-organized criticality: Definition. Examples. Sand-pile models. Finite size analysis. Energy conservation effects.
9. Complex networks: Introduction. Examples. Modern graph theory. Scale invariance networks. Models of growing complex networks. Dynamical processes on complex networks. Applications.
10. Applications: Evolution and extinction of species. Structure and evolution of the Internet. Epidemics. Adaptative complex systems. Social networks. Biological systems.

Method:

The teaching methodology will consist in lectures and problem solving classes. There will be two types of problems. One part will be delivered to the student to be solved at home and delivered back next week. These problems will contribute to the final score. The other part of the problems will be solved by the teacher in the classroom.

Distribution: 3 lectures + 1 problem solving hours per week.

Evaluation:

There will be a final written test, which will contribute with a 60% to the final score. The problems solved by the student will contribute with a 40%.

Bibliography:

Bar-Yam, Y. Dynamics of Complex Systems. Perseus Books, 1997.

Ódor, G. Universality classes in nonequilibrium lattice systems. Rev. Mod. Phys 78, 663, 2004.

Pastor-Satorras, R.; Vespignani, A. Evolution and Structure of the Internet: A Statistical Physics Approach. Cambridge University Press, 2004.

Newman, M.E.J.; Palmer, R.G. Modeling Extinction. Oxford University Press, 2003.

Jensen, H.J. Self-Organized Criticality. Cambridge University Press, 1998.

Stanley, H.E. Introduction to phase transitions and critical phenomena. Oxford University Press, 1987.

Marro, J.; Dickman, R. Nonequilibrium Phase Transitions in Lattice Models. Cambridge University Press, 1999.

Risken, H. The Fokker-Planck equation: Methods of solution and applications. Springer 1996.

Strogatz, S.H. Nonlinear dynamics and chaos. Perseus Books, 2001.

Binney, J. J; Dowrick, N. J.; Fisher, A. J.;Newman, M. E. J. The Theory of Critical Phenomena. Cambridge University Press, 1992.

Christensen, K; Moloney N.R. Complexity And Criticality. Imperial College Press, 2005.

Boccara, N. Modeling complex systems. Springer, 2004.

Pikovsky, A.; Rosenblum, M.; Kurths, J. Synchronization: A Universal Concept in Nonlinear Sciences, Cambridge University Press, 2003.

Caldarelli, G. Scale-Free Networks: Complex Webs in Nature and Technology. Oxford University Press, 2007.

Barabasi, A.-L.; Stanley, H.E. Fractal Concepts in Surface Growth. Cambridge University Press, 1995.