Theory and Applications of Complex Networks

Class One

College of the Atlantic

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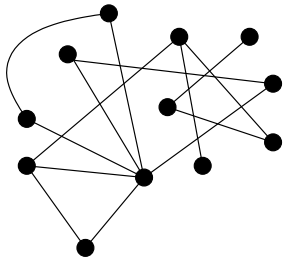
1. What is a network?
2. Many examples
3. Many questions

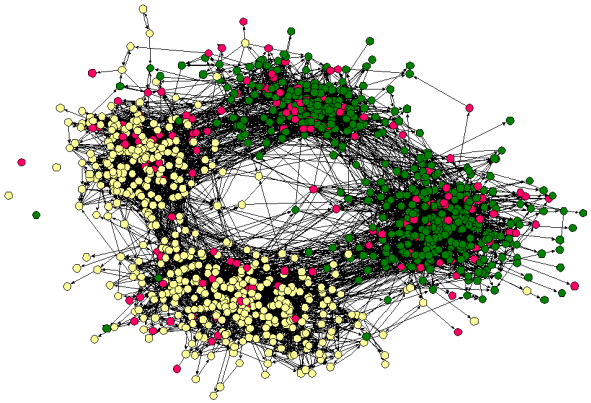
What is a Network?

1. A collection of **nodes**
2. A collection of **edges** connecting nodes



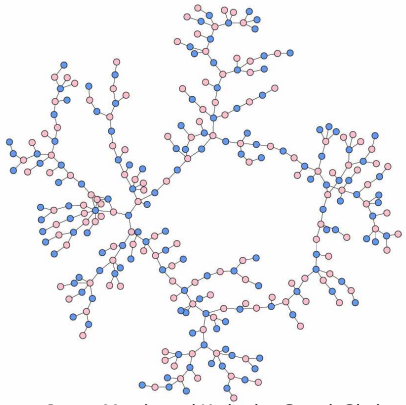
- A network model treats all nodes and links the same
- In a picture of a network, the spatial location of nodes is arbitrary
- Networks are abstractions of connection and relation
- Networks have been used to model a vast array of phenomena

Network Example 1: High School Friendships



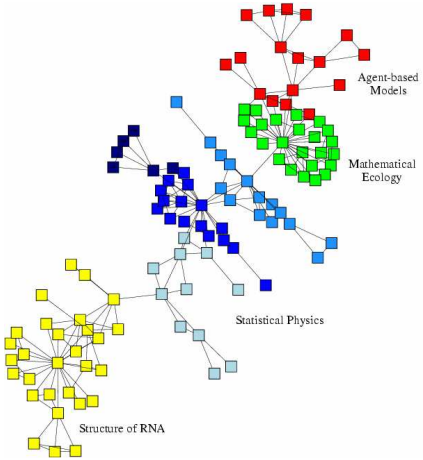
- Nodes = Students, Links = Friendships, Color = Race
- Data: J. Moody, Race, school integration, and friendship segregation in America, *American Journal of Sociology* 107, 679-716 (2001).
- Figure: M.E.J. Newman, The structure and function of complex networks, *SIAM Review* 45, 167-256 (2003). www-personal.umich.edu/~mejn/networks/

Network Example 1.5: High School Dating Networks



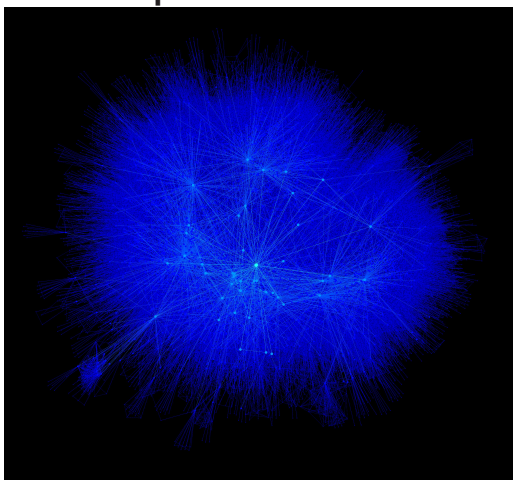
- Data: Peter S. Bearman, James Moody, and Katherine Stovel, Chains of affection: The structure of adolescent romantic and sexual networks, American Journal of Sociology 110, 44-91 (2004).
- Figure: M.E.J. Newman, The structure and function of complex networks, *SIAM Review* 45, 167-256 (2003). www-personal.umich.edu/~mejn/networks/

Network Example 2: Interdisciplinary Collaborations



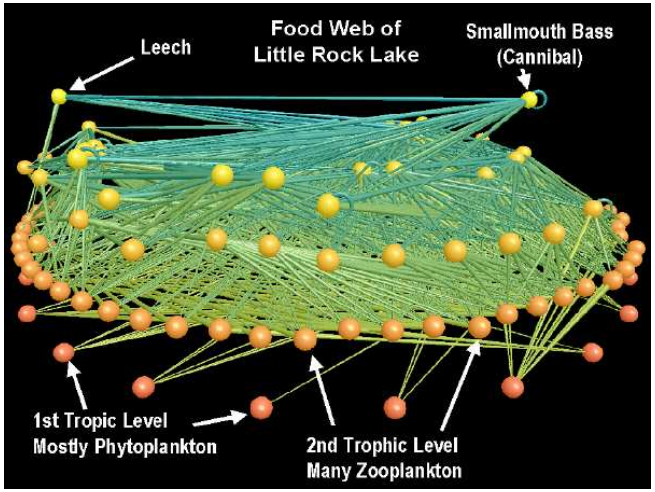
- Nodes = Researchers, Links indicate that the researchers have co-authored one or more papers.
- Figure: M. Girvan and M. E. J. Newman, Community structure in social and biological networks, Proc. Natl. Acad. Sci. USA 99, 8271-8276 (2002).

Network Example 3: Online Social Network



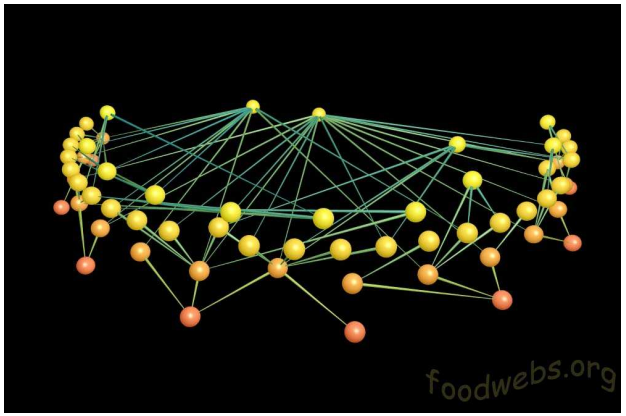
- Nodes = Accounts (47,471) on Friendster, Links (432,420) indicate that accounts are friends.
- Figure: Jeffrey Heer. `http://www.cs.berkeley.edu/~jheer/socialnet/`

Network Example 4: Food Webs



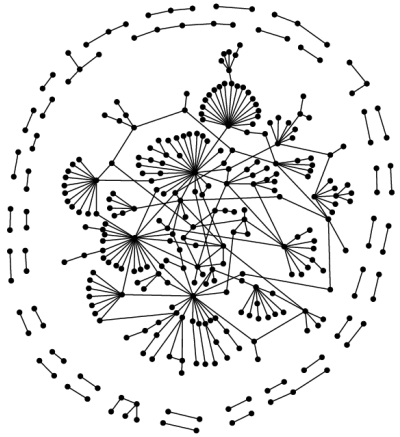
- Image produced with FoodWeb3D, written by R.J. Williams and provided by the Pacific Ecoinformatics and Computational Ecology Lab (www.foodwebs.org, Yoon et al. 2004).

Network Example 5: Food Webs



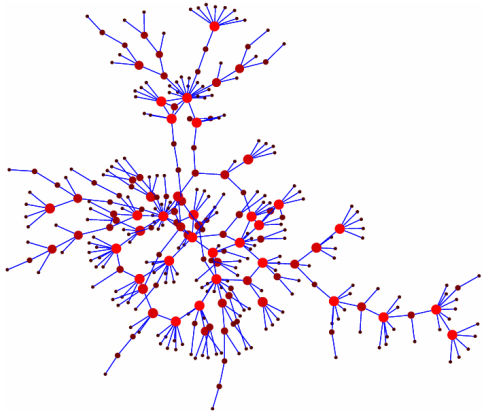
- This is the foodweb for a UK grasslands.
- Image produced with FoodWeb3D, written by R.J. Williams and provided by the Pacific Ecoinformatics and Computational Ecology Lab (www.foodwebs.org, Yoon et al. 2004).

Network Example 6: Protein Interaction Networks



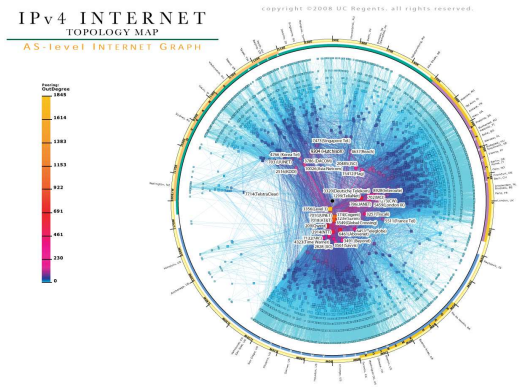
- Nodes = proteins in yeast nucleus. Links indicate interactions.
- Sergei Maslov and Kim Sneppen, Specificity and stability in topology of protein networks, Science 296, 910-913 (2002). `http://arxiv.org/abs/cond-mat/0205380`

Network Example 7: Sexual Contacts



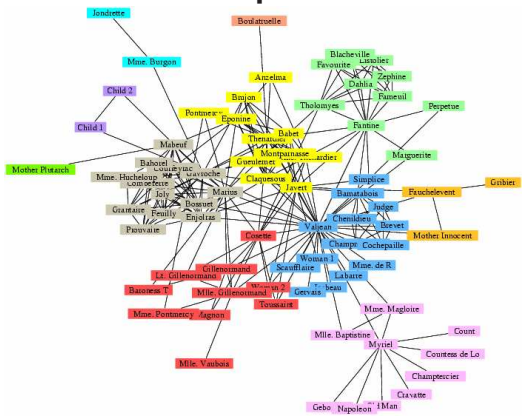
- Figure source: M.E.J. Newman, The structure and function of complex networks, SIAM Review 45, 167-256 (2003).
- Data from: Potterat et al,, Risk network structure in the early epidemic phase of HIV transmission in Colorado Springs, Sexually Transmitted Infections 78, i159-i163 (2002).

Network Example 8: The Internet



- Figure source: `http://www.caida.org/research/topology/as_core_network/`.
- Figure includes almost 5 million IP addresses.

Network Example 9: Literature



- Notes = characters in Les Miserables. Links indicate two characters appeared in the same scene.
- Figure source M.E.J. Newman and M. Girvan, Finding and evaluating community structure in networks, Physical Review E 69, 026113 (2004).

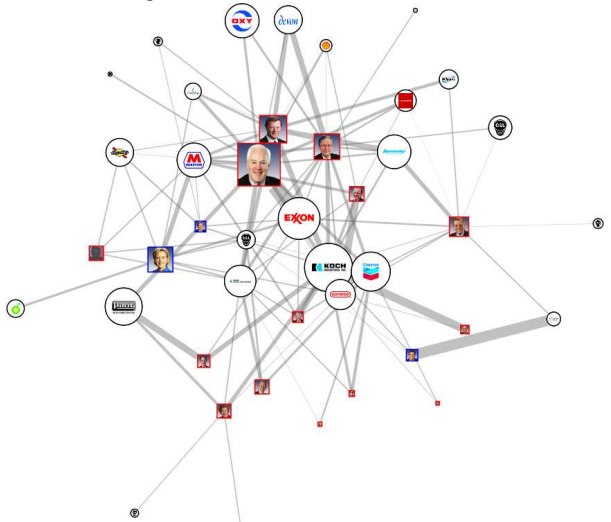
Network Example 10: Transportation Networks: Roads

- U.S. interstate highway map. Source:
  `http://www.fhwa.dot.gov/planning/nhs/`.

Network Example 11: Transportation Networks: Airlines

- United airlines U.S. route map.
  `http://www.united.com/page/article/0,6722,1024,00.html`.

Network Example 12: Politics and Sustainability(!)



- Links are senators or corporations. `http://oilmoney.priceofoil.org/`.

Network Questions: Structural

Given a network, there are a number of structural questions we may ask:

1. How many connections does the average node have?
2. Are some nodes more connected than others?
3. Is the entire network connected?
4. On average, how many links are there between nodes?
5. Are there clusters or groupings within which the connections are particularly strong?
6. *What is the best way to characterize a complex network?*
7. *How can we tell if two networks are "different"?*
8. *Are there useful ways of classifying or categorizing networks?*

Deeper, bigger questions are in *italics*.

Network Questions: Communities

1. Are there clusters or groupings within which the connections are particularly strong?
2. What is the best way to discover communities, especially in large networks?
3. *How can we tell if these communities are statistically significant?*
4. *What do these clusters tell us in specific applications?*

Network Questions: Dynamics *of*

Things are the way they are because they got that way. (Richard Levins.)

1. How can we model the growth of networks?
2. What are the important features of networks that our models should capture?
3. Are there “universal” models of network growth? What details matter and what details don’t?
4. *To what extent are these models appropriate null models for statistical inference?*
5. *What’s the deal with power laws, anyway?*

Network Questions: Dynamics *on*

1. How do diseases/computer viruses/innovations/rumors/revolutions propagate on networks?
2. What properties of networks are relevant to the answer of the above question?
3. If you wanted to prevent (or encourage) spread of something on a network, what should you do?
4. What types of networks are robust to random attack or failure?
5. What types of networks are robust to directed attack?
6. *How are dynamics of and dynamics on coupled?*

Network Questions: Algorithms

1. What types of networks are searchable or navigable?
2. What are good ways to visualize complex networks?
3. How does google page rank work?
4. If the internet were to double in size, would it still work?

There are also many domain-specific questions:

1. Are networks a sensible way to think about gene regulation or protein interactions or food webs?
2. What can social networks tell us about how people interact and form communities and make friends and enemies?
3. Lots and lots of other theoretical and methodological questions...
4. What else can be viewed as a network? Many applications await.

Network Questions: Outlook

1. Advances in available data, computing speed, and algorithms have made it possible to apply network analysis to a vast and growing number of phenomena.
2. This means that there is lots of exciting, novel work being done.
3. This work is a mixture of awesome, exploratory, misleading, irrelevant, relevant, fascinating, ground-breaking, important, and just plain wrong.
4. It is relatively easy to fool oneself into seeing thing that aren't there when analyzing networks. (This is the case with almost anything, not just networks.)
5. For networks, how can we be more careful and scientific, and not just descriptive and empirical?