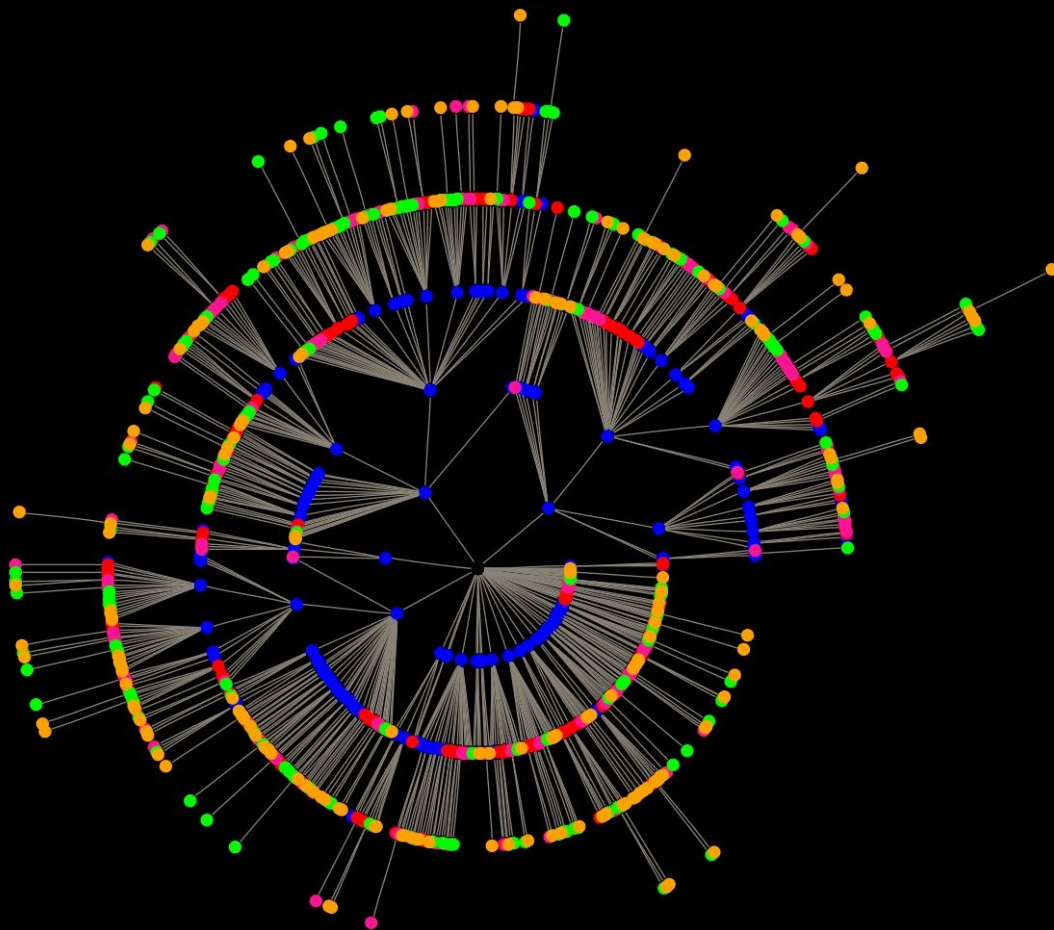
“Tipping Points and Networks of Interaction”



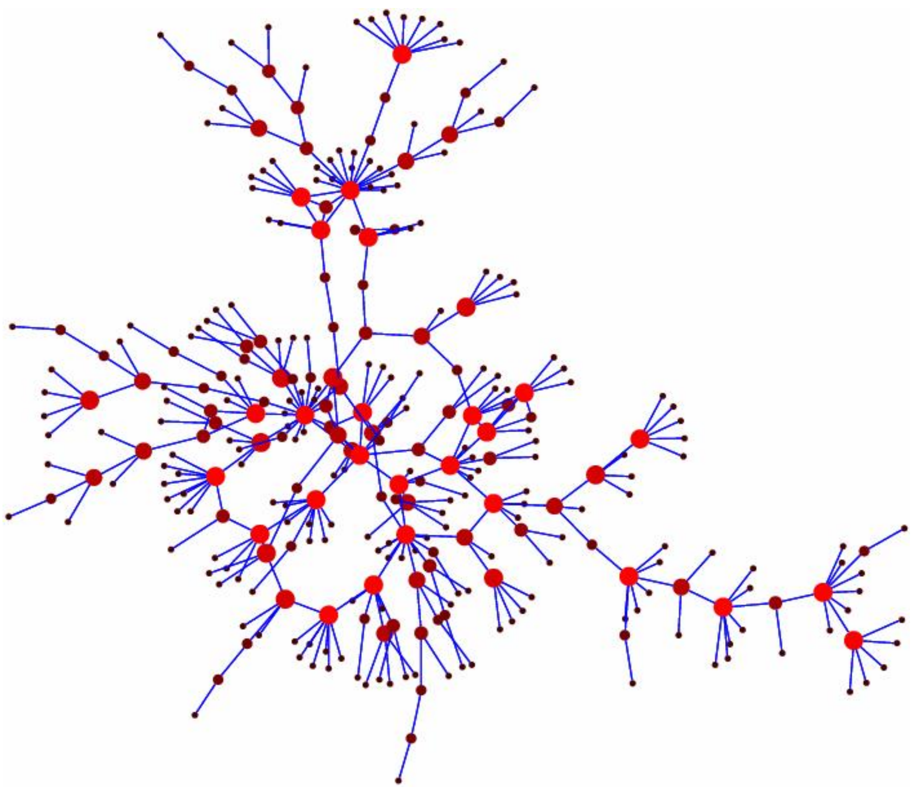
Raissa D’Souza **UC Davis**

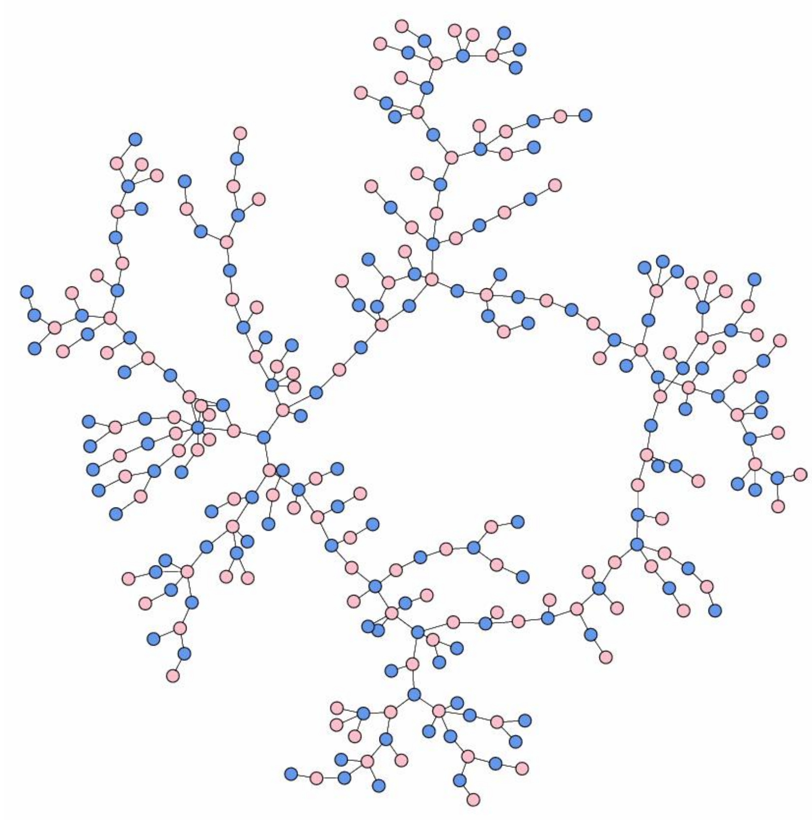
Dept of Mechanical and Aeronautical Eng.

Center for Computational Science and Eng.

Santa Fe Institute

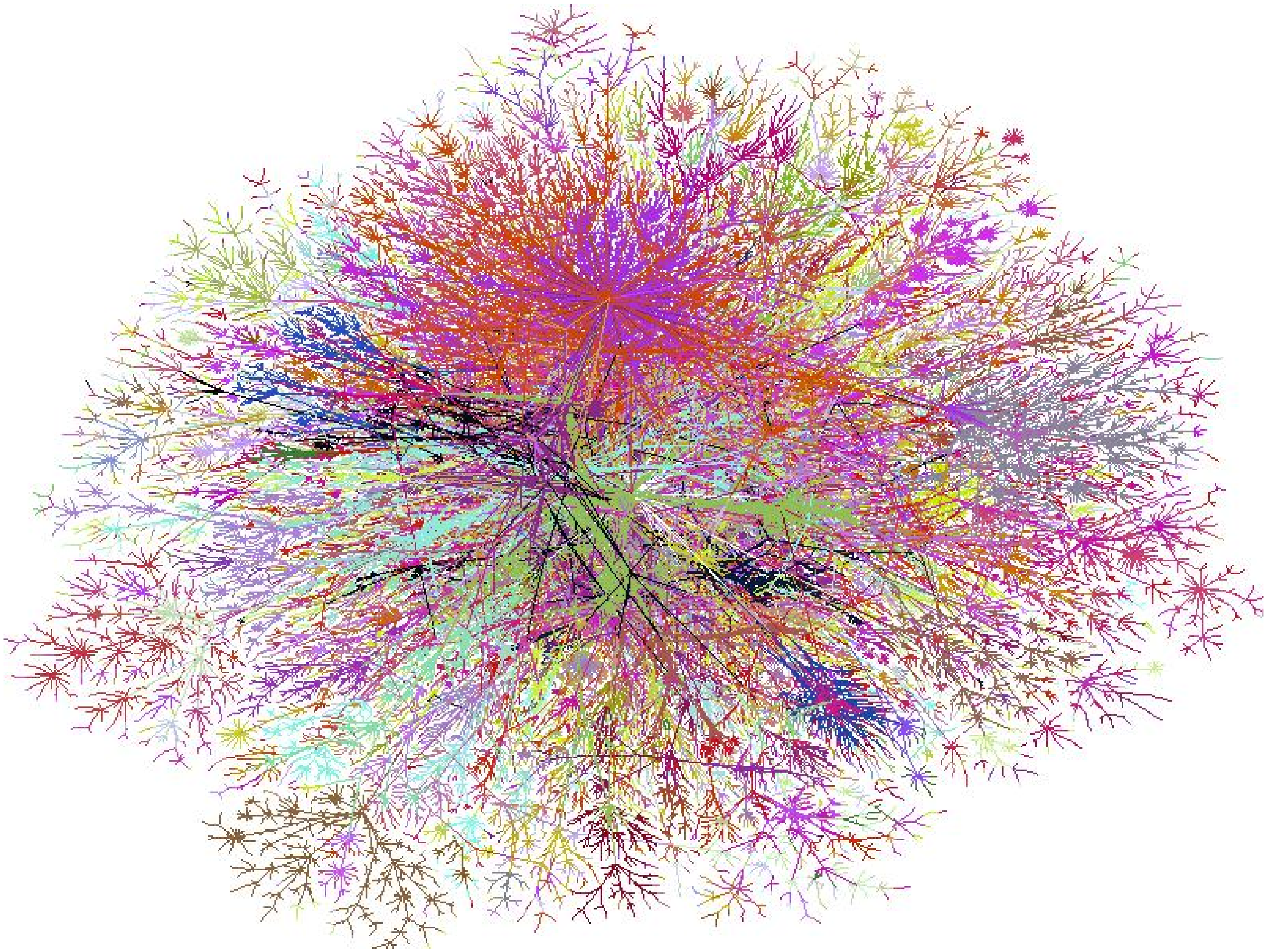
Example social networks
(Immunology; viral marketing)





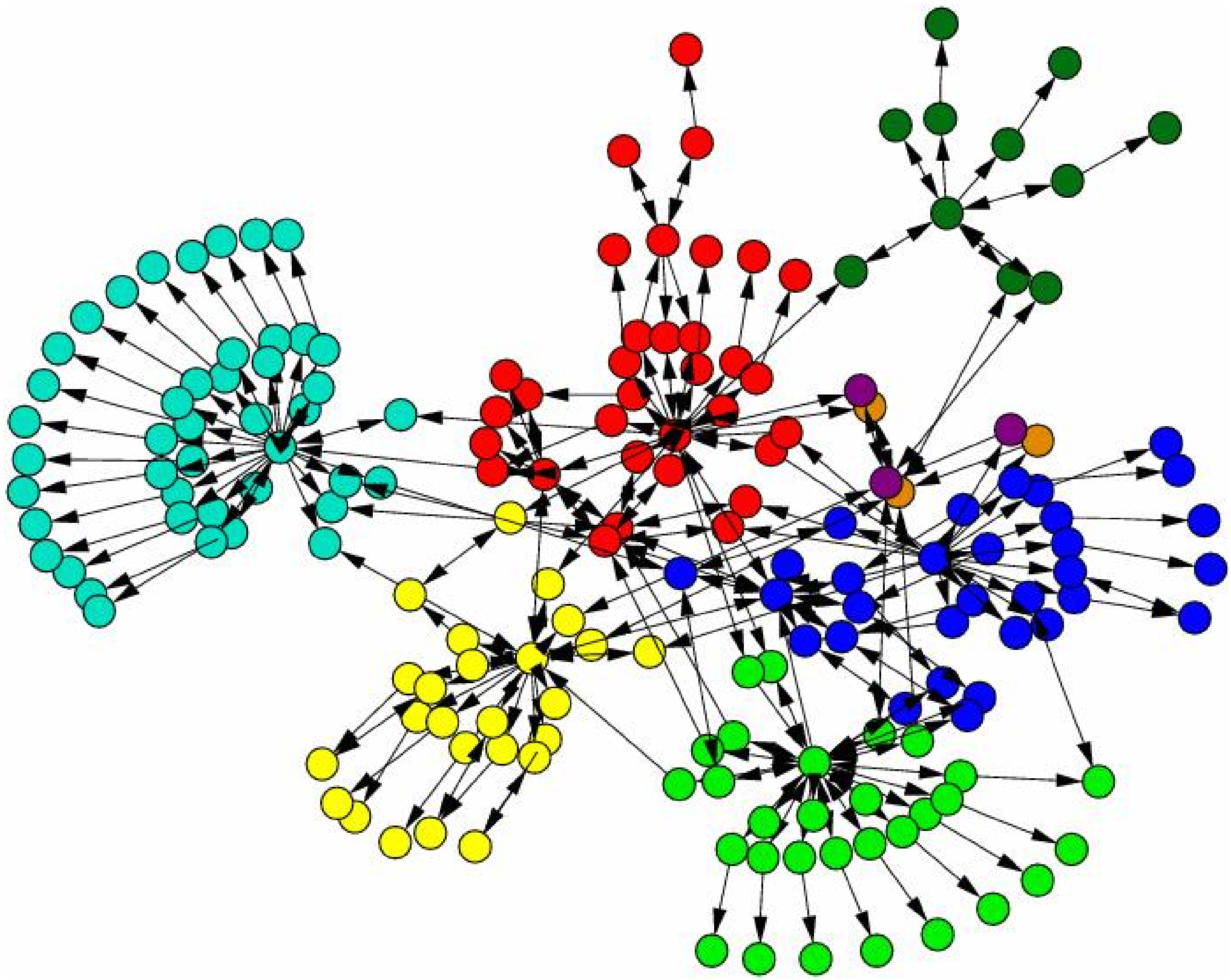
M. E. J. Newman

The Internet
(Robustness to failure; optimizing future growth; testing protocols on sample topologies)



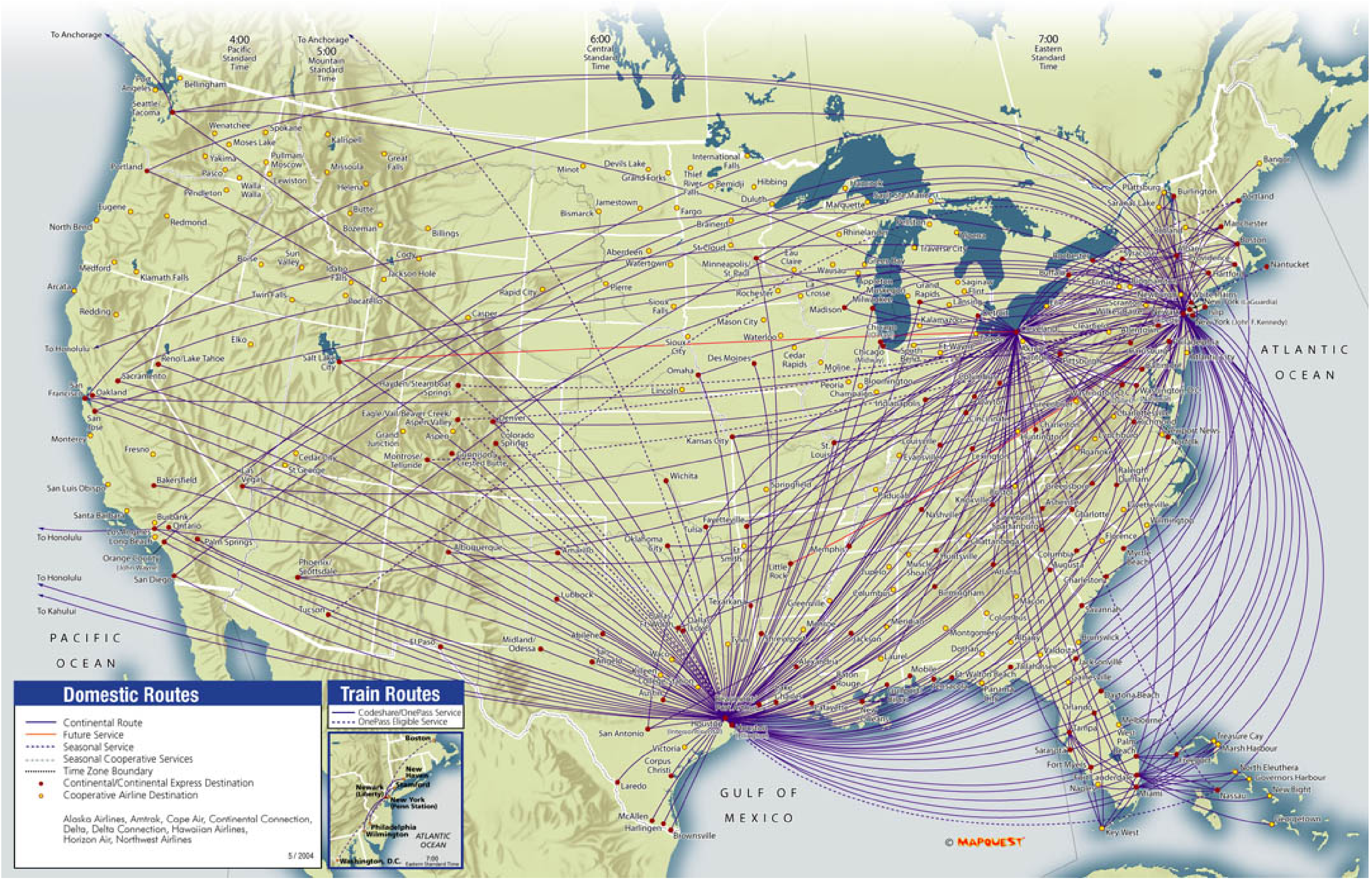
H. Burch and B. Cheswick

A typical web domain
(Web search/organization and growth centralized vs. decentralized protocols)



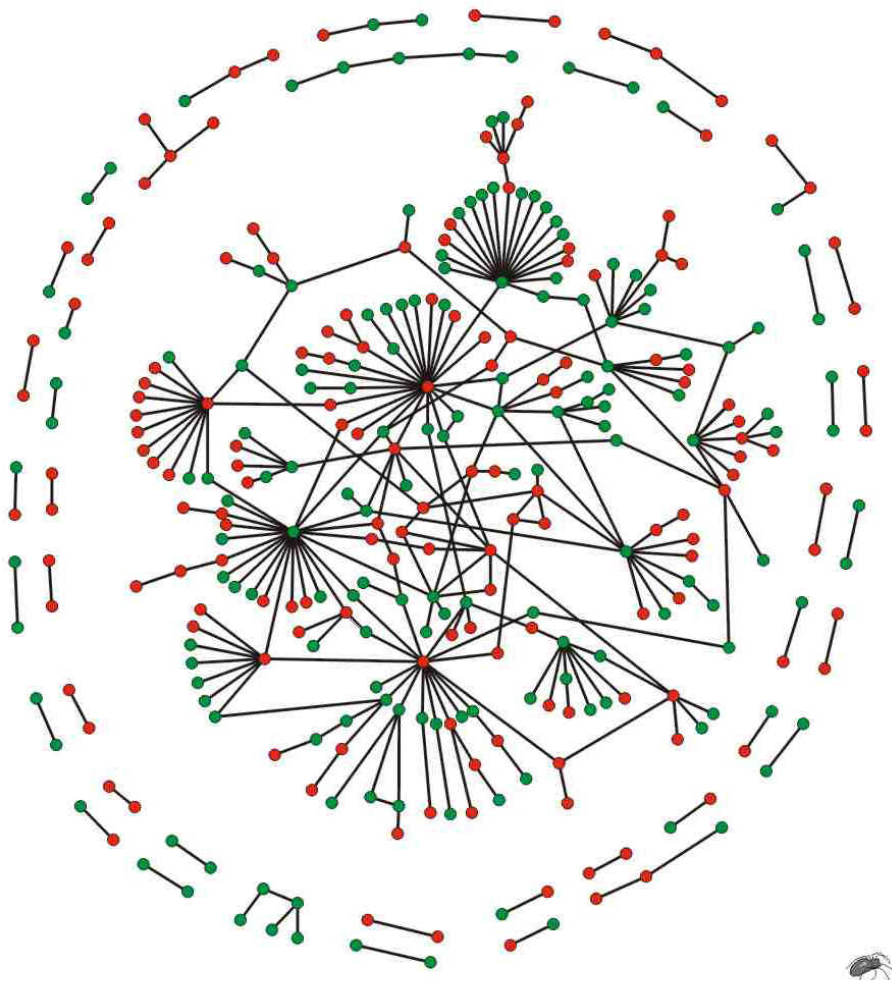
M. E. J. Newman

The airline network
(Optimization; dynamic external demands)



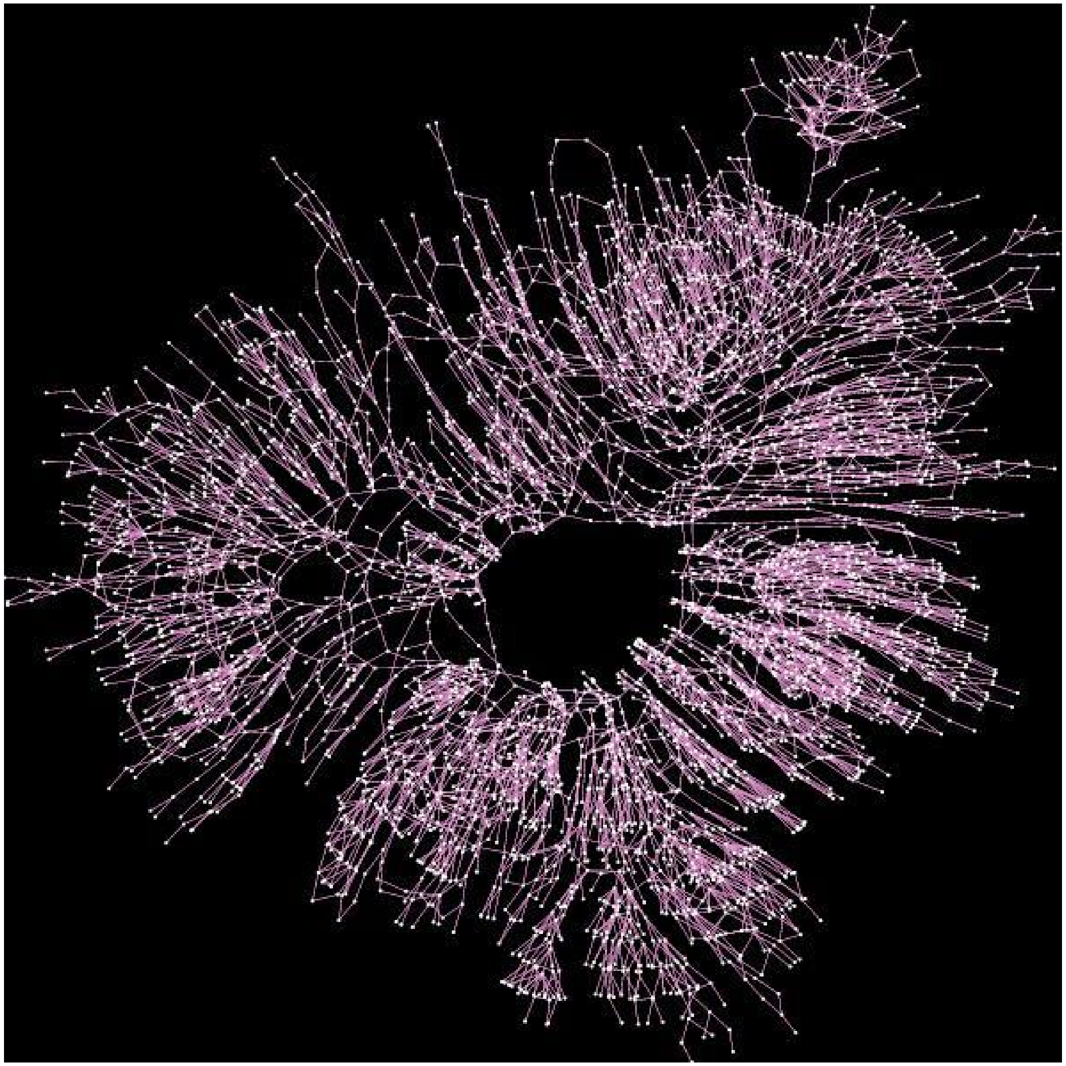
Continental Airlines

Yeast protein signaling network
(Control mechanisms in biology; drug design)



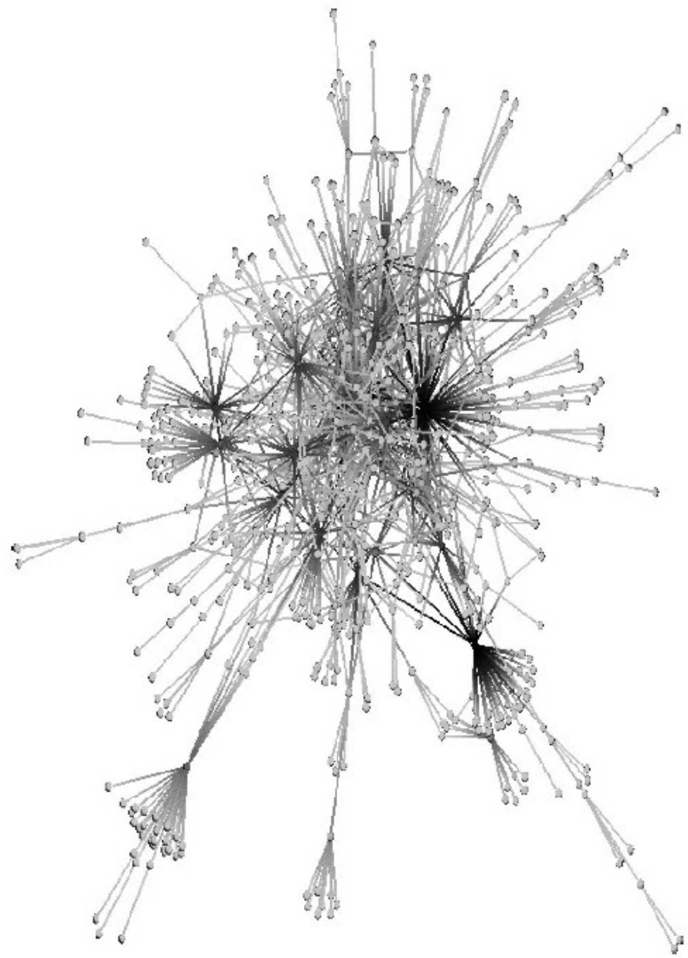
S. Masloc and K. Sneppen

The power grid
(Mitigating failure; Distributed sources)



M. E. J. Newman

Software call graph
(Highly evolveable and robust to mutation)
Open-source software as a “systems” paradigm.



Chris Myers

Physical, Biological, Social, Engineered Networks

Why do networks exist?

- More efficient control, esp through hierarchy?
- Robustness to noise, fluctuations, failures?
- Can we learn function from structure?
- Can we apply these lessons to engineered systems?

  – Would a modern power grid look like the one we have?

  – How do we build a coherent distributed energy system integrating solar, wind, hydropower, bio-diesel, hydrogen, etc.

Studying each network individually (for now)

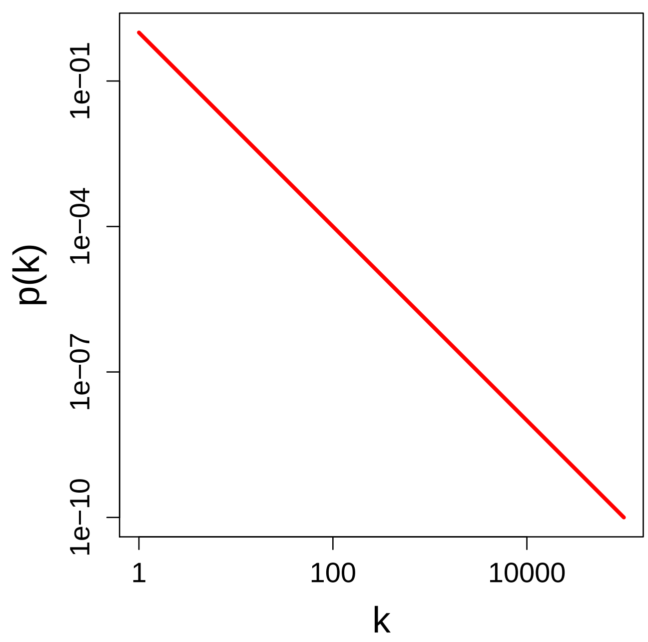
- Topology (Physics – “scale-free”, “small-world”).
- Information flow and search (Computer Science – Page Rank, HITs).
- Still missing: connecting form and function

Topology

- Almost every real-world network studied exhibits high degree of heterogeneity in the degree of nodes.
- Some portion of the distribution is a “power law”.

$$p_k \sim k^{-\gamma}$$

$$\ln p_k \sim -\gamma \ln k$$

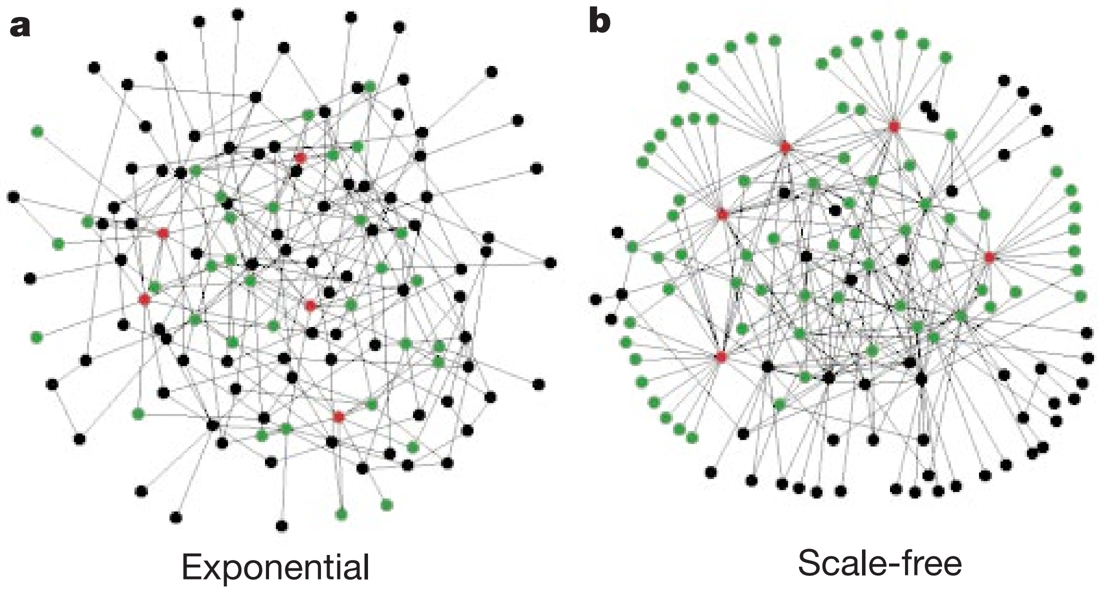


Power laws observed

- Popularity of web pages: $N_k \sim k^{-1}$
- Number of peering relations amongst Internet Service Providers.
- Number of interaction of proteins.
- Rank of city sizes ("Zipf's Law"): $N_k \sim k^{-1}$
- Pareto, 1906. Observed that twenty percent of the population owned eighty percent of the property in Italy ("the 80-20 rule").

Comparing Power Law and Random Graphs

Albert, Jeong and Barabasi, Nature, **406** (27) 2000.

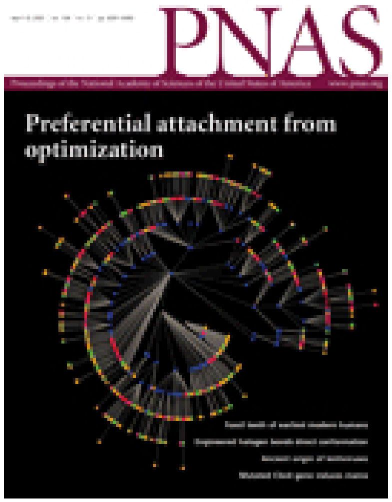


N=130, E=215, Red five highest degree nodes; Green their neighbors.

- Exp has 27% of green nodes, SF has 60%.
- PLRG: Connectivity extremely robust to random failure.
- PLRG: Connectivity extremely fragile to targeted attack (removal of highest degree nodes).

Mechanisms for Power Laws

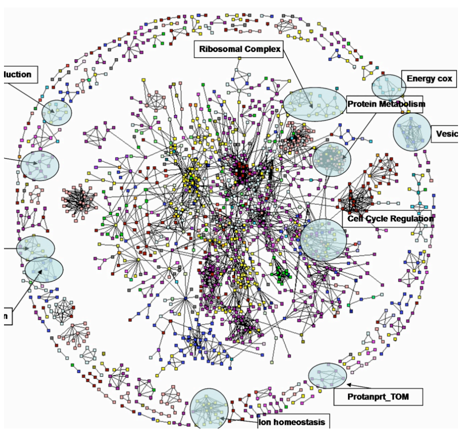
- Preferential Attachment:
  - Polya (1923), Zipf (1949), Simon (1955 – “The rich get richer”)
  - Barabási and Albert, *Science* **286**, 1999.
- Optimization:
  - Mandelbrot (1953)
  - D’Souza, Borgs, Chayes, Berger, Kleinberg, *PNAS* **104**, 2007



All these networks interact!
(Can't study in isolation)

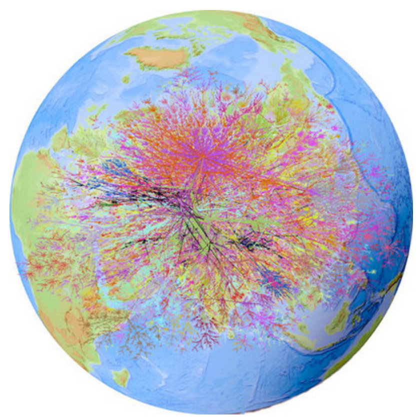
Networks:

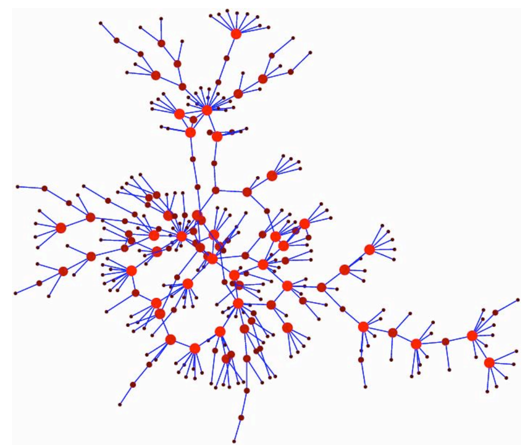
Transportation Networks/ Power grid
(distribution/ collection networks)



Biological networks
- protein interaction
- genetic regulation
- drug design

Computer networks





Social networks
- Immunology
- Information
- Commerce

Example: Consider the spread of the avian flu

Occurs on a dynamic network with multiple length and time scales:

- Long length exchanges of the virus strains:
  – between migrating flocks,
  – between people flying on airplanes.
- Short length (local) exchanges of the virus strains.
- Exchange of additional information each interaction (health warnings, weather patterns, etc.) that influence future connectivity of network.
- Self-organization

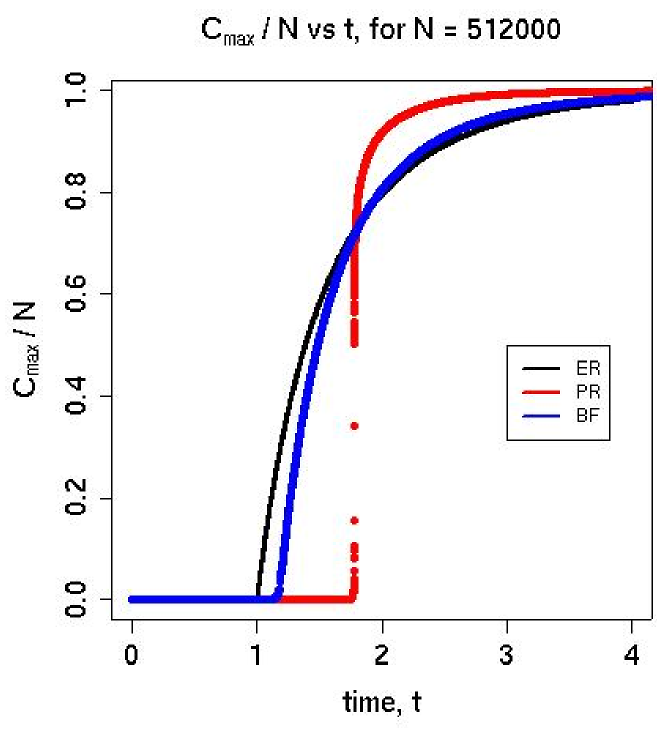
Phase transitions (i.e., "Tipping Points")

An abrupt sudden change in one or more physical properties, resulting from a small change in a external control parameter. Examples from physical systems:

- Magnetization
- Superconductivity
- Liquid/Gas
- Bose-Einstein condensation

Phase transition in connectivity of random graph

- Start with N isolated nodes. Choose two nodes at random, which are not yet connected, add an edge between them.
- Edge $N/2$ is "critical".
- Add some edges get a **giant component**. Remove some edges, destroy connectivity.

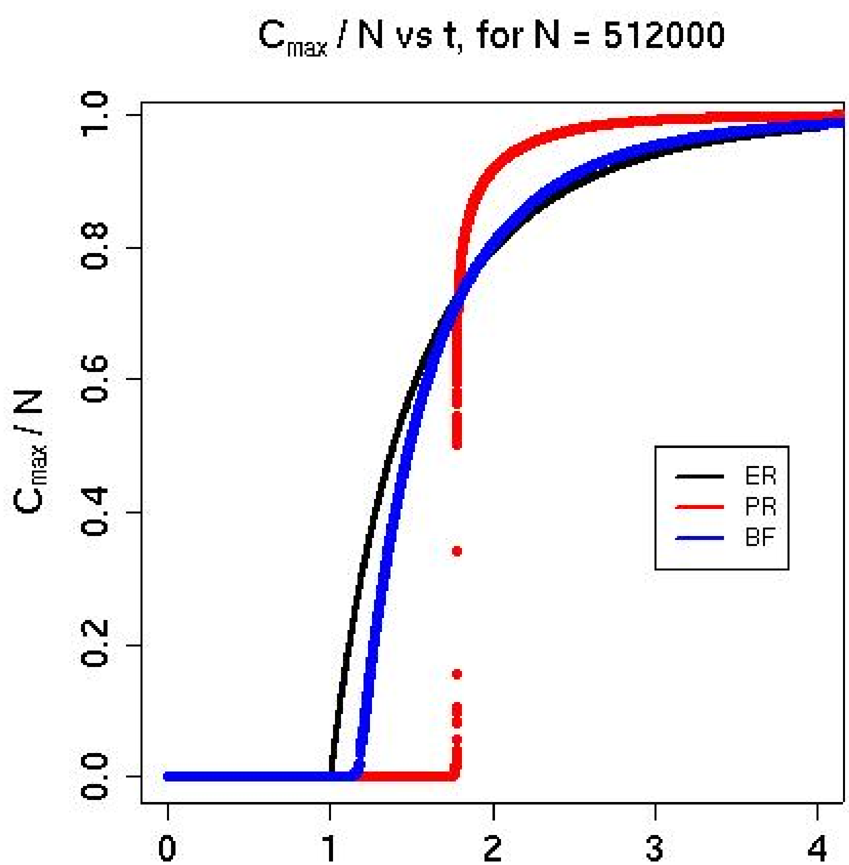


R.D., Achlioptas, Spencer: Control of transitions.

Is connectivity a good thing?

Self-organization can alter Phase transitions

- Choose two candidate edges at random.
- Use local property to decide which one of the two to add to the growing graph.

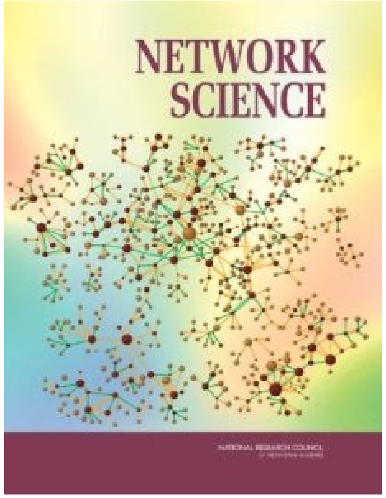


Integrating it all together

- Over the past 8 years, a science of networks is emerging.
  (And the SFI researchers (15+) have been leading the efforts)

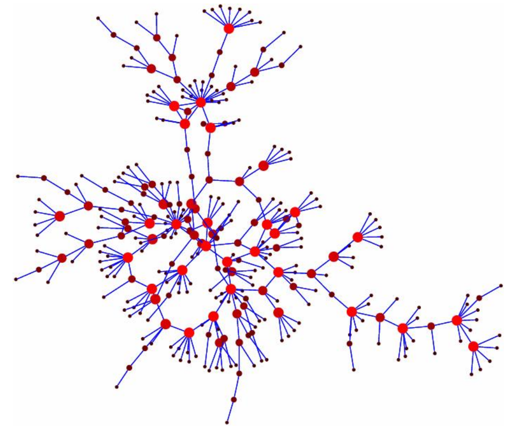
- Learning about *activity* and *topology* of individual networks.

- Natn Acam Sciences/Natn Research Council Study (2005)



"all our modern critical infrastructure relies on networks... too much emphasis on specific applications/jargon/disciplinary stovepipes... need a cross-cutting science of networks... Research for the 21st century"

New UC Davis course
"Network Theory and Applications"



- Grad students, Postdocs, Faculty from across campus.
- General techniques:

  Linear algebra, Simple differential eqns,
  Degree distributions/statistics, Visualization tools.

- Applications:
  - Immunology/contact processes
  - Social networks
  - Biological networks
  - Design of transportation/distribution networks
    (modern power grid)
  - Energy networks
  - WWW Search (Probability and algorithms, distributed computing)

Our modern infrastructure relies fundamentally on layered, interacting, complex networks

- Though each network might scale, each has own unique characteristic length and time scales.
- Robustness in one layer may be vulnerability in another.
- This layering can blurr the definition of what is a node or an edge.