

# Network Science: Introduction

Ozalp Babaoglu  
Dipartimento di Informatica — Scienza e Ingegneria  
Università di Bologna  
[www.cs.unibo.it/babaoglu/](http://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*

© Babaoglu

2

## 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

© Babaoglu

3

## 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

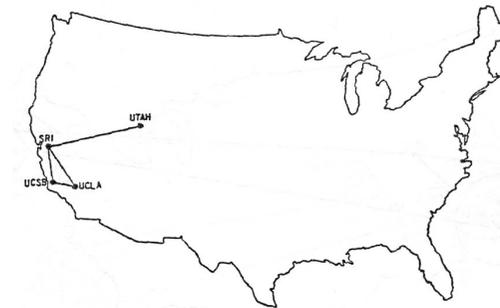
© Babaoglu

4

## 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

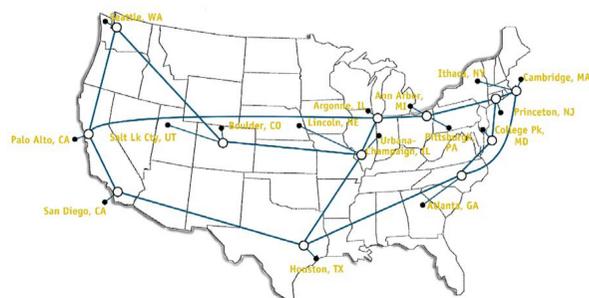


The ARPANET in December 1969

## Communication networks NSFNET

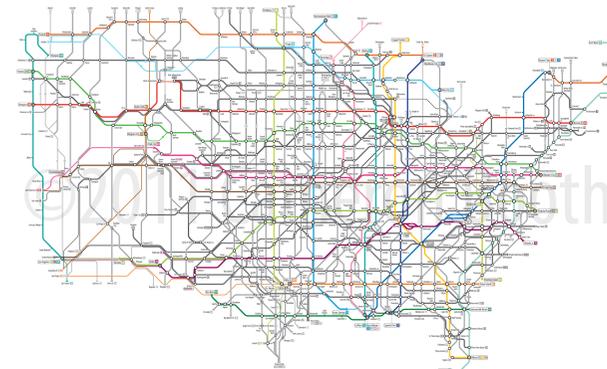
- Computers, communication links

### NSFNET T3 Network 1992



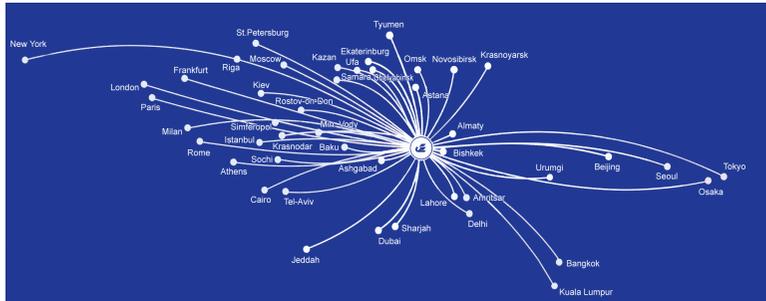
## Transportation networks Interstate highway network

- Cities, highways



## Transportation networks Flight routes

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



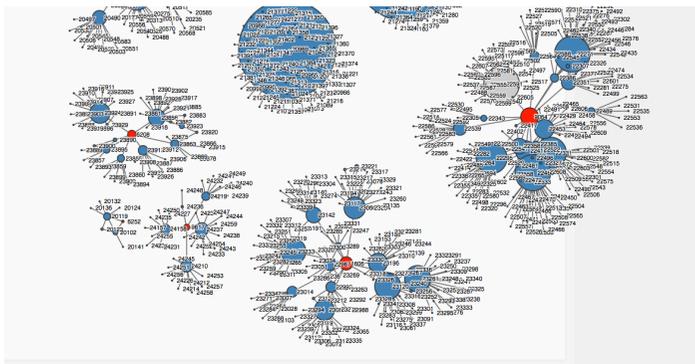
## Transportation networks Flight routes

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



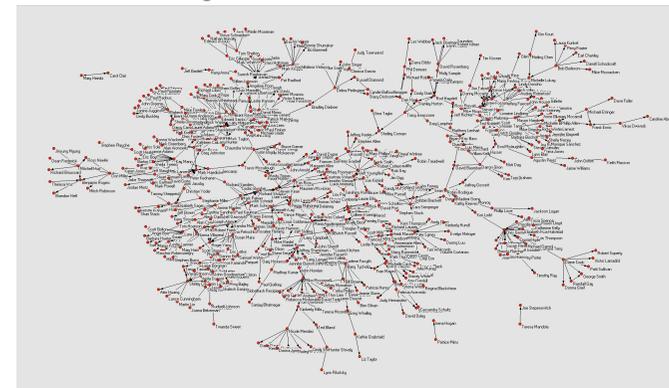
## Interaction networks Telephone calls

- Phone numbers, calls



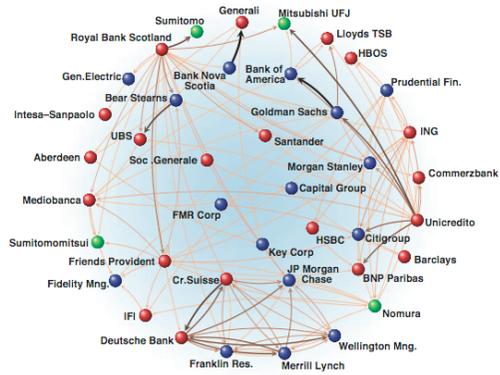
## Interaction networks E-mail exchanges

- Mailboxes, e-mails exchanged



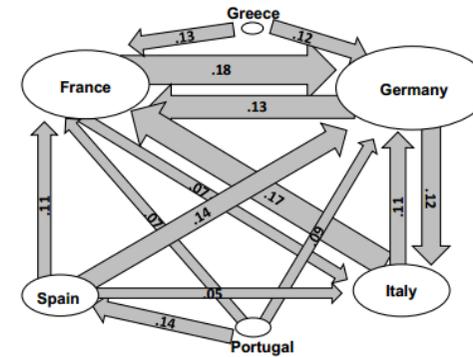
## Global financial networks Bank loans

- Banks, loans



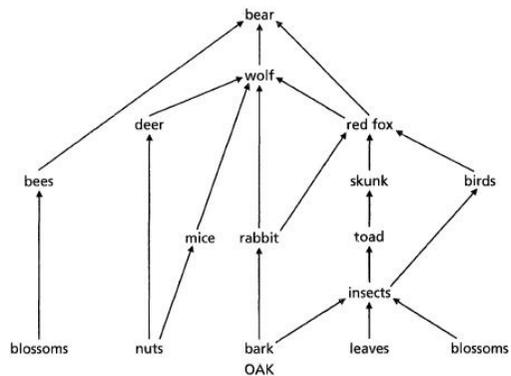
## Global financial networks National debt

- Countries, debt



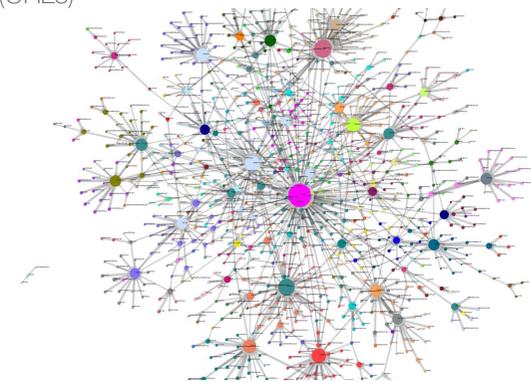
## Food web

- Species, "who eats whom"



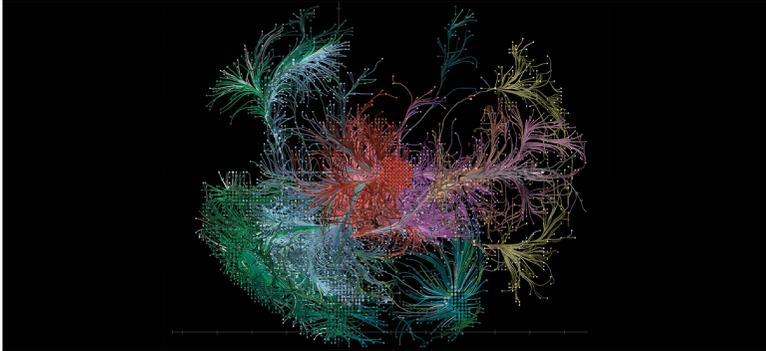
## Web graph

- Web pages, hyperlinks (URLs)



## Biological neural network Mouse connectome

- Neurons, synapses

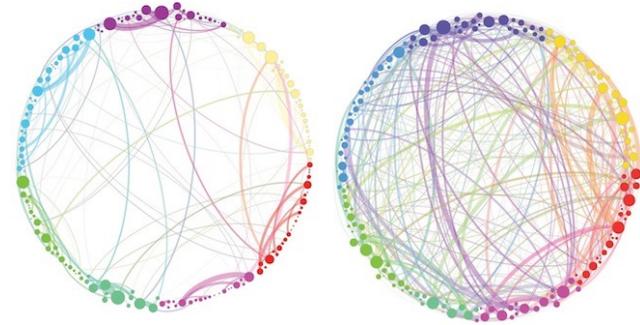


© Bilibaoglu

17

## Biological neural network Human brain functions

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

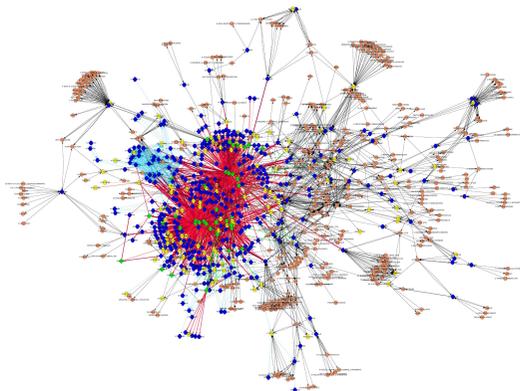


© Bilibaoglu

18

## Gene regulatory network

- DNA segments (genes), physical or regulatory interactions

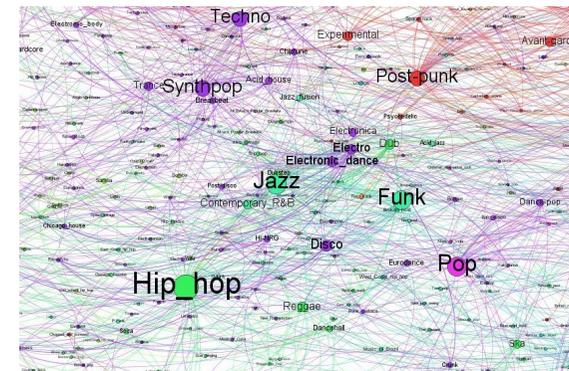


© Bilibaoglu

19

## Music genres network

- Musical genres, stylistic origins

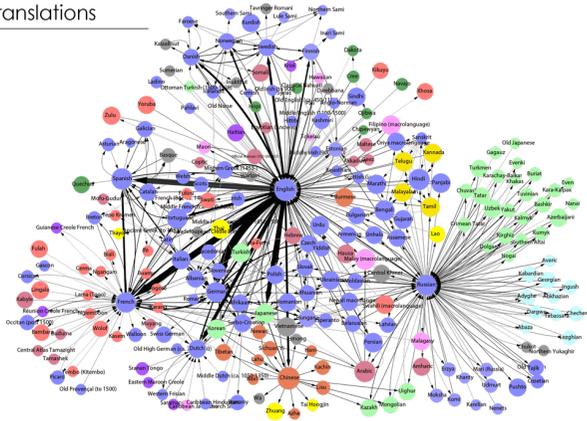


© Bilibaoglu

20

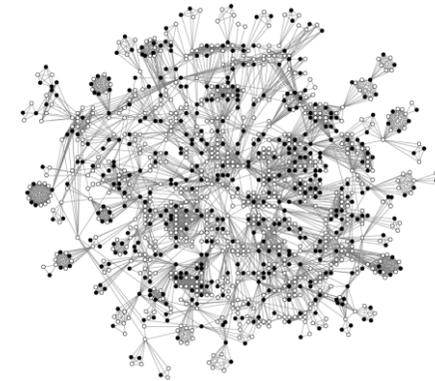
# Global language network

Book Translations



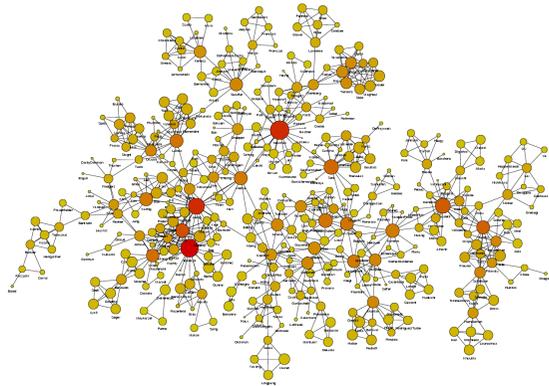
# Social networks Board-of-directors

- Companies, joint board membership



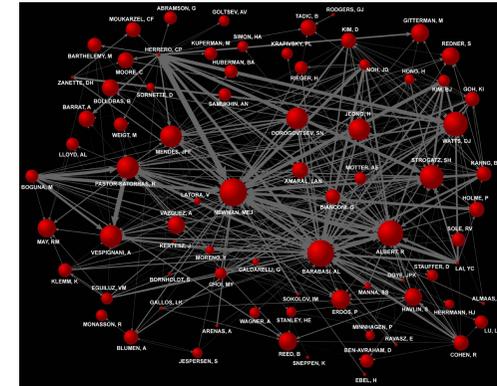
# Social networks Co-authorship

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



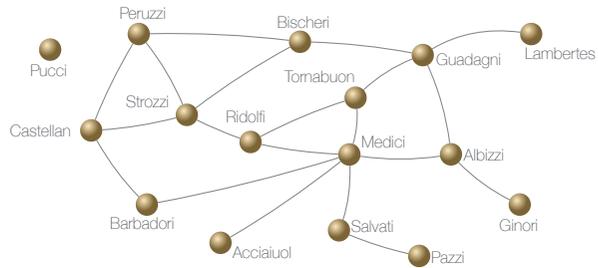
# Social networks Citations

- Authors, citations to the other author



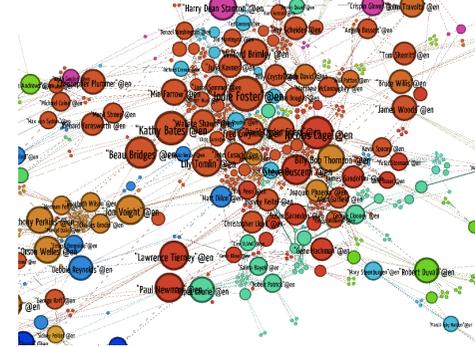
## Social networks 15th Century Florentine Marriages

- Families, cross family marriages



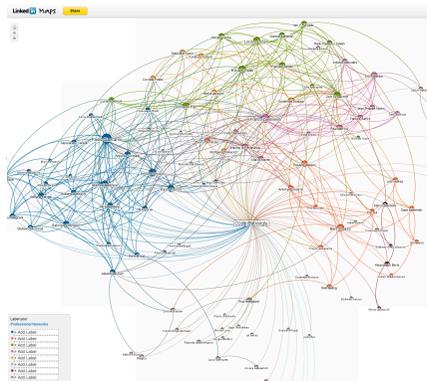
## Social networks Actors

- Actors, movies starring both actors



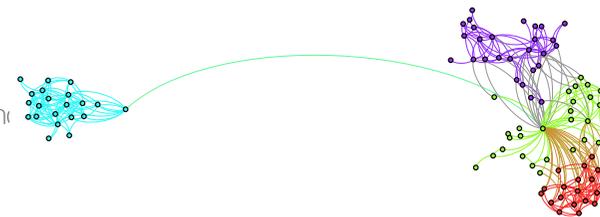
## Social networks LinkedIn

- People, professional



## Social networks Facebook

- People, friend



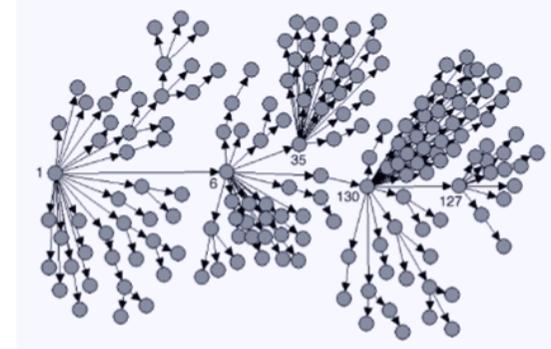
## Social networks Facebook

- People,

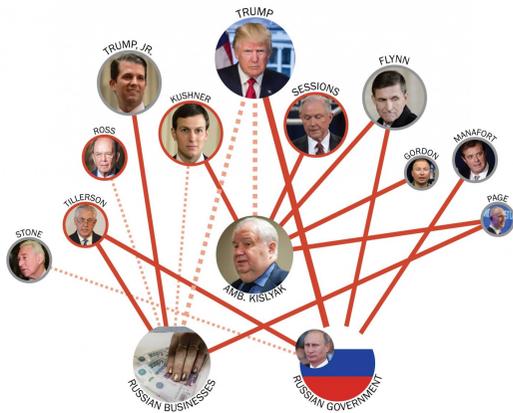


## Social networks Epidemics

- 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?



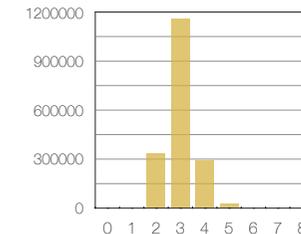
## Bacon numbers

- 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

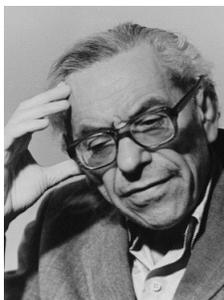
Bacon Number	Number of actors
0	1
1	2902
2	334004
3	1159045
4	290372
5	22589
6	2383
7	239
8	7



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

