Networks, networks everywhere

- Network infrastructure, social networking

- Network - a tool for understanding complex systems

- Many non-identical elements connected by diverse interactions
- 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

- Understand emergent properties – synchronization, phase transitions, homeostasis
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<th>Week</th>
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<td>1</td>
<td>1/15</td>
<td>Introduction</td>
<td>Basic graph measures</td>
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<td>1/22</td>
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Definition of graphs (networks)

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, wireless

Q: Which edges are static and which change?

Internet, domain level
- nodes: domains (ISPs)
- edges: gateway protocols
- Undirected

Q: What is the nature of edges?
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 10 billion nodes, it is increasing.
Search engines can index only a small percentage of the Web.
Structure of a website

Food webs describe the energy flow within species

nodes: species
edges: predator-prey relationship
directed edges
process: nutrient flow
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

Q: does it surprise you that the network is connected?
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

Based on the University of South Florida Word Association, Rhyme and Word Fragment Norms
Many non-identical elements, diverse interactions
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
A GENE REGULATORY NETWORK

INPUT
signal A
receptor proteins
cascade of interacting
kinase proteins or other
molecules
inactive transcription factor A
active transcription factor A
output mRNA
output protein
cell functions

INPUT
signal B
receptor proteins
inactive transcription factor B
active transcription factor B
inhibitory factor

DNA
cis-regulatory
DNA sequence
elements
RNA polymerase
target gene

OUTPUT
protein

feedbacks
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-related questions:
  How do we determine or infer network topology?

  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?