

Networks and Strategic Interactions

Asu Ozdaglar

November 2009
LIDS Paths Ahead Symposium

Department of Electrical Engineering and Computer Science
Massachusetts Institute of Technology

Technological Networks



Internet backbone-
Level 3 US Network

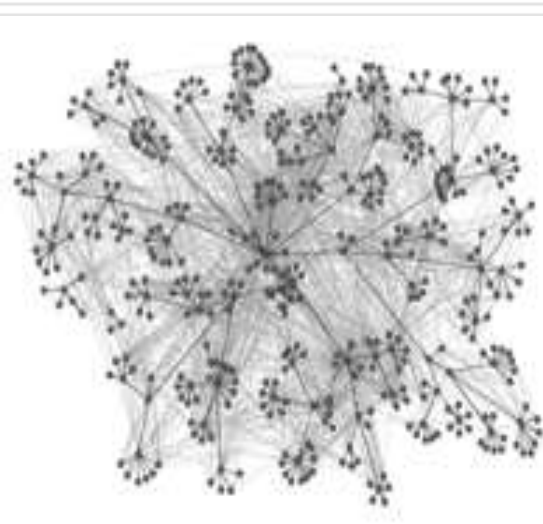


US Power grid



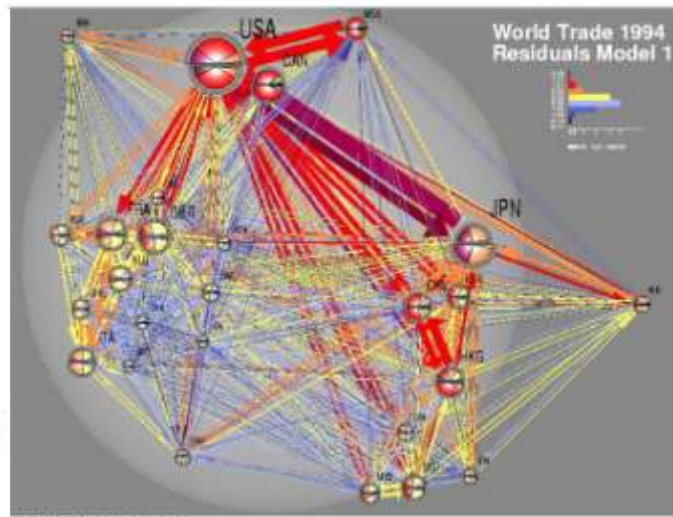
Airline route map

Social and Economic Networks



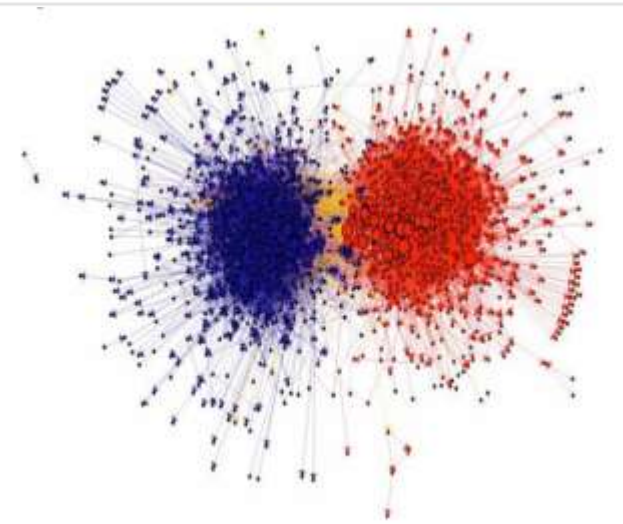
From Adamic

E-mail communication
(mapped onto organizational
hierarchy) at HP Labs



From Krempel and Plumber

A network representing
international trade



From Adamic

Network structure of
political blogs prior to 2004
presidential elections

What is the relationship?

- Economic-social aspects coupled with technological issues.
 - **Technological networks as economic markets:**
 - Operation of Internet as a commercial enterprise.
 - A worldwide system involving entities with different motives, economic interests, and for-profit ISPs in direct competition
 - Interest in design and deployment of technologically viable incentives and mechanisms to enable new end-to-end services
 - Power grid viewed as an economic network.
 - Constraints imposed by the distribution pattern from sellers to buyers have consequences for price and supply
 - **Economic and social interactions as networks:**
 - Network structure important determinant of how societies and markets function.
 - Spread of beliefs, innovations, technologies, and social conventions
 - **Merging of social and technological networks:**
 - Social interactions increasingly mediated by on-line communication

Holistic Framework

- Emerging area of networked-systems with commonalities, intersecting tools and new perspectives
 - All facets of a new emerging constellation of networked-systems
 - Interacting at multiple layers

 - Large area of research at the intersection of Engineering, Computer Science, Economics, Operations Research, Sociology, Physics...

 - **Key tools:**
 - Economic modeling, game theory and mechanism design
 - Optimization and control theory
 - Graph theory
 - Stochastic network analysis
-

Challenges in Communication Networks

- Non-obedient users with heterogeneous performance metrics and private information and interactions among autonomous self-interested agents

- New and recurring approaches for resource allocation
 - Distributed optimization methods (*Network Utility Maximization*) for design of incentive compatible algorithms

 - Game theoretic models for distributed resource allocation
 - Source-based network architectures: Routing, congestion control, power control, scheduling in wireless networks
 - Characterization of network efficiency and externalities
 - Design of remedies (pricing mechanisms, regulation, or new protocols and technology) to improve efficiency

Other Inherently Game-Theoretic Problems

- Economic models for **investment and pricing decisions** of service and content providers, and incentives for network upgrade decisions and evolution
 - Service quality guarantees to support real-time, high bit rate applications
 - Net-neutrality and implications

 - Design and analysis of on-line auctions and web search algorithms
 - Adword auctions (or position auctions) used by search engines
 - Efficient and distributed algorithms for ranking webpages

 - Models and incentives for ensuring security in networks
-

Challenges/Opportunities in Social and Economic Networks

- A group of individuals with dispersed (private) information, which communicate, exchange information, and trade through a network
 - Networks of friends, neighbors, and colleagues; networks of firms
 - Trading networks (supply chain, financial networks, ethnic and caste networks)

Fundamental Problems:

- Predicting dynamics of social behavior over networks
 - How do large groups aggregate information? Dynamics of learning and misinformation.
 - How do trust and friendships form over networks? Dynamics of cooperation and network formation.
 - When do fads and cascades emerge? Dynamics of tipping and diffusion.
- Understanding role of networks in economics
 - Economics about “allocation of scarce resources”
 - Much of this allocation takes place in networked situations. But most of economics studies either one of two extremes: (1) markets, where all interactions anonymous (implicitly anybody can trade with anybody else); (2) games among few players
 - Can we develop new insights by systematically analyzing the network of relations underlying trades?

Challenges/Opportunities in Social and Economic Networks

Fundamental Problems (continued):

- Endogenous instability and limits of robustness because of network interactions
 - Fragility of economic and financial networks
 - Limits of standard central limit theorems

 - Control of a network to induce desirable behavior
 - How can misinformation be contained? Which networks are robust in aggregating information efficiently?
 - Current research on modeling informational strategies of counter-insurgency in Afghanistan

 - Endogenous network formation: Dynamics of decisions and evolving graphs
-

Marriage of Optimization and Game Theory: Mechanism Design

- Design of a game (or incentives) to achieve an objective (eg. system-wide goal or designer's selfish objective)
 - Optimization theory extended for systems in which there are independent agents not under direct control, and must be induced through incentives.
 - Examples:
 - Interdomain routing: Strategic shortest path problem (ISP's interest to lie about routing information, users' interest to skimp on congestion control)
 - Auctions: Online advertising on the Internet (sponsored search auctions), spectrum auctions
- **Noncooperative cooperation for distributed control:**
 - Design game forms or local utility functions such that the equilibria of this game coincide with the system objective (such games exhibit favorable convergence properties)
 - Allows local autonomy
 - Introduces incentive problems
 - **Mechanism design or distributed optimization?**