Many complex interacting systems can be described by networks (graphs)

Cellular interaction networks: signal transduction, gene regulation, metabolism

Graph measures provide information on interaction graphs

Network models explain and predict properties of graph classes

Network topology influences network robustness and the dynamics of flows

Dynamics of cellular networks

Modeling cellular networks
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<th>Week</th>
<th>Date</th>
<th>Tuesday</th>
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<tr>
<td>1</td>
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<td>Introduction</td>
<td>Basic graph measures</td>
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<td>Topology of real networks</td>
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<td>Signal transduction - continuous</td>
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<td>Papers due at 5 pm</td>
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Network (graph): a set of nodes connected by edges
Nodes (vertices): A, B, C...
Edges (links): AC, BC, CD, CJ ...
The spatial arrangement of nodes and edges does not matter.
Can be augmented by additional node and edge information.
Many complex systems have an underlying network topology

**Internet, router level**
- nodes: routers, hosts
- edges: wires, cables
- undirected

**Internet, domain level**
- nodes: domains (ISPs)
- edges: gateway protocols
- undirected
Map of the Internet, colored by IP addresses, by William R. Cheswick
The World Wide Web is the higher level of the Internet

- nodes: webpages
- edges: hyperlinks - directed

The WWW is the largest network with topological information available.

The size of the WWW has surpassed 1 billion nodes, it is increasing.
Search engines can index only a small percentage of the Web.

Structure of a website

Food webs are examples of directed networks.
Social systems can be regarded as networks

- nodes: individuals
- edges: social interaction
- “six degrees of separation”: the social distance between people is small

**actor collaboration**

- nodes: actors
- edges: cast jointly

**scientific coauthorship**

- nodes: scientists
- edges: wrote a paper

Q: Can you propose an alternative network based on actor/movie or author/paper information?
Dating network in a high-school

Blue: boys
Pink: girls
Collaborations at the Santa Fe Institute

Color: inferred node clustering

Q: what do you think is the basic idea of the clustering algorithm?
Spread of disease in a social network

- black: diseased
- pink: infected
- green: healthy

Q: Where do you think the network mapping started?
Network of free semantic associations

Map of yeast protein-protein interactions, by Hawoong Jeong

Red: essential protein
Yellow: growth-affecting protein
Green: non-essential protein
Cell metabolism forms a network of reactions

Metabolism: sum of chemical processes by which energy is stored or released.
Metabolic pathway: sequence of enzyme reactions.

nodes: metabolites
edges: reactions

Different representations possible.
Cellular processes form networks on many levels

**Reaction networks**
- nodes: substrates, enzymes
- edges: chemical reactions

**Regulatory networks**
- nodes: genes, proteins
- edges: translation → or regulation ↔, activating or inhibiting
Two-component signal transduction pathway

E. Coli chemotaxis network
Interaction network of the Drosophila segment polarity genes
ABA signal transduction network

Red: enzymes
Blue: transport
Orange: small molecules
Green: sign. transd. proteins
Black points: unknown intermediary nodes
Purple edges: inferences
Life’s complexity pyramid

Why study networks?

• It is increasingly recognized that complex systems cannot be described in a reductionist view.
• Understanding the behavior of such systems starts with understanding the topology of the corresponding network.
• Topological information is fundamental in constructing realistic models for the function of the network.

• Network topology related questions:
  How can we quantitatively describe large networks?

  How did networks get to be the way they are?

  What are the consequences of a specific network organization?