Syllabus for the course "Fundamental ideas of network science"

1. Course Title: Fundamental ideas of network science

2. Lecturer: Prof. Janos Kertesz

3. No. of Credits: 4cr

4. Semester timing of the course: Fall 2012

5.

6. Course Level: MSc/PhD

7. Background and overall aim of the course:

Networks are ubiquitous. Economic trade, social relationships, terrorist organizations or biochemical reactions – all span networks. Network science has gone through a spectacular development during the last decade. The data deluge due to the information communication revolution enabled to study huge networks like the Internet, the WWW, large social networks, communication (e.g., email and mobile call) networks, ecological and biological networks. It turned out that earlier established models did not work and new paradigms were needed. Surprisingly, universal features of the so called complex networks could be identified in spite of the fact that their range of application covers entirely different systems in economy, sociology, biology or computer science. A truly multidisciplinary endeavor started and has resulted in the new science of complex networks.

In this interdisciplinary course students with different backgrounds can learn about the basic concepts including elements of the theory of graphs, dynamics of and on networks as well as about diverse applications. They will get acquainted with important issues of present day research. Only elementary math prerequisites are assumed.

8. The learning outcomes of the course. By successfully absolving the course the students will be able to:

- Recognize the importance of the network approach in their own fields of studies;

- Map out networks from data on complex systems in diverse fields of applications;

- Carry out statistical analysis of complex networks regarding the basic characteristics;

- Measure dynamic properties of processes on networks;

- Attend the more specialized courses for the Network Science Certificate

9. Planned weekly schedule:

Weel	X	1 st lecture	2 nd lecture	Comments
Sept	17-23	Introduction	Percolation	
Sept	24-30	Random graphs	Small world	
Oct	1-7	Scale free networks	Visualizing and measuring	Assignment 1
Oct	8-14	Configuration model	Network growth models	
Oct	15-21	Weighted networks	Local and hierarchical struct	ures
Oct	22-28	Communities	Robustness and vulnerabilit	y Assignment 2
Oct	29-4	Random diffusion	Spreading	
Nov	5-11	Temporal networks	The Internet	Modeling
Nov	12-18	Social networks I	Social networks II	
Nov	19-25	Human mobility	Ecological networks	WP Article
Nov	26-2	Networks in Economy	Project presentation	
Dec	3-9	Project presentation	Perspectives	

Detailed description:

Introduction

The society, the economics or the brain are examples of complex systems as opposed to complicated ones like a Swiss watch. What makes the difference? The importance of emergence. Networks: the scaffold of complexity – a holistic approach. What makes a network? Examples from diverse fields.

Percolation

How does a coffee percolator work and how is this related to networks? Lattices, the simplest networks. Disorder. Percolation, the simplest phase transition. How to characterize the percolation transition? The beauty of fractals. Self-similarity and power laws. Scales and scale freeness.

Random graphs

A little math: some basic notions of graph theory. The old paradigm: Erdös-Rényi (ER) graph and its properties. Percolation transition in the ER model. The non-uniform society and the failure of the ER model. Why to study it?

Small world

How many handshakes away are you from Barack Obama? The Milgram experiment and its contemporary version. "Six degrees of separation." The Small World model. The direct path is not always the shortest.

Scale free networks

Fame and Fortune. Who cites whom in science? The Kevin Bacon game and the Erdös number. The role of hubs and their evolution. Scale freeness and universality. What do the exponents tell us? Exploding moments.

Visualization and measuring

Practical computer tools to visualize networks and to measure most important statistical properties.

Configuration model

The "most random" model with given degree distribution and its properties. General problem of null models. The best map is "on the scale of a mile to the mile" (Lewis Carrol) - different aims of modeling.

Network growth models

The Matthew effect: Rich get richer. Preferential growth. Networks are not static, they result from growth. The Barabási-Albert (BA) model. How hubs make the world small (or even ultra small). How does a newcomer know, who is most popular: Global vs. local growth rules. The problem with clustering and its resolution. Modifications of the BA model.

Weighted networks

Not all links are the same! Natural weight measures: Traffic on the link, intensity of relationship. Topological weights. Generalization of the characteristic quantities to weighted networks. Weighted network models.

Local and hierarchical structures

What is "important"? Graphs and subgraphs. Important subgraphs: motifs. Relation to the function of the network. Weighted motifs. Hierarchical structures. Deterministic models.

Communities

Quarrel in the karate club. The modular structure of complex networks. Community identification from the topology: Local and global methods. Modularity, resolution limit. Overlapping and hierarchical communities.

Robustness and vulnerability

Random failures and intentional attacks. Terrorist networks. The Achilles heel of scale free networks. Universality classes. Big blackouts: Cascading failures. Network of networks.

Random diffusion

The drunkard's walk. The simple case of lattices. The role of disorder. Random walk in a small world. Relaxation to the steady state. Diffusion and communities.

Spreading

The dilemma of vaccination. How do epidemics spread? Simple spreading models. The case of the swine flu: prediction with network theory. Sexually transmitted diseases, the sexual web. Vaccination strategies. Innovation spreading, peer pressure.

Temporal networks

Links are not permanent. Characterization of temporal networks. The bursty character of human behavior. Models of temporal networks.

The Internet

The brief history of the Internet. Its hierarchical organization. Self-organization with constrains. The scale free character of the Internet. Models. The WWW as a network. Characterization of directed networks. Modeling the WWW.

Social networks I

Historical remarks. Data collection. What can we learn from small networks? The different types of social networks. Dyadic, triadic connections. Egocentric networks. Capacity limit of the brain: the Dunbar number. Null models.

Social networks II

A new era in social science: the use of electronic footprints. Email, mobile phone, twit records. Digital communities. Natural weights. The importance of weak ties. The gender and age dependence in close relationships.

Human mobility

Transportation networks. Travel habits and environmental consequences. Data collection: GPS, mobile phones, smart cards. Identification of locations. Mobility statistics. Gravity law and radiation model.

Ecological networks

The food web and its hierarchical structure, ecological pyramid. Material and energy flow. Types of food webs. Ecological networks. Fragility.

Networks in economy

Trade network. Financial relationships. Cascades and the global economic crisis. Similarity networks and portfolio optimization.

10. Suggested reading:

M.E.J. Newman: Networks – An Introduction (Oxford UP, 2010) (Mathematically demanding) M.O. Jackson: Social and Economic Networks (Princeton UP, 2008)

A. Barrat, M. Barthélemy and A. Vespignani: Dynamical Processes on Complex Networks (Cambridge UP, 2008)

Hanneman, Robert A. and Mark Riddle. 2005. Introduction to social network method, online available: http://faculty.ucr.edu/~hanneman/nettext