Imperial College London

Complexity & Networks

Module Code	PHYS96008	FHEQ Level	Level 6
Pre-requisites	None	Co-requisites	None
Primary Department	Physics		
Module Leader	Prof Kim Christensen and Dr Tim Evans		
Additional Teaching Departments	None		
Teaching Staff	Prof Kim Christensen + Dr Tim Evans + Associate		

Programmes on which the Module is delivered	Core/Elective
All UG Physics programmes (F300, F303, F309, F325, F390, F3W3)	Elective

Learning Outcomes	On completing the Complexity & Networks course, students will be able to: • Discuss the sandpile metaphor to illustrate conceptually the notion of self-organised criticality. • Discuss the notion of a steady state (statistically stationary state). • Write down the algorithm of the BTW and Oslo model in 1 dimension. • Discuss the notion of stable, transient and recurrent configurations. • Define the notion of an avalanche size, s. • Handle probability density functions w.r.t. normalisation and moments. • Discuss the scaling form for the avalanche size probability density, the associated scaling collapse and moments scaling analysis • Define the different types of network in a variety of ways • Analyse the structure networks using a variety of basic measures • Create null models for network analysis • Derive analytical results for simple network models • Analyse basic processes on graphs using linear algebra • Compare theoretical and numerical results for simple models
Description of Content	Stephen Hawking has predicted that the 21st Century will be the century of complexity. A major theme in Complexity Science is seeing how interactions between many small but interacting parts can lead the emergence of dramatic results on large scales. This could be the way that we see rare yet occasionally observed large fluctuations in complex systems: stock market crashes, earthquakes, extreme weather are all good examples. Simple Gaussian statistics cannot describe these problems. If we are to understand these emergent features, we must understand the way the parts of a system interact. This is where networks play an important role. Physicists provided major new insights in the late 1990's showing how to describe the links between parts of a complex system when they were connected neither randomly (gas molecules) nor regularly (as in a regular lattice of atoms). However, Complexity and Networks are areas which are truly cross-disciplinary involving mathematicians, physicists, computer scientists, engineers, biologists,

and even the humanities. Over the last two decades the ideas of Complexity and Networks have become of central importance, and have already made a profound impact on our modern data driven world. For instance, the core idea behind Google's search algorithm relies on insights on how web pages are connected. Controlling the spread of the next flu epidemic will be based on models rooted in concepts from Complexity and Networks. The emergence of Complexity Science reflects the rapid growth in computational power and the role of information in the modern era. This course dips physicists' toes into the basic ideas and tools for describing and analysing complex phenomena.

Complexity
- Criticality - basic properties, examples, emergence of macroscopic behaviour from microscopic rules.
- Describe qualitatively and quantitatively the concept of cooperative phenomena and give examples hereof.
- Describe qualitatively and quantitatively the concept of scale invariance.
- Describe qualitatively and quantitatively the concept of scaling.
- Apply scaling arguments to systems at a phase transition.
- Numerical exercise - investigate simple model displaying complexity behaviour.

Networks
- Definition of network, different types (random, small-world, scale-free, complete, regular), real examples including web pages, social networks, citation networks.
- Basic properties - degree, clustering, shortest paths, degree distribution.
- Random Graphs - analytic results for phase transitions.
- Growing networks - Price (Barabasi-Albert) model, approximate or exact solutions, hubs, fat-tailed distributions.
- Analysis of Networks - shortest paths, centrality measures, betweenness, PageRank.
- Processes on graphs – broadcasting, eigenvalue centrality, random walks, Markov processes, ranking via PageRank.

Assessment	Assessment Type	Weighting
Four on-line tests	Coursework	10%
Two reports: A complexity and a networks report	Coursework	90%

Learning & Teaching Hours	Independent Study Hours	Placement Hours	Total Hours
57	93	0	150

ECTS Credit	6	CATS Credit	12
Date of introduction	October 2013	Date of Last Revision	May 2020