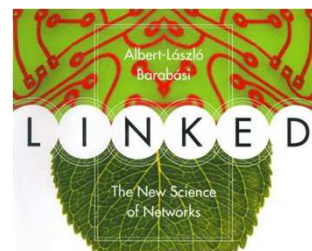


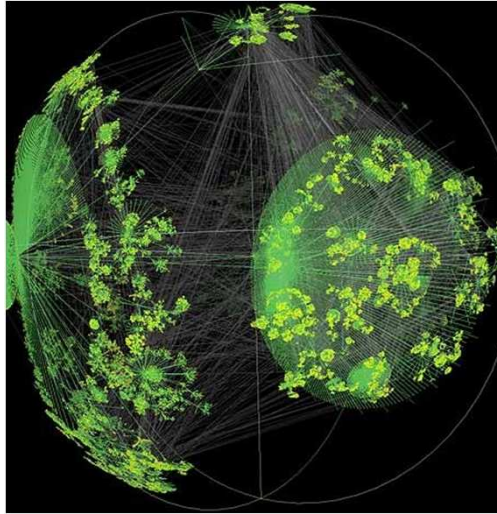
Overview of Networks

Networks

- Growing public fascination with the complex “connectedness” of modern society
- The concept of “network”
 - Objects connected by links
 - depending on the setting, various forms of links
- Networks are everywhere...



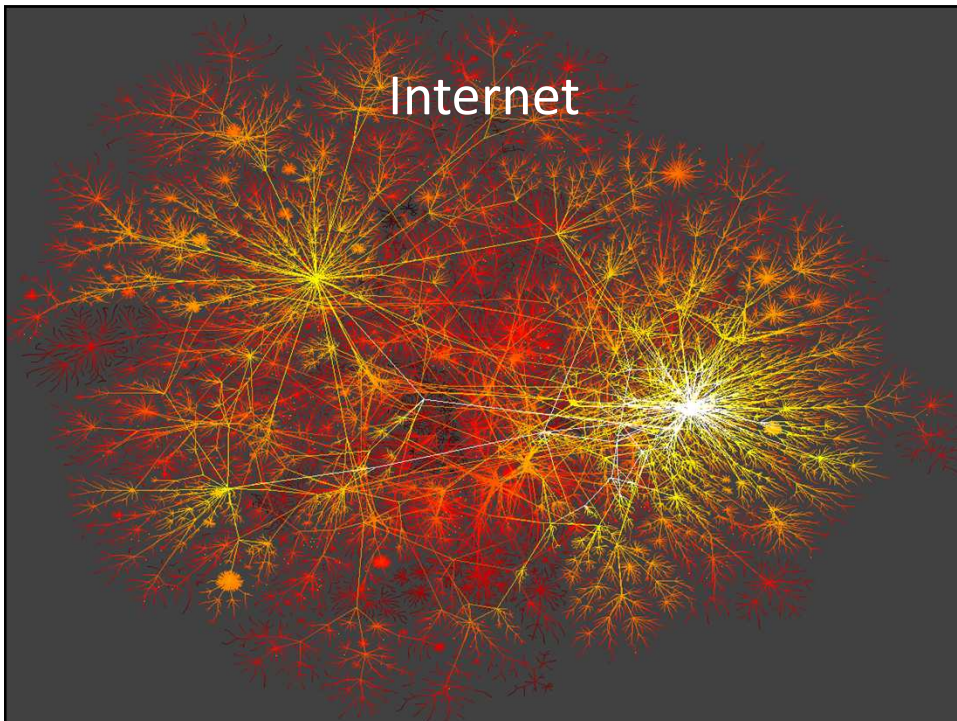
Web



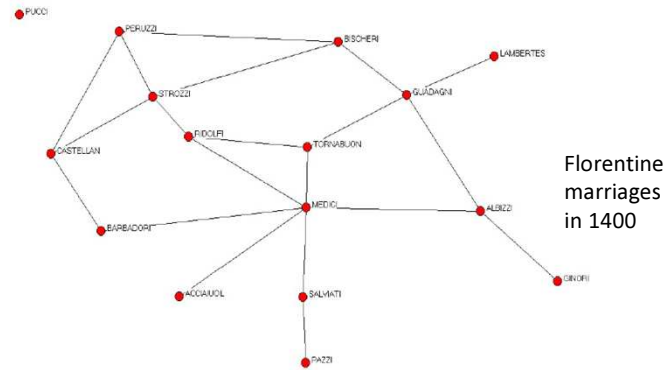
- 3 data points about the google index
- 1998 → 28 million pages
- 2000 → 1 billion pages
- 2008 → 1 trillion pages

Young Hyun, CAIDA

Internet



Traditional social networks

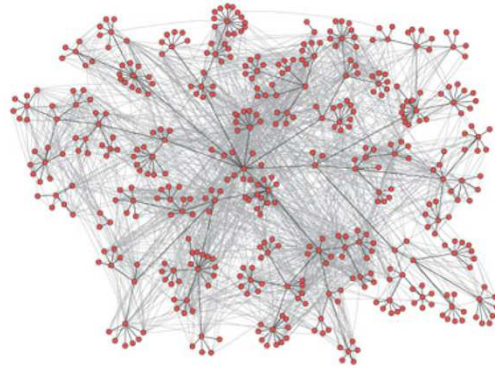


Collections of social ties are **complex** (technological advances facilitating distant travel, global communication, and digital interaction)
 Social networks **depart from geographic** underpinnings

Online social networks (Facebook, Myspace, blogs, flickr, IMs, etc)

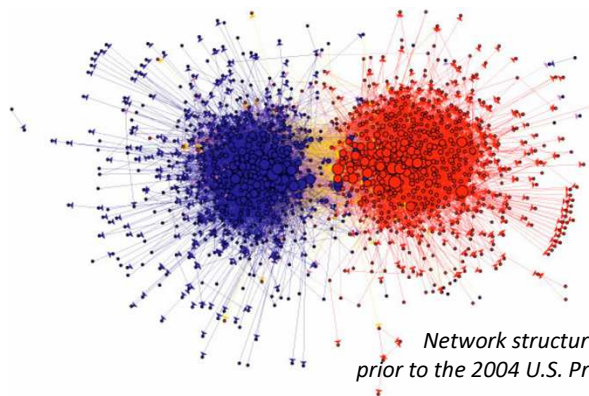


Emailing



Email communication among 436 employees of Hewlett Packard Research Lab is superimposed on the official organizational hierarchy
(Image from <http://wwwpersonal.umich.edu/ladamic/img/hplabsemailhierarchy.jpg>)

Blogosphere links



*Network structure of political blogs
prior to the 2004 U.S. Presidential election*

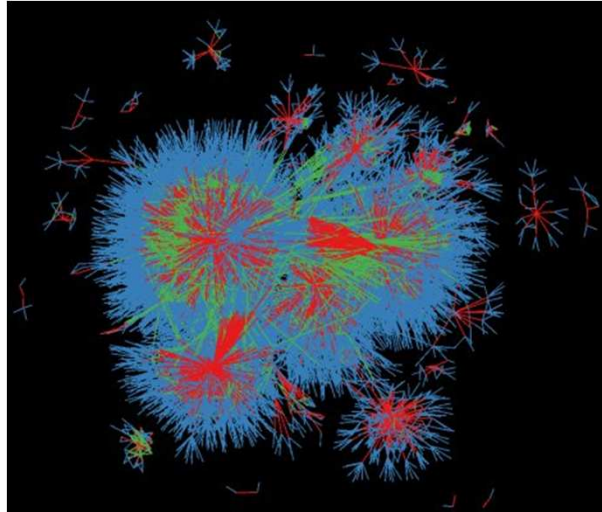
The information we consume has a networked structure grown in complexity

Before: few, high-quality information (publishers, news organizations, the academy)

Now: variety of information sources of wildly varying perspectives, reliabilities, and motivating intentions

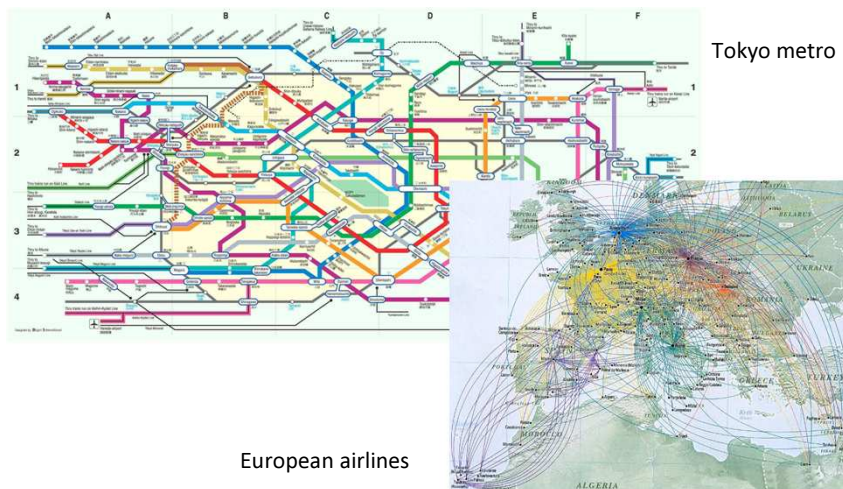
Understanding information depends on understanding the way it is endorsed by and refers to other pieces of information within a large network of links

Coauthor & citation networks



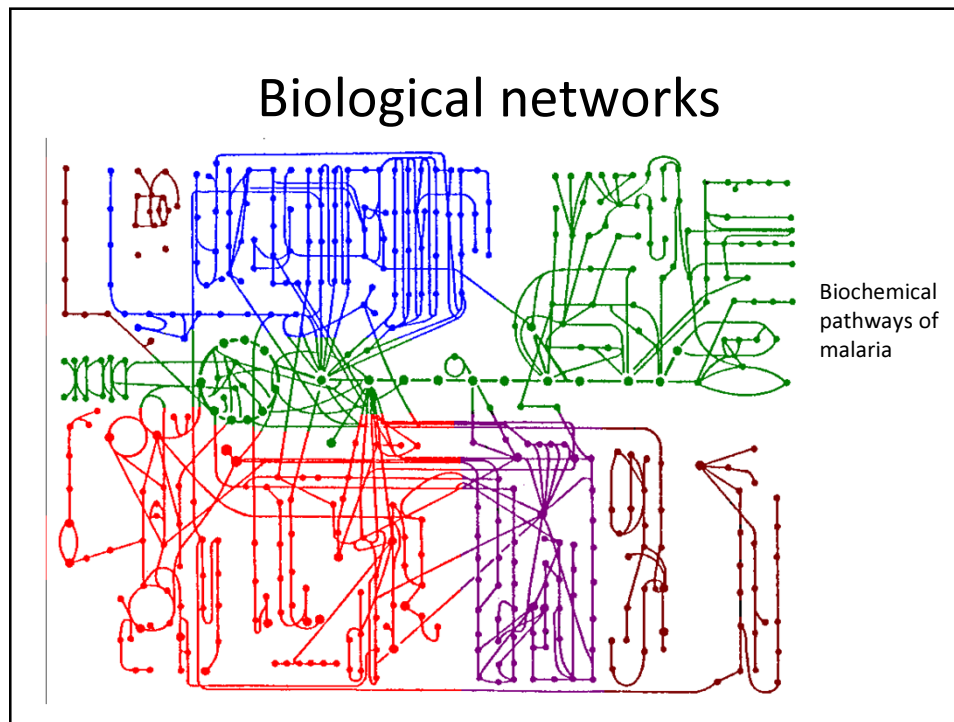
Citations among
biochem patents

Transportation networks



Tokyo metro

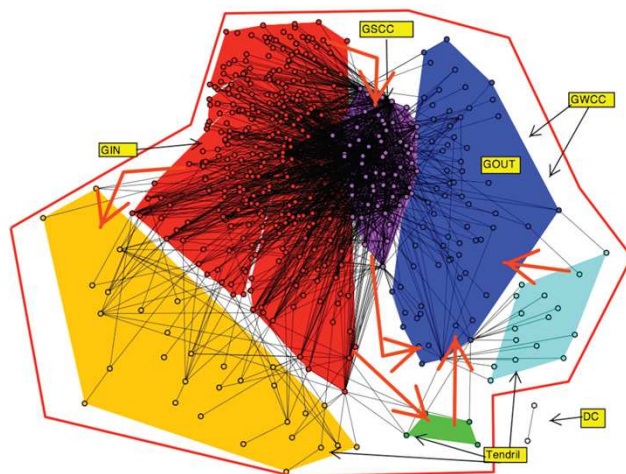
European airlines



Complexity: Why do we care?

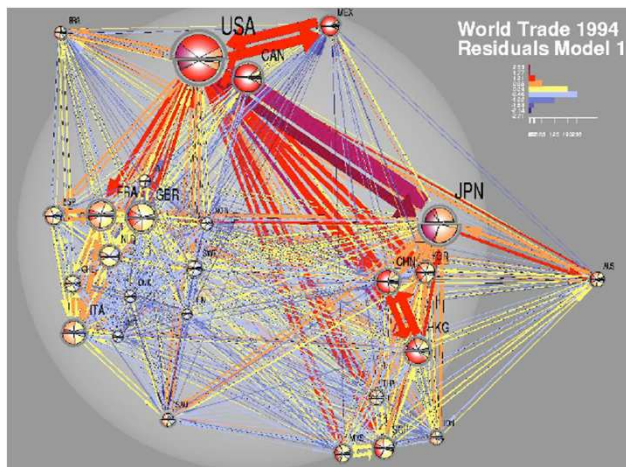
- Our technological and economic systems have become dependent on networks of enormous **complexity**
 - Their behavior is difficult to reason about
 - Susceptible to disruptions that spread through the underlying network structures
- Sometimes: **localized breakdowns** result in cascading failures or **financial crises**

Financial systems



Network of loans among financial institutions: analyze roles that different participants play in the financial system, and how the interactions among these roles affect the health of individual participants and the system as a whole

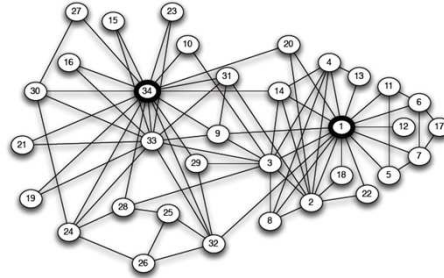
International trade



a network representation of international trade among 28 countries, with the size of each country depicting its total amount of trade, and the thickness of each link connecting two countries indicating the amount of trade between them.

Structural properties of networks

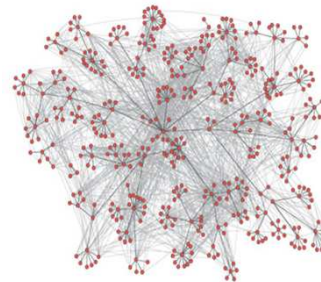
- It is generally difficult to summarize the whole network succinctly
- There are parts that are more or less **densely interconnected**
 - sometimes with central “**cores**” containing most of the links
 - sometimes with natural splits in multiple tightly-linked regions
- Nodes can:
 - be more **central** or more **peripheral**, or
 - straddle the boundaries of different tightly-linked regions, or
 - placed in the middle of one



The social network of friendships within a 34-person karate club

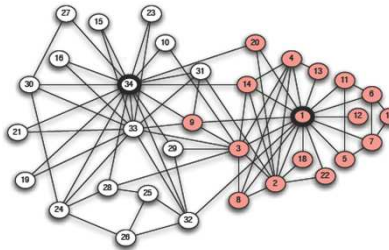
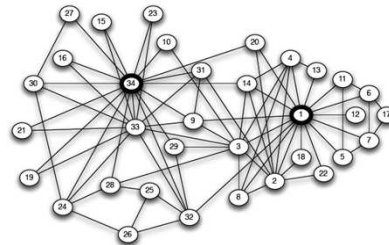
“Small worlds”

- *strong ties*: close and frequent social contacts embedded in tightly-linked regions
- *weak ties*: casual and distinct social contacts cross between these regions
- strong ties interact with each other through weaker ties
 - Ex: communication balanced between staying within small organizational units and cutting across organizational boundaries
- Weak ties as “short-cuts” for “small worlds” (6 degrees of separation)



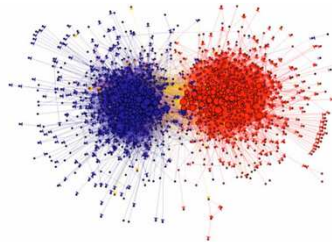
Structural balance

- Network structure reflects dynamics of **conflict** and antagonism
- Ex:
 - 1 and 34 are central (many connections to other people)
 - 1 and 34 not friends and most others are only friends with one or the other
 - non-interacting clusters as visible symptom of a conflict that **split** into two rival karate clubs



Links as information

- Links among Web pages help to understand how:
 - these pages are related,
 - they are grouped into different communities, and
 - which pages are the most prominent or important
- Ex: clear separation of the blogging network into two large clusters (liberal and conservative)
 - More detailed analysis to pick out the prominent blogs within each of these clusters



Structure and Search Engines

- Web search engines (such as Google) make extensive use of network structure in evaluating the quality and relevance of Web pages
 - For producing search results, they evaluate the prominence of a Web page not simply based on the number of links it receives,
 - but based on more subtle aspects of its position in the network
- A page can be viewed as more prominent if it receives links from pages that are themselves prominent
- A reinforcing kind of notion in which prominence is defined in terms of itself

Search engines and Web pages

- Interaction between search engines and the authors of Web shows “connectedness” at the level of behavior:
 - Whenever a search engine introduces a new method for evaluating Web pages (deciding which pages to rank highly),
 - the creators of Web content react to this and optimize what they put on the Web so as to try achieving a high rank under the new method (“Google bombs”, “link farms”)
- The Web inevitably adapts to the ways in which search engines evaluate content
- Search methods must be developed with these feedback effects in mind

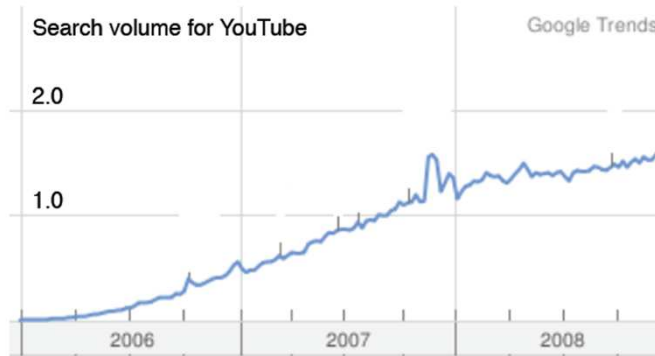
From structure to interactions

- The structure of the network:
 - It's about "who is linked to whom?"
 - and it is only a starting point
- The next point is: "interaction"
 - each individual's actions have consequences for the outcomes of everyone in the system
- Message: in a network setting, we should evaluate actions not in isolation, but with the expectation that the rest of the network will react to what individuals do

Interactions at population level

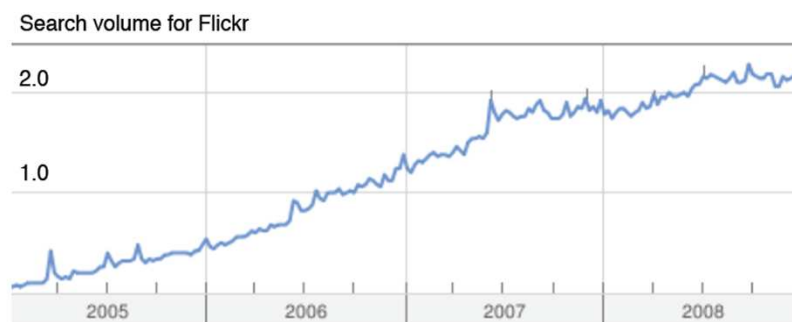
- Large groups of tightly interconnected people, often respond in complex ways that are only apparent at the population level
 - feedback effects in the behavior of many individuals across a population
 - even though these effects may come from implicit networks that we do not directly observe
- Example: the way in which new products, Web sites, or celebrities rise to prominence
 - e.g., growth in popularity of the social media sites

Example: YouTube



Number of Google queries for YouTube over time (units on the y-axis are suppressed)

Example: Flickr



Number of Google queries for Flickr over time (units on the y-axis are suppressed)

Dynamics of aggregate behavior

- Growing awareness and adoption of a innovation that is visible in **aggregate**, across a whole population
- What are the **underlying** mechanisms that lead to such success?
- Standard refrains:
 - “the rich get richer”; “winners take all”; “new ideas get attention that becomes “viral”

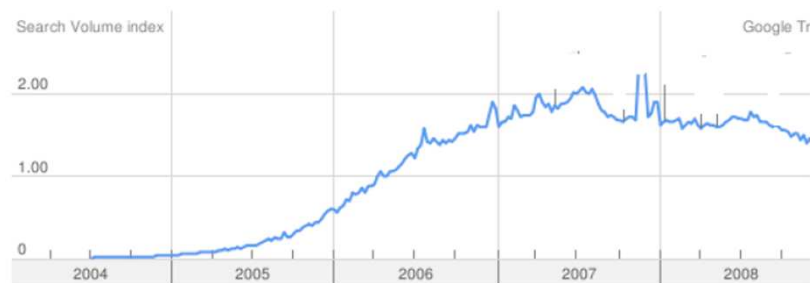
“The rich get richer”

- The way in which new practices spread through a population depends in large part on the fact that people *influence* each other
 - as you see more and more people doing something, you generally become more likely to do it as well
 - human tendency to *conform*: we have a fundamental inclination to behave as we see others behaving
- But why? Where is our intelligence?
 - the behavior of others conveys *information*
 - if you see many people making a particular choice, it is natural to assume that they too have their own information
 - Ex: seeing a lot of people using YouTube or Flickr suggests that these people know something about its quality (what about restaurants?)
- Amplification: regardless of whether YouTube had better features than its competitors, once it became the most popular video-sharing site, it dominated and became the standard

Allow for exceptions

- But the rich don't always get richer
 - this type of dominance is not necessarily permanent
- It is possible for a new technology to displace an old one
- Examples:
 - Google vs. Yahoo!
 - Some social networking sites flourish (Facebook), while others (MySpace) go down

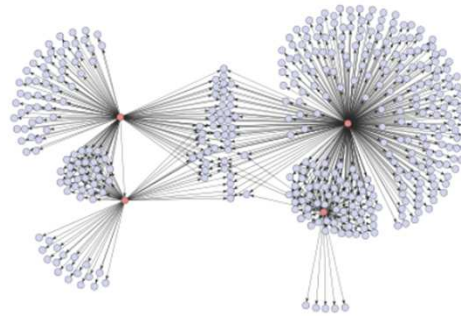
Example: MySpace



a life cycle of rapid adoption followed by a slower period of decline, as MySpace's dominance was challenged by newer competitors including Facebook

Cascading effects

- A new behavior can start with a small set of initial adopters and spread through the network
 - a.k.a. “Social contagion”
- Ex:
 - e-mail recommendations for a particular Japanese graphic novel spread outward from four initial purchasers
- Explains how it becomes possible for a new behavior to displace a universally-used, if the new starts in a portion of the network where it progress incrementally (a few people at a time)



e-mail recommendations for a Japanese graphic novel