

Network Science: Introduction

Ozalp Babaoglu
Dipartimento di Informatica — Scienza e Ingegneria
Università di Bologna
www.cs.unibo.it/babaoglu/

What is “Network Science”?

- The study of complex systems by exploring the structure and dynamic evolution of the underlying *networks*
- Can be applied to gain insight into modern *society, economy, biology, technology* and many *basic sciences*

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What is “Network Science”?

- Interdisciplinary study based on a mathematical foundation, blending ideas from other fields
 - Physics
 - Computer science
 - Sociology
 - Economics
- Can be approached from two different perspectives
 - Theoretical
 - Experimental — Explosion with recent availability of huge datasets
- Two different aspects
 - Structure — the “shape” of a network
 - Dynamics — how the shape changes over time

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Why study networks?

- The *structure* of networks are critical for regulating many interactions be they economic, political or social
 - Trade of goods and services in markets
 - Sharing of information, favors, risk
 - Spread of diseases, opinions, fads, cultural trends, innovations
 - Access to information for jobs, travel, purchases
 - Choices of behavior, education, habits, tastes
 - Political orientation, trade alliances
 - Adoption of new technologies (PC vs Mac, Android vs iOS, drugs, hybrid crops)
- Social networks play a critical role in many settings
 - Crime, employment, voting, smoking

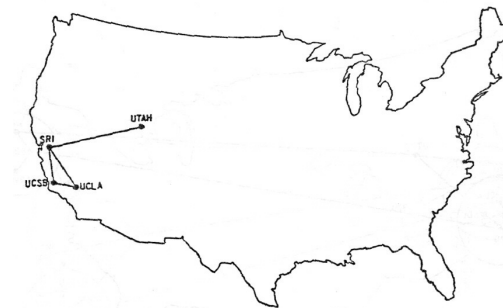
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What is a network?

- An abstract mathematical construct representing the *relations* that exist between *pairs* of objects
- Networks can represent any *binary* relationship over objects
- Both objects and relationships can be *physical* or *virtual*
- Common to visualize networks graphically
- A network is defined by the list of objects and the relations that exist over objects, *not* by its visualization
- The same network can have *many* different visualizations

Communication networks ARPANET

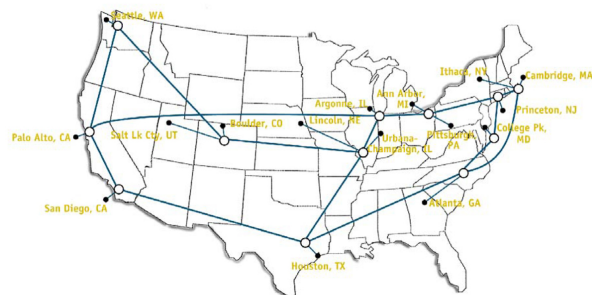


The ARPANET in December 1969

Communication networks NSFNET

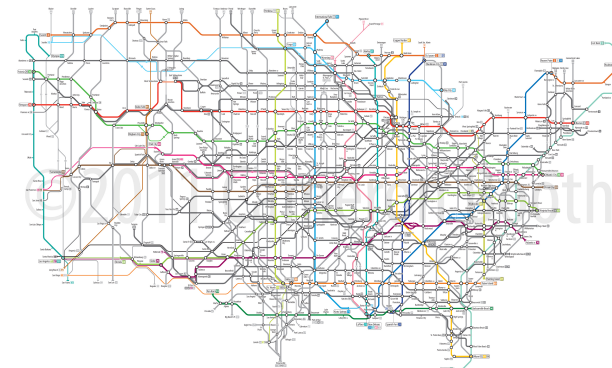
- Computers, communication links

NSFNET T3 Network 1992



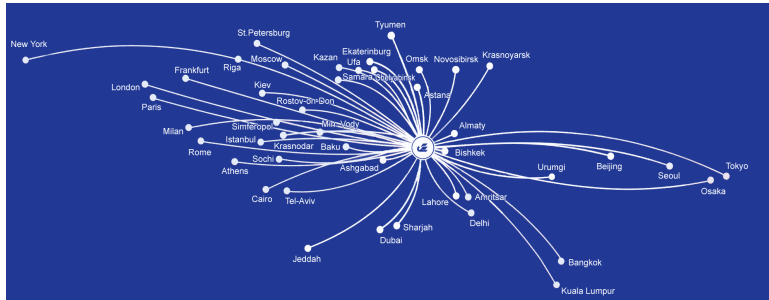
Transportation networks Interstate highway network

- Cities, highways



Transportation networks Flight routes

- Airports, scheduled non-stop flights (single airline)



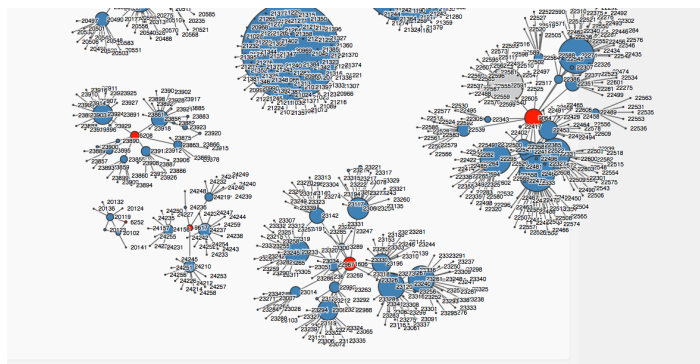
Transportation networks Flight routes

- Airports, scheduled non-stop flights (world-wide)



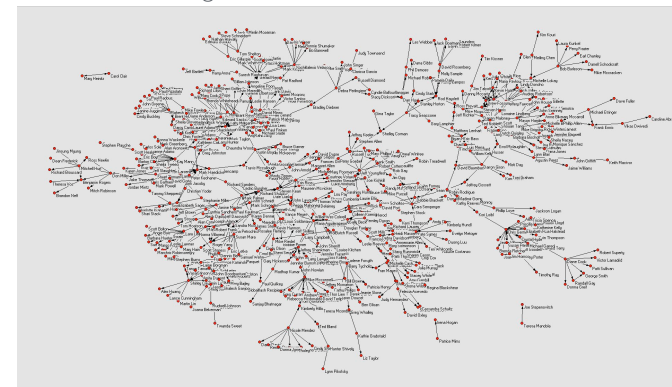
Interaction networks Telephone calls

- Phone numbers, calls



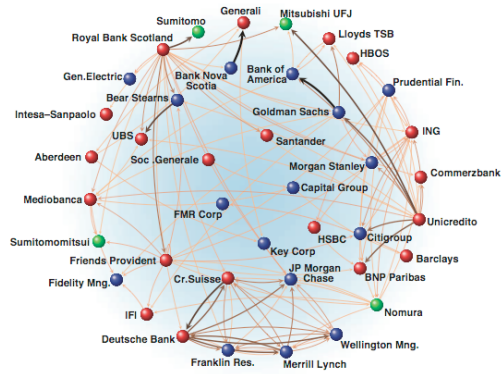
Interaction networks E-mail exchanges

- Mailboxes, e-mails exchanged



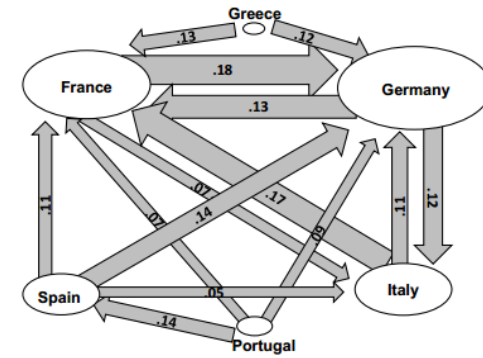
Global financial networks Bank loans

- Banks, loans



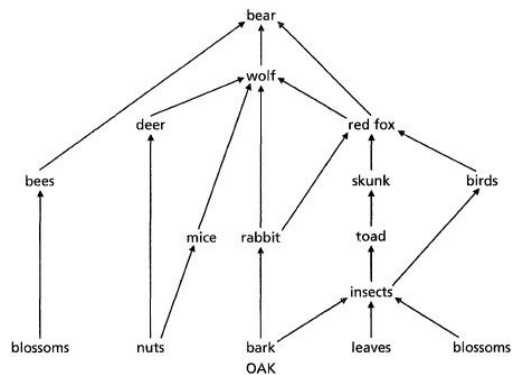
Global financial networks National debt

- Countries, debt



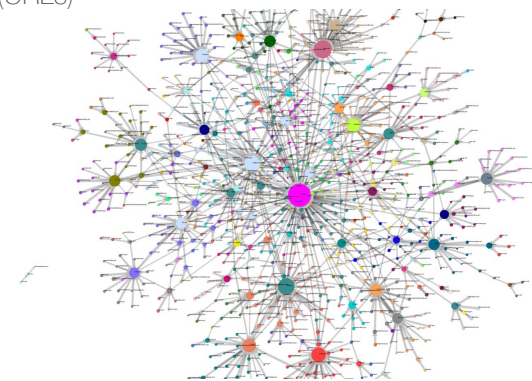
Food web

- Species, "who eats whom"



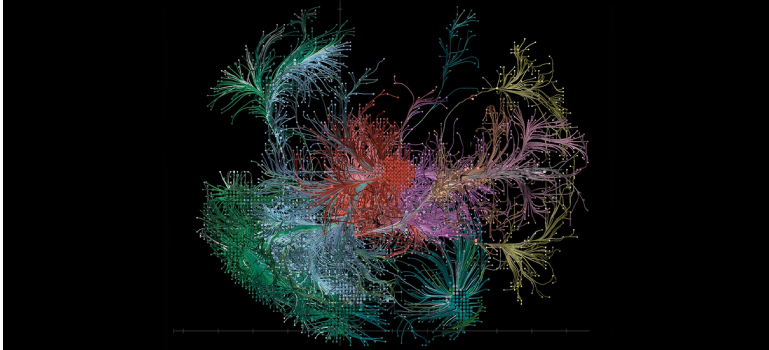
Web graph

- Web pages, hyperlinks (URLs)



Biological neural network Mouse connectome

- Neurons, synapses

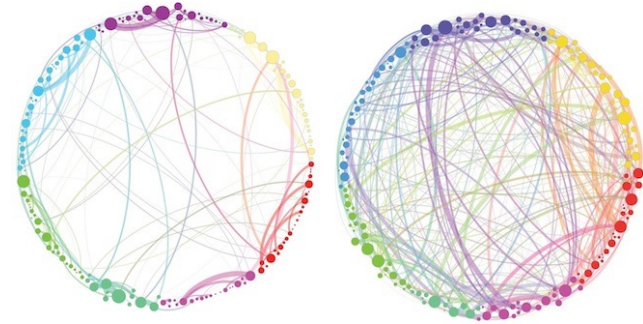


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Biological neural network Human brain functions

- Brain functions, functional connections (before and after ingesting “magic mushroom”)

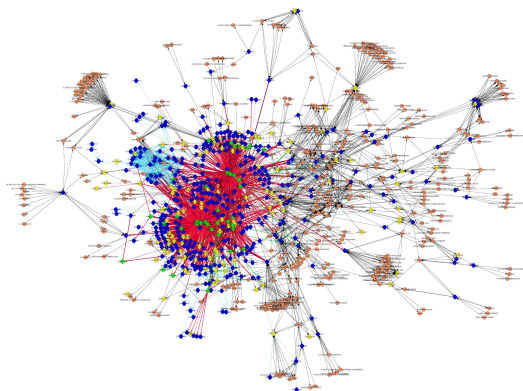


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Gene regulatory network

- DNA segments (genes), physical or regulatory interactions

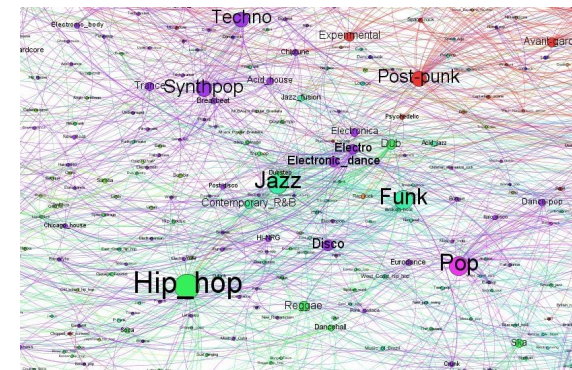


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Music genres network

- Musical genres, stylistic origins

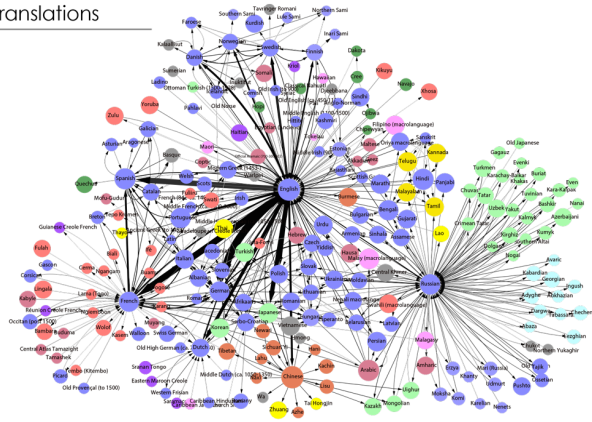


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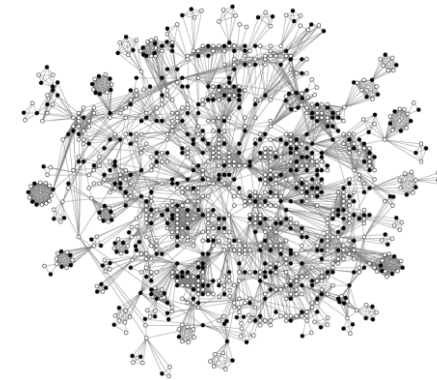
Global language network

Book Translations



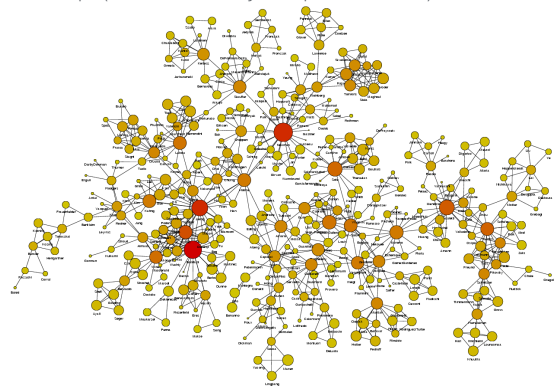
Social networks Board-of-directors

- Companies, joint board membership



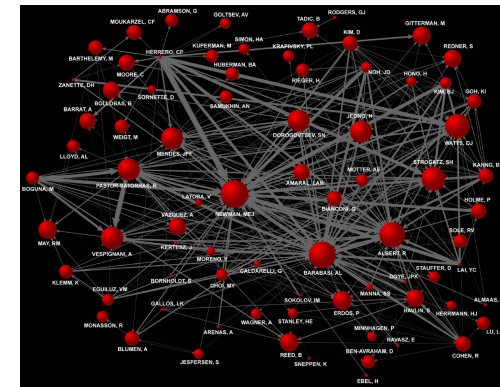
Social networks Co-authorship

- Authors, co-authorship (at least one joint publication)



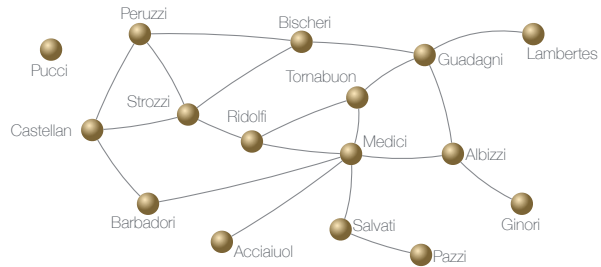
Social networks Citations

- Authors, citations to the other author



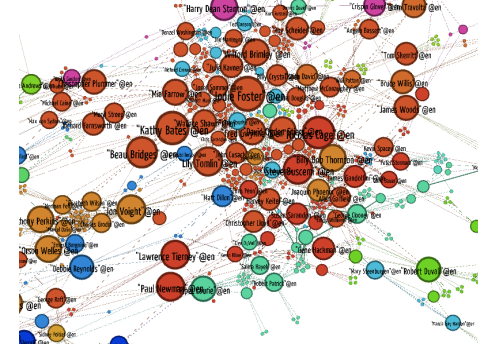
Social networks 15th Century Florentine Marriages

- Families, cross family marriages



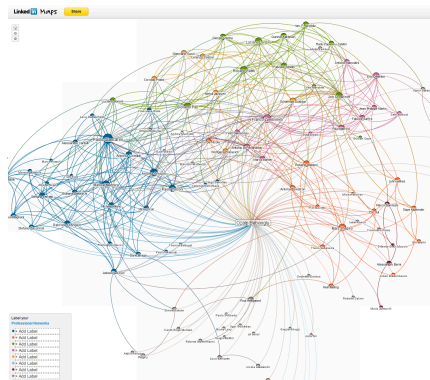
Social networks Actors

- Actors, movies starring both actors



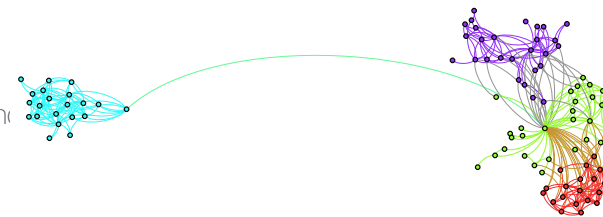
Social networks Linkedin

- People, professional



Social networks Facebook

- People, friend



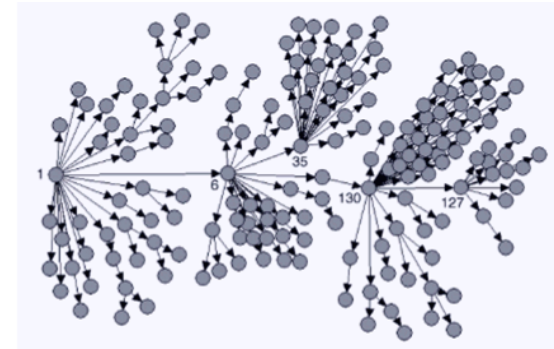
Social networks Facebook

- People,

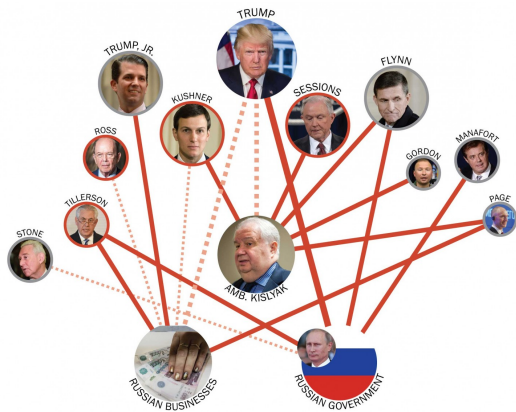


Social networks Epidemics

- People, transmission of disease (2003 SARS epidemic)



Social networks Business relations



Some questions

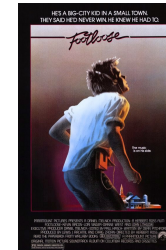
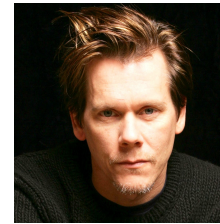
- What are the commonalities of these vastly different networks?
- What are the fundamental properties that define network structure?
- Are there structures that are “universal”?
- How do networks form?
- How can network formation be guided so that the “right” network forms?
- How does network structure affect dynamics?
- How do network dynamics affect structure?
- What are interesting dynamics *of* networks
- What are interesting dynamics *on* networks

Challenges

- Size
 - Current Facebook social network contains more than 2.7 billion monthly active users and more than several hundred billion friendship relations
- Complexity
 - How many different friendships can there be in a class with 24 students?
 - The size of the network is small — only 24 objects
 - The number of symmetric relations among 24 objects is $(24 \times 23) / 2 = 276$
 - The number of *possible* networks is huge — $2^{(24 \times 23) / 2}$ which is 1,200 times the number of atoms in the universe ($\sim 10^{80}$)
- We need a way to represent networks and capture their properties succinctly and abstractly without having to “catalogue” them

Six Degrees of Kevin Bacon

- Parlor game invented by movie buffs based on the “six degrees of separation” concept, but framed in the context of the *actor network*
- Motivated by the title of a news article with the provocative title “Kevin Bacon is the Center of the Universe”
- Who is Kevin Bacon?



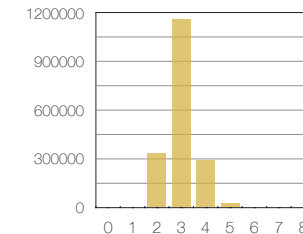
Bacon numbers

- Shortest “distance” between a given actor and Kevin Bacon
- “Oracle of Bacon” — on-line calculator of Bacon numbers
 - <http://oracleofbacon.org/>
 - Data obtained from the *Internet Movie Database (IMDB)*
 - 2.9 million actors
 - 1.9 million movies and TV shows
 - [Actors by nationality](#)

Bacon numbers

- The shortest “distance” between a given actor and Kevin Bacon

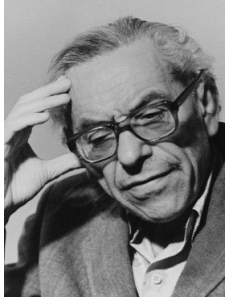
Bacon Number	Number of actors
0	1
1	2902
2	334004
3	1159045
4	290372
5	22589
6	2383
7	239
8	7



Average Bacon number: 3.002

Erdős Numbers

- Equivalent of Bacon number, but for scientists — shortest “distance” between a given mathematician and the Hungarian mathematician Paul Erdős
- Erdős authored more than 1400 papers with 509 different co-authors
 - <http://www.oakland.edu/enp/>
 - <http://www.ams.org/mathscinet/collaboration.html>



Erdős Numbers

- Erdős collaboration network drawn by Ron Graham in 1979

