Scuola Superiore di Catania, ANNO ACCADEMICO 2008-2009

STRUCTURE AND DYNAMICS OF COMPLEX NETWORKS

Vito Latora

"What do metabolic pathways, ecosystems, the World Wide Web, and propagation of HIV have in common? Until a few years ago, the answer would have been "very little": the first two examples are biological and shaped by evolution, the third is a human creation, and the fourth is a mixture of biology and sociological components. However, in the last few years the answer that has emerged is that these systems all share similar network architectures. Seemingly out of nowhere, in the span of a few years, network theory has become one of the most visible pieces of the body of knowledge that can be applied to the description, analysis, and understanding of complex systems. New applications are developed at an ever-increasing rate and the promise for future growth is high. Complex networks is now an essential ingredient in the background of any scientist " [2].

This course is for advanced undergraduates in physics, enginnering, mathematics, biology and computer science, who wants to learn the major ideas developed and the results recently achieved in one of the newest and hottest interdisciplinary research fields. The student will find the main concepts presented in a language which is accessible to a non specialist. He will learn the basic methods of network theory, statistics, nonlinear dynamics and computer science, that allows him to study the structure and the dynamics of complex networks.

The course is divided into four parts. The first two parts are devoted to the characterization of the structural properties of real world networks, and to the development of new network models. It contains topics of graph theory, social networks analysis, statistical physics, molecular biology, urban planning. Part three is on the study of different kinds of dynamical processes that take place over a network. Special emphasis is given to percolation processes and network tolerance to errors and external attacks, cascading failures in infrastructure networks, diffusion of infectious diseases in a population, dynamics of social groups, searching in the World Wide Web. Part four is on collective behaviors, such as synchronization, in networks of dynamical units. In each of the four parts, the theory is supplemented with examples and applications, databases of real world networks, and with numerical algorithms.

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1. STRUCTURE OF COMPLEX NETWORKS I: BASIC CONCEPTS
Graphs and graph theory. Social networks and centrality measures. Degree and eigenvector centrality. Betweenness. Random graphs. Scientific collaboration networks. Erdős and Rényi models. Small-world networks. Six degree of separation and the nervous system of C.elegans. Degree distributions. The World Wide Web. Generalized random graphs. Random graphs with a given degree sequence. The Molloy and Reed criterion. Citation networks and the linear preferential attachment. The Barabási-Albert model. Other models of growing graphs.

2. STRUCTURE OF COMPLEX NETWORKS II: ADVANCED TOPICS
Degree correlations. Joint and conditional probability. Assortative and disassortative networks. Cycles. Motifs. Community structures. Partitions and the Bell formula. Spectral bisection and hierarchical clustering methods. The Girvan-Newman algorithm. The modularity and its optimization. Weighted networks. Edge weight and node strength. The world-wide airplane connection network. Models for weighted networks.

3. PROCESSES ON NETWORKS
The Achille's heel of the Internet. Percolation theory. Critical exponents. The theory of tolerance to random failures and to intentional attacks. P2P networks. Random walks on graphs. Markov chains formalism. Search time and bandwidth. Web search engines. Google and page rank. Routing and congestion in the Internet. Congestion-aware routing strategies. Disease spreading. SIR and SIS model. Homogeneous mixing hypothesis. Epidemic threshold in scale-free networks. Boolean Networks. The yeast cell-cycle network. Evolutionary games on networks. Cooperation and altruism.

4. NETWORKS OF DYNAMICAL UNITS
Networks of coupled maps. Logistic map. Bifurcation diagram and chaos. Geographic spreading of populations. Networks of coupled oscillators. The Kuramoto model. The Millenium bridge. Networks of coupled chaotic systems. The master stability function. Laplacian matrix. Synchronization. Pinning control of networks.

BIBLIOGRAPHY

[1] **Exploring Complex Networks**, S. H. Strogatz, Nature **268**, 268 (2001).
[2] **Complex networks**, L.A.N. Amaral and J.M. Ottino, Eur. Phys. J. B **38**, 147 (2004).
[3] **Statistical Mechanics of Complex Networks**, R. Albert and A.-L. Barabási, Rev. Mod. Phys. **74**, 47 (2002).
[4] **Handbook of Graphs and Networks: From the Genome to the Internet.**, Edited by S. Bornholdt and H. G. Schuster, Wiley-VCH, Germany, 2003.
[5] **Evolution of Networks**, S.N. Dorogovtsev and J.F.F. Mendes, Oxford University Press (2003).
[6] **The Structure and Function of Complex Networks**, M.E.J. Newman, SIAM Review **45**, 167 (2003).
[7] **Evolution and Structure of the Internet: A Statistical Physics Approach**, R. Pastor-Satorras, A. Vespignani, Cambridge University Press, 2004.
[8] **Structure and Dynamics of Complex Networks**, S. Boccaletti, V. Latora, Y. Moreno, M. Chavez, D.-U. Hwang, Phys. Rep. **424**, 175 (2006).
[9] **The Structure and Dynamics of Networks**, M. Newman, A.B. Barabasi, D. J. Watts, Princeton University Press 2006.

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POSSIBLE SCHEDULE (10 Lectures of 3 hours each)

1. Centrality measures
2. Graphs and graph theory
3. Static and growth models.
4. Degree correlations. Motifs. Community structures.
5. **PROF. RUSSO**: Numerical algorithms for graphs
6. Percolation
7. Random Walks and Markov chains. Google and page rank.
8. Epidemic models.
9. **DR. GOMEZ GARDENES**: Evolutionary games on networks. Cooperation and altruism.
10. Networks of dynamical units
11. SEMINAR 1 **DR. FORTUNATO (ISI Torino)**: Scientific Citation Networks
12. SEMINAR 2 **DR. FORTUNATO (ISI Torino)**: Modularity and modules in Complex Networks
13. SEMINAR 3 **DR. FRASCA**: Networks of moving agents

BIBLIOGRAPHY

[1] **Complex networks: methods and applications (VOL I: STRUCTURE)** V. Latora and G. Russo, Springer Verlag, in press by the end of 2009.

[2] **Complex networks: methods and applications (VOL II: DYNAMICS)** S. Boccaletti V. Latora and G. Russo.....a first draft of the manuscript by the end of 2009 ?