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Complexity and Networks: Syllabus

Level 3 Physics Course

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This course will be run for the first time in Spring 2014 and so it is still under development. The details given below may change but we anticipate this outline is close to the final form.

1 Practicalities

- This is a **theoretical and numerical** course.
- Level 3 theory course.
- Term 2 (Spring term 2013-14).
- Prerequisites: Level 3 "Statistical Mechanics" (now in term 1).
- 14 Lectures in addition to (around) twelve hours in computing lab.
- Maximum 72 students on course due to computer lab limitations. **First come first served**.
- Assessment: One project (hand in end of term 2), one exam (probably a short mastery style exam).
- Computational examples are likely to be given in the programming language `Python`.
  However work (examples, project etc) can be done in **any** language e.g. `C++`, `MatLab`.
  `Python` is easy to learn and allows for rapid prototyping. The code is easily understood by those with experience in other computer languages making the course examples intelligible by all. `Python` is open source and can be run on without any cost on any computer.

2 Draft Syllabus and setup

With a larger lab based component, lengthy exact solutions in lectures may on occasions be dropped in favour of back-of-the-envelope style derivations. Students would learn the details by programming examples and may need to include theoretical derivations in their project.

2.1 Complexity — 1st half — Kim Christensen

- Criticality – basic properties, examples, emergence of macroscopic behaviour from microscopic rules; quick review of scaling and criticality in equilibrium systems.
- Review examples of non-equilibrium systems in nature displaying complex behaviour such as fluctuations of an observable that are not described by Gaussian statistics.
- Theoretically, we will address the phenomena of complex behaviour in non-equilibrium systems using the framework of simple numerical models.
- Describe qualitatively and quantitatively the concept of self-organised criticality, that is, systems displaying criticality without any external fine-tuning of a control parameter.
- Emphasise the fundamental conceptual difference between scaling in an equilibrium system at a phase transition and a non-equilibrium system displaying self-organised criticality.
- Describe qualitatively and quantitatively the concept of scaling and apply scaling arguments to non-equilibrium systems displaying finite-size scaling.
- Numerical exercise — investigate simple model displaying complexity behaviour.

2.2 Networks — 2nd half – Tim Evans

- 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 — exact results for phase transitions (possibly via approximate derivations).
- Growing networks — Price (Barabasi-Albert) model, approximate or exact solutions, hubs, fat-tailed distributions.
- Analysis of Networks — algorithms for components and shortest paths, defining and measuring centrality measures: degree, in-degree (citation count), betweenness and currents, PageRank.
- Processes on graphs — random walks, Markov processes, ranking via PageRank, epidemiology.
- Numerical exercises — write code to implement one of the algorithms, use to test random graph theorems, use to do open ended investigation of a real network

3 Support and Assessment

- Problem sheets with practical and theoretical exercises to support lectures.
- Computing lab to develop theoretical ideas through applications
- Computing lab to support work on assessed project.
- Project assessed through a report.
- Exam, probably short, mastery style exam.

References

[1] H.Jensen, "Self-organised Criticality", CUP 1998.

[2] K.Christensen and N.Moloney, "Complexity and Criticality", IC Press, 2005.

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[4] M.Newman, "Complex Networks", OUP 2011.

[5] David Easley and Jon Kleinberg, "Networks, Crowds, and Markets: Reasoning About a Highly Connected World" (Cambridge University Press, 2010 but free downloadable copy).

[6] Maarten van Steen "Graph Theory and Complex Networks", 2010 (free download from web site).

[7] Robert Hanneman and Mark Riddle, "Introduction to social network methods", 2005 (free download from web site).