PHYS 597A: Graphs and networks in systems biology

Spring 2006
T Th 9:45 - 11:00 am
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Office hours: Monday 2:00 - 4:00 pm

Many complex systems are hard to describe and understand because they are composed of large numbers of elements interacting in a non-ordered way. A good example is cellular biology; diverse cellular components (genes, proteins, enzymes) participate in various reactions and regulatory interactions, forming a robust system. A very useful representation of complex systems is given by graphs (or networks), where we denote the components with nodes and their interactions by edges. The properties of these interaction graphs can then be analyzed by graph theoretical and statistical mechanics methods and this information can lead to important conclusions about the dynamics of the system.

This class will introduce network measures that can be used to describe complex networks as well as models of network topology and dynamics. A special focus will be given to biological networks, and the connections of network theory to systems biology. We will study diverse modeling approaches used in cellular networks such as dynamical models based on mass-action kinetics or boolean logic.

Prerequisites

- MATH 017 (finite mathematics) or similar introduction to probabilities and combinatorics
- MATH 110 (techniques of calculus) or MATH 140B (calculus and biology) or similar introduction to calculus
- BIOL 011 or similar introductory biology
- BMB 211 or similar elementary biochemistry

These are not absolute prerequisites in the sense that the necessary background can be obtained by some extra reading during the class. Supporting reading materials will be available upon request.

Grades

Grades for this class will be based on homework assignments (30%) and work on a project (70%). Weekly homework will include exercises and critical reading assignments. There will be 10 homework assignments, graded on a 1-10 basis. Project topics can be selected from a list of suggestions or can be based on the research interests of participants. Work on projects will continue throughout the semester, and more refined versions of a report will be due monthly. In addition to the reports, each participant will give a 20 minute project presentation during the last 3 classes. The final papers will be due on the last day of classes (Apr. 26), at 5 pm.

Main topics covered

1. elements of graph theory: node degree, distances between nodes, clustering, node betweenness, subgraphs, directed graphs
2. introduction to cellular networks: gene regulatory networks, signal transduction networks, metabolic networks
3. random graph theory
4. network models and theory: lattices, small-world networks, scale-free networks, evolving networks
5. network robustness and vulnerability
6. percolation and flow processes on networks
7. modeling reaction networks: elements of chemical kinetics
8. signal transduction network models: lambda phage development, bacterial chemotaxis, quorum sensing, cell cycle
9. modeling gene regulatory networks using continuous and discrete dynamics

Important references

There is no textbook for this class; the following review articles will be provided as part of a course pack.

1. Réka Albert and Albert-László Barabási, Statistical mechanics of complex networks, Reviews of Modern Physics 74, 47-97 (2002).

2. Mark E. J. Newman, The structure and function of complex networks, SIAM Review 45, 167-256 (2003).

3. Réka Albert, Scale-free networks in cell biology, Journal of Cell Science 118, 4947-4957 (2005)

4. Harley H. McAdams and Adam Arkin, Simulation of prokariotic genetic circuits, Annual Review of Biophysics and Biomolecular Structure 27, 199-224 (1998).

5. John J. Tyson, Katherine C. Chen and Béla Novák, Sniffers, buzzers, toggles and blinkers: dynamics of regulatory and signaling pathways in the cell, Current Opinion in Cell Biology 15, 221-231 (2003).

6. Réka Albert, Boolean modeling of genetic regulatory networks, in: Complex Networks, E. Ben-Naim, H. Frauenfelder and Z. Toroczkai (eds.), Springer Verlag 2004.

Reference books

1. Albert-László Barabási, Linked: The New Science of Networks (2002).
2. Duncan J. Watts, Six Degrees: the Science of a Connected Age (2003).
3. Stefan Bornholdt, Heinz G. Schuster (eds.), Handbook of Graphs and Networks: from the Genome to the Internet (2002).
4. Eli Ben-Naim, Hans Frauenfelder, Zoltan Toroczkai (eds.), Complex Networks (2004).
5. James M. Bower and Hamid Bolouri (eds.), Computational Modeling of Genetic and Biochemical Networks (2001).

Table 1: Preliminary syllabus

Week	Date	Tuesday	Thursday
1	1/9	Introduction	Basic graph measures
2	1/16	Basic graph measures Homework 1 due	Topology of real networks
3	1/23	Topology of cellular networks Homework 2 due	Random graph theory
4	1/30	Network algorithms Homework 3 due	Network algorithms
5	2/6	Generalized random graphs Homework 4 due	Watts-Strogatz model
6	2/13	Barabási-Albert model Homework 5 due	Evolving networks
7	2/20	Evolving cellular networks Homework 6 due	Network resilience
8	2/27	Network resilience Homework 7 due	Resilience of cellular networks
9	3/6	No class	No class
10	3/13	Spreading processes Abstract due	Epidemic models
11	3/20	Dynamics of cellular networks Homework 8 due	Chemical kinetics
12	3/27	Reaction network dynamics Homework 9 due	Signal transduction- continuous
13	4/3	Signal transduction -continuous Preliminary paper due	Gene regulation - continuous
14	4/10	Random boolean models Homework 10 due	Gene reg. netw. - boolean
15	4/17	Current modeling literature	Project presentations
16	4/24	Project presentations	Project presentations Papers due at 5 pm